CAN EFFECTIVE SYNTHETIC VISION SYSTEM DISPLAYS BE IMPLEMENTED ON LIMITED SIZE DISPLAY SPACES?

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ABSTRACT

The Synthetic Vision Systems (SVS) element of the NASA Aviation Safety Program is striving to eliminate poor visibility as a causal factor in aircraft accidents, and to enhance operational capabilities of all types or aircraft. To accomplish these safety and situation awareness improvements, the SVS concepts are designed to provide a clear view of the world ahead through the display of computer generated imagery derived from an onboard database of terrain, obstacle and airport information. An important issue for the SVS concept is whether useful and effective Synthetic Vision System (SVS) displays can be implemented on limited size display spaces as would be required to implement this technology on older aircraft with physically smaller instrument spaces. In this study, prototype SVS displays were put on the following display sizes: (a) size "A" (e.g. 757 EADI), (b) form factor "D" (e.g. 777 PFD), and (c) new size "X" (Rectangular flat-panel, approximately 20 x 25 cm). Testing was conducted in a high-resolution graphics simulation facility at NASA Langley Research Center. Specific issues under test included the display size as noted above, the field-of-view (FOV) to be shown on the display and directly related to FOV is the degree of minification of the displayed image or picture. Using simulated approaches with display size and FOV conditions held constant no significant differences by these factors were found. Preferred FOV based on performance was determined by using approaches during which pilots could select FOV. Mean preference ratings for FOV were in the following order: (1) 30°, (2) Unity, (3) 60°, and (4) 90°, and held true for all display sizes tested. Limitations of the present study and future research directions are discussed.

INTRODUCTION

The goals of the Synthetic Vision Systems (SVS) element of the NASA Aviation Safety Program are to eliminate poor visibility induced accidents and to enhance operational capabilities of all types of aircraft. To accomplish these safety and situation awareness improvements the SVS concept is designed to provide a clear view of the world ahead through the display of computer generated imagery derived from an onboard database of terrain, obstacle, and airport information. It has also been demonstrated in simulation and flight tests at the NASA Langley Research Center, that low-cost computers now have sufficient processing speed and power to combine the necessary database information to create a perspective view display scene.

Limited visibility has been cited as the single greatest contributing factor in many fatal worldwide airline and general aviation crashes. One major type of aviation accident involving visibility issues is Controlled Flight Into Terrain (CFIT) and is the greatest cause of aviation fatalities. A CFIT accident is defined as "one in which an otherwise-serviceable aircraft, under control of the crew, is flown (unintentionally) into terrain, obstacles or water, with no prior awareness on the part of the crew of the impending collision" (Wiener, 1977). In 1998, the CFIT accident rate reversed a downward trend and began getting worse (Khatwa and Roelen, 1996). Research and testing has begun on a revolutionary cockpit display system to provide the needed awareness and information to help avert these types of accidents. Such a system can be thought of as giving the flight crews sunny conditions all the time, at least as far as information presented on SVS displays is concerned.

There are considerable payoffs for such a system. For commercial transport aircraft, instant recognition and correction of visibility-induced errors would eliminate CFIT, and runway incursions (RI), if accurate traffic position information is incorporated in the system. Enders, et. al., (1996) note that worldwide the chances of CFIT accidents are 5 times higher in non-precision approaches, a problem which synthetic vision could help to solve. For General Aviation aircraft a lower cost implementation of such a system could help to prevent visibility-induced loss-of-control accidents by providing an intuitive, easy-to-fly visual reference for VMC-like (Visual Meteorological Conditions) operations in Instrument Meteorological Conditions. It would also be anticipated that SVS technology could serve to increase national airspace system capacity by providing the potential for VMC-like operations more of the time.

There are also payoffs for military applications. One such payoff would be a passive, onboard database-driven system immune to being blinded, spoofed, or detected. Such a system could provide visual approach capability to many worldwide airfields in low visibility conditions without surface equipment deployment requirements. Other military payoffs include worldwide terrain-following guidance in all weather and visibility conditions and realistic pre-mission simulation of flight to and from target areas. Another payoff would be a technology solution for crew laser protection by offering the potential for a windowless-cockpit flight capability.

To provide a better definition of the concept of operations (CONOPS) of synthetic vision technology for commercial and business aircraft, a workshop resulting in a CONOPS document was held in early 2000 (Williams, et. al., 2001). The focus of this event was to obtain wide ranging input on the benefits and features which synthetic vision might incorporate. This meeting included representatives from NASA, DoD, FAA, industry professional organizations, pilots, airlines, aircraft and avionics manufacturers, airports, and academic institutions.

Challenges to developing SVS

There are numerous challenges and research issues to explore in developing SVS display concepts. Many of these issues can be considered general human perceptual issues and include display size and Field-of-View (FOV) issues. Display size is driven largely by the need for displays compatible in size with older aircraft displays (the retrofit issue), current generation displays, and potential next generation larger display surfaces. Another approach to cover the retrofit issue, where aircraft are generally equipped with electro-mechanical gauges, is through Head-Up Display technology, but that issue is beyond the scope of the present paper.

For the present investigation, the primary questions center around the efficacy of using small display spaces for presentation of forward-looking perspective view terrain information with overlaid "HUD-like" graphical symbology. Three display sizes were evaluated in this study: (1) Size "A/B" representing the size of the Electronic Attitude Director Indicator (EADI) found on 757 aircraft, (2) Size "D" representing the size of the Primary Flight Display (PFD) on the 747-400 or 777, and (3) Size "X" representing a still larger advanced display. The exact size and details of these displays are presented later in the Methodology section. A related issue when displaying visual scene information is the scale factor to be used. Each display could be shown with unity gain in displayed visual angle making the display analogous to an electronic "window" of that size at the front of the aircraft, or the scene can be minified permitting additional angle to be shown on the display. A question to be answered by this study is whether there is an optimal Field-of-View for each display size. Figure 1 shows a SVS scene with phototexture on approach to the Asheville, NC airport.

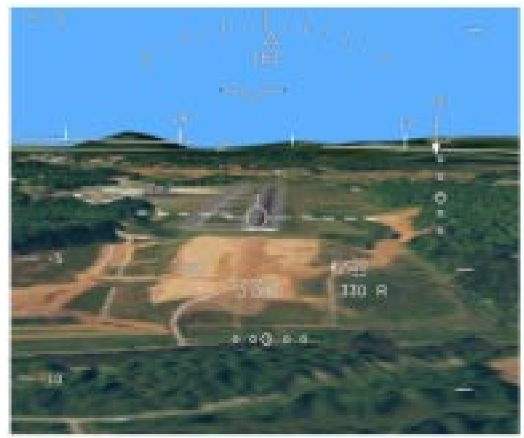

Figure 1. SVS photo-textured scene showing approach to Asheville, NC airport.

Beyond the issues noted above (the following issues will not be addressed in the present study but are noted here for completeness), there are other perceptual issues concerning the content and type of information in the pictorial scene. SVS display scenes can be constructed from terrain elevation data and smoothed with generic terrain algorithms or photorealistic terrain can be created by adding color and texture content information from aerial photographs. Another approach that has been employed elsewhere is the overlay of a "fishnet-like" grid of equally spaced gridlines as an important distance or depth cue. A research question to be answered is which type of information provides the best information and situation awareness gain to the pilot. Is the additional data cost and computing requirements for photorealistic terrain worthwhile in terms of enhancements to pilot performance? Another perceptual issue concerns the portrayal of obstacles (buildings, towers, etc.) in the database. What type of rendering, coloring, highlighting, coding, and range filtering (when not to show, clutter issue) should be employed?

Additional display issues to be addressed in future studies include the following: (1) Examination of the utility of presentation of SVS-like information on the Navigation Display, (2) Integrating SVS database information with enhanced vision sensors (e.g., millimeter wave radar, forward-looking infrared camera images) to confirm position with "truth" data, and (3) Formatting issues when presenting traffic, weather, obstacle, and terrain information all simultaneously.

The focus of the present study was on evaluating candidate Fields-of-View on each of the three display sizes under test on approach and landing tasks. Specific hypotheses include the following:

(1) All display sizes would provide adequate information for the successful conduct of the approach and landing tasks, as determined by performance and subjective response data.

(2) There is an optimal or preferred Field-of-View for each display size as reflected in pilot selectable trials and in subjective response data.

METHODOLOGY

Subjects and Simulation Facility

Separate simulator testing sessions were conducted for the Asheville (AVL), North Carolina, database and for the Dallas-Fort Worth (DFW), Texas, database. For the Asheville test sessions eight transport-rated pilots served as test subjects. Asheville was chosen prior to this study 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. Six additional transport-rated pilots served as test subjects for the DFW test sessions. These test sessions were part of training sessions for pilots involved in subsequent flight tests at DFW using the NASA 757 aircraft. This location was chosen to represent a high-density visual scene airport area.

The VISTAS I (Visual Imaging Simulation for Transport Aircraft Systems) facility at the NASA Langley Research Center was used for evaluating synthetic vision display concepts for both areas. The VISTAS I facility consists of a large head-down display surface which uses two back-of-the-panel projectors (JVC model DLA-S10U) to achieve approximately 70° horizontal field-of-view from the pilot's designed eye point. For this study only the left of the two projectors was used. An "out-the-window" scene was available through a ceiling mounted projector (Electrohome Marquee 8000) directed at a large curved screen above and about 2.5 meters beyond the top of the head-down display area. To reduce pilot reliance on using this scene in place of the synthetic vision head-down display, simulated fog, restricting visibility to about 5 miles, was used on the AVL test trials. This capability was not available for the DFW scene. The aircraft model in the simulation was 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 AVL scene and displays were generated using a Silicon Graphics, Inc., Onyx-2, Infinite Reality computer. The DFW scene and head down displays were generated using two Intergraph model ZX-1, computers each with two Intel Pentium III processors. The Intergraph computers were running the Windows NT operating system and used Wildcat model 4110 high-speed graphics cards.

SVS Display Sizes and Format

Three display sizes were evaluated in the study and the dimensions of these SVS display concepts are shown in Table 1. The smallest size, designated "A/B", approximated the size of the EADI in the current generation 757 aircraft along with traditional round-dial representations of the airspeed, altitude, and vertical rate indicators, that were about 9.5 cm in diameter. This display concept represented the case of extracting the current EADI and replacing it with a SVS display. The "A/B" size SVS display concept did not incorporate airspeed or altitude information, as this information could be obtained from the traditional round dial instruments adjacent to the SVS display. The next size represented a form factor "D" display, the size of the CRT primary flight display in the 747-400 or the flat panel display in the 777 aircraft. The largest of the displays tested, designated "X" represents the approximate size of popular flat panel displays as found on laptop computers.

TABLE 1
Dimensions of head-down SVS displays and Field-of-View angles from pilot eye-point.

	Size "A/B"	Size "D"	Size "X"
Width	12.9 cm	16.0 cm	25.0 cm
Height	12.6 cm	16.0 cm	20.2 cm
Horiz.	11.5°	14.2°	22.0°
Vert.	11.2°	14.2°	17.8°

Both the "D" and "X" displays were PFDs and incorporated airspeed, altitude, and vertical rate information in a "tape" format. All sizes of SVS displays had superimposed symbology showing the horizon, body axis indicator (waterline symbol), pitch information, roll scale, horizontal and vertical path deviation scales, radar altitude (below 500 feet above ground level), and the flight path vector.

A rudimentary navigation display was presented for each of the three display sizes. The navigation display showed moving map format waypoints (track-up) along the programmed magenta path but contained no terrain information or features. The SVS primary flight display showed the perspective terrain with photo-texturing of terrain features around the airport area. Photo-texturing consists of superimposing of high altitude photography on the terrain elevation information, such that a realistic perspective scene can be constructed by the SVS display computer. At AVL the photo-texturing covered an area 3 miles wide by 8 miles long centered about the airport. Outside the photo-textured area, generic shading of terrain features was presented. At DFW the photo-textured area was larger extending in excess of 30 miles from the airport in all directions.

Display Field-of-View

For any of the three display sizes noted above, the field-of-view shown within the display area could be changed. At unity scaling, such that a degree on the display corresponds to a degree as seen out the window, the field-of-view for each display size is shown in the lower half of Table 1. By minification of the scene larger fields of view could be shown on each of the display sizes. For the present tests horizontal FOVs that could be selected included unity (see Table 1 for actual FOV), and 30° to 90° in 10° increments. One consequence of changing the FOV was that the pitch indicator scaling also changed such that it remained in agreement with the angular perspective of the synthetic scene. This meant a very limited pitch scale for the unity FOV condition especially for the size "A/B" display (11.2°), as contrasted with the traditional PFD having about a 50° vertical pitch scale visible. For many of the experimental trials the FOV was selected according to the experimental test matrix and held fixed for the duration of the approach and landing scenario. On some selected trials, buttons at the pilot station were active and the pilot could change the FOV as desired at any point during the approach.

Procedure

For the AVL test sessions, six different scenarios were constructed. These consisted of three starting points for approaches to the North-bound runway (RWY 34) and three starting points for the South-bound runway (RWY 16). Using these scenarios, each test subject was presented each of the display size conditions and while display size was held constant, the FOVs were varied between unity, 30°, and 60° on subsequent trials. Additional pilot-selectable FOV trials were conducted for each display size condition. The order of presentation of display size was counterbalanced across subjects. The order of presentation of FOV was counterbalanced across display size conditions. Performance data and subjective ratings and comments were recorded throughout the trials.

The DFW test sessions consisted of a subset of the AVL FOV test conditions, as these trials were primarily training for the upcoming 757 flight tests. Scenarios included turns from downwind to base to final for different runways, and a runway change maneuver (sidestep) where the new runway to acquire had no raw glideslope or localizer information on the display, only the SVS scene.

RESULTS

There were two types of experimental trials during a test session for each subject. The first type involved holding display size and FOV at a fixed setting through the simulated approach and landing in order to measure performance during that particular display condition. The second type permitted pilot selection of the FOV any time during the approach in order to measure objectively preferred FOV. The results of each of these types of experimental trials for the AVL scenarios are presented below.

Performance effects

To examine the test subject's piloting precision, horizontal and vertical path error information was examined. For the test trials with fixed display size (3 levels) and FOV (3 levels), there were a total of nine combinations that could be compared at selected points on the approach. The absolute value of horizontal path error for these nine display configurations for five approach segments is shown in Figure 2. The approach segments consisted of mean path error derived over a 10,000 foot path segment. For example, the segment labeled "Seg-45" represents data obtained from –50,000 to –40,000 feet prior to runway threshold crossing. "Seg –35" represents the next 10,000 foot interval, with the additional flight segments calculated in the same manner.

A repeated measures analysis of variance conducted on these data showed a significant effect for flight segment ($F(4,28)=9.15$, $p<.01$), but no significant differences were noted for display size or FOV levels, or for any interactions of these conditions. The significant difference for flight segment is not surprising and shows the importance of being more accurately on the horizontal path in proximity to the runway threshold. The non-significant differences for the size and FOV conditions indicate that none of the display combinations were detrimental to maintaining horizontal path.

Vertical path error was examined next. The same method for defining flight segments was used as had been used with the horizontal path error data.

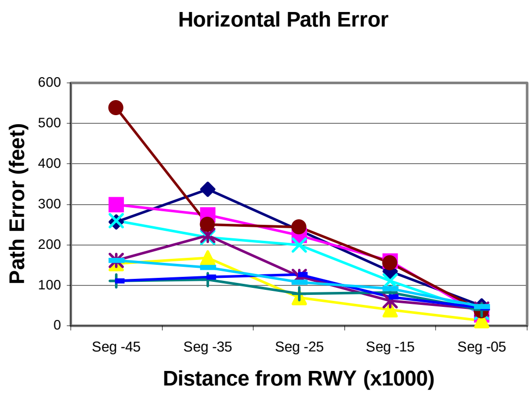

Figure 2. Horizontal Path Error as a function of distance from runway threshold.

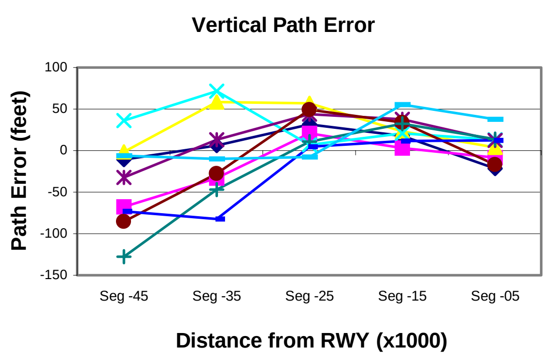

Figure 3. Vertical Path Error as a function of distance from runway threshold.

The vertical path error data by approach segment for each of the display size and FOV conditions are shown in Figure 3. A repeated measures analysis of variance conducted on these data showed a significant effect for flight segment ($F(4,28)=7.52$, $p<.01$), but no significant differences for the display size or FOV conditions or their interactions. As in the case for horizontal path, the significant difference by segment reflects decreased vertical error near the runway. No significant display size or FOV effects shows that no display condition was detrimental to maintaining vertical path error.

Preferred FOV

For the set of trials during which the test subject was free to change the Field-of-View setting at any time during the approach and landing task it was found that the FOV was changed to Unity (1:1 scaling; least minification) several miles prior to touchdown on 80% of the trials. The 30° FOV was selected on 15% of the trials, and a 60° FOV was selected on 5% of the trials. For analysis and plotting purposes, FOV selections between the major categories of 30°, 60°, and 90° were grouped with the nearest major category. The distance prior to runway threshold where the last change in FOV was made was tested with an Analysis of Variance and showed no significant difference by display size condition ($F(2,4)=.193$, $p>.83$). Changes in FOV were seldom made near the runway, and averaging across pilot selectable trials, the mean distance for the final FOV change was 3.7 nautical miles prior to runway threshold crossing. Figure 4 shows the amount of time that each FOV was selected for each of the display size conditions. It is interesting to note the decrease in larger FOV selections for the smaller display sizes, which matches subjective comments that indicated that information in the size "A" display "just gets too small" with larger FOV selections.

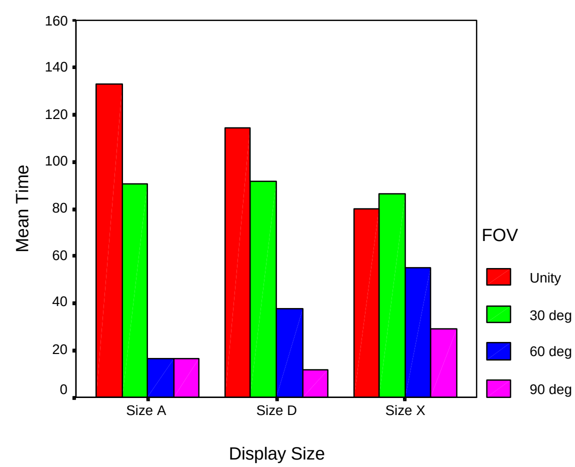

Figure 4. Mean Time (seconds) that each FOV was selected for each display size during pilot selectable trials.

The distribution of FOVs selected by the pilots and shown in Figure 4 is closely mirrored by subjective comments in answer to the question "If you could select only two FOVs to be displayed, which two would you choose?" In response to this question, 86% included Unity (1:1) in their choice of two FOVs, 57% chose 30°, and fewer selected the larger FOVs, where 28% chose

60°, and 28% chose 90° (totals to 200% due to choice of two FOVs).

Based on the mean ratings of the test subjects, the order of preference for FOV was in the following order: (1) 30°, (2) Unity, (3) 60°, and (4) 90°. It is interesting to note that all of the display sizes tested were rated in this same order.

DISCUSSION

Based on the data gathered in this study, the answer to the question posed by the title of this paper is that small display spaces, while not the preferred size, may be utilized without positional performance penalties when raw horizontal and vertical guidance information is present. Future studies will have to be conducted to investigate the efficacy of photo-realistic terrain versus other types of distance and depth cueing, especially when small display spaces are used.

A number of valuable comments were received from our test subjects. One limitation identified in the present study was that the FOVs evaluated may have been in steps or increments that were too large. For example, for the size "A/B" display, a selection between unity (11.5°) and 30° would have been desirable. Likewise a 45° selection would also have been advantageous to test. Another comment noted that small FOVs may make one "seasick" in turbulent conditions, unlike in the smooth air of this fixed-base test environment. The general philosophy noted by several subjects was that they would like a wide FOV at higher altitudes in order to spot traffic more easily, or to see areas they may be turning towards. Then they would like the ability to narrow the FOV prior to landing, at which point the runway would be the primary object of interest.

Another FOV issue surfaced as a result of the flight testing at DFW and can be further examined in future simulator testing. In those tests, cross-winds would drive the flightpath vector off-screen on the smaller display sizes with small FOVs. This and other findings regarding small FOVs calls for careful specification of the operational concept and requirements for the SVS PFD.

Display resolution is also an issue of importance to consider in the evaluation of candidate SVS displays on small spaces. In the present study, a single high-resolution projector created the back projected images creating the PFD, Navigation Display and all other ancillary instruments of interest. That meant that the PFD resolution or pixel count, since it was only a portion of the image, was considerably lower than what might be typical of a stand-alone flat-panel display of similar size. This means that the present method used in this study to generate the SVS display may understate the true quality that may be obtained on smaller display spaces.

A display format issue for future research is that of pitch scaling, especially if a display is capable of varied FOVs. Depending on how the display is designed, the pitch scale or "ladder" may vary with FOV, unlike the scale on conventional PFDs. A related issue is symbology, scaling, and scene content when unusual attitude recovery is required.

Other SVS display research perceptual issues include evaluations of how pilots handle discrepant information given the potential "compellingness" of pictorial scenes. Such an investigation might examine mismatches between "raw" guidance data, or other issues of sensor disagreement. The goal would be to make failures in a part of the system obvious. A related issue is that of examining attention switching when using complex, dynamic, information rich displays. Plans are presently underway to use eye-tracking technology in a series of studies of candidate SVS displays to assess the display features least and most used by pilots.

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