AIRCRAFT LOCALIZATION USING ELECTRONIC MAPS

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The purpose of the present study was to examine the effects of rotation of map display, the relative position of aircraft, and compass format on a pilot's ability to localize traffic in his or her airspace. The experiment showed that percent error was significantly affected by all three variables, but further examination of the maps themselves revealed several different types of errors that occurred on some of the maps. One of these errors, referred to as a distortion error, is a phenomenon that raises new safety concerns about the ability of pilots to effectively localize traffic so that they will make appropriate maneuver decisions.

With the potential for increased air traffic in General Aviation (GA), the risk of Mid-Air collisions and growing interest in Free Flight, research on the factors associated with aircraft separation maintenance becomes necessary. Should Free Flight become implemented in future air travel, particularly in GA, localization of other aircraft will become essential. Research on Cockpit Displays of Traffic Information (CDTI) has been around for over 20 years, (Hart and Loomis, 1980), but due to costs and other concerns CDTI is not likely to surface in GA cockpits anytime soon. Since pilots will not be able to rely on CDTI for localization of traffic, pilots must communicate their own position through the use of current GPS technology and a radio. Since traffic localization requires not only knowing one's own position, but also the position of traffic in one's airspace, it is important to consider the types of displays that support this task in current in GA cockpits.

Viewing an electronic map display indicating current heading, pilots are able to navigate through their airspace. Issues surrounding navigation include the types of displays most appropriate for various tasks imposed on pilots. North-up displays are preferred when tasks require a world-centered reference frame, while track-up maps are best when tasks require an ego-centered reference frame (Aretz, 1991). Wickens and Prevett (1995) report that local guidance tasks (which take place in the pilot's forward field of view) are ego-centered and therefore a track-up map indicating current heading is more appropriate. Global awareness tasks, such as localization of other traffic, are world-centered and require a north-up map that indicates the relative position of objects in the pilot's airspace (Wickens and Prevett).

Unfortunately, electronic map displays that are currently available to GA pilots show a rotating compass to reflect a pilot's current heading, which can make traffic localization on such a display difficult. This means that the dual tasks of navigation and traffic localization cannot be done easily on the same display. Although research has been done on creating a dual display sufficient for completing both tasks (cf. Tlauka, Stanton, and McKenna, 2000), such a display is not currently available. If localization of traffic is to be done with existing electronic map displays, other relevant issues must be considered.

One such issue is the Two-Point Theorem introduced by Levine (1982) to explain why at least two landmarks are necessary to match the orientation of the map to the orientation of the actual environment. In addition to this theory, Levine, Jankovic, and Palij (1982) hypothesized that forward-up equivalence, the notion that the map should be aligned with the orientation of the environment, is necessary for optimal performance in spatial tasks. In opposition to the Levine et al. theories, Sholl (1987) theorized that a cognitive map acts as an orienting schema driving environmental exploration, rather than have a specific orientation. Another useful theory when studying electronic map displays is the idea that an image can be mentally rotated to align it with the environment. Shepard and Hurwitz (1984) and Aretz and Wickens (1992) report studies in which there is evidence that mental rotation occurs. However, this research also indicates that there is a cost in response time due to mental rotation, which presents implications for safety issues. Direct application of such theories in an aviation task was done by Aretz and Wickens regarding self-localization. Peterson and Maas (2001) expanded on the notion of self-localization to consider what would happen when participants were asked to localize other aircraft on their display using auditory location information.

Previous research regarding other localization using existing displays has found that the rotation of maps affects an individual's ability to localize traffic on a display, and the relative position of aircraft with respect to a given landmark also affects performance

(Peterson and Maas, 2001). It is important to note that the Peterson and Maas study used non-pilots as participants, and therefore the conclusions cannot be generalized to the licensed pilot population.

Current Research

The purpose of the present study was to extend the findings on the effect of traffic localization based on the experiments previously conducted by Peterson and Maas (2001), using licensed general aviation pilots. As with the Peterson and Maas research, it was expected that rotation of the map displays would again affect performance, such that as the rotation moved further from North (0/360 degrees), the response times and error would increase. The current study also revisited an issue addressed in Peterson and Maas regarding the notion of quadrants based on the position of aircraft on the display. It appeared that traffic located opposite the pilot's aircraft on the display (opposite quadrant condition) was easier to localize than traffic located on the same side of the display (same quadrant condition), and the placement of aircraft relative to the landmarks was similar to the aircraft depicted in Figure 1. In addition to map rotation and relative position of aircraft, changes to the compass format were expected to affect pilot performance. The types of displays general aviation pilots typically view include a compass that uses both numbers and letters to indicate the direction in which a pilot is currently heading. Because information about traffic location is given with reference to cardinal compass directions, performance was expected to improve when the compass included letters.

Method

Participants. The current study employed 17 licensed pilots from the Midwest. The ages of the pilots ranged from twenty-five to sixty-five (M = 49), and their years of flying ranged from one to forty (M = 16).

Experimental Design. A 7 x 3 x 2 (map rotation x compass format x relative position) within-subjects factorial design was used. The first variable, Rotation, varied from 0 to 180 degrees in 30-degree increments. The second variable, Compass Format, was presented with a compass ring indicating directions that were depicted with either **letters** or **numbers**, or a **combination** of letters and numbers. For the third variable, Relative Position, aircraft were either on opposite sides if an imaginary line or on the same side of the line formed by the reference points on the display (Figure 1 a & b).

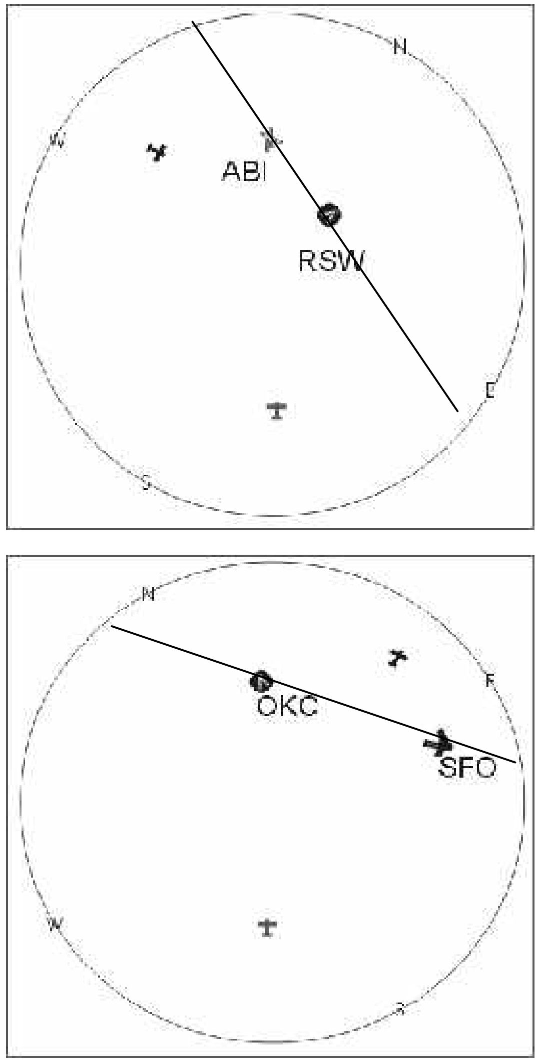

Figure 1 a & b. Same side and Opposite side.

Procedure. The displays consisted of a single aircraft located at the bottom center of the display depicting the pilot's current heading. The pilot's aircraft is depicted in Figure 2. Two other objects representing the location of reference airports were also included on the display. The background was provided by sectional charts to supply a more realistic experience for the pilots.

At the onset of a trial, the display was presented on a computer monitor followed 3 seconds later by location information. Pilots heard locations through an aviation headset. Pilots were allowed to hear the location information only once, and then they were required to make a judgment regarding the position of traffic by moving the cursor to that location and clicking on the display. For instance, the pilots would hear "Minneapolis traffic, Mooney 231BT, 20 miles W-SW of Minneapolis." Participants indicated the position of traffic by clicking on the display. The display that corresponds with the above location is shown in Figure 2. There were 3 practice trials followed by 42 actual trials.

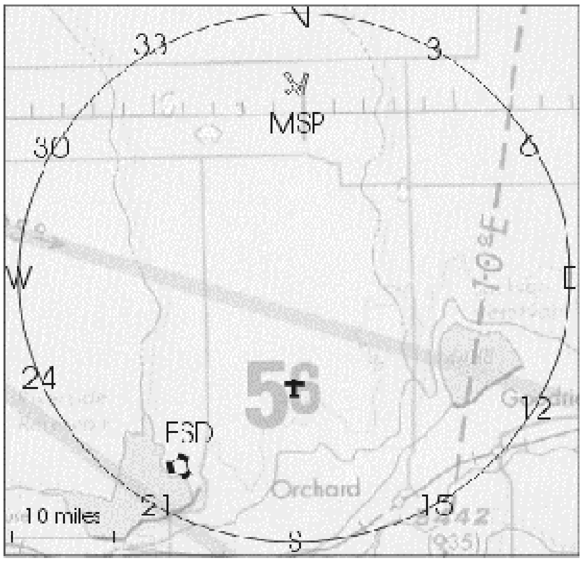

Figure 2. Sample map display.

Results

Error. Error was calculated using the actual position of traffic and the mouse click position. Percent error was recorded to compensate for the natural tendency of error to increase with distance from the reference point.

As expected, Rotation was found to have a significant effect on percent error, $F(6, 96) = 11.61$, $p < .05$. Figure 3 shows the M-shaped line associated with this effect.

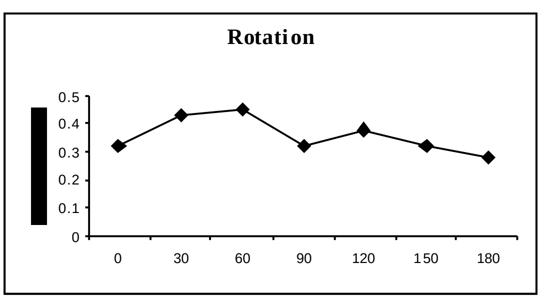

Figure 3. Percent Error as a function of Rotation.

Figure 4 shows the significant effect of Relative Position on percent error, $F(1, 16) = 5.67$, $p < .05$, such that more errors were unexpectedly made in the **opposite** condition.

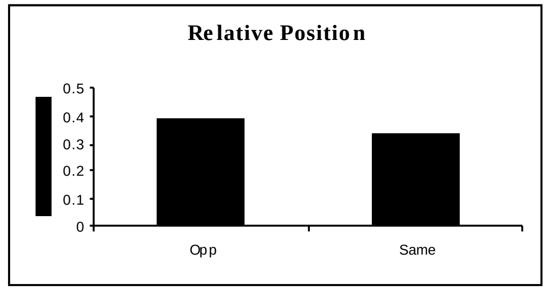

Figure 4. Percent Error as a function of Relative Position.

The significant effect that Compass Format had on error, $F(2, 32) = 4.64$, $p < .05$, is depicted in Figure 5. As expected, percent error was smallest in the **letter** compass format and greatest in the **number** compass format. However, the difference between the three conditions is rather small (.32, .40, .36 for **letter**, **number**, and **combination** respectively).

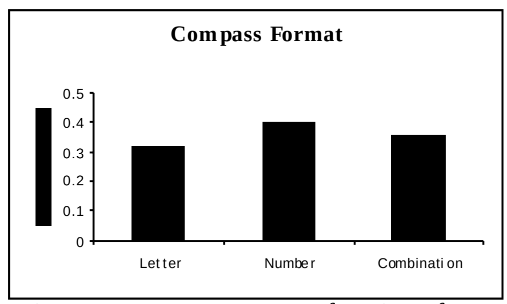

Figure 5. Percent Error as a function of Compass Format.

Response Time. Response time was recorded based on the time that elapsed between initial presentation of the display and the mouse click, which signaled the end of a trial. As with error, response time was affected by the distance between the reference point and the target aircraft. That is, response time increased as the distance between the two objects increased. Because of this unexpected effect, the significant results that occurred made interpretation difficult as to how Rotation, Compass Format, and Relative Position actually affected response time. To confirm the relationship between distance and response time the various map conditions were divided into two distance groups, Near and Far. All the maps that referred to landmarks that were 20 miles or less from the target aircraft fell in the Near group, with a mean response time of 14.81 seconds. Landmarks 21 miles or more from the target aircraft fell in the Far group, with a mean response time of 16.73. As a result of the new analysis, distance was found to have a significant affect on response time.

Classification of Error Type

While percent error was significantly affected by map rotation, compass format and relative position, percent error does not indicate the types of errors that have occurred. To examine the source of errors, each response was plotted on a map as shown in Figure 6. The errors that were found were categorized as distance errors, random (unexplained) errors, or distortion errors. Distance errors were those were made when pilots were accurate in the direction in which they localized traffic, but were not accurate in distance from the reference point. There was no systematic rationale for the occurrence of random errors, but one possibility is that a pilot may have simply misheard the directions.

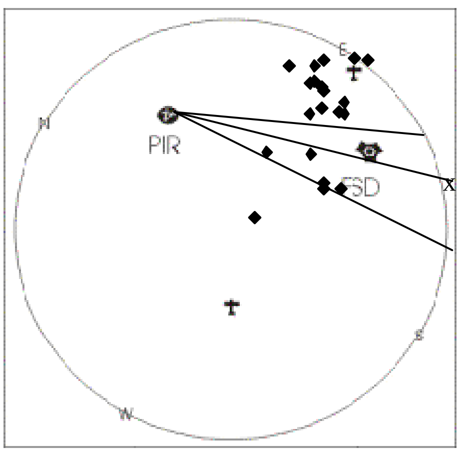

Figure 6. Sample map with distortion errors.

A distortion error is made when a pilot moves in an inappropriate direction toward the place on the compass ring that corresponds with the direction presented in the instructions as if the reference point is located in the center of the compass ring as opposed to its actual location.

The pilots were instructed to click on the map 25 miles southeast of PIR. The 'X' on the map indicates where southeast is on the compass ring, however the target aircraft is in its actual position on the display.

Tables 1, 2, and 3 show the number of distortion errors that were made for Rotation, Compass Format, and Relative Position respectively.

Table 1. Distribution of distortion errors by Rotation.

Rotation	Number of Distortion Errors
0	41
30	29
60	32
90	13
120	27
150	33
180	20

Table 2. Distribution of distortion errors by Compass Format.

Compass Format	Number of Distortion Errors
Letter	57
Number	63
Both	75

Table 3. Distribution of distortion errors by Relative Position.

Relative Position	Number of Distortion Errors
Same	103
Opposite	92

Maps that did not yield distortion errors, and what appeared to be only distance errors consistently had target aircraft that were actually in the direction from the reference point that also fell on the compass ring. Figure 7 is an example of a map condition in which this was the case.

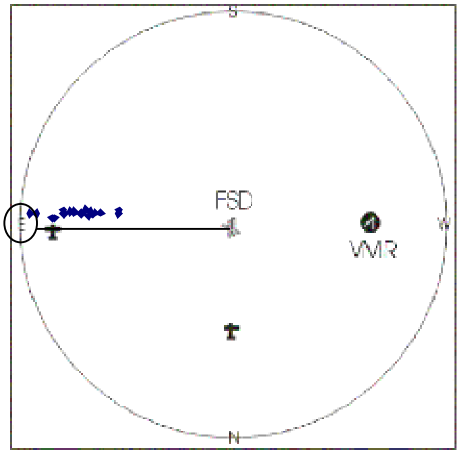

Figure 7. A map without a distortion error.

The distribution of the errors was analyzed using Chi-square. The analysis revealed a significant relationship between Rotation and the number of distortion errors that occurred, $X^2(6, n = 195) = 42.25$, $p < .05$. The largest number of distortion errors occurred for the 0-degree map condition. The question that stems from this result is why would there more be more errors in presumably the easiest condition? The fact that it is the easiest may be the answer. Because no mental rotation was required for these maps, the pilots who committed distortion errors may have been easily distracted by the compass ring, not taking the time to really study the maps. A closer look at some of the maps supports this notion. Another explanation is which reference point was used and the location of that reference point. That is, some rotations may have been less difficult overall because of the reference points that were used. The reference points were chosen at random, and as a result may have made some conditions more difficult than others.

Conclusions

In general the results revealed that display factors do affect performance in the localization of other aircraft using electronic displays. Not only did Rotation significantly affect percent error, the M-shape in Figure 3 clearly demonstrates that a pattern consistent with the findings of Peterson and Maas (2001) was present. Even though the effects of both Compass Format and Relative Position on percent error were significant, they are more difficult to explain in the presence of things such as distortion errors. The results pertaining to Relative Position were inconsistent with the previous research, which prompted further study. One key difference was that Peterson and Maas used location information based on both reference points and generated by a second research participant. It is possible that the tendency to divide the display was more of a factor in how the location information was presented than in how it was interpreted. Should Relative Position be considered in future research, it would be more appropriate to include both reference points when localizing traffic so that the difference between the two conditions can be better distinguished. As for Compass Format, the difference between the three conditions with respect to percent error is actually quite small (e.g., less than .08 between conditions). Although the number condition was expected to show the greatest amount of error, it is possible that the difficulty in that condition was due to something else (distortion or random errors).

While the experiment was not intended to study the effect of distortion on error or response time, it clearly had an effect on pilot performance. One concern as a result of this study is the safety implications of distortion. If pilots are to make a maneuver based on traffic localization, distortion errors present the potential for a collision. Explanations for such errors include the less difficult 0-degree rotation and the reference points selected for each map. A more thorough investigation of the effect of distortion on traffic localization is needed before drawing any final conclusions.

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