Weather Technology in the Cockpit

Analysis of Pilot Decision Making

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Abstract **- Weather is a very important concern for pilots, and even more so for pilots of small, general aviation aircraft as they fly at lower altitudes with less weather managing capabilities. Over the last decade, many emerging technologies have allowed the general public to have real-time weather data on their portable devices. Currently there is little to no guidance for design and usage of these devices. The study analyzed records from the Aviation Safety Reporting System and the National Transportation Safety Board from 2003 to 2013. All weather related incidents and accidents were categorized for both weather factors and presence of weather technologies. In addition to the trend of increasing use of all types of weather technology, more complicated relationships between the use of weather information and outcome of incidents have emerged. Commonly found weather accident patterns were discovered and have been used elsewhere to develop and test the effectiveness of weather training tools. This study will allow for the creation of a custom database that will allow government agencies and other researchers to make informed policy decisions regarding the continued use of these new weather technologies in cockpits.**

Keywords - weather technology, database, pilot decision making.

I. INTRODUCTION

Many new technologies have become popular over the last 10 years that have changed the way weather data is received. It is no longer required to have a radio or television to receive a weather report that is 15 minutes old. The internet has allowed much faster information and smart phones and tablets have allowed the information to become portable. Much of the weather data available, however, is intended for the general public and is not intended for use in aviation. A report of the weather at sea level from five minutes ago is for someone deciding whether he needs an umbrella for the day, but it is entirely inappropriate for a pilot deciding if he needs to change altitude in order to avoid dangerous weather systems.

The purpose of this project was to analyze how pilots use the new weather technologies to aid them in making decisions. Some systems that were discovered are intended for use in aviation while others are not.

The first step in the analysis was to obtain all weather related incident and accident reports during the years of 2003-2013, inclusive. Two different record sources were used: The National Travel Safety Board (NTSB) [1] and the Aviation Safety Reporting System (ASRS) [2]. This yielded approximately 3000 records. The events were categorized and loaded into a custom database for weather related aviation events. Duplicates were removed and then a more in-depth analysis was developed.

II. SUMMARY OF RECENT RESEARCH

In 2002, Feinberg and Tauss (2002) conducted a study sponsored by NASA [3]. The researchers focused on 15 companies that were in the process of developing systems to provide in-flight weather information to pilots. Data from a market survey was analyzed to determine system availability, cost to the end user, system constraints, and technical specifications. The companies proposed to provide services through a variety of means, including the ground-based cellular network, space-based platforms (low earth orbit satellites, geostationary satellites, and Inmarsat) and VHF networks (ARINC/ACARS, VHF GMSK ground-based digital broadcast, and VHF VDL Mode 2 ground-based broadcast). Initial costs ranged from $2,000 to $50,000 depending on receiver/display, with recurring monthly subscription costs ranging between $9.95 and $1300, some with additional per minute or per access fees. The target market for these companies ranged from low-end to high-end GA aircraft, with the more costly systems targeted toward higher end business jets. The researchers concluded that once a well-defined standardized set of GA graphical weather products is validated based on decisions affected, when they are needed, and their characteristics, then various data link solutions can be properly assessed to determine which architecture can best satisfy the users' graphical weather needs [3].

In 2002, one study described how aviation operator communities gather and use weather information and make weather-related decisions [4]. The authors used a 136-question survey; 85% of the respondents were GA pilots. Many of the questions focused on use of weather information prior to flight; however, the most highly-rated weather information sources for in-flight use are those associated with hazards. These hazards include lightning, SIGMETs, low-level wind shear and icing. PIREPs were also rated as important weather information to have in-flight. Cost of service was also explored in that over 88% of the respondents were willing to pay under $5000 for an in-flight weather information system.

In 2006, one study provided a summary of progress made in the dissemination of weather information in flight [5]. Much development has occurred since these studies were published. Pilots can opt to receive text and graphical weather products via VHF and satellite-based delivery systems. These products may be displayed on panel-mounted or portable display units. Software designers seek to improve their ability to display the various weather products through continual updates. A 2011 study of 1,339 pilots provides some insight into how GA pilots obtain in-flight weather information, how they prefer to receive weather information in the cockpit, and what level of automation they would prefer for the delivery of the data [6]. Most of the pilots who responded preferred that weather information be visually integrated on a multi-function display (MFD), while others responded that they would like it provided on an additional display. The vast majority of the respondents also indicated that they prefer a visual display of weather information over traditional voice transmission via VHF communication radios [6].

Over the years, studies have investigated the weather-related decision making of GA pilots [7] [8] [9] [10] [11]. A few of these studies identified that the use of weather technology can increase situational awareness [10] [11] [12]. However, some of the studies warned of the potential negative implications of this advanced technology [12] [13] [14] [15]. Further studies have addressed perceived training deficiencies [16] [17] [18] [19] [20].

III. PERCEIVED BENEFITS AND CONCERNS

In 1997, one study documented the results of a field study in which 60 GA pilots received individual training on the capabilities and use of data link services [15]. These services included Traffic Information Service (TIS), Text Weather Service (TWS), and Graphical Weather Service (GWS). The pilots subsequently used these services during a predefined flight. When questioned after the flight, over 90% of the pilots who participated agreed that the package of services enhanced the utility and safety of GA operations. Their answers also revealed that the new services brought up new concerns. Their concerns included the effects of the age of GWS data, the effects of compression-induced distortion in the GWS maps, and whether the "head-down time demands of the system are acceptable" [15].

In another example, one study documented the results of a field study conducted in the Bethel, AK, area [12]. Here the information was collected by interviewing 41 pilots regarding their use of Automatic Dependent Surveillance-Broadcast (ADS-B) displays in day-to-day flight operations. Analysis of the pilots' responses indicated that they realized a substantial number of safety benefits by utilizing the ADS-B displays. These included increased navigational awareness, the ability to be visible if communications are lost, increased ability to avoid traffic, increased ability to maintain aircraft separation during holding procedures, and an increased ability to recognize waypoint entry errors. The pilots in this study also had concerns regarding the potential negative safety implications of using the ADS-B displays. Their concerns included the degradation of conventional flying skills, increased head-down time, increased risk taking, and database inaccuracies [2].

These benefits and concerns have appeared in other research projects. One study conducted analyzed the performance of 30 pilots flying a simulated VFR cross-country flight into deteriorating weather [13]. The pilots utilized one of three types of display, either a standard instrument display, a synthetic vision system (SVS) display depicting terrain or a highway in the sky (HITS), or the same SVS HITS display with a moving map depicting weather. The results showed that all but one of the pilots with the standard instrumentation avoided IMC. Sixty percent of pilots utilizing either of the SVS displays failed to observe deteriorating weather conditions outside the cockpit and continued the flight in zero visibility. This failure was a result of "a dominance of head-down scanning" [13]. The researchers also noted that the results could demonstrate the effectiveness of SVS displays in preventing loss of control GA accidents that occur due to low visibility conditions, as all 12 of the non-instrument-rated pilots utilizing a SVS display landed safely at their destination [13].

Clearly these weather services are an integral part of GA and are used on a wide array of devices. However, the lack of industry-wide standards for the presentation of cockpit weather information creates human factors concerns that must be addressed to ensure that weather information is provided to pilots in a manner that minimizes workload, clutter, and confusion, while providing as much relevant weather information as possible. A 2012 analysis of the performance of 25 instrumented-rated GA pilots determined that variations in colors and symbols create very different images that can affect interpretation and information retrieval [14]. Researchers also suggested that variations in colors and weather symbology can have an effect on pilot behavior and decision making [10].

If pilots are to receive any benefit from the weather technology available, they must be able to effectively utilize the specific weather tools that are present in their cockpit. One report noted that while the availability of updated NEXRAD data in flight can improve a pilot's situational awareness, the user needs to be aware of its limitations [11]. In response to two accidents in which pilots may have attempted to use in-flight NEXRAD images to tactically circumnavigate severe weather, the National Transportation Safety Board issued its In-Cockpit NEXRAD Mosaic Imagery safety alert [12]. The image age depicted on weather displays available in the cockpit do not necessarily reflect the actual age of the radar information being depicted. Furthermore, when encountering fast-moving weather systems, even a small lag can have a detrimental effect on flight safety [12].

IV. CATEGORIZATION OF EVENT

All weather-related incidents recorded in either the National Travel Safety Board database [1] or the Aviation Safety Reporting System [2] that occurred between January 1, 2008 and December 31, 2013. The Aviation Safety Reporting System records included went back to January 1, 2003.

Using the included biographical information with the report, each report's narrative was read in order to determine the primary weather factor that caused the accident or incident. Each event was also categorized according to any weather technology the pilot used in order to aid in his decision. There appears to be no record of this type of analysis having ever been done prior to ours. As such, the researchers had to rely heavily on the narrative of each event.

The primary weather condition that lead to the problematic situation needed to be categorized in order to allow a computer to follow trends in the data. Ten conditions were decided on in order to help. Any situation that resulted in an attempted mountain landing was listed as 'Mountain Landing'. A situation that resulted in a pilot flying into conditions that he didn't feel properly trained or certified to be in was called 'Underqualified'. If a pilot who had previously filed a Visual Flight Rules (VFR) plan needed to change to Instrument Meteorological Conditions (IMC) but was properly trained and certified to do so, the event was listed 'VFR to IMC'. Ice buildup on any control surfaces, landing gear, wings or other structure on the outside of the aircraft was categorized 'Plane Ice'. Ice buildup on internal engine components was called 'Carb Ice'. Any event that had wind as the primary concern including crosswinds, was listed as 'Windshear'. If a pilot found himself in a situation that he wasn't trained for or hadn't received a proper briefing, then the event was categorized as 'Unprepared'. Fog and quickly changing weather were called 'Fog' and 'Rapid Weather', respectively. If a single weather event could not be isolated, then 'Multiple' was used.

The weather technology inventoried were ground proximity warning system (GPWS), automated surface observing system (ASOS), functional movement systems (FMS), automatic terminal information system (ATIS), and personal digital assistant (PDA). Proprietary systems looked at were Strikefinder Nexar WX and Navaids. On board radar and full device systems were also categorized. If weather technology was present but the narrative did not specify the type, then that was also noted.

The primary weather condition and any present weather technologies were attached to each record. The records from each database were put into a common format in preparation for combining the databases.

If as an industry we are reduce the general aviation accident rate then better training is required to support pilot education needs. However, as a review of accident summaries and close calls, it is not enough to simply discuss weather conditions that should be avoided. A more meaningful approach and one that is based on sound data and subsequent analysis would be the development of training modules that illustrate the insidious nature of the most common weather related causes extracted from the data. When performed, we discovered that there were eight primary themes that emerged. Below we have listed these themes and the typical type of pilot represent in the data.

- Decision Making (VFR cross-country – experienced pilot)
- Convective weather avoidance (IFR cross-country)
- Using weather sources not intended for aviation (VFR local – student pilot)
- Risk taking (VFR cross-country – inexperienced pilot)
- Wind Conditions (VFR cross-country – pilot recently transitioned to new aircraft)
- Icing Conditions (IFR cross-country – unplanned flight into icing conditions)
- Turbulence Encounter (VFR cross-country – clear air turbulence)
- Distraction using cockpit technology (VFR local flight)

From this list we were able to assist other researchers in the PEGASAS consortium with the creation of weather events that can be tested in a flight simulator. In that other study, this information was used to build these scenarios and evaluate subjects, some of which received specific training and others did not as to their weather decision making skills.

V. CUSTOM DATABASE CREATION

The record set for each database and year were in Microsoft Excel spreadsheet files. This format was convenient because it did not require any technical knowledge to manipulate and view the data; however, analysis was extremely difficult and time consuming. Finding trends across multiple years was not possible.

The data was loaded into a structured query language (SQL) database. MySQL was chosen as the database because it is open source and supports multiple host systems. This was a very important consideration since the data will soon be moved from its Windows Server 2012 R2 host to a Linux, Apache, MySQL, PHP (LAMP) host.

In order to move from Microsoft's proprietary format to something that could be loaded into an open source database, an intermediate format had to be used. Comma separated values (CSV) fit this bill perfectly. Rather than loading old data into the new database, the record sets were again downloaded from their origin sources. The technique varied slightly based on the origin database.

The Aviation Safety Reporting System record numbers were loaded into the agencies user portal [2]. The results were saved as a comma separated value file. Using MySQL import commands, the list of record numbers, weather factors, and weather technology was combined with the full ASRS record including biographical details and pilot narratives.

The National Travel Safety Board records proved to be more difficult to merge. In addition to accident numbers, the agency also assigns an event identifier to each accident. While neither of these designations is arbitrary, there is no way to link one identifier to the other directly. After receiving permission from the National Travel Safety Board database administrator, the NTSB website [1] was scraped in order to create a comprehensive list of all report numbers and event identifiers. Once the link between the two was created, all the records could be updated directly from the source and combined.

In order to allow the database to be used by nontechnical users, a web front end was created. The original website was created with hypertext preprocessor (PHP) for Microsoft's Internet Information Services (IIS). PHP allowed for the webpages to be easily, but dynamically, created with minimal performance degradation of the host machine. The web front end allowed easy sorting and searching of all loaded records. It also provides number of records for different cross-referenced categories. For example, one could see exactly how many accidents or incidents were recorded in 2009 from both databases that had any type of weather technology present which was classified as 'VFR to IMC'. The system generates the total reports as well as presenting a list where any individual record can be accessed.

Another advantage of the custom database with a web front end is that it allows an administrator, even a nontechnical one, to easily edit the records or reclassify them. Mistakes can be corrected in seconds and reports regenerated.

Below shows some functionality even at this early stage of the combined database development. For example, Figure 1 shows the entry point for database search query.

Figure 1 - Entry point for search query

Once ready to search, you can select the search criteria from the categories that were used in the re-work of the events (see Figure 2). To increase the utility of the search effort, you can select multiple criteria. All of them are not included yet as this is still an alpha version that is being tested. New design capabilities are still being discovered.

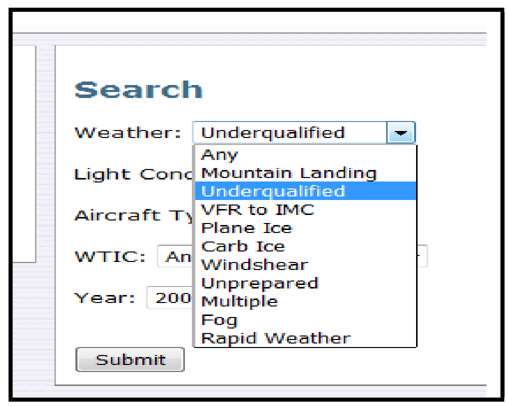


Figure 2 - Search query

Once the search criteria is selected and submitted, any records that meet the chosen selections will be presented in the presentation form below. Once here you can then choose the record you wish to view See Figure 3.

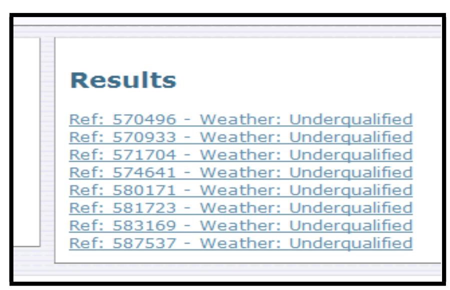
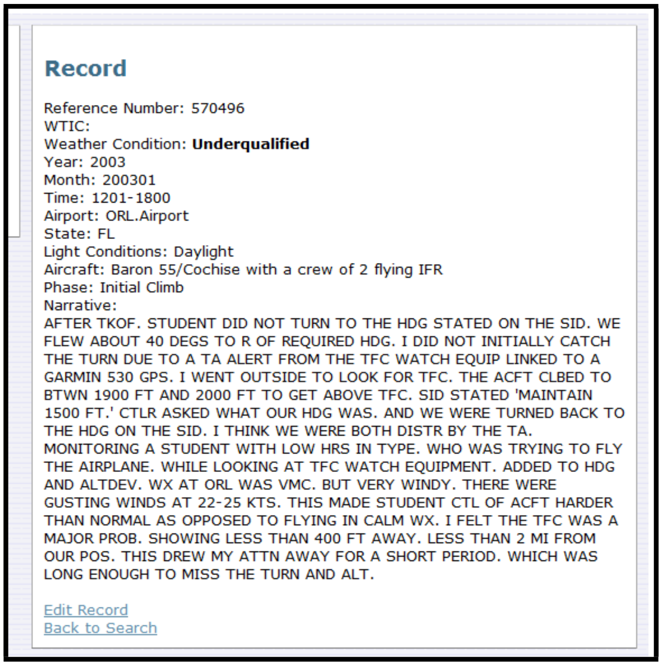


Figure 3 Search query results

From here, a specific accident/incident record can be selected for a more specific review of the event (See Figure 4).



Record

Reference Number: 570496
WTIC:
Weather Condition: **Underqualified**
Year: 2003
Month: 200301
Time: 1201-1800
Airport: ORL.Airport
State: FL
Light Conditions: Daylight
Aircraft: Baron 55/Cochise with a crew of 2 flying IFR
Phase: Initial Climb
Narrative:
AFTER TKOF. STUDENT DID NOT TURN TO THE HDG STATED ON THE SID. WE FLEW ABOUT 40 DEGS TO R OF REQUIRED HDG. I DID NOT INITIALLY CATCH THE TURN DUE TO A TA ALERT FROM THE TFC WATCH EQUIP LINKED TO A GARMIN 530 GPS. I WENT OUTSIDE TO LOOK FOR TFC. THE ACFT CLBED TO BTWN 1900 FT AND 2000 FT TO GET ABOVE TFC. SID STATED 'MAINTAIN 1500 FT.' CTLR ASKED WHAT OUR HDG WAS. AND WE WERE TURNED BACK TO THE HDG ON THE SID. I THINK WE WERE BOTH DISTR BY THE TA. MONITORING A STUDENT WITH LOW HRS IN TYPE. WHO WAS TRYING TO FLY THE AIRPLANE. WHILE LOOKING AT TFC WATCH EQUIPMENT. ADDED TO HDG AND ALTDEV. WX AT ORL WAS VMC. BUT VERY WINDY. THERE WERE GUSTING WINDS AT 22-25 KTS. THIS MADE STUDENT CTL OF ACFT HARDER THAN NORMAL AS OPPOSED TO FLYING IN CALM WX. I FELT THE TFC WAS A MAJOR PROB. SHOWING LESS THAN 400 FT AWAY. LESS THAN 2 MI FROM OUR POS. THIS DREW MY ATTN AWAY FOR A SHORT PERIOD. WHICH WAS LONG ENOUGH TO MISS THE TURN AND ALT.

Edit Record
Back to Search

Figure 4 – Specific accident/incident event

These are examples of a prototype database and significant changes in the design and functionality are still underway. However, we have already been able to discern numerous points of interest in the results obtained thus far. Further development is expected to yield even greater results.

VI. Results

Some of the results were well in line with the intuition which had long been the only rules governing the use of weather technology: appropriate weather technology helped pilots make better, more informed decisions that lead to an increase in overall safety. However, there were two types of cases that went against this idea.

A. Lowering of Personal Minimums

Pilots have a certain severity of weather conditions in which they are comfortable flying. Often, this level is below where the pilot is legally certified to fly e.g. an instrument rated pilot will fly around a storm in order to continue using visual flight rules. Analysis of records, especially those classified as either Underqualified or Unprepared, showed that some pilots will lower their personal minimum when given more weather information. This sometimes led to the pilot making a decision differently than they would have in the absence of such information. When current information showed weather ahead wasn't as bad as the pilot predicted it would be, be would choose to continue on his planned path rather than make the more conservative decision, and the one he would have made with the weather information, to avoid the weather. Pilots would sometimes find themselves in situation that they or their aircraft were unable to handle after they lowered their personal minimums.

B. Technology Inappropriate for Use in Aviation

Pilots who found themselves in reportable events would sometimes use weather technology that was not intended for use in aviation. Sometimes this was simply checking the weather on a smartphone app prior to departure. The outdated information for conditions on the ground did not give an accurate picture of what the pilot should expect at altitude. Some accident reports showed tablet or smart phone devices found in the cockpit that had accessed weather data during the flight. The problems of using outdated information are further compounded when severe weather is present. These two types of cases did not occur in isolation. A combination of the two consistently ended negatively.

VII. Conclusions

After looking at weather related events for the previous ten years and from multiple databases, the trend is that increased access to weather information and weather technology help pilots make better, safer decisions. Pilots need to be made aware, however, of the dangers in lowering their personal minimums and especially of using weather information not approved for use in aviation.

To help facilitate future pro-active analysis of weather related accident trends, here we describe the creation of new, combined, and custom databases which allows more accurate analysis of large amounts of data. However, this tool if fully developed will not only allow researchers to access this large pool of data but to examine it from different perspectives and categories yielding a richer picture and understanding of what this data can tell us to inform policy decision makers and educators alike. The more accessible the data is to nontechnical users, the more useful it is. Plots and other customizable graphs would largely benefit both pilots and policy makers as well.

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