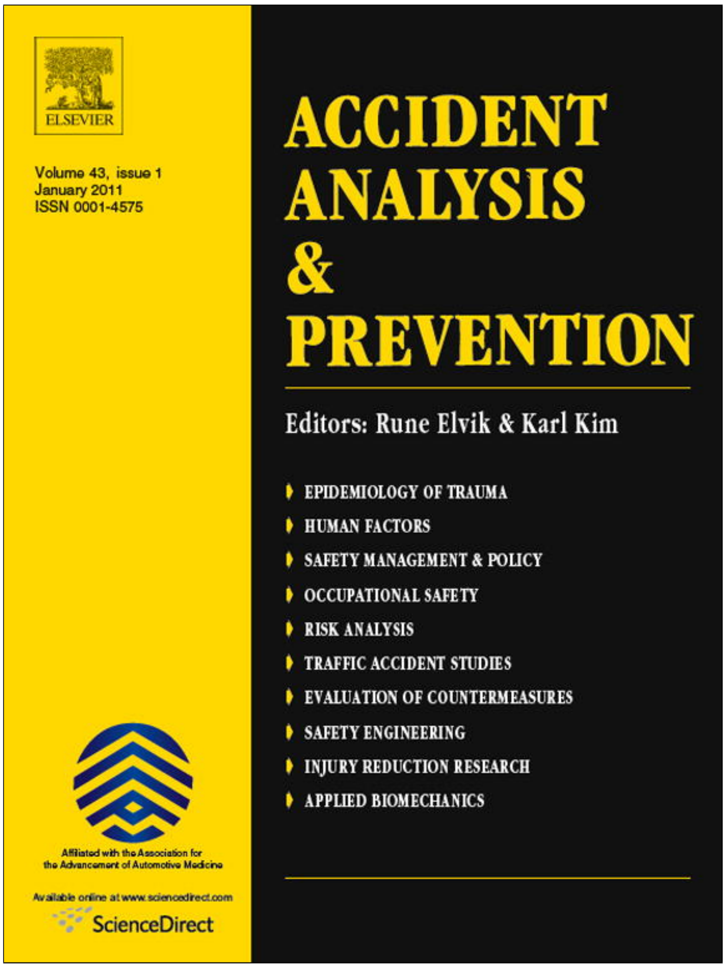
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Situational and personal characteristics associated with adverse weather encounters by pilots

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ABSTRACT

Weather conditions are significant hazards impacting the safe and efficient operation of aircraft. In this study, a large number of pilots were surveyed regarding weather events, and the circumstances associated with those events. Pilots completed a web-based questionnaire containing demographic questions, a risk perception scale, a hazardous events scale, and a pilot judgment scale. The pilots who reported a flight in which they penetrated weather without authorization or were concerned about the weather also completed 53 questions regarding their weather encounter. Usable data were obtained for 364 participants: 144 who reported flying into weather, 114 who experienced a flight on which weather was a concern, and 106 who reported no flights on which weather was entered or was a major concern. Significant differences were evident between the three groups on the measures of pilot judgment, personal minimums, and hazardous events where pilots flying into weather recorded the poorest scores (least conservative minimums, most hazardous events, and poorest judgment). Significant differences were also noted between the two weather groups for a number of circumstances surrounding the events. Compared to the in-weather group, pilots in the near-weather group had acquired greater instrument hours, were older, and were more likely to have an instrument rating. Their aircraft were more likely to have an autopilot. More pilots in the in-weather group (28%) reported that they would be much more careful in the future regarding weather, compared to 17% of the near-weather group. The study provides data not previously obtained on both the situational and personal characteristics that are related to involvement in different degrees of weather-related encounters. These data should promote a better understanding of these individuals and the situations in which they are involved, and should inform future research and intervention efforts.

1. Introduction

Weather conditions represent one of the most significant hazards impacting the safe and efficient operation of aircraft. The loss of visual contact with the horizon caused by weather conditions such as clouds, snow, or heavy rain can result in a loss of aircraft control for pilots who are not trained and experienced in the use of aircraft instrumentation to maintain the attitude of the aircraft. Novice pilots are trained initially to operate the aircraft under visual meteorological conditions (VMC) by reference to external visual cues. Although they receive some training in the control of the aircraft by reference to instruments, that training is very limited (typically 2–3 h during a 40–80 h course of instruction), and is focused on maintaining a minimum level of control of the aircraft sufficient to return the aircraft to straight and level flight if it has entered an extreme condition of bank or pitch, and to execute a level, 180° turn out of the weather (Childs, 1986).

Encounters with instrument meteorological conditions (IMC) by pilots who are operating under Visual Flight Rules (VFR) account for a substantial portion of the fatal accidents among pilots of general aviation aircraft. These events (typically termed VFR into IMC) are associated with approximately 73% of fatal weather accidents in single-engine aircraft (AOPA, 2007), and 19% of all general aviation fatalities (NTSB, 1989).

As a consequence, weather-related decision-making has generated considerable research interest at both an applied and a

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theoretical level (Ball, 2008; National Transportation Safety Board, 2005). In general aviation, in particular, a number of interventions have been developed and tested, with varying degrees of success (Diehl and Lester, 1987; Jensen et al., 1998; Wiggins and O'Hare, 2003a,b). However, despite the impact of these initiatives, inappropriate or ineffective weather-related decision-making remains a relatively pervasive factor associated with aircraft occurrences (National Transportation Safety Board, 2005).

Previous approaches to understanding the nature of weather-related aircraft accidents have typically focused on individual differences in pilots' personality, attitudes, or cognition, or pilots' strategies in response to deteriorating weather conditions prior to, and during flight (Beringer and Ball, 2004; Hunter, 2005; Latorella and Chamberlain, 2002; O'Hare and Smitheram, 1995; Wiegmann et al., 2002). Each of the approaches has contributed to an understanding of weather decision-making as a complex activity involving a range of motivational and cognitive elements. Contributions to an understanding of the nature of weather-related decision-making have also emerged from epidemiological approaches to aircraft accidents and incidents where weather-related decision errors were identified as a significant factor in precipitating the occurrence (Australian Transport Safety Bureau, 2004; Batt and O'Hare, 2005; NTSB, 2005; Wiegmann et al., 2005). The data arising from these studies have normally been examined from one of two perspectives: (1) the precursors to involvement in a weather-related accident or incident or (2) survivability.

In the case of the precursors to involvement in a weather-related accident or incident, a relatively consistent set of predisposing factors has been identified, including a moderate level of operational experience, whether the pilot is also the owner of the aircraft, the characteristics of the terrain, and the type of weather information available (Batt and O'Hare, 2005; NTSB, 2005; National Aeronautics and Space Administration, 2007; Transportation Safety Board of Canada, 1990).

At an applied level, the precursors to weather-related accidents and incidents are likely to inform regulatory and safety authorities as to whether there are opportunities to mitigate the likelihood that pilots will engage in activity that increases the likelihood of involvement in a weather-related accident or incident. Errors in in-flight weather-related decision-making have variously been considered a product of inexperience, inappropriate attitudes, or cognitive bias (Wiggins and O'Hare, 1993). This distinction in the emphases of researchers parallels an expectation that the problem of poor weather-related decision-making relates to difficulties in information-acquisition, the interpretation of the information, the integration of information to form meaningful conclusions, and/or the development of expectations on the basis of the information available (Driskill et al., 1997).

In relation to operational experience, evidence of the impact on weather decision-making is mixed, with some researchers identifying differences between aspects of information-acquisition, while others have failed to identify such differences (Latorella and Chamberlain, 2002; Wiggins and O'Hare, 2003a,b). Variable results have also been reported between experienced and inexperienced pilots' reasoning strategies (Giffin and Rockwell, 1987; Wiggins and O'Hare, 1995). There are a number of explanations in the variability of these results, not least of which is the process by which experienced and inexperienced pilots are classified.

Less variable have been the results associated with generalized cognitive errors such as plan-continuation, sunk cost, and prospect theory (Burian et al., 2000; O'Hare and Smitheram, 1995; Pauley et al., 2008; Wiegmann et al., 2002). In each case, these cognitive biases evident in the general population are also applicable in the context of weather-related decision-making. Whether the relative impact of cognitive bias can be moderated by task-related experience, again, is a matter of some debate. Indeed, most interventions are oriented towards pilot education, presumably with the expectation that awareness of the potential for cognitive failure will increase the vigilance of pilots to a point where appropriate interventions will be initiated.

A similar approach has been advocated towards improving pilots' attitudes in relation to weather-related decision-making. Using the so-called hazardous thoughts classification of judgment, there is some evidence to suggest that an education program that incorporates education in the hazardous thoughts model is associated with improvements in pilot judgment (Hunter, 2005).

Despite these different approaches to understanding the characteristics of poor weather-related decision-making, few studies have examined the etiology of encounters with weather conditions and, in particular, differences between the precursors of successful and unsuccessful encounters. Arguably, understanding the basis of successful and unsuccessful decision-making will provide the basis on which future interventions need to be based.

The present study was designed to contribute to an understanding of weather decision-making by adopting an epidemiological approach that differentiated incidents in which pilots reported a flight in which weather was a concern, but in which they did not lose visual reference to the horizon, from incidents in which visual reference to the horizon was lost. By using self-reports from pilots who had recently experienced one or other kind of close encounter with weather, this study provides data not previously obtained on both the situational (e.g., the conditions and events leading up to the encounter) and personal (e.g., pilot qualifications and experience; risk perception and risk tolerance) characteristics that are related to involvement in different degrees of weather-related encounters.

Previous research (Hunter et al., 2003) that examined the weather-related decision-making of American, Australian, and Norwegian pilots found that pilots from those three countries used the same mental models when evaluating the safety of weather conditions for a flight. The present study provided an opportunity to explore further multicultural differences and similarities among pilots by using samples from those same sources. Although examinations of differences among these groups are planned, they will not be addressed in this report.

2. Materials and methods

2.1. Participants

A total of 412 participants visited the web site hosting the study and completed some or all of the scales. Of that total, 48 were excluded from the study because they reported a weather-related event more than 5-years prior to the date of the data collection, or they failed to provide a date for the event. Of the remaining 364 valid records, 144 reported flying into weather, 114 experienced a flight on which weather was a concern, and 106 reported no flights on which weather was entered or a major concern. Of the 364 valid records, 70 originated from the Norwegian language web site, while the remainder came from the English language site. Approximately two-thirds of the respondents reported their residence as North America, while 20% were from Norway. The remainder was primarily from Australia or New Zealand (approximately 5% each). The mean age of respondents was 47.3 years (SD = 13.9), with a range of 16–76.

2.2. Measures

Pilots in both the near-weather and in-weather groups responded to 53 questions dealing with their respective events. These questions were divided into categories and given in roughly the following order: (1) general questions, such as when the event occurred, what happened (e.g., injuries), and duration of the event; (2) circumstances, including questions such as, source of the weather brief, content of the briefing, and weather encountered; (3) aircraft questions, such as aircraft configuration, presence and use of autopilot, and presence and use of GPS; and (4) event details, which included questions such as, the reason for entering the weather (or flying near the weather), difficulties in maintaining control, and personal perceptions (e.g., danger) of the event.

In addition to the 53 questions regarding the event, all pilots completed the background questions. These questions addressed total and recent aviation experience, aeronautical ratings, recent training events, personal minimums for local and cross-country flights, and hazardous events that had occurred during the preceding 24 months. Hazardous events is the sum of the responses to nine questions that asked how many times in the preceding 24 months some particular event had occurred.

Failure to accurately assess the risks inherent in situations has been suggested as a contributing factor to accident involvement by both pilots (O'Hare, 1990) and drivers (Trankle et al., 1990). Because of the clear relevance to weather encounters, an abbreviated version of a risk perception scale developed by Hunter (2006) was included in the study. That scale had been shown to be related to involvement in hazardous aviation events, such as flying into adverse weather or running short of fuel. The current version consisted of 10 items (drawn from the original 26-item scale) to represent a broad range of situations ranging from relatively low-risk situations to relatively high-risk situations. Participants rated (on a scale of 1–100) the risk that would be present if they were in a specified situation. Eight of the items represented aviation situations, such as: during the daytime, fly from your local airport to another airport about 150 miles (240 km) away, in clear weather, in a well-maintained aircraft. Two of the items presented everyday situations, such as: drive your car on a freeway (motorway) near your home, during the day, at 65 MPH (100 kph) in moderate traffic, during heavy rain.

The abbreviated 10-item scale had an internal consistency reliability of .90, based on the current sample. This is a close approximation to the internal consistency estimate for the 10-item subscale from the original validation sample.

Finally, pilots were asked to complete a 10-item Pilot Judgment Scale, in which they were presented with brief descriptions of scenarios where some action or decision is required. Participants were asked to choose the best course of action to be taken in response to the problem posed in the situation from among four alternatives, none of which were clearly correct or incorrect.

For example: you are preparing to enter the VFR traffic pattern at the regional airport and hear the tower report winds from 280 at 15 knots, and they are vectoring traffic to the primary 8800 ft runway 35. A Piper Cherokee asks to use the 7753 × 150 runway 27. The Cherokee is told the runway is not active, but to you it looks OK. You decide to:

A. Accept clearance to runway 35 and follow the traffic.
B. Ask to use runway 27.
C. Insist on using runway 27 stating that the crosswinds are unsafe for you to use runway 35.
D. Divert to the Southside Business Airport where the runway is almost directly aligned with the wind.

These 10 items were selected from the original 39-item scale (Hunter, 2003) to represent a variety of situations. In a study of 467 pilots who completed the Pilot Judgment Scale over the Internet, pilots who had higher (e.g., better) scores on the scale were reported to have experienced significantly fewer hazardous aviation events. Internal consistency reliability of the 39-item scale was .75; however, reliability of the 10-item scale using the present data was .40. This rather low value approximates the reliability of the same 10 items using the original evaluation data, and is probably a reflection of the heterogeneous character of these items. While concerns over limiting the burden on respondents necessitated a short scale in the present study, future efforts should consider using a longer, more reliable set of items.

2.3. Procedure

Participants were solicited from among visitors to a web site (http://www.avhf.com) oriented toward general aviation safety issues. Notices were placed in publications and on web sites likely to be read by pilots, and email invitations to participate were sent to pilots who had participated in previous web-based research or whose email addresses could be obtained from various sources. Both an English language version of the web site and a Norwegian language version were created. The web address of the Norwegian language version was distributed to flying clubs and other organizations in Scandinavia, while the web address of the English language version was distributed elsewhere.

A prominent notice was placed on the home page of the web site directing visitors to another page on which detailed information regarding the study was contained. This second page provided potential participants with all the information necessary to make an informed decision to take part in the study. Upon indicating their consent to participate, they were then re-directed to a web page on which they created a unique personal identifier and answered the following two screening questions:

- Q1. During the last 5 years, how many times have you been on a flight (as pilot-in-command) in which weather conditions prior to or during the flight were a significant factor, perhaps even a threat to the safety of the flight?
- Q2. During the last 5 years, how many times have you (as pilot-in-command) entered IMC when you were not on an instrument flight plan and/or did not have an instrument rating? That is, you flew into cloud or into an area where the visibility was clearly below the 3-mile [5-km] minimum without ATC clearance.

Pilots who responded to the first question with anything other than zero and responded with zero to the second question, were designated as members of the near-weather group. They were then re-directed to a web page containing questions regarding a recent flight in which weather was a concern. Previous research (O'Hare and Wiggins, 2004) has shown that the age of recalled events varies linearly with the pilot's age. This would potentially lead to difficulty interpreting data relating to aircraft and equipment characteristics as these may change over time (e.g., the increasing use of GPS as a navigation tool). In addition, memories for the details of events fade, although stress can contribute to better recollection of an event (Anderson et al., 2006; Henckens et al., 2009). Consequently, it was decided to limit the recalled weather events to those from the preceding 5 years. To some degree the choice of 5 years as the cut-off point was arbitrary, reflecting a balance between sample size and response accuracy. A test of the adequacy of this cutoff was provided by asking participants to indicate how well they remembered the event. For the in-weather and near-weather groups, 71% and 84% of participants, respectively, indicated that their memory of the event was very clear or clear. Additionally, 22% and 13% of the respective groups indicated that their memory was somewhat hazy. Relatively few (i.e., 8% and 3% of the respective groups) participants indicated that their memory was hazy or very hazy. In addition, 70% of the participants reported on events that had occurred not more than 2 years previously. Relatively few (6%)

Table 1
Demographic characteristics of the three groups.

	In-weather N = 144			Near-weather N = 114			No-weather N = 106			F	p	Eta²
	M	SD	Mdn	M	SD	Mdn	M	SD	Mdn			
Flight experience												
Total civilian flight time	1542	3173	450	2371	5595	850	1599	4293	402	1.30	.27	.01
Total military flight time	103	490	0	553	3444	0	92	514	0	2.07	.14	.01
Actual instrument time	185	639	9	823	3597	25	307	1402	5	2.71	.07	.02
Simulated instrument time	61	125	20	103	305	40	68	152	20	1.37	.26	.01
Recent civilian time	39	56	20	41	99	20	27	45	10	1.22	.30	.01
Recent military time	1	7	0	2	16	0	2	24	0	0.28	.76	.00
Recent actual instrument time	4	15	0	4	8	0	3	19	0	0.10	.92	.00
Recent simulated time	2	5	0	3	11	0	2	8	0	0.49	.61	.00
Personal minimums[a]												
Min ceiling VFR local	2.30	1.26	2	2.62	1.44	3	2.89	1.40	3	5.64	.01	.03
Min visibility VFR local	3.60	1.21	3	3.94	1.30	4	4.16	1.25	4	6.20	.01	.03
Min ceiling VFR cross-country	3.49	1.16	4	3.70	1.52	4	4.17	142	4	6.28	.01	.04
Min visibility VFR cross-country	4.50	1.24	5	4.61	1.34	5	5.03	1.34	5	5.21	.01	.03
Other												
Age	44.85	14.75	46	49.27	12.60	51	49.27	14.19	51.5	4.03	.01	.02
Hazardous events	1.84	2.01		1.47	1.71		1.14	1.55		4.51	.01	.03
Risk perception[b]	51.58	14.97		52.60	15.65		53.00	14.86		0.26	.77	.00
Pilot judgment[c]	5.13	1.53		5.72	1.46		5.96	1.79		4.04	.02	.05

[a] For the personal minimums larger numbers indicate more conservative personal minimums.
[b] Sample sizes for the risk perception variable are 138, 106, and 85, for the in-weather, near-weather, and no-weather groups, respectively.
[c] Sample sizes for the pilot judgment variable are 61, 47, and 51 for three groups, respectively.

occurred over 4 years previously. Overall, these results suggest that the choice of the cutoff point was appropriate.

The second question served to identify pilots who had experienced a VFR into IMC event. Pilots who gave a non-zero response to the second question were designated as members of the in-weather group, and were re-directed to a web page containing questions regarding their best-remembered event. The questions for the near-weather and in-weather groups were virtually identical. However, whereas the questions for the near-weather group sought information about their flight in which weather was a significant factor, the questions for the in-weather group asked about the flight in which they entered IMC without clearance.

Pilots who responded zero to both of the screening questions were designated as members of the no-weather group, and were re-directed to the web page that collected demographic information. On completing the questions regarding their weather experiences, the pilots in the near-weather and in-weather groups were also directed to the same demographic information web page. All pilots then completed the risk perception scale and, optionally, the pilot judgment scale. Because the nature of web-based data collection allows participants to drop out of a study at any point, some participants were lost after entering the information for the weather event. That is, they chose not to continue the study and to complete the risk perception scale. Similarly, some participants chose not to complete the pilot judgment scale, which was the last activity in the study. In recognition of the rather lengthy section dealing with the weather event, the pilot judgment scale was offered as an optional task to those pilots willing to continue. About half of the pilots in each of the three groups completed this final scale.

2.4. Statistical analyses

Statistical analyses were performed using SPSS (Version 9.0). Analyses consisted primarily of computations of the proportions of subjects in each subgroup and in the total sample that selected each of the alternative responses for each individual question. In accord with the primary purpose of this study, these results are intended mainly to be descriptive. However, we also analyzed each individual variable, using ANOVA or χ^2 as appropriate to identify those variables on which the groups differed. This entailed the computation of 125 inferential statistics. The level of significance after a Bonferroni adjustment would be .05/125 = .0004, which represents an overly conservative approach for the control of experiment wise error rate (EWER). Therefore, we have chosen not to control for EWER in the interest of highlighting potential variables of interest for future research. Readers should be aware, of course, that with the large number of inferential statistics computed in this study, it is likely that a small proportion may have achieved significance merely because of random variation. However, consistent with Harris (1991), we believe that this less conservative approach is warranted in the case of safety-related research.

3. Results

In order to keep this report within a reasonable length, we have not listed in the tables all the questions used in the study. However, a complete set of the tables containing all the questions with the numbers and proportions of respondents selecting each alternative is available upon request from the first author. They may also be downloaded directly from the web site.[4]

3.1. Participant demographics

Table 1 contains the results for those questions and scales that were completed by all three groups. This includes the demographic variables, hazardous events, risk perception, and pilot judgment scales. Clearly, these participants represent a sample of convenience, recruited using methods that may have resulted in samples of individuals who are not representative of their populations or in samples of events (e.g., weather encounters) that are not representative of the population of weather events. The first issue may be addressed, to some degree, by comparing the demographic characteristics of the sample to the pilot populations from which they were primarily drawn. Because of the complex mix of pilots from multiple nations, exact comparisons were not undertaken. However, since approximately 60% of the total sample (all three groups combined) reported North America (presumably, the United States) as their residence, it is possible to make some compar-

[4] http://www.avhf.com/wx_study_results.htm.

isons for that group. In the United States, private and commercial pilots represent 36% and 20% of the pilot population, respectively (FAA, 2009).[5] Overall, 59% of the present sample held a private pilot license, while 25% held a commercial license. Thus, private pilots are somewhat over represented, with respect to the population. Given the nature of this study, it is not unexpected that airline transport pilots would be largely absent from the samples. Private and commercial pilots (particularly those holders of a commercial license who do not actually fly professionally) are the primary group who experience weather-related accidents; hence, their weather encounters are of primary concern. For the private pilots, the present sample approximates to a reasonable degree the population of private pilots. Specifically, they are identical in mean age (M_{pop} = 47, M_{sample} = 47), and have somewhat less instrument flight time (M_{pop} = 60, M_{sample} = 45) and total flight experience (M_{pop} = 819, M_{sample} = 634). None of these differences is statistically significant.

Perhaps the more important question is whether the events reported by these respondents accurately represent the population of events experienced by pilots. It is possible that a pilot's decision to participate in this study may have been related to the severity of the weather encounter. That is, pilots who made particularly egregious errors in judgment and came close to having an accident may have elected not to participate out of a fear of disclosure or simple chagrin over the experience. Clearly, a case could be made for the opposite effect, and the question of how well the present results match the population of weather encounters cannot be answered from the present (or perhaps any existing) data. To our knowledge, there is no database of non-accident events for non-airline pilots that could be used to address this issue. Indeed, that is, to a large degree, the point of the present study.

Putting aside considerations of representativeness for the present, the three groups were virtually identical with respect to pilot certificates, with private pilots constituting the majority (approximately 59%) of each group, followed by commercial pilots, who made up approximately 25% of the groups. The proportions were not significantly different (χ^2 (12, N = 358) = 11.7, p = .47). However, the groups differed significantly with respect to possession of an airplane instrument rating (χ^2 (2, N = 356) = 8.78, p = .01). This rating was held by 43%, 59%, and 41% of the in-weather, near-weather, and no-weather groups, respectively. Significant differences were also evident among the three groups on age, hazardous events, personal minimums, and pilot judgment. The differences among the three groups on the last three variables are particularly striking. For all those variables, the relationship between the group membership and what might arguably be described as indices of a positive safety orientation are consistent. The no-weather group has the most conservative personal minimums, least number of hazardous events, and highest scores on the pilot judgment scale, while the in-weather group has the least conservative personal minimums, largest number of hazardous events, and lowest scores on the pilot judgment scale. The near-weather group fell between the no-weather and in-weather groups on all three of these measures. The difference between the no-weather and in-weather groups for personal minimums represents a medium to large effect in terms of Hedges' g (Cohen, 1988), while the differences for the hazardous events and pilot judgment represent small to medium effects. Interestingly, there were no differences among the groups on their risk perception scores.

[5] Corresponding values for Norway are 40% and 31% (CAA Norway, personal communication, January 5, 2010) for private and commercial pilots, respectively, while the values for Australia are 51% and 16% (CASA Australia, 2009), and the values for New Zealand are 51% and 32%. (CAA New Zealand, 2009).

3.2. Aircraft configuration

The results in this and the following sections are restricted to members of the in-weather and near-weather groups. Both of these groups were flying similarly configured and equipped aircraft. Typically, this was a single-engine, piston-powered airplane with fixed landing gear. Both high-wing and low-wing configurations were approximately equally represented. About 80% of the aircraft in both groups were equipped with a GPS (the question did not specify whether the unit was hand-held or mounted in the instrument panel), and the unit was being used in the majority of both cases. An autopilot was available in approximately 46% of the near-weather aircraft, compared to only 34% for the in-weather group. Interestingly, even in the in-weather aircraft equipped with an autopilot, it was being used in only half the cases. None of the differences between the two groups on the aircraft configuration questions achieved statistical significance; however, the wing configuration and autopilot status approached significance.

3.3. Background and circumstances of flight

The majority (77%) of participants in both groups had a clear or very clear recollection of the events, although the near-weather group reported a significantly (χ^2 (4, N = 257) = 11.63, p = .02) better recollection than the in-weather group. Pleasure flights were the modal reason for the flights in both groups and, together with business flights, accounted for the clear majority of flights, with no differences between the groups. For the most part, the flights were conducted during daylight over flat or hilly terrain, without another pilot on-board. Solo flights were most common (accounting for 51% and 42% of the in-weather and near-weather flights, respectively), and there was a single passenger on about one-third of the flights.

In the majority of cases (84%), the flight on which the event occurred was planned as a cross-country flight lasting from 1 to 4 h, along a route that the pilot had taken previously. The two groups differed significantly on both those questions. The in-weather group reported a higher percentage of local flights (21%) compared to the near-weather group (11%). In addition, 19% of the in-weather group reported a planned length of flight of <1 h, compared to 8% of the near-weather group. Of those pilots who had flown this route previously, approximately 60% of both groups reported not having encountered these weather conditions previously. Of those pilots who had encountered similar weather along this route previously, most (about two-thirds) reported having 'dodged' around the weather.

3.4. The weather – planned and actual

Several questions were included to assess the participants' acquisition of weather information, its apparent accuracy, and the precise weather conditions experienced during the flight. Table 2 presents those questions on which the two groups differed significantly.

For both groups, approximately two-thirds of the participants reported having used their computer to access weather information prior to the flight. The next most common source of information was a telephone conversation with a weather briefer; 45% of the in-weather group and 57% of the near-weather group reported using that source. The difference was not statistically significant.

The forecast weather for the departure airport, en-route, and destination airport were predominately VMC, although for all of those variables, the forecasts were significantly better for the near-weather group than for the in-weather group. Actual weather at the departure airport was the same as the forecast for about 73% of both groups, and worse than the forecast for about 21% of the two groups. However, the actual weather en-route and at the des-

Table 2
The weather – planned and actual.

Question	Options	In-weather		Near-weather		χ^2	p
		Count	%	Count	%		
Pre-flight weather sources?[a]							
	Telephoned weather briefer	65	45.1	65	57.0	3.59	.06
	Talked to other pilots	24	16.7	9	7.9	4.39	.04
	Other	11	7.6	16	14.0	2.78	.10
Forecast for departure airport?						8.69	.01
	VMC	112	80.6	84	75.0		
	Marginal VMC	26	18.7	19	17.0		
	IMC	1	0.7	9	8.0		
Forecast for en-route?						34.48	.01
	VMC	91	65.9	65	58.0		
	Marginal VMC	46	33.3	21	18.8		
	IMC	1	0.7	26	23.2		
Forecast for destination?						12.38	.01
	VMC	115	83.9	78	70.9		
	Marginal VMC	20	14.6	19	17.3		
	IMC	2	1.5	13	11.8		
What kind of weather did you encounter?[a]							
	Deteriorating weather ahead	57	39.6	61	53.5	4.97	.03
	Flew into clouds or fog	66	45.8	21	18.4	21.39	.01
	Icing	9	6.3	15	13.2	3.60	.06
	Lowering ceiling	68	47.2	42	36.8	2.80	.09
	Rain	35	24.3	39	34.2	3.05	.08
	Thunderstorms	9	6.3	31	27.2	21.30	.01
	Turbulence	17	11.8	38	33.3	17.58	.01
Had you flown in adverse weather/IMC previously?						7.54	.01
	No	56	39.4	26	23.2		
	Yes	86	60.6	86	76.8		

[a] Participants were instructed to check all that apply. Figures reflect the number of "Yes" responses to each alternative.

tination airport were worse than the forecast for about 62% and 43%, respectively, of the combined groups. A variety of weather conditions were encountered. However, the modal condition was reduced visibility (51%), followed by deteriorating weather ahead (46%), and lowered ceilings (43%).

There were significant differences between the two groups in the weather encountered. The near-weather group reported significantly more encounters with thunderstorms and turbulence than the in-weather group. In contrast, the in-weather group reported significantly more instances of flying into clouds or fog than the near-weather group.

When asked whether they had previously flown in adverse weather conditions or in IMC, significantly (χ^2 (1, N = 254) = 7.54, p = .01) more of the near-weather group (77%) than the in-weather group (61%) indicated they had done so.

3.5. Conditions and events leading up to the encounter

Approximately one-third of each group reported that, prior to the weather event, the weather had been rapidly becoming worse, while a little less than half of each group reported a slow deterioration in the weather conditions. As shown in Table 3, for the in-weather group, that is, those participants who actually entered IMC, 32% reported that they did so deliberately. In contrast, 50% of the near-weather group indicated that they entered the area of adverse weather deliberately. We did not compare these proportions statistically, because there were substantive differences between the wording of these two questions for the in-weather and near-weather groups.

The two groups differed significantly (χ^2 (6, N = 242) = 27.52, p = .01) on the reasons they entered either IMC or the adverse weather conditions. For the in-weather group, the modal response (26%) was, 'Other', followed by 'Gradual change' (19%); while, for the near-weather group both 'Other' and 'Decided I could handle it' were selected by 26% of the group.

For the in-weather group, 25% of participants reported that they entered IMC more than once during the flight. There was no corresponding question for the near-weather group. Instead, they were asked whether they had entered marginal VMC (MVMC) conditions at any time during the flight. Approximately two-thirds of that group indicated that they had done so.

The duration of the events differed significantly for the two groups, possibly reflecting, once again, the method used for creation of the groups. The encounters with IMC for the in-weather group tended to be relatively short, with one-third of the participants reporting that they were in IMC for 1 min or less (the modal response). In contrast, the encounters with adverse weather by the near-weather group tended to be much longer, with about one-third of this group reporting that the encounter lasted from 10 to 30 min (the modal response).

Arguably, encounters with IMC or adverse weather are more hazardous at low altitudes, since there is less margin for error with less vertical space for maneuvering around or over obstacles. It is interesting to note, therefore, that relatively few participants in either group (6.7% and 0%, for the in-weather and near-weather groups, respectively) reported entering IMC or encountering the adverse weather while below 500 ft. However, 17% of the in-weather group and 13% of the near-weather group reported being below 500 ft when they exited the conditions. Similar downward shifts in recovery altitude are noted for the other response alternatives.

An unplanned encounter with IMC or adverse weather while low on fuel would make the situation even more hazardous, as it would limit the options (divert to another airfield, hold above the cloud deck, etc.) available to deal with the situation. Fortunately, the responses of both groups regarding the amount of fuel on-board at the start of the weather encounter indicate that, except for a very few, this was not an issue. Almost without exception the pilots in both groups had more than adequate fuel to allow them to concentrate on dealing with the weather without worrying about running out of fuel.

Table 3
Conditions and events leading up to the encounter.

Question[a]	Options	In-weather		Near-weather		χ^2	*p*
		Count	%	Count	%		
Did you enter the IMC/adverse weather deliberately or inadvertently?						8.34	.01
	Inadvertently	97	68.3	51	50.0		
	Deliberately	45	31.7	51	50.0		
Why did you enter IMC/adverse weather?						27.52	.01
	To avoid terrain	17	12.5	2	1.9		
	Did not want to deviate	7	5.1	13	12.3		
	Did not realize severity	21	15.4	21	19.8		
	Did not see	21	15.4	8	7.5		
	Gradual change	26	19.1	8	7.5		
	Decided I could handle it	18	13.2	27	25.5		
	Other	26	19.1	27	25.5		
Did you enter IMC multiple times?							
	No	105	75.0	–	–		
	Yes	35	25.0	–	–		
Did you enter marginal VFR conditions at any time during this flight?	No	–	–	35	32.4		
	Yes	–	–	73	67.6		
How long were you in IMC/adverse weather?						49.98	.01
	<1 min	44	33.1	6	5.8		
	1–3 min	29	21.8	14	13.5		
	3–5 min	22	16.5	11	10.6		
	5–10 min	14	10.5	18	17.3		
	10–30 min	19	14.3	33	31.7		
	30–60 min	3	2.3	12	11.5		
	Over 60 min	2	1.5	10	9.6		
What was your altitude when you entered?						25.19	.01
	<500 ft.	9	6.7	0	0		
	500–1000 ft.	26	19.3	11	10.5		
	1000–1500 ft.	16	11.9	16	15.2		
	1500–2000 ft.	25	18.5	12	11.4		
	2000–4000 ft.	32	23.7	27	25.7		
	4000–6000 ft	19	14.1	15	14.3		
	Over 6000 ft.	8	5.9	24	22.9		
What was your altitude when you exited?						11.29	.08
	<500 ft.	23	16.5	13	12.5		
	500–1000 ft.	28	20.1	16	15.4		
	1000–1500 ft.	15	10.8	16	15.4		
	1500–2000 ft.	20	14.4	13	12.5		
	2000–4000 ft.	32	23.0	22	21.2		
	4000–6000 ft	15	10.8	8	7.7		
	Over 6000 ft.	6	4.3	16	15.4		
Were you deviating from course when the event occurred?						2.96	.09
	No	90	63.4	59	52.7		
	Yes	52	36.6	53	47.3		

[a] In the actual surveys, the wording of the questions was appropriate for each group. That is, the in-weather group was asked about IMC encounters, while the near-weather group was asked about adverse weather encounters. The wording of the two questions is consolidated here to save space.

A somewhat higher proportion of the near-weather group (47%) compared to the in-weather group (37%) indicated that they were deviating from their original course when the weather encounter occurred.

When asked how long after takeoff the weather event occurred, the modal response for both the in-weather (31%) and near-weather (28%) group was 30–60 min. Responses to all alternatives were very similar for both groups.

3.6. *During the event*

As shown in Table 4, the two groups differed with respect to the actions they took while the event, either the incursion into IMC or the encounter with adverse weather, was underway. These differences begin with their attempts to get help from an air traffic control facility. Significantly more (χ^2 (1, N = 254) = 7.44, p = .01) of the near-weather pilots requested assistance (54%), compared to the in-weather pilots (36%). For the most part, the near-weather pilots sought information regarding the weather and pilot reports (presumably about the weather) much more frequently than the in-weather pilots. This activity probably accounts for the significantly larger number of radio calls by the near-weather pilots.

The in-weather pilots displayed a tendency for vertical maneuvering (climbing or descending), whereas the near-weather pilots described manipulating power and airspeed. Although the pilots who actually entered IMC might have been expected to have more difficulties in maintaining control of the aircraft, the near-weather pilots actually reported significantly more difficulty maintaining control. Only about 7% of the in-weather pilots reported any level of control difficulties, while 15% of the near-weather group reported some level of difficulty in maintaining control. These difficulties might be associated with the fairly large excursions in airspeed and vertical speed reported by the near-weather group, and the turbulence reported by this group.

3.7. *Perceptions of the encounter*

The perceptions of stress during the events were very similar for the two groups. Although well over half of both groups reported that they felt some degree of tension and anxiety, relatively few (5% and 3.5%, for the in-weather and near-weather groups, respec-

Table 4
During the event.

Question	Options	In-weather Count	In-weather %	Near-weather Count	Near-weather %	χ^2	p
Did you attempt to get help from ATC?						7.44	.01
	No	89	63.6	53	46.5		
	Yes	51	36.4	61	53.5		
What kind of help? (For those who answered "yes" to the previous question.")[a]							
	PIREPS	5	9.6	12	19.7	2.22	.14
	Weather update	26	50.0	31	50.8	.01	1.0
	Other	7	13.5	19	31.1	4.91	.03
What did you do immediately after entering?[a]							
	Climb	33	22.9	14	12.3	4.83	.03
	Descend	49	34.0	25	21.9	4.55	.03
	Reduce airspeed	22	15.3	38	33.3	11.62	.01
	Reduce power	9	6.3	21	18.4	9.17	.01
	Increase power	13	9.0	6	5.3	1.32	.25
Did you do any of these?[a]							
	Make radio call	57	39.6	59	51.8	3.81	.05
Did you have difficulty maintaining control of aircraft?						5.31	.07
	No	132	93.0	93	84.5		
	Yes, a little difficulty	9	6.3	13	11.8		
	Yes, a great deal of difficulty	1	0.7	4	3.6		
Did any of these happen to you?[a]							
	Vertical speed >1000 fpm	5	3.5	15	13.2	8.35	.01
	Airspeed varied by >20 kts.	12	8.3	33	28.9	18.78	.01

[a] Participants were instructed to check all that apply. Figures reflect the number of "Yes" responses to each alternative.

tively) reported an extreme level. Indeed, many more (almost a third) of both groups reported that they felt relaxed to some degree during the events. This is roughly the same proportion who felt that they were never in any real danger during the event.

Both groups reported that, prior to this experience, they generally regarded flight in IMC or in adverse weather as being a higher risk than flight in VMC, with the near-weather group reporting a slightly higher level of perceived risk. A minority of both groups (28% and 17%, for the in-weather and near-weather groups, respectively) felt that the event was moderately to extremely dangerous. Following the event, both groups increased their assessments of the risks slightly, with the increase being somewhat greater for the near-weather group than for the in-weather group. None of the differences between the two groups achieved statistical significance.

The final question of the study addressed the issue of behavior change, and asked participants whether they had become more careful regarding weather following their experiences. Interestingly, even though the near-weather group had reported, as noted above, that they perceived greater risk in the situations than did the in-weather group, 28% of the in-weather group reported that they would be much more careful in the future regarding weather, compared to 17% of the near-weather group. Differences between the two groups on this question were statistically significant (χ^2 (3, N = 255) = 8.99, p = .03).

4. Discussion

The primary outcome of our study was the development of a qualitative and quantitative description of the pilots who were involved in adverse weather encounters, particularly those involving VFR into IMC events. Specifically, the data provide a reasonably comprehensive description of the pilots who had experienced these events, how their aircraft were equipped, and the events leading up to, during, and following the weather encounter. We contend that such a description is essential to the formulation of relevant research programs and the development and fielding of effective interventions, which should be informed by an understanding the sequence of events and the sources of information accessed by a pilot leading up to an encounter with adverse weather.

The training and other interventions directed at reducing weather-related accidents could be described as having two general objectives: (1) avoid entering the adverse weather conditions, and (2) survive the encounter, if weather is actually penetrated. Avoiding weather encounters is dependent upon knowing what weather conditions are likely to be experienced along a specific route of flight, continual observation of the weather conditions while en-route, and taking timely, effective actions to avoid weather if it is encountered. The present data suggest that improvements could be made in all of those areas. With respect to knowledge of the weather that might be encountered, only 45% of the pilots in the in-weather group actually talked with a weather briefer. Since these briefers are trained to impart information on hazardous conditions to pilots, they should be the first choice for weather information, particularly for relatively low-time pilots.

In addition, the present data indicate that the personal minimums for pilots in the in-weather group are too liberal. That is, they indicated that they would take off in conditions (visibility and cloud height) that were significantly worse than that reported by members of the other groups. For about 33% of the pilots in the in-weather group, marginal visual meteorological conditions (MVMC) were forecast along their route of flight. Training pilots to adopt more conservative personal minimums might encourage pilots to avoid flights in these marginal conditions. Alternatively, pilots might be trained to construct more detailed alternative plans, to be executed in the event the forecast marginal conditions deteriorate.

Two other factors suggest methods for intervention. First, pilots in the in-weather group reported a history of involvement in hazardous aviation events that was significantly higher than members of the other groups. In addition, their judgment (as assessed by the Pilot Judgment Scale) tended to be inferior to the other groups. At a minimum, efforts could be undertaken to improve the self-awareness of pilots of their risk factors in these areas. Research should also be undertaken to develop more specific methods of improving pilots' standing in those areas.

To mitigate the risk of an accident during an actual weather encounter, pilots could be better trained to make use of on-board equipment and specifically, to use the autopilot to help maintain aircraft control and GPS to maintain spatial awareness and avoid terrain. A mandate from regulatory agencies that all new aircraft be equipped with such devices might eventually lead to a decline in accidents attributed to loss of control after entering clouds.

About 66% of the in-weather pilots did not seek help from ATC after entering weather. This may be due, in the present case, to the relatively brief encounters (half of the events lasted 3 min or less). Nevertheless, pilots entering areas of reduced visibility (cloud, fog, or haze) may not know how long the event will last. Therefore, seeking help from air traffic control facilities in a timely manner could prove beneficial. However, the issue is complicated by the need, as a prime requirement, to maintain control of the aircraft, and to attend to other matters (such as navigation and communication) as time and resources allow. Further, fine-grained analyses of these data may better illuminate the issue. However, concerns over possible punitive actions by regulatory authorities for an unauthorized entry into IMC may also have influenced pilots' decisions not to contact ATC, and that issue was not addressed in the current study.

Although most of the training materials produced by the regulatory authorities and the various associations focus on avoiding weather, almost a third (32%) of the present sample reported that they entered IMC deliberately. Since a large part of the training programs are directed at convincing unqualified pilots that they will die if they enter IMC, these results call into question the effectiveness of that aspect of the training and, arguably, the entire premise of scare tactics as a training strategy. A national probability sample survey of over 7000 US pilots found that 23% of private pilots had flown VFR into IMC at some point (Hunter, 1995). Since significant numbers of pilots fly into IMC and survive, a more balanced, nuanced approach to training pilots to prepare them for weather encounters may be needed.

In addition to developing a comprehensive description of the pilots who are involved in weather-related events and the circumstances that led to the events, the secondary outcome was an assessment of the degree to which differences existed among the three groups (no-weather, near-weather, and in-weather) in terms of demographics, prior hazardous events, judgment, risk perception, and specific weather encounters. While there were very few differences among the groups in their demographic characteristics and they did not differ on the measure of risk perception, significant differences were evident among the three groups on the measures of personal minimums, pilot judgment, and hazardous events. In each of these comparisons, the pilots comprising the in-weather group recorded the poorest scores (least conservative minimums, most hazardous events, poorest judgment), the pilots who reported no-weather encounters recorded the best scores, and the scores for the near-weather group fell between these extremes. Since the data are cross-sectional, we would not suggest that liberal personal minimums, poor judgment, and a history of hazardous events necessarily cause pilots to enter risky weather conditions. However, there is certainly a level of association here that suggests the need for further intervention-based research or the possibility of using the measures for differential risk assessment for pilots.

While the groups share many characteristics, statistically significant differences were noted for a large number of the variables included in this study when the in-weather and near-weather groups were compared. Compared to the in-weather group, pilots in the near-weather group had more actual instrument time, were older, and were more likely to have an instrument rating. Their aircraft were more likely to have an autopilot. More of the pilots in the near-weather group were on cross-country flights, with durations longer than the in-weather flights. The pilots in the near-weather group used a telephone briefer for their weather information, were more likely to have a forecast of IMC for en-route and the destination, and tended to encounter deteriorating weather, thunderstorms, and turbulence more than the in-weather group.

The adverse weather events tended to be longer (10–60 min) for the near-weather group, and pilots most commonly reported that they entered the conditions because they believed they could manage the situation. More of the pilots in the near-weather group attempted to get assistance from ATC (typically, a weather update or PIREP), and more of them reported some difficulty maintaining control, with more vertical speed and airspeed variations than the in-weather group. Quite possibly the latter differences are associated with the more frequent instances of encounters with turbulence and thunderstorms reported by this group. Pilots in the near-weather group believed that the weather presented a higher risk than VFR flight both before and after their weather encounter, and tended to be unchanged with regard to how careful they were about weather on flights following the encounter.

Perhaps the most remarkable thing about the pilots involved in these weather encounters (specifically, the in-weather group), is that they are not remarkable. The descriptions of the pilots (46 years of age, with 450 h median experience), aircraft (single-engine), and flights (day, pleasure) could well apply to the majority of general aviation pilots, aircraft, and flights in North America, Australia, New Zealand, and Scandinavia.[6] Typically, after taking off on a flight into forecast visual meteorological conditions, these pilots encountered gradually deteriorating weather conditions, leading to a relatively brief encounter with IMC. During this brief event, they felt somewhat tense and anxious, but did not feel that they were in any great danger, and afterwards were somewhat more careful about weather when flying.

The principal lesson that a pilot may take away from such a weather encounter is that he or she can enter IMC and survive unscathed. For a pilot lacking an instrument rating and currency, this is arguably a bad lesson, since it may encourage the pilot to attempt similar IMC incursions in the future. If all goes well, then they will survive and grow even more confident of their abilities (and perhaps more scornful of the warnings of instructors and regulatory agencies regarding the dangers of weather incursions), until the flight in which, for any of a number of reasons, the demands exceed their capacity. Clearly, some intervention is required to break this chain of events. Historically, much of the training for weather avoidance consisted primarily of detailed instruction in aviation meteorology with an implicit hope that pilots would properly apply that knowledge when conducting a flight, and an occasional warning to "be careful." However, some recent efforts undertaken to sensitize pilots to the risks of adverse weather have provided more specific guidance. These efforts have included guidance in pre-flight planning and decision-making (Personal Minimums Checklist; Jensen et al., 1998) and training in the recognition of deteriorating weather conditions while in-flight (WeatherWise; Wiggins and O'Hare, 2003a,b). Both these training products were produced in an interactive computer format, and additional efforts to impart specific decision-making skills to pilots should be explored.

The regulatory agencies should be pleased to note that even pilots without an instrument rating (about half of the in-weather group) seem to be able to survive brief encounters with IMC. The reasons for this outcome (initial training, recurrent training, etc.) cannot be determined from the present data. However, the present data do suggest that regulatory agency efforts to train unqualified or unprepared pilots to avoid IMC may not be effective, since there were no differences among the three groups in the average number (one) of state-sponsored safety seminars attended in

[6] A national statistical probability survey of US pilots conducted in 1995 found that the average age of private pilots was 49, and they had a median total flight time of 445 h. These pilots reported flying predominately single-engine aircraft on day, pleasure flights. (Hunter, 1995).

the previous 24 months. Since, as noted earlier, a sizable portion of pilots lacking an instrument rating will penetrate IMC at some point, perhaps the regulatory agencies should shift their training focus to encourage pilots to make better use of on-board devices (autopilots, specifically) during the event. They might also consider whether the current safety seminar approach to continuing education of rated pilots is accomplishing the goal of improved safety; or, whether alternative approaches (for example, Internet-based training) would better serve the needs of pilots who are increasingly accustomed to computer-based interactions.

While we recognize that the limitations of the Internet-based questionnaire approach we adopted for this study, we believe that this study has provided data that allow us to address the questions we posed. First, and perhaps foremost, the data provide a rich description of pilots who have experienced an encounter with IMC for which they either did not plan or were not qualified to enter and a description of the circumstances surrounding those encounters. These are comprehensive data that, to the best of our knowledge, are not otherwise available. Extant studies of pilots who were involved in accidents attributable to IMC or other adverse weather conditions are severely limited in this respect since, for the most part, the pilots involved in such accidents do not survive. Hence, while it might be possible to piece together some of the information provided in this study (for example, aircraft characteristics, pilot qualifications, sources of weather information, etc.), other information (for example, their perception of the risks before and after the encounter, their reasons for entering IMC, and the specific conditions just prior to the event, etc.) would likely be impossible to obtain. These data may profitably be used to inform future research and the development of future interventions.

One future research effort might address the degree of similarity between the pilots in this study and the pilots involved in weather-related accidents. One might argue that there are substantive differences between pilots who encounter IMC and survive to participate in a survey and the pilots who encounter IMC and crash. Such differences, should they exist, could form the basis for training or other interventions. Unfortunately, the high fatality rate associated with weather-related accidents makes such a study very difficult. Although some data, for example pilot license and experience, are usually available from accident investigation records, more detailed information of the sort presented here is usually lacking. However, those pilots who experienced a weather-related accident and survived would be a rich source of information that would be comparable to that reported here. Future research should exploit that information source, in lieu of the relatively uninformative review of accident investigators' reports.

Even without such a study, the present results suggest several approaches to intervention. For example, it is interesting to note that about one-third of the aircraft involved in IMC encounters had autopilots on-board. Presently, the generally accepted approach to the training of pilots to deal with IMC encounters focuses on recovery from unusual attitudes by use of the traditional flight instruments. Perhaps an equally or more effective approach would be to train pilots to turn on the autopilot, and then use it to escape from the situation.

Over the last two decades, there has been a growing recognition, particularly in the military community, of the need to understand the users for whom new systems are being developed (Booher, 1990). For military materiel developers, this often takes the form, at a minimum, of a target audience description. Such a document provides data on the skills, qualifications, training, experience, and physical, sensory, psychological, social, and cultural characteristics of the individuals who will operate or maintain a new weapons system. These data are essential to ensure that the new system fits the user and maintainer. In the same sense, for the aviation accident community, relevant research cannot be conducted and effective interventions cannot be developed without an in-depth knowledge of the audience of pilots for whom such research and interventions will be targeted.

The data presented in this study represent a first step in establishing such a description of pilots and their experiences that can be used to shape research and interventions to maximize their ultimate utility. Ultimately, this will allow us to answer the question: What beliefs, attitudes, skills, and knowledge do we need to modify in order to shape the behavior of which pilots under what circumstances?

5. Limitations to generalizability

The data comprising the present study were gathered from a self-report questionnaire, administered over the Internet. Thus, the data are subject to bias that may result from self-selection for participation in the study, erroneous recall of the events, or deliberate distortions. In addition, it is possible that pilots mis-interpreted or mis-responded to the screening questions, with the result that they were inappropriately assigned to one of the three groups. To the extent that these errors or distortions were random with respect to group membership, then the result would be to increase error variance and attenuate the statistical tests.

As was pointed out earlier, the present data cannot demonstrate that the characteristics and results reported here also hold for pilots who were involved in actual accidents. Indeed, such a comparison is suggested as a future research topic.

Readers are further reminded that this was an exploratory study, and we elected not to attempt any experiment-wide error correction. This may have led to some instances in which spurious results were obtained, simply because of random variation. Readers are, therefore, again reminded to be cautious in interpreting the results.

Nevertheless, the results provide an intriguing picture of the situational and personal characteristics that differentiate among pilots reporting quite different experiences with weather. Although they share many characteristics, as enumerated in the tables and summarized above, there are nevertheless multiple areas in which they differ. Knowledge of these similarities and differences should empower researchers and intervention developers in their quests to better understand the causal factors in accidents and to develop methods to attenuate or at least to manage those causal factors.

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