HUMAN FACTORS CONSIDERATIONS FOR INTEGRATING TRAFFIC INFORMATION ON AIRPORT MOVING MAPS

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The purpose of this research effort was to identify human factors considerations in the integration of traffic information and surface indications and alerts for runway status on airport moving maps for flight deck displays. The information is primarily intended to support the development of Federal Aviation Administration (FAA) policy and guidance for surface conflict detection and alerting (e.g., runway incursion alerting). The Volpe Center gathered information in two ways: (1) from observations made during FAA-sponsored demonstrations of Automated Dependent Surveillance – Broadcast (ADS-B) surface conflict detection algorithms, and (2) collecting pilot feedback on the use of ADS-B in the general aviation environment. Four human factors issues pertaining to the integration of traffic information and alerting are addressed in this paper: use of color, the presentation of indications and alerts, the design of traffic symbols, and position accuracy.

The Federal Aviation Administration (FAA) has requested human factors input to support the development of policy and guidance for surface conflict detection and alerting on airport moving maps. A surface conflict detection function has two components: an airport moving map that depicts a dynamic image of the airport along with the aircraft's current position (see Yeh and Eon, 2009 for examples); and a traffic function to overlay aircraft traffic based on Automatic Dependent Surveillance – Broadcast (ADS-B) or other surveillance technologies. Figure 1 presents an example of an airport surface moving map that shows traffic information. In the figure, ownship is represented via a magenta triangle (in the center of the figure), and traffic aircraft are represented via the chevron, diamond, and bullet-shaped symbols.

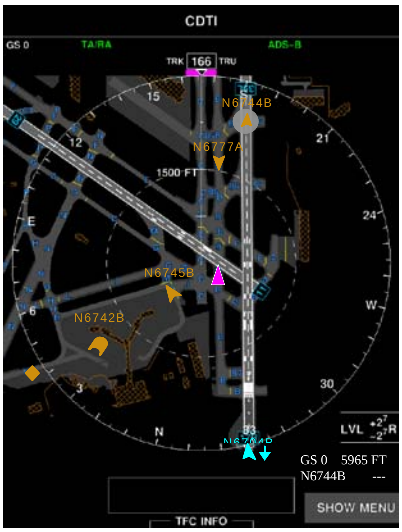

Figure 1. Photo courtesy of ACSS (Excerpted from Yeh and Eon, 2009).

The FAA provides guidance for the design and approval of airport moving maps and traffic surveillance applications in Technical Standard Orders (TSOs) and Advisory Circulars (ACs). TSO-C165, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*, (FAA, 2003), and Advisory Circular (AC) 20-159 (FAA, 2007), *Obtaining Design and Production Approval of Airport Moving Map Display Applications Intended for Electronic Flight Bag Systems*, address airport map displays. Both TSO-C165 and AC 20-159 reference RTCA DO-257A, *Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps*, which defines the minimum standards for equipment that is intended to provide ownship position on an electronic map display, whether it is on the airport surface, in-flight, or vertical situation display. TSO-C195, *Avionics Supporting Automatic Dependent Surveillance – Broadcast (ADS-B) Aircraft Surveillance Applications (ASA)* provides guidance for a traffic function (FAA, 2010). TSO-C195 references RTCA DO-317, *Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications System (ASAS)*, which addresses requirements for the presentation of traffic information.

Although existing FAA guidance addresses many human factors considerations associated with individual traffic and airport surface map depictions, guidance is needed for the integration of this information, as well as advanced capabilities such as the presentation of surface indications and alerts. The performance standards specified in RTCA DO-257A and RTCA DO-317 define the *minimum* capabilities required for an airport moving map and traffic display, respectively, but higher performance standards may be needed to support more advanced capabilities. Industry input for the airport surface conflict detection concept is documented in RTCA DO-323, *Safety, Performance and Interoperability Requirements Document for Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts (SURF IA)*(RTCA, 2010). RTCA DO-323 defines a concept for airport surface conflict detection consisting of the presentation of *indications* and *alerts*. RTCA DO-323 defines indications for "a normal operational condition that could become a runway safety hazard" (p. 6) and *alerts* for "non-normal operational situations where collision hazard exists or a collision appears imminent" (p. 2). The concept for displaying indications and alerts consists of highlighting the potentially incurring (i.e., conflict) traffic aircraft or conflict runway, showing symbols for traffic aircraft that are offscale or outside of the current display range, presenting text information, and presenting an auditory message for alerts. The design of each of these elements is specified by the manufacturer.

The FAA has requested additional human factors guidance to support the development of minimum performance standards for surface conflict detection. To support the FAA, the Volpe Center gathered information in two ways:

(1) Observing demonstrations of ADS-B surface conflict detection algorithms sponsored by the FAA Surveillance & Broadcast Services Office.
(2) Observing demonstrations of the airport moving map and traffic display at Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida, and interviewing their flight instructors to understand the impact of the airport moving map and traffic display in a general aviation operating environment.

The methodology used to gather information is described in the next section. The preliminary findings from these efforts are then described. This paper presents a brief overview of this research effort; more detail is provided in Yeh and Gabree (2010).

Method

Observations during FAA-sponsored ADS-B Demonstrations

In 2008, the FAA Surveillance and Broadcast Services (SBS) Office sponsored a program to demonstrate surface conflict detection algorithms and alerting using ADS-B, and to test and validate requirements for an ADS-B surface application. The Volpe Center observed four demonstrations. The first three were conducted in November and December, 2009, at Philadelphia International Airport (PHL) by ACSS in partnership with US Airways. An US Airways Airbus A330 and an ACSS–owned Beechcraft King Air were equipped with ACSS-prototype software. The software was displayed in the A330 on two Electronic Flight Bags (EFBs), one installed under the left and right side windows. In the King Air aircraft, the software was displayed on an EFB, temporarily mounted for the demonstration in between the pilots' seats. Both aircraft were used to simulate potential conflict scenarios in night-time and day-time conditions.

The fourth observation occurred in January 2010 and was conducted by Honeywell at Seattle-Tacoma and Paine Field airports. Honeywell equipped two aircraft (a Cessna Citation Sovereign and a Beechcraft King Air) with their prototype software. In the Citation Sovereign, the software was presented as part of an integrated navigation display located in front of the captain. In the King Air, the software was shown on a temporary display, installed for the demonstration, and located in front of the first officer.

The demonstrations were scheduled at times when there would not be many operations of other aircraft to minimize the impact of the demonstrations on the airports' operations. During the demonstrations, the Volpe Center took the opportunity to observe the airport moving map and traffic display. The primary purpose of these demonstrations was to evaluate the technical feasibility of surface conflict detection and to examine the human factors and safety impacts. During the ACSS-US Airways demonstration, there was an opportunity to interview the A330 pilots to gather their opinions on the EFB, airport moving map, and the display of traffic, indications, and alerts. Three of the ACSS-US Airways demonstration participants completed a short questionnaire on the usability of the displays. Honeywell also conducted human-in-the-loop simulator evaluations and flight tests of their display concepts in conjunction with their demonstrations (see Khatwa and Lancaster, 2010a, 2010b).

Use of ADS-B on Airport Moving Maps in a General Aviation Environment

The Volpe Center visited Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida in March, 2010 to gather information on the use of an airport moving map and traffic display in a general aviation operating environment. ERAU has equipped 63 aircraft with airport moving map displays as well as technologies to transmit and receive ADS-B. The airport moving map is provided via a Garmin 1000 display (installed in 51 ERAU aircraft) or MX20 (installed in 12 aircraft), which have different capabilities with respect to depicting the airport surface. The Garmin G1000 provides the SafeTaxi application, which shows ownship position on a database-driven airport surface depiction (as shown in Figure 1), if an airport database is available and installed. Some of ERAU's aircraft did not have the full airport database. If no airport database is installed, SafeTaxi will show an airport depiction of runways only (with centerline markings and runway labels). The Garmin MX20 provides a runways-only (with centerline markings and runway labels) depiction of the airport surface.

Information was gathered in three ways. First, ERAU provided a demonstration of the Garmin G1000 and Garmin MX20, both with traffic capabilities. Second, interviews were conducted with eight of ERAU's instructor pilots. The interview sessions had two parts: a paper questionnaire, in which the pilots rated their opinions on the usability of the airport moving map and traffic information on the ground, and a discussion of human factors concerns related to the use of the airport moving map and/or traffic display. The questionnaire consisted of Likert-scale items, in which pilots indicated their level of agreement on a scale of 1 (strongly disagree) to 5 (strongly agree). Pilots who completed both the interview and the questionnaire received a $30 gift card for their participation. Because some pilots were interested in providing input but could not participate in the interviews, ERAU coordinated the distribution of the paper questionnaire to all their instructor pilots. The questionnaires were distributed in April, and pilots were given two weeks to complete it. The Volpe Center provided 150 questionnaires, and 44 were returned. (The eight pilots who participated in the interviews were excluded.) Pilots who completed only the paper questionnaire received a $10 gift card for their participation.

In total, 52 Embry Riddle Aeronautical University (ERAU) flight instructor pilots provided input to this effort, but one of the pilots' feedback was excluded because his primary aircraft was not equipped with an airport moving map. Most of the pilots (48) primarily used the Garmin G-1000. The other three indicated they primarily used the Garmin MX-20. To gauge pilots' flight experience, participants selected one of four categories corresponding to their total hours flown: 24 pilots had 1,500 flight hours or less, 18 pilots had between 1,501-3,000 flight hours, 6 pilots had between 3,001-7,000 flight hours, and 3 pilots had more than 7,000 flight hours.

Results

In general, pilots perceived that the use of an airport moving map showing traffic aircraft, indications, and alerts was a positive enhancement to the safety of surface operations. The general aviation pilots interviewed reported that an airport moving map showing ownship supported their position awareness on the airport surface better than a paper chart alone. The display of traffic information was an additional benefit.

However, several potential human factors concerns were identified through observations of the implementations of the airport moving map and traffic displays and through interviews with pilots using the displays. The concerns noted here focus only on those issues that affect the integration of traffic information and alerts on airport moving maps. General human factors concerns for airport moving maps are addressed in the full report and in other research reports (Gabree and Yeh, 2010; Yeh and Gabree, 2010). Please note that the intent of this effort was not to compare manufacturer displays. Additionally, specific details regarding a manufacturer's implementation of the airport moving map, traffic function, or alerts are not included.

Use of color

Color can be used to call attention to information on the display, but in some cases, color may attract attention when none is warranted. For example, color is often used to code aircraft traffic symbols to indicate whether the aircraft is in the air or on the ground. Aircraft on the ground are often colored as tan/brown, whereas aircraft in the air are cyan. The change in the color of the traffic symbol when an aircraft transitions from the air to the ground (or vice versa) is salient. During one of the demonstrations, this color change indicating the change in aircraft state was observed to be more attention-getting than the onset of a traffic indication. The use of color to indicate the transition from air to ground was proposed to be an effective means to distinguish the two states without increasing the complexity of the symbol set, but it is important to understand the implications of such designs. Color may be an effective way to convey this information if the design can be implemented so that the color changes does not attract attention inappropriately. It will be important to understand the implications of this color change, particularly during routine operations when aircraft are repeatedly taking off and landing.

There are also issues in the colors used for indications and alerts. In the demonstrations, the color blue was often used to indicate a potential conflict, by outlining the active runway or traffic symbol to highlight it. The use of the blue on avionics display may be problematic. First, many airport moving maps have a black background, and the presentation of pure blue on a black background may not be salient at all map ranges. Second, from a physiological standpoint, blue is the shortest wavelength, so it is difficult to bring blue display elements into focus when it is used in combination with other colors. Third, the use of a blue border to highlight the runway led to a yellow afterimage – the illusion of a yellow border surrounding the runway, when the blue border disappears. Afterimages were observed during the demonstrations even upon glancing at the display.

Indications/Alerts

A surface conflict detection algorithm may have several states, including normal operations, indications, cautions, and warnings. Each of these states is represented differently. Additionally, each of the manufacturers participating in the surface conflict detection demonstrations developed their own algorithm defining the operating conditions for presenting a surface indication or alert. As a result, it is conceivable that slight differences in the way each state is represented as well as in the output behavior may be observed. Such differences may make it difficult for pilots to understand the operating conditions under which indications and alerts may be presented, thereby reducing the usability of that information. RTCA DO-323 provides recommendations for the general behavior of the surface conflict detection algorithms, which may ensure consistency. However, the complexity of the algorithms for presenting runway indications and alerts will also require manufacturers and operators to consider how to optimize the training so that pilots understand the symbology, the meaning of the attributes used, and the rules in which the indications and alerts are presented. More training will be needed as the complexity of the algorithms increase.

During the demonstrations, the airport moving map was located on an EFB mounted to the left or right side of the pilot. Visual indications and alerts were presented directly on the EFB and were out of the pilot's primary field of view. Information is most quickly detected if it is presented within the pilot's primary field of view, an area is generally considered to be approximately 15° horizontal and ±15° vertical in front of the pilot (Cardosi and Huntley, 1993). Research is needed to understand the usability and effectiveness of surface conflict indications and alerts depending on the location in which they are presented on the flight deck to ensure that the presentation of alerts is sufficient to attract attention during non-normal operating conditions (e.g., with an auditory alert or a separate visual alert in the primary field of view). Discussion regarding the location of surface conflict alerting has included integrating their presentation to the aircraft's master caution and warning systems, which are presented in the pilot's primary field of view. There is general consensus, however, that the master caution and warning systems are reserved for aircraft-specific failures; consequently, the presentation of a traffic or runway incursion alert in the master caution and warning panel would be inconsistent with current flight deck philosophy.

Traffic Symbols

Symbols for depicting traffic are intended to convey several attributes, including whether the aircraft is in the air or on the ground, its directionality, and its reliability. These symbol attributes must also be interpreted with respect to the different potential aircraft states (i.e., the display of indications and alerts). There are a limited number of symbol attributes for conveying this information (e.g., shape, color, fill). The properties of aircraft that are depicted and how they are depicted may differ from one display to another, and sometimes the depiction may be inconsistent on displays developed by the same manufacturer. For example, one attribute which has been used inconsistently across avionics displays is the fill of a symbol. Symbol fill was used on one display to indicate the aircraft that is the selected target whereas another display used it to indicate those aircraft that are in close proximity to ownship. Color was generally used to indicate whether aircraft is in the air (cyan) or on the ground (tan/brown), but the application of this color varied; on one display, this coding scheme was applied only for aircraft within a certain distance from ownship, but on another display, this coding scheme was applied to all aircraft traffic. Inconsistency in the properties of traffic symbols can make it more difficult for pilots to learn the symbol set, and increase the potential for confusing the meaning of the attribute. Pilots who fly different types of airplanes may use different avionics systems and may not know what information is readily available. When designing new methods for presenting symbology, it is important to consider consistency with applicable standards, as well as related standards such as for TCAS (Traffic Alert and Collision Avoidance System). Recommendations for conveying different traffic symbol attributes are provided in RTCA DO-317.

One open issue is how traffic aircraft should be depicted with respect to the airport moving map when the traffic aircraft falls outside the current display range; that is, when the aircraft is off-scale. The position of the traffic aircraft symbol may be depicted using its relative bearing with respect to ownship, which would be consistent with TCAS conventions for depicting off-scale traffic (when ownship is in the air). However, when an airport moving map is used for reference, the depiction of traffic position using relative bearing could provide misleading information regarding that aircraft's actual position. For example, the relative bearing of a traffic aircraft that is on approach to an airport could lead to the aircraft being depicted as approaching on one runway when it will in fact land on a different runway. Depicting the projected track of the aircraft would offer a more accurate representation of where the selected aircraft will be, although current position may not be precise. Research is needed into the level of precision required for operations on or near the airport surface and how to ensure consistency in the presentation of traffic information with current technologies, such as TCAS. Other open issues for symbols include whether and how to depict traffic that does not meet the performance required for indications and alerts.

Position Accuracy

The position accuracy with which ownship, traffic, and airport information are depicted on an airport moving map must support the intended function. Several errors can contribute to the accuracy of ownship or traffic depiction, including but not limited to position error, latency, survey error, and display resolution. RTCA DO-257A provides accuracy requirements for ownship position on an airport moving map, RTCA DO-317 defines the accuracy requirements for the depiction of traffic on an airport moving map, and RTCA DO-323 recommends accuracy standards for the presentation of ownship and traffic to support indications and alerts. Traffic aircraft, indications, and alerts are *not* intended to be presented if aircraft do not meet their respective accuracy and other data quality requirements.

The demonstration observations and general aviation pilot interviews provided examples of position *in*accuracy to consider in the implementation and integration of traffic information on the airport moving map. During the demonstrations, there were a few instances when the ADS-B signal was lost, likely due to reflection from nearby buildings. There was also one instance where a "false" target was observed on the active runway when ownship was on final approach, because that aircraft target was transmitting erroneous values (zero) for the Navigation Integrity Code (NIC), the Navigation Accuracy Code for Position (NACp), and the Surveillance Integrity Level (SIL). In the general aviation domain, pilots indicated that the information shown by the airport moving map usually matched the out-the-window view, but 25% noted position errors of ownship, traffic, or the airport map. The types of errors reported included the depiction of ownship on or near the edge of the taxiway (2 reports); ownship drawn in the grass (3 reports); and "other," a category which included shadow "ownship" targets, errors in ownship headings, and incorrect depictions of traffic aircraft (6 reports). Of significance is that one pilot noted that a traffic aircraft holding short of one runway was depicted on the airport moving map as being *on* the runway. The participants noted that these errors were rare. Some tended to occur when the system was first turned on or because the airport moving map database was not up-to-date; for example, several of the participants noted a closed taxiway that was still shown on their airport moving map.

Finally, it is important to consider the accuracy/consistency of traffic symbols shown on the airport moving map with the view out the window. All traffic aircraft may not be shown on the airport moving map, presenting an incomplete picture. There are several reasons why a traffic aircraft may not be displayed. First, the introduction of a traffic function will lead to a mixed equipage operating environment, so all aircraft may not yet be equipped. Second, even if all aircraft are equipped with surveillance technologies, some aircraft may not have their transponders on whereas others may not be visible via the surveillance technology. Third, technical limitations can affect the completeness of the traffic picture. During the demonstrations, several instances were noted in which an ADS-B signal was lost and aircraft on the airport surface did not appear or disappeared from the airport map.

Conclusions

This paper provides a preliminary glimpse into human factors concerns with the integration of traffic information, indications, and alerts on an airport moving map. It is important to understand issues faced in the current state of implementation and identify where additional guidance may be needed to support this functionality. This information was gathered in support of the FAA, but manufacturers may also find the information useful for their design and evaluation process.

Acknowledgements

This report was prepared by the Behavioral Safety Research and Demonstration Division of the Human Factors Research and Systems Applications Center of Innovation at the John A. Volpe National Transportation Systems Center (Volpe Center). It was completed with funding from the FAA Human Factors Research and Engineering Group (AJP-61) in support of the Aircraft Certification Service Avionic Systems Branch (AIR-130) and the Technical Programs and Continued Airworthiness Branch (AIR-120). Our FAA program manager is Dr. Tom McCloy, and our technical sponsors are Colleen Donovan and Dr. Bill Kaliardos. We would like to thank Jim Duke and David Gray from the FAA SBS Program Office, Dr. Peter Moertl at MITRE, and ACSS, Honeywell, and US Airways for allowing us to attend and observe the SURF IA demonstrations. We would also like to thank Blake Kelly at Embry-Riddle Aeronautical University for demonstrating ERAU's airport moving map and ADS-B technologies. The views expressed herein are those of the authors and do not necessarily reflect the views of the John A. Volpe National Transportation Systems Center, the Research and Innovative Technology Administration, or the United States Department of Transportation.

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Erratum (14 June 2011). In the original version of this paper in the Proceedings of the 16th International Symposium on Aviation Psychology, May 2-5, 2011, there was an incorrect figure reference on Page 3. This copy of the entire paper contains the correction.