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Adherence to Selected Air Carrier (Airline) Operational Regulations for Improved General Aviation Flight Safety in Degraded Visibility

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Abstract

Introduction: General aviation largely comprises fixed-wing piston-engine light aircraft (<12,500 lbs). Unfortunately, this civil aviation sector suffers a vastly inferior safety record when compared with air carriers (60- to 80-fold higher accident rate). Additionally, such mishaps pose a considerable financial burden to both the affected family and the United States: US$1.64–4.64 billion annually. We hypothesize that this safety disparity partly reflects more stringent operational regulations for air carriers. Herein, we determined whether compliance with six selected air carrier regulations could potentially reduce general aviation accidents in degraded visibility (IMC) the majority of which are fatal. Methods: Accidents (2005–2019) were identified from the National Transportation Safety Board Access database. Fleet data for rate calculations were per the general aviation survey and the Bureau of Transportation Statistics. Statistics used Poisson distributions. Results: Of 219 general aviation accidents in IMC, 43 (20%) could potentially have been averted had one, or more, of the selected air carrier regulations been complied with. The largest percentage (62%) of the 43 mishaps were due to pilots operating contrary to the air carrier regulation specifying takeoff or landing weather minimums. The second largest group related to more conservative weather minimums required for an inexperienced airline pilot-in-command, eschewed in 19% of preventable general aviation IMC mishaps. Conclusions: Alignment with the aforementioned air carrier operational rules could potentially blunt the IMC accident rate (by 20%) for general aviation. Practical Applications: Adherence to the aforementioned air carrier regulations should be advocated to general aviation pilots operating in IMC.

Keywords: general aviation, air carrier, instrument meteorological weather, aviation safety, crashes, weather

Introduction

Statement of the Problem/Prior Work

General aviation largely comprises fixed-wing, piston-engine-powered light aircraft (<12,500 lbs) (Boyd, 2017) and (in the USA) operate in accordance with a set of federal regulations encapsulated in the Code of Federal Regulations (14CFR91) (Electronic Code of Federal Regulation, 2015a). Unfortunately, this segment of civil aviation suffers a vastly inferior safety record when compared with air carriers (also referred to as airlines). Indeed, published research has documented a 60- to 80-fold all-weather higher accident rate for general aviation compared with air carriers over the 1984–2017 period (Boyd, 2017; Li & Baker, 2007). It is also noteworthy that general aviation accidents pose a considerable

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financial burden to both the affected family and the United States: estimated at US$1.64–4.64 billion annually in terms of medical outlays, aircraft/property damage, and investigative costs (Sobieralski, 2013).

Why the disparity in aviation safety between general aviation and air carriers? Several reasons likely contribute. First, the regulations governing air carrier operations articulated in 14CFR121 (Electronic Code of Federal Regulation, 2017c) are considerably more stringent than the corresponding rules for general aviation promulgated in 14CFR91 (Electronic Code of Federal Regulation, 2015a). By way of examples, weather minima dictate whether an air carrier airplane is allowed to undertake an approach (to land) or depart per 14CFR121.613 (Electronic Code of Federal Regulation, 2017c) whereas no such rules limit general aviation. Additionally, weather minima are raised for airline pilots-in-command with less than 100 flight hours in a particular airplane type. Also, air carrier pilots, upon completion of their crew training, are required to fly under the oversight of a "check airman" (Electronic Code of Federal Regulation, 2017c) (referred to as "initial operating experience") for a specified period of time. Of course, a plethora of other reasons also likely contribute to the superior safety evident for air carriers, e.g., (i) more demanding training and recurrency for airline pilots (Electronic Code of Federal Regulation, 2015c), (ii) redundancy of equipment systems mandated for transport category (i.e., passenger) airplanes (Electronic Code of Federal Regulation, 2017b) but, for the most part, lacking in light aircraft (Electronic Code of Federal Regulation, 2017a), and (iii) a greater pilot flying frequency and instrument meteorological conditions (IMC) encounters.

Study Objective

Considering the stellar safety record evident for air carriers (Boyd, 2017), the objective of this retrospective study was to determine whether compliance with a subset of the more stringent operational regulations (14CFR121) could potentially blunt the general aviation accident rate in degraded visibility (herein also referred to as IMC and operationally defined as a cloud ceiling of <1,000 ft above ground and/or forward visibility of <1 statute mile). Accidents in such adverse conditions were selected since the risk of a general aviation fatal outcome increases over sixfold (Bazargan & Guzhva, 2007; Li & Baker, 1999).

Methods

Identification of Accidents

The National Transportation Safety Board (NTSB) Access accident database was downloaded (NTSB, 2021) and queried for piston-powered airplane accidents (2005–2019) in IMC across the 48 contiguous US states. Accidents were restricted to those involving instrument-rated private or commercial pilots operating in accordance with 14CFR91 regulations for the purpose of personal or business missions. It should be noted that commercial pilots are occupationally distinct from airline transport pilots. While the former may exercise their flying privileges in revenue-generating enterprises (e.g., flight training, charter flights), nevertheless they are prohibited from acting as a crewmember for an air carrier (Electronic Code of Federal Regulation, 2015a). In a separate query, a search for scheduled air carrier accidents in IMC while operating under 14CFR121 over the corresponding period was performed. Scheduled air carrier mishaps in which a passenger/flight attendant was injured by turbulence in the absence of airplane damage were omitted. General aviation flight histories, official weather forecasts, demographics, and injury severity were all per the NTSB database.

Airplane fleet times per the general aviation survey (Federal Aviation Administration, 2021b) and the Bureau of Transportation Statistics (2021) were used as denominators to determine accident rates for general aviation and air carrier operations respectively. Fleet time for the former was restricted to fixed-wing piston aircraft operations conducted for personal or business missions. For air carriers, fleet times used were those for scheduled domestic passenger operations only.

Air Carrier Operational Regulations Evaluated

Six air carrier operational rules (14CFR121) (Electronic Code of Federal Regulation, 2017c), which do not have to be legally complied with by pilots operating under general aviation regulations (14CFR91) (Electronic Code of Federal Regulation, 2015a), were selected for this retrospective study:

1. 14CFR121.651 describes departure and arrival weather (forward visibility) minimums which must be met for airline aircraft to take off or to perform an instrument approach (to land). For departure flights, since weather minima are approved on an air carrier case-by-case basis by the Federal Aviation Administration, we opted to use the lowest minimum forward visibility specified in the instrument approach procedure (Federal Aviation Administration, 2020) for that airport from which a departure was undertaken by the general aviation accident airplane.
2. 14CFR121.613 disallows aircraft from departing if the forecast flight visibility at the intended destination airport(s) at the estimated time of arrival is below specified minima.
3. Transition (14CFR121.419) and difference (121.418) training are mandatory for airline pilots prior to operating another make–model airplane (for which he/she has no prior logged flight time) or a more recent iteration of the same aircraft (e.g., 737-400 to 737-500)

respectively. Comparable general aviation examples would be a pilot seeking to fly a Piper PA-32 with no prior experience in this make–model aircraft (transition training) or seeking to operate a Cessna 172SP having logged flight time in a Cessna 172N (difference training). Operationally, we also defined an avionics upgrade in the "difference training" category.

4. For a pilot-in-command (in common vernacular also referred to as captain) with less than 100 hours accrued flight time in airplane make–model to perform an instrument approach (to land) in IMC, the current airport vertical visibility must be no less than the sum of the minimum specified in the charted instrument approach procedure (Federal Aviation Administration, 2020) plus an additional 100 feet. Similarly, the required forward visibility for such a pilot-in-command represents the sum of that specified in the charted instrument approach procedure (Federal Aviation Administration, 2020) plus an additional ½ mile (14CFR121.652). Considering that light aircraft are almost invariably certificated (Electronic Code of Federal Regulation, 2017a) for single-pilot operations, the pilot, by definition, assumes the role of pilot-in-command. Hence in the context of the current project, this regulation was applied to any general aviation mishap involving a solo pilot who had accrued less than the aforementioned 100 hours in the accident aircraft make–model.
5. Following completion of their training to serve as a crewmember of a particular airplane make–model, a pilot must fly under the supervision of a "check-pilot" for a pre-determined period of time—15 hours for piston-engine airplanes (14CFR121.434). In the context of the current study, a check-pilot was defined as any second pilot occupying a crew position and with an excess of the aforementioned 15 hours in the corresponding airplane make–model.
6. Lastly, flight time limitations applicable to air carriers (14CFR121.481) specify a maximum of 8 flight hours per any 24 consecutive hours. For the current study, flight time also included any time in which the pilot was engaged in his/her professional occupation immediately preceding the accident flight.

The aforementioned regulations were evaluated in the context of whether IMC accidents (2005–2019) involving instrument-rated private/commercial pilots operating piston-engine light aircraft under the auspices of general aviation rules (14CFR91) could potentially have been averted had the more stringent air carrier regime been followed.

Statistics

Changes in accident rates over the 2005–2019 period were tested for statistical significance using a Poisson distribution (Dobson & Barnett, 2008) using the natural log of fleet times. All statistics were performed with SPSS v26 (IBM Corp., Armonk, NY).

Non-Human Subject Research

This study was not considered human subject research by virtue of all data used in the current investigation being in the public domain. Accordingly, the research was exempt from IRB review.

Results

Unabated General Aviation IMC Accident Rates

Since over the past two decades general aviation safety, as an aggregate, has improved (AOPA Air Safety Institute, 2019), we first determined whether a parallel trend was evident for IMC (cloud ceiling $<$1,000 ft above ground) operations over the 15 years of the current study. While the IMC accident rate (Figure 1) diminished ($p = 0.004$) from 2.2 to 1.4 (per million flight hours) initially, (2010–2014), this decrease was not sustained with an increased IMC accident rate (to 1.8 mishaps per million hours) evident thereafter (2015–2019). In fact, this most recent IMC accident rate was statistically unchanged ($p = 0.177$) relative to the initial period (2005–2009). The differential in general aviation IMC accident rates compared with that evident for air carriers (Figure 1) was also noteworthy (varying between 32-fold and infinity). These findings clearly demonstrate that general aviation operations in IMC continue to represent a safety challenge.

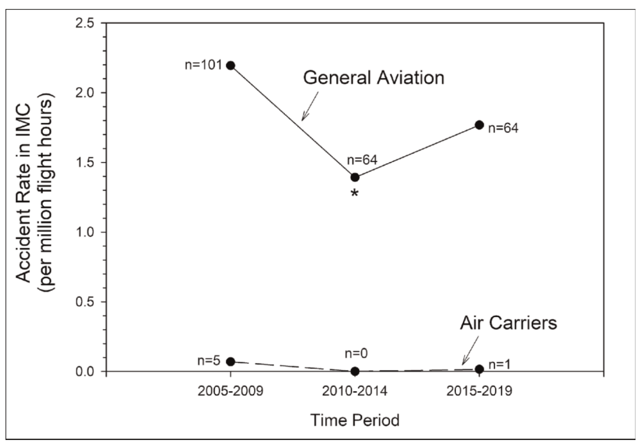

Figure 1. General aviation IMC accident rate in degraded visibility (2005–2019). Accident rates (in IMC) are shown for both air carriers and general aviation (involving IFR-rated private/commercial pilots) operating under airline (14CFR121) or general aviation (14CFR91) operational regulations respectively. The accident count is *n*. A Poisson distribution (using the natural log of fleet times) was employed to determine if differences in the general aviation accident rates were statistically significant relative to the initial period (2005–2009); $*p = 0.004$.

Are General Aviation Accidents in Degraded Visibility Preventable by Adherence to Air Carrier Regulations? A Retrospective Study

NTSB reports for a total of 219 IMC accidents occurring over the 15 years (2005–2019) (excluding those involving taxying or stationary aircraft) involving IFR-rated private/commercial pilots (the IFR rating provides the pilot with the necessary skills to fly the aircraft in the absence of external visual cues) operating under general aviation regulations (14CFR91) were manually inspected. Of these, we identified 43 (19.6%) which could potentially have been averted had one, or more, of the six selected air carrier (14CFR121) regulations, examined herein, been complied with. Below, in this retrospective study, we review accidents grouped according to each of the six 14CFR121 regulations.

Interestingly, of the 43 IMC mishaps cited above, by far the most (61.9%) were related to operations at variance with the air carrier (14CFR121.65) regulation specifying takeoff or landing weather minima (Figure 2). In degraded visibility, these weather minima must be met for airline aircraft to take off or to perform an instrument approach (to land). Thus, while not a breach of 14CFR91 regulations pertinent to the general aviation IFR-rated private/commercial pilots operating in IMC, 26 of these IMC mishaps could have been precluded had this air carrier regulation been subscribed to (Figure 2). We next determined whether this subset of IMC accidents was biased in favor of departure or approach mishaps. However, such crashes partitioned almost equally between those in which departure (42.3%) and approach (57.7%) minimums were discordant with those specified per 14CFR121.65 (Figure 3).

The high-minimums pilot-in-command (14CFR121.652) group represented the second largest group of IMC accidents which could have been averted. This air carrier regulation stipulates that an airline pilot with less than 100 hours as pilot-in-command (“captain” in layman’s parlance) in a specific aircraft make–model must satisfy more stringent vertical and forward visibility weather conditions in context of landing in diminished visibility. Specifically, the cloud ceiling at the arrival airport must be 100 ft higher and forward visibility half a mile greater than that stated in the instrument approach chart for the intended landing runway. Had this regulation been applied by the IFR-rated private/commercial pilots, potentially, 19% of the IMC accidents (of the total mishap cohort in which 14CFR121 rules were not observed) could have been prevented (Figure 2).

After completion of training, air carrier regulations dictate that the pilot flies under the supervision of a “check-airman” for a specified period of time (15 hours for an airplane with a reciprocating engine) referred to as initial operating experience (14CFR121.434). For a general aviation equivalency, we operationally deemed IMC accidents as not in concordance with this regulation if (a) the flying pilot had less than the requisite 15 hours in aircraft make–model and (b) a second pilot with at least that experience level (make–model) was absent. Of the 43 aforementioned accidents, 9% (Figure 2) were associated with practices contradictory to this 14CFR121 regulation.

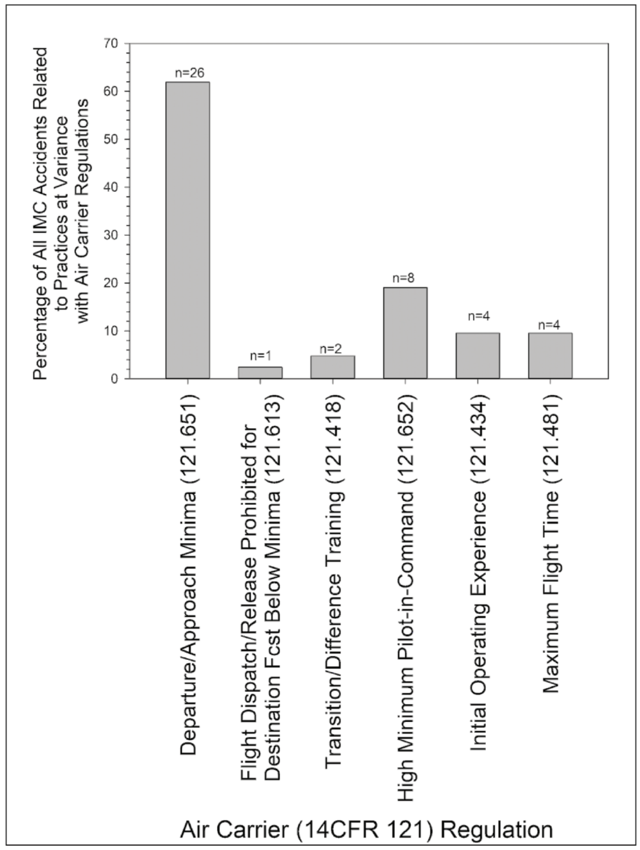

Figure 2. General aviation IMC accidents—grouping by nonadherence to air carrier (14CFR121) regulations. IMC mishaps were grouped by the air carrier regulation(s) (121.xxx) which, had it been complied with, could have averted the general aviation accident. Data are expressed as a percentage of the sum ($n = 43$) of all accidents noncompliant with the air carrier rules. Note that a particular mishap may have been at variance with multiple 14CFR121 regulations; accordingly, the summed count for each category exceeds $n = 43$; n, accident count; Fcst, forecast.

Maximum flight time limits, articulated in 14CFR121.48, restrict airline pilots to a maximum of 8 in any 24 consecutive hours. In contrast no such comparable rule applies to IFR-rated private/commercial pilots operating under general aviation (14CFR91) regulations. In the context of the current study, any accident in which the NTSB stated that the involved pilot was engaged in his/her professional occupation prior to undertaking the accident flight such that in combination with his/her flight time the aforementioned 8 hours were exceeded was regarded as breach of this regulation. This 14CFR121 category of mishaps represented 9% of the accident cohort (Figure 2) deemed as incompatible with air carrier regulations.

On the other hand, two other air carrier regulations were infrequently implicated in IMC accidents involving

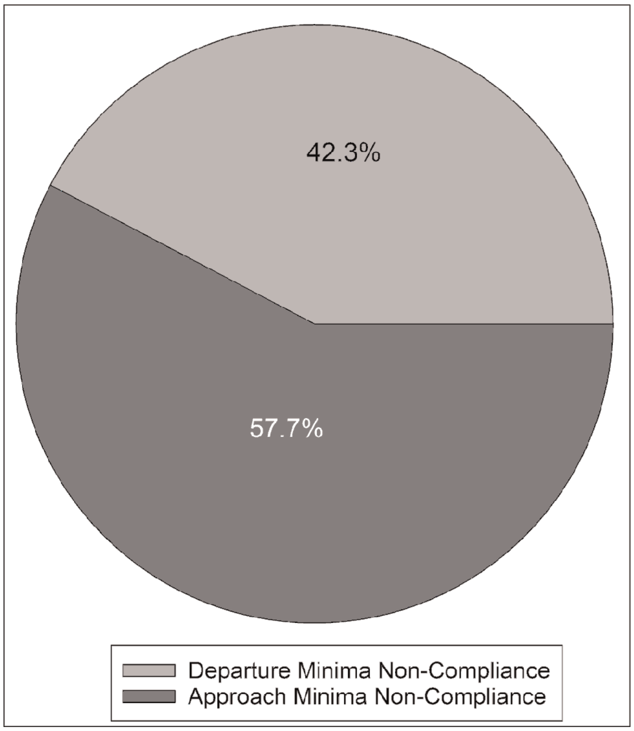

Figure 3. Subcategorization of departure/approach IMC accidents contrary to 14CFR121.651. IMC accidents which were noncompliant with the air carrier regulation specifying weather minimum for departures and approaches were segregated into the two corresponding groups. For each group, data are expressed as a percentage of the total ($n = 26$) of the accident count for which 14CFR121.651 was in noncompliance.

IFR-rated private/commercial pilots operating under general aviation regulations (14CFR91). Transition (14CFR121.419) and difference (121.418) training are required for airline pilots moving to another make and/or model airplane or to a more recent iteration of the same aircraft make–model respectively. Herein, and considering the increasing retrofitting of older general aviation aircraft with more updated avionics (including electronic flight displays) (Federal Aviation Administration, 2021b), we operationally included such upgrades as requiring "difference training." However, only 2 of 43 IMC accidents (in which the 14CFR121 rule(s) were not complied with) could have been precluded had this regulation been adhered to. In one of these two accidents new avionics had been installed in the airplane less than one week prior to the accident flight. Similarly, the release/dispatch of air carrier aircraft is prohibited unless the forecasted weather at the planned destination is above minima (14CFR121.613). However, again, IMC accidents due to practices contrary to this air carrier regulation were rare (1 accident). In this single case, logged access to official weather forecasts by the involved pilot was evident indicating that the pilot was aware of the below minimums weather at the destination prior to departure.

Flight History/Demographics of Pilots Involved in General Aviation IMC Accidents (2005–2019)

Towards determining if the aforementioned IMC accidents were biased towards inexperienced pilots, flight histories for the general aviation accident pilots were compiled. However, we saw little evidence favoring this contention. Thus, the IFR-rated private/commercial pilots involved in the general aviation IMC accident cohort had accrued a median total flight (all aircraft) and actual IMC times of 1,357 and 77 hours respectively (Table 1). This level of total flight experience well exceeded that required for initial commercial/IFR certification (250 hours) (Electronic Code of Federal Regulation, 2020) and that of a random sample of general aviation aviators (600 hours) (Urban, 1984).

Discussion

To the knowledge of the authors, this is the first study to report that adherence to a subset of air carrier operational rules (14CFR121) could augment safety (effecting a 20% reduction in the IMC accident rate, the majority of which have a fatal outcome) for IFR-rated private/commercial pilots operating under the auspices of general aviation regulations (14CFR91). The current study is noteworthy considering that general aviation safety in IMC has shown little improvement over the 15-year period spanning 2005–2019.

The two air carrier regulations most frequently implicated in the current accident cohort merit more extensive discussion: (a) nonadherence to departure and approach (to land) weather minima per CFR121.651 and (b) high minimum pilot-in-command (14CFR121.652) which mandates more conservative landing minima. Takeoffs and landings are two of the most task-intensive phases of flight and even more so when such operations are in IMC. For example, for departures under instrument flight rules (required for flying in IMC), a pilot commonly has to fly an assigned heading at the same time as climbing the aircraft, adjusting power settings and "cleaning up" the airplane by way of retracting the landing gear (and in some instances flaps). It is important to note that the aforementioned workload is added to immensely by the pilot having to transition to instrument flying for takeoffs seamlessly ignoring various vestibular illusions which may lead to spatial disorientation (Partmet & Ercoline, 2008). Landing an aircraft can be equally challenging in IMC as the pilot has to sequence his/her attention from the flight instruments (to maintain runway and glideslope alignment) to visual conditions (to acquire the runway or runway environment) and back to instruments in the absence of the latter. Clearly, for a solo pilot, the lower the cloud ceiling or the shorter

Table 1
Pilot demographics and flight histories for general aviation accidents in IMC.

Parameter		Count (*n*)	Median	Q1	Q3
Instrument-Rated Pilot Certification	Private	135	N/A	N/A	N/A
	Commercial	99	N/A	N/A	N/A
Crew Demographics	Age (years)	233	56	47	63
	Male *n* (%)	192 (97)	N/A	N/A	N/A
	Female *n* (%)	5 (3)	N/A	N/A	N/A
Flight History	All Aircraft Total Flight Time (h)	228	1,357	632	2,807
	Make–model Total Time (h)	149	300	80	695
	All Aircraft—Last 90 Days (h)	125	30	15	50
	Total IMC time (h)	129	77	23	273
	IMC Time—Last 90 Days (h)	65	4	2	8

Note. Demographics, pilot certification, and flight histories are shown for the general aviation accident pilots. N/A, not applicable; IMC, actual instrument meteorology flight time; h, hours; Q, quartile; *n*, count.

the forward flight visibility the more challenging this phase of flight and even more so for a pilot with a limited time in the make–model airplane. Consequently, general aviation pilots would be well served by adhering to these two more conservative air carrier regulations. This viewpoint is reinforced by multiple reports citing deficient instrument skills for general aviation pilots (Bennett & Schwirzke, 1992; Fanjoy & Keller, 2013; Shao et al., 2014) involved in IMC (even more so at night) accidents.

Another consideration worth mentioning in the context of exercising conservative practices for IMC operations is the inaccuracy of aviation forecasting. Meteorology is an inexact science and perhaps this is best illustrated by a recent study of the accuracy of the terminal aerodrome forecast (TAF) often relied on heavily by general aviation pilots (Vasquez, 2018) undertaking relatively short flights (e.g., for the proverbial "$100 hamburger"). In that report, TAF-based categorical forecasts (Federal Aviation Administration, 2018) for IFR conditions (cloud ceiling 500 to <1,000 ft above ground) were 45% accurate, missing the even more challenging low-IFR (ceiling <500 ft above ground) 55% of the time (Boyd & Guinn, 2021).

One issue which merits discussion is the preponderance of departures/approaches below minimums per air carrier regulations but perfectly permissible under the less restrictive 14CFR91 regulations applicable to general aviation (Electronic Code of Federal Regulation, 2015b). Are such practices discussed during IFR student training? The authors consider such a possibility less likely as emphasis would be placed on regulations not to be breached rather than nonexistent rules. On the other hand, considering the findings herein this would well be a topic that deserves more emphasis during recurrent training (e.g., flight reviews, FAA-sponsored seminars) especially in the context of aeronautical decision-making (Federal Aviation Administration, 2016).

Notwithstanding the benefits to safety that could be achieved by adherence to the air carrier operational regulations discussed herein, it is very unlikely that general aviation could ever realize the stellar safety record witnessed for airlines for a plethora of reasons. For example, a minimum of two flight crewmembers is mandatory (Electronic Code of Federal Regulation, 2015c) per 14CFR121.385 for air carrier operations with the flying and nonflying crew performing prescriptive and nonoverlapping duties (Federal Aviation Administration, 2014). Moreover, air carrier regulations (14CFR121.395) specify that the flight crew be in constant communication with an aircraft dispatcher (Electronic Code of Federal Regulation, 2015c) for any flight. Such an individual partakes in the preflight planning, monitors the progress of flights (under his/her control), and issues relevant information for the safe completion of the flight (14CFR121.533). This practice differs from general aviation operations conducted by IFR-rated pilots, the majority of which are conducted as single-pilot operations (Weislogel, 1983). Accordingly, the pilot operating in IMC is responsible for tasks that, in an air carrier environment, would be accomplished by three separate individuals. Another marked difference between general aviation and airlines which again likely contributes to improved safety for the latter is much more rigorous (often a multi-day program versus 2 hours) and more frequent (at least yearly versus alternate years) recurrency training/evaluations encapsulated in 14CFR121.427 and 14CFR61 respectively (Electronic Code of Federal Regulation, 2015c, 2018). Finally, a third reason underpinning the improved air carrier safety is the redundancy of equipment mandatory for transport category aircraft certification (Electronic Code of Federal Regulation, 2017b). At variance with the aforementioned redundancy, certification of light aircraft used in general aviation places little such emphasis (Electronic Code of Federal Regulation, 2012).

The research was not without limitations. In all probability, several of the 14CFR121 categories analyzed herein were under-represented. For example, since to the knowledge of the authors, TAFs are not archived, it was difficult, in this retrospective study, to determine (unless stated in the NTSB report) if any of the accident flights departed under conditions where the destination forecast indicated less than the minimums approved for the accident aircraft. We also suspect that fatigue may have been undercounted for some IMC accidents since it was often unclear from the NTSB report whether the accident pilot was working in a professional capacity at his/her occupation (and the corresponding number of hours) prior to undertaking the accident flight. Another shortcoming relates to incomplete flight histories for IMC accidents, especially those which are fatal—in such cases, pilot logbooks are frequently inaccessible/destroyed. For example, of 219 general aviation accidents in IMC, pilot flight times for airplane make–model were available for only 149. As a consequence, there is a real possibility that the 14CFR121 regulations pertinent to flight time (i.e., high minimum pilot-in-command, initial operating experience, transition/difference training) may have been undercounted.

Some of the aforementioned limitations could very well be addressed in future research employing a prospective (rather than a retrospective) methodology. For example, the mandate effective January 2020 that general aviation aircraft operating in certain US airspace have to be Automatic Dependent Surveillance-Broadcast (ADS-B)-Out equipped (Federal Aviation Administration, 2021a) could allow insight into the behaviors/decision-making of instrument-rated general aviation pilots in regard to operating in degraded visibility.

In conclusion, towards improving flight safety in degraded visibility, IFR-rated general aviation pilots should be encouraged to align their operational practices with the aforementioned air carrier regulations which, with little doubt, have contributed to the stellar safety evident for the latter. We encourage advocacy of such air carrier practices via (a) pilot recurrency programs, e.g., flight reviews (Electronic Code of Federal Regulation, 2018), (b) FAA safety meetings, (c) national flight instructor organizations, and (d) insurance carriers.

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