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WEATHER TECHNOLOGY IN THE COCKPIT (WTIC): CONCEPT OF OPERATIONS, USER NEEDS, EDUCATION, AND TRAINING

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1. INTRODUCTION

Currently, there are vast amounts of weather information and numerous sources available to general aviation (GA) pilots for preflight planning. However, research evidence indicates that weather-related decision-making during the in-flight phase remains problematic. Accident statistics bear these findings out. An examination of National Transportation Safety Board (NTSB) analyses, Aircraft Owners and Pilots Association (AOPA) Nall reports, Department of Transportation (DOT) statistics, and results from the National Safety Council reveal that the lethality rate for GA weather-related accidents ranges from 62 to 87% depending on the year and analysis method used. These results suggest that an emphasis on weather information available to the pilot in the cockpit, while in-flight, can be directly related to decision-making and flight safety. Unfortunately, the only weather information sources widely available to most pilots in-flight today are inefficient aural sources and "out-the-window" cues.

However, the situation is changing. Within the last 10 years, the advent of affordable WTIC services from a number of vendors is changing the way that a lot of GA pilots obtain weather information during the enroute phase of flight. As this capability expands and the National Airspace System (NAS) evolves towards the Next Generation Air Transportation System (NextGen), key steps in the transition will involve determining what types of weather information users need, how they intend to use the information during different phases of flight, and whether they have the necessary education and training to use them safely and effectively. These issues are the motivation for a three-part WTIC research study presently being undertaken by the Federal Aviation Administration (FAA) sponsored Center for General Aviation Research (CGAR). The CGAR university consortium consists of four universities, three of which [University of Alaska-Anchorage (UAA), University of North Dakota (UND), and Embry-Riddle Aeronautical University] are participating in this project.

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The first part of the study is the development of a comprehensive User Needs Statement and is being led by UND. The second part of the project, led by UAA, is focused on developing a suitable Concept of Operations (CONOPS) for WTIC usage by the GA community. The third part of the project is the development of updated or new guidelines for required aviation meteorological knowledge and creation of learning tools for WTIC products, specifically focused on the GA community. This portion of the study is being led by Embry-Riddle.

2. WTIC USER NEEDS SEGMENT

To develop a viable User Needs Statement, it is necessary to sample a large enough portion of the GA community to discern their requirements for WTIC product and concerns about WTIC. To accomplish this task, the UND research team created a survey that examined how GA pilots currently employ weather information, and polled them for their WTIC product delivery preferences during different phases of flight. The survey results were mapped by different demographic groups such as pilot certification levels, age groups, and U.S. geographic region. The survey results were then analyzed statistically to determine if each demographic group's preferences matched an "expected" value, and statistically significant differences were noted. A total of 1,315 responses were collected and analyzed for this portion of the study. Table 1 summarizes the pilot demographic groupings used in this portion of the study.

Table 1. Pilot demographic groups.

Pilot Certification	**Pilot Ratings**	**Aircraft Category flown**	**CFI***	**Age Group**	**Geog Region**
Student	Instrument	Fixed Wing	Y/N	$\geq$ 65	Central
Sport	Multi engine	Rotorcraft		46-64	Eastern
Recreational		Not Specified		29-45	Great Lakes
Private	.			17-28	New England
Commercial					NW Mountain
Airline Transport					Southern
					SW
					W Pacific
					Alaska

* CFI—Certified Flight Instructor

2.1 Data Analysis

The UND research team analyzed the survey results for three demographic classes: 1) pilot certificates and/or ratings held; 2) pilot age group; and 3) region of flight. Since the primary goal for this segment is to identify pilot needs for WTIC services, the data analysis was performed by examining responses to survey questions in five areas: 1) preflight weather information used; 2) method of obtaining weather information in-flight; 3) preferences for receiving weather information in-flight; 4) preferences for delivery of weather information in-flight; and 5) use of a mobile device to access weather information.

The Chi-square statistical analysis was used for this study because the demographic data are arranged into various nominal categories. In this study, the level of significance used for the Chi-square analysis was $p < .05$. Table cell results with less than five responses were not analyzed due to the violation of Chi-square assumptions.

Table 2 shows which of the demographic group responses were statistically significant for the five areas of analysis outlined above. These demographic group responses were different from the "expected" responses and are marked with an 'X'. Due to space limitations, the following subsections highlight only the most significant results from surveys, and the five areas outlined above are collapsed into Preflight, In-flight, and Mobile Device Usage discussions. The more detailed statistical results from the surveys are not included here, but will be available once the final project report is released this summer.

Table 2. Summary of Survey Findings

Pilot Categories	Five Areas of Analysis				
	Pre-flight Wx Info	**In-flight Wx Info**	**Receipt of In-flight Wx**	**Delivery of In-flight Wx**	**Use of Mobile Devices**
Pilot Certificates					
Private	X	X	X	X	
Commercial		X	X		
ATP*	X	X		X	
Pilot Age					
≥ 65			X	X	
46 - 64		X			
29 - 46			X	X	
17 - 28		X			
Pilot Region					
Central				X	
Great Lakes	X	X			
Southern		X			
Southwest			X		
Combination of Regions		X			

* ATP – Airline Transport Pilot

Preflight Weather Information Used. Regarding preflight weather sources, there were significant categorical differences between various groups of certified pilots and how they chose to gather meteorological data. Private Pilots utilized Internet-only weather sources less than expected, while ATP's utilized Internet-only sources more than expected. However, when looking just at the frequency of responses, there appears to be a large number of pilots overall who are utilizing Internet-based sources. With any new technology there is a need to ensure that adequate education and training is taking place so that pilots can use the technology safely and efficiently. This issue has strong links to the Embry-Riddle portion of the study, and there were a number of statements throughout the Pilot Comments section of the User Needs Survey supporting the need for improved education and training:

> "One of the biggest mistakes NEXGEN is making is not to include more pilot training on weather."

> "…all this technology is great but pilots with huge windshields have been flying into thunderstorms and low IFR and killing themselves for years. The problem is less about availability of Wx info, and more about poor Aeronautical Decision Making."

While these comments are not directed at any specific phase of flight, the points they are making about the need for improved education and training on weather certainly translates to the use of WTIC for smart aeronautical decision making during the in-flight phase.

In-flight Weather Information Used. There were significant categorical differences between various groups of certified pilots regarding the ways they chose to access weather data in-flight. Private Pilots' response rates indicated that they do not access weather information in-flight as much as expected. Why do Private Pilots underutilize weather in-flight? This could be due to the equipment installed in the aircraft they are flying. If they are flying a conventional GA aircraft, it may not have weather radar, XM™ or a handheld GPS unit due to the cost associated with procuring such equipment. To illustrate the problem, one participant in the User Needs Survey stated that "GA pilots can't always afford all the gizmos", and another stated, "Much of what I want is available now, but not with the equipment I have. The cost of installing new equipment (including reconfiguring the panel) would be prohibitive. The cost of data-link subscriptions would be annoying but feasible…" Survey analysis revealed that the "Baby Boomer" generation of pilots (46-64) used either XM™ or similar resource more frequently than expected, while "Generation Y" pilots (17-28) used these resources less than expected. How can we explain these results? The higher-than-expected use of XM™ or similar products by the Baby Boomer pilots could be a result of these pilots flying in larger aircraft that have more equipment, or perhaps that they have the money necessary to equip their aircraft with these weather resources. This assumes some overlap between the Baby Boomer age group and the ATP pilot category, and needs to be cross-checked to see if our explanation is reasonable. Conversely, Generation Y pilots' less-than-expected use of XM™ or similar resources is likely due to these pilots flying for companies that may not have as much access to weather resources in the cockpits as the Baby Boomer-generation pilots. This would also explain their higher-than-expected usage of FSS. Other factors could be the cost of installing such equipment into their aircraft, or even their lack of training on such equipment. Here are two comments from pilots on the User Needs Survey supporting the explanation presented here:

> "Train pilots to use the weather during flights."

> "I am an airline pilot, but I fly GA often in a conventional (non-glass) IFR PA28-200 with a Garmin 430. While the glass technology is good it is also too expensive for most GA pilots. Even if you can afford the glass, the Jeppesen data updates, terrain and chart updates are so expensive we can't afford to use them. At present these services alone would increase the operating cost of my aircraft cost as much as 25%. At a time when most pilots can barely afford to keep their aircraft due to the rising cost of 100LL, technology is great gee-whiz stuff, but it is an unnecessary option. I'll stick with my iPad for good pre-flight planning."

As discussed earlier, many of the qualitative comments received from the User Needs Survey indicated that WTIC is currently too expensive. These results are consistent with those from UAA regarding current users of weather information provided by the Automatic Dependent Surveillance-Broadcast (ADS-B) currently operating in Alaska. Many pilots forego the cost and purchase satellite weather information, as evidenced by comments such as, "I think the X-M weather feature on the 396 – 496 is the greatest boon to aviation safety since the parachute." The survey numbers also showed that an ideal situation would be a combination of WTIC and a resource that one can call up. Our qualitative survey comments are consistent with the results of a survey-based study conducted by Feinberg and Tauss (2002), which found that "…over 88% of the GA respondents were willing to pay under $5000 for the in-flight weather system.", while "…over 75% of respondents were unwilling to pay over $1000/year for weather graphics subscription service." Our preliminary results suggest that there is a desire to have weather readily available in the cockpit, but pilots are not willing to pay a lot of money for it.

Use of a Mobile Device to Access Weather Information. Regarding the use of a mobile device or cell phone in the cockpit to gather weather information, there were not any significant categorical differences within the demographic groups of pilot certificates and/or ratings, age, or region. Even though there were no statistically significant differences in categories, it was apparent that pilots of all ages, certificate levels and regions are using various mobile devices in the cockpit. Companies such as Pilot My-Cast state that pilots are telling them that they have used the pre-flight weather products on their cell phones or other mobile devices while in-flight. Many of the 300-plus qualitative comments on the User Needs Survey agree with what these companies are saying, such as, "I expect to have in-cockpit WX display as map overlay via smart phone available in 2011," "OUR GPS has weather now. We need a feed from government for all our devices. One antenna to receive all data without monthly fees. We want communication capability too. Text or email in the air." It appears that some pilots are, or would like to use, a mobile device to access in-flight weather information in-flight.

3. WTIC CONCEPT OF OPERATIONS (CONOPS)

In contrast to the UND approach to surveying GA pilots on WTIC *service preferences*, the UAA team focused more on WTIC *product types*. Knowledge of pilot preferences for specific types of aviation weather products is crucial to develop a CONOPS that contains guidance on types of products that should be delivered to the cockpit and how they should be delivered. Because the pilots' use of weather depends on the usefulness of the weather information and how it is presented in the cockpit, the CONOPS development involved a tremendous amount of discussion with GA pilots on weather products and what weather information they consider to be useful. As pilots became more aware of the possible use of WTIC, a survey conducted by the Aircraft Owners and Pilots Association (AOPA) in 2000 laid the groundwork for the selection of data products that best serve aviation in-flight activities where weather is a key decision aid. These results served as an early benchmark survey taken in response to the new innovations in earlier WTIC-like applications that began emerging on the market in the last 10 years. The AOPA survey preferences in priority order are summarized below:

1. Significant Meteorological Information (SIGMETs) and Airmen's Meteorological Information (AIRMETs)
2. Weather Radar Maps
3. Pilot Reports (PIREPs)
4. Nearby Traffic
5. Lightning
6. Ceiling & Visibility Graphic
7. Icing Maps
8. Meteorological Report (METAR)/Terminal Aerodrome Forecast (TAF)
9. Notices to Airmen (NOTAMs)

The UAA survey goal is to identify those *weather products* that GA pilots would find most useful and useable if displayed in the cockpit. This survey is unique in that it polled 483 pilots who are already receiving WTIC via an ADS-B data-link in a program known as Alaska Capstone (for more information, see http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/surveillance_broadcast/wsa/). Alaska does not have services such as WSI or XM radio weather available for data-link, so this survey dealt with pilots looking only at ADS-B available products produced by the National Weather Service and sent to the cockpit. This survey is essential to the development of a WTIC CONOPS because it shows a distribution of products that are determined useful and usable. The survey asked the pilots to rate a list of products that could be data-linked to the cockpit in order of importance on a scale of 1-10, with '1' being most desirable and '10' being least desirable. Shown below is the prioritized list of products from the survey:

1. NEXRAD
2. METAR (primary concern ceiling and visibility)
3. TAF (plain language or graphical)
4. Icing
5. Turbulence
6. PIREPs
7. Weather Camera Images
8. Winds and Temperatures
9. Other products such as volcanic ash, river forecasts and river tide tables

A comparison of this list with that from the AOPA survey reveals some similarities and differences. NEXRAD, METARs, TAFs, Icing, and PIREPs are common to both lists. The Alaska list includes Turbulence products while the AOPA list includes SIGMETs and AIRMETs; there are overlaps but the two product types are not identical (similar to graphical TAF versus Ceiling and Visibility graphics). Several of the differences between the two lists can be explained. First, the top three products on the Alaska list match those already being received by the ADS-B pilots, so it should not be surprising that this group would pick these three as their top choices. Second, the appearance of Weather Camera Photos as a choice is likely due to the popularity of FAA Web cameras at many locations in the state (see http://akweathercams.faa.gov/). The notable lack of convective weather products (e.g., lightning) on the Alaska list is likely a reflection of the relative occurrence frequency of thunderstorms there compared to other aviation weather hazards. Pilots considered the METAR beneficial and it was read by most pilots, while the TAF format was not easily interpreted by many pilots who have depended on telephone-based weather briefings. It should be noted that some pilots did not know how to read the current TAF format while a smaller number had difficulty with the METAR as well. There was no attempt made to quantify the number of pilots or percentages who could not read or understand the METAR or TAF delivered. As in the UND Survey, these survey responses indicate the need for increased pilot education and training on use of WTIC products.

4. PILOT EDUCATION AND TRAINING ON USE OF WTIC PRODUCTS

We determined that WTIC education and training must be approached from the point of view of required pilot knowledge. The team developed three main "domains" of aviation meteorological knowledge:

1. *Weather phenomenology* (the extent to which GA pilots should be educated on weather phenomena in general, and hazards in particular, to make best use of WTIC)
2. *Weather hazard products* (the products on which GA pilots should be educated, and which of these are most appropriate for in-cockpit usage as the technology advances)
3. *Weather hazard product sources* (not the same as '2' since the sources can present different versions of a product and there is no guarantee that a pilot who "self-briefs" from the Internet has the same level of preparedness to deal with weather encounters enroute as one who gets a pre-flight brief from a traditional source such as FSS).

Figure 1 shows a conceptual diagram that the team is presently using as a means to analyze these domains in more detail.

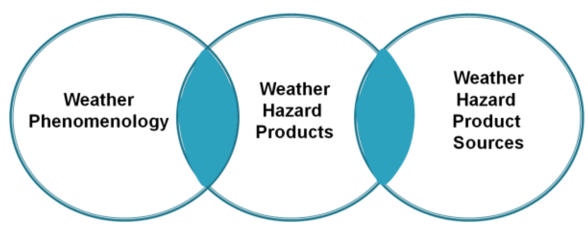

Figure 1. Domains of aviation meteorological knowledge.

Figure 1 essentially displays three distinct, but overlapping areas of pilot weather knowledge: 1) meteorological theory and knowledge of weather phenomena; 2) products developed for analysis and prediction of aviation weather hazards; and 3) sources of aviation weather hazard products. Examples of "Weather Phenomenology" include cloud/precipitation formation processes and types, characteristics of fronts, cyclones and anticyclones, and knowledge of the polar and subtropical jet streams. In this category, we were initially concerned only with the phenomenon and not its effects on flight. However, the team is considering creating either a separate domain for “Weather Effects on Flight” or adding it to the first domain. “Weather Hazard Products” include text-based and graphical products generated by FAA-approved sources which are disseminated and available to airmen to use for flight planning. Examples of these include METARs, TAFs, Surface Analysis and Weather Depiction chart, Winds Aloft and upper-air isobaric analyses, Radar Summaries, AIRMETs, SIGMETs, Area Forecasts, and Low/Med/High Significant Weather prognostic charts. “Weather Hazard Product Sources” refers specifically to the classification of official and supplemental product sources, highlighted in Chapters 1 and 2 of Advisory Circular 0045-G (FAA, 2010). The third domain category becomes important when discussing WTIC product sources and issues associated with standardization of products such as “graphical METARs” and radar displays. Our research indicates that formal guidance in this third critical area is thin compared to the first two. In Figure 1, the overlaps (shown by shading) between the “Phenomenology” and “Products” domains, and between the “Products” and “Product Sources” domains imply that knowledge must carry over from one domain into the next in order for WTIC products to be used safely and effectively during flight.

Our preliminary approach is to employ the conceptual model in Figure 1 to analyze FAA weather guidance and test questions to determine: 1) the distribution of required pilot weather knowledge among the three domains; and 2) the required level of cognition from pilot weather test questions. Our results are incomplete at present, but previous studies in this area have revealed some disturbing information about required pilot weather knowledge. A 1994 National Research Council report (NRC, 1994) found a poor connection between weather phenomenology discussed in Advisory Circular AC 00-6A (FAA and NWS, 1975) and the hazards products described in then AC 00-45C (FAA, 1985). Additionally, the majority of the weather test questions were found to be at the “rote-memorization” level of cognition, the lowest of the four domains used by the FAA (see FAA, 2008, Figure 2-10 for definitions of the four levels of cognition). Although AC 00-45 has been updated several times in the last 15 years, AC 00-6A is still in print and is the current publication available for pilot weather education, a 35-year difference which strongly suggests that the “disconnect” observed in the NRC report has either remained the same or gotten worse. Regarding current pilot weather test questions, a recent study by Wiegmann et al. (2008) found that the majority of weather-related questions available for the private-pilot written exam are at the rote-memorization level with no scenario-based questions, even though the scenario-based technique is used in other parts of the exam relating to weight and balance and cross-country planning. Both NRC (1994) and NTSB (2005) also found that it is possible to answer all aviation weather questions incorrectly on a written airman knowledge test but still pass it. Further, the NTSB (2005) noted that during the required biennial flight review (BFR), “the instructor giving the flight review is free to determine the content; therefore, the BFR may or may not include a demonstration of the weather knowledge and instrument flight skills required for initial certification.” (p. 9). Burian and Feldman (2009) stated that instructors typically spend only 10 to 12 hours on general weather education. Therefore, it is possible that after becoming certified, a pilot may not be required to demonstrate knowledge on some aviation-specific weather information products again.

When we progress to the “Hazards Product Sources” domain of Figure 1 (the one most relevant to WTIC), we find that AC 00-63 (FAA, 2004) provides some limited guidance on data-link products (including weather) and their proper usage during flight. However, it is our assertion that the conceptual “disconnect” between the guidance for “Weather Phenomenology” and “Weather Hazard Products” presumably translates into a poor understanding of employing WTIC products correctly and safely in-flight, despite the warnings about inappropriate use of data-link weather products for tactical avoidance of severe weather contained in official guidance.

The literature-based and anecdotal evidence presented above strongly suggests that there is much-needed improvement in the official guidance used for pilot weather education and training, and a better connectivity between the three knowledge domains in Figure 1. As this investigation continues, the research team has developed a methodology for addressing pilot training and evaluation criteria. We decided to approach this goal by concentrating on a specific WTIC product (NEXRAD) and weather type (convective). This decision was based on the previous education and training research discussed above and the results of the UND and UAA user surveys discussed earlier. Roberts and Lanicci (2011) are developing and preparing to test an education and training module on the proper interpretation and usage of NEXRAD-based products in the cockpit, with specific application to convective weather using a scenario-based approach. Convective weather has a significant impact on all parts of aviation, and is especially mission-limiting over Florida during the warm season.

The protocol being developed by Roberts and Lanicci will involve student pilots and flight instructors from Embry-Riddle’s Daytona Beach, Florida campus. The instructional sequence will have three parts: 1) a pre-test on radar basics and products; 2) a formal education and training seminar; and 3) post testing of seminar participants to assess their learning of the material. To provide a baseline for the data analysis, a control group will be given the same tests but will not receive the NEXRAD seminar as a formal part of the experiment. The inclusion of the control group is intended to compare performance on the pre- and post-tests with those of the experimental group to determine the degree to which learning took place and decision-making behaviors may or may not have been altered as a result of the seminar.

5. CONCLUSIONS

At this stage of the project, there are some promising initial results from the three segments that form a strong foundation for the project's completion later this year.

From the UND User Needs Segment, preliminary results reveal that GA pilots across all demographic groups are using a variety of methods to access weather information during preflight planning, including on-line sources. A number of pilots responding to the User Needs Survey commented on the need for increased pilot education and training on the use of weather products. As WTIC technology advances, this will become crucial, especially as a number of pilots surveyed are interested in using mobile devices to obtain their weather information. The survey results also illustrated that many pilots do not have adequate access to WTIC due to the expense involved. Many pilots prefer to have a combination of WTIC and a resource that they can call up.

As the project moves towards completion, the UND group will be using pilot survey inputs in developing a User Information Needs Statement. The statement will be analyzed with industry stakeholder support, and the statement will be revised to reflect all stakeholder concerns. The result will be aligned closely with identified industry needs, user feedback, and other CGAR school research data. The information will be keyed to an index, tracking user comments and feedback, so subsequent rulemaking, policy, or guidance research will have reliable data upon which to base decisions.

To this point, the CONOPS being developed by the UAA group has involved a literature search on cockpit weather delivery and a survey of nearly 500 GA pilots who are receiving weather products through the ADS-B system. The survey intended to find out what types of weather products the pilots want in-flight in addition to NEXRAD, METARs, and TAFs that they already receive through ADS-B. Not surprisingly, the survey results showed that NEXRAD, METARs, and TAFs are the most popular products, but a number of flight-hazard products are also desired by this user group. The survey results indicate a preference for "useable" products that do not interfere with pilot workload. The UAA team intends to develop the WTIC CONOPS further through a scenario-based approach. The flight scenarios will provide examples of different situations and examine tactical and strategic decisions using weather tools in the cockpit.

The third segment of the study intends to develop a set of recommendations for guidance regarding GA pilot education and training on WTIC products. This effort, led by Embry-Riddle, has defined three "domains" of aviation meteorological knowledge: 1) basic meteorological knowledge (to include effects of weather on an airplane's performance); 2) knowledge of aviation meteorological products (especially those related to flight hazards); and 3) knowledge of aviation meteorological product sources. The rationale for this classification is to determine the depth of knowledge required by pilots, air traffic controllers/managers, aircraft dispatchers, and others operating in the NAS, all of whom represent a very specialized community of meteorological information users. The FAA has guidance about types of aviation meteorological knowledge required of these groups, and part of this segment seeks to examine the types of knowledge and comprehension level being asked on general-knowledge exams. This investigation will define the present-day education and training environment, and allow the research team to recommend changes to existing policies regarding knowledge testing and the updating of guidance such as Advisory Circulars on meteorology and meteorological products and services. To test this approach, the research team has developed an education and training module on the use of NEXRAD in the cockpit for convective weather situations, which will be tested on a sample of GA pilots.

The linkage among these three segments can be summarized as follows. The User Needs Segment captures the WTIC usage requirements of a representative sample of the U.S. GA community. The CONOPS addresses the types of WTIC products and the ways in which they may be employed in different scenarios. The education and training segment will describe the state of today's learning environment regarding WTIC products, and make recommendations on guidance for education and training. Taken together, the three efforts will ensure that user needs are addressed and that they will also have the opportunity to learn the correct and safest ways to employ WTIC technology. The safe employment of WTIC will be a key part of the successful transition of the NAS to the NextGen operating environment.

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