AIR TRANSPORT PILOTS' INFORMATION PRIORITIES FOR SURFACE MOVING MAPS

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The use of a surface map display for operations on or near the airport surface (taxi out, takeoff, final approach and landing, taxi in) is expected to enhance safety. There is a lack of research, however, detailing how the airport surface should be depicted to air transport pilots during taxi operations. In order to address this question, an information analysis was conducted in which air transport pilots provided self-reported ratings of need for display elements found on current airport diagrams or made available on prototype surface map displays for operations on or near the airport surface. The ratings highlighted the value of presenting runway location and traffic information across all operational phases and showed the changing utility for display elements across different phases of operations. Comparison of the air transport pilot ratings with general aviation pilot ratings showed general agreement as to which display elements were of high value. Differences between the two groups were largely attributable to differences in the nature of operations.

INTRODUCTION

The Federal Aviation Administration (FAA) Safe Flight 21 program office is examining the use of electronic surface map displays to enhance safety and reduce incidents on or near the airport surface. The airport is a complex and highly dynamic environment; unfamiliarity with the airport layout, deficiencies in airport surface markings (e.g., poor signage), or non-optimal weather or lighting conditions increases the difficulty of determining ownship position as well as the position of other vehicles and could lead to disorientation (Andre, 1995). In fact, an analysis of accident statistics, which included near misses, revealed that the airport surface had the highest potential for catastrophe, leading the then FAA Administrator, Jane Garvey, to note that "taxiing on the airport surface is the most hazardous phase of flight" (Gerold, 2001).

As shown in Figure 1, the surface map is presented on an electronic display, constructed from a database that contains positional data describing the location of runways, taxiways, non-movement areas, ramp areas, and buildings. Data from the Global Positioning Satellites (GPS) combined with other surveillance technologies, e.g., Automated Dependent Surveillance-Broadcast (ADS-B), provide a means to display real-time ownship position and the position of other aircraft and surface vehicles. It is expected that the presentation of this information will aid in the visual acquisition of surface elements (e.g., runways and taxiways) and increase pilots' awareness of the airport layout (Batson, Harris, and Hunt, 1994; Battiste, Downs, and McCann, 1996). Additionally, it is anticipated that this display of vehicle information will increase pilots' awareness of traffic on or near the runways and allow pilots to infer traffic intent with respect to surface movements (RTCA, 2002a,b).

The determination of which display elements to show and when requires an understanding of the value pilots place on the presentation of different display elements throughout different phases of operations. Schvaneveldt, Beringer, and Lamonica (2001) conducted such an analysis to determine information priorities during flight. In their study, a taxonomy of display elements for seven flight phases and two planning phases was created by analyzing the information used in normal flight operations. Items included in their questionnaire represented both broad categories of information (e.g., general

Database, providing positions of:
- Runways and taxiways
- Non-movement areas
- Buildings

Ownship position

Position data for traffic on/near the airport surface (e.g., ADS-B)

Operational Goals
Allow the pilot to determine location of ownship and other traffic and obstacles while operating on or near the airport surface. These operations are defined here to include the following phases:
- Taxi out
- Takeoff
- Final approach and Landing
- Taxi In

Figure 1. Surface map display system. The prototype display shown here is developed by the William J. Hughes FAA Technical Center.

weather) and very specific items (e.g., altitude, distance). The analysis presented an overall ranking of information priorities across flight phases, and revealed a shifting of priorities across the phases of flight as well as between flight and planning phases.

There is a lack of research, however, detailing the display elements that are useful in describing the airport surface (FAA, 2001). The design of surface map prototypes has so far been based on assumptions regarding the value of various airport map attributes. Using a technique similar to that of Schvaneveldt, et al., Yeh and Chandra (2003) conducted a study to determine a set of display elements useful to general aviation (GA) operations. While Schvaneveldt, et al. focused on flight phases, Yeh and Chandra placed emphasis on operations on or near the airport (i.e., up to 1000 feet above ground level). GA pilots were presented with a list of display elements, and asked to rate the need for each display element for different operations on or near the airport surface. The questionnaire included airport features found on current taxi charts (e.g., runway and taxiway information) or that have been made available with ADS-B technology (e.g., the location of air and surface vehicles). Only a handful of items were found to be highly useful for all phases of operations. In fact, the results reflected the changing value of display elements throughout the different operational phases, similar to those reported by Schvaneveldt, et al.

The study conducted by Yeh and Chandra focused on GA operations, however, and does not address the issue of how to organize display elements for air transport operations. This was the objective of the current experiment. Our interest here was to determine how display elements may be organized for air transport operations, so that the pilot is presented with the appropriate display elements at the appropriate time. Additionally, it was of interest to compare the results of the air transport analysis to those of the GA analysis, discussed above.

METHODS AND PROCEDURE

Participants

Nineteen pilots from a commercial airline participated in the study. Seventeen were 757/767 pilots and two were 777 pilots. The pilots averaged 7391 flight hours.

Questionnaire

Pilots were presented with a set of forms, including a consent form, a demographics questionnaire, forms listing display elements for four phases of operations on or near the airport surface (taxi out, takeoff, final approach and landing, and taxi in), a glossary of terms, and an airport diagram for reference. Pilots were informed that the goal of the surface map application was to support their knowledge of ownship position, traffic location, and runway occupancy. Additionally, pilots were told that the surface map was intended to supplement the information that was available on a paper chart and out-the-window.

The display elements consisted of items that are currently available on paper charts or that will be available with ADS-B technology. A list is presented in Table 1.

Runway Information
Runways
Runway centerlines
Runway displaced thresholds
Runway edges
Runway elevation
Runway end elevation
Runway heading
Runway hold short lines
Runway labels
Runway landing length
Runway length
Runway lighting
Runway markings
Runway shoulder
Runway slope
Runway stopways
Runway surface information
Runway weight bearing capacity
Runway width

Taxiway Information
Taxiways
Taxiway bearing strength (when less than associated runway)
Taxiway centerlines
Taxiway edges or boundaries
Hold short lines
Taxiway labels
Taxiway width
ILS critical areas
ILS hold lines

Geographical Features
Air traffic control boundaries
Airport beacons
Airport name
Airport reference point
Airport terrain features
Aprons
Areas under construction
Buildings
  - Building identification
  - Control tower
  - Fire station
  - FBO
  - Hangars
  - Terminal buildings
Deicing areas
Grassy areas
Helicopter landing pads
Holding pens
Latitude/Longitude
Magnetic variation
Non-movement areas
North indication
On airport navaids
Pole line
Railroads
Ramp areas
Restricted areas
Roads
Spot elevations
Trees
Wind cone / wind sock
Water features

Ownship Information
Ownship
Ownship heading
Ownship ground speed
Lubber line

Traffic Information
Indication of traffic status (in air/on ground)
  - Traffic in air
  - Traffic call sign (traffic in air)
  - Traffic on the ground
  - Traffic call sign (traffic on ground)
Traffic altitude
  - Absolute
  - Relative
Traffic location
Selected target indicator
  - Selected target speed
  - Selected traffic identification
  - Selected target aircraft class
  - Selected target distance
Predictor

Obstacles
Condition of surface areas (other than runways)
Obstructions

Status Indications
Compass rose/arc
Range information
Full range ring
Half-range ring
Map scale

Taxi Information
Ground track vector
Gate numbers

Table 1. Display elements considered.

The elements can be categorized into eight classes: runway information, taxiway information, ownship information, traffic information, status indications, geographical features, and obstructions. For each of these display elements, pilots were asked to rate how much they *needed* it for each phase of operations on or near the airport surface, using the following scale:

5 Very high need
4 High need
3 Moderate need
2 Low need
1 Very low need
0 No rating

The phases of operations were defined as follows:
o taxi out: taxi from the gate (or hangar) to the runway
o takeoff: enter the runway to wheels off the ground
o final approach and landing: established on the final approach to landing and turnoff
o taxi in: taxi from the runway to the gate (or hangar)

RESULTS

Mean ratings were calculated for each display element within each of the four phases of operations. A single factor analysis of Variance (ANOVA), conducted on the data for each phase of operations, revealed significant differences in the display element ratings [taxi out, $F(87, 1516) = 10.22$, p < 0.01; takeoff, $F(87, 1489) = 6.43$, p < 0.01; final approach and landing, $F(87, 1515) = 6.90$, p < 0.01; taxi in, $F(87, 1504) = 8.65$, p < 0.01)]. We were interested in determining if the pilot ratings could be used to identify a set of display elements to depict for each operational phase. As with the GA information analysis, we attempted to determine if a set of minimum display elements could be identified based on the similarities in the need ratings using a Newman-Keuls analysis for each operational phase. The sample size here, however,

was not sufficient for any meaningful results. Consequently, the display elements were prioritized based on the defined rating scale, shown above, a method similar to that used by Schvaneveldt, et al. The results will focus on the display elements considered to be high value, those with a rating of 4.0 or higher, and display elements of low value, those with a rating of 2.0 or lower.

Highly Rated Display Elements

The display elements that were considered to be of high value are presented in Table 2.

The ratings highlight the changing value for display elements depending upon the operational phase. Only two display elements were given a rating of 4.0 or higher across all operational phases: the depiction of runway-pavement location and traffic location. Items related to runways, e.g., the depiction of runway-pavement and runway markings (centerlines, displaced thresholds, and edges), were rated higher during taxi out, takeoff, and final approach and landing than during taxi in. In fact, paired comparisons revealed that the mean rating for the depiction of runway-pavement was significantly higher during taxi out (4.89) and final approach and landing phases (4.84) than it was during taxi in (4.05) [$t(36) = 3.42$, p < 0.01 and $t(36) = 3.15$, p < 0.01, respectively]. This finding is inconsistent with the actual importance of runway pavement during taxi in, particularly if pilots are given complex clearances that require them to cross runways on their way to the gate or parking area.

Additionally, the ratings reveal a subset of display elements important specifically to taxi phases (taxi in, taxi out). Here, pilots reported that airport information relevant to their surface movement, i.e., about where they could move (taxiways, taxiway labels and taxiway edges), where they could not (areas under construction, ILS critical areas, restricted areas), who might be in the way (traffic on the ground), and where to wait for instructions (ILS hold lines, hold short lines) were of high value. For operations near the

Taxi Out		Takeoff		Final Approach and Landing		Taxi In	
1 Runways	4.89	1 Runways	4.53	1 Runways	4.84	1 Taxiways	4.68
2 Hold short lines	4.84	2 Traffic in air	4.37	**2 Runway displaced thresholds**		2 Hold short lines	4.68
3 Runway hold short lines	4.79	3 Runway centerlines	4.32		**4.79**	3 Taxiway labels	4.47
4 Areas under construction	4.68	4 Traffic location	4.26	3 Runway centerlines	4.58	**4 Gate numbers**	**4.32**
5 Taxiways	4.67	5 Indication of traffic status (in air/on ground)		4 Traffic location	4.26	5 Runway hold short lines	4.32
6 Runway displaced thresholds	**4.53**		4.24	5 Runway edges	4.26	6 Traffic location	4.32
7 Runway edges	4.42	6 Traffic altitude	4.13	6 Runway landing length	4.26	7 Taxiway centerlines	4.32
8 Taxiway labels	4.37	7 Runway edges	4.11	7 Indication of traffic status (in air/on ground)		8 Taxiway edges or boundaries	
9 Ownship	4.32	8 Runway hold short lines	4.06		4.24		4.26
10 Traffic location	4.26	**9 Runway displaced thresholds**		8 Runway lighting	4.11	9 Ramp areas	4.26
11 Traffic on the ground	4.21		**4.05**	9 Airport terrain features	4.05	10 Areas under construction	4.21
12 ILS critical areas	**4.21**			10 Ownship	4.05	11 Traffic on the ground	4.21
13 ILS hold lines	**4.21**			**11 Obstructions**	**4.00**	12 Ownship	4.21
14 Restricted areas	**4.11**					**13 Restricted areas**	**4.11**
15 Taxiway edges or boundaries						14 Runways	4.05
	4.11					**15 ILS hold lines**	**4.05**
16 Runway labels	4.11					**16 Obstructions**	**4.00**
17 Indication of traffic status (in air/on ground)	4.11						
18 Runway centerlines	4.00						

Table 2. Highly rated display elements. Items in bold are not currently depicted or marked on prototype surface map displays. (Item rank is given on the left side within each column. Mean rating is given on the right.)

Taxi Out			Takeoff			Final Approach and Landing			Taxi In		
88	Airport beacons	1.47	88	Railroads	1.47	88	Magnetic variation	1.59	88	Railroads	1.53
87	Railroads	1.54	87	FBO	1.63	87	Railroads	1.60	88	Magnetic variation	1.53
86	Trees	1.69	86	Airport beacons	1.67	86	Latitude/Longitude	1.67	86	Water features	1.65
85	Magnetic variation	1.73	85	Building identification	1.68	85	Deicing areas	1.81	85	Trees	1.67
84	Helicopter landing pads	1.80	84	Magnetic variation	1.71	85	FBO	1.81	84	Wind cone / wind sock	1.71
83	Water features	1.88	83	Hangars	1.74	83	Hangars	1.88	83	Pole line	1.75
			82	Ramp areas	1.75	82	Building identification	1.94	82	Runway elevation	1.82
			82	Roads	1.75	82	Pole line	1.94	82	Runway slope	1.82
			80	Non-movement areas	1.80	80	Helicopter landing pads	2.00	80	Airport beacons	1.83
			79	Spot elevations	1.88				80	Spot elevations	1.83
			78	Airport reference point	1.89				78	Runway end elevation	1.88
			78	Trees	1.89				77	Helicopter landing pads	1.94
			76	Helicopter landing pads	1.93				76	Airport reference point	1.95
			75	Water features	1.94				75	Latitude/Longitude	2.00
			75	Holding pens	1.94						
			73	Gate numbers	2.00						
			73	Latitude/Longitude	2.00						
			73	Pole line	2.00						

Table 3. Low rated items. Item rank out of a total of 88 elements is given on the left within each column. Mean rating is given on the right.

surface (i.e., takeoff and final approach and landing), pilots found detailed information regarding the airport layout (airport terrain features and runway markings) as well as the positions of proximate traffic in the air valuable.

A comparison of the display elements that received the highest ratings to those elements depicted on prototype displays identified some additional display elements which would add value if depicted. The prototype displays used for this comparison were demonstrated at a Safe Flight 21 evaluation in Memphis in May 2002. The surface maps already depicted ownship and traffic positions, runways, runway labels, taxiways, taxiway labels, non-movement areas, and buildings. Items that received high ratings by pilots that were not depicted on surface map displays are presented in bold in Table 2. For taxi phases, pilot ratings highlighted the value for ILS information (hold lines and location information of ILS critical areas) and restricted areas. For phases near the surface, display elements that would add value included runway displaced thresholds and obstructions. It is important to note that some of these display elements, e.g., runway landing length, may be found on current airport diagrams but may still need to be incorporated into airport databases.

Low-Rated Display Elements

The ratings were also examined to determine what display elements pilots considered to be of little value, i.e., those display elements receiving a mean rating of 2.0 or lower. These items are presented in Table 3 in order of lowest need. The ratings identified three display elements that received low ratings through all four operational phases: railroads, magnetic variation, and helicopter landing pads. Additionally, subsets of display elements could be determined based on similarities in operational phases, i.e., *on* the ground versus *near* the ground. For ground operations, the ratings show the low value for geographical elements such as airport beacons, trees, and water features. For operations near the airport surface, low rated items consisted of display elements regarding buildings.

Comparison with GA Pilots

The ratings from the air transport pilots may be compared to the GA ratings to determine the degree of similarity between the two groups. For the purposes of this analysis, the display elements that received a rating of 4.0 or higher for both populations were compared. The results showed approximately 60% agreement between air transport pilots and GA pilots regarding which display elements were high need. The similarities in high need display elements were greater for taxi phases, in which approximately 68% of the display elements were in common, than for phases near the surface (50% of the display elements in common). The comparison showed three similarities between air transport and GA ratings: (1) high value for traffic location information and other data about traffic, available with the introduction of ADS-B, throughout all four operational phases, (2) high value for information regarding taxiways and airport geography for taxi operations on the surface, and (3) a drop in ratings for runway information during taxi in relative to the other three phases.

In general, the differences in high need items were largely attributable to the differences in the types of operations. For example, air transport pilots rated the depiction of ownship position higher than GA pilots for three of the four operational phases. This result may be attributable to differences in the complexity of the airports to which the two pilot populations are accustomed. Typically, air transport operations are conducted at larger, more complex airports than those used by GA pilots. As a result, a constant indication of aircraft location with respect to the airport surface could be especially valuable.

DISCUSSION

The goal of this research was to identify the value air transport pilots place on various display elements for different operations on or near the airport surface. The results showed that only a handful of elements were rated useful for all operations. These elements provided information regarding

the location of runways and the position of other vehicles and aircraft. More importantly, the results demonstrate the changing value of display elements for operations on or near the airport surface, similar to that reported by Schvaneveldt, et al. (2001) for flight phases.

Our results were recently presented to a group of subject matter experts from the Society of Automotive Engineers (SAE) G-10 Aeronautical Charting sub-committee. This group is drafting an Aerospace Recommended Practice (ARP) document to recommend priorities for display elements on electronic database-driven charts. While the scope of the display elements and the operational phases considered by the SAE group was considerably greater than those examined here, there was some overlap, and a preliminary analysis was conducted to assess the level of agreement between our air transport ratings and the draft ARP priorities for surface operations. The results of the analysis showed general agreement in the pilot ratings, but highlighted the fact that our questionnaire did not consider the situational context for different display elements. For example, pilots were not asked to consider the need for display elements for non-normal operations or atypical airfields. Hence, it is important to note that low ratings for an item may not indicate low need for the item at all times but rather, they may simply suggest that the item is used infrequently, may be non critical, or have limited utility in dynamic situations.

The results presented here provide a starting point in examining display element priorities. The results suggest the need for more data from air transport pilots. First, the data collected from 19 pilots was not sufficient for rigorous statistical analysis, despite the fact that the pilot population was fairly homogenous. All 19 pilots worked for the same commercial airline and 17 of the 19 pilots flew the same type of aircraft. Second, the information analysis was focused on pilot self-reports and still need to be validated through simulation, as there is evidence that pilots do not always perform best with what they say they prefer (Andre and Wickens, 1995). Nevertheless, the results provide some insight into the value of display elements for air transport operations and are of interest to designers of surface map displays.

The pilot is inundated with information about operations on the airport surface. Sources range from paper charts to that shown on flight deck displays to new surveillance capabilities such as ADS-B. The goal of the designer is to transform all the information available into a usable form. The changing value of display elements highlights the need for user-configurable displays and/or intelligent displays that provide pilots with the most appropriate elements depending on the current operation. The results reported here contribute to an understanding of what information is needed for surface operations.

ACKNOWLEDGEMENTS

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