PEGASAS: WEATHER TECHNOLOGY IN THE COCKPIT

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Research shows that a high percentage of weather-related General Aviation (GA) accidents can be attributed to pilots flying into Instrument Meteorological Conditions (IMC) without experience or appropriate certifications to safely operate beyond Visual Flight Rules (VFR). To make safety-critical decisions, pilots often use weather indication delivered on screens of portable electronic devices. This information often is obsolete with a latency up to 20 minutes. Web-based experiential education modules, using a flight simulation system for demonstration of this weather indication latency, can potentially mitigate this problem. Modules will be designed to provide pilots with the ability to "experience" different weather phenomena and will include tools to improve knowledge and skills for assessing deteriorating conditions and making effective decisions at imbedded decision points. This research also studied methods for delivering weather alert messages to pilots in-flight to support pilot reception of critical messages, examining effects of decision-making, workload, and situation awareness.

The Weather Technology in the Cockpit (WTIC) program is a Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) weather research program comprised of a portfolio of research projects in the Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability (PEGASAS). The overarching goal of the FAA's WTIC Program is to identify, develop, verify, and validate a set of FAR Part 121, 135, and 91 Minimum Weather Service (MinWxSvc) recommendations to enhance pilot weather decision-making when faced with potentially hazardous weather conditions. The WTIC MinWxSvc will be associated with: the minimum cockpit meteorological information; the minimum performance standards and characteristics of the meteorological information; rendering guidance for the meteorological information; and enhanced meteorological information pilot and technology training.

The portfolio of projects will perform the research necessary to address the overarching WTIC research questions**.** Instrumental in gaining answers to these questions is research to identify and address weather-related "gaps" and "shortfalls" in; cockpit meteorological (MET) information, pilot training, pilot understanding and interpretation of MET information, technological and human factors issues associated with presenting cockpit MET information, and any operational, efficiency or safety risks associated with these gaps and shortfalls.

Information Technology Based Demonstration of Weather Indication Latency

Weather related accidents in GA often are caused by a pilot's inability to adequately perceive and assess actual meteorological conditions (Pearson, 2002; Aarons, 2014). While making in-flight weather relevant decisions, pilots of many GA light aircraft rely on information displayed on screens of various portable electronic devices capable of producing weather radar images (Pope, 2015). These images show weather situations that existed some time ago at the aircraft's current position. The time difference between the radar weather image and actual flight weather conditions may be as long as 20 minutes (Trescott, 2012; Zimmerman, 2013). The outdated weather information can prompt GA pilots' making safety-threatening decisions to continue flights into rapidly deteriorating weather conditions for which they or their aircraft are not certified.

Studies aimed at understanding and preventing the weather radar latency harmful influence on decisions made by GA pilots can benefit from researchers' ability to demonstrate the weather radar latency in simulated aircraft flight environment. This ability has been achieved by means of simultaneous utilization of commercially available software and hardware products in a weather information latency demonstrator (WILD). The WILD consists of two flight simulators that can be run simultaneously imitating the same flight scenario. While the aircraft current geographical position in both of the simulated flights is identical, a time difference (latency) can be set between two moments of the weather system development shown in each of the flight simulators at the geographical area corresponding to the aircraft actual position.

One of the flight simulators replicates a GA aircraft cockpit surroundings showing a visual picture of the weather environment seen through the aircraft windows. Another flight simulator generates the weather system status as it was some time ago. The information of this previously existed status of the same weather system is shown in the first flight simulator as an image on an electronic display imitating the weather radar information that GA pilots can see on screens of their portable electronic devices. The researcher can establish the time difference (latency) between two manners of the same weather system representation: the actual weather picture seen from the cockpit at the current moment of the flight, and the radar screen image showing the status of the same weather system that existed earlier at the current location of the aircraft.

In each of the two flight simulators, the Microsoft Flight Simulator X (Williams, 2006) or its successor Prepar3D (Lockheed Martin Corporation, 2015) software programs generate the aircraft cockpit environment and the flight progress. Active Sky (HiFi Simulation Technologies, 2015) software products run in each flight simulator generate correspondingly ether current or previously existed (delayed) weather conditions expressed in two appearances: as a visual picture seen from the aircraft cockpit, and as a weather radar image [Figure 1].

Figure 1. The weather radar image on the portable device screen shows a better weather situation that existed earlier at the aircraft current position.

To achieve realism of the weather relevant flight simulation, identical flight control inputs must be applied in both of the flight simulators. The WidevieW (Napolitano, 2015) software makes possible simultaneous control of the simulated aircraft flight path in both of the flight simulators by using only one set of flight controls (control wheel, rudder pedals, and engine power control) located in the flight simulator that imitates the aircraft cockpit.

Experiential Education - A New Approach to Helping Improve Judgement and Decision Making Skills of General Aviation Pilots in Adverse Weather

As previously stated, several gaps associated with VFR-IMC transitions, have been identified by the WTIC research team. These gaps include factors addressing pilot knowledge, skills and abilities (KSAs), where KSAs are defined as: Knowledge - Memorized facts/information - assessed by question/answer tests compared to a standard; Skills - Understand how to apply the knowledge - assessed by manipulating something compared to a standard; Abilities - The proficiency to take action at appropriate prompt(s) - assessed by timely application of appropriate knowledge and skills to novel prompts compared to a standard time range. The gaps identified by the WTIC team in these areas are:

Knowledge Gaps

1. *Lack of training (mainly due to little opportunity) for student pilots to fly in and experience different weather patterns and their associated visual and other cues.*
2. *GA pilots often do not understand the limitations of the technology in the cockpit.*

Skill Gaps

3. *There is a perceived gap in skills related to VFR-into-IMC decision-making.*
4. *Lack of Situational Awareness relating to VFR-into-IMC.*
5. *Retention of weather knowledge was identified as a gap.*

Ability Gap

6. *Lack of ability of pilots to correlate, interpret, and apply weather information related to VFR-into-IMC weather factors, specifically convection, icing, lowered ceilings, quickly emerging weather events, precipitation, or pilot-reported turbulence.*

Research conducted during a previous phase of the WTIC research project to address Gaps 4 and 5, showed only limited effects when using classroom-style, knowledge-focused education modules to affect pilot situation awareness and decision making in simulator tasks.

Other researchers (Wiggins & O'Hare, 2003; Ball, 2008; Knect, Ball & Lenz, 2010a; Knect, Ball & Lenz, 2010b; and Vincent, Blickensderfer, Thomas, Smith, and Lanicci, 2013) have also studied pilot awareness and decision-making, and much of their research has been studying training in the use of and understanding of weather products and weather information in aviation. One of their findings shows that pilots rarely receive any formal training on the use of weather-related equipment and tools, and often lack the skills to apply weather knowledge to effective decision-making.

Since increasing weather knowledge did not result in improving GA pilot's skill in applying their increased knowledge, the next step in trying to mitigate the higher-level gap, the "Ability" gap, is to develop a method of improving "skill" rather than "knowledge." Therefore, in this phase of the research, the team is developing several "Experiential Education" modules, which are designed to improve GA pilot's skill, gaps 3, 4 and 5, in applying weather knowledge rather than just increasing a GA pilot's knowledge/understanding of weather. An analogy would be to "show" someone how to do something rather than try to just try to "explain" how to do it.

The Experiential Education modules are being developed using the WILD simulator to provide video clips of specific flight environments. The flight environments will be based in different areas of the United States with a typical weather phenomena that may be associated with that specific area, e.g. Lake Effect Snow in Western Michigan. The modules will "fly" the pilot through weather phenomena such as decreasing visibility, developing convective clouds (thunderstorms), icing conditions, etc. The modules will start with a practice session on recognizing important aspects of the flight conditions in which they are "flying," such as estimating flight conditions (VFR, MVFR or IFR) based on their estimate of in-flight visibility, or identifying possible icing conditions, etc. Following the practice session, the pilots will "fly" a scenario which will include decision points, where the pilot will be asked, based on the in-flight conditions at that time, if the flight should continue or a diversion be initiate. Feedback will be provided, based on the decision made. These modules are designed to help improve a pilot's skill in applying weather knowledge to effective decision-making, and thus help mitigate the "Skill" and "Ability" gaps.

General Aviation Weather Alerting: Effectiveness of Display Characteristics in Supporting Weather-Related Decision Making

To employ effective decision making, pilots must first be aware of changes in conditions requiring an amendment to their actions (i.e decision points). Weather and visibility at takeoff can degrade quickly while in-flight, prompting pilots to rely on in-cockpit weather technologies to alert them to these changes, and provide some information necessary to modify their flight plan.

Methods

A research study was conducted in flight training devices at the FAA's William J. Hughes Technical Center and investigated two methods for receiving weather alert messages: via text messages embedded in a complex graphical map display, and via messages displayed on a smartwatch worn by participants. The text of the alerts followed the Lockheed Martin Flight Services Adverse Condition Alerting Service (LMFS ACAS) format. See Figure 2 below for an illustration of these two display conditions, as well as a representative flight training environment.

Figure 2. Flight training environment with weather alerts displayed as textboxes embedded in graphical display (right side, touch activated) and as text on a Pebble smartwatch worn by pilots on the left wrist.

Various measures of pilot decision-making accuracy and timing, as well as situational awareness, were collected to assess differences attributable to the display format. Additionally, vibrotactile cueing conditions (presented via the vibrating motor in the smartwatch) were examined to determine how nonvisual cues could support attention and interruption management during flight. While each participant completed two flight scenarios, one set in Alaska and one in New Mexico, each with a different display configuration (complex graphical and smartwatch), the vibrotactile cueing condition was handled as a between-subjects variable. Participants either received no vibratory cues (visual text only), received a single vibration pulse with each incoming message, or received "urgency-mapped" graded pulses, which would present pulses with higher frequency and duration when messages were more important and urgent.

Thirty-two pilots (3 female; ranging from age 20 to age 79 with an average age of 53 years) participated in the study. Each scenario began with the pilots mid-flight and with different types of degrading weather and visibility developing at the intended destination. A scenario was complete when pilots either verbalized their intent to divert or otherwise flew into IMC conditions. Completion of each scenario took approximately between 10 and 25 minutes. Scenarios involved three experimental alert messages of varied importance/urgency, and delivered when pilots were under varied task loads. Time and accuracy in responding to the alerts were coded by multiple observers and represent the main dependent variables of interest. Additionally, situation awareness probes in the forms of ATC-issued status checks were issued following the Situation Present Assessment Method (Durso, Dattel, Banbury, & Tremblay, 2004), and NASA-Task Load Index (TLX) surveys (Hart & Staveland, 1988) and functional near-infrared spectroscopy (fNIRS) were used to measure pilot workload while performing flight-related tasks.

Results

Due to unforeseen issues in data recording, some datasets were lost, leaving the data from 27 pilots for statistical analysis. Of these, few pilots (9 of 27, 33%) made the explicit decision to divert their aircraft as conditions deteriorated, and not a single pilot correctly diverted in both scenarios. For the measure of decision making accuracy, no significance was found for the main variables of interest: display configuration and vibrotactile cuing condition.

Response time to the alerts, however, was significantly ($p < 0.05$) affected by the vibrotactile cuing condition, showing considerably faster responses when a vibratory cue accompanied the delivery of the text-based alert message (see Figure 3, left side). Although there is an apparent trend showing faster responses for the text embedded in the graphical display of the Tablet, these differences did not reach significance.

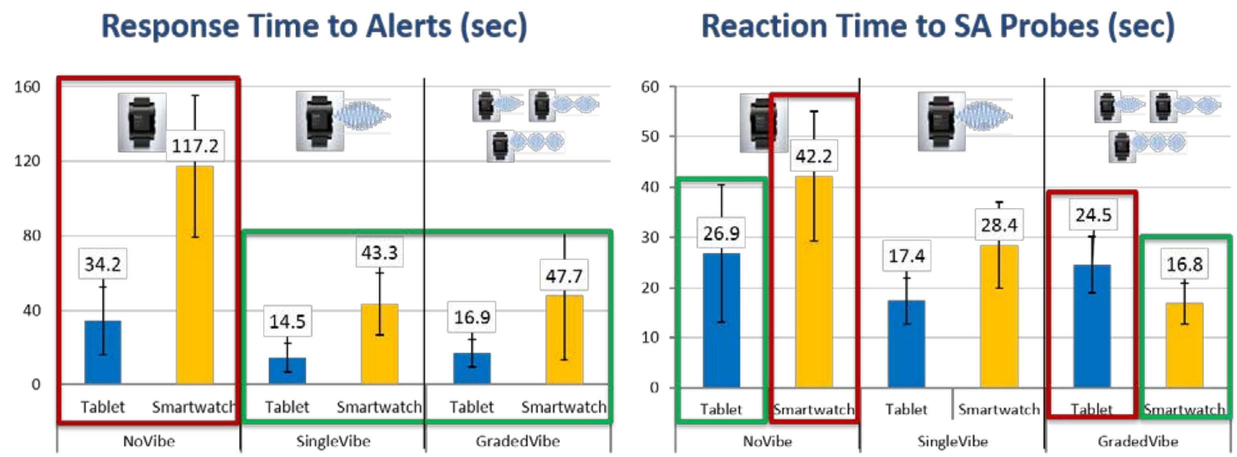

Figure 3. Left: Response time (in seconds) to alerts under each display configuration (Tablet or Smartwatch) and vibratory cuing condition (no vibration, single vibration, or graded vibration). Right: Reaction time to situation awareness (SA) probes. In each case, boxes around the data represent significant differences in the data.

The response time to situation awareness (SA) probes (status report requests from ATC) was also significantly affected by an interaction between display configuration and vibratory cuing condition (see Figure 2, right side). This effect shows that when no vibratory cues are presented, probe responses are faster (thus, SA levels are higher; Durso et al., 2004) with the Tablet-based presentation of alerts. With urgency-mapped graded vibratory cues, however, the Smartwatch conditions showed the higher levels of SA.

Workload measures showed no significant differences in NASA-TLX survey data, but a significant effect was found with the fNIRS data that suggested lower overall workloads when alerts were embedded in the graphical display (mean HbO_2 level of 0.21; max of 2.94) than when they were displayed on the smartwatch (mean HbO_2: 0.72; max: 3.34).

Conclusion

The results offer some answers for appropriate means of providing weather information to GA pilots and also new questions for future research. Messages displayed in existing onboard visual displays, such as GPS maps, show some significant benefits over exclusively watch-based messaging in terms of the time it takes to receive and process the messages. However, using vibrotactile cuing to accompany the arrival of new weather messages was more impactful, showing a substantial benefit over conditions that did not involve vibratory cuing. Building on this work and those of others that investigated vibrotactile cuing to support pilot awareness (e.g., Ahlstrom, Caddigan, Schulz, Ohneiser, Bastholm, & Dworsky, 2015; Sklar & Sarter, 1999), future research will seek to define more clearly effective urgency-mapped tactile encodings for common weather alerts and messages.

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