

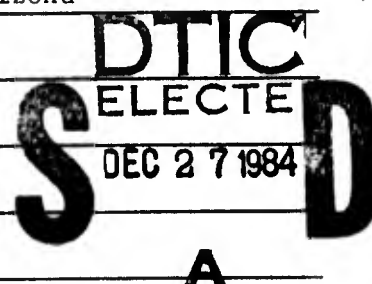
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## PROGRESS REPORT ON AN EYE-SLAVED AREA-OF-INTEREST VISUAL DISPLAY



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PROGRESS REPORT ON AN EYE-SLAVED  
AREA-OF-INTEREST VISUAL DISPLAY

ABSTRACT

↙ A dome-projection real-image system based on an eye-slaved area-of-interest (AOI) concept has been under development for some time at the Link Flight Simulation Division of The Singer Company. The Link approach provides a high-resolution area set within a wide-field-of-view background. The display image is presented to the trainee using light valve projection on a dome screen, with the high-resolution AOI inset slaved to the trainee's eye line of sight. The display development program at Link has progressed past the system integration phase and is undergoing proof-of-concept test and evaluation. The system approach and preliminary test findings are discussed in this paper.

INTRODUCTION

The need to provide a high-detail, large-field-of-view visual training environment to the pilot-trainee, at reasonable cost, continues to pose a major challenge to flight simulation technology. Of the several candidate solutions being considered, an area-of-interest (AOI) approach to the high-resolution, wide-angle display remains the most attractive in terms of cost-effectiveness. Currently, several AOI techniques are being pursued by Government and industry. The AOI display under development at Link addresses the particular visual needs of tactical air combat flight simulators where the field-of-view (FOV) requirements are most stringent, although typically the display is to be provided only for a single observer. The Link display will offer an effective resolution of 3 minutes of arc per optical line pair (1.5 minutes per pixel) over a large FOV that is expandable to 360°. The proof-of-concept system was successfully integrated recently, and system test and evaluation is in progress.

PROGRAM BACKGROUND

The display development is being conducted under a Link IR&D program entitled "Eye-Slaved Projected Raster Inset (ESPRIT)." The ESPRIT program is an outgrowth of the engineering effort initiated under U.S. Air Force Project 2360. Although Project 2360 was terminated in 1980 due to funding problems, important results were achieved in the visual simulation area. In particular, the feasibility of an eye-slaved AOI display concept proposed by Link was studied in detail under Project 2360, and critical system components were developed which greatly reduced the technical risks of the approach. Test and evaluation of these components and the eye-slaved AOI concept have been continued under a joint Air Force and Navy program called "Eye-Slaved Display Integration and Test (EDIT)."

In 1982, encouraged by progress on various visual display component development efforts, Link consolidated the related research and development projects into the multiyear ESPRIT IR&D program. This program has led to the construction of an engineering proof-of-concept system, which is described in this paper.

## ESPRIT DISPLAY CONCEPT

The ESPRIT display approach provides a high-resolution AOI area set within a wide-field-of-view background of lesser resolution, as illustrated in Figure 1. The display image is presented to the trainee by light valve projection onto a dome screen.

Separate projectors are used for the AOI (foveal) and background (peripheral) images. The background projection is fixed relative to the observer, while the AOI projection optics are servo-driven and directed by the trainee's eye line of sight. A "hole" is cut out of the background image and replaced by the AOI high-resolution inset. At the border of the AOI, the foveal and peripheral images are blended together electronically to give the appearance of a continuous picture.

On the basis of earlier psychophysical experiments conducted under Project 2360, which indicated that an eye-slaved AOI as small as  $10^\circ$  in diameter may be acceptable to the observer, the ESPRIT AOI is nominally set at  $18^\circ$ , including a  $3^\circ$  band for blending. Flexibility has been built into the ESPRIT design, permitting the size of the AOI and the blend region to be varied for optimization.

### System Configuration

For the purpose of specifying system performance, a baseline system has been defined for the ESPRIT display. The baseline system can be expanded to enlarge the total field of view while maintaining the same system resolution by employing additional projectors. As shown in Figure 2, the ESPRIT baseline system consists of the following major components:

- 1) A helmet-mounted oculometer system (HMOS) that detects the observer's eye line of sight
- 2) A foveal projector for the AOI inset, driven by the foveal servos under HMOS command
- 3) Three peripheral (background) projectors for the baseline system. The number of projectors can be reduced if the FOV required is less than  $270^\circ$ H
- 4) Merge electronics that provide the blending region for the foveal and peripheral images
- 5) Distortion correction electronics to properly map the projected image

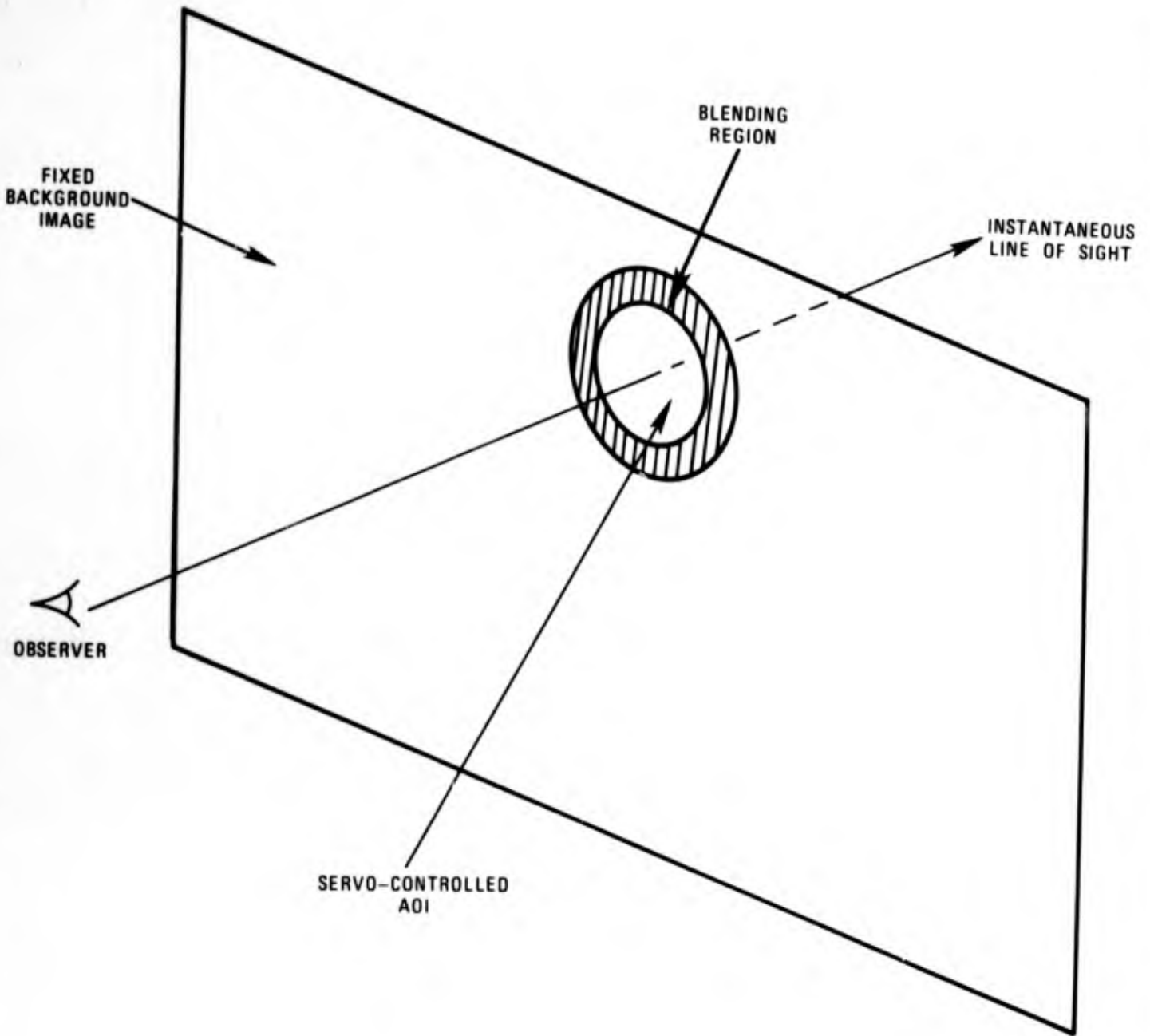


Figure 1 ESPRIT DISPLAY CONCEPT

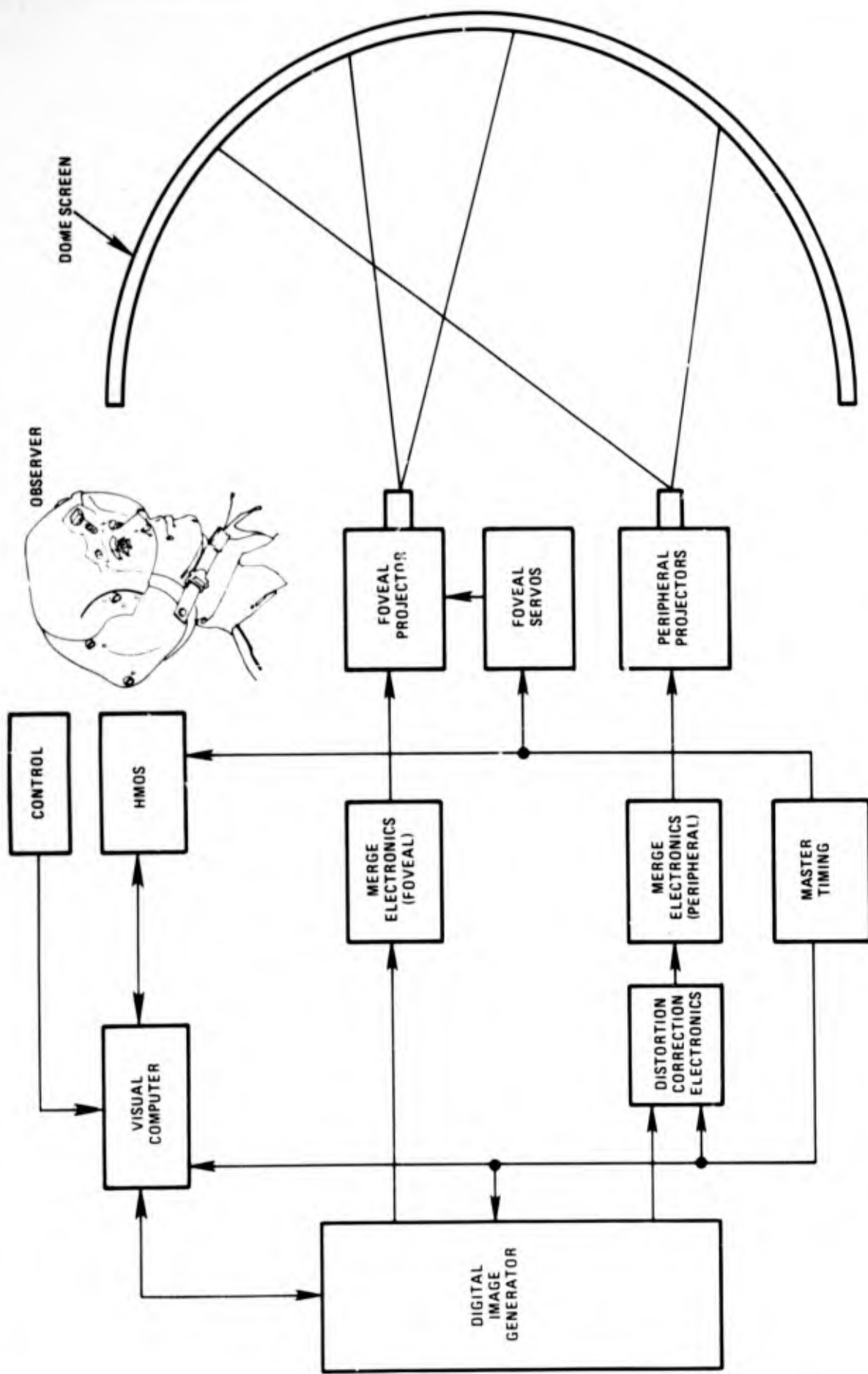


Figure 2 ESPRIT BASELINE SYSTEM BLOCK DIAGRAM

## 6) A high-gain, motion-compatible dome screen

The image is provided by a four-channel Digital Image Generator (DIG) fully integrated with the ESPRIT display and the host computer complex.

### System Performance

The expected performance of the ESPRIT baseline system is shown in Table 1. Two items should be noted. The first is that the 270°H by 130°V FOV is limited only by the background projectors. As a result of careful design of the AOI projection system, the AOI can actually be moved to cover a larger area, as shown in Figure 3. By increasing the coverage of the background projectors, in a tradeoff against the background resolution, greater total FOV with the same high-resolution AOI can be obtained with no increase in system complexity.

The second item to be noted in Table 1 relates to head motion compensation. Most displays, real-image projection or collimated, have inherent problems in image position as a function of observer head motion. The picture presented to the trainee does not respond correctly in perspective as the trainee moves his head. This lack of parallax cues becomes more critical for objects close to the observer. The ESPRIT system design solves this problem by using the helmet positional information to shift the DIG imagery in response to the trainee head motion. The result is correct image movement so that objects located at infinity move as if they were at infinity and objects at, say, 10 feet move as if they were at 10 feet. An interesting effect will be that the observer can look "around" a small object at close range by moving his head from side to side, as in the real world.

### PROGRAM STATUS

The ESPRIT proof-of-concept "brassboard" system has been assembled and successfully integrated. Initial engineering performance measurements on the system are complete. A series of psychophysical experiments will be conducted as an integral part of the proof-of-concept evaluation. These experiments are designed to address issues relating to the acceptability of the eye-slaved AOI approach. The questions to be answered range from the purely technical to those relating to visual perception and psychophysical response. For instance:

- 1) How well does the HMOS track the eye?
- 2) Critical system timing requirements were defined by early Link experimental results on saccadic suppression, using video emulation techniques. How does the proof-of-concept system perform relative to those requirements, particularly with respect to foveal servo performance and system throughput?
- 3) Presentation of the foveal/peripheral image does not exactly follow the visual acuity response of the human eye. What effect might that have on its acceptability to the observer?

Table 1 ESPRIT BASELINE SYSTEM PERFORMANCE GOALS

<i>RESOLUTION</i>	3 ARCMINUTES/OLP 22 ARCMINUTES/OLP	FOVEAL PERIPHERAL
<i>FOVEAL (AOI) FOV</i>	18° DIAMETER	
<i>PERIPHERAL FOV</i>	HORIZONTAL ±135° VERTICAL + 80° - 50°	(270° TOTAL) (130° TOTAL)
<i>BRIGHTNESS</i>	5 FT-L	
<i>DISTORTION</i>	< 10 ARCMINUTES	
<i>COLOR</i>	FULL	
<i>DOME</i>	MOTION COMPATIBLE	
<i>HEAD MOTION COMPENSATION</i>	YES	

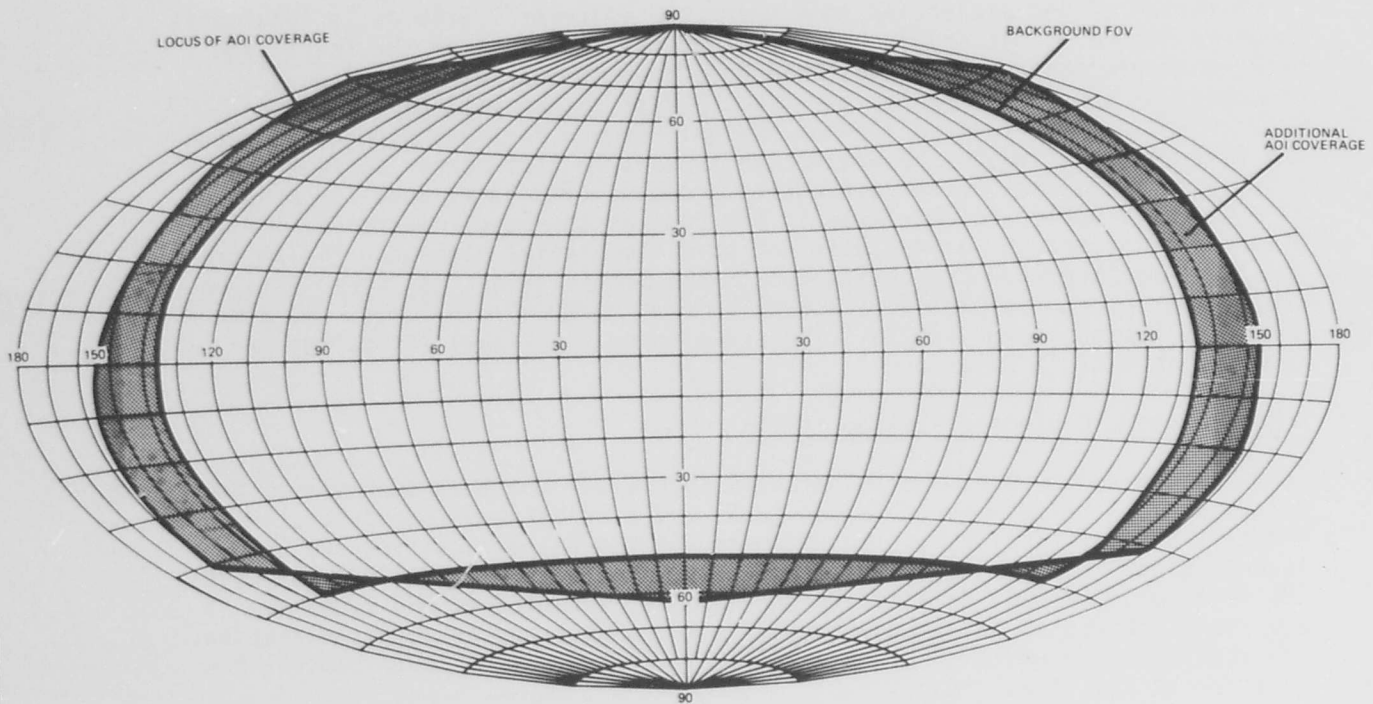


Figure 3 ESPRIT BASELINE SYSTEM FIELD OF VIEW

4) How may the AOI size and characteristics of the blending region affect that acceptability?

5) With an 18° high-resolution inset, the observer will probably be aware of the existence of the inset. Does this have an effect on his ability to perform the assigned visual tasks?

### PROOF-OF-CONCEPT SYSTEM

Measurements are being taken on the ESPRIT proof-of-concept test bed to answer these and other questions. The test bed comprises nearly all the major system components shown in the baseline system block diagram (Figure 2). The difference between the proof-of-concept system and the baseline system lies primarily in the use of a flat screen as opposed to a spherical dome screen. The background FOV is reduced so that the AOI concept can be evaluated while using only a single background projector. The foveal projector is the same as in the baseline system. Distortion correction electronics, required for the final baseline system, are not needed for the test bed.

The initial evaluation of the test bed is being performed using a monochrome image. The proof-of-concept system is being upgraded to provide full color so that task performance measurements on observers can be repeated to check for any differences in results. An overview of the test bed components and performance highlights follows.

A sketch of the projection room where the observer's station is located is shown in Figure 4. It should be noted that the locations of the foveal and background projector for the test bed have been chosen for convenience. Placement of the projectors in the final ESPRIT system will be an integral part of the overall trainee station design. Figure 5 is a photograph showing the observer relative to the projection screen. A flat screen 18 feet square is used for this step of the evaluation process. The background FOV measures 74°H by 67°V, while the AOI inset is the same as the baseline system, 18° in diameter. The screen surface does not have the special high-gain finish since it is not required for the test bed. In the final design the screen will be specially prepared to provide a screen gain of up to 4, similar to the dome screen delivered to the Navy by Link and used on the Visual Technology Research Simulator in Orlando.

### Helmet-Mounted Oculometer System (HMOS)

A photograph of the HMOS is shown in Figure 6. The HMOS consists of two subsystems: a helmet-mounted sight (HMS) and a helmet-mounted oculometer (HMO). The magnetically coupled HMS measures the helmet position and helmet line of sight (LOS) relative to the observer station, while the HMO measures the observer's eye LOS relative to the helmet. The HMS and HMO measurements are then combined to obtain the eye LOS with respect to the observer station. The resultant eye LOS and helmet position information is used to control the position of the foveal image.

The HMOS uses a charge coupled device (CCD) camera to view the pilot's eye, which is illuminated by a low-intensity, near-IR light source. The CCD picks up the illuminator's reflection from the observer's cornea along with his pupil image. Using this information, the HMOS system computes the observer's eye LOS with respect to the helmet.

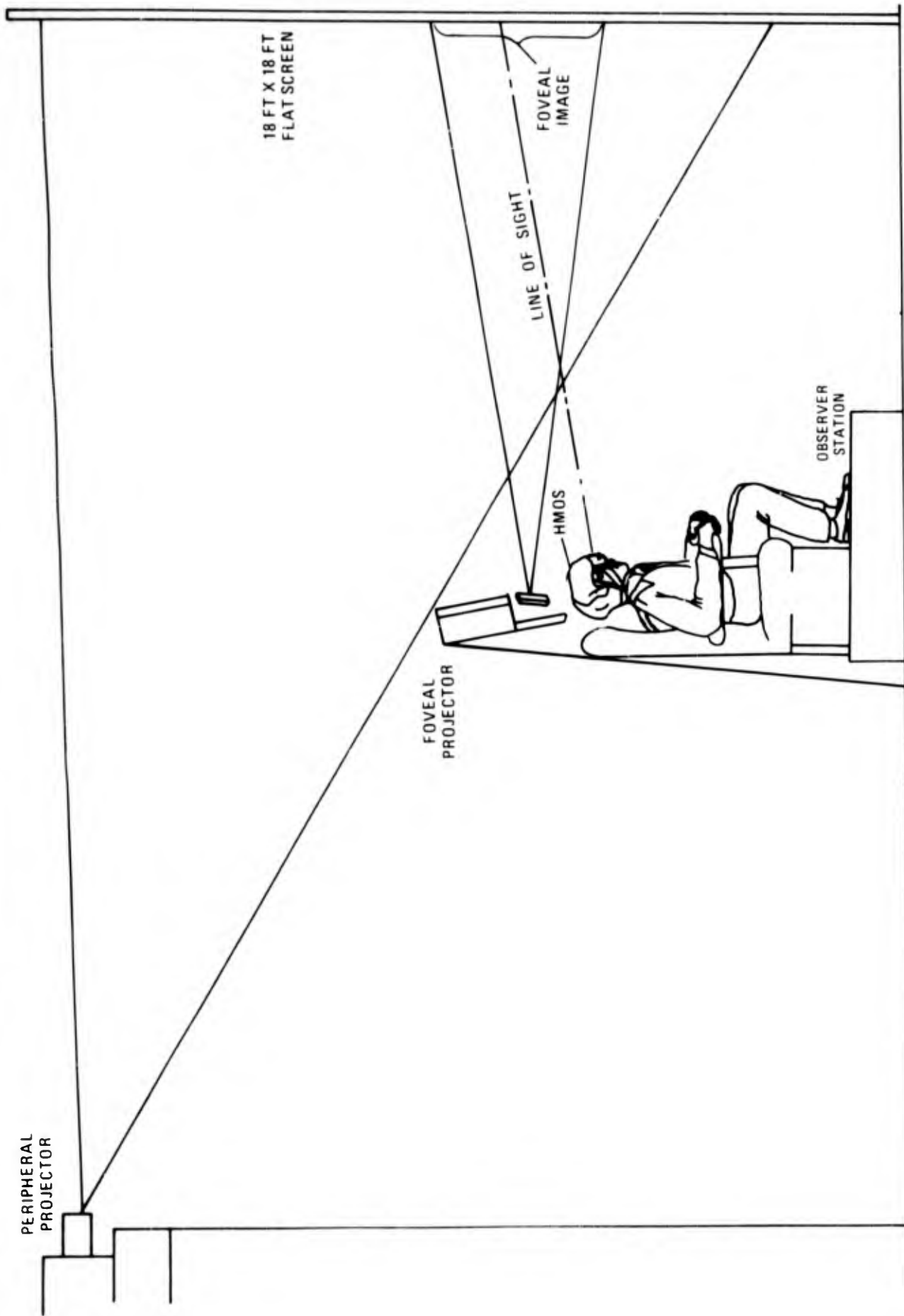


Figure 4 PROJECTION ROOM ARRANGEMENT

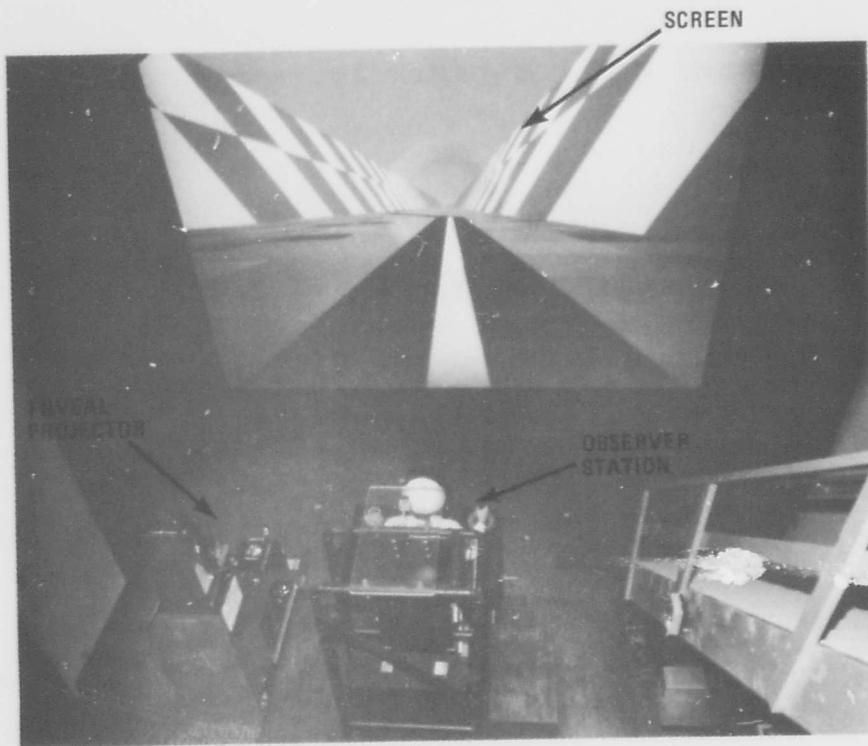


Figure 5 PHOTOGRAPH OF OBSERVER AND SCREEN

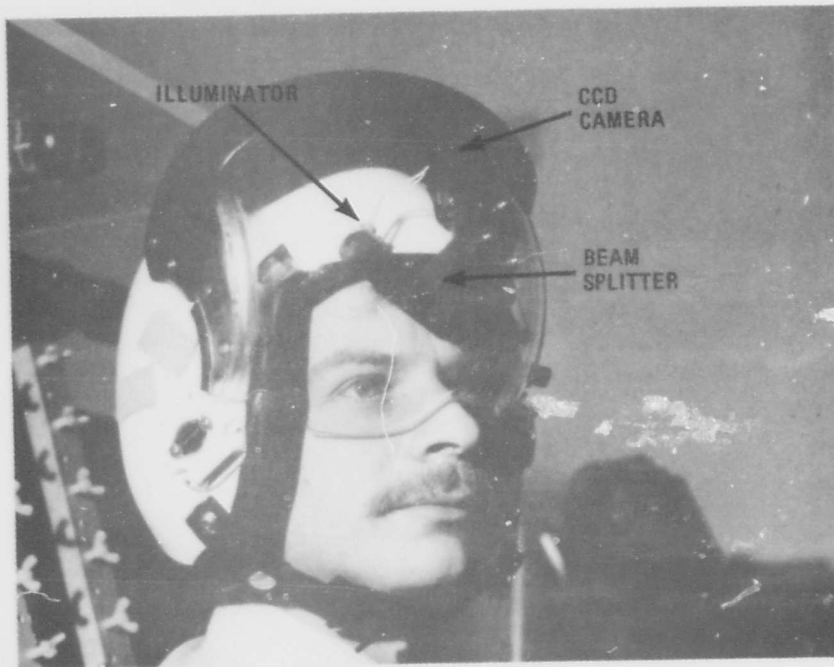


Figure 6 HELMET-MOUNTED OCULOMETER SYSTEM

The accuracy and repeatability of the HMOS exceed the requirements originally specified under Project 2360. The integrated HMOS/foveal projector is able to consistently place the foveal image where the observer is looking. The positional accuracy of the DIG picture in the central region of the screen is better than 6 minutes of arc. The picture is composed of the AOI high-resolution zone and the background portion. Placement of the high-resolution zone is to within 3 degrees of the actual eye LOS. What this means is that, given the HMOS accuracy, the observer LOS will always be within the AOI area. He cannot look directly at the blending region or go past it into the peripheral area.

### Foveal Projection Assembly

The foveal projection assembly for the AOI inset image is shown in Figure 7. In addition to the light valve projector display image source, the assembly contains all the optics and servos needed to project the AOI image. The azimuth/elevation servos (shown in closeup in Figure 8) drive the output projection mirror as directed by the observer's eye LOS. (Derotation of the image, required for proper orientation as the azimuth servo turns, is provided in the digital image generator.) Three other servos are used to maintain constant image size, focus, and brightness as the LOS changes and the foveal projection throw distance varies.

The azimuth/elevation servo design is among the most difficult engineering tasks accomplished for the test bed. Angular velocities of up to  $200^\circ/\text{s}$  are required when the eye is in the tracking mode. Eye saccade step responses can demand velocities that exceed  $700^\circ/\text{s}$  and accelerations of up to  $50,000^\circ/\text{s}^2$ .

These velocity and acceleration requirements, as well as smooth operation at minimum speed, are all met by the brassboard hardware. The static LOS accuracy of the azimuth/elevation servos is better than 1 minute of arc. The dynamic accuracy is better than 3 minutes at an angular velocity of  $700^\circ/\text{s}$ . Errors in AOI placement caused by the servos are thus negligible.

The five servo subsystems use the same design, that of a single micro-processor-based digital position loop controller. This commonality has been achieved although the servo requirements differ greatly. Some are continuous servos, others noncontinuous, with different requirements in velocity, acceleration, and output resolution. In addition to superior performance and modular design, the foveal servos are highly maintainable. An adaptive, self-calibration capability has been built into the servo system, operating off-line.

The AOI size on the test bed, as mentioned earlier, is set at an  $18^\circ$  diameter. At this FOV the measured display resolution is better than 3 arcminutes per optical line pair.

### Peripheral Projector Assembly

The peripheral projector assembly in the test bed is located above and behind the observer (see Figure 4). A light valve equipped with a wide-angle lens provides the full screen coverage. The background image resolution is

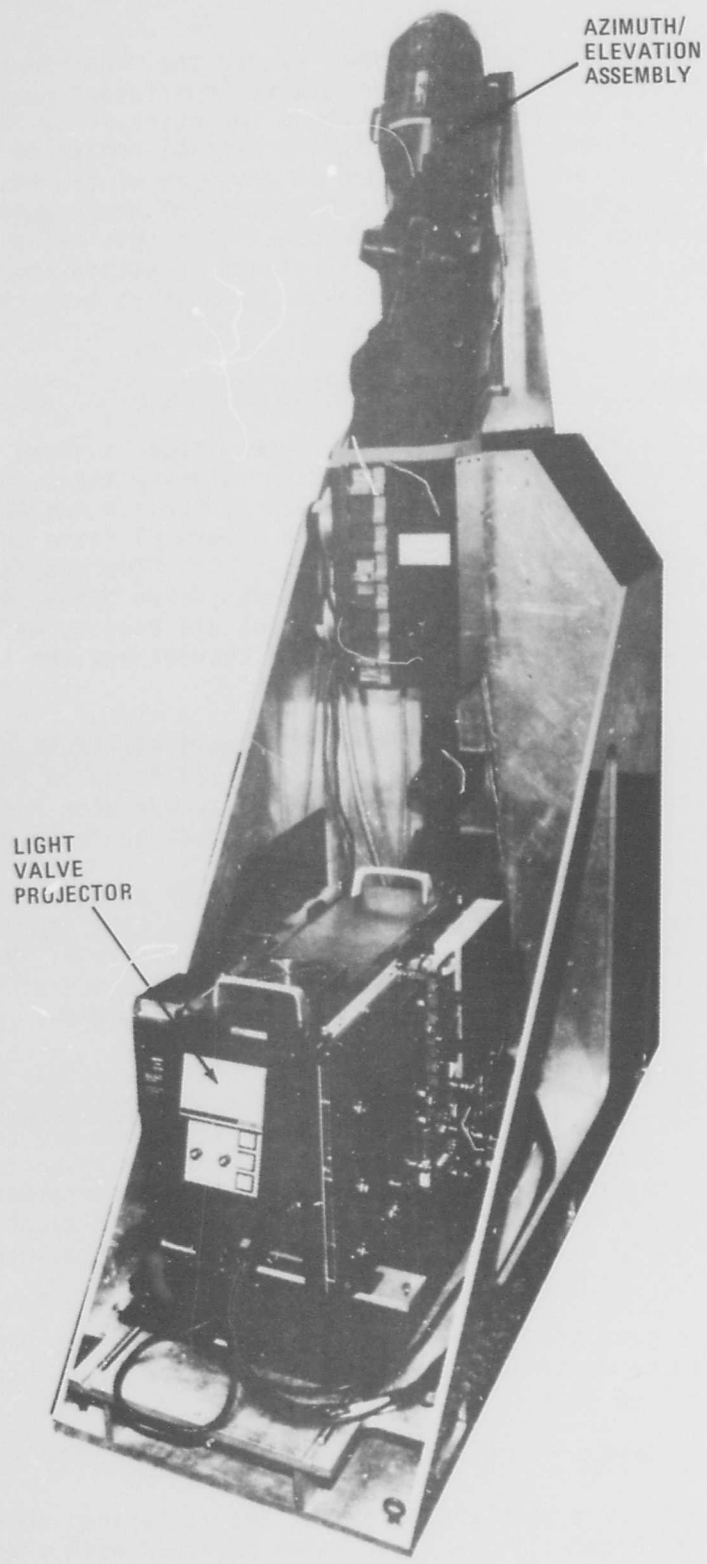


Figure 7 FOVEAL IMAGE PROJECTOR

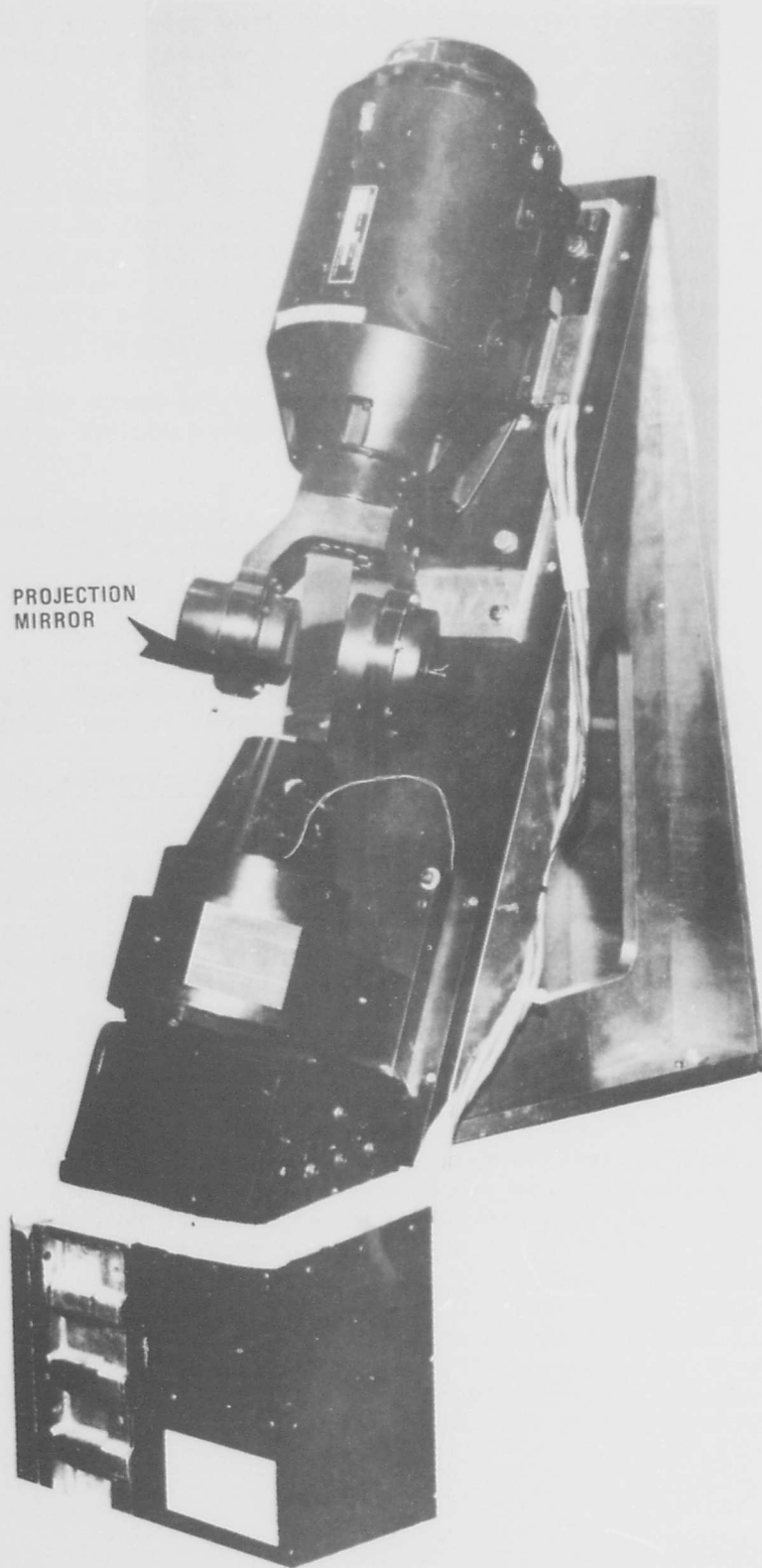


Figure 8 CLOSEUP OF AZIMUTH/ELEVATION SERVO ASSEMBLY

approximately 11 arcminutes per optical line pair, with a peak-white brightness measured at 5 foot-lamberts. A contrast ratio of better than 15:1 is obtained.

### Merge Electronics

The merge electronics provides the proper blending of the foveal image with the peripheral. An elliptical hole is cut out of the peripheral image by blanking the video drive signal for the peripheral projector. The edge of the hole is feathered to blend with the foveal inset. Positioning of the peripheral hole is controlled by the observer LOS. The size of the hole and width of the feather functions are under software control.

The foveal image is similarly shaped by the merge electronics and projected into the peripheral hole. The combined picture gives the appearance of a continuous image.

Tests results so far are encouraging. As discussed above, the HMOS provides precision eye-tracking so that the observer's LOS is always within the foveal image high-resolution inset under normal operating conditions. Consequently, the observer can never look directly at the blending region. It has been reported that with an AOI size of  $18^\circ$ , the observer is generally aware of the existence of a high-resolution AOI that is different from the background; however, it was also found that the distinction between foveal and peripheral images tends to be forgotten once the observer is task-loaded.

### Host Visual Computer Complex, Master Timing Electronics, and Miscellaneous Items

Additional hardware items make up the balance of the proof-of-concept test bed. There is a host visual computer complex as well as master timing electronics to synchronize the throughput of the system. Video test patterns are built into the test bed electronics to aid routine maintenance.

A summary of the ESPRIT proof-of-concept system performance is given in Table 2.

### Psychophysics Experiments

Informal, subjective evaluation of the ESPRIT test bed from a human factors standpoint has been proceeding for some time. Link is about to begin a series of formal, human-in-the-loop measurements to obtain some quantitative behavioral results. Psychophysical experiments will be conducted to assess the perceptual acceptability of the Link AOI approach. Subjective response to the picture, particularly to the high-resolution inset, will be evaluated. Effect of the AOI size and characteristics of the blending region on the observer will be recorded. Attempts will be made to quantify the ability of the test subjects to perform tasks that require a high-resolution picture over a large FOV while using the AOI display.

Table 2 PROOF-OF-CONCEPT SYSTEM PERFORMANCE SPECIFICATION

<i>FOV</i>	74°H x 67°V
<i>RESOLUTION</i>	3 ARCMINUTES/OLP FOVEAL 11 ARCMINUTES/CLP PERIPHERAL
<i>BRIGHTNESS</i>	5 FT-L
<i>CONTRAST</i>	15:1
<i>COLOR</i>	MONOCHROME
<i>HEAD MOTION COMPENSATION</i>	YES

Test data bases for the DIG have been prepared in accordance with the experimental design. Initially, a group of people who are technically oriented and knowledgeable in visual flight simulation will participate as observers. The reason for the initial special sample is to provide feedback so that technical imperfections reported can be corrected on the test bed as rapidly as possible. The enhanced test bed will then be used for a broader sample of the general population in formal experiments.

#### CONCLUSION

While behavioral aspects of the ESPRIT system have yet to be fully evaluated, the technical feasibility of the Link display approach has clearly been demonstrated. The objective of an eye-slaved AOI display is to give the observer-trainee the perception of a high-resolution image anywhere within the FOV. If the performance of the ESPRIT test bed is an indication, the effect of a display with 1.5 arcminute/pixel resolution, covering a field of view of 270° to 360°, can be breathtaking.

As the psychophysics experiments progress on the test bed, Link will continue working on system improvements. Development of additional components needed for the baseline system is proceeding, including the distortion correction electronics design. Other engineering tasks, such as construction of the dome and refining the high-gain screen finishing process, will be added.

As the ESPRIT display development gets closer to completion, work on the image generation process to take advantage of the eye-slaved display will be pursued; i.e., concentration of scene detail in the AOI. The rapidly advancing technology of computer-based image generation coupled with the ESPRIT display will permit a level of performance never before achieved in visual flight simulation.

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