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A Comparison of General Aviation Accidents Involving Airline Pilots and Instrument-Rated Private Pilots

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Abstract:	Introduction The extremely low accident rate for U.S air carriers relative to that of general aviation (~1 and ~60/million flight hours respectively) partly reflects advanced airman certification, more demanding recurrency training and stringent operational regulations. However, whether such skillset/training/regulations translate into improved safety for airline pilots operating in the general aviation environment is unknown and the aim of this study. Methods Accidents (1998-2017) involving airline pilots and instrument-rated private pilots (PPL-IFR) operating non-revenue light aircraft were identified from the NTSB accident database. An online survey informed general aviation flight exposure for both pilot cohorts. Statistics used proportion testing and Mann-Whitney U tests. Results In degraded visibility, 0 and 40% (p=0.043) of fatal accidents involving airline and PPL-IFR airmen were due to in-flight loss-of-control, respectively. For landing accidents, airline pilots were under-represented for mishaps related to airspeed mismanagement (p=0.036) relative to PPL-IFR but showed a dis-proportionate count (2X) of ground loss-of-directional control accidents (p=0.009) the latter likely reflecting a preference for tail-wheel aircraft. The proportion of FAA rule violation-related mishaps by airline pilots was >2X (7 vs. 3%) that for PPL-IFR airmen. Moreover, airline pilots showed a disproportionate (p=0.021) count of flights below legal minimum altitudes. Not performing an official preflight weather briefing or intentionally operating in instrument conditions without an IFR flight plan represented 43% of airline pilot accidents involving FAA rule infractions. Conclusions These findings inform safety deficiencies for: (i) airline pilots, landing/ground operations in tail-wheel aircraft and lack of 14CFR 91 familiarization regulations regarding minimum operating altitudes and (ii) PPL-IFR airmen in-flight loss-of-control and poor landing speed management. Practical Applications For PPL-IFR airmen, training/recurrency should focus on unusual attitude recovery and managing approach speeds. Airline pilots should seek additional instructional time regarding landing tail-wheel aircraft and become familiar with 14CFR 91 rules covering minimum altitudes.

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ABSTRACT

Introduction: The extremely low accident rate for U.S air carriers relative to that of general aviation (~1 and ~60/million flight hours respectively) partly reflects advanced airman certification, more demanding recurrency training and stringent operational regulations. However, whether such skillset/training/regulations translate into improved safety for airline pilots operating in the general aviation environment is unknown and the aim of this study. **Methods**: Accidents (1998-2017) involving airline pilots and instrument-rated private pilots (PPL-IFR) operating non-revenue light aircraft were identified from the NTSB accident database. An online survey informed general aviation flight exposure for both pilot cohorts. Statistics used proportion testing and Mann-Whitney U tests. **Results**: In degraded visibility, 0 and 40% (χ^2 p=0.043) of fatal accidents involving airline and PPL-IFR airmen were due to in-flight loss-of-control, respectively. For landing accidents, airline pilots were under-represented for mishaps related to airspeed mismanagement (p=0.036) relative to PPL-IFR but showed a dis-proportionate count (2X) of ground loss-of-directional control accidents (p=0.009) the latter likely reflecting a preference for tail-wheel aircraft. The proportion of FAA rule violation-related mishaps by airline pilots was >2X (7 vs. 3%) that for PPL-IFR airmen. Moreover, airline pilots showed a disproportionate (χ^2 p=0.021) count of flights below legal minimum altitudes. Not performing an official preflight weather briefing or intentionally operating in instrument conditions without an IFR flight plan represented 43% of airline pilot accidents involving FAA rule infractions. **Conclusions:** These findings inform safety deficiencies for: (i) airline pilots, landing/ground operations in tail-wheel aircraft and lack of 14CFR 91 familiarization regulations regarding minimum operating altitudes and (ii) PPL-IFR airmen in-flight loss-of-control and poor landing speed management. **Practical Applications:** For PPL-IFR airmen, training/recurrency should focus on unusual attitude recovery and managing approach speeds. Airline pilots should seek additional instructional time regarding landing tail-wheel aircraft and become familiar with 14CFR 91 rules covering minimum altitudes.

Keywords: general aviation, light aircraft, flying accidents, airline pilots, aviation safety

INTRODUCTION

Civil aviation can be arbitrarily divided into (i) revenue-based transportation comprised mainly of air carrier operations utilizing transport-category aircraft (>12,500 lbs.) and (ii) general aviation employing light aircraft (≤12,500 lbs.) [1]. While air carrier operations have, over the last few decades, boasted a stellar safety record [1], alas general aviation, despite a modest decrease in accident rate over most recent years, still shows a lackluster record with a >60 times higher accident (herein also referred to as mishaps) rate [1, 2].

The discrepancy in safety between airline and general aviation operations probably reflects multiple factors. First is the advanced certification and recurrency training requirements for airline aircrews. Presently, to exercise flying privileges for an air carrier, pilots must be air-transport pilot (ATP) certificated [3] whereas for general aviation operations the majority of general aviation airmen [4] hold a private pilot (PPL) certificate. In this regard, greater precision in regard to both instrument flight (i.e. operating the aircraft by sole reference to flight instruments) [5, 6] and landing operations are demanded for the ATP certificate. Specifically for instrument flight, a one quarter versus a three quarter scale lateral deflection of the course deviation indicator is allowed for the ATP [5] and private pilot instrument ratings [6] respectively. Similarly landing operations have tighter tolerances for ATP certification (a 100 versus 200 foot margin for spot landings). Transport-category aircraft spot landings (to mitigate against the possibility of a runway overrun) require precise energy-management [7, 8] due to greater landing distances required than a light aircraft. Recurrency training for air carrier pilots is also more frequent and demanding compared with general aviation [9]. Crews have to undertake such training every 6 (Captain) or 12 months (first officer) whereas a flight review for general aviation airmen operating light aircraft for non-revenue is only required once every 24 months [10]. Moreover, recurrency programs for airline pilots are more extensive typically consisting of a multi-day program (comprised of maneuvers, abnormal procedures, upset recoveries and line-oriented flight training [9]). In contrast a flight review for a PPL requires only 1 hour of flight and tasks are at the sole discretion of the instructor “as necessary for safe flight” [10]. A second reason for the superior safety of the air carriers is the more stringent regulations (14CFR 121) [11] governing their operations (relative to the corresponding rules (14CFR 91) governing general aviation [12]) as well as the use of standard operating procedures [13] the latter absent from general aviation. For instance, whilst airport minimum visibility requirements apply to departing air carrier flights

(14CFR 121.637), no such restrictions limit general aviation (14CFR 91) operations [11]. Third, although not mandatory, many US carriers have adopted safety management systems (SMS) and threat and error management training per Federal Aviation Administration recommendations [14, 15]. Lastly, aircraft employed for air carrier operations are certificated (14CFR 25) to a higher safety standard [16] with a greater level of equipment redundancy than airplanes (14 CFR 23) [17] used in general aviation.

Nevertheless, for the airline pilot operating light aircraft under 14CFR 91, certain aspects of air carrier operations could potentially offset the safety-promoting factors cited above. For example, automation, more prevalent for transport-category aircraft, has raised concern as to the erosion of manual flying skills with one research study demonstrating degraded Boeing 747 pilot performance when tasked with manual flying [18]. In addition, the typical general aviation light aircraft requires more control inputs of the primary flight control surfaces for any given wind conditions than a much heavier transport-category airplane subjected to identical conditions. Lastly, virtually all transport-category aircraft employed by air-carriers require two person crews (14CFR 25 certification [16]) allowing for a prescriptive division of tasks for the pilot flying and pilot monitoring (14CFR 121.542-545 [11]). In contrast, the vast majority of light aircraft are operationally approved for, and piloted, by a single crew member [19] with an attendant increase in workload [19]

Thus, whether more rigorous airman certification/recurrency training/stringent operational rules for airline pilots translates into improved safety in the general aviation environment or conversely, whether lesser automation coupled with lighter aircraft performance (more subject to winds) offsets such safety benefits has yet to be determined. Accordingly, we undertook a study to determine the level of safety of airline pilots flying non-revenue, light aircraft in operational areas where their professional training/experience/regulations, as described above, would be expected to impact. Specifically, the following question was posed: are airline pilots superior to their instrument-rated private pilot (PPL-IFR) counterparts as evidenced by a reduced proportion of (i) accidents attributed to an in-flight loss-of-control in degraded visibility- an event [20] previously cited on the NTSB “Most Wanted List” [21] (ii) landing accidents ascribed to deficient pilot technique and (iii) mishaps involving violation of the general aviation operations regulations (14CFR 91).

MATERIALS AND METHODS

Procedure

Accidents were identified from a retrospective search of the downloaded NTSB Microsoft Access database (2018 Oct release) [22] involving (i) airline pilots the latter defined as an ATP-certificated professional airman holding a Class 1 medical, a type rating in a transport-category aircraft (or employed by an air carrier) and 65 years or younger and (ii) as a control group, instrument-rated PPLs holding a Class 3 medical. It should be noted that the PPL population was deliberately restricted to those airmen concurrently holding an IFR rating (hereafter referred to as PPL-IFR pilots) to afford a comparison for airman performance in degraded visibility - instrument flying proficiency representing a core element of the ATP certificate [5].

The database was queried for accidents occurring over the period spanning 1998-2017 involving piston engine-powered airplanes ($\leq$12,500 lbs.) in which flights were conducted under general operating flight rules (14CFR 91 [12]) for personal missions. Accidents in Alaska were excluded from the query strategy. Data were exported to Excel and checked for duplicates (which were deleted). Accident causes were per the NTSB final report. Airline pilot type rating data was obtained from a variety of publicly available resources [23, 24] and by the FAA Office of Accident Investigation and Prevention.

High-energy landings were defined as those for which the NTSB final report cited porpoising, multiple bounces or floating of the accident airplane [25, 26]. 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 [25].

An anonymous online survey as to non-revenue, 14CFR 91 operations of light aircraft by PPL-IFR and airline pilots (approved by the Embry Riddle Aeronautical University Institutional Review Board) to inform flight times and ambient conditions was constructed in SurveyMonkey^{R} (www.surveymonkey.com) and pre-tested by four FAA Safety Team general aviation pilots as well as co-authors MS and DC. Responses from the airline and PPL-IFR pilot populations at large were collected over the period spanning Feb 14-April 05, 2020.

Statistical Analysis

Proportion testing used contingency tables and a Pearson Chi-Square or Fisher's Exact (2-sided) tests to determine where there were statistical differences [27, 28]. The contribution of individual cells in proportion tests was determined using standardized residuals (Z-scores) in post-hoc testing. Differences in median values for non-normally distributed data (determined using a Shapiro Wilks test) were tested using a Mann-Whitney test. All statistical analyses were performed using SPSS (v24) software.

RESULTS

Accident Pilot Population

In the retrospective analysis, a query of the NTSB Access database for general aviation accidents in the USA involving light aircraft occurring over the period spanning 1998-2017 returned 124 and 934 airline and PPL-IFR pilots with median ages of 49 and 54 years respectively. These two airman cohorts had accrued a median total flight experience of 12,917 and 1,042 hours in all aircraft respectively.

In-Flight Loss-of-Control Accidents in Degraded Visibility.

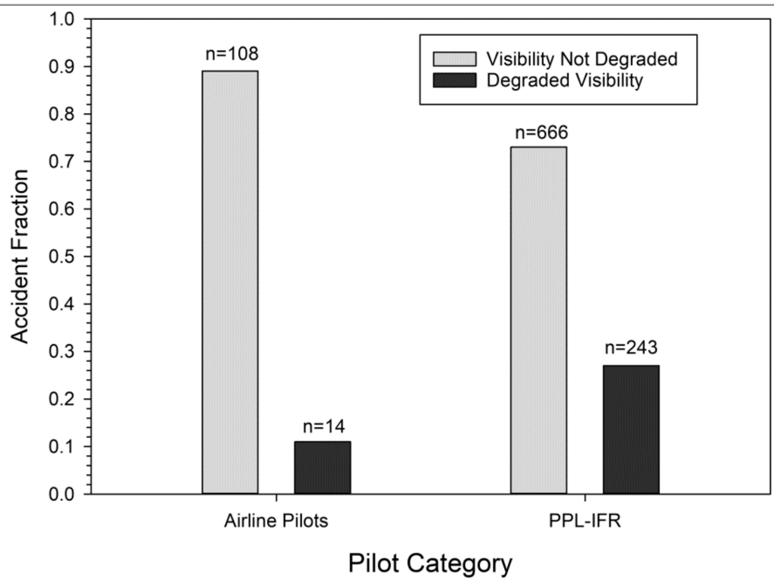

Figure 1 Accidents in Degraded Visibility.
The proportion of light aircraft accidents in degraded visibility is shown for each pilot cohort. Degraded visibility was operationally defined as a cloud ceiling of equal to or less than 3000 ft. AGL or ambient night lighting. Proportion differences were tested with a 2-sided Chi-Square test. PPL-IFR, instrument rated private pilots, n=accident count.

We argued, that with the greater precision required for instrument flight per ATP certification [5, 6] and an increased exposure to degraded visibility concomitant with their professional occupation a reduced proportion of in-flight loss-of-control accidents in such visibility would be evident for airline pilots. Herein, degraded visibility was operationally defined as less than visual flight rules (i.e. cloud ceiling of $\leq$ 3000 feet (AGL)) and/or ambient night lighting [29].

While 27% of instrument-rated private pilot (PPL-IFR) accidents occurred in degraded visibility (Figure 1), airline pilots showed a lower proportion (11%) of such mishaps, a difference which was statistically significant (χ^2 p<0.001). Loss-of-control accidents often have a fatal outcome [30] and indeed, this cause was previously cited on the NTSB "most wanted" list [21]. Perhaps not surprisingly, 40% of fatal accidents in degraded visibility involving PPL-IFR airmen were ascribed to this event (Figure 2). In contrast, for airline pilots, there were no accidents in degraded visibility attributed to in-flight loss-of-control. Again, this difference in proportions between the two pilot groups was statistically significant (χ^2 p=0.043).

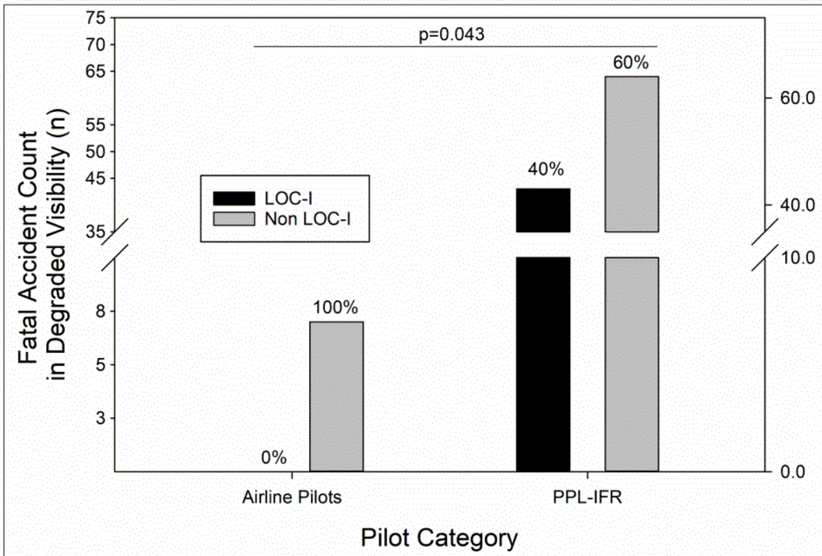

Figure 2. Fatal In-Flight Loss-of-Control accidents in Degraded Visibility
Fatal accident counts in degraded visibility (as described in Figure 1) due to in-flight loss-of-control (LOC-I) or other causes (Non LOC-I) for the specified pilot category are shown. The difference in proportions of accidents was tested for with a Fisher's Exact Test.

To determine if this absence of in-flight loss-of-control accidents incurred by airline pilots was due to diminished general aviation flying in degraded visibility, the air carrier and PPL-IFR pilot populations at large were, in a prospective online survey, queried for their flight times and environmental conditions whilst operating light aircraft under 14CFR 91. Of 913 respondents, 295 airline and 618 PPL-IFR airmen completed the survey (Table 1). While indeed, the latter airmen showed an approximately 3 fold increase in annual IMC/night flight times compared with air carrier pilots, this difference unlikely accounts for the complete lack of in-flight loss-of-control accidents involving airline pilots operating in degraded visibility.

Landing Accidents.

Landing a transport category aircraft requires a higher degree of precision than a comparable operation with a light aircraft due to the greater weight and physical dimensions. Specifically, a substantially higher weight (e.g. maximum landing weight of a Boeing 737-800 is 146,275 lbs. [31] 57 fold higher than that of a Cessna 172S (2,550 lbs.) [32]) necessitates a faster landing speed which must be closely adhered to in order to avoid a runway overrun. Likewise, the greater lateral spacing of the main landing gear wheels also demands precision in directional control of a transport-category aircraft after touchdown. In contrast, operating a light aircraft at the majority of US civil aviation airports [33] with their relatively long and wide runways allow for deficiencies in the aforementioned skills with a reduced risk of a runway excursion. To determine if the airline pilot landing skillset transferred to the operations of light aircraft, landing accidents were compared for the two pilot cohorts.

Across all phases of flight operations, landing accidents were the most frequent for both airline and PPL-IFR pilots accounting for 39% (n=22) and 27% (n=259) of mishaps, respectively. Although the elevated proportion for air carrier airmen relative to the PPL-IFR cohort was not statistically different (χ^2 p=0.069), nevertheless, it contravenes the notion that landing proficiency skills in transport-category aircraft transfers to light aircraft operations.

		Airline Pilots	PPL-IFR	P Value
	n	295	618	
Age	Median (h)	53	60	<0.001
	Q1 (h)	43	48	
	Q3 (h)	60	68	
Total Time Light Aircraft (h) Most Commonly Flown	n	293	615	
	Median (h)	500	730	0.011
	Q1 (h)	260	323	
	Q3 (h)	1350	1700	
Annual Light Aircraft Time (h) Airplane Most Frequently Flown	n	292	613	
	Median (h)	75	80	0.005
	Q1 (h)	44	50	
	Q3 (h)	100	120	
Last 90 Days Flight Time (Make-Model)	n	295	618	
	Median (h)	10	16	<0.001
	Q1 (h)	5	9	
	Q3 (h)	20	30	
Number of Flights in Light Aircraft Most Commonly Operated Last 90 Days	n	295	618	
	Median	8	10	0.069
	Q1	3	5	
	Q3	15	17	
Annual IMC Time (h) Light Aircraft Most Frequently Operated	n	295	618	
	Median (h)	2	7	<0.001
	Q1 (h)	0	2	
	Q3 (h)	10	15	
Annual Night Time (h) Light Aircraft Most Commonly Used	n	295	618	
	Median (h)	2	7	0.005
	Q1 (h)	0	2	
	Q3 (h)	10	15	
Landing Gear Type	Tail-Wheel (n)	90	32	p<0.001
	%	31	5	
	Nose-Wheel (n)	205	586	
	%	69	95	

Table 1. Prospective Survey of Airline and PPL-IFR Pilots.

Results of an online survey conducted of the airline (Airline) and instrument-rated private (PPL-IFR) pilot population-at-large. Data were non-normally distributed per a Shapiro-Wilk test and accordingly differences in median values tested using a Mann-Whitney U Test. Proportion differences for landing gear type was tested using a Chi-Square test. h, hours; Q, quartile. IMC, instrument meteorological conditions.

Landing accidents ascribed to deficiencies in pilot stick and rudder skills were then categorized as to cause. Airline pilots were superior to their PPL-IFR counterparts in energy management with zero landing mishaps ascribed to either excessive (High-energy Approach) or insufficient speed (Low-Energy Approach) (Figure 3). On the other hand, approximately 26% of landing mishaps by PPL-IFR airmen were due to a high-energy approach (defined as any in which the aircraft porpoised, floated or bounced multiple times) a difference which was statistically significant (χ^2 p=0.036).

Conversely, a higher (χ^2 p=0.009) proportion of landing accidents which the NTSB binned into the "ground loss of directional control" category (0.92 vs. 0.53) was evident for airline pilots (Figure 3). This was unexpected as managing this vector component is more critical for a transport category aircraft with its substantially wider main wheel base compared with that of a light aircraft. We considered the possibility that this surprising finding was related to the type of aircraft landing gear. Tail-wheel (conventional) and tricycle (nose) landing gear-equipped aircraft exhibit different handling characteristics and are well recognized as more challenging to maintain ground directional control particularly in a cross-wind [34]. Indeed, consistent with this argument, while over 70% of landing accidents involving air carrier pilots were

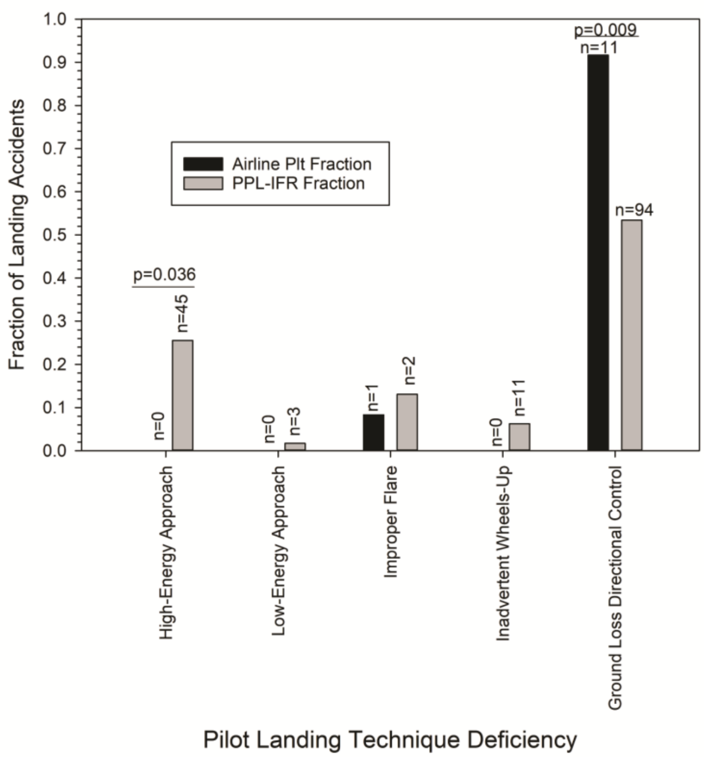

Figure 3. Causes of Landing Accidents Related to Deficiency in Pilot Technique.

The proportion of landing accidents for the specified causes related to pilot stick-and-rudder skills is illustrated as a function of pilot category. A high-energy landing accident was one in which the NTSB report cited porpoising, floating or multiple bounces of the aircraft. A low-energy landing mishap was one in which the aircraft stalled above the runway. The p values shown were derived from adjusted residuals of a Chi-Square test. n, count of accidents.

incurred with tail-wheel airplanes, this proportion was substantially lower (<30%) for such mishaps involving PPL-IFR airmen (Figure 4). This difference in accident aircraft landing gear type was statistically significant for the two pilot cohorts (χ^2 p<0.001). Presumably, the over-representation of this type of landing accident for airline pilots reflects their preference for such-equipped aircraft for general aviation operations (Table 1). It is worth noting that none of the ground loss of directional control accidents involving airline pilots in tail-wheel equipped airplanes was due to an exceedance of the maximum demonstrated cross-wind component.

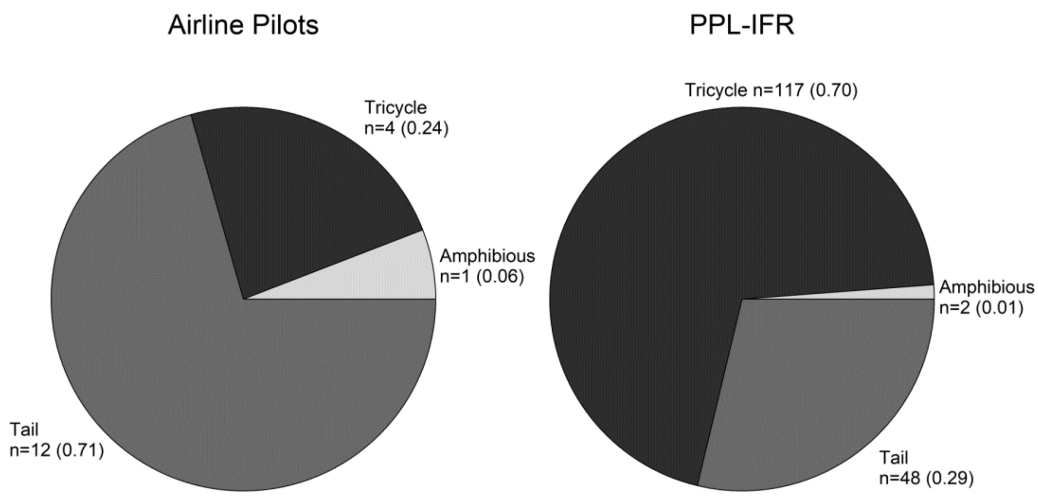

Figure 4. Landing Gear Type for Accidents Ascribed to a Deficiency in Pilot Technique.

The proportion of accident aircraft with the specified undercarriage equipment shown (values in parentheses) for landing mishaps ascribed to a deficiency in pilot stick-and-rudder skills. Difference in proportions was tested using a Fisher's Exact Test. n, accident count.

Violation of FAA Regulations.

Airline operations are under strict vigilance for infringement of the FAA regulations via a variety of mechanisms including flight quality assurance programs [35] and audio recordings of the flight deck [11]. In contrast, little comparable oversight exists for general aviation. Moreover, airline pilots are well aware that infractions of the regulations leading to an incident or accident may culminate in the revocation of flying privileges and hence income. With these factors in mind, we hypothesized that a diminished fraction of FAA violation-related general aviation accidents would be evident for these airmen whilst operating light aircraft.

Contrary to expectations, the proportion of 14CFR 91 rules transgression-related mishaps by airline pilots, although low, was more than double (7 vs. 3% respectively) that for accidents involving PPL-IFR airmen. There was little evidence of a temporal trend in such accidents as 3 and 4 of mishaps involving an infraction of the FAA regulations occurred over the 1998-2007 and 2008-2017 periods respectively, The infractions of the

FAA regulations were then sub-categorized (Table 2). Interestingly, there was a disproportionate (χ^2 p=0.021) number of violations involving airline pilots in which the light aircraft was

	Airline Pilots			PPL-IFR		
FAA Violation	Count (n)	Fraction		Count (n)	Fraction	Pvalue
Disqualifying Medical Condition/Use of Illegal Drugs	0	0.00		4	0.10	>0.05
Intentional Visual Flight Departure into Instrument Conditions OR No Pre-Flight WX Briefing	3	0.43		22	0.54	>0.05
Lack of IFR Currency	0	0.00		2	0.05	>0.05
Maneuvering Flight below Legal Minimum Altitude	4	0.57		7	0.17	0.021
Un-Airworthy aircraft	0	0.00		6	0.15	>0.05
						>0.05
TOTAL	7	1		41	1	

Table 2. Categories of FAA Violations for Airline and PPL-IFR Pilots.

The count (n) and proportion (fraction) of accidents in which the NTSB cited the specified FAA violation is tabulated. P values were derived from adjusted residuals from a Fisher's Exact Test. Wx, weather.

operated below the legal minimum altitude -accounting for 57% of FAA rule infractions. In contrast, this subcategory accounted for 17% of all PPL-IFR accidents in which the FAA regulations were breached. Interestingly, the second most common (constituting 43% of all FAA transgressions) violation of the FAA regulations for accidents involving airline pilots was the "No Pre-Flight WX Briefing OR Intentional Flight Operations in Instrument Conditions." However, in statistical testing, the proportions corresponding to this violation category for the two groups of accident pilots were comparable (p>0.005).

DISCUSSION AND CONCLUSIONS

We show herein that, for general aviation operations, airline pilots show both safety improvements and deficits relative to PPL-IFR airmen. Regarding improvements the absence of in-flight loss-of-control accidents in degraded visibility was notable for airline pilots. Conversely, and initially surprising, these airmen were more likely to experience a ground loss of directional control during the landing roll. Finally, in regard to violations of the FAA regulations, despite the regimented nature of air carrier operations, airline pilots showed a greater proclivity for disregarding the minimum altitudes prescribed by 14CFR 91.

The safety of the airline pilots operating in degraded visibility, as witnessed by an absence of any in-flight loss-of-control accidents, merits some discussion especially since such mishaps under corresponding conditions in the general aviation sector are frequent and moreover carry a high fatality rate [30]. Certainly, these professional airmen have a high exposure to such weather conditions as part of their professional occupation. In contrast PPL-IFR pilots eschew operating in such weather [36] and struggle to maintain currency to legally operate in instrument conditions [37]. Nevertheless, transport-category aircraft are highly automated and there is current debate as to whether such automation adversely affects stick-and-rudder skills. Indeed, in a study of Boeing 747 aircraft pilots tasked with performing an instrument approach in which aircraft automation was progressively degraded [18], 44% were in error in identifying the missed approach fix and 16% descended below the minimum altitudes prescribed by the approach chart. How then do these findings reconcile with the stellar performance of airline pilots operating light aircraft with less automation [36] in degraded visibility in the general aviation environment? We suspect that a combination of increased experience operating transport-category aircraft under such conditions and ATP certification [38, 39] demanding a higher level of proficiency in instrument flight (relative to the IFR rating held by PPL airmen) more than offset any decrements caused by frequent automation usage.

The sub-classification of landing accidents related to pilot technique informs performance deficiencies for both the PPL-IFR and airline pilot cohorts. Indeed, the preponderance of landing accidents caused by poor landing speed control (mainly high-energy) for the former airmen contrasting with the absence of such mishaps for the latter pilots is noteworthy. Our findings are congruent with those of prior studies [25, 26] reporting on the tendency of general aviation pilots to carry excessive landing speeds (higher than $V\text{-}_{Ref}$ –airplane speed in the landing configuration, at the point where it descends through the 50 ft. height) [40]. Such a practice with transport category aircraft would lead to an abundance of runway overruns and air carrier pilots must adhere closely to the approach speed regimen. On the other hand, airline pilots relative to their PPL-IFR counterparts showed a greater deficiency in maintaining ground directional control during the landing roll. We argue that several reasons likely underlie this observation. First, airline pilots accrued a lower amount of time-in-type as evident from both a prospective survey of the airline pilot population-at-large as well as that for the accident airmen (median make-model flight times-132 and 261 hours for airline and PPL-IFR respectively). Second, compared with operating a transport category aircraft, light aircraft demand more control inputs for identical landing wind conditions. Third, and likely most important, is the preference of airline pilots for operating light aircraft with tail-wheel landing gear (conventional undercarriage). It is well established that such airplanes show ground handling characteristics at variance with tricycle aircraft [41]. Specifically, conventional aircraft are inherently unstable on the ground and exhibit an exaggerated tendency to weathervane during ground operations in a cross-wind [41]. In regard to this latter point, we considered the possibility that the involved conventional under-carriage aircraft had unique ground handling characteristics based on (i) being of experimental build or (ii) less rigorous certification standards in effect for older aircraft. However, these arguments are unlikely for two reasons. First none of the ground loss of directional control mishaps involved experimental (i.e. non-certificated) aircraft. Second, whilst indeed the involved aircraft were of older vintage and subject to earlier certification regulations (i.e. civil air regulations-CARs [42]), such standards with respect to ground handling were identical to those promulgated for later aircraft certification per 14CFR 23.231-233 [43] effective up to 2017.

Surprisingly, airline pilots involved in accidents did not show greater compliance with the FAA regulations than PPL-IFR airmen. For this accident category, more than half of mishaps were due to these airmen operating the aircraft below the minimum altitudes prescribed by 14CFR 91.119 (500 and 1,000 feet above ground for other-than-congested and congested areas respectively) [12]. Why is this? One must consider that airline operations are all conducted under IFR rules requiring adherence to minimum altitudes defined by jet routes, standard arrivals and departures [44] absent for VFR operations. Whether airline pilots were unfamiliar with the minimum altitudes for VFR operations per 14CFR 91 [12] or were deliberately operating contrary to such regulations is currently unknown. Based on anecdotal information we suspect the former. Thus, for three of the four minimum altitude infractions, in their NTSB statements one pilot admitted to flying “ along a creek” another, “through a valley” with the third airman stating descending to what he ”thought was a safe VFR altitude.” Notably, none of these accidents were due to degraded visibility ruling out “scud-running” as a causal factor. Another question raised by this infraction relates to the role of surveillance evident in the airline industry but absent from general aviation. Consequently, general aviation pilots may be tempted to infringe such minimum altitudes with immunity nevertheless developing a greater skillset with respect to operating below legal minimum altitudes.

Also noteworthy was the disregard by airline pilots for the FAA regulations necessitating preflight weather briefings and intentional flight into instrument conditions. We entertain the possibility that the former transgression relates to the role of the airline dispatcher in preparation of a weather briefing for their pilots. It may be that (i) the airline pilot is so habituated to receiving this prepared material that such a task is overlooked for general aviation and/or (ii) he/she may be unaware of the tools to obtain a weather brief via official sources typically used by the general aviation pilot.

Although our research is the first to report on airline pilot safety in general aviation, an older study of accidents spanning the 1973-1983 period merits discussion [45]. The authors of that report noted that most ATP-certificated pilot accidents were due to aerobatics whereas, in the current study, aerobatics was cited for a single airline pilot accident. Moreover, only 4% of the airline pilot population-at-large survey respondents indicated this as the primary purpose of their general aviation flights. How can the differences in the results between the two studies be reconciled? A key difference in study design is pertinent. Specifically, the Salvatore and co-author study was not limited to airline pilots per their two inclusion criteria: (i) ATP-certificated and (ii) a self-description as a “professional pilot.” Thus, the cohort would also include pilots engaged in charter operations (14CFR 135), corporate flying and other non-air carrier professions with corresponding lower levels of training/recurrency/oversight. In addition, much has changed in general aviation over the intervening three decades in regard to technology such as in-flight data-linked weather and in the case of general aviation scenario-based training [46].

Our study was not without limitations. First, the absence of denominator data for both pilot cohorts operating under 14CFR 91 regulations precluded the determination of accident rates. Second, the count of airline pilot accidents was, in some cases, small. Third, risk exposure was determined in a prospective study with accident data obtained in a retrospective query. Fourth, type rating data, used as one of the criteria to operationally define an airline pilot, was in some instances based on information current at the time (2019-2020) over which the research was conducted. As a result, for a subset of non-fatal accident pilots, a type rating may have been achieved after the mishap. Fifth, we accept that the multiple criteria used concurrently (ATP certification, a Class 1 Medical and type rating in a transport category aircraft) to operationally define an airline pilot might also lead to the inclusion of a few airmen who do not fly for an air carrier. Finally, (and not addressed in the current study) it would be of particular interest in a future survey to determine how airline and PPL-IFR pilots' views compare with respect to safe operations of a light aircraft. In a similar vein, endeavors to capture accident pilot attitudes in NTSB reports with respect to "thrill-seeking" in an environment absent for surveillance are lacking.

Although the objective of the current study was to determine the safety of airline pilots in the general aviation environment, the findings inform performance deficiencies for both these and PPL-IFR pilots which warrant redress. Notably, regarding the preponderance of in-flight loss-of-control fatal accidents involving PPL-IFR pilots, such airman would be well served by increasing the frequency of recovery from unusual attitudes maneuvers by reference to instruments in recurrency training. Moreover, for airmen with deficient IFR proficiency skills, safety could be improved by development of computer-based training systems which provide pilots with skills to recognize cues (e.g. cloud bases, visibility, darkening) associated with impending IMC as reported elsewhere [47]. The wide availability of advanced aviation training devices should make for a cost-effective means of achieving/maintaining such proficiency. PPL-IFR safety would also benefit from an increased emphasis on landing energy/speed management in training/recurrency. As to airline pilot safety, airmen seeking to operate a light aircraft with tail-wheel landing gear should consider, post tail-wheel endorsement, additional dual time with an instructor (well experienced in conventional landing gear operations) focusing on landing/ground operations particularly under crosswind conditions. This recommendation would be on par with the initial operating experience required (14CFR 121.913) for airline pilots [11]. Finally, it would behoove airline pilots to adhere more closely (and if necessary familiarize themselves with) to 14CFR 91 regulations pertinent to general aviation operations (in particular minimum altitudes) towards improving their safety whilst operating light aircraft.

PRACTICAL APPLICATIONS

For PPL-IFR airmen, training/recurrency should focus on unusual attitude recovery and managing approach speeds. Airline pilots should seek additional instructional time regarding landing tail-wheel aircraft and become familiar with 14CFR 91 rules covering minimum altitudes. Lastly, future accident reporting should seek to capture airline pilot attitudes in the "overconfidence/misplaced motivation" nano-codes in the

Preconditions for Unsafe Acts/Adverse Mental States domain per the established Human Factor Classification System [48, 49].

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