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The Effect of Experiential Education on Pilots' VFR into IMC Decision-Making

Geoffrey R. Whitehurst
Western Michigan University, geoff.whitehurst@wmich.edu

Lori Brown
Western Michigan University, lori.brown@wmich.edu

William G. Rantz
Western Michigan University, william.rantz@wmich.edu

Dominic Nicolai
Western Michigan University, dominic.nicolai@wmich.edu

Jessica M. Bradley
Western Michigan University, jessica.m.bradley@wmich.edu

Introduction

Visual Flight Rules into Instrument Meteorological Conditions (VFR-into-IMC) Research

Visual flight rules (VFR) are a set of regulations under which a pilot operates an aircraft in weather conditions that allow the use of visual references, i.e. visual meteorological comditions (VMC). If the weather is less than VMC, i.e. instrument meteorological conditions (IMC), pilots are required to use instrument flight rules, and operation of the aircraft will primarily be through referencing the instruments rather than visual reference. A pilot's decision to continue from VFR-into-IMC is not caused by training or overall flight experience (Goh & Wiegmann, 2001). The largest factor that determines whether a pilot will choose to continue or divert is the amount of time flying in adverse weather (Johnson & Wiegmann, 2015). A pilot's decision to continue from VFR into IMC has also been explained by poor perception of the risks (Civil Aviation Authority, 1988), motivational factors (O'Hare & Smitheram, 1995), lack of experience in IMC (Johnson & Wiegmann, 2015), spatial disorientation (Taneja, 2002), weakness in weather knowledge (Major et al., 2017), and poor situation assessment and limited weather training (Major et al., 2017). Goh and Wiegmann (2001) determined that "pilots who chose to divert were more accurate in their visibility estimates than pilots who chose to continue…accuracy of visibility estimates [are] the most important factor in predicting whether pilots would continue to divert from a VFR into IMC situation."

Many studies have researched the effect situation awareness has on a pilot's decision to continue into IMC (Endsley, 1995a; Goh & Wiegmann, 2002; O'Hare & Smitheram, 1995; Wiegmann, Goh, & O'Hare, 2002; Wiggins & O'Hare, 2003). A study by Durso, Bleckley, and Dattel (2006) determined that situation awareness could be used to determine behavioral outcomes in complex tasks, even more than cognitive, personality, and demographic variables.

Situation Awareness Research

Situation awareness has been researched on a lot of different topics including but not limited to: air traffic controllers (Vu et al., 2009), submariners (Loft, Morrell, & Huf, 2013), chess players (Durso et al., 1995), human/machine collaborations (Ziemke, Schaefer, & Endsley, 2017), and pilots (Goh & Wiegmann, 2001).

Dominguez (1994) created a table of situation awareness definitions that have been used by other researchers since its compilation. The first definition of situation awareness was by Morishige and Retelle (1985) which stated that situation awareness is "awareness of conditions and threats in the immediate surroundings." Endsley (1995b) has a definition that is much more detailed. She defines situation awareness as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." This definition identifies three steps to achieving situation awareness. Step one is perceiving the elements in the environment. An example of step one is when a pilot is able to identify that the visibility is low. Step two is having comprehension of the current situation. An example of this step is when a pilot estimates that the visibility is still under VFR. Step three is projecting future status. An example of this step is when a pilot is able to predict whether or not the visibility is improving and if he/she will be able to continue to the destination. All three aspects of situation awareness are important, and all three are not skills that most general aviation pilots learn in typical flights.

There are at least nine ways to measure situation awareness. The measurement can be done through a direct question asked to the subject, a subject rating him/herself or others, or a measurement of the subject's performance. The Situational Awareness Global Assessment Technique (SAGAT) is the most publicized technique (Jeannot, Kelly, & Thompson, 2003).

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This technique involves freezing the simulation and participants are queried on specific data or criteria corresponding to the three steps of situation awareness. SAGAT was developed by Endsley in 1990.

An alternative approach to the use of highly intrusive freeze probe techniques is the use of real-time probe techniques. Real-time probe techniques involve the administration of situation awareness related queries during task performance, but with no freeze of the task under analysis. The Situation Present Assessment Method (SPAM) (Durso et al., 1998) is a real-time probe technique developed for use in the assessment of air traffic controllers' situation awareness. The technique involves the use of on-line, real time probes to evaluate operator situation awareness. The method used to measure situation awareness in this study is the Situation Present Assessment Method (SPAM). This method is useful because the simulation does not need to be stopped, as demonstrated in Durso et al.'s 1995 study with chess players. All the information is available to the subject, so he/she can provide a correct answer by consulting the available material.

Experiential Education

Experiential Education (ExpEd) modules have been developed for the Federal Aviation Administration's (FAA) Weather Technology in the Cockpit research project under the Partnership to Enhance General Aviation's Safety, Accessibility and Sustainability (PEGASAS) Center of Excellence. ExpEd modules use computer simulation videos to provide the subject with "experiences" of hazardeous weather not normally encountered in training or when flying under visual flight rules. Computer or web-based education modules are particularly useful with general aviation pilots because of the easy accessibility to the modules and their ability to show non-instrument certified pilots the problems encountered when inadvertently flying into hazardeous weather. In addition to this benefit, computer-based learning has been determined to be just as effective if not more effective than traditional learning (Wisher & Olson, 2003; Sitzmann, Kraiger, Stewart, & Wisher, 2006). Knecht, Ball, and Lenz (2010) determined that video instruction with pilots was not effective, possibily because of the complexity of the material and lack of interaction with the video. Keller, Carney, Xie, Major, and Price (2017) determined that interactive training modules did not significantly increase post-test weather knowledge scores; however, no investigation was done on whether or not the modules improved pilot's situation awareness or decision making.

This research will investigate the effect of an ExpEd module (estimating visibility) on the situation awareness and decision-making of general aviation pilots. It is predicted that by providing visual experience of deteriorating weather, a pilot's situation awareness and subsequent decision making will be improved.

Methodology

The goals of the study were to select one or more weather knowledge gaps identified in prior research by PEGASAS researchers, Major et al. (2017), for educational interventions of a selected group of volunteer pilot test participants in a simulation, and to compare the effects of the respective educational interventions on the pilots' actions in the treatment groups, with the actions of the pilots of the control group, where all groups were asked to fly the same flight scenario. The flight scenario was flown in a ground-based flight simulator. In the simulation, the educational treatment interventions were designed to improve the participants' ability to recognize deteriorating weather (reducing visibility) conditions. For the study, there were two training interventions: intervention one used a web-based module showing interactive video clips providing training in estimating changing meteorological visibilities and a final video 'flight'into deteriorating weather, with pauses to ask participants estimation of visibility at that point. Feedback on their estimations of the visibility was automatically provided. Intervention two provided the same estimating visibility training, but instead of a final video ‘flight’ the participant hand flew a PC-based simulator with questions on visibility asked at similar positions during the flight.

The research question to be considered was: can either of the educational training methods significantly affect general aviation (GA) pilot’s recognition of deteriorating weather conditions and subsequent effect flight behavior in VFR-into-IMC situations?

Participants

The population included general aviation pilots in the United States. The focus of this research was directed toward FAA-certificated private pilots, although pilots with higher certification levels did participate. Participants were considered without limitation of gender, ethnic background, or any other non-flight-related factor. Preference was given to private pilots who met the requirements for the three levels of instrument flying experience in IMC (less than 5 hours, > 5 hours to < 50 hours, and > 50 hours), pilots having less than 1,000 hours of total flight experience, and pilots who have recent flight experience.

Prior to arriving at the testing facility, participants were provided with pre-flight briefing materials on the aircraft, the route to be flown, the actual and forecasted weather for the departure, destination and enroute airfields. On arrival, the 36 general aviation pilots of varying instrument flight experience (IF) were allocated, using stratified random sampling based on their IF, to one of three groups, a control group and two educational treatment intervention groups.

Each simulation experiment began with a formal pre-flight briefing to participants. Then, prior to flying the research simulation, participants were familiarized with the simulator, and flew a baseline training scenario of basic flight maneuvers (which was roughly 15 minutes in length). The training scenario included all the basic maneuvers required in the scenario and interactions with air traffic control (ATC). The last segment of the training scenario involved practicing the verbal protocol of think aloud (describing their current focus of attention, decision-related thoughts and actions as they perform them in the sim), but participants were reminded that their primary task was to safely and effectively fly the aircraft, and therefore, verbalizing their thoughts should only occur when doing so would not interfere with the primary task.

Equipment

The research study was conducted at the Federal Aviation Administration's W. J. Hughes Technical Center's Cockpit Simulation Facility, using a single-engine Redbird motion base simulator with a 180° out-the-window view (see Figure 1), configured to emulate a Mooney Bravo single-engine aircraft with the G1000 type GA glass cockpit control display. For flight dynamics, the Redbird simulator used Microsoft Flight Simulator X and to meet the weather display needs, X-Plane 10 was used to drive the six out-the-window view monitors. The simulator is equipped with a stand-alone portable weather display running on a Windows Surface Pro 3 and a voice communication system that provides a link between the pilots and ATC through a push-to-talk (PTT) capability.

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Figure 1. Left: an exterior view of the Redbird C172 fuselage. Right: the cockpit out-window view, the G1000 type GA glass cockpit control display, the instruments, and the stand-alone weather display running on a Windows Surface Pro 3.

During the study, the Redbird simulator cockpit was equipped for video recording (H.264 format) and sound recording with playback capability. To capture pilot behavior, three cockpit-mounted cameras were used to provide a top view (dome camera, 360°), a front view (bullet camera), and a side view (fisheye camera). These three camera views captured the entire cockpit environment and the videos were, therefore, suitable for a behavioral analysis of pilot actions during flight. In addition to the camera views, the display of the G1000 type GA glass cockpit control display and the auxiliary weather display (Microsoft Surface Pro 3) were also captured and recorded.

Real Time Streaming Protocol was used to capture live Internet Protocol camera streams. The iSpy surveillance software was used for recording as well as for video playback at the researcher control station (Figure 2). The iSpy software synchronizes the recordings of video and sound, and displays the five individual video streams from the cockpit simulator. The cockpit sound system captures voice recordings from pilots and ATC, and allows playback of pre-recorded Automated Weather Observing System (AWOS) weather messages.

The PLEXYS software was used to simulate the radio PTT communication between the pilot and ATC. PLEXYS also managed the playback of pre-recorded live ATC/pilot sector communication. In addition, PLEXYS managed the synchronization and playback of AWOS messages during the simulation flights.

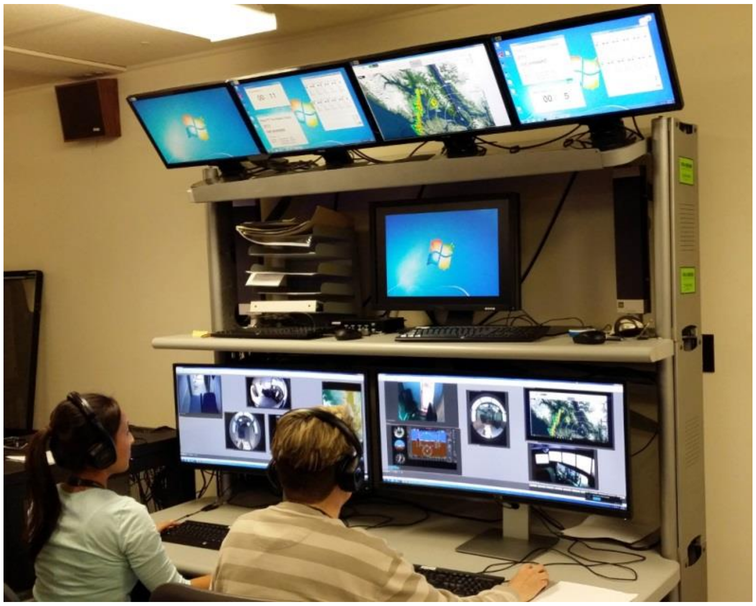

Figure 2. The researcher control stations.

Procedure

While flying the scenario, participants were instructed to use a version of think-aloud verbal protocol. The instructions were to pilot the aircraft (simulator) in a safe and effective manner as their top priority. As a secondary priority, participants were asked to verbalize their thoughts as they fly the aircraft and make flight-related decisions (i.e., they would verbalize thoughts only if doing so did not interfere with piloting the aircraft safely and effectively). In cases for which participants would have a thought but needed to remain focused on flight-related activities and therefore did not verbalize it, they were encouraged to gesture to observing members of the research team (e.g., hold up a finger) so that the thought can be explained later when the workload levels decrease, or after the experiment (aided by a review of a video of the participant during the simulation scenario).

Video recordings captured the participants from several angles (cockpit camera, overhead/over-the-shoulder). One observer coded the participant's activities live during the experiment, and a separate observer coded while viewing the captured video and simulator data for inter-rater reliability. Data was collected for Situation Awareness Points (SAPs) - using the Situation-Present Assessment Method (SPAM). Air Traffic Control queried the pilot for altitude, flight conditions and visibility, if not given as flight conditions, the timing and correctness of their response will be recorded for situation awareness data.

Data Analysis

Dependent Variable

The dependent variable for the experiment was the participant's decision-making (DM) to continue into visibility of less than 3 statute miles (Instrument Meteorological Conditions [IMC]) or to divert, by initiating a significant turn (> 90°) away from the flight planned track or informing ATC of diversion.

Independent Variables

The independent variables for the experiment were:

1. Type of training intervention utilized (IV):
    a. No intervention - Control (1)
    b. Web-based intervention (2)
    c. Web plus WILD-based intervention (3)
2. Non-simulated flight hours in IMC (IF):
    a. Less than 5 hours of non-simulated flight in IMC – Low IF (1)
    b. More than 5 hours, but less than 50 hours of non-simulated flight in IMC –Medium IF (2)

   c. Fifty or more hours of non-simulated flight in IMC – High IF (3)

3. Reporting abeam a specific landmark – Situational Awareness (SA):
   a. Failure to report or reporting abeam wrong landmark – Poor (1)
   b. Reporting abeam correct landmark – Good (2)
4. Age of participant (A)
   a. Less than 20 years of age – (1)
   b. Between 20-29 years of age – (2)
   c. Between 30-39 years of age – (3)
   d. Between 40-49 years of age – (4)
   e. Between 50-59 years of age – (5)
   f. Greater than 60 years of age – (6)
5. Total hours flown (FT):
   a. Less than 100 hours – (1)
   b. Between 100 - 250 hours – (2)
   c. Between 251 - 500 hours – (3)
   d. Between 501 - 1,000 hours – (4)
   e. Greater than 1,000 hours – (5)

Data was analyzed using descriptive statistics and analysis of variance (ANOVA) on MINITAB statistical software.

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Results

Table 1

IFR Group Descriptive Statistics

IFR Group	N	A (Yr.)			FT (Hr.)			IF (Hr.)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	12	27	45.1	62	81	308.4	1200	0.0	0.46	4.0
2	12	19	48.4	74	130	579.2	1600	5.0	13.25	25.0
3	12	48	65.2	80	500	2161.4	5500	50.0	219.58	500.0

Table 2

Intervention Group Descriptive Statistics

IV Group	N	A (Yr.)			FT (Hr.)			IF (Hr.)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	12	27	53.9	72	120	1209.8	4500	0	103.42	400
2	12	27	55.9	80	81	709.3	2400	0	34.46	250
3	12	19	48.8	66	130	1130.0	5500	0	95.42	500

Analysis of Variance

The data was split into several data sets and analyzed using multiple one-way analysis of variance (ANOVA) between a pilot's decision-making (DM) to divert before entering IMC and the independent variables: type of intervention (IV), non-simulated flight hours in cloud (IF), situational awareness (SA), age (A), and total flight time (FT).

None of the factors were statistically significant for alpha = 0.05. However, type of intervention (IV) was closest to statistical significance, $F(2,35) = 3.20$, $p = 0.0538$, see Table 3. However, if the study was redone on a larger sample size this factor, most likely, would gain statistical significance.

Table 3

ANOVA of Pilot Decision (IMC) vs Intervention (IV)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
IV	2	1.38889	0.694444	3.20	0.0538
Error	33	7.16667	0.217172		
Total	35	8.55556			

Post-hoc analysis of IMC vs IV, using Fisher's LSD method, showed that the number of pilots who made the decision to divert before the visibility became less than 3 statute miles (IMC) was significantly different for those that received IV2, the Web-based ExpEd module, than those who received both IV1, no intervention, and those that received IV3, the intervention using the web plus WILD-based intervention. There was no significant difference between IV1 and IV3, see Table 4.

Table 4

Grouping Information Using the Fisher LSD Method

	N	Mean	Grouping	
3	12	0.7500	A	
1	12	0.7500	A	
2	12	0.3333		B

Means that do not share a letter are significantly different.

Two-way ANOVAs between IMC and all independent variables were used to check for inter-action effects, but no statistically significant inter-action effects were found between any of the factors. However, the two-way ANOVA with factors IV and SA showed an improvement in the statistical significance of IV {F (2, 35), F = 4.07, p = 0.0274}, suggesting that although there

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was no significant inter-action effect, including SA would improve regression model fit, see Table 5.

Table 5

ANOVA of IMC vs IV and SA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
IV	2	1.67887	0.839437	4.07	0.0274
SA	1	0.22241	0.222415	1.08	0.3076
IV*SA	2	0.73770	0.368849	1.79	0.1849
Error	30	6.19286	0.206429		
Total	35	8.55556			

Discussion

The participants' ages ranged from 19 to 80 years, with a mean of 52.9 years and a median of 56 years. Their flight time ranged from 81 hours to 5,500 hours, with a mean of 1016.3 hours and median of 530 hours. Their Instrument flight time ranged from 0 hours to 500 hours, with a mean of 77.8 hours and a median of 11 hours. Flight certification ranged from Private, with no instrument rating, to commercial with instrument certification. Although this provided participants of varying ages, experiences, and certifications, experience or lack of experience was not a strong influence on safe weather-related decision-making. The Web-based ExpEd module intervention (IV2), although not statistically significant, for alpha = 0.05, had the strongest influence on safe weather-related decisions. This would suggest that flight training and recurrent training, especially in the area of estimating visibility, is not providing pilots with the necessary skills to accurately assess in-flight visibility to the level required to make informed decisions on deteriorating visibility, and hence avoid instrument meteorological conditions. These findings support Johnson and Wiegmann's (2015) analysis of current weather-related training methods, which seem inadequate. These results illustrate gaps in weather-related flight training for both VFR- and IFR-rated pilots, and experience in simulated hazardous weather conditions seems to be necessary for the development of critical decision making skills.

Conclusion

The findings from this study showed that the use of the ExpEd module, which is designed to help pilots recognize decreasing visibility and the potential hazard of continued flight into IMC, improved pilot decision-making when flying in a situation where visibility was deteriorating below VFR minimums. This suggests that the immersive ExpEd type training, which is designed to provide visual experience of hazardous weather situations, might be able to fill gaps in current weather-related flight training, to train pilots to make safer weather-related decisions when encountering other types of hazardous weather phenomena.

Limitations

Some pilot decision-making observed in this study might have been due to limitations with the simulation, such as the absence of real danger and/or the possible lack of personal motivation to complete the flight; however, most of the pilots indicated that they carried out their PIC duties as though they were faced with a real-life situation. The relatively small sample size of participants was due to funding and the availability of facilities. The time available was restricted to one intensive week. The selection of the participants was from a limited geographical location, within 200 miles of the facilities, due to travel time to get to the facilities.

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