A Preliminary Examination of Situation Awareness and Pilot Performance in a Synthetic Vision Environment

Julie M. Stark[1], J. Raymond Comstock, Jr[2]., Lance J. Prinzel[2],
Daniel W. Burdette[3], and Mark W. Scerbo[1]
[1] Old Dominion University, Norfolk VA
[2] NASA Langley, Hampton VA
[3] Lockheed Martin Langley Program Office, Hampton VA

Synthetic vision displays utilize computer generated imagery derived from an onboard database of terrain, obstacle, and airport information to provide pilots with an unobstructed view of the world ahead. A major goal of these displays is to reduce low visibility related aviation accidents such as CFIT. In addition to improving pilot performance, synthetic vision displays may also affect pilot situation awareness. Prototype synthetic vision displays were examined in a high-resolution graphics simulation facility at NASA Langley Research Center. Two display sizes, two fields of view, and the presence of a tunnel guidance system were manipulated to investigate the effects on pilot performance and situation awareness. Use of a tunnel guidance system improved pilot performance and lowered reported mental workload. Participants reported lower workload and increased situation awareness with the smaller display size. There were no profound performance differences as a function of display size. Implications of retrofitting synthetic vision displays into existing aircrafts is discussed.

Display technologies designed to enhance pilot situation awareness (SA) are of prime importance during periods of reduced visibility. The problem of reduced visibility is commonly cited by the NTSB as the largest contributing factor to fatal aircraft accidents. Wiener and Nagel (1988) suggests that the most problematic outcome of limited visibility is controlled flight into terrain (CFIT) accidents.

Modern aircraft implement advanced systems designed to enhance spatial awareness to prevent CFIT and runway incursion (RI) incidents. However, the occurrence of these types of incidents suggests that current ground proximity warnings systems may not be sufficient. One problem may be that the 60-second warning provided by ground proximity warning systems (GPWS) does not always provide an adequate amount of time to successfully avoid terrain.

For example, American Airlines Flight 965 crashed during controlled flight on approach to Cali, Columbia in 1995. The Boeing 757 was equipped with GPWS and the incident occurred during clear weather night operations. The GPWS warning did not occur in time for the crew to avoid the terrain. The probable cause of the crash was attributed to loss of crew SA. The FAA cited this incident, along with similar others, as support for the need for systems that can adequately warn pilots of impending terrain and other hazardous obstacles. The need for technologically advanced systems that convey this type of information in a timely manner is extremely apparent.

Synthetic vision systems (SVS) convey exactly this type of information. SVS incorporate database information on visual representations of terrain and other obstacles and may incorporate real time information on weather and air traffic. These systems can potentially include display warnings, alerts, and advisories that can aid in tactical guidance decisions that in turn render safety and operational benefits. The overall goal of a synthetic vision system is to improve a pilot's ability to visualize the aircraft relative to the outside environment. The system is designed to provide the pilot with a perspective view that is highly intuitive. Further, the philosophy of SVS designs is to incorporate a display that is congruent with the pilot's natural mode of spatial information gathering.

The Synthetic Vision Systems Program under NASA's Aviation Safety Program maintains a goal of reducing low visibility accidents. The SVS program set out to design intuitive displays that integrate database information of terrain and obstacles with real-time information regarding air traffic, weather, and airport information. A pivotal objective of this program is to facilitate proactive avoidance of CFIT or RI. This is important because the majority of CFIT and RI incidents are attributed to a pilot's loss of SA at critical times in the flight profile.

SVS displays are designed to improve pilots' spatial situational awareness by presenting the relative location of objects within the environment. This type of display conveys information such as the aircraft's position, location of terrain and other ground-based obstacles, positions of other important landmarks (e.g., airports) and may provide information regarding current atmospheric conditions such as turbulence and thunderstorms.

Given the types of displays inherent in SVS, it is important to identify which perceptual cues will most enhance a pilot's spatial situational awareness. The perceptual issues regarding display size and field of view (FOV) manipulations are very important. The size of the display is largely driven by the existing cockpit configuration. As such, the display size must be compatible with older aircraft displays to mitigate retrofit issues. Of course, the FOV must also be compatible with the display size yet at the same time provide sufficient display area to promote enhanced visibility and spatial SA.

Along with display size and FOV, the perceptual impact of tunnel guidance systems must be considered. Wiener and Nagel (1988) describe the tunnel-in-the-sky concept as a three-dimensional pathway guidance system that serves to guide pilots to their destination. Tunnel guidance systems have been shown to improve pilot performance as well as reduce pilot workload (Regal & Whittington, 1995). The impact of tunnel guidance systems on pilot performance and SA is still under investigation.

The present study was designed to extend the results of Comstock et al. (2001) and to explore varying display sizes, fields of view, and the impact of tunnel guidance in a synthetic vision display. A tunnel guidance system was present in half of the trials. Two horizontal FOVs and two display sizes were manipulated within subjects and all combinations were presented to each subject. The FOV and display size was not pilot selectable and remained constant throughout each trial. It was expected that the use of tunnel guidance would improve pilot performance, increase SA, and decrease workload. Significant performance differences were expected for the different FOV conditions. No significant differences in performance were expected between the two display sizes. The effect on SA produced by the different display sizes and fields of view was explored.

METHODOLOGY

Participants and Simulation Facility

Six pilots (five men, 1 woman) with normal or corrected-to-normal vision participated in the study. Pilot experience varied: three participants had previous military experience; one pilot was transport-rated; and all pilots had extensive simulator training.

The NASA-LaRC Visual Imaging Simulator for Transport Aircraft Systems – Generation 1 (VISTAS 1) was used. VISTAS 1 is a highly flexible, rapidly reconfigurable, large-screen flight display workstation for evaluation of a wide variety of enhanced/synthetic vision and spatial display formats. The aircraft model in the simulation in the High Speed Civil Transport, but with reduced approach pitch attitude to more closely match subsonic transports. The flight path command system incorporated rate command attitude control and was auto trimming.

The VISTAS 1 facility consists of two back-of-the-panel projectors (JVC model DLA-S10U) to produce a 38 x 51 cm (standard 3:4 aspect ratio) image with a 1280 x 1024 pixel resolution. Only the left projector was used in the current study. An out-the-window (OTW) representation of the forward cockpit window was also presented. The OTW view is simulated by a high-resolution, ceiling- mounted projector (Electrohome Marquee 8000) directed at a 2 meter wide curved screen located about 2.5 meters in front of the SVS display.

Simulator testing sessions were conducted using the Asheville (AVL) North Carolina database. AVL was chosen from a list of domestic "terrain challenged" airports as a location for which the desired Digital Terrain Elevation Data (DTED) and aerial photography could be obtained for flight and simulation testing. The AVL scene was generated using a Silicon Graphics Onyx-2 Infinite Reality computer. The SVS primary flight display presented the perspective terrain with photo-texturing of terrain features around the airport. Photo-texturing involves superimposing high altitude photography onto database terrain elevation information to produce a realistic perspective scene. The photo-texturing area constructed for this simulation was three miles wide by eight miles long, centered around AVL. Generic shading of terrain features was presented outside of the photo-textured area.

SVS Display Sizes and Fields-of-View

Two display sizes were manipulated within-subjects in the current study. The smaller display (A/B) is 12.9 x 12.6 cm. This display approximates the size of the Electronic Attitude Director Indicator (EADI) in the current generation 757 aircraft along with traditional round-dial representation of airspeed, altitude, and vertical rate indicators (9.5 cm diameter). This display concept represents the case of extracting the current EADI and replacing it with a SVS display. The larger display (D) is 16.0 x. 16.0 cm. This display approximates the size of the CRT primary flight display in the 747-400 or the flat panel display in the 777. This display incorporates airspeed, altitude, and vertical rate information in a "tape" format.

Both SVS displays have superimposed "HUD-like" symbology displaying the horizon, body axis indicator (waterline symbol), pitch information, roll scale, horizontal and vertical path deviation scales, radar altitude (below 500 feel AGL), and the flight path vector. A rudimentary navigation display is also presented with each size display. The navigation display indicates moving map format waypoints (track-up) along a programmed path. Pilots could adjust the range scale on the navigation display from 4 to 80 miles.

Subjective Measures

Workload ratings were measured using the NASA Task Load Index (NASA-TLX) which consists of six scales to assess the relative contributions of task, behavior, and subject related experiences along six dimensions of workload: effort, frustration, performance, mental demand, physical demand, and temporal demand (Hart & Staveland, 1987). A higher composite score on the TLX indicates increased mental workload. The Situational Awareness Rating Technique (SART; Taylor, 1990) was also given to participants. The SART is a questionnaire that assesses the pilot's knowledge in three areas: demands on attentional resources, supply of attentional resources, and understanding of the situation. The SART questionnaire items can be summed to produce a composite assessment of SA or assessed by construct. A higher SART score indicates increased SA. A questionnaire was constructed to ascertain pilots' subjective comparison of the different FOVs and tunnel for each display size. A questionnaire was also given after completion of all scenarios in which open ended questions were asked regarding the different candidate SVS displays.

Upon arrival, participants were given a brief study overview and completed a brief demographic questionnaire. Pilots were given training on the VISTAS facility. Pilots practiced all eight combinations of display size, FOV, and tunnel during the training session. After completion of the training, pilots completed multiple approaches to AVL. Six different scenarios were utilized. Three scenarios consisted of approaches to a north-bound runway (AVL RWY 34) and three to a south-bound runway (AVL RWY 16). The FOV and tunnel presentation order was counterbalanced across subjects for each display size. Display size was not counterbalanced because it was thought that switching back and forth between the two different display sizes would have a disruptive affect on pilot performance. Two mile limited visibility due to fog was simulated on the OTW scene to reduce pilot reliance on OTW information during the approaches.

RESULTS

A series of repeated measures general linear model analyses of variance (GLM-ANOVA) was conducted with an a priori alpha level set at .05. Mean horizontal and vertical path error were assessed as the primary dependent measures.

Mean Horizontal Path Error Results

An ANOVA revealed a significant tunnel main effect for horizontal path error, $F(1,5)=38.23$, $p<.05$. Pilots demonstrated significantly less horizontal path error with the tunnel (M =72.92 ft, SD=19.36) than without the tunnel (M =250.19 ft, SD=32.63). There was also a segment main effect for horizontal error, $F(4,20)=11.31$, $p<.05$. As expected, pilots demonstrated less horizontal error as the experiment progressed with the least amount of error in the last segment prior to landing. There was a significant interaction between segment and FOV, $F(4,2) = 16.89$, $p<.05$. A significant segment by tunnel interaction was also demonstrated for horizontal path error, $F(4,20)=31.99$, $p<.05$.

Mean Vertical Path Error Results

An ANOVA revealed a tunnel main effect for mean vertical path error, F $(1,5)=9.27$, $p<.05$. Pilots demonstrated less error with the tunnel (M=3.20 ft, SD=4.29) than without the tunnel (M=47.66 ft, SD=12.82). There was also an interaction between display size and tunnel for vertical path error, $F(1,5)=7.22$, $p<.05$. Pilots displayed the least amount of vertical path error with the size D display with the tunnel (M=.40, SD=4.26) and the greatest vertical path error with the size D display without the tunnel (M=76.48, SD=16.10).

Subjective Results

A tunnel main effect was revealed for workload by the TLX, $F(1,5)=7.22$, $p<.05$. That is, pilots reported lower workload during scenarios with the tunnel (M=48.46, SD=1.69) than in scenarios without the tunnel (M=57.68, SD=1.36). There was also a significant effect of display size for workload, $F(1,5)=14.23$, $p<.05$. Pilots reported lower workload with the smaller display (M=49.93, SD=.38) than with the larger display (M=56.09, SD=1.22). An ANOVA of composite SART ratings revealed a FOV main effect for SA, $F(1,5)=7.22$, $p<.05$. Pilots reported increased SA with the 60 degree FOV (M=39.21, *SD*=.83) than with the 30 degree FOV. A display size main effect was also found for SA, $F(1,5)=13.99$, $p<.05$. Pilots reported greater SA with the smaller display size (M=39.30, SD=.37) than with the larger display size (M=36.26, SD=.40).

DISCUSSION

The goals of the current study were to support Comstock et al. (2001) and explore issues of display size, FOV, and tunnel guidance on pilot performance and SA. Tunnel guidance was expected to improve pilot performance, increase SA, and decrease workload. Initial results show partial support for these hypotheses. Both horizontal and vertical path error was indeed reduced by tunnel guidance. Pilots were able to stay on path more accurately with the assistance of the tunnel. This rather intuitive finding supports previous research (see Doherty & Wickens, 2001 for a review). This result also confirms pilots self-report; pilots verbally reported "feeling" like they were better able to stay on path when using the tunnel guidance system.

The tunnel guidance system also significantly reduced mental workload. These findings are congruent with vast research (i.e.; Barrows, 1997; Wickens et al. 1988) as well as subjective reports from the pilots. All pilots commented that they recognized the usefulness of the tunnel. One pilot commented that he was so "in tune" with the guidance system that it was almost "too easy" to fly. This may be why no significant differences were identified for SA. It is possible that providing pilots with the tunnel guidance system may lead to complacent behavior that interferes with SA.

Significant performance differences were also expected for the different FOV conditions. The only significant FOV finding for performance was an interaction between FOV and segment for horizontal path error. Pilots performed better at the last segment of the approach with the 60 degree FOV. Greater SA was also reported for the 60 degree FOV. There were no performance differences as a function of display size; further, pilots reported reduced workload and increased SA for the smaller display. This finding is quite important for practicality. The smaller (A/B) display size is easily retrofitable into older aircrafts and as such, is operationally more cost effective to implement.

The usefulness of SVS displays is unquestionable. Additional research is needed to identify how use of SVS displays can mitigate and/ or reduce aviation accidents. Future research needs to address attention switching in these complex, dynamic SVS display.

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