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DEVELOPMENT OF A STEREO 3-D PICTORIAL PRIMARY FLIGHT DISPLAY

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INTRODUCTION

Computer-generated displays are becoming increasingly popular in aerospace applications. The use of stereo 3-D technology provides an opportunity to present depth perceptions which otherwise might be lacking. In addition, the third dimension could also be used as an additional dimension along which information can be encoded.

Historically, the stereo 3-D displays have been used in entertainment, in experimental facilities, and in the handling of hazardous waste. In the last example, the source of the stereo images generally has been remotely controlled television camera pairs.

This paper describes the development of a stereo 3-D pictorial primary flight display used in a flight-simulation environment. The purpose of this research is to investigate the applicability of stereo 3-D displays for aerospace crew stations to meet the anticipated needs of the 2000-2020 time frame. Although the actual equipment that could be used in an aerospace vehicle is not currently available, the laboratory research is necessary to determine where stereo 3-D enhances the display of information and how the displays should be formatted.

HARDWARE/SOFTWARE CONFIGURATION

The hardware consists of a VAX 11/780 computer, an Adage 3000 raster programmable display generator (PDG), and a Stereographics 3-D display stereoscopic system. A FORTRAN aircraft simulation is used to provide parameters to the display programs residing in the Adage 3000. The display programs are written in a "C" language known as ICROSS-3000, with a graphics-enhancement package known as the Real-Time Animation Package (RAP). (RAP is a proprietary software product developed at the Research Triangle Institute.)

The Stereographics display uses liquid crystal shuttered glasses and specially adapted hardware which divides each video frame into two fields corresponding to the left- and right-eye views, each at half the resolution. The PDG outputs a 60-Hz repeat field, 512 x 512 pixel image. The stereo display system converts this input to a 120-Hz repeat field, 216 x 512 pixel output with

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alternating left- and right-eye fields. Figures 1 and 2 show a monocular version of the display. Figure 3 shows a similar display with left- and right-eye stereo views as they would appear on a conventional 60-Hz monitor. The Stereographics system converts the input shown in figure 3 and generates the stereo pairs similar to those in figures 1 and 2, but with only half the vertical resolution. The liquid crystal shuttered glasses are synchronized so that each eye sees only one of the stereo views.

A stereo image pair contains twice the information contained in a monocular image. Therefore, on a system with limited video bandwidth, either the video frame rate or the number of lines must be reduced when stereo displays are being generated. The current system maintains frame rate by halving the number of lines. Flicker, which was a problem with other systems, is thus eliminated. The system also performs the conversion of the video signal, and the PDG responds as if it were outputting its customary 60-Hz repeat field image. The liquid crystal shutter technology is much faster than the video frame-rate-display capabilities; therefore, the stereo system does not impose any bandwidth limitations.

DISPLAY FEATURES

The main features of the display are an own-ship symbol, a perspective follow-me target ship, two different 3-D tracks showing the path of the target ship, a ground grid around the runway, a pitch grid on both the left and right sides of the display, and digital readouts for altitude/heading/airspeed. The digital readouts display the instantaneous values for the own-ship and the desired preprogrammed flightpath. Because the own-ship remains fixed relative to the other display elements, an inside-out (i.e., moving horizon) display is represented.

Generating the Stereo 3-D Effect

The display program needs to generate the left- and right-eye views of the display. Given distinct x, y locations of each eye, the calculation of the viewing transformations are described by Foley and Van Dam (ref. 3).

Two parameters are used to control the stereo 3-D effect: zero-parallax distance and interocular separation. In general, parallax refers to the positional discrepancy in the left- and right-eye views of a point in the display. The parallax is zero when the corresponding points in each view occupy the same relative screen location. Points in the display at the zero-parallax distance from the eye appear to lie in the plane of the screen. Points closer to the pilot than the zero-parallax distance appear to lie in front of the screen, while points farther from the pilot appear to lie beyond the screen. In addition, the interocular distance controls the apparent relative depth of objects in the display. The greater the interocular distance, the more powerful the stereopsis effect. By comparing the apparent depth of the target ship with the own-ship symbol, the pilot has an indication of position error. This stereo 3-D effect reinforces the depth cue provided by the relative size of the perspective target ship.

When viewing objects in the natural environment, the eyes must perform the separate functions of converging and focusing on a point of interest. In a stereoscopic display, although the eyes must converge on an object, they focus on the plane of the screen regardless of the apparent distance. One requirement of a stereo 3-D display is to minimize that disparity (ref. 4). This is accomplished by keeping the principal objects near the zero-parallax distance where the focus and convergence relationship is correct.

After setting the zero-parallax distance at the desired distance from the aircraft to the target ship, the size of the target ship becomes a distance cue. For example, if the pilot is following too closely, the target ship appears larger on the screen and projects out of the plane of the screen towards the pilot. Conversely, if the pilot drops behind the target ship, it appears to shrink in size and recede into the background. The combination of stereo and size cue serves as an important error indicator.

In this display, the zero-parallax distance is set to a nominal following distance. The inter-ocular distance was established empirically at 8 ft. Moving the eyes that far apart is equivalent to shrinking the scale of the scene proportionally. Such distortions enhance the pilot's ability to perceive the sensations of depth. They are also necessary because of inherent limitations of the hardware. The precision in rendering the left- and right-eye views is limited both by the display resolution and the arithmetic precision of the display processor (i.e., 16-bit fixed point).

If a fixed time lag rather than a fixed distance is desired, the zero-parallax also could be dynamic. In that case, the zero-parallax distance would be a function of the time lag and the instantaneous velocity of the target ship.

Within the 3-D display, apparent depth had to be assigned to 2-D symbols such as digital readouts and the pitch scale. Two possible choices are the zero-parallax distance or the maximum distance. If they are set at the zero-parallax distance (i.e., drawn with the same left- and right-eye view), they would be perceived by the pilot as if they were being looked past in order to see the part of the 3-D display beyond the zero-parallax distance. Earlier informal evaluation has shown the resulting perception to be disorienting. Instead, by placing the 2-D symbols at the maximum distance, they appear natural and unobtrusive.

Care must be taken when defining the left- and right-eye transformations. Figure 4 illustrates two ways of conceptualizing the transformations. In figure 4a, the views are converged by rotation of the viewing pyramid. In figure 4b the viewing pyramids are sheared. The latter approach is preferred, as the projection planes in each view remain parallel. Achieving convergence by rotation creates artifacts which can not only cause eye fatigue, but also can interfere with the pilot's perception of depth (ref. 4). Although the rotation method is easier to implement, the shearing approach has become the standard in 3-D graphics software (refs. 1 and 2).

Own-Ship Symbol

Figure 5 shows the evolution of the own-ship symbol. The original configuration, figure 5a, presented the pilot with two problems. First, it was impossible to perceptually fuse the right- and left-eye viewpoints to form the 3-D image. This fusion problem was surprising, because the signposts also were made of single, straight lines, but there was no problem with their visual fusion. An additional problem was that the own-ship symbol tended to "get lost" in the display. The signpost symbol was constructed of perpendicular horizontal and vertical lines; the same was true of the own-ship symbol. Therefore, there were many instances in which the own-ship symbol would overlay the signposts and could not be perceived.

In order to increase the pilot's ability to perceive the own-ship symbol, the center slanted lines were drawn as shown in figure 5b. Although the ability to perceive the symbol was greatly increased, there was still the problem of inability to visually fuse the stereo 3-D image.

Figure 5c was originally constructed to further enhance the pilot's ability to perceive the own-ship symbol; it worked. A serendipitous benefit was that the symbol now visually fused. At this time there is no theoretical explanation for the fusion phenomena.

INITIAL RESEARCH

The initial research with the display will be a study of recovery from flightpath offset. Pilots will be initiated on the nominal flightpath. After 2 sec, they suddenly will experience a flightpath offset. They will be required to make the stick input to rejoin the nominal flightpath. Visually evoked potentials will be triggered from the sudden flightpath offset. In addition, reaction times, response accuracy, and a projected workload estimate also will be recorded. The Subjective Workload Assessment Technique (SWAT) will be used for the workload estimate (refs. 5 and 6). A test for stereoscopic acuity will be administered prior to data collection. Recent anecdotal evidence indicated that some subjects tend to lose the ability to use the stereoscopic cue after prolonged exposure to it. Therefore, stereoscopic acuity also will be measured immediately after a long series of trials with the stereo 3-D cues.

In addition to using stereo 3-D or monocular cues as an independent variable, the inclusion or exclusion of the target ship will be the second independent variable. The last independent variable will be the pathway. There either will be the signpost or a monorail pathway for the subjects to follow.

FUTURE RESEARCH

The initial research will use the stereo 3-D cues to represent geographic information. In the "real world," objects are geographically separated by space, and the displays will attempt to create the perception of that geographic separation.

In contrast, one line of future research will use the third dimension as a dimension to encode new information for the pilot. For example, presume that there is a pictorial display which is entirely in the plane of the screen and that depth perception is simulated with monocular cues such as linear perspective. If a pilot were using that display in a current aircraft, and if the airspeed were to get too low, an audio display (i.e., a horn) would sound. The audio display is an alerting display, and the pilot must know to then look at the visual display for speed.

However, part of the pictorial display is a box with digital readouts for instantaneous actual and desired airspeed. Using the same airspeed error example, the box with the airspeed would modulate in the third dimension (i.e., along the z-axis) as the alerting cue instead of using the audio cue as the alerting cue. In this manner, new information would be presented to the subjects in the third dimension.

From a human factors perspective, that is a potential way of decreasing the total number of cockpit displays and also to make the alerting cues more nearly intuitively obvious. There are many research questions to be addressed. First, can it be demonstrated that the proposed use of stereo 3-D is quantifiably better than the use of audio alerting cues? Some of the other questions concern the rate and perceived depth of modulation in the third dimension. For example, should the rate or perceived depth of modulation be proportional to the amount of error? Should the modulation only be from the plane of the screen towards the pilot or should it also modulate from the plane of the screen away from the pilot?

Other uses of stereo 3-D also are possible. The "natural" use of stereo 3-D is to represent the 3-D geography. Part of the true test of the technology will be to go beyond that approach and determine if there are more effective applications.

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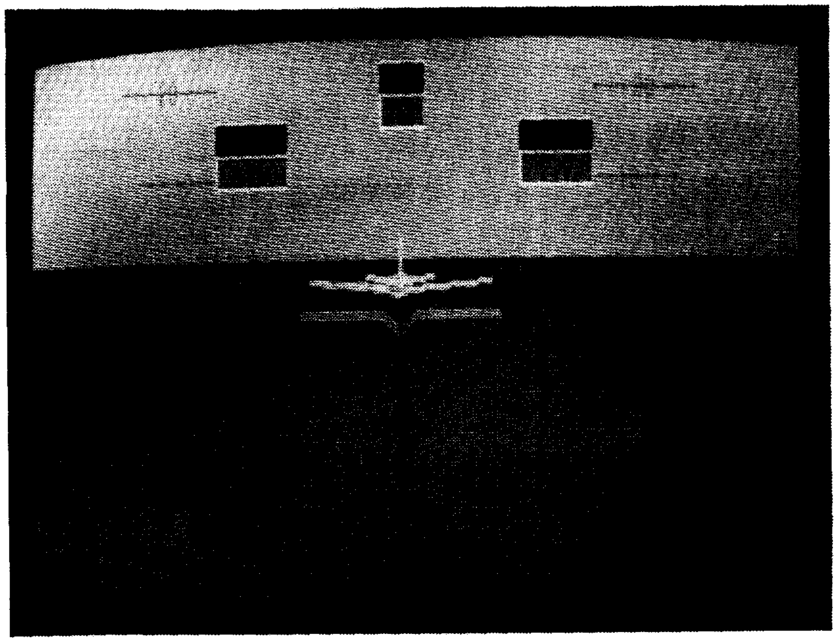

Figure 1.- Monocular "monorail" display.

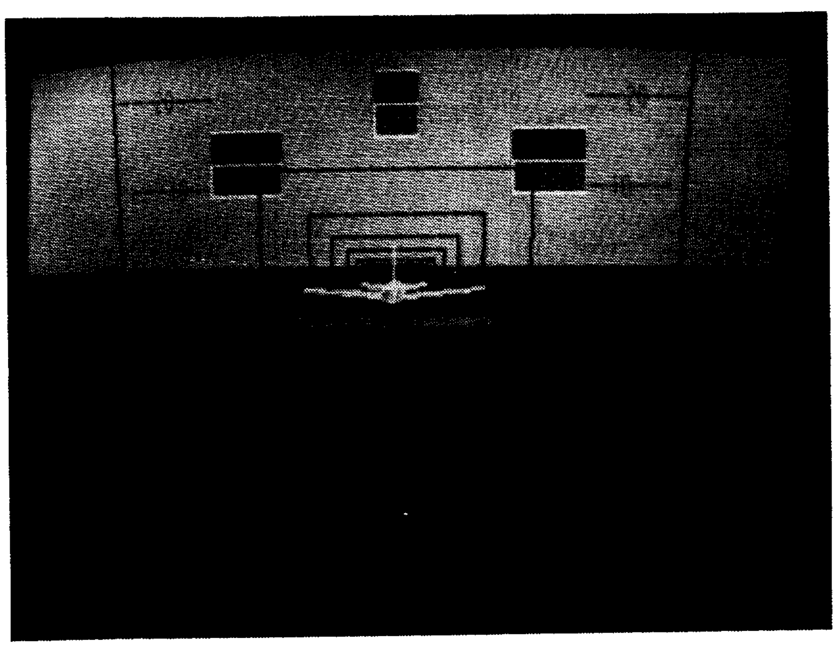

Figure 2.- Monocular "signpost" display.

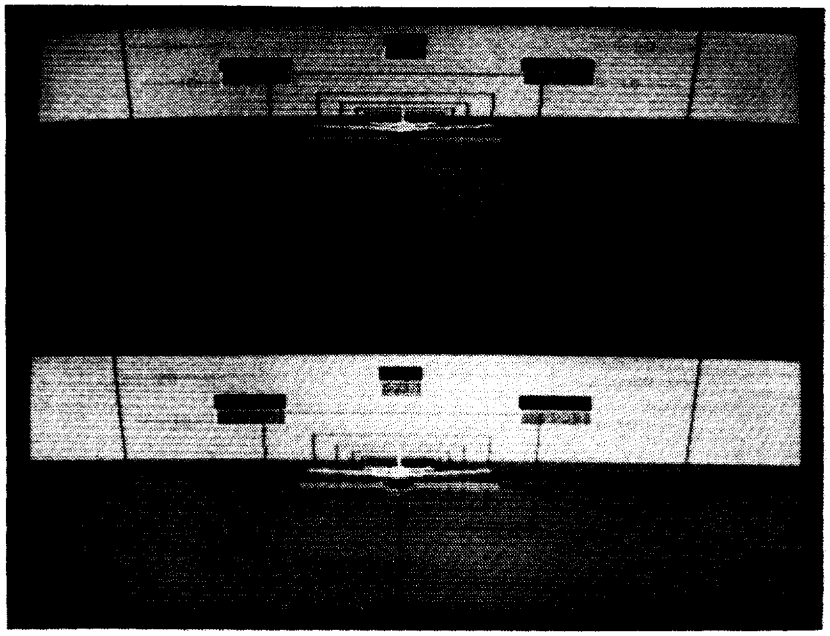

Figure 3.- Stereo display as seen on a conventional CRT.

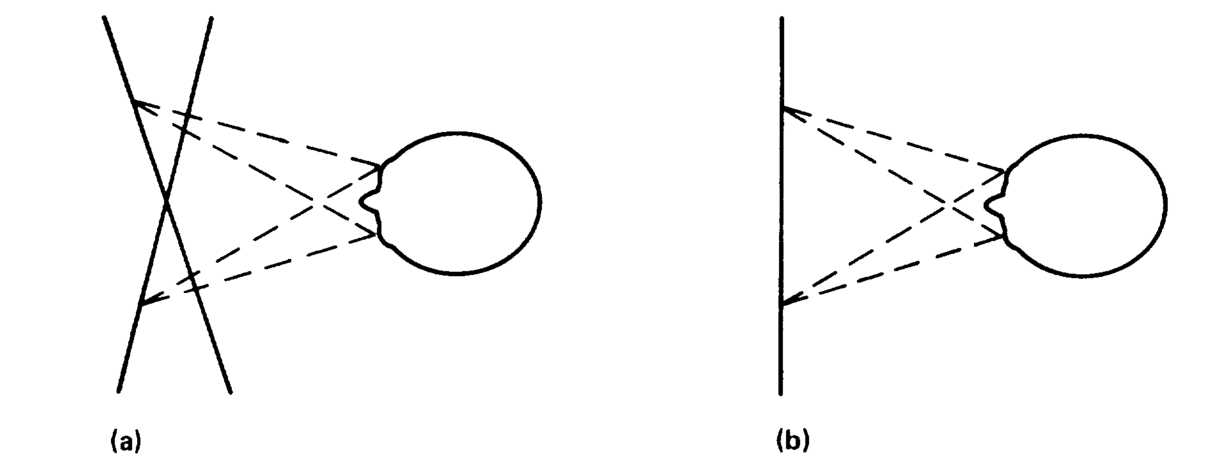

Figure 4.- Generation of stereo pairs by eye rotation (a); generation of pairs by shearing the viewing pyramid (b).

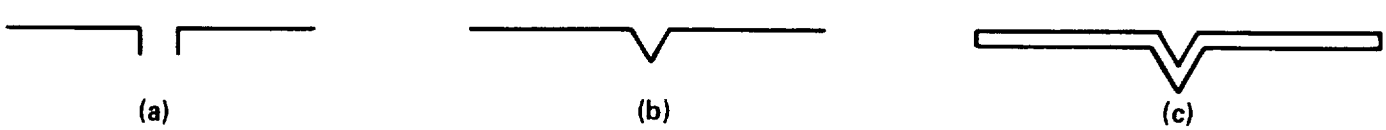

Figure 5.- Evolution of own-ship symbol: Stereo pairs for (a) and (b) would not visually fuse; (c) would visually fuse.