CURRENT DEVELOPMENTS IN VISUAL DISPLAY TECHNOLOGY FOR FIGHTER TYPE SIMULATORS

by
Jon Dugdale, Michael Fortin, James Turner
Raytheon Systems Co.
Arlington, Texas and Binghamton, New York

The trend in simulation systems for current fighter type aircraft is to employ increasing numbers of components that have been developed for commercial markets. The reason for this trend stems from two factors; the remarkable improvement in the performance of these system elements, and the relatively low cost of those elements.

This availability of low cost image generation equipment and high performance projectors has enabled the revival of a class of simulation display devices long thought too expensive to be put into general use in training simulations. These rear-projection display systems take a brute force approach to providing the pilot with high resolution imagery throughout his field of regard. This abundance of imagery, while a great improvement over systems with area of interest and/or reduced field of view images, has only recently become cost effective.

One new system that takes advantage of this progress is the SimuSphere developed by Raytheon. This display makes use of a well established dodecahedron structure. The modernization of the design has included advancements in all areas of the technology, from manufacturing to image generation. This paper will discuss a number of these improvements to the display hardware, including manufacturing tolerances and repeatability, mechanical and electronic alignment concerns, and ingress/egress issues. The benefits to the system wide solution resulting from image optimization and a compatible HUD design will also be detailed. Finally, any system that makes significant use of commercial components must have a clear upgrade path which benefits from their characteristically rapid evolution. Potential system enhancements resulting from improved projection and image generation products will also be explored.

Jon Dugdale is a Principal Engineer with Raytheon Systems Company with over 30 years experience in simulator and visual design. He has directly performed or supervised the design and fabrication of over 300 visual displays for U.S. and foreign, military and commercial customers. He designed the first U.S. Phase II and Phase III FAA certified visuals, first refueling rotating visual displays, the only beamsplitter/mirror display rated for 10g use in a centrifuge, the U.S. Navy/Marine F/A-18 Operational Flight Trainer VIVID-35 Displays, the Raytheon SimuSphere Display and was Technical Lead on the Raytheon VIVID development program. He has been awarded five U.S. patents and has several U.S. and foreign patents currently pending. He studied Mechanical Engineering at the University of Texas at Arlington.

Michael Fortin joined Raytheon Systems Company (then Rediffusion Simulation) in 1974. Since then he has been involved in many technical areas of visual simulation including Visual Database development and production, Technical Marketing and Product Management. His experience covers a wide range of real-time computer graphics devices from the early Rediffusion Novoview systems to today's state of the art systems from various manufacturers. He is currently in Visual Systems Engineering at Raytheon in Arlington (Texas) working on the integration of new image generation products, databases and display devices to meet current applications. Mr. Fortin received his bachelor's degree in math from Florida State University and served as a Naval Aviator prior to joining Raytheon.

James Turner is a Staff Scientist with Raytheon Systems Company with over 25 years experience in visual systems for simulators. He holds many patents with several more pending. He was a key member of the eye-slave development team and was directly responsible for essential developments in servo systems, oculometer technology, AOI blending, mapping, system throughput and display software. His contributions led to the first eye-slaved visual system (ESPRIT) ever to be delivered on a full mission operational simulator (GR5 & GR7). His visual system display designs have run the gamut including domes, collimated displays and flat panels. Mr. Turner received his Master's degree in physics from Ball State University.

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SimuSphere Development Decision

From the earliest days of aviation and aviation training there has been a special interest in teaching the skills associated with the single seat fighter and attack missions. One reason for this attention is the danger inherent in this type of flying, another is the limited availability of airborne training generally imposed by the aircraft itself. This special training interest has also permeated flight simulation requirements from the earliest days of that technology. Two early systems that attempted to provide training and/or training research were the Simulator for Air to Air Combat (SAAC) and the Advanced Simulator for Undergraduate Pilot Training (ASUPT). These devices were developed in the early 70's and are still in use today.

Figure 1. Simulator for Air to Air Combat

Since those early devices there has been a large number of simulators developed that have attempted to satisfy the training requirements of the fighter/attack community. Two of the more difficult areas to simulate have always been the motion associated with high-g maneuvering and the "full field of view" visual system to provide the pilot with a view of his environment, including hostile targets and threats. While the motion question seems to have boiled down to "no motion is better than limited and inaccurate motion", the quest for a full field of view visual has accelerated with each new development in projector and image generator technology.

Many of these visual display devices took the form of a spherical dome with the pilot located at or near the center. In order to avoid the difficulties and costs of providing high-resolution imagery throughout this very large area (• 360° x 120°) a number of Area of Interest (AOI) strategies were developed. These systems provide background imagery that is lower resolution and brightness and a small area of higher resolution and brightness that is moved around the dome surface. The area may move in response to a target or other feature in the scene, or be directed by a tracker on the pilot's head. Raytheon (Link) developed the ESPRIT system that uses the movements of the pilot's eye to direct the AOI image. Some systems make use of one or more target projectors to draw high resolution targets that can move around the screen area separate from the AOI image. While the dome approach provides a screen on which to display the full field of view image, there is an inherit problem of where to put the projectors to supply that image. The physics and geometry involved make it almost impossible to provide imagery at all points of the spherical screen while not obscuring the pilot's view, particularly in the upper rear areas of his field of view (six o'clock high). Configurations that place the projectors outside the dome can resolve some of these issues, but brightness and image continuity problems arise.

In recent years the availability of high performance projectors and image generators at relatively low cost have allowed a return to display configurations similar to the SAAC and ASUPT mentioned above. Unlike the dome/AOI approaches these devices supply high resolution and brightness images throughout the pilot's field of view at all times. Rather than a spherical dome, a faceted geometry is used to surround the pilot, with the images being projected onto the rear side of the facet screens. The pilot is provided with a much more realistic environment that is free of many of the artifacts and false cues associated with the older systems. While these devices provide much higher resolution than the dome background images, they may not match the resolution of a dome's AOI image. Target projectors may be used to somewhat compensate in this area.

In looking to satisfy the ongoing demands for improved field of view, resolution and brightness associated with current government procurements, Raytheon looked closely at these new display devices as part of standard make/buy decision processes. One major concern with the available systems was an inconsistency in resolution and brightness across the system. This is generally the result of providing a smaller screen with higher resolution in the front channel, and larger, lower resolution images elsewhere. This disparity also resulted in inconsistent screen brightness as well as pilot's eye to screen distances.

It was felt that experience and expertise resident within the company would enable the development of a superior faceted dodecahedron type display that would provide optimum performance today and also provide an upgrade path as contributing technology continues to improve. In the Spring of 1997 it was decided to proceed with the development of SimuSphere.

History of Dodecahedron Systems

A dodecahedron is a twelve-sided solid with regular pentagon shaped facets of equal size. The benefits of a partial dodecahedron shape (nine or less facets) as a visual display configuration have been recognized since the early 70's. Both the SAAC and ASUPT devices make use of this configuration. Those systems originally used monochrome CRT displays and pancake optics to provide the pilot a virtual image of his environment. The SAAC system used an analog terrain generator to provide a ground/horizon reference and models of aircraft seen via a television and mini-raster process to provide high resolution targets (see Figure 2). This system, with some upgrades, is still in use today as part of the Air Force TAC ACES program at Luke AFB.

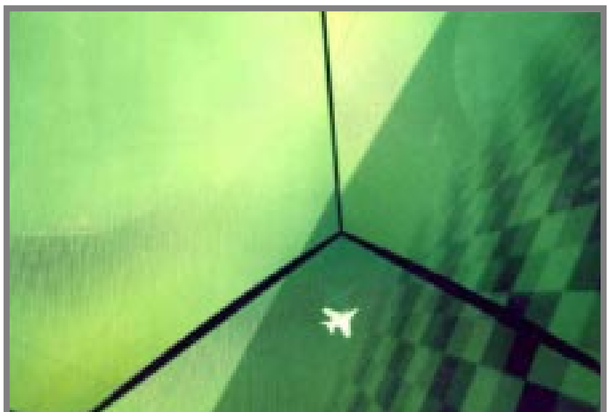

Figure 2. SAAC Imagery

The ASUPT imagery was originally provided by one of the first GE image generators. It was used primarily for research purposes and was an important contributor to the science and techniques of simulation for many years. In the early 90's the basic structure of the ASUPT display was used as the foundation for the Display for Advanced Research and Training (DART) at the Air Force's Armstrong Laboratory (see Figure 3). The DART system makes use of CRT projectors and rear projection screen facets. Multiple image generation devices have been used over the years to provide the imagery. The DART continues to be used for research purposes at Armstrong and has led to the development of similar devices that make use of other facet sizes and shapes (e.g. M2DART).

Figure 3. Display for Advanced Research and Training (DART)

Benefits and Features of SimuSphere

The SimuSphere was designed as a dodecahedron display making use of nine display facets in its full configuration. Figure 4 shows a rendering of the overall system. In this configuration fold mirrors are used on some of the facets to reduce the facility footprint of the system.

Facet Uniformity - Raytheon decided to stay with the dodecahedron shape as the foundation for SimuSphere in order to take advantage of a number of intrinsic benefits associated with the common size and shape of the facets. This consistency is particularly important for brightness and resolution, both within a facet and between adjacent facets.

Figure 5 shows a plot of display brightness for a given projector and screen material configuration. The equal fall off in brightness toward the edges of the pentagon ensures that the pilot will see a consistent image throughout the facet without distracting artifacts. Even more significant is the benefit of consistency between facets. When adjacent displays with these same values

Figure 4. Rendering of SimuSphere configuration

are considered it is very easy in the projector setup to match the brightness across the seam. The bend angles of the light rays from the projector to the screen, and from the screen to the pilot's eye are consistent for all facets (max. of 37º). The resolution performance of the system also benefits from this uniformity of screen size (see Figure 11). The pixel size variation over each screen is limited to a ratio of 1.6:1. This means that targets and other scene features do not change in appearance as they pass from one facet to another, and the chance of the pilot losing contact due to system artifacts is greatly reduced.

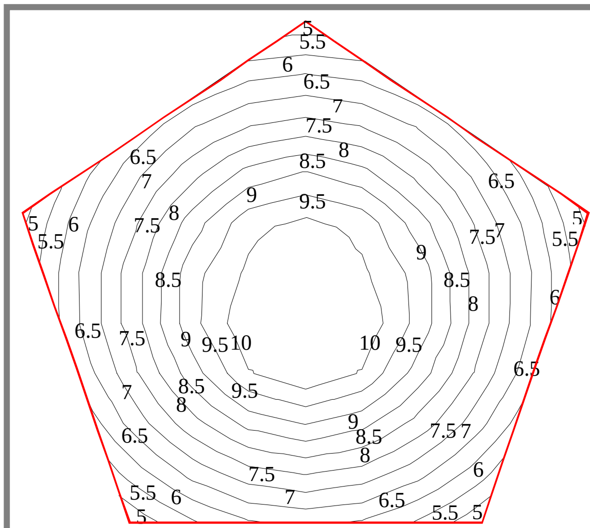

Figure 5. Plot of brightness across facet.

The use of the basic dodecahedron geometry as the basis for the system also means that the distance from the pilot's eye to the center of each screen is identical. This distance is 40 inches in the SimuSphere. This consistency, along with the resolution and brightness discussed above, aid in the pilot's accommodation to the system as his view of his environment moves around the display.

Minimize Seams - The size of the seams or gaps between images is an important issue when considering any visual display device that makes use of multiple pictures to create a large field of view. This is particularly true in a faceted display where typical edge blending techniques are not appropriate. The goal for SimuSphere was the effective elimination of the seams as a visible distraction.

Figure 6. Facet assembly and bonding tool

In order to accomplish this goal new techniques in the manufacture and mounting of the individual facets had to be designed and developed. The process had to be repeatable to the extent that any two (or three) facets when mounted adjacent to each other would fit together with essentially no gap. The original design objective for the seams between facets was .09".

In order to achieve this kind of repeatability between facets it was necessary to develop special tooling that would allow for the assembly of the facets (see Figure 6). The Facet Bonding Tool provides continuous accurate clamping forces during the bonding of the facet components. High volume fabrication of the assemblies to close tolerances is provided, as well as a minimizing of tolerance accumulation when multiple facets are installed together. The tool also reduces expensive hand labor techniques that have been necessary on previous systems of this type.

Eliminating the seams between facets as an artifact in the visual scene also removes, or reduces, concern over where the seams fall in the image. One criticism of the DART system has been that two of the seams fall at the 90° and 270° positions (3 and 9 o'clock) where a wingman or flight lead is normally positioned for many tactical formation maneuvers. To address this problem, we employed a three pronged attack: 1) elimination of seams as a visible distraction, 2) pitching SimuSphere relative to the cockpit so that the seams pass through ±90° at a single point, and 3) the use of Virtual Collimation to further separate the seams from the scene and insure that the single point crossing varies with the pilot's head movement

Virtual Collimation - One concern with faceted, rear projection display systems is that the distance from the pilot's eye to the screens is relatively small. In the DART system this distance is 36". The design for SimuSphere increased this distance to 40" for compatibility with other simulator components. The problem is that when the pilot moves away from the design eyepoint, parallax errors between the location of features in the visual scene and the same features in a real-world situation are incurred. This could occur when he looks around the HUD for carrier lineup, or looks behind his aircraft (and the ejection seat) for a target or threat. It even occurs with more subtle movements such as those associated with viewing HUD information or simply shifting into a more comfortable position. The smaller the eye to screen distance, the larger this angular disparity.

Figure 7. Upper image shows head movement to the left without Virtual Collimation. Lower image shows the same movement with Virtual Collimation resulting in real-world parallax effects.

One remedy for this problem in previous display systems, most notably the eye-tracked ESPRIT system, is a technique referred to as Virtual Collimation. Virtual Collimation makes use of head position data from the headtracker to reposition the calculated eyepoint within the image generator. When a pilot on approach moves his head to look around the HUD, for example, the position of the image on the screen is recalculated and displayed correctly (see Figure 7). The airfield details are moved to the correct position so that the amount of head movement required is the same as is required in the actual aircraft when on short final.

In addition to these specific parallax issues discussed above, Virtual Collimation provides the pilot a more realistic interaction with his virtual environment. The effect is to separate the image from the screen itself. The feeling of sitting in a relatively small dome is greatly reduced because the imagery responds to subtle head movements by the pilot during normal maneuvers. Proprietary algorithms are used to minimize delays between the pilot's movements and the responding imagery. This implementation also filters the inputs so that the out the window imagery is stable and no artifacts are introduced into the scene.

A compatible HUD implementation is also required so that alignment of scene features and HUD symbology is maintained as the pilot's head (and the image) move. A projected Virtual HUD™ is available as one alternative.

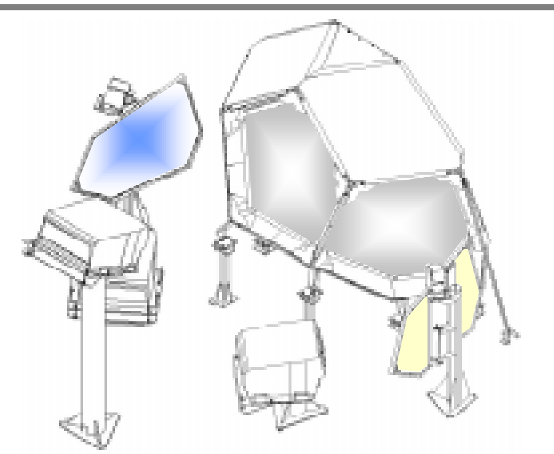

Figure 8. Three facet SimuSphere configuration

Modularity - Another design goal of SimuSphere was modularity. It was recognized that not every application would have the immediate need and/or budget for a full field of view system. While the system is best applied as a full field of view nine facet display, the performance benefits discussed above are also applicable to smaller versions with fewer facets. Included in the modularity approach is a capability to readily increase the number of facets once the system is in service. Here again the basic dodecahedron structure can be called on to provide the geometric structure that is needed.

The standard options considered for the SimuSphere were 3, 5, 7 and the full 9 facet systems. There are two alternatives for the 5 facet configuration; the 5 (vertical) and 5 (horizontal). Refer to the Aitoff plot in Figure 13 and the fields of view shown below in Table 1. Other configurations are possible as well, including even numbers of facets. Figure 8 is a CAD drawing of the three facet configuration.

The modularity of the system also extends to additional projectors for some or all of the facets. These can provide increased resolution for a portion of the facet or could include target projectors that provide multiple target images per facet if required. The configuration of the fold mirrors can also be customized. Figures 4 and 8 show a SimuSphere with the basic mirror design. It is possible to increase the number of mirrors and/or modify their location in order to meet a particular requirement. A system with no fold mirrors (and a larger footprint) is also available.

Image Generator and Projector Independence - Another important feature designed into SimuSphere is image generator and projector independence. This implied flexibility is important during at least two points in the implementation of a given system. One is the original configuration of the overall visual system to meet specific application and/or customer requirements at the beginning of the program. The other is to allow performance improvements through the incorporation of new technology as both image generation and projector technology advances over the life of the system.

SimuSphere Development

Prototyping methodologies, trade studies, and system performance evaluations were initiated in the Spring and Summer of 1997 to optimize the system design. The three main areas to be prototyped were the basic facet construction, the support structure and the ingress/egress door needed for the 7 and 9 facet systems. Some of the design changes and improvements that were implemented as a result of the prototyping process are discussed below.

Facet Prototyping - The basic arrangement of the facets is shown in Figure 9. They consist of commercially available rear projection screen material and light baffles made from a different acrylic material. The design called for these to be bonded together and various mounting fixtures to be attached. The SimuSphere structure and all the mounting hardware are positioned within the wedge shaped area between the projector ray paths (where the divider baffles are located) in order to prevent them from obscuring part of the image.

The first prototype facet assemblies revealed that the bond joints between the dissimilar acrylics were not strong enough to stand up to installation and adjustment. The design team brought together the necessary polymer and adhesives expertise from other Raytheon sites to determine the optimum bonding design and materials. The team studied specification data and performed tests on adhesion strength, tensile strength and lapshear strength using ASTM certified testing devices in our Massachusetts laboratory. Using the specification data and test failure data the team refined process specifications for materials, for surface cleaning and preparation, and for handling and mixing of the bonding ingredients.

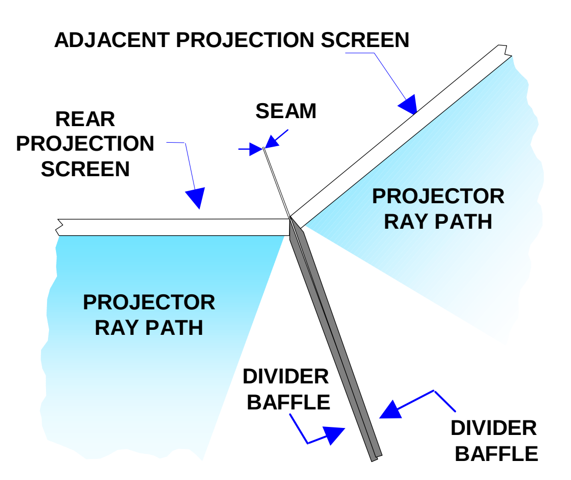

Figure 9. Basic facet construction and layout.

In addition, a Finite Element Analysis (FEA) was performed for the panel support and attachment areas and the bond areas to determine the magnitude of those stresses. The data from the FEA allowed design changes that resulted in average stress reductions of 80% in the facet bond areas and as much as 98% in other areas.

Support Structure – The support structures originally developed for the ASUPT and SAAC simulators were relatively massive in size, partly because those devices were mounted on motion systems. The SimuSphere is not designed for motion so the structure was designed to be much lighter weight than those earlier systems. The original design used flat aluminum bars joined at the apexes of the dodecahedron. After examining the prototype results it was decided to alter the material to a T section aluminum extrusion in order to increase the rigidity of the overall frame. This was necessary in order to maintain the tight seam tolerance goals mentioned above.

It was also determined that a better facet mounting and adjusting mechanism was needed. The final design incorporates six degree of freedom adjustments that allow micro positioning of the facets. This feature was again necessary in order to achieve the small seam size for all parts of the display.

Despite these increases, the weight of the structure has remained low. It is possible for four or five people to lift and position the SimuSphere frame before the facets are installed. This greatly simplifies the assembly process during installation.

Ingress/Egress – In the larger 7 and 9 facet versions of SimuSphere it is necessary to provide a door for entry and exit of the cockpit. It was decided that the left rear facet would be hinged in order to provide this access. A major concern with this design was maintaining the alignment of the facet when it is in the closed position, particularly after a large number of open/close cycles.

The original design was to incorporate the hinges into the divider baffles for the left rear facet. The attachment point for the pneumatic actuator would also be located on the facet. Prototyping showed that the facet bonding problems mentioned above also affected the design for the door, and a number of improvements were incorporated. Figure 10 shows the final design.

In addition to the pneumatic actuator that operates the door, a nitrogen charged damping cylinder is included to slow the movement of the panel and limit the contact force when the door closes. The damper is similar to those on hatch back cars.

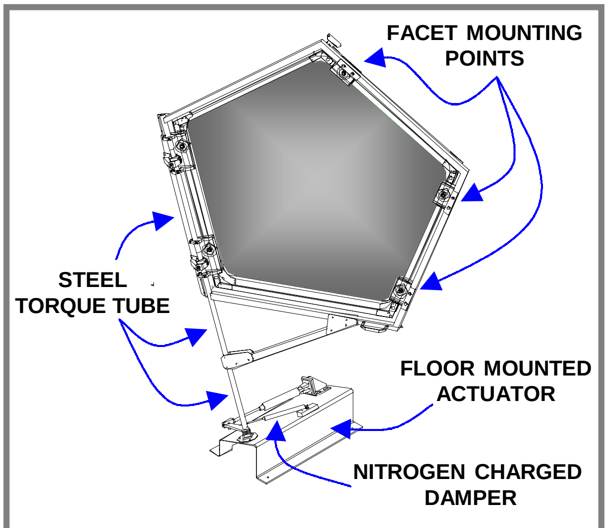

Figure 10. Ingress/Egress features

Operation of the hinged facet is by one of three methods; an external switch that activates the door, operation of the canopy open/close switch in the simulator cockpit, or manually from inside or outside the display for emergency access. There is no mechanical latching mechanism designed into the SimuSphere door. The pneumatic pressure from the actuator is sufficient to keep the door in the open or closed position.

A pilot wishing to enter the simulator cockpit and display system pushes the open switch on the External Control Panel. The pilot then enters through the open left rear facet and climbs into the cockpit. After being seated he engages the canopy swtich as if he were closing the aircraft canopy. On exiting the simulator he operates the canopy switch as if he were opening the canopy, which actuates the air cylinder to open the hinged facet. An instructor or observer outside the simulator can at any time open the facet either from the External Control Panel or by manually pulling the facet by hand. The pneumatic actuator force holding the facet closed is only a few pounds and can be easily overcome manually in the even of an emergency or system failure.

Screen Material Trade Study **–** In researching available projection screen technology for use with SimuSphere, the team members were able to benefit from new screen coating and manufacturing techniques in the marketplace and to draw from Raytheon experience on many previous displays designed and delivered. For SimuSphere, the engineers and technicians tested numerous samples from multiple vendors in order to identify the materials that had just the right set of characteristics to present an optimum image to the pilot. Vendors and vendor samples were down selected, and then individual parameters were tested and recorded, such as screen peak gain, half gain point, per cent transmission, reflectance gloss angle, optical tint and screen resolution or MTF. Then, using the Raytheon Mathcad software (see below), the recorded data was analyzed for the effects of each coating on the performance of the SimuSphere.

One of the challenges for SimuSphere as an enclosed rear projection display was that light from each of the nine facets would bounce around within the display and wash out or lower the contrast of the displayed imagery. Optical tint and other antiglare coatings were studied to improve system contrast. Fresnel and other lenticulated screens were not selected at this time because those products proved to be resolution limiting at the line and pixel rates being planned for SimuSphere. Since no individual coating possessed all the qualities determined to be necessary for the system, the design team worked with the manufacturer to develop a custom process specification to control the screen and coating product. The result is a screen system that allows SimuSphere to implement resolution improvements as projector and image generator technology evolves.

New Display Design Software Tools – The initial development of SimuSphere relied heavily upon a suite of Raytheon developed tools using Mathcad Plus 6.0 as the platform. These tools allow designers to evaluate the impacts of geometry, head motion, projector selection, lens selection, screen material selection, IG selection, and IG configuration on various system parameters including polygonal resolution, texture resolution, brightness, FOV coverage, and mapping. The tools will even determine projector position and attitude automatically given a particular channel's desired FOV coverage, projector selection and lens selection.

As an example, the resolution tool (probably the most complex) takes into account:

- IG type (ESIG, SGI, SE2000, etc.)
- IG pixel/line rate
- IG anti-aliasing filter/sub-pixel configuration,
- Video format (interlace, progressive scan, frame/field rate, horizontal retrace time, vertical retrace time, calligraphic time, etc.)
- IG window FOV/mapping
- Geometry (eye point position, screen position, screen curvature, projector position, projector attitude, etc.)
- Projector resolution
- Optical mapping and distortion
- Optical resolution
- Screen resolution

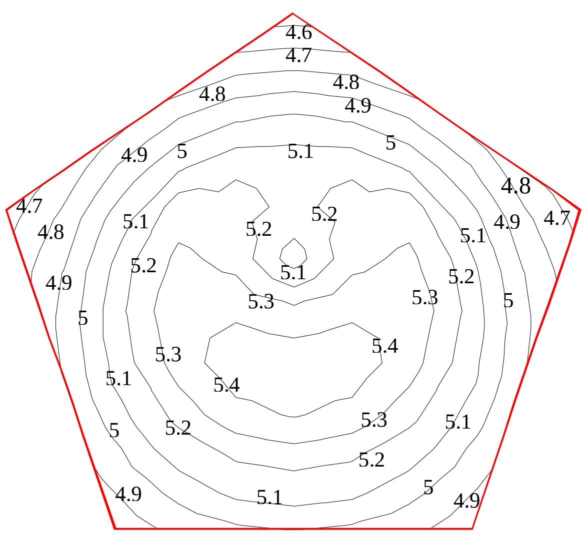

Figure 11. Mathcad resolution plot (arc-min/OLP)

The resolution tool then allows the user to request resolution at best, average or worst case pattern to IG phasing. The system resolution can either be determined at a given Modulation Transfer Function (MTF) (3%, 10%, etc.) or the system MTF can be computed for a given resolution (3, 6, 10, etc. arc-minutes per optical line pair). The result is output as a contour plot that covers the selected channels IG FOV. Another output depicts the relative contribution of each one of the system components. Figure 11 is a plot of resolution for a given set of parameters. Figures 5 and 13 were also developed with the Mathcad tools.

For collimated displays, a set of tools exists to compute vergence for given display configurations as well as allowing the user to develop display systems that fall within user established vergence limits and FOVs. The collimation display tools also allow the computation of system resolution, system brightness and FOV coverage. Another set of tools handles dome visual systems. All three tool sets (flat screen, dome, and collimated displays) have been used to design visual systems delivered on a variety of simulators.

For SimuSphere, these tools are currently playing a vital role in the continuous evaluation of performance impacts resulting from evolving technologies as well as the selection of the most cost effective configurations that meet each customer's needs. To insure the continued effectiveness of these Mathcad based tools, Raytheon has become a Mathcad Beta site which has proven to be mutually beneficial to both parties.

Maintenance and Supportability – The largest maintenance concern for a display device with multiple projectors is the effort and frequency of adjustments. This is particularly true of the larger SimuSphere systems. The answer to that question depends largely on the projector that is selected for use in the system. The stability in brightness, convergence, focus and other important performance areas become major contributors to the decision process when making this selection. Regardless of the projector selected, it will be necessary to align the image on the facets, and between facets.

Proper alignment of any projected display requires the comparison of reference points located or projected onto the viewing surface of the display device with similar points in an appropriate test pattern. The first 3 and 5 facet SimuSphere displays used modified slide projectors and specially designed optical slides. Because of the complexity and cost of using slide projectors on 9 facet displays, the SimuSphere design was modified to use the Raytheon (Hughes) patented Invisible Ink Alignment System (IIAS). The IIAS is also presently used on other Raytheon display devices, including the VIVID-35 wide angle virtual image system.

The IIAS uses a fluorescent ink that is visible only when illuminated under ultraviolet light. Use of the fluorescent ink allows the alignment pattern to be permanently marked directly on the facet screens. When the alignment pattern is viewed by illuminating it with an ultraviolet light source, any misalignment of the projected image to the fluorescent ink reference pattern is obvious without the use of additional equipment. Use of the IIAS also reduces the installation time and system maintenance since there are not 9 individual slide projectors and related special mounting devices.

Another maintenance feature of the system is a light weight hoist for raising and lowering the projectors from their mounts. With the inclusion of the fold mirrors into the system most of the projectors are located close to the floor where they can be worked on more easily.

Development Results – Specifications, Performance

After a successful development and prototyping period the SimuSphere went into production in the spring of 1998. A total of six SimuSpheres are currently being provided on U.S. Navy and U.S. Air Force programs. The modularity built into the design has also been exercised in that the production configurations include three, five and nine facet systems. Figure 12 shows one of the three facet production systems during integration.

Figure 12. Production SimuSphere (three facet)

Production Configuration - As discussed above, the detailed configuration of a SimuSphere system is image generator and projector independent. Many of the performance specifications are therefore dependent on the major components selected. For the systems currently in production two different configurations of the Silicon Graphics, Inc. Onyx2 have been selected as the image generators and the Electrohome 9500 as the projector.

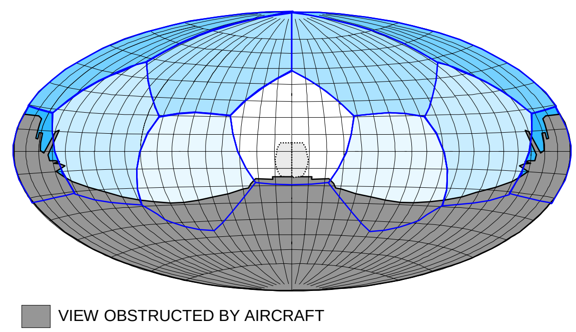

Figure 13. Aitoff plot of SimuSphere field of view for a nine facet system.

Field of View – The fields of view provided by the nine facets of SimuSphere are shown in the Aitoff plot in Figure 13 and are listed in Table 1 along with the number of image generator channels/images that are required. In order to optimize image generator resources in the larger 7 and 9 facet systems a video switching technique is used. Only six of the facets are generated at full resolution, with the remaining facets displayed at lower resolution and content. A headtracker is used to determine where the pilot is looking at any given time and the six facets closest to his viewing angle are selected as high resolution.

# of Facets	Approximate FOV		I.G. Chan.
	Horizontal	Vertical	
3 Facet	190°	70° +	3/0
5 Facet (h)	300°	70° +	5/0
5 Facet (v)	190°	140°	5/0
7 Facet	300°	140°	6/1
9 Facet	360°	140°	6/3

Table 1. Field of View and IG requirements

This same switching technique has been used on other systems (e.g. DART) in the past, but in most cases the screens behind the pilot's head are turned off altogether. In evaluating this approach the Raytheon team felt that even though these screens are outside the pilot's useable field of view, the abrupt change in brightness is noticeable and distracting. It was decided that these facets should be illuminated, but that the resolution and content of the image could be greatly reduced. The assumption is that the imagery for these facets can be provided by a single channel of the image generator (as indicated in Table 1) or that smaller, lower cost image generators could be used (assuming database commonality issues are resolved). In this way the facets behind the pilot are kept at or near the same brightness as the images he is looking at, and there are no distracting flashes as his view moves around the display.

Resolution – The optimum SimuSphere resolution available with today's image generation and projector technology provides 2 arc-minute pixels across the entire field of view. It is recognized that this does not represent eye-limiting resolution for the purposes of training fighter and attack pilots. It is not currently cost effective to provide that resolution across a large field of view.

One approach to compensating for this shortfall is provided by separate target projectors. An option being explored allows for simultaneous display of up to four eye limiting resolution, full color targets in each facet. Additional targets would be included in the background imagery.

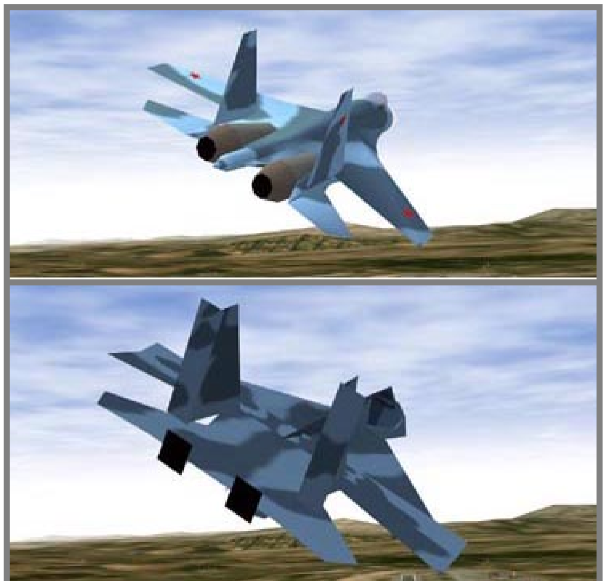

Figure 14. Model with enhanced level of detail

Present target projectors capable of near eye limiting resolution in simulator visual display systems are large and difficult to package. They are also expensive and typically provide only monochrome images. These drawbacks are especially true when multiple targets in different areas of the display field of view are desired. The target projection configuration being explored by Raytheon for use with SimuSphere provides full color 2 arcmin/OLP targets from a package smaller and less costly than most comparable target projectors.

An alternate approach to target detection and identification is to enhance the visual database models so that they have an effective resolution that is near eye limiting. This is accomplished by enlarging various components of an aircraft or ground model so that they are more recognizable, and so that they contribute more to the individual display-space pixel(s) they occupy (see Figure 14). These changes are made as part of the normal level of detail process as the model's distance from the eyepoint changes. It is also possible to scale the overall size of the model to compensate for interactions between the pilot's eye and the real image display. It has been found that some adjustment is required in order for the pilot's perception of an aircraft to match that of the real world[1].

The Raytheon design team, working in conjunction with subject matter experts felt that this approach to making aircraft and targets more visible had several advantages over target projectors. Since the models are included in the overall image, as opposed to an overlay, they can have a much more natural appearance (dark targets on a light background). It is easier to tune the detection and recognition appearance of the targets for the degree of difficulty desired. Also, the complexities of additional projectors, database masking issues and limiting the number of targets per facet are avoided.

Neither approach to approximating eye-limiting resolution is 100% correct. It is felt that enhancing the target models to approximate the desired result is the better approach at this time, and offers more potential to take advantage of future performance improvements.

Brightness and Contrast - Again, these areas depend greatly on the projectors selected for use in the SimuSphere. For the production configuration mentioned above the peak brightness is 15 ft-Lamberts with a contrast ratio of 15:1.

Figure 15. Photo of SimuSphere facet seam

Facet Seams - This is one area of the development program where the prototyping of components truly paid off. The original goal of .09 inches was improved on significantly. The facet seams on the production systems are currently specified at • .05 inches, with actual seams measuring closer to .02 inches. That's about the thickness of a typical credit card. When viewed from the pilot's seat the seam subtends less than 2 arc-minutes. Figure 15 is a photograph of a SimuSphere production unit showing the seam between the front and left side facets. Figure 16 shows the seam between the left side facet and the left rear facet that is hinged for ingress/egress.

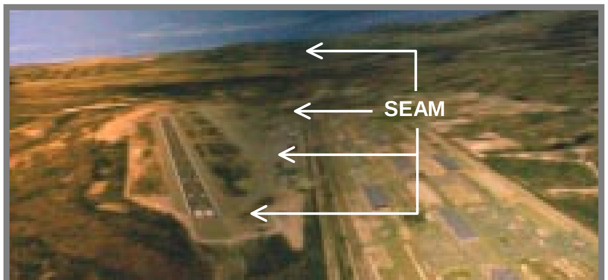

Figure 16. Photo of SimuSphere facet seam

Future Growth Potential

As stated earlier, one of the design criteria incorporated into SimuSphere was the ability to readily upgrade system performance as new technology becomes available. The projector and Image Generator markets are constantly monitored for new developments that are applicable to the SimuSphere. Coordination with vendors in these areas is also pursued to ensure that new products will be compatible with future applications wherever possible.

In the near future there will be image generation devices available with significantly higher pixel capacities that will allow even higher resolution imagery throughout the SimuSphere field of view. As eagerly as that development is anticipated, it will be of little use if matching projector technology is not forthcoming as well. New developments in laser projectors are being monitored to help in this area. Both the image generator and the projector will undoubtedly require a digital interface in order to achieve the pixel formats desired.

Another image generator feature that would further optimize the system performance is some form of programmable pixel placement. In current implementations the image generator outputs a square or rectangular image from which the SimuSphere pentagon image is derived. The pixels in the corners, outside the pentagon, are effectively wasted. In some configurations this part of the image can be used to extend the field of view for specific applications. Performance would be improved if a system had sufficient pixel format controls to only process the pixels within the pentagon portion of the image plane

In the projector area we are working with selected vendors to explore auto alignment techniques. Auto align is already available with some projectors, but only for rectangular display formats. Optimizing this process for the SimuSphere pentagon facets would further simplify maintenance procedures.

Summary

SimuSphere is a visual display device designed to train the single seat fighter and attack pilot in the complexities of his mission. It brings modern technology to a visual display technique that has long been seen as the optimum configuration to provide that training. The SimuSphere additionally provides for ready upgrade to even higher system performance as contributing technologies become available. This technology is currently being provided on Navy and Air Force programs and is also being proposed on a number of new and upgrade programs.

Reference:

1) B. Pierce, G. Geri, J. Hitt "Display Collimation and the Perceived Size of Flight Simulator Imagery", USAF Research Laboratory, AFRL-HE-AZ-TR-1998-0058