Analysis of Air Taxi Accidents (2004–2018) and Associated Human Factors by Aircraft Performance Class

Don Budde; Jochen Hinkelbein; Douglas D. Boyd

INTRODUCTION: Air taxis conduct nonscheduled transport and employ aircraft in various performance categories hereafter referred to as low, medium, and high performance, respectively. No study has yet addressed fixed-wing air taxi safety by performance category. Herein, we compared accident rates/occupant injury across air taxi airplane fleets grouped by performance category and identified human factors contributing to fatal accidents for airplanes in that category with the highest mishap rate.

METHODS: Accidents (2004–2018) in the United States were identified from the National Transportation Safety Board database. General Aviation/Part 135 Activity Surveys provided annual fleet times. Fatal accident contributing factors were per the Human Factors Classification System (HFACS). Statistics utilized Poisson distributions, Chi-Square/Fisher, and Mann-Whitney tests.

RESULTS: There were 269 air taxi mishaps (53 fatal) identified. Over the 15 yr, the accident rate (1.10/million flight hours-all categories) declined 50%, largely due to a reduction in medium/high performance category airplane crashes. However, little temporal change was observed for low performance airplanes (1.5/million flight hours) and injury severity trended higher. At the aircrew/physical environment levels, HFACS revealed decision (improper choices), skill-based (stick and rudder) and perceptual (night, instrument conditions) errors contributing to $>$ 60% of fatal accidents involving low performance airplanes. At the organizational level, failing to correct problems, time pressures, and incentive systems contributed to 16% of fatal mishaps.

CONCLUSION: Safety deficits remain for the low performance category air taxi fleet warranting increased pilot instrument flight training/utilization of the mandatory 3-axis autopilot in degraded visibility. Safety culture improvements to address issues of personnel/equipment/training deficiencies, failing to correct problems, and time pressures/a safety-compromising incentive system all need to be addressed.

KEYWORDS: air taxis, general aviation, human factors, charter flights.

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Civil aviation can be broadly divided into operations undertaken by 1) scheduled air carriers commonly utilizing transport-category aircraft ($>$ 12,500 lb); and 2) general aviation employing nontransport category light ($<$ 12,500 lb) airplanes.[3] Alas, while a stellar safety record has been witnessed for air carrier operations over the last few decades, this is less evident for general aviation. Indeed, despite a modest decrease in accident rate over the most recent years, general aviation overall still shows a $>$ 60-fold elevated accident rate (all injuries)[7] and a substantially higher fraction of fatal accidents.[3,7,31]

Although it is clear that general aviation safety is inferior to that of the air carriers, nevertheless, the former encompasses a wide range of flying activities, some with more restrictive operational rules. For example, a private pilot undertaking a

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nonrevenue, personal mission is subject to the less restrictive 14CFR (Code of Federal Regulations) 91 operational rules[14] compared to a crew of a revenue-generating air taxi, the latter of which must adhere to the more stringent 14CFR 135 regulations.[16] By way of definition, in the United States, air taxis represent commercial enterprises approved for nonscheduled passenger/freight transport utilizing aircraft with a maximum of 30 passengers or payload capacity of 7500 lb.[11,15] In common vernacular, such on-demand air taxis are often described by the nonaviation community as charter flights and herein we use both terms interchangeably.

How do 14CFR 135 and 14CFR 91 regulations differ? For example, 14CFR 135 regulations require minimum pilot flight experience (1500 and 500 h for pilot-in-command and second-in-command, respectively), advanced certification (at least a commercial license), more extensive initial[12] and more frequent recurrency training (annually[16] vs. alternate years[13]) and duty/rest time requirements. Moreover, in the absence of a second-in-command, aircraft employed for air taxi operations must be equipped with a 3-axis autopilot per 14CFR 135.105[15,17] whereas no such requirement exists for operations conducted under 14CFR 91. Lastly, minimum visibility requirements at the estimated time of arrival at the destination airport must be met for an air taxi aircraft to depart (14CFR 135.210).[11,15] Such a requirement is absent from 14CFR 91 regulations.

Considering the greater safety-promoting regulations governing air taxi operations in the general aviation sector, we undertook a study with three objectives: 1) determine the safety of fixed-wing air taxis over the 15 yr period spanning 2004–2018 using non-air taxi, personal mission, airplane flights conducted under 14CFR 91[14] as comparator; 2) considering the performance deficits of piston engine aircraft (particularly in terms of service ceilings), which can limit weather-avoidance options and obstacle clearance in high terrain operations, compare accident rates for air taxis powered by piston engines (defined herein as low performance category) with those aircraft equipped with turbo-prop or turbo-jet/fan powerplants referred to hereafter as medium and high-performance categories, respectively; and 3) identify the human factors contributing to lethal accidents for airplanes in the performance category with the worst accident rate per objective 2. Objective 2 is of particular interest in view of the rapidly evolving state of electrical/hydrogen fuel cell/hybrid engine-powered aircraft,[25,32] which will likely populate air taxi fleets in the foreseeable future.

METHODS

Procedure

Accidents were identified from a retrospective search of the downloaded National Transportation Safety Board (NTSB) Microsoft Access® database (2020 May release).[30] The database was queried for accidents occurring over the period spanning 2004–2018 involving airplanes operating under 14CFR 135 regulations and for which the operator held an Air Taxi operator certificate. Accidents in Alaska and those whose missions were air-medical/air-tour related were all excluded from the query strategy for the following reasons: 1) the latter operate under more stringent regulations;[1] and 2) operational conditions are substantially more challenging in Alaska, e.g., use of unimproved airstrips, whiteout, and mountainous terrain. Data were exported to Excel and de-duplicated. Engine type, pilot certification and flight times, injury severity, and flight conditions were all per the NTSB final report. Occupant injury severity definitions were per 14CFR 830.2.[17] The current research did not constitute "human subjects research" by virtue of all the data employed being in the public domain.

Annual fleet times, used to calculate accident rates, were from the General Aviation and 135 Activity Surveys[22] which separates air taxi flight times for fixed-wing aircraft by powerplant type (and hence performance category as defined herein). Data for 2011, absent from the survey, were interpolated from the years 2010 and 2012. For aggregate periods, fleet times represented the sums for the specified years.

Accident classification by the Human Factor Classification Analysis (HFACS)[5,36] was performed by all three authors, all of whom are subject matter experts. Where scores diverged, the corresponding case was discussed and rescored based on consensus.

Statistics

Poisson distributions,[9] using the natural log of fleet times, were used to determine whether temporal changes were statistically significant. Proportion testing used 2×2 contingency tables and a Pearson Chi-Square/Fisher (2-sided) test to determine where there were statistical differences.[2,24] Differences in median values for non-Gaussian data were tested using a Mann-Whitney test.[24] All statistical analyses were performed using SPSS® (v26) software (IBM® Armonk, NY).

RESULTS

Over the 15 years spanning 2004–2018, a query of the NTSB aviation accident database returned a total of 269 mishaps involving airplanes operating under an air taxi certificate and 14CFR 135 flight regulations. Of these mishaps, 53 had a fatal outcome (20%).

Temporal Decrease in Accident Rates for Air Taxis

We first determined whether accident rate for air taxi flights varied over the 15-yr capture period. For the earliest period (2004–2008), the all-injury accident rate (aggregated for the three performance categories) was 1.10 per million flight hours (**Fig. 1A**). This value decreased thereafter with a 50% reduction evident for the most recent years (2014–2018). Using a Poisson distribution, this latter reduction was statistically significant ($P < 0.001$) relative to the initial period. Similarly, the fatal accident rate also showed a parallel decline over the 15 yr from 0.27 to 0.06 (per million flight hours). Again, the reduction evident for the most recent years was statistically significant ($P = 0.001$) relative to the referent period (2004–2008).

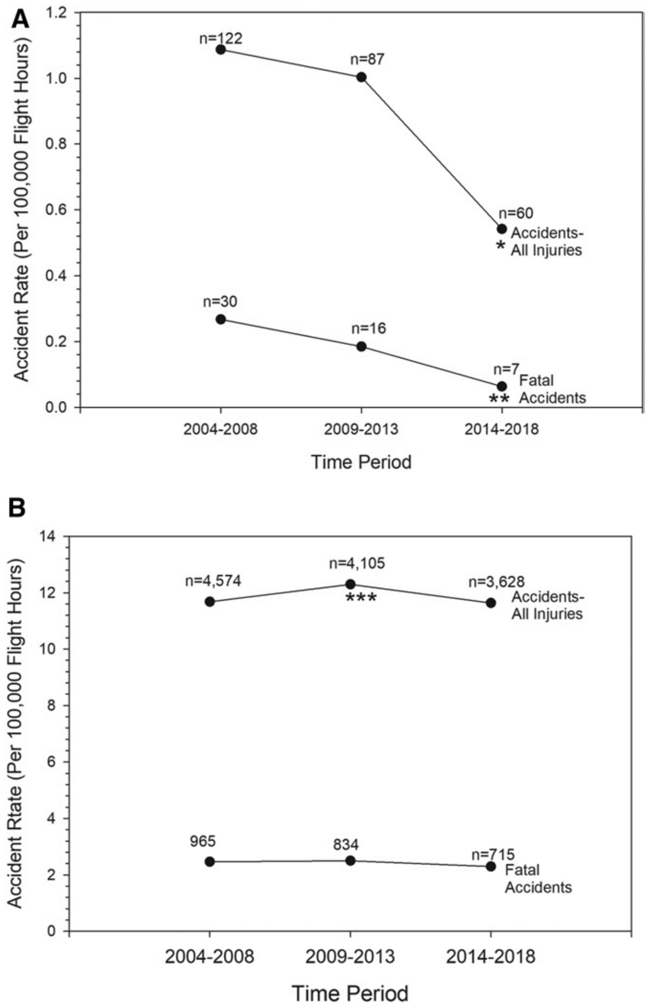

Fig. 1. Air taxi accident rates. All-injury or fatal accident rates for air taxis operating under 14CFR 135 (Panel A) or for non-air taxi aircraft under 14CFR 91 (Panel B) for the purpose of a personal mission are shown. Statistical testing was with a Poisson distribution using the 2004–2008 period as referent. n = accident count for the specified period. *$P < 0.001$; **$P = 0.001$; ***$P = 0.016$.

For comparative purposes, a similar analysis was performed for non-air taxi, fixed wing aircraft accidents undertaken under 14CFR 91 regulations by airmen for personal missions (**Fig. 1B**). Interestingly, for all time frames the accident rate (all injuries) was approximately 10-fold higher than that seen for air taxis. Moreover, unlike the decline in accident rate evident for charters over the 15 yr (Fig. 1A), no such reduction was apparent for 14CFR 91 operations (Fig. 1B). Similarly, the fatal accident rate for 14CFR 91 operations, again ten-fold higher than that for air taxis, showed no diminution over the 15 yr (Fig. 1B).

Air Taxi Accident Rates and Airplane Performance Classification

Airplanes powered by piston engines are most often inferior in performance to those equipped with either turboprop or turbojet engines in terms of service ceilings and climb rates. This limitation could present a safety hazard in situations of, for example, convective weather avoidance or high elevation/mountainous terrain. For this reason, a comparison of air taxi accident rates was made between aircraft fleets in the different performance categories (**Fig. 2**). Interestingly, for the initial period (2004–2008), the accident rate for airplanes in the low performance category was comparable to that of aircraft in the medium performance category (1.5/million flight hours). However, while there was little reduction in accident rate for aircraft in the former category, a steady reduction was evident for the latter air taxi airplanes over the 15 yr with a 50% decline ($P = 0.004$) for the most recent period (2014–2018). Perhaps most impressive, in terms of safety, was the accident rate for high-performance aircraft (Fig. 2). Thus, across the entire study period, accident rates were 60–90% lower than that of the two other airplane performance category fleets at all time points. Moreover, the accident rate for the high-performance airplanes declined over time with a statistical reduction ($P = 0.001$) evident for the most recent 5 yr relative to the initial period.

Accident Airman Flight History and Solo vs. Paired Flight Crews

We speculated that safety deficits for the low performance category air taxi airplane fleet reflected, at least in part, lower airman flight experience. Therefore, flight histories were determined for accident pilots according to the three airplane fleet performance categories. Accident pilot certification and flight times are shown in **Table I**. In proportion analysis, accidents involving aircraft in the high-performance group were over-represented ($P < 0.001$) for airmen with airline transport pilot (ATP) certificates relative to pilots in mishaps with low performance category aircraft—the latter more likely to hold a commercial certificate. Similarly, accident pilots in high-performance category airplanes showed higher total times in all aircraft (1.6×; $P = 0.046$) and make-model (2.2×; $P = 0.016$) relative to airmen of the low performance category airplanes. Pilots involved in accidents in which the aircraft was either in the medium-performance or high-performance category also showed 3.2 and 2.2 greater total times, respectively, in instrument meteorological conditions (IMC) than airmen in low-performance category airplanes ($P = 0.002$ and $P < 0.001$, respectively).

Accidents involving both high- and medium-performance category airplanes had a higher proportion of two flight crewmembers (97 and 18%, respectively) referencing low-performance category air taxi aircraft for which that value decreased to only 3%. The overall differences in these proportions were statistically significant (Pearson Chi-squared $P < 0.001$).

A Comparison of Occupant Injury for Air Taxi Aircraft in Different Performance Groups

We next compared the fraction of fatal charter accidents for airplanes in the three performance categories over the entire study period (2004–2018). Of the low-performance category air taxi airplane accidents, 24% had a fatal outcome (**Fig. 3**). In comparison, the proportion of fatal accidents was lower for the medium- and high-performance category aircraft (17 and 11% of mishaps, respectively). Despite this downward trend in fatal accident proportions for aircraft with the latter two propulsion types, the difference in proportions was not statistically significant ($P = 0.169$).

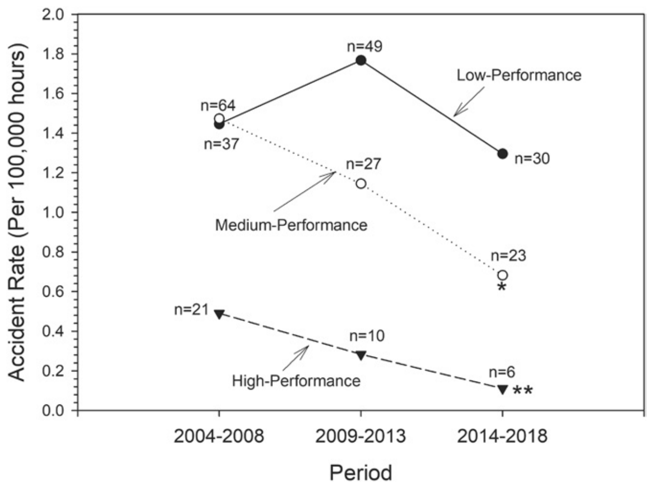

Fig. 2. Air taxi accident rates categorized by airplane performance. All-injury accident rates for air taxis operating under 14CFR 135 are shown for aircraft in the indicated performance category for the specified period. Air taxi fleet times used as denominator to calculate accident rate were those per the general aviation survey for fixed wing aircraft with the corresponding powerplant. Statistical testing was with a Poisson distribution using the 2004–2008 period as referent. n = accident count for the specified period. **P* = 0.004; ***P* = 0.001.

Human Factors Contributing to Fatal Reciprocating Engine-Powered Air Taxi Accidents

Considering the elevated and unabated accident rate as well as the trend toward a higher proportion of fatal outcomes for the low-performance category air taxis, we endeavored to identify human factors contributory to such mishaps. Identifying such deficiencies could lead to strategies toward rectifying shortfalls ultimately improving their safety. Toward this end, we employed the well-established Human Factors and Classification System (HFACS)[36,37] to determine which factor(s) contributed to fatal reciprocating engine-powered airplane accidents.

Of 34 fatal accidents involving air taxi low-performance category airplanes, complete NTSB final reports were available for 32, which were scored. The highest level of the HFACS framework is comprised of four failure categories: "Organizational Influence," "Unsafe Supervision," "Preconditions for Unsafe Acts," and "Unsafe Acts (aircrew)".[36] Of these four failure categories, the latter scored the highest (50%) followed by "Preconditions for Unsafe Acts" (23%) (**Table II**).

To further explore these deficiencies, underlying subcategories and nano-codes in the "Unsafe Acts" hierarchy were investigated (Table II). "Errors" and "Violations" comprise the two underlying subcategories and for the current set of fatal accidents, issues with the former scored well in excess of the latter (68% and 22%, respectively). Alternatively stated, for fatal accidents in the "Unsafe Acts" category, errors on the part of the aircrew contributed to 68% of lethal accidents. Aircrew errors are comprised of three nano-codes: 1) decision errors, 2) skill-based errors, and 3) perceptual errors,[36] and all three were contributing factors to the majority of fatal mishaps. Thus, decision failures (poorly executed procedures, improper choices, misinterpretation/misuse of information) contributed to 66% of all fatal accidents. Similarly, skill-based errors (stick & rudder, visual scanning, use of checklists) was a factor in 78% while perceptual errors (degraded sensory input, e.g., impoverished lighting, IMC) contributed to 63% of all fatal accidents.

Interestingly, "Organizational Influence" and "Unsafe Supervision," both of which address deficiencies at the charter operator

Table I. Accident Pilot Flight Times and Airman Certification.*

		LOW-PERFORMANCE	MEDIUM-PERFORMANCE	*P* VALUE	HIGH-PERFORMANCE	*P* VALUE
Airman Certificate	Commercial, *N* (%)	113 (66.1)	63 (54.8)	0.063	16 (31.4)	<0.001
	ATP, *N* (%)	58 (33.9)	52 (45.2)		35 (68.6)	
Age (years)	*N*	149	105	0.425	67	0.513
	Median (h)	43	39		45	
	Q1 (h)	30	30		34	
	Q3 (h)	57	52		54	
All Aircraft Total Time	*N*	144	101	0.177	60	0.046
	Median (h)	3713	4625		5918	
	Q1 (h)	2026	2292		3200	
	Q3 (h)	7701	7116		9950	
Make-Model Total Time	*N*	129	96	0.317	58	0.016
	Median (h)	468	690		1029	
	Q1 (h)	219	193		485	
	Q3 (h)	1560	2086		1773	
Last 90 Days (Make-Model)	*N*	111	82	0.534	44	0.898
	Median (h)	100	116		96	
	Q1 (h)	42.5	71		71	
	Q3 (h)	177	150		123	
Total IMC Time	*N*	108	77	0.002	34	<0.001
	Median (h)	172	382		544	
	Q1 (h)	83	142		319	
	Q3 (h)	435	920		1015	

* Data are from the NTSB final reports. Statistical testing for differences in median values was with a Mann-Whitney test using accident pilots in low-performance category aircraft as referent. Proportion differences for airman certification were tested for statistical significance using a two-sided Chi-Square test and again using the low-performance category airplanes as comparator. n, count, Q, quartile, IMC, actual instrument meteorological conditions. Counts (n) may exceed the total number of accidents for the indicated powerplant-powered for cases where there were two crewmembers.

level rather than the aircrew, showed relatively low scores (11 and 12%, respectively). For the latter category, the operator failing to correct a problem (known deficiencies in personnel, equipment, or training) contributed to 16% of fatal accidents. Similarly, time pressures, a safety-compromising incentive system, and/or deficient oversight within the organization itself, all encapsulated in the "Operational Process" nano-code,[36] contributed to 16% of fatal mishaps.

Piston engine airplanes (due to their lower service ceilings) are at disadvantage with respect to safe operations over high elevation/mountainous terrain and convective weather avoidance. Hence, we were curious as to the extent to which the HFACS "physical environment" was a contributing factor to lethal accidents for airplanes in this performance category. Indeed, of the fatal accidents in the "Preconditions for Unsafe Acts" category, nearly one half (44%) were scored in the "Environmental Factors" subcategory. Furthermore, the underlying "physical environment" nano-code was identified as a contributing factor to 75% of the 32 fatal accidents (Table II). However, and contrary to our expectations, fatal mishaps in which the low-performance category airplanes were operating over high terrain/mountainous regions or due to thunderstorm encounters was evident only for a minority (4 and 17%, respectively) of such crashes in this accident subset. Rather, IFR/marginal VFR (83%) and/or at night/dusk conditions (71%) represented the most frequent adverse flight conditions constituting the "physical environment" scores for these accidents.

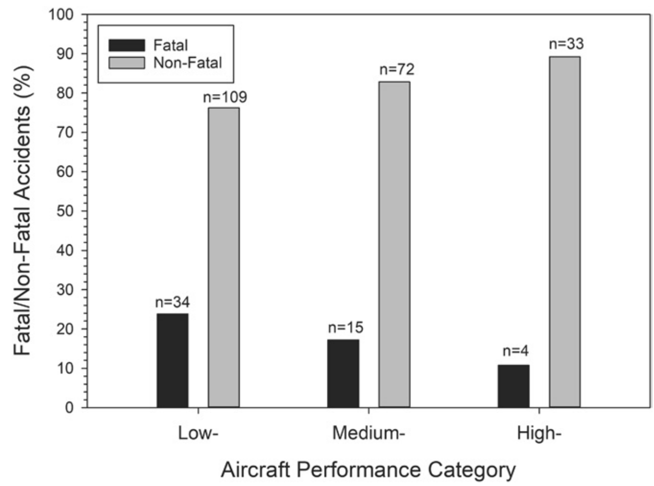

Fig. 3. Fatality for air taxi accidents categorized by aircraft performance category. The percentage of accidents with a fatal/nonfatal outcome was binned according to aircraft performance category over the study period (2004–2018). Proportion differences were tested for using a Chi-Square test. n = accident count.

DISCUSSION

We report herein a reduction in air taxi accident rates (aggregated for the three performance categories) over the 15 yr period spanning 2004–2018. However, this safety improvement largely reflected diminished air taxi accident rates for airplanes in the medium- and high-performance categories rather than those in the low-performance group. For the latter, deficient decision making and skill-based errors on the part of the aircrew and degraded visibility all represent frequent human factors contributing to a fatal outcome.

Although other studies have previously reported on air taxi safety,[33,34,36] ours is distinct and novel in two respects. First, we are unaware of any prior study which distinguishes between accidents for air taxi airplanes in varying performance categories. Second, it is the first to address air taxi safety without the confounding influence of commuter, air medical, and air tour operations.

One obvious question is why air taxi aircraft in the low-performance category are less safe than those in the medium- and high-performance categories, considering a commonality in mission (commercial passenger/freight transport) and regulations (14CFR 135.323-335) governing pilot training/recurrency. Our initial conjecture that powerplant limitation was a major factor in the safety deficit for the former airplanes appears less probable. Thus, only a minority of fatal accidents involved operations over elevated terrain/mountainous area or convective weather. That said, lower-performance aircraft are typically lighter than those in the medium- and high-performance categories and thus more subject to turbulence-induced vertical/lateral deviations.[18] Indeed, in the current study the median maximum certificated weights for airplanes in these three performance categories were 5400, 10,900, and 18,400 lb, respectively. We suspect that under flight conditions where outside visual references are absent (night, IMC) turbulence may increase the chance of pilot spatial disorientation.[4] What other reason(s) might account for the divergent accident rates between air taxi airplanes in the low-performance category and those in the high-performance group? In all probability, differences in aircrew flight experience contribute. Notably, accident pilots of the former aircraft had less total time in all aircraft, fewer hours in time-in-type and in IMC and less advanced pilot certification (i.e., a disproportionate count of commercial rather than ATP-certificated airmen). Less flight experience[6,28,29] and less advanced certification[8,35] have previously been shown to be risk factors for pilot errors and airplane accidents. Less time in IMC and lower pilot certification (commercial and ATP training focuses on visual maneuvers and instrument flight, respectively[10,19]) would be especially pertinent to the excess count of fatal low-performance category airplane accidents involving encounters with low ambient lighting and/or IMC and consistent with the high (78%) skill-based error score per HFACS analysis. Based on the aforementioned literature,[6,28,29] it is worth conjecture that a higher accident rate would have been evident had lower-experienced pilots (total time and instrument flight conditions times) been operating the higher performance airplanes. We also suspect that the greater prevalence of two-man crews (vs. solo pilot) evident for high-performance category airplane flights (97%) compared with that for low-performance airplanes (3%) contributes to the enhanced safety for the former operations. Two-man crews allow for a prescriptive division of tasks for the pilot flying and pilot monitoring

Table II. HFACS Classification of Fatal Air Taxi Accidents Occurring With Low-Performance Category Airplanes.*

	HFACS CATEGORY				SUB-CATEGORY					NANO-CODE				
	YES (*N*)	NO (*N*)	TOTAL (*N*)	% YES		YES (*N*)	NO (*N*)	TOTAL (*N*)	% YES		YES (*N*)	NO (*N*)	TOTAL (*N*)	% YES
Organizational Influence	11	85	96	11.5	N/A					Resource Management	2	30	32	6.3
										Organizational Climate	4	28	32	12.5
										Operational Process	5	27	32	15.6
Unsafe Supervision	15	113	128	11.7	N/A					Inadequate Supervision	3	29	32	9.4
										Planned Inappropriate Operation	4	28	32	12.5
										Failed to Correct Problem	5	27	32	15.6
										Supervisory Violations	3	29	32	9.4
Preconditions For Unsafe Acts	51	173	224	22.8	Environmental Factors	28	36	64	43.8	Physical Environment	24	8	32	75.0
										Technological Environment	4	28	32	12.5
					Condition of Operator	16	80	96	16.7	Adverse Mental States	8	24	32	25.0
										Adverse Physiological States	8	24	32	25.0
										Physical/Mental Limitations	0	32	32	0.0
					Personnel Factors	7	57	64	10.9	CRM	0	32	32	0.0
										Personal Readiness	7	25	32	21.9
Unsafe Acts (Aircrew)	80	80	160	50.0	Errors	66	30	96	68.8	Decision Errors	21	11	32	65.6
										Skill-Based Errors	25	7	32	78.1
										Perceptual Errors	20	12	32	62.5
					Violations	14	50	64	21.9	Routine	10	22	32	31.3
										Exceptional	4	28	32	12.5

* Accidents were scored per published HFACS scheme/definitions. For each fatal accident, the specified category/subcategory/nano-code was scored "Yes" where applicable or "No" if irrelevant to the mishap. Table columns represent sums for the scored 32 fatal accidents and the corresponding "% Yes." It should be noted that the sum of scores for the HFACS Category and Sub-Category exceed the total number of accidents as mishaps are typically a result of multiple causal/contributory factors. CRM, crew resource management; N/A, not applicable.

per crew resource management training mandatory for charter operations,[12] all toward eliminating human error. For example, the pilot monitoring commonly undertakes radio communications, reads checklists, programs the avionics, and operates the flaps/landing gear, allowing for the pilot flying to focus exclusively on that task.

Also meriting discussion is the reason(s) responsible for the reduced accident rate for medium- and high-performance category air taxis over time (no such temporal change was evident for airplanes in the low-performance category). We speculate that the introduction of various voluntary safety programs[23,27] has played a vital contribution in the diminution for the former over the 15 yr. For example, in 2006, the Federal Aviation Administration (FAA), per AC120-92, advocated the use of voluntary Safety Management Systems (SMS) by air taxi flight departments with a shift toward a systems approach that focuses more on control of processes rather than efforts targeted toward remedial actions. Moreover, in 2002 (and hence just prior to the accident capture period for the current study) the International Business Aviation Council developed and launched the "International Standard for Business Aircraft Operations" for the business aviation community.[27] This program promotes the use of high quality operating practices and establishes a framework for effective safety and operation processes, deriving an SMS appropriate to all operational profiles. Finally, via the Aviation Safety Action Program (ASAP), since 2003 individuals involved in aviation have been encouraged (under anonymity) to provide the FAA with safety-related information,[20] again toward improving safety of the charter operator. If the aforementioned programs have led to improved safety for air taxi operators utilizing medium- and high-performance category airplanes why not so for those using aircraft in the low-performance category? Two possible reasons may underlie the lack of improvement. First, since some of the safety-enhancing programs require financial commitments, charters employing a low-performance category airplane fleet with less profit margins may eschew participation. A second possibility may relate to the smaller size and scope of air taxi operations commonly using low-performance category aircraft. Operators satisfying certain criteria (e.g., maximum of 5 pilots, 5 aircraft, no aircraft certificated for more than 9 passenger seats) qualify as a "Basic Part 135 Operator."[21] In such instances, the FAA may authorize modifications of training programs per 14CFR 135.341.[21]

Although the current study is the first to exclusively focus on fixed-wing air taxi accidents, an earlier HFACS analysis of commuter/air taxi crashes[33] occurring over the 1990–2002 period deserves discussion. At variance with our findings, few deficiencies in "Organizational Influence" and "Unsafe Supervision" were cited in the earlier study.[36] By way of example, in our study of air taxi crashes, a poor organizational climate was cited 26 times more frequently (0.5% vs. 13%). Similarly, "failed to correct known problems" (HFACS nano-code in the "Unsafe Supervision" Category) was not reported as a deficiency for commuter/air taxi accidents in the prior report. This was in stark contrast to the current investigation where 16% of air taxi accidents showed such an insufficiency. Likewise, the study herein found a 45 fold greater prevalence of supervisory violations (9% vs. 0.2%) in air taxi mishaps. Nevertheless, caution should be exercised in comparing both studies for a multitude of reasons. First, commuter and air taxi operations were aggregated for the previously published study. This is an important distinction from a safety perspective since air taxis commonly operate out of/into general aviation aerodromes which are equipped with fewer (and more likely nonprecision) instrument approaches (adversely affecting safety for IMC operations) than major civilian "hub" airports, the latter frequented by commuter "feeders" for air carriers, and anecdotally, there is a tendency to prioritize passenger (as for commuters) operations at the expense of freight operations (in the current study 54% of accidents were cargo transportation) with assignments of the most experienced flight crew/maintenance personnel to the former. Second, HFACS was primarily performed on both fatal and nonfatal accidents,[36] whereas for the current investigation, only lethal mishaps were analyzed. Third, both fixed-wing and rotary wing aircraft were combined in the earlier study. Finally, the accident capture period for the two studies were distinct and nonoverlapping (1990–2002 vs. 2004–2018).

Our study was not without limitations. First, it was a retrospective analysis with the inherent limitations of such a research design. Second, only accidents performed under 14CFR 135 were analyzed. Thus, crashes during ferry or relocation flights conducted under 14CFR 91 were not examined. Third, in some instances (medium- and high-performance category airplanes) our sample size was small. Fourthly, we suspect that our scores of "Organization Climate" represent undercounts of this HFACS nano-code as NTSB reports contain little by way of interviews of nonaccident pilots in current and/or past employment of the charter enterprise. Lastly, we did not explore the geographical patterns of the air taxi accidents which may have biased our observed fatality rate. A previous report[26] had clearly demonstrated a more than twofold higher fatal accident rate in northern states when compared to the southeast region of the USA.

Our findings are likely germane to the future of the air taxi fleet. Several airplane manufacturers[25] are in the process of flight-testing electrical/hydrogen fuel cell/hybrid propulsion aircraft.[25] Moreover, the FAA has certified its first normal category electric aircraft—a 2-seat airplane approved for day visual flight and private pilot training. Admittedly this airplane is currently limited to low payloads (378 lb) and endurance (50 min).[32] Nevertheless, future advances in battery storage (and the other technologies stated above) will almost certainly overcome this shortcoming and, in all likelihood, aircraft with electrical (and other) propulsion will become increasingly attractive to air taxi operators. That said, it is probable that due to the aforementioned limitations, such aircraft would most likely fall into the low-performance category fleets and safety would still be impacted by the findings herein of airman inexperience and single pilot operations.

In summary, tremendous gains have been made in safety for air taxi charters operating medium- and high-performance category airplanes over the 15 yr study period. Alas, similar improvements are notably absent for the air taxi fleet comprised of low-performance category airplanes per a 10-fold higher accident rate with little signs of diminution over time. Considering that safety deficiencies for the latter reflect more the challenging environmental conditions (darkness, IMC) and aircrew errors (possible associated with single pilot operations) rather than powerplant limitations, charter operators with low-performance fleets should focus on additional instrument training and, equally important, utilization of the 3-axis autopilot (mandatory under 14CFR 135.105 regulations[16] for single pilot operations) for such flight conditions. Toward correcting deficiencies in the "Organizational Influence" and "Unsafe Operation" HFACS categories, improvement in safety culture to address personnel/equipment/training deficiencies, failing to correct problems, time pressures, and a safety-compromising incentive system is warranted. Toward this end, operators, yet to adopt SMS programs as advocated by both government and business aviation organizations,[23,27] should be further encouraged to do so. Lastly, our findings beg the question as to whether the FAA permitting modification of training/recurrency programs (from those specified in 14CFR 135.323-335)[12] for small charter operators adversely impacts safety.

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