Use of Tablet Computers as Electronic Flight Bags in General Aviation

Marty Ohme

Embry-Riddle Aeronautical University

Author Note

Marty Ohme, Embry-Riddle Aeronautical University, Worldwide

Marty Ohme is now the writer of SaferAviator, an aviation safety blog available at www.SaferAviator.net.

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Correspondance concerning this work should be addressed to Marty Ohme via e-mail at marty.ohme@SaferAviator.net.

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Abstract

Over the last 20 years, Electronic Flight Bags (EFBs) have developed from flight publication storage devices hosted on modified laptop computers into fully interactive near-avionics-quality navigation equipment based on consumer-grade tablet computers. Broadly speaking, the Code of Federal Regulation (CFR) 14 regulates the use of this type of equipment for commercial airlines, commuter operations, and fractional ownership operators, but not for General Aviation (GA). Due, in part, to this lack of governance, little is known about EFB use in GA. Using an internet-based survey, this study found strong correlation between tablet EFB use and flight type, e.g. Visual Flight Rules, multi-leg Instrument Flight Rules, among GA pilots. Further, survey data reveal which EFB capabilities are desired by GA pilots and their perceptions of EFB usability compared to paper flight publications. Analysis of these results led to recommendations for GA stakeholders, including the National Transportation Safety Board and tablet computer manufacturers.

Keywords: tablet computer, electronic flight bag, EFB, general aviation

Use of Tablet Computers as Electronic Flight Bags in General Aviation

Tablet computers have revolutionized many aspects of transportation. For example, Tablet by PeopleNet provides Global Positioning System (GPS), delivery tracking, and text communication to truck drivers (Nicolai, 2011). MobileDemand's xTablets can be used across transportation modes for rolling stock tracking, inventory management, and GPS location (MobileDemand, 2012). In aviation, tablets are available for parts tracking, safety compliance, and maintenance management (MobileDemand, 2012). Consumer grade tablet computers have also found their way into the cockpit.

In December of 2011, American Airlines (AA) pilots stopped carrying their flight bags filled with paper charts, paper instrument approach plates, and other paper-based (i.e., printed) flight publications (O'Grady, 2011). Instead of thirty-five pounds of paper, the Federal Aviation Administration (FAA) approved American Airlines to use the 1.5-pound Apple iPad as an Electronic Flight Bag (EFB) (O'Grady, 2011). This change is expected to save AA $1.2 million a year in fuel costs due to the weight reduction of the pilot's flight gear (O'Grady, 2011).

AA is the first airline with approval to use the iPad, but not the first operator to use an EFB. Pope reported (2001) fractional jet operator Flight Options was among the first to outfit their aircraft with EFBs through the use of a product made by Advanced Data Research (ADR) (2009). For the purposes of this paper, the definition of EFB found in FAA Advisory Circular 120-76B, *Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Devices*, (2012a) will be used:

> An electronic display system intended primarily for flight deck use that includes the hardware and software necessary to support an intended function. EFB devices can display

> a variety of aviation data or perform basic calculations (e.g., performance data, fuel calculations, etc.). In the past, some of these functions were traditionally accomplished using paper references or were based on data provided to the flightcrew by an airline's flight dispatch function. The scope of the EFB functionality may include various other hosted databases and applications . . . An EFB must be able to host Type A and/or Type B software applications. (p. 2)

ADR was the first company to offer a Commercial-Off-the-Shelf (COTS) EFB, called the FG-3500 (Fitzsimmons, 2002). As of Fitzsimmons 2002 work, their products were based on a Fujitsu P600 computer that was 9.6 x 6.3 x 1.1 inches in size, weighed 2.65 pounds, had an 8.4 inch 800 x 600 SVGA display, and cost about $4700 in 2013 dollars (Bureau of Labor Statistics, 2013a) for the base model. A decade later, the iPad had far more capability in a package 9.5 x 7.3 x 0.4 inches in size, weighs 1.45 pounds, has a 9.7 inch 2048 x 1536 Retina display, and cost $929 for the top of the line model. (Apple, 2013)

Both the ADR EFB and Apple's iPad are examples of tablet computers, which Wikipedia described in 2012 as:

> . . .a mobile computer, larger than a mobile phone or personal digital assistant, integrated into a flat touch screen and primarily operated by touching the screen rather than using a physical keyboard. It often uses an onscreen virtual keyboard, a passive stylus pen, or a digital pen.[1]

[1] While Wikipedia is a living document and constantly under revision, the 2012 definition is inclusive of both ADR EFBs and similar products of the past and current consumer tablet computers available as of this writing. Therefore, the above definition will be used for the purposes of this work.

In addition to the technology differences between Apple and ADR products, the iPad is designed for consumers while ADR's FG-3600 is modified for cockpit use, i.e. improved screen treatments, 70-degree viewing angle, night vision goggle compatibility, external CD-ROM, and keyboard (Fitzsimmons, 2002). Other consumer tablets running Google's Android operating system or Microsoft-provided Windows are available, but Apple (iOS) has as much as 70% of the tablet computer market (Gustin, 2012) and serves as good example of what 52.4 million US tablet owners are using (Aquino, 2013). Between the number of tablets owed, whether they be iPads or Androids or Windows-based, and the fact that the FAA is approving iPad EFBs for commercial use, it is not a great leap of logic to say that General Aviation (GA) pilots are currently using or may desire to use this technology.

Such a statement is bolstered by the 610 software applications (apps) listed by www.AviatorApps.com for Apple products, updated September 18, 2012. Additionally, www.incomediary.com rated ForeFlight, the developer of a flight planning and flight support app, among the Top 20 App Developers of 2011. Incomediary.com (2012) goes on to say that ForeFlight was the sixth top grossing iPad app that year.

Both the FAA and its parent organization, the Department of Transportation (DOT), have been aware of EFBs for some time and have taken steps to promote their safe use. For example, FAA Advisory Circular (AC) 120-76*, Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Devices*, was published in 2003. AC 91-78, *Use of Class 1 or Class 2 Electronic Flight Bag (EFB)*, was published in 2007. Additionally, DOT's John A. Volpe National Transportation Systems Center published Version 1 of *Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs)* in 2000. Under the current versions of the Aviation Circulars, EFBs are regulated carefully in the transport and passenger categories, but very little in GA.

The National Transportation Safety Board (NTSB) has also taken an interest in EFBs, in part, because of the July 1997, crash of a FedEx MD-11 in Newark, New Jersey. A Safety Recommendation in the Aircraft Accident Report (AAR) on that mishap resulted in the FAA's release of Information for Operators (InFO) 08031 (FAA, 2008), which discusses the use of Auxiliary Performance Computers (APCs) for the calculation of aircraft performance data.

The purpose of this study was to determine who among General Aviation pilots is or is not using Electronic Flight Bags, why they are or are not, and how those who make use of EFBs operate with them. In addition to collecting data to understand context, this study specifically describes the relationship between the use of EFBs by GA pilots and typical flight type. Further, information on EFB utility and usability was gathered and analyzed.

Review of Relevant Literature

Much of relevant literature reviewed by the researcher was produced by the United States government. The FAA produces regulatory material and the DOT Volpe Center publishes work on human factors issues. To provide context for regulatory and human factors issues, tablet computers will be discussed in general, followed by EFB capabilities advertised and promoted by industry and media.

Tablet Computers

General Aviation pilots who use tablet computers as Electronic Flight Bags are a subset of both the total tablet computer user population and the GA pilot population. comScore (as reported by New Media Trend Watch, 2013), research indicates the largest single group of tablet owners by age is 25 to 34 years old at 24.2%, but nearly 40% of users are 35 to 64 years of age. Again from comScore (as reported by New Media Trend Watch, 2013), over 38% of tablet computer owners have a household income of over $100,000. Most pilots fall in the middle of the upper age range above at 40 to 59 (Formichelli, 2008). Among pilots who are also aircraft owners, estimated annual income is $125,000 (Formichelli, 2008). When compared to the population of the United States (US), one sees both tablet users and private aircraft owners tend to be in their highest earning years and have above average income. US workers 35 to 64 have the highest incomes by age with an average over $75,000 per year (Vo, 2013).

Tablet-Based Electronic Flight Bag Capabilities and Benefits

Brown's 2010 description of how an iPad combined with ForeFlight would change the GA cockpit focused on the app ForeFlight and the in-flight weather and paper replacement it provided to Part 91 operators. Since then, Sporty's Pilot Shop (2013), an online aviation merchandise retailer, has introduced two generations of a product called Stratus™, specifically designed to work with Foreflight. Stratus™, Second Generation, combines a Wide Area Augmentation System (WAAS) capable GPS, terrain warning, Flight Information System Broadcast (FIS-B) receiver, traffic advisory, back-up attitude, and Wi-Fi capability to bring wireless position and weather data to ForeFlight in the cockpit (Sporty's, 2013). WingX Pro7 paired with iLevil AW provide the same and add synthetic vision and pitot-static inputs for about $500 more (hardware only) (Levil Technology Corp., 2012). To gain synthetic vision capability on the Garmin G500 costs about $5000 after spending near $21,000 for purchase and installation of the basic unit (Sarasota Avionics International, 2013). With the difference in cost, driven by regulation (McClellan, 2012), one can see why tablet-based EFBs would appeal to GA pilots.

The list of capabilities above does little explain the benefits provided by these products. Details of the above and other advantages follow.

WAAS capable GPS applies a ground-based correction signal to position data received from satellites to provide a highly accurate position to the unit. From an aviation perspective, this means a certified WAAS capable GPS is accurate enough to guide an aircraft with the same level of accuracy as a Category I Instrument Landing System approach down to weather minimums of a 200-foot ceiling and one-half mile visibility. It also means exact aircraft position or “own-ship” position can be displayed on the chart (ForeFlight, 2012). Combined with terrain data, this level of accuracy may also provide terrain warning via color highlighting on the two-dimensional charts to prevent controlled flight into terrain (CFIT) (ForeFlight, 2012).

Current airport and facility information for every airfield along the route is quickly available to iPad users through the ForeFlight airport/facility directory, which includes frequencies, runway information, and diagrams (ForeFlight, 2012). For Notices to Airmen (NOTAMs) and Temporary Flight Restriction (TFR) information, which are issued between publication updates or for temporary situations, the FAA Flight Information Services – Broadcast (FIS-B) (FAA, 2005) can be accessed with Stratus™ (Sporty’s, 2013) or iLevil (Levil Technology Corp., 2012) to ensure pilots have information to comply with the most current regulations and procedures. Additionally, FIS-B provides weather in the form of current conditions, forecasts, and weather RADAR images (FAA, 2005).

Both Stratus™, Second Generation, and iLevil provide an Attitude and Heading Reference System (AHRS). Stratus™, combined with Stratus Horizon, is able to show a basic attitude gyroscope with heading (Sporty’s, 2013). Taking this concept a step further by combining

WAAS capable GPS and terrain data with AHRS information, WingX Pro presents the pilot with a synthetic vision representation of what is in front of the aircraft (Levil Technology Corp., 2012). Arthur, Prinzel, Williams, and Kramer (2006) showed with a significant increase in situational awareness leading to fewer CFIT close calls in a study using the National Aeronautics and Space Administration's Mission Rehearsal Tool. Additionally, iLevil can be connected to the aircraft pitot-static system to include indicated airspeed and altitude in the display (Levil Technology Corp., 2012).

Weight savings leading to lower fuel consumption (and, therefore, cost) is one of benefits cited by American Airlines as they shift from paper flight publications to the iPad (O'Grady, 2011). Thirty-five pounds makes a much bigger difference proportionately to common general aviation aircraft than to a commercial airliner. A gallon of aviation gasoline weighs six pounds (WhatToFly.com, 2013). A Piper Cherokee 140 burns 5.9 gallons of fuel per hour (gph) at 55% power and 8.1 gph at 75% power (Plane and Pilot, 2006). Trading 35 pounds of paper for fuel by switching to a tablet computer EFB potentially gains somewhere between 40 minutes and an hour of flight time for a pilot in this aircraft. Alternatively, 35 pounds more cargo might be carried.

Increased fuel load or cargo are not the only benefits of reducing paper in aviation, general or commercial. Publication updates are handled automatically through data push capability from app publishers. For example, Jeppesen's Mobile Flight Deck provides subscription access to enroute and terminal charts (Jeppeson, n.d.).

Publications and flight plan data are stored in a solid state drive (SSD) within the tablet (Genesys, 2012). While there are risks to data, no power is required to maintain information in memory (Genesys, 2012). Particularly if there is no fire, data from a SSD might provide information to investigators of a GA plane crash. Additionally, software developers could introduce a recoding feature for use during flight. While not exactly the same as a flight data recorder, such functionality has the potential to provide much more to an investigator than paper publications.

Tablet computer based EFBs are also capable of improving pilot and aircraft records and compliance. For example, AvConnect from LisiSoft (2013) provides a pilot logbook function and aircraft maintenance tracking, including schedules and automatic downloading of service bulletins.

Without the need for special software or added hardware, a tablet computer can provide access to training materials more easily than desktop or laptop computers simply because of portability. The Aircraft Owners and Pilots Association's (n.d.) Air Safety Institute provides one example of web-enabled training through articles, courses, and video. A tablet owner has the ability to learn more about flying anywhere he or she has internet access.

Regulatory

Of great importance to the discussion is the lack of EFB regulation under Code of Federal Regulations 14 Part 91, General Operating and Flight Rules, with three exceptions. The first is the condition that the EFB not replace any required system or equipment (FAA, 2012a). The second is large transport category aircraft operated under Part 91Subpart F (FAA, 2012a). The third is Fractional Ownership Operations governed by Part 91 Subpart K (FAA, 2012a). General Aviation operations fall under Part 91 and, as such, use of EFBs is generally not regulated.

Knowledge of definitions and what impacts the EFB field is, nevertheless, important for understanding of the study.

Advisory Circular 120-76B (FAA, 2012a) provides much of the guidance for the use of EFBs, including the EFB definition presented earlier in this paper. AC 120-76B (FAA, 2012a) also defines three Classes of EFB hardware and three types of software. This study concentrates on equipment qualifying as Class 1 and Class 2 hardware, which is portable. Class 3 EFBs are installed and beyond the scope of this work. Type A and Type B software is intended to replace paper flight publications and Type C software carries out airborne functions, such as communication and navigation. Software and add-ons can make consumer table computers capable of Type A, Type B, and some Type C functionality, but most do not meet the necessary requirements for certification, including configuration control and rapid decompression testing. Of particular note, Advisory Circular 120-76B (FAA, 2012a) prohibits own-ship position display in flight on Class 1 and Class 2 EFBs.

For operators requiring authorization to use EFBs (e.g. Part 91K, Part 121, Part 135), FAA Order 8900.1 (2012b) thoroughly lays out the process. In addition to procedures required to gain authorization for EFB use, specifications for both EFB hardware and software are found within Order 8900.1 (2012b). Some of these technical requirements are described here and in Human Factors below to provide an understanding of why consumer tablet-based EFBs do not qualify for certification.

EFBs operating software intended for use during critical phases of flight (Type B) in pressurized aircraft require rapid decompression testing in accordance with RTCA/DO-160, *Environmental Conditions and Test Procedures for Airborne Equipment* (FAA, 2012b). It is unlikely a consumer product manufacturer has or will spend the money required to meet this standard. Jeppesen has filled this gap, in the case of the fourth generation Apple iPad and iPad Mini (Wilson, 2012). To support the approval of iPads operating Jeppesen software, the company conducted rapid decompression testing to an altitude of 51,000 feet (Wilson, 2012). Wilson did not mention other tablet computers, implying the iPad and iPad Mini are unique in their ability to pass this test. No testing is required for EFB use in unpressurized aircraft (FAA, 2012b).

Most tablet computers are considered Transmitting Personal Electronic Devices as they are typically are capable of transmitting and receiving radio signals (FAA, 2012a). As a result, AC 120-76B (2012a) requires tablet computer-based EFBs running Type B applications to meet the RTCA/DO-160 standard. Order 8900.1 provides more detailed testing procedures. Briefly, a frequency assessment must be conducted in accordance with RTCA DO-294, *Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft.*
This is followed by electromagnetic interference testing with isolated aircraft equipment and, finally, operating the tablet-based EFB in the aircraft (FAA, 2012b).

In order to meet the standards set forth in FAA Order 8900.1 (2012b), the Class I and Class II EFBs that are the focus of this study must be configuration controlled. Major components must be evaluated and any change requires re-evaluation to ensure functionality, non-interference, and reliability remain acceptable (FAA, 2012b). Configuration control is also required for EFB software (FAA, 2012b). Baseline hardware/software configuration must be established, along with procedures to maintain control and update databases (FAA, 2012b). The nature of consumer tablet computers and how they are used by most owners makes the required level of control impractical, at best. Addition or removal of apps by the typical user, to include general aviation pilots, changes software configuration.

Up to this point, regulation in only one Advisory Circular, one FAA Order, and one TSO governing the certification and airworthiness of EFBs have been briefly described. Each of these references standards and/or requirement from other documents, including Code of Federal Regulations (CFR), other ACs, other TSOs, and Directive Orders. AC 91-78 (FAA, 2007) regulates the actual use of the Class 1 and Class 2 EFBs that are the focus of this study and permits the use of these devices in all phases of flight providing:

a. no required equipment or systems are replaced
b. display is limited to only pre-composed or interactive information which is functionally equivalent to the paper being replaced
c. information is current
d. there is no interference with required equipment or systems.

Note the tablet-based EFB capabilities earlier in this work far exceed the information display limits above. Certifying avionics capable of those additional functions is so complex, Amazon.com (2013) carries a 244 page book to guide potential designers/manufacturers through the process of meeting DO-178 *Software Considerations in Airborne Systems and Equipment Certification* and DO-254 *Design Assurance Guidance for Airborne Electronic Hardware* standards. This is in addition to other standards, including TSO-C165 *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*, TSO-C2D *Airspeed Instruments*, and TSO-C47A *Fuel, Oil, and Hydraulic Pressure Instruments*. These cost-driving regulations are the type McClellan (2012) refers to when lamenting the high cost of certified avionics.

Human Factors

Human factors matters discussed in AC 120-76A (FAA, 2003) are based, in part, on the Volpe Center's Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs), Version 1: Basic Functions. Version 1 has been superseded by Version 2, which is referenced by this study and appears to have been incorporated more fully into AC 120-76B (FAA, 2012a) than Version 1 was integrated into AC 120-76A. Chandra, Yeh, Riley, and Mangold (2003) make recommendations on over 100 human factors matters for EFB hardware and software in Version 2.

Human factors have already been shown to be an important consideration in the use of EFBs. Chandra and Kendra (2010) of the Volpe Center conducted a study of 67 Aviation Safety Reporting System (ASRS) events involving EFB use. Twenty-six of the 67 involved heading, altitude, or speed deviations. Thirty involved aircraft performance calculations (Chandra & Kendra, 2010). Separately, two NTSB reports identified issues with EFBs and the determination of landing distance, including the FedEx accident alluded to earlier (NTSB, 2000). No details are provided other than "misinterpretation" of landing distance calculations in the report (NTSB, 2000), but performance calculation is one of the areas Chandra, Yeh, Riley, and Mangold (2003) chose to provide recommendations to developers. These include blank data entry fields where no default value is provided, validate and provide error messages when data is entered in an incorrect format, units of each variable should be clearly indicated, units should be consistent with other sources used in the cockpit, and the user should be able to modify previous computations quickly.

Research Methodology

This study was carried out using a Mixed Methods design and included both qualitative and quantitative analysis. A survey of General Aviation pilot behaviors, preferences, and opinions was conducted. Numerical data collected were statistically analyzed in search of correlations and trends. Non-numerical data was aggregated and coded to identify trends in the respondent's opinions. The goal of this design was to capture the generalizability of quantitative data while capturing the depth of the respondent's opinions by capturing qualitative data.

A convenience sample consisted of 1,700 members of a web-based Piper Cherokee discussion group hosted by Yahoo! who voluntarily agreed to complete an internet-based survey. Over 32,000 Piper Cherokees were built (Aviafilms, 2013) and Plane and Pilot (2003) listed the Cherokee Six as one of their top ten all-time favorite aircraft. These two facts point to pilots of the Cherokee family of aircraft as a well suited population to sample for this study. Due to a low number of responses, the survey announcement was also disseminated through personal channels and an aviation related Facebook page.

The internet-based survey was hosted by www.surveymonkey.com, a widely recognized on-line survey collection and administration tool. All prospective participants received an invitational e-mail or saw the Facebook post explaining the nature of the study and a general link (i.e. with no specific user tracking information) to the on-line survey. Participation was not specifically incentivized (i.e., gifts, rewards, etc.) but encouraged through the invitation.

Non-sampling errors were likely to be introduced by the probability of EFB users responding to the survey as a greater proportion of the population than non-users. To a lesser degree, respondents who misunderstood the questions or who did not understand the aviation or technological vocabulary may have been more likely not to respond or to terminate the survey prior to completion. This effect was mitigated by using definitions in addition to specific vocabulary and providing the respondent with background information on certain topics, where appropriate. Partial surveys were individually analyzed for usefulness and retained or discarded on a case-by-case basis. All data was downloaded directly from the on-line survey system and imported into a numerical analysis software package for sorting, coding, and analysis. Data entry errors were not a factor because the participants entered responses directly into the collection system and all data was handled electronically. Survey bots (i.e., fictitious electronic responses not generated by an individual) were not expected to be a factor because of the targeted nature of the population and the use of a bot-proof validation question before acceptance of the data.

A hypothesis of no correlation between EFB use and flight type was tested by plotting frequency of EFB use on a histogram categorized by type flight. The researcher listed the type flights, in order of increasing complexity, based on personal experience. Using the histogram plot, the Pearson correlation coefficient (r_{type}) was calculated to reject or fail to reject the hypothesis. In addition to the testable hypotheses, data was collected and analyzed to find what functionality is important to and what challenges are faced by GA pilots when using tablet computer based EFBs. Quantitative and qualitative data was combined to draw conclusions about the GA population in support of research conclusions and recommendations to industry and government.

Results

Thirty-three valid surveys were collected from 36 complete responses. Two indices were calculated to aid in comparing EFB Users and Non-Users. Using survey data on technology devices used and activities conducted, a Tech Savvy Index was determined for each participant. A sum of scores assigned to each device and activity represents the range of technology experience/skill of the individual. Scores ranged from 1 point for a basic cell phone or desktop computer to 5 points for maintaining a website.

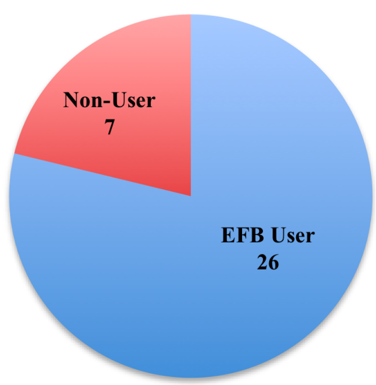
In order to account for different flight experience of surveyed pilots, a Flight Experience Index was developed and applied using the following formula.

Flight Experience Index = 0.4 x Tot Flt Hrs + 0.6 x Flt Hrs in Last 5 Years

The index was designed to give more weight to recent flying experience because of the more recent availability of technologies like the tablet EFBs that are the subject of this study. Figure 1 depicts the median Tech Savvy Index and Flight Experience Index for EFB Users and Non-Users, as well as other general statistics of the sample.

7 Non-Users

Instrument Rated	**29%**
Median	
Age	**50**
Flight Experience Index	**440**
Tech Savvy Index	**12**
Average	
Pattern Work/Local	**39%**
VFR	**20%**
Multi-leg VFR	**37%**
IFR Proficiency	**10%**
Multi-leg IFR	**20%**
Night	**15%**



26 EFB Users

Instrument Rated	**35%**
Median	
Age	**58**
Flight Experience Index	**365**
Tech Savvy Index	**11**
Average	
Pattern Work/Local	**25%**
VFR	**35%**
Multi-leg VFR	**40%**
IFR Proficiency	**12%**
Multi-leg IFR	**31%**
Night	**15%**

Figure 1. General sample characteristics. This chart depicts selected information from the sample broken out by EFB Users and Non-Users.

Tech Savvy Index shows EFB Users and Non-Users to be about equal in level of technological experience or skill. Flight Experience Index reveals EFB Users have less flight experience than Non-Users. This is consistent with a comparison of average total flight hours and flight hours in the past 5 years for each group (not shown). Non-Users also tend to be younger. More telling may be the higher percentage of flight time spent in pattern work/local flying for Non-Users (39%) versus EFB Users (25%) and lower percentage of time operating under IFR (30% vs 43%).

It should be noted, among EFB users, one more pilot conducts multi-leg IFR flights than the number of EFB users with Instrument Ratings. It is possible this individual is seeking an instrument rating and uses these flight for training. Not all non-EFB Users who responded to the survey indicated why they choose not to use this technology. Of those who did, reasons included use of a smart phone or iPod, dislike of yoke-mounted equipment, and “don’t fly enough.”

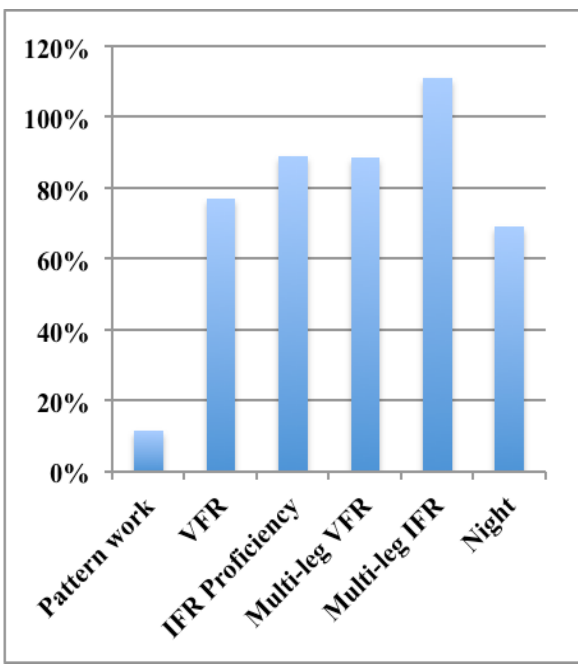


Figure 2. EFB use by flight type. This chart depicts the percentage of participants who use a table EFB for each type of flight with consideration for pilot qualification.

Hypothesis - H_0: $r_{type} = 0$, $H_1 = r_{type} > 0$

Figure 2 shows the types of flights for which tablet EFBs are used. Data was converted to percentage of EFB users qualified to conduct each flight type. For example, among all EFB Users, 88% use their EFB to conduct Multi-leg VFR flights; among 8 Instrument Rated pilots, 89% use their EFB for IFR proficiency flights.

Four correlation values were calculated using the data shown. Pattern work/local flights near home airfields likely do not require the navigation capabilities offered by EFBs. This is a possible reason for the very low usage rate compared to other flight types. Night is less a flight type and more of a condition, not unlike weather. Any of the flights listed may be conducted day or night. As a result, correlations were calculated with and without these pattern work/local flight and night. VFR flight over 100 NM, IFR Proficiency, Multi-leg VFR, and Multi-leg IFR were listed in order of complexity, based in the researcher's personal experience. The four correlation results are shown below.

- All flight types r_{type} = 0.6162
- Excluding Pattern work/local r_{type} = .0682
- Excluding Night r_{type} = 0.8818
- Excluding Pattern work/local and Night r_{type} = 0.9224

Of the four calculations, the last two are most relevant as they exclude the Night condition. In both cases, strong correlation is indicated and the research rejects the hypothesis. An alternate explanation for the high correlation of flight type to EFB use is flight distance. As one reads Figure 2, flight distance generally increases from left to right across the x-axis. Again, this holds true if night is considered a flight condition, rather than a flight type.

Tablet EFB Capabilities

Figure 3 depicts selected results from the survey section dedicated to capabilities available with the tablet EFBs being studied. A Likert Scale comprised of Built-In, Add-On, Desire, and Not Important was offered to participants to indicate what capabilities were part of their tablet EFB and software, what they chose to add, what they desire, or what is not important to them. Capabilities most often Built-In or Added-On to tablet EFBs are flight planning, navigation related, weather, and zoom/pan. These are consistent with the top four flight activities (fight planning, weather briefing, and single and multi-leg VFR) survey respondents reported they use tablet EFBs to carry out. IFR Charts were not in the top group of possessed capabilities, but nearly three times the number of pilots who are qualified to fly IFR have this resource. ADS-B, TCAS, AHRS, and synthetic vision are the most Desired capabilities. Flight rehearsal and hardwire power are the characteristics most respondents considered Not Important.

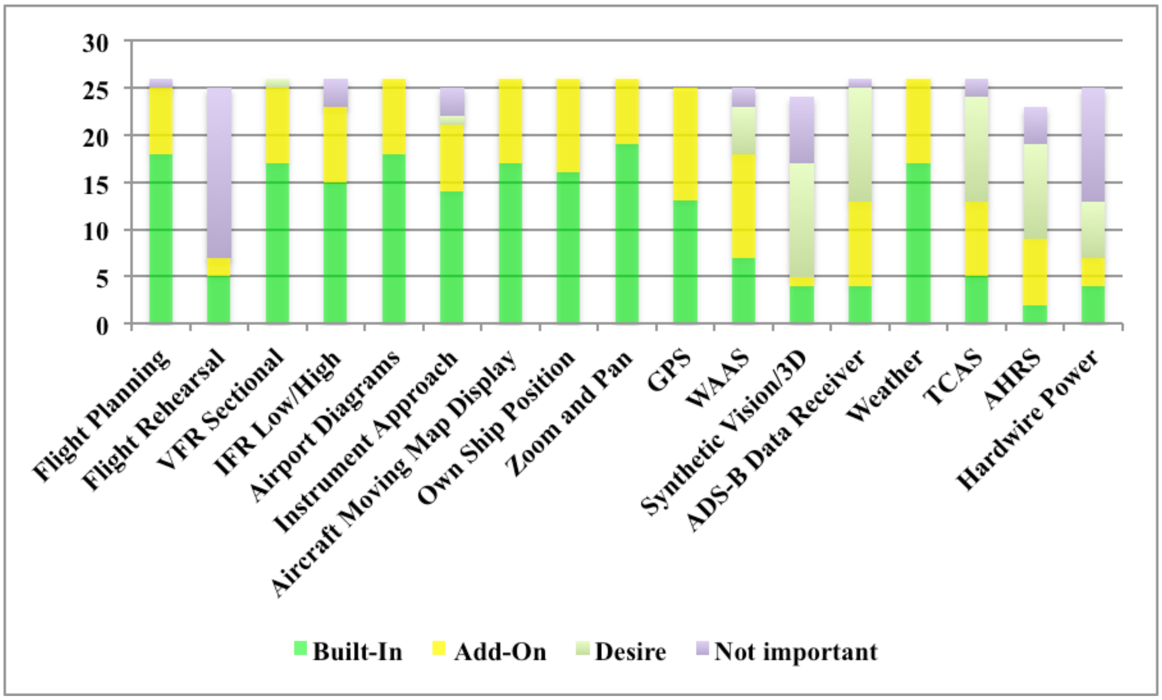


Figure 3. Selected EFB User capability choices. A selection of capabilities EFB Users have chosen or desire to have in their tablet EFBs.

Respondents were also asked what functions they prefer not to carry out using their tablet EFB. Pilot and aircraft logbooks were the most frequent answers. Among those who chose to explain why, preference for paper was expressed due to reliability, usability, or familiarity. One respondent indicated aircraft records were kept by the maintainer.

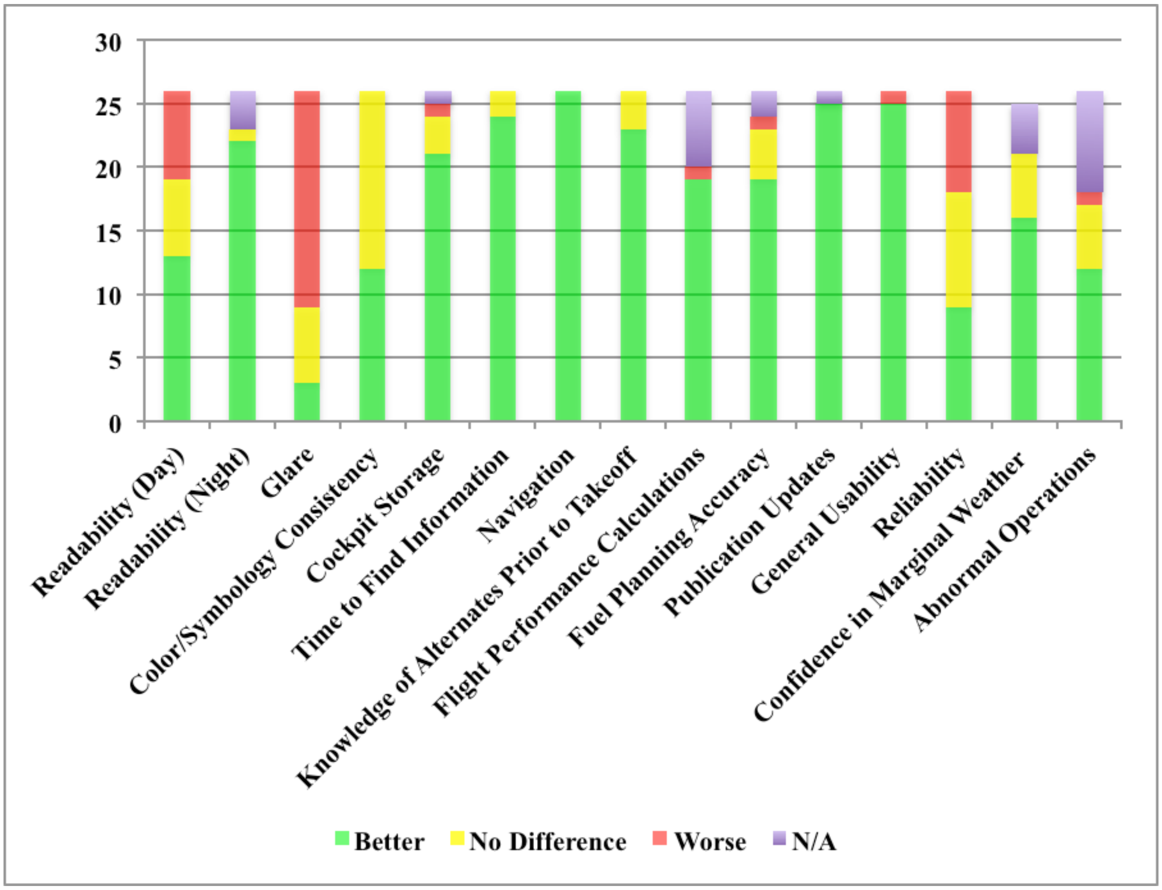


Figure 4. Human Factors Experiences. This chart depicts the human factors experiences of EFB Users.

Human Factors

Study participants were asked to indicate whether their experience with tablet EFBs was Better, No Different, Worse, or Not Applicable, when compared to paper flight publications in 15 human factors related questions. Results are shown in Figure 4. Looking back to the FedEx accident (NTSB, 2000), flight performance calculations are improved for the sample group over the use of paper, which may indicate acceptance of recommendations made by Chandra, Yeh, Riley, and Mangold (2003) by app developers. Navigation is the only area 100% of respondents indicated tablet EFBs are Better than paper. Improvements in this area from better situational awareness support a reduction in flight violations and CFIT accidents (Arthur, et al, 2006).

Publication Updates and General Usability were rated as Better by 25 of 26 tablet EFB users. Improved update processes ensure timely receipt and accurate incorporations of changes to flight publications, NOTAMs, and TFRs. Improved usability speaks to two matters discussed earlier in this work 1) airmanship errors in the departure stage of flight while using navigation apps 2) minimizing head-down time when using this type of software. Readability (Day), Glare, and Reliability were the only areas with more than one Worse response. Glare was the greatest with 19 Worse responses, although 15 respondents indicated they had a glare reduction film or shade.

Conclusion

Technology has provided pilots the ability to increase their range or payload, save money, and increase their situational awareness in flight in the form of Electronic Flight Bags (EFBs). Consumer-grade electronics and the availability of data have extended this capability to General Aviation. Perhaps because use of EFBs is not regulated under Part 91, little is known about the uses by and challenges of the pilots in this segment. This study has shed light on topics of interest to the Federal Aviation Administration, Department of Transportation, National Transportation Safety Board, hardware manufactures, software developers, and General Aviation pilots.

Recommendations

This study provides matters to consider for government and private entities to ensure the safe and effective use of tablet computer based EFBs. Recommendations for specific organizations and groups are provided below.

Federal Aviation Administration – Develop regulations allowing the display of own ship position in flight on Class 2 EFBs.

Department of Transportation – Update *Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags Version 2* and release Version 3 to provide information on new capabilities and technological advances since 2003.

National Transportation Safety Board – Recommend the FAA require EFBs to provide flight-recording capabilities, i.e. flight plan, GPS derived position, altitude, heading, and ground speed.

EFB software developers – 1) Increase reliability 2) Add synthetic vision, ADS-B, TCAS, and AHRS provisions to capabilities.

Tablet computer manufacturers – 1) Increase reliability 2) Provide glare reduction screen options 3) Increase available screen brightness for use during bright daylight.

Academia – 1) Refine answer choices or type to allow for statistical analysis 2) Conduct a similar version of this study at a large General Aviation event like Sun 'n Fun to gather a larger sample for study.

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