Deficient Aeronautical Decision-Making Contributions to Fatal General Aviation Accidents

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INTRODUCTION: General aviation (GA), mainly comprised of light (≤12,500 lb) aircraft, maintains an inferior safety record compared with air carriers. To improve safety, aeronautical decision-making (ADM) practices have been advocated to GA pilots since 1991. Herein, we determined the extent to which GA pilots disregard such practices.

METHODS: Fatal accidents (1991–2019) involving private pilots (PPLs) in single-engine airplanes were identified ($N = 1481$) from the National Transportation Safety Board Access[R] database. Of these, deficient go/no-go and in-flight ADM-related mishaps were scored using the PAVE (pilot, aircraft, environment, external pressure)/IMSAFE (illness, medicine, stress, alcohol, fatigue, eating) and PPP (perceive, process, perform) models, respectively. Statistical testing used Poisson distributions, Fisher exact tests, and Mann-Whitney *U*-tests.

RESULTS: Of the 1481 accidents, 846 were identified as deficient ADM-related. Electing to depart into a hazardous environment (PAVE), disregarding wellness (IMSAFE), and poor aircraft familiarity (PAVE) represented the most common categories (54%, 21%, and 20%, respectively) of errant go/no-go ADM. A 64% decline in fatal accidents related to errant go/no-go decisions for the environment category was evident over the 30-yr period, with little decrements in the other domains. Within the errant environment-related category accidents, the decision to depart into forecasted adverse weather (e.g., degraded visibility, icing, thunderstorms) constituted the most prevalent subcategory (56%, $N = 195$). Surprisingly, of this subcategory, accidents were overrepresented by over nine- and threefold for instrument-rated PPLs disregarding icing and thunderstorm forecasts, respectively.

CONCLUSION: With little decrement in ADM-related accidents in the pilot, aircraft, and external pressure domains, new strategies to address such deficiencies for PPLs are warranted.

KEYWORDS: aeronautical decision-making, general aviation, wellness, human factors.

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General aviation (GA) is mostly comprised of civil, fixed-wing, single-piston engine-powered, light aircraft (≤12,500 lb)[5] engaged in nonrevenue operations. Unfortunately, this segment of civil aviation has long shown an inferior safety record in comparison with the airlines (also referred to as air carriers), as evidenced by a 60–80-fold higher accident rate.[5,24] Importantly, this difference is further amplified if only fatal mishaps are considered.[5] That said, it should be noted that for the year 2021, there was a total of 268 GA fatalities per a query of the National Transportation Safety Board (NTSB) database.[25] Several reasons likely contribute to the inferior safety for GA: 1) less stringent operational regulations[15,16] and 2) less rigorous and more infrequent pilot training/recurrency.[11] Regarding the former, for example, 14CFR 91 regulations[15] governing GA operations allow for a legal departure with zero lateral and vertical visibility. In contrast, strict weather minima must be met[16] for an aircraft, operating under the auspices of air carrier regulations (14CFR 121), to legally depart an aerodrome.

With the flexibility of GA operational regulations, and in an effort to improve safety, the aviation industry introduced the concept of sound aeronautical decision-making (ADM) to GA pilots some three decades ago.[12,13,18] By definition,[9] ADM is a

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systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances, be it preflight or in flight. Prior research had demonstrated that pilots who were taught this subject were safer than those aviators who did not receive such instruction.[9] From a practical perspective, preflight, a pilot weighs a variety of factors (all of which impact a flight's safety) in their decision to, or not to, initiate a flight (go/no-go decision). These include, for example: 1) the pilot's experience/currency, 2) the pilot's wellness/fatigue state, 3) aircraft capability, 4) environment viz-a-viz terrain and weather, and 5) external pressures to complete a flight.[9,18] Good ADM is equally pertinent to in-flight operations. Thus, a change in the flight situation (e.g., unforecast weather, equipment failure) will require the pilot to recognize the change and undertake appropriate measures in a timely manner to complete the flight safely.[10]

Notwithstanding the emphasis on ADM in training/recurrency over the last 30 yr, the authors are unaware of any studies to address the extent to which GA pilots have adopted (or as a corollary, disregarded) the safety practices intrinsic to such training. This gap in knowledge represents the thrust of the investigation herein. Accordingly, the specific aims of the current study were: 1) use standardized ADM schema in fatal accident analyses to identify which, if any, element(s) of the pre- and in-flight decision-making models are most frequently disregarded and 2) determine whether the rate of fatal accidents related to poor ADM has declined since introduction of the concept in 1991.

METHODS

Subjects

The research performed herein did not constitute human subject research by virtue of all data being obtained from sources/databases in the public domain.

Procedure

The National Transportation Safety Board (NTSB) aviation accident Microsoft Access® databases[25] were downloaded and queried for fatal accidents (1991–2019) occurring in the United States (excluding Alaska) involving single-piston engine airplanes (≤12,500 lb) operating under GA regulations (14CFR 91). The query was further restricted to mishaps involving aviators with a private pilot license (PPL) and for which the accident flight was undertaken for a personal mission. Instrument flight rules (IFR) rating status for PPLs and total flight experiences were determined from the NTSB accident reports. The following accidents were excluded from the study: 1) in which a second pilot was present; 2) involved a stationary aircraft; 3) for which the ownership title included entities such as LLC, LTD, Inc., Corp., or a flying club; and 4) involved homebuilt aircraft. It should be noted that querying the NTSB accident database has clear advantages over the "front-ended" web-accessible NTSB dashboard (https://www.ntsb.gov/safety/data/Pages/GeneralAviationDashboard.aspx) in that the latter does not analyze accidents prior to 2012 or allow for specific inclusion (e.g., PPLs only, IFR rating) or exclusion (e.g., second pilot, LLC, Inc., flying club) criteria as per the current study.

For the aforementioned accident cohort, those related to deficient preflight (go/no-go) ADM were identified by reviewing the corresponding final NTSB accident reports in the context of the PAVE (pilot, aircraft, environment, external pressure)[9,18] and IMSAFE (illness, medication, stress, alcohol, fatigue, eating)[9] models. For errant in-flight decision-making culminating in a fatal mishap, an adaptation of the PPP (perceive, process, perform)[10] model was employed. These schemata and their corresponding criteria are described in **Table I**. Ambiguous accidents in context of ADM were discussed and resolved by common agreement between both authors. Where departure airport weather conditions were absent from the NTSB accident report, these data were obtained from the University of Iowa ASOS network, a repository of archived weather data.[2]

ADM-related accident rates were determined using, as denominator, fleet times aggregated for the indicated period involving single-piston engine airplanes engaged in personal missions per the GA annual survey.[20] Data for 2011 were derived by interpolating 2010 and 2012 fleet times.

Statistical Analysis

A Poisson distribution[8] was used to determine if differences in fatal accidents rates were statistically significant over time. The natural log of aviation fleet time was used as an offset. Differences in proportions were tested using a Fisher exact test (two-sided).[1,21] Adjusted residuals (*Z* scores) were used to identify contributing cells. A Mann-Whitney *U*-test[21] was used to determine if differences in aviator median total flight times (h) were statistically different. All statistical testing was performed using the SPSS v27 package (IBM®, Armonk, NY).

RESULTS

A total of 1481 fatal accidents (1991–2019) involving single-piston engine airplanes operated by PPLs under the auspices of GA regulations (14CFR 91)[15] for the purpose of a personal mission were identified from the NTSB accident databases covering this period. Final NTSB reports corresponding to the aforementioned fatal accidents were manually inspected to identify those in which poor ADM was a contributing factor. Toward this end, the PAVE/IMSAFE and PPP models (Table I) for preflight (also referred to as go/no-go decision) or in-flight ADM were employed, respectively. Any accident for which a factor(s) within the PAVE/IMSAFE and/or PPP schemata was evident per the NTSB final accident report was scored as related to deficient ADM. It should be emphasized that findings in the current study are restricted to those fatal accidents related to deficient go/no-go or in-flight decisions.

Table I. Description of the ADM Models used for Fatal Accident Evaluation.

MODEL	CATEGORY	SUBCATEGORY, FACTOR, OR DESCRIPTION	ACCIDENT SCORED AS RELATED TO POOR ADM IF:
		Preflight	
PAVE	Pilot	Aviator inexperience, deficient flight recency and/or currency	One/multiple factor(s) was/were implicated in accident flight
	Aircraft	Lack of aircraft familiarity, insufficiently equipped, unable to carry planned load, incapable of operating at planned altitude, insufficient fuel for trip/leg; unairworthy	
	Environment	Adverse weather, winds, terrain (e.g., selection of inappropriate altitude), night VFR pilot in area devoid of ambient lighting	
	External pressure	"Get-there-itis", passengers, impress someone (ostentatious behavior)	
IMSAFE	I	Illness	
	M	Cognitively impairing levels of medicine, including illicit substances	
	S	Stress	
	A	Alcohol	
	F	Fatigue	
	E	Eating	
		In-Flight	
PPP		Change in flight situation (e.g., equipment malfunction, weather encounter)	Change was overlooked and/or a corrective action delayed or not undertaken

The PAVE/IMSAFE models were used to determine if an unsound go/no-go decision was made by the accident aviator. The PPP (Perceive Process Perform) schema was adapted to identify accidents relating to poor aeronautical decision-making (ADM) brought about by a changed in-flight situation which was either not recognized by the pilot or for which a corrective action was delayed or not undertaken. Equipment malfunction excludes any rendering the aircraft uncontrollable. VFR = visual flight rules.

Categorization of Deficient Go/No-Go ADM Mishaps

Using the PAVE/IMSAFE model (Table I), fatal accidents involving errant go/no-go ADM were categorized for the aforementioned 1481 fatal accidents. Interestingly, a poor preflight decision to depart into a hazardous environment (V) (e.g., adverse weather, terrain) contributed by far to the most (54%) fatal mishaps (**Fig. 1**). Fatal accidents involving pilots disregarding their impaired physical/mental well-being (e.g., illness, stress, alcohol, fatigue, cognitively impairing medicines/illicit substances) as assessed by IMSAFE (Table I) represented a smaller (21%) fraction of the fatal accidents (Fig. 1). A similar percentage (20%) of fatal accidents involved pilots who made a poor decision to initiate a flight despite a lack of familiarity with the mishap airplane (A) (e.g., equipment, flight capabilities/limitations, fuel burn). Conversely, deficiency in the pilot's flight skills in context of their experience/recency/currency (P) was evident for a smaller fraction (12%) of fatal accidents (Fig. 1). Somewhat surprisingly, flights with a fatal outcome undertaken in response to external pressure (E) represented only a modest fraction (10%) of mishaps. It should be noted that an accident may have involved multiple categories concurrently.

Sub-Categorization of Fatal Accidents Involving Errant Environment-Related Go/No-Go Decision-Making

As shown above, the majority of fatal go/no-go ADM-related accidents binned into the environment category per the PAVE/IMSAFE protocol. Since this group comprises multiple subcategories (see Table I), we then endeavored to subclassify such mishaps. Interestingly, the decision to depart into forecasted or known adverse weather represented the most prevalent subcategory (56%) of fatal accidents binned into the environment group (**Table II**). Note that adverse weather represented either: 1) any forecasted conditions cited by a Federal Aviation Administration (FAA)-approved provider in a preflight weather briefing[15] and received by the accident aviator that would be contrary to the safe completion of a flight; or 2) such weather at the departure airport at the time of departure. The preflight selection of an altitude insufficient to maintain terrain clearance or in breach of FAA regulations per low-level operations [1,000 and 500 ft (304.8 and 152.4 m) above ground level for operations over inhabited and non-inhabited areas, respectively[15]] represented the second most common group (34%) within the environment category of the PAVE/IMSAFE model.

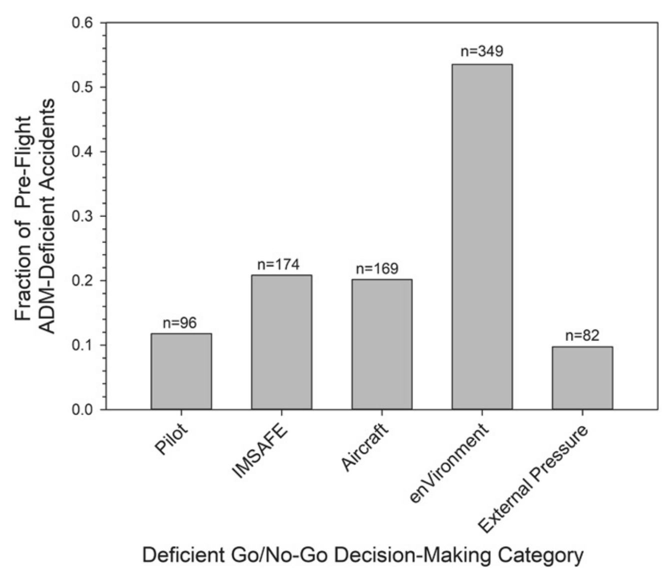

Fig. 1. Categorization of deficient go/no-go aeronautical decision-making (ADM) accidents. Fatal accidents (1991–2019) were scored for unsound preflight ADM using the PAVE/IMSAFE model per Table I. The fraction (the total representing the count of accidents related to deficient preflight ADM) of mishaps corresponding to each of the PAVE/IMSAFE categories is illustrated. Note that an accident could be scored for multiple PAVE/IMSAFE factors concurrently. *N* = accident count.

Table II. Sub-Categorization of Fatal Accidents Binned in the Environment Group.

ENVIRONMENT SUB-CATEGORY (PRE-FLIGHT ADM)	ACCIDENT FRACTION	COUNT (*N*)
Adverse Weather	0.56	195
Terrain	0.34	120
Deficient Lighting (non-IFR PPL)	0.07	23
Other	0.03	11

Mishaps related to poor go/no-go decision-making restricted to the environment category of the PAVE/IMSAFE model were subclassified per the schema in Table I. The fraction of accidents (of a total represented by the "V" category count) for each subcategory is shown. Non-IFR PPL = non-instrument-rated PPL; *N* = accident count.

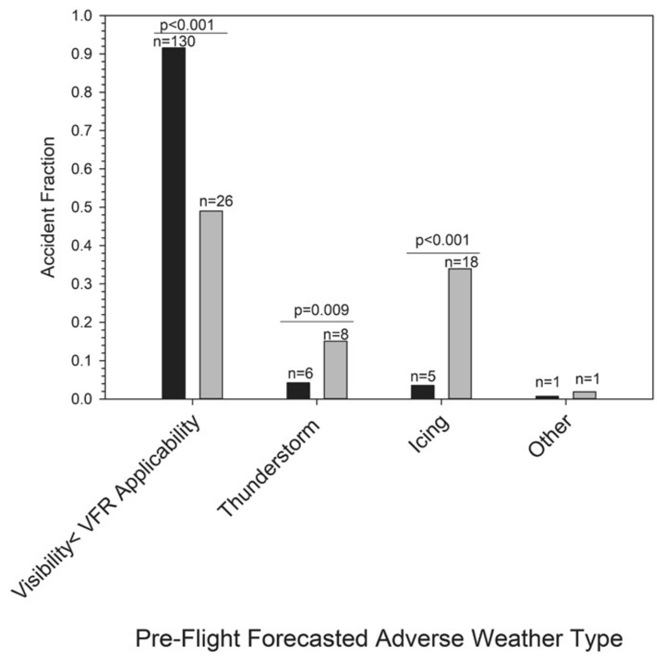

Fig. 2. Varying adverse weather types for IFR-rated and non-IFR-rated PPLs. Fatal accidents involving errant decision-making for the adverse weather subcategory (per Table II) were grouped by the indicated forecasted weather received by the aviator and whether he/she held an instrument rating. For each pilot group (non-IFR PPL = black bars; IFR-Rated PPLs = gray bars) accident fractions were determined using the sum of the constituent weather groups mishaps as denominator. "Visibility < VFR Applicability" represents forecasted cloud ceiling of <3000 ft (914.4 m)[19] for accident flights in which the pilot elected to operate by visual flight rules. Other group represents forecasted windshear and wind exceeding the maximum demonstrated crosswind limit of the accident aircraft. A Fisher Exact test (two-sided) was performed to determine if difference in proportions was statistically different. Contributions of cells were calculated from adjusted residuals (*Z* scores). *N* = accident count.

The findings of "adverse weather" as the predominant subcategory of the environment group then raised the question as to the types of such weather (e.g., degraded visibility, icing or thunderstorms). It is noteworthy that adverse weather may be a function of an aviator's qualifications. By way of background, an instrument rating allows a pilot to safely conduct a flight, under the auspices of an IFR flight plan, by sole reference to instruments (e.g., in clouds, commonly referred to as instrument meteorological conditions, or IMC).[17] Conversely, in the absence of an IFR flight plan, such pilots, as well as non-IFR-rated aviators, are limited to operating using external visual references and in accordance with visual flight rules (VFR). These rules specify minima cloud-ceiling heights and lateral visibility distances.[19] On the other hand, a go/no-go decision in regards to forecasted icing and convection (thunderstorms) applies to all PPLs, regardless of IFR rating, since the majority of light aircraft are not certificated to fly in icing conditions[20] and the strong up/downdrafts associated with thunderstorms can cause structural failure of such airplanes.[23,14,34]

The decision to initiate a flight under the auspices of VFR despite forecasted weather not meeting these minima criteria was the most frequent errant preflight decision for PPLs, regardless of their IFR rating (**Fig. 2**). For the non-IFR-rated pilot, electing to depart into such hazardous conditions represented 92% of fatal accidents within the adverse weather subcategory. Note that for each pilot group (IFR rating status) accident fractions were determined using the sum of the constituent weather groups mishaps as denominator. Perhaps not surprisingly, this fraction of accidents was lower for pilots holding an instrument rating, accounting for 49% of mishaps binned into the adverse weather subcategory. Presumably these aviators, by virtue of their instrument training, are more able to maintain aircraft control upon loss of external visual cues. This difference in proportions between IFR-rated and non-IFR-rated PPLs was statistically significant ($P < 0.001$).

Interestingly though, IFR-rated PPLs were overrepresented (relative to PPLs not holding an instrument rating) for fatal accidents related to the poor decision to initiate flight into forecasted or known thunderstorms or icing (Fig. 2). Thus, the fraction of IFR-rated PPLs involved in a fatal thunderstorm encounter was threefold higher (0.15 vs 0.04, respectively) than their non-IFR-rated counterparts, a difference which was statistically significant ($P = 0.009$). Even more dramatic was the difference between IFR-rated and non-IFR-rated PPLs regarding their preflight decision to depart into forecasted or known icing. Again, there was a disproportionate count of IFR-rated PPLs involved in such accidents when compared to non-IFR PPLs. More specifically, for the adverse weather subcategory, while 34% of fatal accidents involved IFR-rated PPLs making the poor decision to depart into forecasted/known icing conditions, this percentage was reduced nearly tenfold for the PPLs restricted to visual flight operations. This difference was strongly statistically significant in proportion testing ($P < 0.001$).

Considering that "terrain" represented the second most common environment subcategory (see Table II) in accidents involving deficient go/no-go decision-making, we endeavored to subclassify accidents within this group. Accordingly, mishaps within this subcategory were empirically divided using the following criteria: 1) operations at low level, commonly referred to as "buzzing", i.e., flights below 500 or 1000 ft (304.8 or 152.4 m) above ground in unpopulated and populated areas, respectively, per GA regulations[15]; 2) flights for which an altitude insufficient to clear mountains/ridges was selected; and 3) low-level aerobatics performed below an altitude of 1500 ft (457.2 m)

Table III. Deficient Preflight Altitude Decision-Making.

TERRAIN	ACCIDENT COUNT (*N*)	ACCIDENT FRACTION
Low level operation/buzzing	92	0.77
Insufficient mountain/ridge clearance	11	0.09
Low level aerobatics	17	0.14
TOTAL	120	1

The fraction of fatal accidents relating to poor preflight aeronautical decision-making in context of the terrain subcategory of the environment group is shown. The sum of the accidents across constituent terrain groups represented the denominator for fraction determinations.

above ground.[15] Of particular concern, "buzzing" represented, by far, the most prevalent group (**Table III**), comprising 77% of accidents within the terrain subcategory of errant preflight ADM. In contrast, the choice of an altitude incompatible with clearing a mountainous region/ridge enroute and pilots' preflight decision to perform aerobatics at a height lower than that prescribed by FAA regulations[15] constituted only 9% and 14% of accidents, respectively, within the terrain subcategory of mishaps (Table III).

Faulty In-Flight ADM

The aforementioned data addressed accidents related to errant go/no-go ADM. However, manual inspection of the 1481 fatal mishaps occurring over the 1991–2019 period identified 296 mishaps involving unsound in-flight decision-making, using an adaptation of the PPP model[10] (see Table I). Such accidents were then subclassified using an empirical schema based on the errant ADM-related mishaps within the current cohort. Failing to recognize, or a delayed action in avoiding IMC, was by far the most common deficient in-flight decision for non-IFR-rated PPLs (77%) and IFR-rated PPLs (38%) operating under VFR (**Fig. 3**). In proportion testing, non-IFR-rated PPLs were overrepresented ($P < 0.001$) for fatal accidents in this category of deficient in-flight ADM.

Conversely, failing to recognize in-flight icing conditions or a delayed corrective response to this hazard was more likely to involve IFR-rated PPLs than aviators not certified for instrument flight (Fig. 3). More specifically, while deficient in-flight ADM applicable to icing contributed to 21% of all such fatal accidents for IFR-rated PPLs, less than 1% of mishaps could be attributed to this threat for non-IFR aviators. This difference was strongly statistically significant in proportion testing ($P < 0.001$). It is noteworthy that the same threats to flight safety were evident for accidents binned in the go/no-go ADM model (see Fig. 2).

Temporal Trends in ADM-Related Accidents

Considering the emphasis on ADM in ab initio and recurrent GA flight training since 1991,[9,12,18] the next question posed was whether the rate of fatal accidents related to deficient go/no-go ADM has diminished for each of the PAVE/IMSAFE categories over the intervening three decades. The most compelling decline in fatal accidents related to errant go/no-go decision was in the environment category, as evidenced by a 64%

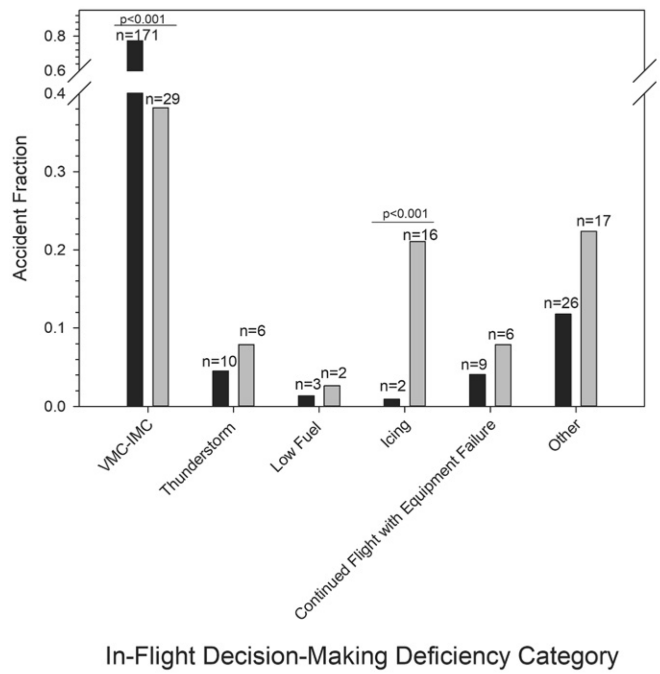

Fig. 3. Differences in errant in-flight aeronautical decision-making categories distinguish IFR-rated PPLs and non-IFR-rated PPLs. Fatal mishaps involving unsound in-flight decision-making were binned into the stated categories and by IFR-rating. Accident fractions were determined using the sum of mishaps for each pilot cohort (non-IFR PPL = black bar; IFR-rated PPLs = gray bar) as denominator. A Fisher Exact test (two-sided) was used to determine if the difference in proportions was statistically different. Contributions of cells were calculated from adjusted residuals (*Z* scores). VMC-IMC = continued flight from visual to instrument conditions; *N* = accident count.

reduction ($P < 0.001$) over the 30-yr period (**Fig. 4**). In fact, decrements in mishap rate in this category for the 2001–2005 and subsequent periods were statistically significant in a Poisson distribution ($P < 0.001$), using the initial period as referent. In contrast, reductions in the fatal accident rate related to faulty go/no-go decision making in the other PAVE/IMSAFE categories were more modest over the three decades. While improvements in go/no-go decision-making in the context of the pilot physical/mental well-being (per IMSAFE) were evident based on an accident rate reduction of up to 50% for this category for the period spanning 2006–2010, this reduction was unchanged for the most recent period ($P = 0.641$), using the initial period as referent. Regarding the pilot category, a mere 5% reduction, which was not statistically significant ($P = 0.876$), was witnessed when comparing the most recent and initial periods. Similarly, the accident rate in the preflight ADM aircraft category varied across the three decades. It diminished ($P = 0.009$) for the 2011–2015 period but not for the most recent period ($P = 0.060$), again using the initial period as referent.

Considering the prominence of deficient go/no-go ADM regarding forecasted <VFR weather, we then determined if the rate of such fatal mishaps declined over time. Indeed, this was evident with the accident rate for such accidents decreasing ($P = 0.013$) by 60% relative to the initial period (1991–1995). Presumably, aviators are making more sound decisions in the

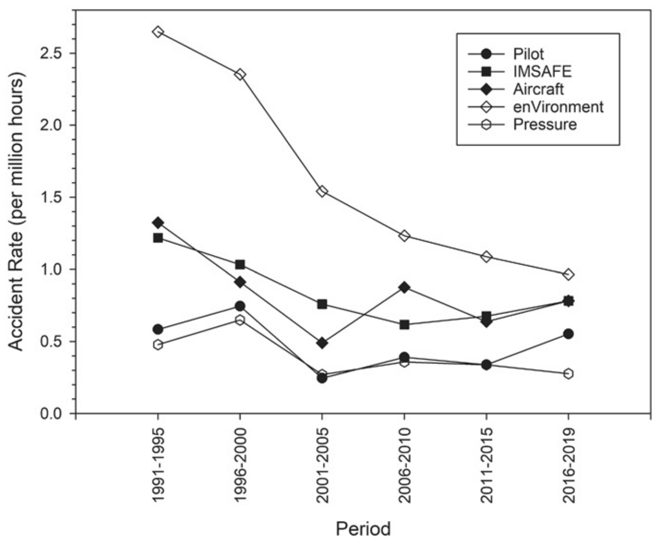

Fig. 4. Temporal changes in rates of accidents related to go/no-go deficient aeronautical decision-making. Fatal accident rates related to the indicated PAVE/IMSAFE category were determined using fleet times for single-piston engine airplanes engaged in personal missions as denominator. A Poisson distribution was employed to determine if the accident rate changed over time.

context of refraining from departing into forecasted <VFR conditions, although improvements in forecasting methodologies could be contributory.

Total Flight Experience for Aviators Involved in Accidents Related to and Un-Related to Failed ADM

Lastly, we entertained the notion that pilots with less total flight experience would be more likely to be involved in unsound ADM-related accidents than aviators who had accrued more total time. To address this question, we compared total flight times (where included in the NTSB report) for pilots involved in an accident related to deficient ADM (pre- and/or in-flight) with those in which the fatal mishap was caused by situations deemed unrelated to ADM (i.e. in-flight catastrophic equipment failure or a midair collision). While the median total flight times trended lower for aviators faulted for poor ADM (594 h and 772 h, respectively), this difference was determined not to be statistically significant using a Mann-Whitney *U*-Test ($P = 0.444$). These data do not align with the notion that inferior ADM skills correspond to lesser flight experience, although a caveat is that this conclusion is based on accident flights only.

DISCUSSION

Herein, we have shown improvements in GA safety, especially in the context of the preflight decision to initiate flights into forecast adverse weather. Notwithstanding this encouraging finding, two observations still warrant concern. First, there is a very modest (if any) decrement in go/no-go ADM in the context of the pilot, IMSAFE, and aircraft categories. Secondly, and equally important, the fraction of accidents related to errant ADM for the most recent period (2016–2019) still remains high, representing 58% of all GA accidents involving PPLs operating single-engine airplanes for the purpose of a personal mission.

Although substantial gains have been made in the go/no-go decision to initiate flight into adverse weather, this category still remains the largest for ADM-related accidents. It should be noted that this observation applied to both IFR-rated and non-IFR-rated pilots who chose to undertake a VFR flight (rather than an IFR flight) into such weather. It remains to be determined why aviators would depart into such hazardous conditions. One possibility could be the modest accuracy of the terminal aerodrome forecasts as reported in two prior studies.[6,7] In this regard, it would behoove pilots to also add the Localized Aviation MOS Program (LAMP) forecast to their preflight ADM toolkit, especially when departing aerodromes for which no Terminal Aerodrome Forecast is issued.[6] On a related note, our conservative decision to use VFR with its prescribed minimum ceiling of 3000 ft (914.4 m) above ground was based on two reasons: 1) the aforementioned poor accuracy of terminal aerodrome forecasts; and 2) the potential of man-made structures, such as antennae, reaching in excess of 2000 ft (609.6 m) AGL.

As to poor in-flight decision-making, a plethora of overlapping human factors and behavioral studies[4,36,37] have cataloged motivation type,[36,37] continuation bias,[4,26,33] and an individual's risk tolerance[27] as factors leading aviators to continue a flight[3,4] in the face of deteriorating weather (i.e., ceilings progressively lowering enroute). Unexpectedly, however, our finding of a low score (10%) of ADM-related accidents in the external pressure category of the preflight PAVE/IMSAFE model was inconsistent with this notion. We suspect though that this low fraction is due to a lower emphasis by NTSB accident investigators on capturing human factors information surrounding the accident flight.

The dramatic reduction in the rate of errant ADM-related accidents (environment category) through 2001–2005 merits comment. It is unlikely that this was due to reduced GA fleet time associated with the terrorist activities of September 11, 2001, as, by definition, the accident rate represents an adjustment for fleet activity. On the other hand, could it be that technological advancements in GA in the last 30 yr, rather than improved ADM, have yielded an artificial diminished rate of ADM accidents through 2001–2005? For example, there has been a slow but steady transition from analog flight instruments to electronic flight displays starting circa 2003.[32] Also, the introduction of the IPad^{R} tablet and mobile pilot applications such as Foreflight^{R} and GarminPilot^{R}, both compatible with this device, has allowed the aviator to identify weather hazards immediately preceding departure as well as enroute. These include, for example, thunderstorms, prevailing visibility, and cloud ceilings at enroute and destination weather-reporting airports. Thus, a potential weather-related accident could be averted, yielding an apparent lower ADM-related accident rate. However, this latter argument is improbable since the founding of the Foreflight company (2007)[22] and the introduction of the IPad^{R} device (2010)[35] occurred subsequent to the improvement in ADM-related accident rate, with the latter witnessed prior to 2001–2005.

So, why then did the accident rate related to some of the go/no-go categories (pilot, aircraft, IMSAFE, external pressure) remain relatively unchanged over the 30-yr period? One possibility is the existence of a segment of the GA pilot population resistant to any notion of safety practices (and unchanged in numbers over time), instead favoring "thrill-seeking" flight activities. A second possibility is that some GA pilots are still unaware of ADM practices. Thus, while such subject matter is now integrated into ab initio flight training[18] and the WINGS program,[12] the latter activity is noncompulsory for the certified pilot. Moreover, ADM represents only a discretionary activity in mandatory flight reviews for certified GA pilots.[13] Nevertheless, whatever argument is advanced must take into account the substantial improvement in safety regarding go/no-go decision-making in context of adverse weather.

The authors recognize that faulty ADM represents a contributing rather than a causal factor for the aviation accidents herein. Still, it is well accepted[28,30] in the "Swiss cheese" model that any accident represents the contribution of multiple human failures leading to the breakdown of a complex system and, in this case, a fatal accident. Thus, had the aviator practiced sound ADM (e.g., heeding an adverse weather forecast), a fatal accident would likely have been averted.

Our current study was not without limitations. First and foremost, only deficient ADM (i.e., one which culminated in a fatal accident) could be investigated. Related to this, although the psychological (to family/friends) and financial impact of a fatal accident far exceeds that of a nonfatal mishap,[29,31] thereby rationalizing the current study, an aviator who has succumbed to his/her injuries cannot be interviewed for motivations to their ADM. Second, but equally important, we suspect the number (and hence, rate) of ADM-related accidents represents an under-count for a multitude of reasons, all related to the NTSB investigative reports: 1) earlier ones had a paucity of details on the accident flight; 2) they sometimes did not include the weather forecast or whether the accident pilot was in receipt of the corresponding hazardous conditions; and 3) they tend to focus more on regulations violated than human factor details preceding/contributing to the accident flight itself (e.g., external pressure on the aviator to complete the flight and/or mental/physical state). Indeed, it should be noted that the PAVE/IMSAFE/PPP ADM schemata are instruments developed by the FAA, whereas the NTSB has not adopted any specific instrument in their accident analysis (Dr. Loren Groff, NTSB. Personal communication; 2023). Third, we also assumed that the decision to perform low altitude operations ("buzzing", low-level aerobatics) in breach of FAA regulations was premeditated and, accordingly, binned such mishaps in the pre- rather than the in-flight decision category. Regardless, either case would represent poor ADM. Lastly, in restricting the study to the PAVE/IMSAFE and PPP models, some elements of ADM, namely hazardous attitude or antiauthority personalities, were not examined.

Finally, the findings herein raise the question: how can ADM be improved in GA? Practices recently adopted by some insurance companies for operations of light jets under 14CFR91 regulations may offer some guidance. These practices specify the requirement for a mentor pilot to be assigned and work directly with the aviator to assist in ADM practices. More specifically, new owners of turbojets require a mentor during the first 25–50 h of operating experience. In addition, such owners are also mandated to have a mentor for any flight with a family member. As another potential intervention regarding a pilot who has inadvertently encountered IMC, an air traffic controller could plainly state that "no violation will be filed" to reduce arousal associated with the fear of legal ramifications.

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