A Review of General Aviation Safety (1984–2017)

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INTRODUCTION: General aviation includes all civilian aviation apart from operations involving paid passenger transport. Unfortunately, this category of aviation holds a lackluster safety record, accounting for 94% of civil aviation fatalities. In 2014, of 1143 general aviation accidents, 20% were fatal compared with 0 of 29 airline mishaps in the United States. Herein, research findings over the past 30 yr will be reviewed. Accident risk factors (e.g., adverse weather, geographical region, post-impact fire, gender differences) will be discussed. The review will also summarize the development and implementation of stringent crashworthiness designs with multi-axis dynamic testing and head-injury protection and its impact on mitigating occupant injury severity. The benefits and drawbacks of new technology and human factor considerations associated with increased general aviation automation will be debated. Data on the safety of the aging general aviation population and increased drug usage will also be described. Finally, areas in which general aviation occupant survival could be improved and injury severity mitigated will be discussed with the view of equipping aircraft with 1) crash-resistant fuel tanks to reduce post-impact conflagration; 2) after-market ballistic parachutes for older aircraft; and 3) current generation electronic locator beacons to hasten site access by first responders.

KEYWORDS: general aviation, accident, injury, risk factor, aviation accident, human factors, aviation.

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General aviation includes all civilian aviation apart from operations involving paid passenger transport such as the airlines and charter operations. Unfortunately, compared with airline operations, the rate of general aviation accidents is substantially higher, notwithstanding a modest decline over recent years (**Fig. 1**). Historically, general aviation, mostly comprised of piston engine-powered aircraft,[34] has accounted for the overwhelming majority (94%) of civil aviation fatalities,[47] with 18–23% of accidents having a fatal outcome.[45,56] In 2014, of 1143 general aviation accidents, 236 (20%) were fatal in the United States (**Fig. 2**). In comparison, of 29 airline accidents for the same year, none were fatal. Therefore, reducing general aviation accident rates represents an important safety challenge for aviation.

As to financial burden, accidents for this sector of aviation carry substantial annual costs ($1.6–4.6 billion). These values represent expenses associated with injury (inclusive of hospital costs) and/or loss of life, accident investigations, loss of pay with a fatal accident, and loss of the aircraft.[66] In all likelihood, these financial outlays represent under-estimates since they do not take into account assessed litigation costs.

In this review, various risk factors for general aviation accidents will be discussed. In addition, several topics not previously addressed in an earlier review of general aviation accidents[47] will be examined: 1) the potential impact of new training approaches and technology; 2) the protective effect of new aircraft crashworthiness designs on injury severity; 3) human factors/aviation psychology; and 4) pilot physiology/toxicology. It should be noted, considering the breadth of general aviation, this review will focus on fixed-wing aircraft certificated under 14CFR Part 23,[24] excluding revenue-generating operations such as crop-dusting, photography, or emergency medical transport. The reader should also keep in mind that the majority of general aviation safety studies are based on investigations undertaken in the United States, so caution should be exercised in extrapolating these findings to operations in other countries, where training and aircraft certification procedures may differ.

METHODS

A literature search was performed using the U.S. National Library of Medicine search engine (https://www.ncbi.nlm.nih.

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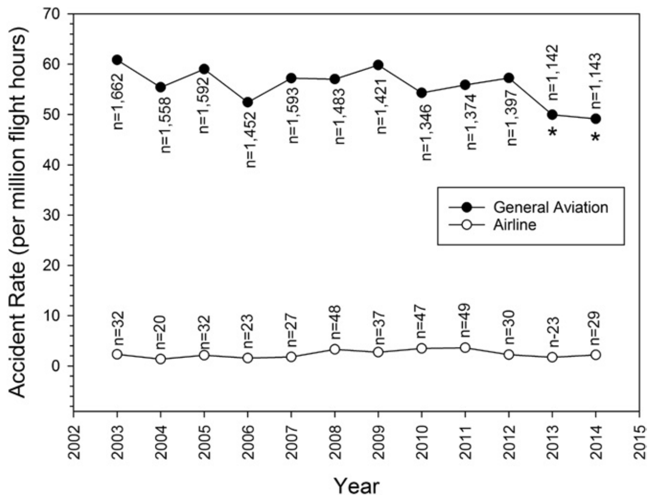

Fig. 1. Accident rates for domestic airlines and general aviation. The NTSB accident database (Dec. 2016 release) was queried for accidents in the United States for the period indicated. Airline and general aviation fleet hours were from the Bureau of Transportation Studies and the General Aviation and Air Taxi Survey, respectively. Accident count is indicated by n. $^{*}P < 0.001$, determined by employing a Poisson probability distribution analysis and using the earliest year (2003) as reference.

gov/pubmed) or Google Scholar (https://scholar.google.com/). Search terms used, individually or in a Boolean query, included: general aviation, aviation accident, human factors, age, risk factor, psychology, weather, mountain, convection, fatal accident, crashworthiness, injury, injury severity, pilot error, automation, electronic flight displays, survivability, HFACS, pilot health, toxicology, obesity, medication, drug. To determine accident rates for domestic airlines and general aviation, the National Transportation Safety Board (NTSB) accident database (Dec. 2016 release)[55] was queried for accidents in the United States. Airline (domestic carriers) and general aviation fleet hours were from the Bureau of Transportation Studies[16] and the General Aviation and Air Taxi Survey,[34] respectively. A Poisson probability distribution analysis[23] was used to determine if accident rate changed over time using the SPSS statistical program (v. 23).

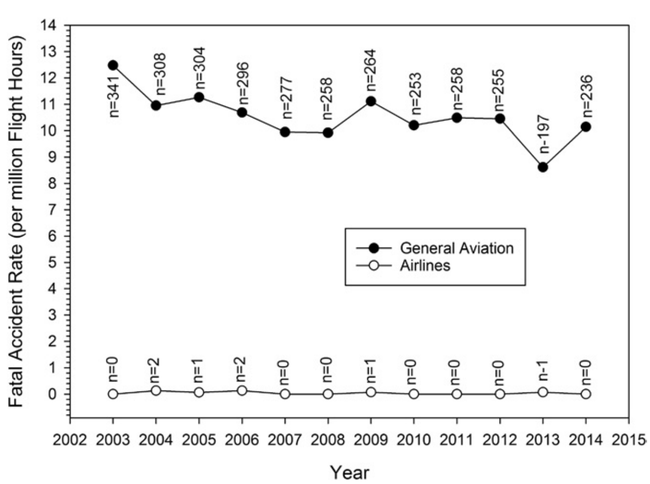

Fig. 2. Fatal accident rates for domestic airlines and general aviation. The NTSB accident database (Dec. 2016 release) was queried for fatal accidents in the United States for the years indicated. Airline and general aviation fleet hours were from the Bureau of Transportation Studies and the General Aviation and Air Taxi Survey, respectively. Accident count is indicated by n.

RESULTS

Risk Factors for General Aviation Accidents

Over the past three decades there have been several studies undertaken to identify the risk factors associated with all or fatal general aviation mishaps. These, as well as recent findings, will be described in this section.

There are abundant data demonstrating that flight in degraded visibility, such as clouds, rain, or fog [referred to as instrument meteorological conditions (IMC)], requiring a pilot to control the aircraft by reference to instruments in the absence of outside visual cues, increases the risk of a general aviation mishap.[5,47] This is of particular importance for unexpected/unplanned visual to IMC operations and especially pertinent to airmen who are either not certified to fly by reference to instruments or for pilots who are no longer current in this environment. Thus, while only 9% of general aviation accidents occur during IMC, they account for 28% of all general aviation fatalities.[47] Reinforcing this notion, Bazargan and Guzhva[5] reported that general aviation flight under degraded visual conditions carried a sevenfold increased risk of fatality.[5] In addition, flight operations concurrently conducted under IMC and at night further elevate the risk.[8] Notwithstanding these sobering findings, a recent temporal analysis showed a statistical decrease in the accident rate for instrument-qualified (but not for airmen who were not certified for instrument flight) general aviation pilots in this challenging environment.[64]

General aviation safety in the United States is heavily influenced by geographical region.[43] Indeed, flying over mountainous and/or high elevation terrain poses a set of challenges mostly relating to the weather. For example, severe, localized, gusty winds and mountain waves, which may vary from the synoptic forecast, are often associated with mountainous terrain.[27,39] Also, winds blowing perpendicular to a mountain ridge can generate rotor patterns on the leeward side, potentially leading to aircraft upset by virtue of exceeding the roll authority of a small airplane. Mountain ranges may also create downdrafts of greater than 1500 ft/min in excess of the climb rate of many single engine piston aircraft.[3,27,28] As to convective activity, a moist air mass lifted orographically (due to a mountain slope) may culminate in thunderstorms with a prevailing unstable atmosphere.[27] Regarding visibility, mountain weather can be highly changeable, with rapid onset of degraded visibility.[21] It should be noted that some of these weather conditions may extend well beyond the immediate mountain environment. Mountain waves, for example, can propagate 70-100 nm downwind of a ridge.[26,27,39] Finally, the climb performance of normally aspirated (i.e., nonturbo-charged)[29] piston engine-powered aircraft diminishes with altitude,[28] potentially leading to high elevation accidents where the aircraft is unable to clear rising terrain.[3] Therefore, not surprisingly, a higher accident rate and a disproportionate increase in fatal mishaps are evident for general aviation operations in these regions. One study reported that states characterized by mountainous terrain and high elevation carry a higher accident rate than those featuring low lying, relatively flat terrain (15.3 and 8.5 accidents per 100,000 flight hours, respectively).[43] The fatal accident rate is also greater—a study published over two decades past[3] documented a 68% increase in fatal general aviation mishaps in the Colorado Rockies relative to the rest of the state. Later reports mirrored these findings again, showing a higher fatality rate for accidents in the U.S. Rocky Mountains and Appalachia regions, again characterized by their mountainous terrain when compared with the Great Plains.[1,40]

Planned flight distance has also been previously reported as a risk factor for general aviation accidents. Thus, cross-country flights (defined as >50 nm) carry a fourfold elevated risk of a fatal outcome compared with those of shorter distance.[58] A separate study reporting a 44% higher median distance for fatal accidents was consistent with these findings.[12] In a prospective study, operations with an intended distance of 300 nm or longer were shown to carry an augmented risk of an accident (odds ratio 4.6) compared with those of shorter planned distance.[41] O'Hare and Owen[58] argued, from a human factors perspective, that the higher risk associated with longer planned distances may be related to the fact that pilots, facing adverse weather, are more likely to attempt to complete a flight closer to the destination.

Studies of flight experience as a risk factor in general aviation accidents have yielded conflicting results. One study[6] reported that airmen with more experience were more likely to be involved in fatal general aviation accidents. Conversely, a separate report demonstrated a protective effect of flight experience on accidents involving pilot error.[48] However, in a third study,[46] no association was found between flight experience and fatal general aviation accidents.

Nondaylight operations, not surprisingly, are more hazardous than those conducted during the day due partly to the potential for spatial disorientation[9] or reduced landing options in the event of a malfunction. An analysis of 667 accidents occurring between 1985 and 1999 revealed a more than twofold higher risk of a fatal outcome for night flights.[46] A more recent study on mishaps in twin-engine, general aviation aircraft for the period spanning 2002–2012 confirmed an elevated risk of a fatal outcome for operations conducted at night.[11]

Regarding pilot certification, independent studies have supported the view that advanced airman certification reduces accident risk. For example, airline transport pilot certified airmen, while constituting 7.5% of the pilot population, only account for 3.5% of fatal accidents.[61] However, it should be noted that this study did not take into account differences in general aviation flight hours among the various airman cohorts. Along similar lines but now correcting for differences in flight times, a study comparing commercial and private pilot-certified airmen reported a lower fatal accident rate for the former group.[15] Somewhat surprisingly though, instrument flight rule (IFR) certification of private pilots was associated with a higher fatal accident rate using as reference their non-IFR certified counterparts.[63] However, caution should be exercised with the latter study since, like the research of airline transport pilot certificated airmen, accident data were adjusted to the pilot population rather than the annual hours accrued by these separate cohorts.

Several research studies have investigated gender differences in general aviation accidents. The preponderance of evidence suggests that male pilots are at a higher risk for accidents.[6,49] One possible reason may relate to observations that in some neurocognitive tests, including that for attention, females outperform males.[42] On the other hand, a recent study of training accidents reported that female primary students were more likely to be involved in excess speed landing accidents.[14] The authors speculated that these types of mishaps could be related to observations that males excel at spatial processing and motor skills,[42] attributes likely to promote the acquisition of landing skills.

Published research on a postcrash fire as a risk factor for a fatal outcome is compelling. In an analysis of general aviation accidents spanning the period 1985–1999, Li and Baker[46] reported that accidents with post-impact fires were more than 13 times likely to be fatal than those accidents without a conflagration. Similar findings were published in a study of 8411 accidents for light aircraft[60] and, more recently, for multiengine piston aircraft.[11] What is unclear from these studies, however, is whether occupants were unable to egress the aircraft prior to its conflagration due to a sustained head injury. As discussed in a later section on aircraft crashworthiness, new standards for general aviation airplane certification requires an assessment of occupant protection from serious head injuries in dynamic crash tests.[52]

Perhaps not surprisingly, considering the potential for unsuitable terrain, off-airport landings carry an excess risk of a fatal mishap. In a study of light aircraft (defined in that study as 10 or fewer seats), accidents involving aircraft landing away from an airport were threefold more likely to be fatal than those occurring at an aerodrome.[60] In a separate investigation[46] of general aviation accidents in North Carolina and Maryland, an even higher fatality risk (9.9) was documented for off-airport accidents. Although both studies included single and multiengine aircraft, the latter potentially confounding the analysis (due to higher landing speeds and hence impact forces[38]), a recent study restricted to twin-engine airplanes again showed an increased risk of a fatal mishap for off-airport crashes.[11]

Improving Safety and Aircraft Accident Survival

It can be argued that two complementary approaches can be employed, proactively, to improve general aviation safety. First is by seeking improvements in pilot performance via training and or currency requirements aided and abetted by advances in technology. The second method is to improve the probability that pilot and passengers survive and/or injuries are mitigated in an accident. Injuries in general aviation accidents are largely due to blunt force trauma and decelerative forces.[69]

A plethora of studies have indicated that, unfortunately, pilot error is a cause of, or factor in, the majority (55–85%) of general aviation accidents.[22,48,58] In contrast, pilot error is cited in the minority (38%) of airline accidents.[48] Recognizing this shortcoming in general aviation, the FAA in a partnership with industry and academia have since 2003 worked diligently toward enhancing flight training programs (inclusive of flight reviews for certificated airmen). The overall goal has been to increase the relevance of training/currency to general aviation operations. Toward this end, a major focus has been managing real-world challenges via scenario-based training, risk management, and single pilot resource management.[32] Although this program is still relatively new and its contribution to improving general aviation safety unclear, the decrease in general aviation accident rate witnessed for 2013 and 2014 is encouraging.

The advent of affordable FAA-approved advanced aviation training devices for general aviation (commonly referred to as flight simulators) in the last decade may prove beneficial for pilot currency in several respects. First it has been well known for decades[68] that IFR-certificated airmen struggle to maintain their instrument proficiency. Indeed, as discussed above, an abundance of data have shown that flight in degraded visibility poses a hazard to general aviation safety.[5,47] Second, airmen too often show a deficiency in single engine procedures following engine failure in twin-engine aircraft.[11] Increased usage of such training devices could very well allow for these deficiencies to be corrected.

Electronic flight displays were first introduced into general aviation aircraft in 2003[53] and, with few if any exceptions, newly manufactured airplanes are equipped with such instrumentation. Additionally, electronic flight displays are now offered after-market for older general aviation aircraft. Although flight displays vary by manufacturer and model, they often hold several advantages over the older analog displays they replace: 1) a lower failure rate due to the absence of moving parts; 2) providing greater situational awareness via moving maps; 3) increased automation; and 4) providing onboard weather, the latter allowing for strategic planning for convective weather avoidance. As to the last benefit, it should be noted that thunderstorms still pose a threat to general aviation. A query of the NTSB accident database has shown, on average, seven thunderstorm-related accidents annually over the past two decades.

Notwithstanding such potential benefits, an earlier study conducted by the NTSB found little enhanced safety for such equipped aircraft.[53] However, it should be emphasized that this study was based on airframe number rather than fleet air-time, so caution should be exercised in interpreting these findings. Another point worthy of discussion is the potential for degraded manual flying skills with over-use of automation. As discussed later, a study of professional airline pilots revealed subpar manual flying skills in a simulator study where automation was progressively disabled.[18]

In addition to the aforementioned proactive approaches via training/currency/improved avionics, the NTSB and the Federal Aviation Administration (FAA) have in the past striven for enhancements in the crashworthiness of general aviation aircraft. Since 1965, aircraft have been required to protect occupants in a crash involving forces of: 9 G forward, 3 G upward, or 1.5 G sideward. Restraint mechanisms have also been improved. Shoulder harnesses were first required for front seats in 1977 and thereafter for all occupants[25] in 1985.

However, subsequent research deemed the aforementioned crashworthiness requirements inadequate in protecting occupants in what should have been survivable accidents.[69] As a consequence, multi-axis dynamic tests were incorporated into the aircraft certification process in 1988 to demonstrate both occupant and seat-restraint system structural performance.[25,67] The first of these dynamic tests emphasized occupant vertical loading toward reducing spinal loading and paraplegic/quadriplegic injury outcomes[52] with 19 G forces for the first row of seats. The second dynamic test assessed the occupancy restraint system and seat structural performance, taking into account floor warpage, which occurs in 50% of accidents.[52] The restraint system was required to withstand a minimum of 26 G for the front seats and 21 G for other seat/restraint systems and protect the occupant from serious head injury.[52] Alas, these dynamic tests for crashworthiness were not retroactive. Thus, aircraft manufactured after 1988 but for which certification occurred prior to 1988 (e.g., Cessna 182) were/are not subject to these criteria.

Have these more stringent crashworthiness standards mitigated occupant injury severity? Indeed, research would suggest this to be the case. Injury severity in accidents involving aircraft certified to these standards were compared with those for airplanes manufactured over the identical time period (1999–2012), but exempt from the new dynamic crash tests. This study clearly showed that for all accidents, as well as those deemed survivable, occupant injury severity was reduced for aircraft certified to the higher crashworthiness standards.[12]

One other issue pertinent to survivability merits discussion. An analysis of general aviation accidents by the FAA indicated that one-third of such mishaps should have been survivable[35] had occupants used their restraint system. For occupants not using the restraint system, an encounter with the airplane controls or instrument panel can lead to serious or fatal injury.[35] Indeed, prior research has shown a clear benefit in shoulder harness restraint affording occupant protection.[54] Unfortunately, past accident analyses have indicated under-utilization of this component of the restraint system,[54] although a more recent study documented a substantially higher compliance for aircraft with separate lap belt and shoulder harness.[12]

Equally importantly, for remotely located accident sites with poor accessibility to first responders, postcrash survivability may also depend on time to rescue. This is of particular importance where adverse ambient temperatures prevail and/or in the event of life-threatening injuries which need to be expediently addressed. A prerequisite for rescue personnel reaching the accident site is determination of its location. For remote locations, this will likely depend on activation of the emergency locator transmitter (ELT) equipment mandatory in the United States for general aviation operations per CFR 91.207. These units can be divided into two types: 1) a newer generation

406 MHz transmitting; and 2) older generation 121.5 MHz-broadcasting units.[57] The former group is superior in accuracy and shows a higher rate of activation in an accident.[57] Indeed, search and rescue crews are able to access the accident site, on average, 6 h faster compared with mishaps involving aircraft equipped with the older generation (121.5-transmitting) ELTs.[57] Unfortunately, as of 2014, only 22% of U.S. general aviation aircraft were equipped with 406 MHz-transmitting ELTs.[34]

Human Factors

So far, while this review has discussed risk factors associated with general aviation accidents and postmishap survival, it is also important to consider human factors leading up to the event. Indeed, the methodology (Human Factors And Classification System—HFACS) for examining such issues in aviation is well established,[59,65] but has been under-used for general aviation.[22] This may be partly related to the fact that general aviation accident reports (and especially those which are nonfatal) rarely capture elements such as organizational influence, adverse mental and physiological states, or resource management, all required for such analyses.[65]

Nevertheless, there are several non-HFACS studies which have sought to identify human factors in general aviation pilot decision-making. In a retrospective study of Alaskan pilots as to previously completed flights,[7] several situations (rescue operations, meeting significant others, time constraints, financial pressures) were identified as motivating pilots to unsafe behaviors. In a similar vein, physical discomfort, or the lack of maintenance facilities or lodgings at an airport were likely to motivate a pilot away from safe behavior.[7]

In-flight decision-making is another element of aviation critical in a dynamically changing environment, especially in the context of weather, and has been the subject of several studies. In the face of adverse weather, general aviation pilots show bias toward completing flights,[58,70] especially after the midway point.[4] In the study of Batt and O'Hare,[4] the researchers demonstrated that 66% of airmen flew from visual to instrument conditions after the midpoint of the flight compared with 33% prior to reaching that point. On the other hand, technology may enhance the decision-making process. In a simulator study, Ahlstrom and coinvestigators[2] reported a positive effect of portable weather data in promoting weather situation awareness and decision-making regarding thunderstorm avoidance. Pilots equipped with onboard weather data were more likely to make larger route deviations and maintain greater distance from convective weather. Importantly, these airmen also showed higher cognitive engagement than those not provided with such information.[2] These findings are important considering the increased prevalence of in-flight weather data in the general aviation cockpit.[34]

However, research has also shown that technology may have a detrimental impact on aviation safety. An early report[10] examining 35,000 NASA Aviation Safety and Reporting System records determined that boredom and complacency associated with increased automation were factors contributing to loss of aircraft separation. However, the number of general aviation pilots in that study was not stated. In a separate study undertaken with airline pilots,[18] an association between task-unrelated thoughts and prolonged struggles in resolving conflicting instrument indications was identified. The authors concluded that the retention of cognitive skills required for manual flying depended to a high degree on airmen being actively engaged in supervising the automation. These findings are particularly germane to general aviation, where automation (in common parlance, "set it and forget it") is becoming increasingly commonplace.

Pilot Health and Toxicology

In this section, health issues relevant to the general aviation pilot and of growing concern over the past decade will be discussed. These include obesity, pilot aging, and the use of potentially cognitive-impairing medications.

One of the greatest concerns over recent years has been the growing obesity epidemic across the United States, with 35% of Americans currently categorized as obese [body mass index (BMI) $\geq$ 30 kg $\cdot$ m^{-2}].[20,37] Regarding flight safety, increased aircraft weight adversely affects aircraft performance in a variety of flight parameters (longer takeoff and landing distances, degraded climb gradients).[30,31] Moreover, airframe failure may occur under turbulent flight conditions when the aircraft is loaded beyond its maximum certified weight.[62] Indeed, a recent study reported a persistent rate of general aviation accidents related to exceedance of the maximum certified aircraft weight,[13] although it was unclear if this weight exceedance was due to occupants or luggage. Nevertheless, over half of these types of accidents had a fatal outcome much higher than the 21% for mishaps unrelated to operating the aircraft outside of this limit. Another concern related to obesity is the potential for sleep apnea,[36,50] since nearly all (90%) individuals with a BMI in excess of 40 are positive for this condition. Not surprisingly, one of the manifestations of sleep apnea is cognitive impairment[36] and, hence, its negative impact on an airman's duties.

The general aviation population is also aging[64] and, unlike air carrier operations, there is no upper limit by which an airman must terminate his/her flying privileges. Nevertheless, research has demonstrated that older airmen are at higher risk for accidents than their younger counterparts.[6,46,49] Indeed, in a flight simulator study of 72 general aviation pilots, older pilots were more likely to make poor in-flight decisions and show less precise flight control during approach to landing in degraded visibility.[44] However, these researchers also found that expertise attenuated the age-related decline.[44] In a separate study of 32 general aviation pilots, while a decline of mental processing was evident for older airmen, wide interindividual variability was evident and the authors concluded that cognitive assessment, rather than chronological age, was superior in predicting flight performance.[19]

Increased usage of potentially cognitive-impairing medications and illicit drugs in general aviation pilots is also of growing concern. In a study of 1353 pilots (the vast majority were general aviation airmen) who perished in aviation crashes, diphenhydramine, an antihistamine, was the most commonly found drug and its usage increased threefold over the preceding two decades.[17] A third of airmen were positive for prescription medications, with 89% of these being general aviation pilots.[17] Additionally, usage of citalopram (a selective serotonin reuptake inhibitor), the use of which could disqualify an airman for medical certification, doubled from 0.7 to 1.8%. A more recent toxicology study on 6677 fatally injured pilots reported similar findings.[51] Overall, 20% of pilots were positive for potentially cognitive-impairing drugs. Over the study period (1990–2012) more than 7% of airmen were positive for sedating antihistamine medicines and, as in the prior study, diphenhydramine was the most frequent drug identified in tissue samples. Interestingly, marijuana use showed an increase mostly over the latter decade of the study.[51]

DISCUSSION

Advances in technology (e.g., onboard weather data, automation) and a shift to scenario-based training bode well for improvement in general aviation. Indeed, the decline (albeit modest) in accident rate over the last few years is consistent with this premise. Wider adoption of new technology, notably angle of attack indicators and synthetic vision,[71] could also improve general aviation safety. That said, enthusiasm in embracing any new technology should be tempered by a thorough knowledge of its limitations and any unintended effect on pilot performance. First and foremost, any use of technology should not allow for the decay of manual flying skills. Second, airmen need to be cognizant as to the limitations of a new technology, e.g., delay in data-linked imagery (**Fig. 3**), absence of wind-shear information, and delay in traffic information (for non-ADS-B equipped aircraft) displayed in the cockpit via the Traffic Information Service Broadcast (FAR/AIM 4-5-8c).

Another area worthy of pursuit is improved occupant survivability. Specifically, how can injury severity be mitigated for the older general aviation fleet exempted from the more current crashworthiness standards? Indeed, the high cost of a new aircraft purchase (> $250,000) means that in all likelihood the majority of the general aviation fleet will, for the foreseeable future, be comprised of aircraft certificated to the lower crashworthiness standards. For such aircraft, installation of after-market airbags, proven effective in reducing injury severity,[54] could represent a cost-viable means. A second option would be for such aircraft to be installed with after-market ballistic parachutes, which may prove efficacious with loss of control events or where off-airport landing sites are unsuitable. Another issue related to survivability is under-usage of the shoulder harness[54] for systems where this component and the lap belt are separate. Introducing an annunciation system to alert airmen as to the disengagement of the shoulder harness or an interlocking system could potentially reduce injury severity. Also, owners/operators and especially those who operate in remote areas should be encouraged to upgrade ELTs to 406 MHz transmitting units in order to reduce rescue times. Finally, keeping in mind the high fatality risk with postimpact fires, manufacturers should consider the development of crash-resistant fuel tanks for airplanes akin to those mandated for rotor-craft.[33] Indeed, such equipage should be made easier with the recent modification of the 14CFR 23 regulations toward consensus-based standards.

As to future general aviation safety research, several areas are worth pursuing. For example, with the advancing age of the general aviation population,[64] their increased accident risk,[49] and the potential for diminished cognitive function,[19] how well do these airmen perform in technologically advanced aircraft? Such aircraft are showing an increased presence in the general aviation fleet.[34,53] Another question is how does the performance of the renter pilot compare with the aircraft owner considering the varied equipment (including aircraft of same make/model but with different avionics) that the former airman may use? Lastly, future research should address the impact of the Small Airplane Revitalization Act of 2013 (Public Law 113-53) on general aviation safety. This law has been promulgated in the form of light aircraft certification per 14CFR Part 23,[24] effective as of late 2016. Specifically, are consensus-based standards (developed by voluntary consensus standard bodies) for aircraft manufacture and retrofitting of existing aircraft with new safety technologies as effective in maintaining general aviation safety compared with certification methods used prior to 2016?

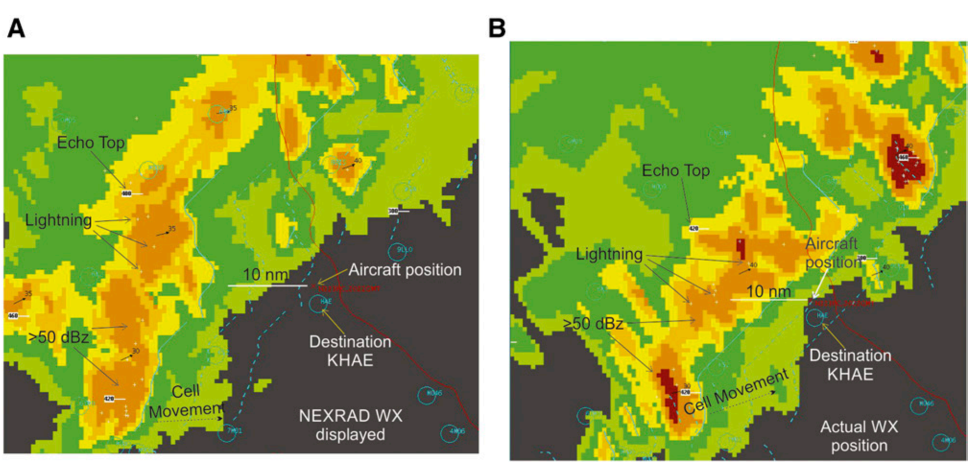

Fig. 3. Delay in in-flight data-linked convective activity display. Aircraft position was determined from a commercially available web-based flight-tracking program. Weather data were from CoSPA (https://cospa.wx.ll.mit.edu). A) Weather display corresponds to what would have been displayed to the pilot at the indicated aircraft position based on a 6-min delay associated with in-flight data-linked weather products. B) The image corresponds to the real-time proximity of the convective weather to the aircraft.

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