MULTICHANNEL WIDE-ANGLE COMPUTER GENERATED VISUAL SYSTEMS

P. MARR and L. SHAFFER
Ground Systems Department, General Electric Company

ABSTRACT

In today's visual technology there are many parameters, the values of which must be correctly chosen, to achieve an effective visual training simulator. Some of these parameters are resolution, brightness, contrast ratio, real image versus infinity image, collimation, field of view, field of view gaps, realism, target and area of interest fields of view, detectability and aircraft discernibility relative to slant range. True perspective and scene continuity across juxtaposed channels also are important parameters and are the subject of this report.

If single displays are used, scene continuity and true perspective is not usually a problem but most wide-angle visual systems today are composed of several optical windows, projectors or monitors to form a wide field of view while retaining good resolution.

When a specification requires juxtaposed displays, the designer must solve the problems of scene continuity with distortion-free perspective.

INTRODUCTION

The intent of this paper is to show the advantages of using a computer generated image generator (CGI or CIG) in a juxtaposed display system relative to scene continuity with perspective. This will be done by illustrating present, past, and future visual systems.

FUNCTIONAL CHARACTERISTICS

CGI technology inherently allows the extension of field of view through the use of juxtaposed display channels. Prior to the use of computed imagery, extension of the field of view required the use of wide field optical probes coupled into single or multiple cameras. The optical tradeoff necessary to achieve wide fields of view, and depth of focus, led to high sensitivity performance requirements and accompanying signal-to-noise limitations in the video cameras. Although a few organizations have made successful advancements in this area, the physical constraints of the technology are imposing.

The CGI technology released many of these constraints but at the same time brought some challenges of its own. To appreciate the CGI contribution to wide field-of-view simulators, through the use of multichannel displays, consider the previous systems discussed, all of which are multichannel visual systems. With that, couple your knowledge of other similar juxtaposed multichannel systems now being used in successful training applications. Whether the image generation is Contact Analog, STG, DIG, CIG, or CGI, or a combination of one of these with a camera system, computed imagery was the basis for extension to a wide field of view in the vast majority of today's successful multichannel simulators.

It is interesting to consider what constraints computed imagery frees and if it imposes constraints of its own. To answer both questions, consideration must be given to the projection geometry of the CGI system and how it relates to the display system in each case of the previously discussed multichannel simulators.

First, however, a review should be made of what a CGI system is and how it works.

CIG SYSTEM

The computer image generator consists of three major data processing cycles run concurrently, one in the general-purpose processor and two in the special-purpose processor. These computation cycles are slaved to the update rate and are repeated each 1/30 second corresponding to the update rate. The three cycles are connected serially and, therefore, are referred to as Frame I, Frame II, and Frame III operations. These relationships are shown in Figure 1. (The term "Frame" is used here for equipment and computation groupings and should not be confused with update rates.) Frame I operations are performed by software programs resident in the general-purpose computer system. A typical system consists of a single processor, peripherals, and software.

The primary purpose of the visual simulation software (VSS) is to provide overall control for the system during the real-time operation of a mission. To accomplish this purpose, the VSS must perform the following major functions:

a. Acquire vehicle and moving model position and attitude information and

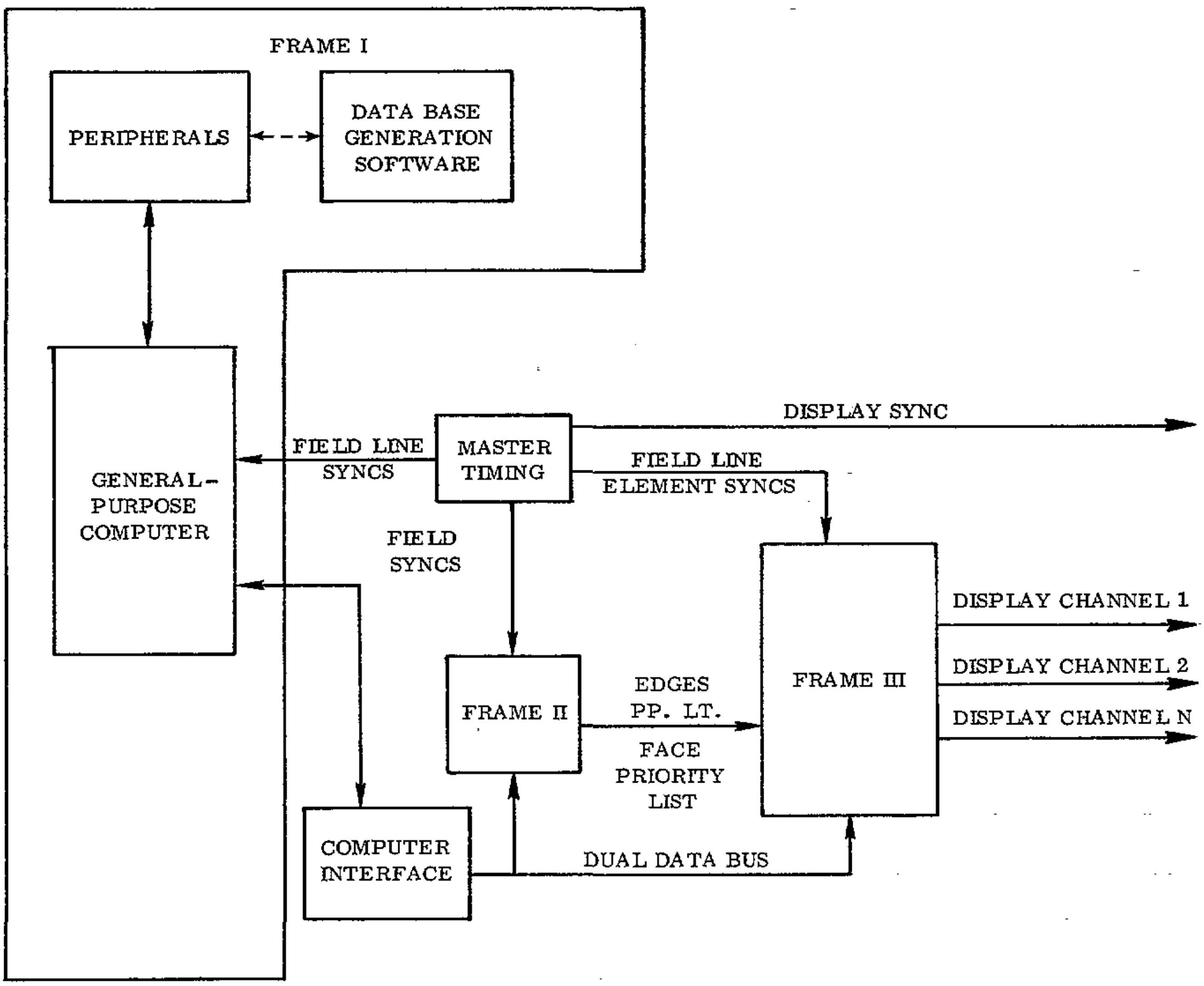

Figure 1. Image Generator Block Diagram

translate the information into the coordinate set and processing cycle of the image processing hardware.

b. Initialize the active gaming area data base.

c. Monitor controls, acquire and interpret commands, and implement any action required.

d. Transfer data and commands to the special-purpose image processor and monitor processing status, implementing any required actions defined by status or operator commands.

In addition to these real-time functions, the process of preparing the system to execute a mission has also been assigned to the VSS. The data received from the primary computer over the computer-to-computer interface consists of environment controls (i.e., cloud parameters, visibility, lighting selection, etc.); discrete controls; and position and attitude for the particular vehicle, such as aircraft, tank, seacraft, etc.

The VSS then processes these inputs to generate data for the Frame II and Frame III operations. Two special data buses provide the communication links to all functions within Frame II and Frame III for the general-purpose computer. These buses are used for on-line transfers during real-time scene generation and for off-line test and diagnostic data transfers.

The Frame II computations process a new two-dimensional image for each display channel during every raster period. The display channel images are true-perspective scenes of the modeled environment as viewed from the current position and orientation of the viewpoint and display channel view planes. The viewpoint and moving model(s) position and orientation data are received from the visual computer at the start of each raster period as a block of edge data words and as a block of point light data words. The number of words may vary from 1000 to 10,000 depending on the application. A face priority list is also transferred to Frame III at the start of each raster period. The face priority list contains the relative priority relationships of the faces bounded by the edges in the edge data word block.

The Frame III function converts two-dimensional image data received from Frame II into composite video that is synchronized to the display raster scan. The Frame III hardware then outputs up to eight channels to the displays.

DETAILS

With an understanding of the CIG, we will now return to the details. Projection geometry is shown in Figure 2. The data base, a mathematical model of the environment, is transformed to a two-dimensional image plane located at some defined position with respect to an eyepoint. The angles subtended by this image plane at the eyepoint are the field of view of a single computed channel. (It is analogous to the photo-sensitive surface of a video camera in a camera/model system.) To extend the field of view, it is merely necessary to add image planes forming a polyhedral array with the eyepoint at the geometric center. This is analogous to a camera system containing a concentric array of lenses and cameras. Packing constraints, finite separations or overlaps at the channel boundaries, and distortions at the boundaries limit the extension of camera systems to multiple channels. None of these constraints of limitations is inherent in the computed images. Distortion is negligible since the transformation from the data base to the image planes is limited in accuracy only by the number of bits chosen for calculating the projections and defining the image planes.

Subsequent to the initial transformation from the data base to the image plane, the CGI system performs additional important functions. For example, perception of the third dimension, depth, is preserved by determining the priority of environmental models, lights and terrain. Another important function is the transformation of the image to a raster, which allows video transmission and display.

The display devices used in the multichannel juxtaposed systems are generally designs of monitors or projectors whose components were initially developed for television or radar applications. These are combined with special optical systems developed primarily for simulation applications. One of the simplest of these combinations is illustrated by Device 2B35 Training System. In the 2B35 system, Figure 3, juxtaposed projection screens combine the images and represent a simple unity transformation of the mathematical image from the computed image planes to the projection screens.

The Eye Reference Point (ERP) of the simulated cockpit must correspond to the computed eyepoint. To fix the ERP with respect to the

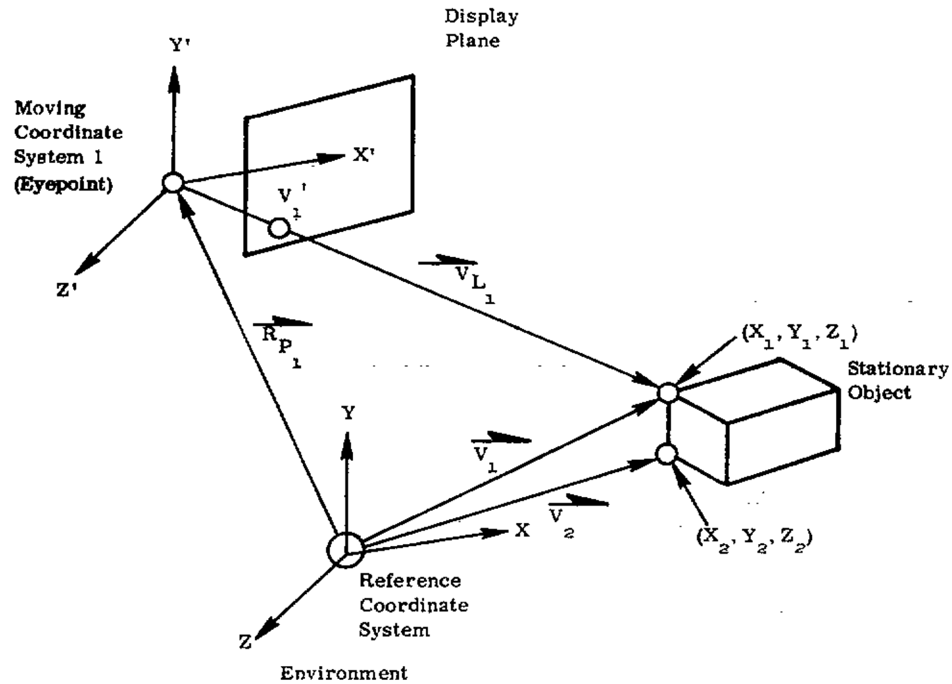

Figure 2. Environment Coordinate System

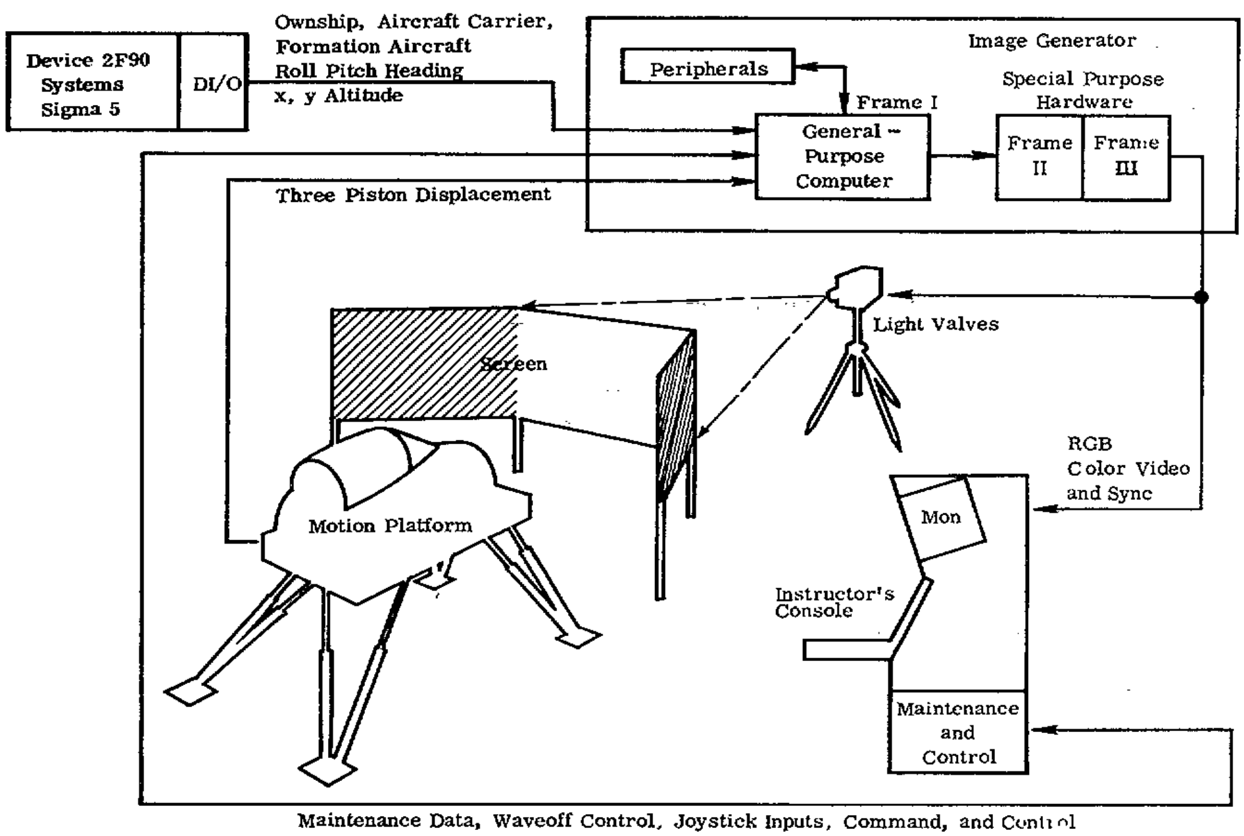

Figure 3. Device 2B35 System

screens would have required the screens and projectors to be fixed to a moving platform. The CGI projection transform provided an alternative solution by allowing a dynamic redefinition of the image plane position with respect to the eyepoint that tracks the ERP motion with respect to fixed screens.

An added simplification of this system was inherent in that the color television projectors used (GE model PJ5000) were designed for flat-screen projection. Since the linearity in these projectors is rigidly controlled to optimize color separation, the distortion in the projected image is low.

The two types of distortion present were pincushion (due to slight lens distortion) and small raster drifts in position and size. Since the pincushion was near one percent, a slight horizontal mismatch was evident over one to two picture elements on each side of the seam. Vertical size was adjusted to bring vertical mismatch to within one line. Horizontal size was adjusted to minimize the horizontal mismatch at a location five degrees to ten degrees above and below the horizon.

The drifts in size and position were stabilized by an edge match control system, Figure 4. This control system used photo-resistive detectors placed at the edge of the screen in the horizontal overlap area to sense video cursors. These cursors were added to the video by the CGI outside the computed image area of the raster. The control electronics algebraically added the error signals to obtain both size and position control signals in the vertical and horizontal. These signals were used to change the sweep voltages and position biases in the projectors to achieve geometrically stable operation.

An example of the use of a polyhedral array of image planes having a larger number of facets is the ASPT system. In this case, the optical system which combines the images, is an In-Line Infinity Optical System (ILIOS) array, Figure 5. Since the ILIOS transforms its focal surface to infinity, it is necessary to transform the image plane to the ILIOS focal surface and still preserve the correct angles. To visualize this, assume that the CGI image planes are mapped to infinity such that all angles subtended at the eyepoint are preserved. The ILIOS must perform the same mapping function. If the image is assumed to be initially at infinity, it can be mapped through the ILIOS to the focal surface. Since the plane beamsplitter images the focal surface of the ILIOS to a sphere concentric with and one-half the radius of the ILIOS spherical beamsplitter, the mapping to this focal surface is used to calculate the transformation. Referring to Figure 6, the mapping of the image plane at infinity to the focal surface can be represented by a tangent image plane at the focal surface with the images mapped to the surface through the center of curvature.

In ASPT, the CRT phosphor surface radius of curvature is the same as the ILIOS focal surface. The scan lines and columns of picture elements are, therefore, mapped as great circles on the CRT surface. Two choices were available to accomplish this transformation; correct the sweep to follow the correct scan line and picture element positions, or use a spherical rear projection screen with a video projector whose lens are located at the center of curvature. Both approaches presented risks, however, the risk of extending CRT technology appeared lower.

In the ASPT system the versatility of CGI again became obvious. In order to maximize resolution, the raster was aligned parallel to one edge of each pentagonal facet. This approach most efficiently covered each facet's field of view with the raster. The juxtaposed rasters, therefore, were put at different angles and the rasters center was not coincident with the pentagonal facet center. This task of symmetry caused no problems of inaccuracy in the CGI system since the only requirement was to correctly define the image plane field of view for each facet with respect to the eyepoint.

Added flexibility in alignments were allowed by this ability to define the image planes. The alignment of each individual channel is performed by using theodolite located at the center of curvature to measure and correct grid intersection locations. It is a tedious and time-consuming procedure. Due to anomalies peculiar to each ILIOS facet and CRT/electronics channel, the alignment is neither perfect nor optimized to any particular viewing location. An alignment algorithm has been devised which redefines the image planes to optimize the overall alignment. Input data is a set of error measurements recorded for selected grid intersections in each channel. After alignment, the stability is maintained by low-drift electronics and the rigid structure which holds the CRT's and optics. Periodic maintenance is required to perform realignment but it is infrequent since the stability requirements were considered in the initial design of the CRT/Electronics.

The next two examples of juxtaposition are represented by the Boeing and MRCA visual systems, Figures 7 and 8. The displays in these systems use a 26-inch high resolution shadow mask CRT. The images from two or three CRT's

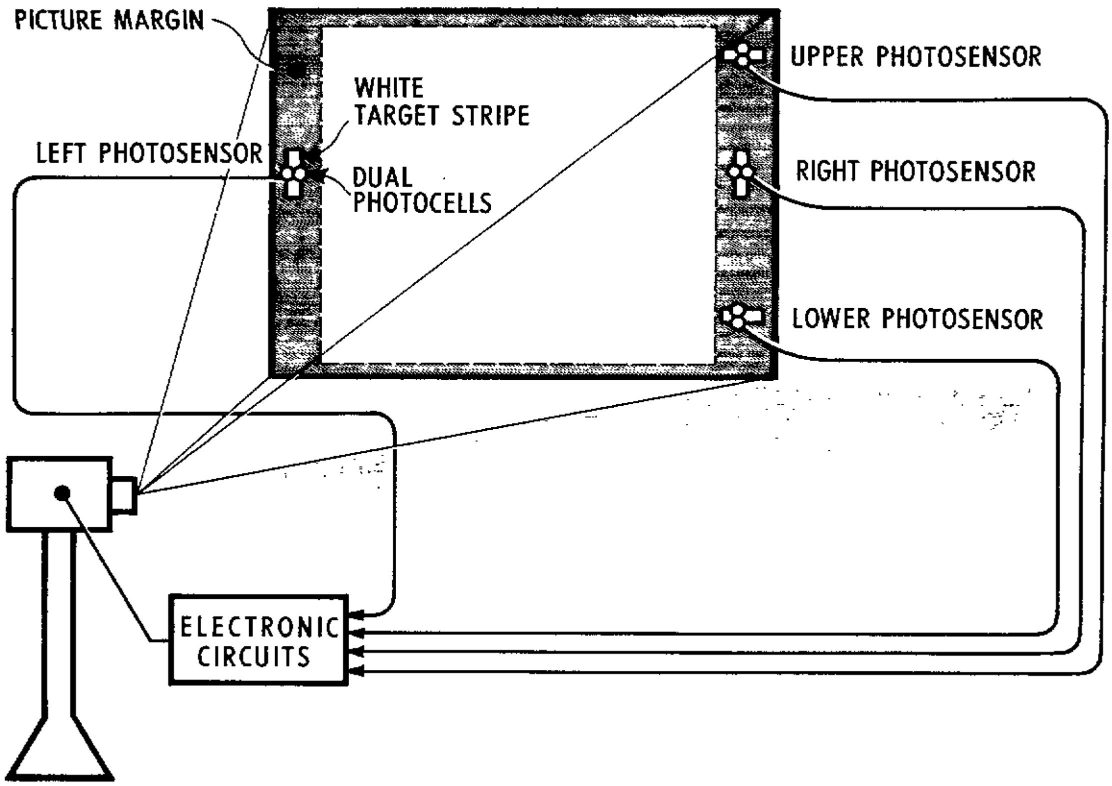

Figure 4. Edge Match Control System

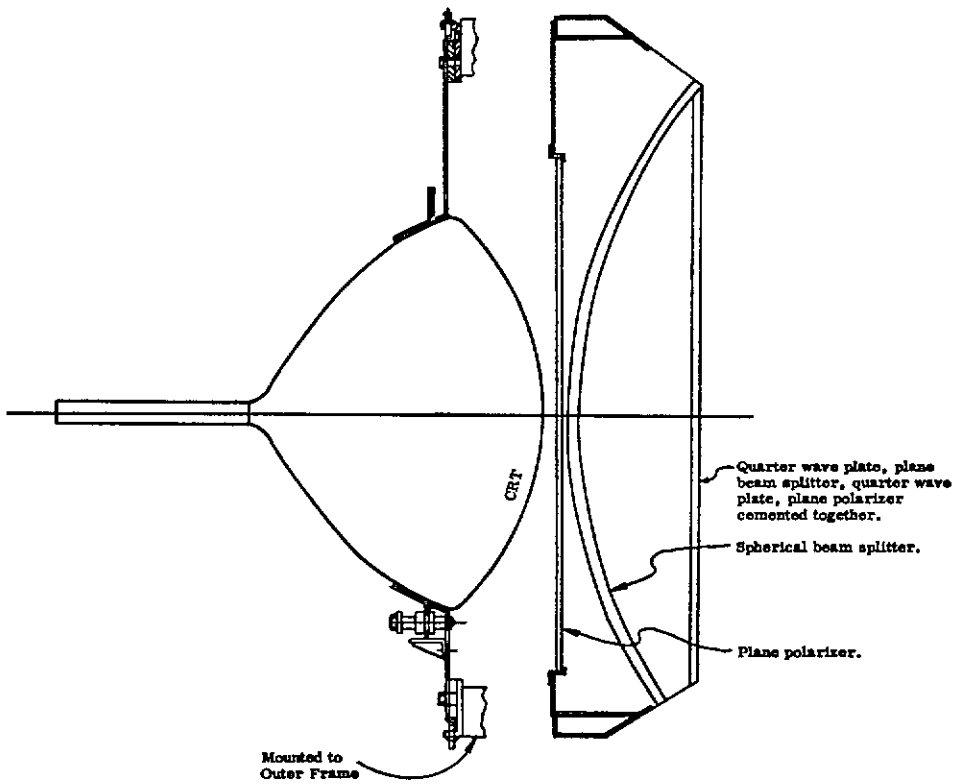

Figure 5. Cross Section of Typical Farrand In-Line Infinity Window

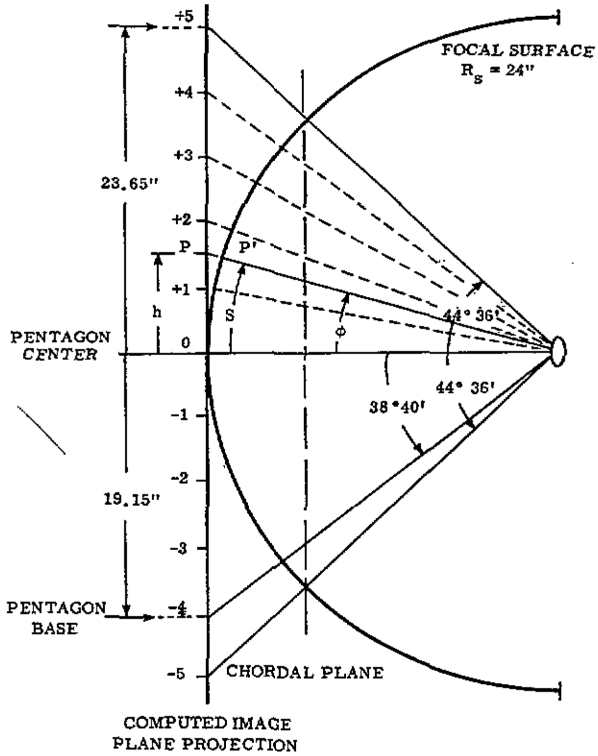

Figure 6. Mapping of Image Plane to ILIOS Focal Surface

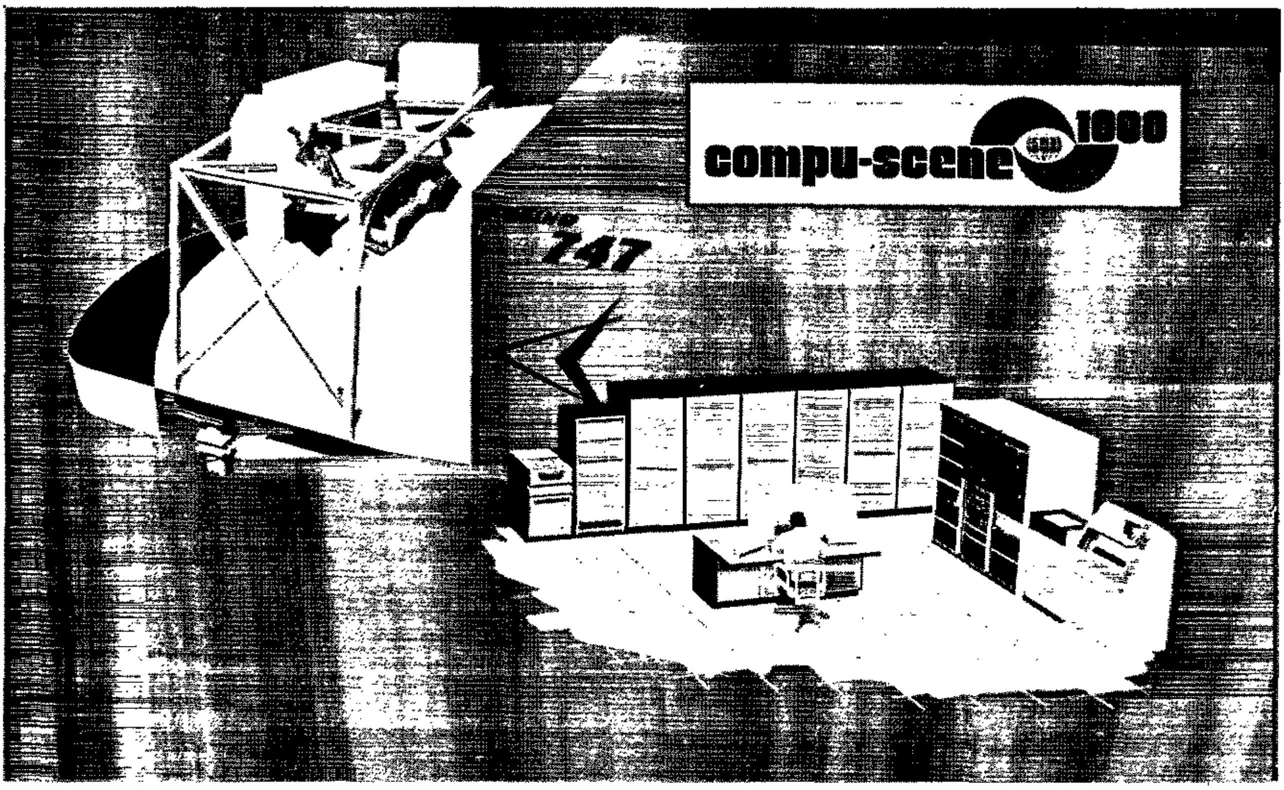

Figure 7. Boeing Visual System

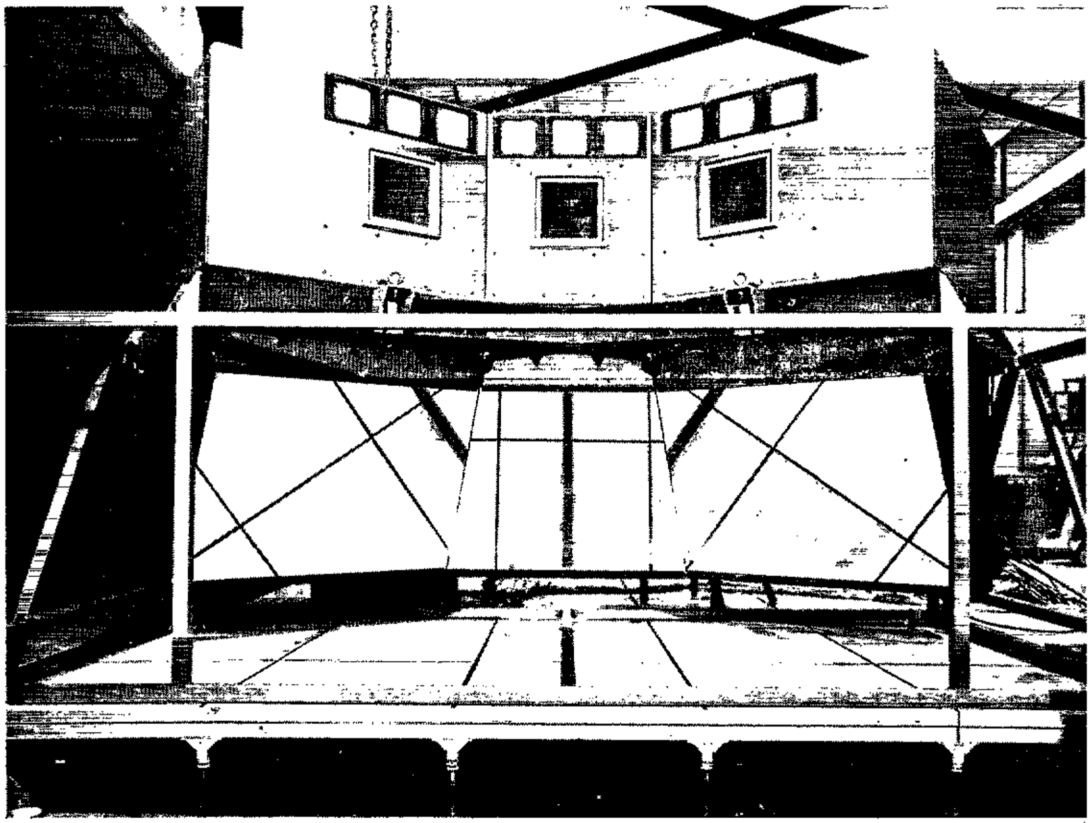

Figure 8. MRCA Visual System

are combined by modified 45-degree beamsplitter/ spherical mirror optics. The CRT's are constructed from funnel and face plate elements used in commercial tubes to minimize cost. For this reason the CRT phosphor surface does not lie in the optics system focal surface and the location of the CRT and focal surface images are shown as transformed by the plane beamsplitter (see Figure 9). If the eyepoint is located at the center of curvature of the spherical mirror, the correct image location on the CRT surface is the projection line through the eyepoint to the tangent image plane similar to the ASPT mapping. In order to increase the instantaneous field of view, the ERP is located closer to the mirror than the center of curvature. Location of correct image points was determined by computer programs, and the CRT/ electronics were designed to achieve this mapping. Accuracy and stability requirements of the sweeps were nearly the same as the ASPT system in order to achieve acceptable juxtaposition accuracy of images.

From the preceding efforts, it was apparent that extensions of the visual simulation technology into wide field of view, color presentations with acceptable resolution and brightness would require large expenditures for high risk development efforts or a unique approach. One approach which was investigated is shown in Figure 10.

Video projectors form an image on a juxtaposed array of field lenses. A wide-angle lens at the center of the array relays the image to another wide-angle lens located at the top focus of a double ellipsoid consisting of a mirror and screen. An image is formed between the output lens and mirror such that the mirror projects the image to the screen. Since the mirror and screen share a common focus point and have the same ellipticity, the pilot located at the bottom focal point of the screen is presented an image with minimum distortion. From first order analysis, the chief rays in this system will be located at angles corresponding to the initial calculated positions.

A full scale prototype of this system was built which confirmed the mapping (see Figure 11). The prototype consisted of available lens, video projectors and a custom-built screen. A peak-screen gain of nine was achieved with good uniformity and no distracting surface blemishes. On axis entrance pupil chips a function of field angle was not accommodated by the available field lens. This caused a per channel brightness fall-off which was distracting. Lateral chromatic aberration and astigmatism

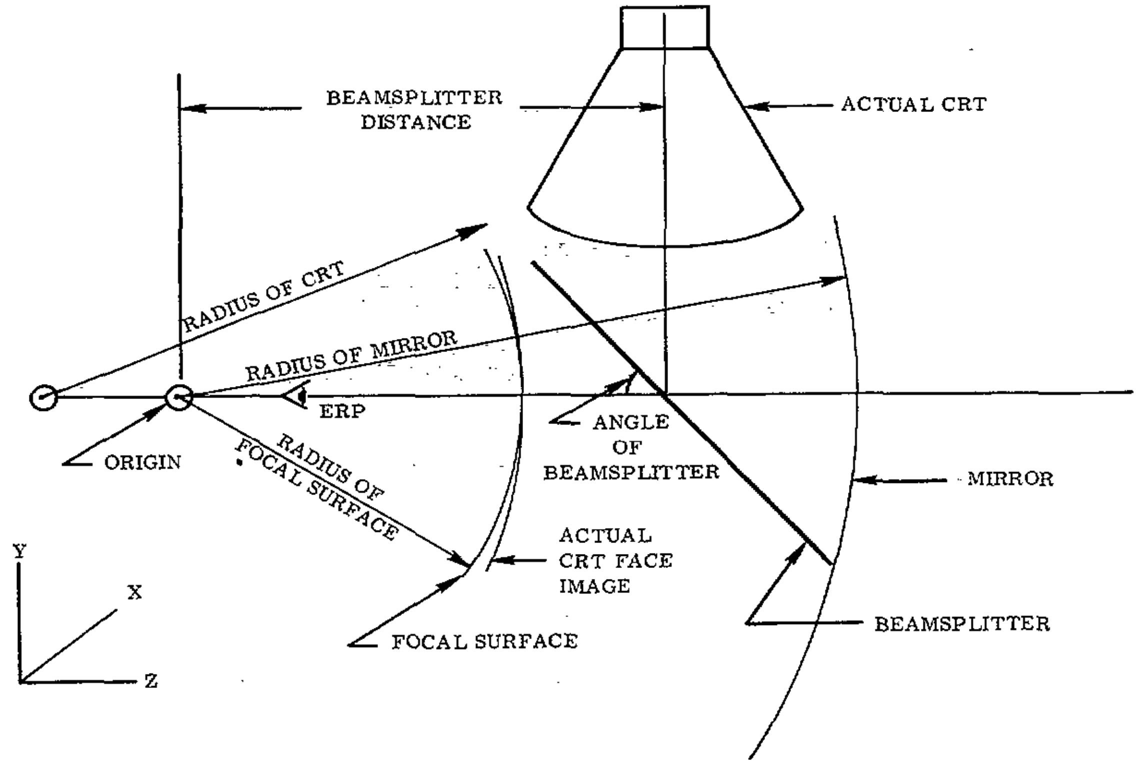

Figure 9. Virtual Image Display Optical Schematic Showing Input Parameters

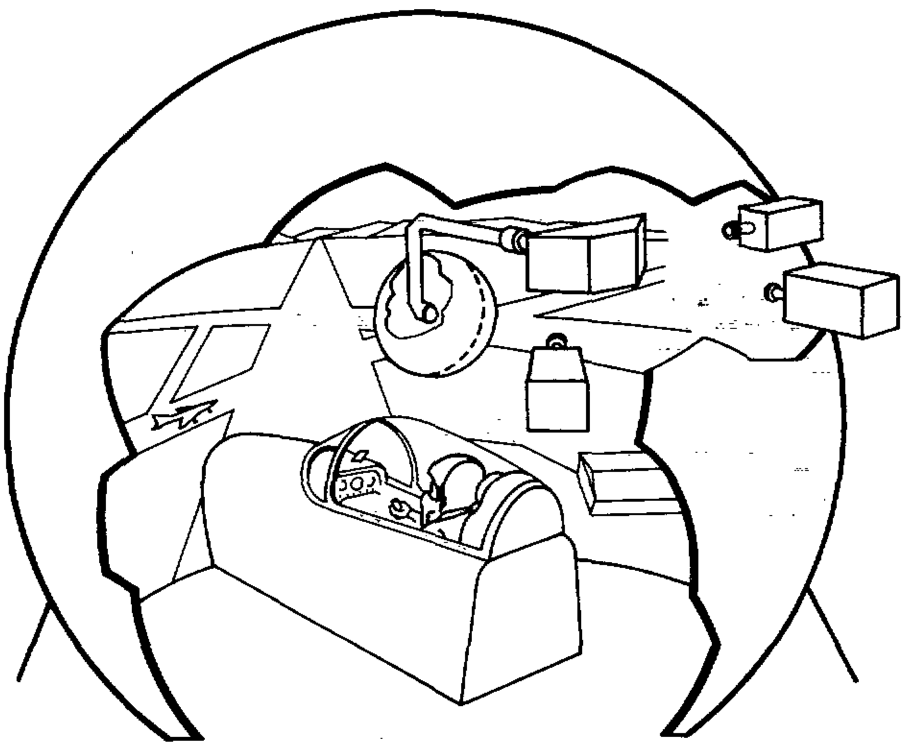

Figure 10. Wide Field, Color Display System

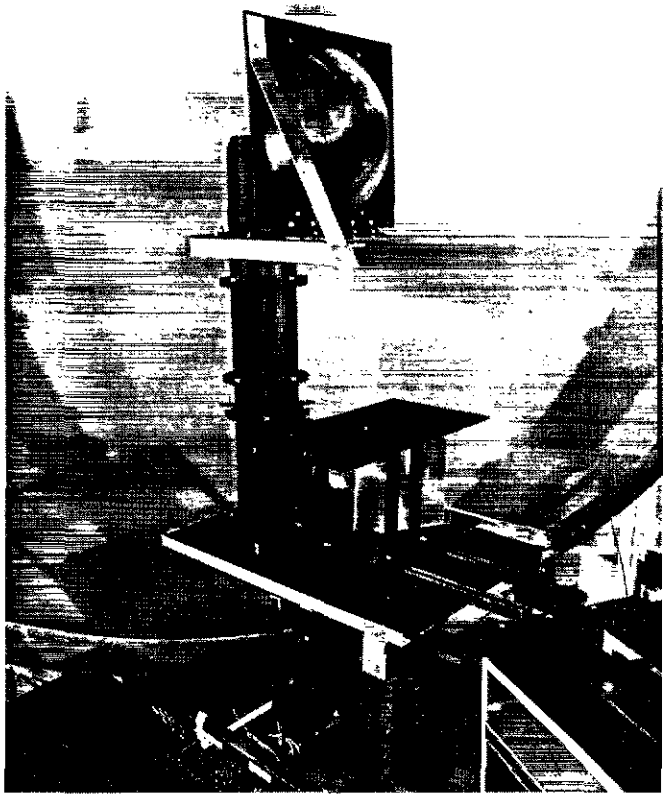

Figure 11. Display Breadboard

in the wide-angle lenses limited acceptable performance to the forward field of view.

An alternate tradeoff in this type of system is to compensate for distortion on the screen and reduce the number of optical elements required in the system. Since the raster of a single gun color light valve cannot be shaped, it is necessary to achieve mapping in other parts of the system. For example, a camera model system allows the raster shaping in the camera. Analogously the CGI system should allow shaping in the image plane.

This concept leads to the discussion of the AWAVS system in which this flexibility of the CGI will be improved and implemented. This implementation of the CGI mapping capability will make the AWAVS system the forerunners in CGI, dome technology.

AVIATION WIDE-ANGLE VISUAL SYSTEM (AWAVS)

The Aviation Wide-Angle Visual System is a complex camera model, CGI dome visual system built by Singer-Link and General Electric (see Figure 12).

General Electric's contribution to the system is the computer image generator and the light projectors. This part of the visual system is significant by the fact that this is the first dome, GE light valve projector system where the CIG will generate partial mapping corrections from the image plane to the pilot. The feature, in turn, will allow future dome, CGI, GE light valve projector systems to be used in both color and monochrome.

FUTURE VISUAL DISPLAY SYSTEM REQUIREMENTS

Due to the demand and requirements of training in visual simulation today, there is an everlasting need to produce sophisticated simulators. But the question is,"What is the optimum visual simulator?" Of course this question is followed by two more very rapid questions. "What is the training requirement and how much will the system cost?"

In the display area alone the requirements for aircraft and tanks seem to be the same old parameters that have been plaguing visual systems for years; color, resolution, brightness, field of view, eye pupil, infinity image or rear image.

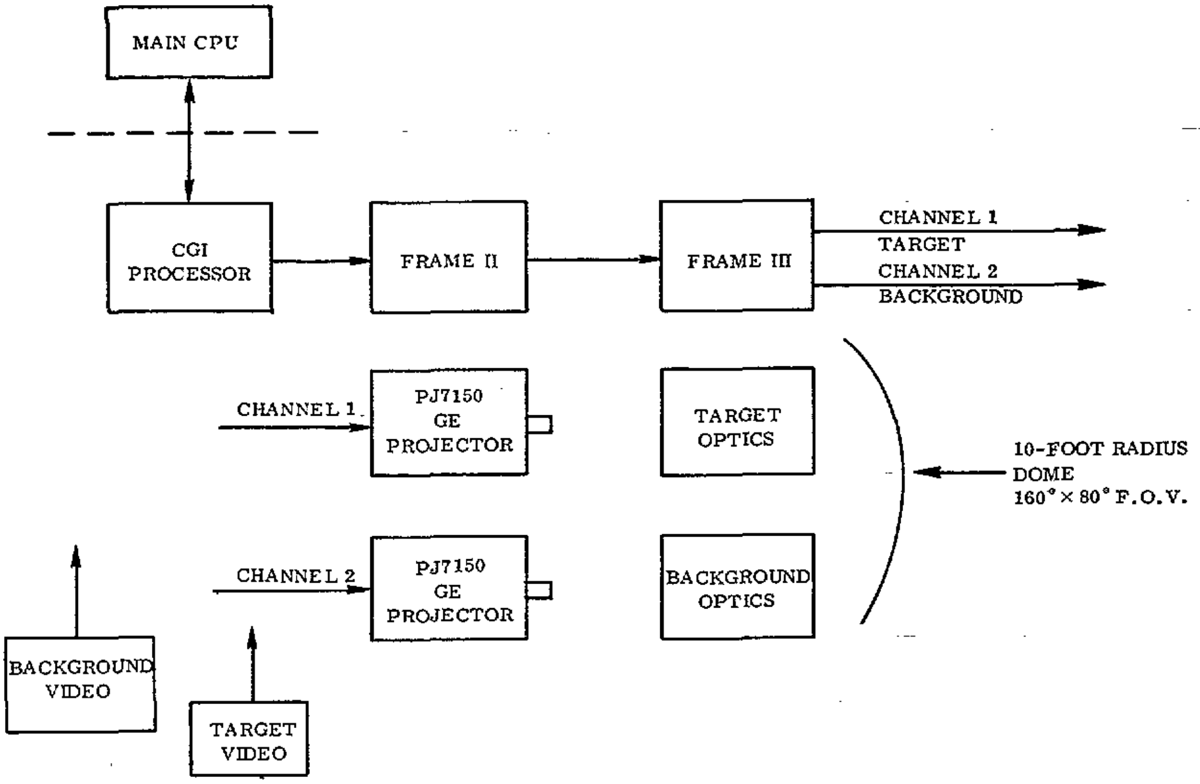

Figure 12. Simplified Display CGI Block Diagram

The above parameters themselves share a wide variation of contention within the users.

If the user must have a large continuous field of view for good trainability, he has two prevalent display choices today; a dodecahedro with pentagonal windows or a dome system with multiple projectors. Both systems lack what the user would ultimately want in performance. But if his pocketbook could afford it, and his schedule were long enough substantial improvements could be made. Consequently, the display parameters mentioned require more research and development to achieve the requirements of future visual systems.

In the image generator area some of the improvements in parameters such as potentially visible edges, variable size point lights, number of edge crossings per scan line, number of raster lines, and number of display channel drives per computer image generator need to be expanded by time sharing or other techniques that will keep the economics reasonable.

With continued improvements in the display and image generator areas, visual simulation will expand, thus giving great savings in manpower, money, material, and in particular, fuel.

REFERENCES

Bunker, W. Marvin, "Computer Generation of Images—The Multi-Purpose Tool"; Simulators and Simulation, Volume 59; March 17-18, 1977, pp 25-39.

Fisher, Robert A.; Lyons, Rubert; Aviation Wide Angle Visual System Trainer Subsystem Design Report; Technical Report NAVTRAEQUIPCEN 75-C-0009-13, May 1977, pp 19-27.

Beardsley, H.; Bunker, W., Eibeck, A; Juhlin, J; Kelly, W; Page, J.; Shaffer, L.; Advanced Simulation in Undergraduate Pilot Training; Report Number AFHRL-TR-75-59 (U), November, 1975, pp 61-86.

ABOUT THE AUTHORS

MR. PHILIP R. MARR is a Visual Consulting Engineer with Ground Systems Department of General Electric Company. He is presently working on conceptual design for Advanced Visual Systems. Some of these areas are: Development of a Wide-Angle Visual System, the Full Crew Interactive Simulator for the M60A3 Tank, the Fighter Attack Visual System and the Advanced Tactical Air Combat Simulator. In the past, he managed and directed large visual systems in both the hardware and software areas. The types of visual systems include the following: calligraphic, camera model, computer image generator, film input systems, synthetic terrain input systems, and camera gimbol systems. He has been directly involved with the following visual systems: Simulator for Air-to-Air Combat, AJ-37 Simulator, 2B31 Helicopter Simulator, 2B33 Helicopter Simulator, 2B38 Helicopter Simulator, Aviation Wide-Angle Simulator, and the Shuttle Mission Simulator. Prior to this, he worked directly with Computer Generated Image Display Systems. During the course of his career, Mr. Marr has held positions in design areas and key management areas. He is a graduate Electrical Engineer from Bridgeport Engineering Institute, and has taken graduate courses from the State University of New York in Computer Science and Business Administration. Mr. Marr has pending patent applications on a Deflection Amplifier Technique and a Computer Alignment Technique with two model boards using optical probes.

MR. LARRY W. SHAFFER is a Manager of Systems Engineering at General Electric Company. He was responsible for the MRCA juxtaposed display design, and was the lead display engineer for the design and intergration of CRT-optics subassemblies of the infinity optics display windows on the Boeing System and for the rear-projection light valve configuration and for the Navy's 2B35 system. He has participated in contracts to establish the interface requirements and define simulation display systems for Air Force Trainers (ASUPT and UAFST). Mr. Shaffer was the Display Systems Engineer for the 2F90 Flight Simulator Visual Attachment, delivered to the Navy in 1972. He leads the effort on the Shipboard Data Display System IR&D and participated in a oint simulation display development activity within General Electric. His work prior to this included a comprehensive analysis and evaluation of motion platform-mounted display equipment compatible with CGI visuals. He designed a display system which combines a film and CRT image for simultaneous viewing in an information management system display. Mr. Shaffer received a B.S. degree in physics at the Rose-Hulman Institute of Technology and an M.S.E.E. degree at the University of Florida.