Human Factors Analysis of Accidents Involving Visual Flight Rules Flight into Adverse Weather

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Background: General aviation (GA) accident statistics indicate that visual flight rules (VFR) flight into instrument meteorological conditions (IMC) is a major safety hazard. However, little research has been conducted to identify the factors that influence VFR pilots' decisions to risk flying into deteriorating weather. The purpose of the present study was to further examine the causes of GA accidents associated with VFR flight into IMC. ***Method:*** A comprehensive review of GA accident reports maintained by the National Transportation Safety Board (NTSB) was conducted to identify accidents involving VFR flight into IMC between January 1990 and December 1997. These accidents were compared with other GA accidents that occurred during the same time period. ***Results:*** Analyses of these accidents revealed that VFR flight into IMC accidents were more likely to involve less-experienced pilots and to have passengers aboard the accident aircraft compared with the other GA accidents. In addition, most VFR flight into IMC accidents were considered by the NTSB to have involved intentional flight into adverse weather by the pilot. ***Discussion:*** These findings are interpreted in terms of their implications for the underlying causes of VFR flight into IMC, including situation assessment, risk perception, and social pressure. Intervention programs that address all of these factors are needed.
Keywords: accident analysis, aeronautical decision making.

VISUAL FLIGHT RULES (VFR) flight into instrument meteorological conditions (IMC), or unqualified flight into adverse weather, has long been a major concern within non-commercial or general aviation (GA). For example, accidents involving VFR flight into IMC accounted for approximately 19% of all GA fatalities in the United States between the mid-1970s and mid-1980s (6). However, 72% of these VFR flight into IMC accidents were fatal, compared with an overall GA fatality rate of 17% during this same time period. The GA accident records in other countries (e.g., United Kingdom and New Zealand) also indicate that VFR flight into IMC is a global safety hazard within the GA arena (8).

Unfortunately, research into the factors affecting pilots' decisions to fly into adverse weather is scant. Nonetheless, a variety of possible explanations for VFR flight into IMC have been proposed in the literature by the authors (3,12) and other researchers in the field (9,11). Several of these explanations provide legitimate hypotheses that might be tested using either laboratory or archival (i.e., accident database) research. These include situation assessment, risk perception, decision framing, and social pressure.

According to the situation assessment hypothesis, pilots risk pressing on into deteriorating weather simply because they do not realize that they are doing so. In other words, pilots continue VFR flight into IMC when they misdiagnose the changes in, or severity of, the weather. Presumably, had they known that the weather was deteriorating into IMC, they would not have flown into it. A growing number of researchers have found that situation assessment and awareness are the most important aspects of good decision-making processes in dynamic problem solving situations (4,5). For example, previous research on information processing failures in aviation (10,13) have shown that errors early in the process (e.g., diagnostic errors) result in more serious accidents than errors made later in the process (e.g., handling errors). The loss of situational awareness that precipitates a VFR-into-IMC event may be due to a variety of reasons, including a lack of experience interpreting real-time weather by low-time or "fair weather" pilots. Another reason may be the gradual transition from minimum VFR conditions, to marginal VFR conditions, to instrument flight rules (IFR) weather that could make discriminations between weather conditions difficult. In general, then, VFR flight into IMC can be seen as a failure of recognition-primed decision making (5).

Another explanation for why pilots would continue VFR flight into IMC is that pilots are overconfident in their abilities and do not fully appreciate the risks of flying into adverse weather. O'Hare (8) has indicated that pilots need to feel confident in their ability to control the aircraft in all flight regimes. However, an unfortunate by-product of this training may be a degree of overconfidence in one's skill level and an unrealistic optimism about the chances of avoiding harm through personal control. Several studies have shown that people tend to rate their chances of being involved in an accident much lower when the threats are perceived as

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being controllable by personal actions. A report by the U.K. Civil Aviation Authority (1) cited several psychological factors contributing to pilot errors related to weather conditions which included "excessive optimism," a "reluctance to admit limited capability," and "lack of appreciation of real dangers." O'Hare (8) obtained similar findings and concluded that general aviation pilots exhibited both relatively low levels of risk awareness and generally high optimistic self-appraisals of abilities and judgment.

In essence, continued VFR flight into IMC can be regarded as equivalent to a risky gamble involving chances of success or disaster. The decision to divert or make a precautionary landing, on the other hand, can be regarded as leading to a somewhat certain outcome. According to the decision-framing perspective, the choice pilots will make under these circumstances depends on how the problem is represented and what frame is used to interpret the situation. If pilots frame their decision of whether to continue flight into deteriorating weather in terms of potential losses of diverting (such as time wasted, money spent, or fuel used up), then they will be more likely to be risk-seeking in their choices. In contrast, if pilots frame the decision to divert in terms of anticipated gains (such as ensuring the safety of the aircraft and its occupants), then they should be more likely to act in a risk-averse manner. Indeed results of a laboratory study by O'Hare and Smitheram (9) showed that decisions to continue a VFR flight into adverse weather conditions were less likely when the prospects or possible outcomes were framed in terms of gains rather than as losses. These researchers have suggested that in a real-world flight environment, decision frames may be induced by the proximity of pilots' goals, such as the destination airport. As goal achievement gets closer, there may be a natural shift to the loss frame when bad weather is encountered, resulting in an increased commitment to a planned course of action (11). Within the field of aviation, this increased desire to reach the destination airport as more time and effort are invested in the flight is referred to as "get-home-itis" or the "sunk cost" effect (9,12).

Similar to decision framing, social pressures may bias pilots' decisions to continue with a flight even though an assessment of the situation suggests they should do otherwise. In the case of VFR into IMC flights, pilots may feel pressured to reach their destination sooner rather than later when passengers are onboard or when other individuals are waiting at the destination airport. In addition, they may also feel the need to impress passengers with their flight skills, especially when faced with difficult flight conditions. O'Hare and Smitheram (9) have noted that there are "numerous examples in the air crash files of low flying 'beat ups' and 'buzzing' that have led to disaster that would not have occurred without the presence or anticipated presence of an audience to observe the maneuvers." However, the extent to which social pressures play a role in VFR flight into IMC has yet to be fully examined.

To date, very few studies have been conducted to empirically examine the plausibility of these different accident causation theories in terms of their ability to account for the actual factors that contribute to VFR flight into IMC accidents. Consequently, without such an empirical understanding of these factors, decision-making training within pilot training programs continues to be based largely on common sense and intuition. Not surprisingly, such programs have been relatively ineffective in reducing the occurrence of these accidents.

While laboratory experiments present one method of investigating the conditions surrounding VFR flight into IMC in a controlled environment, accident reports offer useful insights from "real world" data as well. Indeed, the National Transportation Safety Board (NTSB) has an accident classification system that categorizes VFR flight into IMC events, which allows the direct identification of the probable causal factors associated with these accidents. However few studies have been conducted to examine this dataset since the original report published by the NTSB in 1989 (6). The purpose of the present study was, therefore, to further examine the actual characteristics and causes of accidents involving VFR flight into IMC in light of the possible theoretical explanations of these events postulated in the literature.

METHODS

General aviation accidents are investigated by experienced pilots who are trained investigators employed by the NTSB. These investigators collect and examine a variety of data surrounding the accident, including wreckage patterns, radar data, pilot records, weather reports, and witness interviews. Based on this information, investigators determine the probable cause of the accident and generate possible safety recommendations for preventing similar accidents. This information is summarized in a narrative report and the specific accident causal-factors are entered into a database using a set of standardized codes (e.g., VFR flight into IMC). The narrative report and data are submitted to NTSB headquarters in Washington, DC, where they are checked for accuracy and subsequently endorsed as the official accident report. Both the NTSB and Federal Aviation Administration (FAA) then make this information available to the general public.

Case Selection and Sampling

VFR flight into IMC cases (VFR-IMC sample): A comprehensive review of all accidents involving Federal Aviation Regulations (FAR) Part 91 aircraft, or noncommercial aircraft, between January 1990 and December 1997 was conducted using internet-database records maintained by the NTSB (7) and the FAA (2). Of particular interest to this study, were those accidents attributable to VFR flight into IMC. The analysis was also limited to fixed wing, general aviation airplanes and therefore excluded helicopters, gliders, and experimental aircraft. Of these, only those accidents in which the investigation was completed, and the cause of the accident determined, were examined. A total of 409 accidents met these criteria for further analysis. The narratives, causal codes, and sequence of events presented in

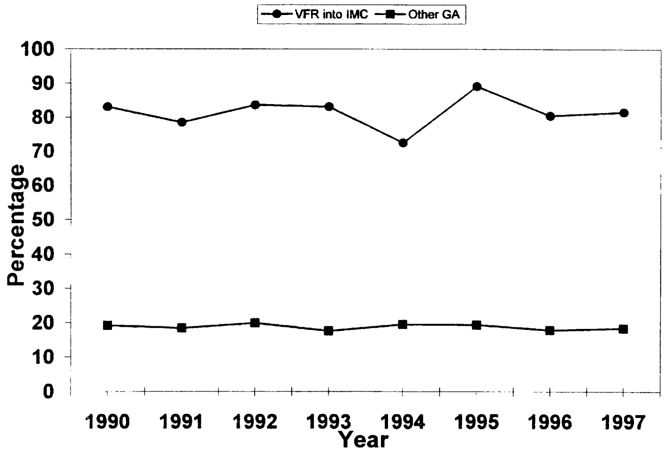

Fig. 1. Percentage of VFR flight into IMC accidents that were fatal compared with other types of GA aircraft accidents that occurred between January 1990 and December 1997.

each of these accident reports were examined and extracted for analysis.

Other GA aircraft accidents (GA sample): To identify any unique characteristics of VFR-IMC accidents, the data from these accidents was compared with other non-VFR-IMC accidents. The accident database structure allowed for some global comparisons to be made using the entire dataset; however, other more detailed comparisons could not be extracted readily from the database. Therefore, a stratified proportionate sampling method was used to select 409 GA aircraft accidents for making these comparisons. This sample was stratified proportionately according to the year and state in which the VFR into IMC accidents had occurred. This procedure was used in order to ensure that the two groups of accident types (VFR-IMC vs. GA sample) did not differ in terms of time and location of occurrence. To allow for comparison, the same information extracted from the VFR-IMC sample was also taken from the GA sample.

RESULTS

Accident Frequency and Fatality Rates

Between 1990 and 1997, approximately 50 general aviation (GA) aircraft accidents were classified each year by the NTSB as being the result of visual flight rules (VFR) flight into instrument meteorological (IMC) conditions. While this number did not constitute a large proportion of the approximately 1900 GA aircraft accidents each year during the same time period, the risk of incurring fatal injuries was higher in the VFR-IMC accidents. By observation, it can be seen in **Fig. 1** that fatality rates for VFR flight into IMC accidents and other GA aircraft accidents remained relatively constant over the 8-yr period. More importantly, the fatality rates of VFR flight into IMC accidents (approximately 80%) were also consistently higher than that of other GA aircraft accidents (approximately 19%) during that time period.

Categories of VFR-IMC Accidents

Within the NTSB classification system, VFR flights into IMC are further categorized into various types. These include: 1) continued, 2) inadvertent, 3) attempted, 4) performed, 5) intentional, 6) initiated, 7) encountered, and 8) unclassified. The 409 VFR-IMC accidents identified in this study consisted of 149 continued, 92 inadvertent, 57 attempted, 45 performed, 34 intentional, 23 initiated, and 6 encountered. Three cases were not further classified in this sample. Definitions of these categories are not provided by the NTSB but the specific nature of these VFR-IMC flights can be inferred from the terms used for classification. It should be noted that two of these categories (i.e., inadvertent and encountered) suggest that the pilot did not "willfully" penetrate or continue with the flight. When combined, these inadvertent and encountered VFR-IMC accidents accounted for 24% of the cases.

Top 10 Factors and Causes

Table I shows the top 10 factors/causes of the 409 VFR flight into IMC and GA accidents in our study, in terms of the proportion of the accidents having these factors/causes. Of the top 10 factors/causes, 3 refer to environmental factors (weather, terrain, and light conditions), while the remaining 7 refer to flight crew factors. Of particular note, however, is the finding that the top three flight crew factors (i.e., spatial disorientation, aircraft control, and lack of total instrument time) pertain to the consequences or causes of the accident after the pilot had penetrated IMC. The remaining flight crew factors pertain to errors made prior to encountering IMC, the lowest of which is weather evaluation.

To investigate whether the top 10 factors were unique to VFR flight into IMC accidents, the proportion of accidents associated with these 10 factors/causes were compared with that of the GA sample. Table I also shows this comparison. A review of this table reveals that other GA accidents share 4 of the top 10 factors/causes of the VFR-IMC accidents. However, a larger percentage of VFR-IMC accidents are associated with these common causes/factors than other types of GA accidents. It should also be noted that "over confi-

TABLE I. TOP 10 FACTORS/CAUSES OF VFR FLIGHT INTO IMC AND GA ACCIDENTS IN TERMS OF THE PROPORTION OF THE ACCIDENTS HAVING THESE FACTORS/CAUSES.

Factors/Causes	Category[1]	% VFR Cases	% GA Cases
Weather Conditions[2]	E	69.2%	22.5%
Terrain Conditions[2]	E	24.9%	19.8%
Spatial Disorientation	F/P	23.7%	0.98%
Aircraft Control[2]	F/A	23.2%	6.40%
Light Conditions	E	23.0%	4.89%
Lack of Total Instrument Time	F/T	15.9%	0.50%
In-Flight Planning/Decision[2]	F/PD	12.7%	5.90%
Preflight Planning/Decision	F/PD	11.2%	4.90%
Weather Evaluation	F/O	11.2%	1.20%
Altitude/Clearance	F/A	8.1%	1.50%

Note: Since accidents may have more than one casual-factor, percentages may not sum to 100%.
[1] E: Environment; F: Flightcrew; P: Psychological/Physiological; A: Aircraft Handling; PD: Planning/Decision-Making; O: Obtaining and Using Weather Information.
[2] These factors are among the top 10 factors/causes related to accidents from the GA sample.

dence" did not make the top 10 list of either type of accident; however, it did rank 11th for VFR-IMC accidents, accounting for approximately 7.5% of these accidents vs. less than 1% of the GA sample.

Pilot Factors

Pilot flight experience: Analyses were performed on the total number of flight hours of accident pilots in order to explore whether pilots involved in VFR-IMC accidents and other sorts of GA accidents differed in terms of flight experience. Cases which had an entry of 0 h for total flight hours were excluded from analysis, generating n = 402 and n = 397 for the VFR-IMC and GA samples respectively. Given that the distributions were not normal, a median test was used. The median flight hours for the VFR-IMC sample (580 h) was significantly lower than that of the GA sample (900 h) (χ^2 (1, n = 799) = 8.62, $p < 0.01$).

Pilot ratings and certification: The proportion of pilots with instrument ratings from both samples was analyzed. This information was missing on four cases from the GA sample and one case from the VFR-IMC sample. A chi-square analysis indicated a significant relationship between the type of accident and whether the pilot had an instrument rating (χ^2 (1, n = 814) = 16.64, $p < 0.01$). A larger proportion of pilots from the GA sample had an instrument rating (n = 187, 46.1%) compared with pilots involved in VFR-IMC accidents (n = 131, 32.1%), while a larger proportion of pilots from the VFR-IMC sample had no instrument rating (n = 277, 67.9%) compared with those from the GA sample (n = 219, 53.9%) (see **Fig. 2**, panel A). The pilot's certification was also used as an additional measure of flight experience. These certifications ranged from the very basic level of a student pilot's license, up to a private pilot's license and beyond (e.g., commercial license). A chi-square analysis revealed a significant relationship between type of accident and pilot certification. A larger proportion of pilots involved in VFR-IMC accidents (n = 293, 71.6%) had only private pilot's licenses or below (e.g., student license) than pilots involved in other types of GA accidents (n = 237, 57.9%); whereas a larger proportion of pilots involved in other types of GA accidents (n = 172, 42.1%) had certifications above private pilot (e.g., commercial) than pilots involved in VFR-IMC accidents (n = 116, 28.4%) (χ^2 (1, n = 818) = 16.81, $p < 0.01$) (see Fig. 2, panel B).

Other Factors

Presence of passengers: The presence of passengers in the aircraft was also examined and used as an indicator of social pressure. The premise was that pilots carrying passengers may feel greater pressure to reach their destination or demonstrate their skill, and hence are more likely to engage in VFR-IMC. The results indicate that a significantly higher proportion of VFR-IMC accidents (n = 222, 54.3%) had passengers than other types of GA accidents (n = 183, 44.7%), whereas the reverse was true when considering accidents with no passengers (VFR-IMC: n = 187, 45.3%; GA: n = 226, 54.7%) (χ^2 (1, n = 818) = 7.4, $p < 0.01$) (see Fig. 2, panel C).

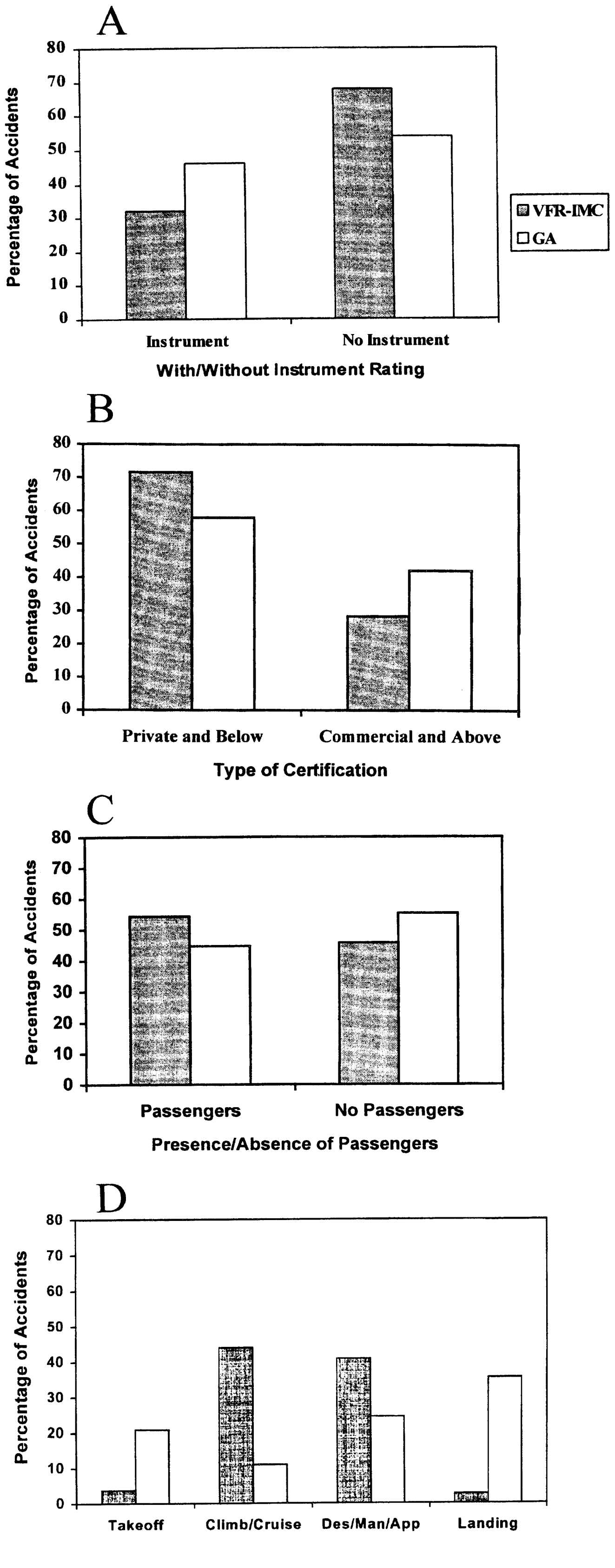

Fig. 2. Percentage of VFR flight into IMC and other GA accidents as a function of pilots instrument rating (panel A), pilot certification (panel B), presence of passengers (panel C), and phase of flight (panel D).

Phase of flight: The exact location of the accidents in terms of their distance from the departure and destination airports was not available in the database. Therefore, the phase of flight in which the accidents occurred was used as a crude estimate of how far into the flight the pilot had flown or, at least, the relative proximity to the destination airport. This analysis was performed to examine whether motivational or cognitive framing factors might lead to greater risk taking behavior. A somewhat larger percentage of VFR-IMC accidents tended to occur in flight, whereas a slightly larger percentage of other GA accidents tended to occur during takeoffs and landings (see Fig. 2, panel D). However, the chi-square analysis indicated that this apparent relationship between the type of accident (VRF-IMC vs. GA sample) and the phase of flight in which the accident occurred was not statistically significant.

DISCUSSION

The results indicate that the rate and severity of VFR flight into IMC accidents has remained high since the NTSB's report on the VFR-IMC accidents that occurred in the mid-1970s and 1980s (6). Furthermore, the types of accident causal factors associated with VFR-IMC accidents have not changed significantly over the past several decades. Together, these results suggest that interventions have either not been implemented or have been unsuccessful in curbing pilots' decision to continue VFR flight into adverse weather conditions. Nonetheless, the analysis of the accident data reported here does provide some support for several of the theoretical explanations that have been proposed by the authors (3,12) and others (9,11) to account for VFR flight into IMC and hence may provide insights into possible interventions.

The VFR-IMC accidents examined in this study were categorized by the NTSB into various types, with 92 being classified as "inadvertent" and 6 as "encountered." These two types accounted for almost 24% of all the VFR-IMC accidents from 1990–1997. This finding suggests that pilots in these accidents may not have realized that the weather had deteriorated, since the NTSB categorization suggests they did not fly into IMC intentionally. This finding bears support for the explanation that erroneous assessment of weather conditions may cause at least some pilots to fly into IMC unwittingly.

Furthermore, it was found that the median flight hours of pilots involved in VFR-IMC accidents was significantly lower than that of pilots involved in other types of GA accidents. Pilots involved in VFR-IMC accidents had less training (certification) and were less likely to have instrument ratings. Therefore, these pilots may have less experience interpreting real-time weather and may make more erroneous evaluations. Indeed, weather evaluation was cited as a factor or a cause in approximately 11.5% of the VFR-IMC accidents. These findings are in line with Klein's (5) work on recognition-primed decision making, which suggests that more experienced individuals are more efficient and proficient in assessing situations than those with less experience.

Approximately 7.5% of VFR-IMC accidents have "overconfidence in personal ability" cited as a factor or a cause, compared with less than 1% of other types of GA accidents, suggesting that overconfidence is a unique factor or cause of VFR-IMC accidents. This supports the notion that pilots who fly VFR into IMC lack appreciation of the risks involved in flying into adverse weather conditions. In addition, given the NTSB categorization of VFR-IMC accidents into various types, approximately 76% of VFR-IMC accidents appeared to involve intentional flight into adverse weather. These findings, together with other laboratory findings that pilots who continue into adverse weather conditions generally rate themselves more highly on skill and judgment than those who do not (8), strongly support the explanation that VFR flight into IMC is due to faulty risk perceptions of pilots. Consequently, pilots' perceptions of risk should be further investigated in laboratory experiments simulating VFR-IMC flights.

The finding that a larger proportion of VFR into IMC accidents involved aircraft that had passengers onboard than did aircraft involved in other types of GA accidents, suggests that social pressure is a viable issue to explore when investigating pilots' decision and motivation to fly VFR into IMC. While previous laboratory studies (8,9) indicate that social pressures are generally downplayed by pilots, it is possible that pilots are generally unaware of or reluctant to acknowledge the effects that social pressures play in their risk-taking behavior. Nonetheless, the results of the present analysis indicates that social pressure warrants further investigation as a possible factor related to pilots' decisions to continue VFR flight into IMC.

In a real world flight environment, decision frames may be induced by the proximity of the pilots' goals, such as the destination airport (9). As goal achievement gets closer, there may be a natural shift to the loss frame when bad weather is encountered, resulting in an increased likelihood to take risks. However, since the exact location of the accidents examined in this study could not be determined from the accident data, the phase of flight in which the accidents occurred was used as a crude indication of the pilot's proximity to the destination airport. No significant relationship between phase of flight and accident type was observed. Nonetheless, given the potential lack of sensitivity of this measure to possible motivational and framing effects, decision framing should not be discarded as a possible explanation for VFR into IMC accidents based on these data.

Implications and Future Direction

The results of the present study provide some support for several theoretical explanations of why pilots would risk "pressing on" into deteriorating weather conditions. These explanations point to failures in various stages of the decision-making process, as well as the role that social pressures play in influencing risk-taking behavior. Indeed, differences between VFR-IMC accidents and a random, stratified proportionate sample of GA accidents were found on key variables related to aeronautical decision making. While such a sampling procedure helped control for confounding variables such as time of year and location of accidents, there are other potentially confounding factors that were not addressed (e.g., aircraft type and age of the pilots). Therefore, additional laboratory and field research is needed to develop a better understanding of how these factors combine to precipitate the decision to fly VFR into IMC. The end result should be the development of aeronautical decision-making training and other safety programs that are more focused on the underlying causes of VFR flight into IMC.

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