

Laser System for Visual Simulation

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The most challenging aspect of flight simulation is representation of the visual scene as it appears through the aircraft windshield. A review is made of the techniques that have been used and a discussion is included of film systems, television cameras and models, and the latest fully digital systems. Helicopter flying at low altitude necessitates the generation of a large amount of visual detail over a very large field of view. Currently in development is a system that uses a scanning laser beam over a detailed model of the terrain over which the simulator is flying and producing a video signal by using a bank of sensitive photodetectors. For display, a direct-writing laser projector is used to cover a field-of-view of $180^\circ \times 70^\circ$ in full color. Prototypes of both the image generator and the projector have been built.

Visual systems were introduced to flight simulators just over 20 years ago and, during that time, a wide variety of techniques has been used. Until the 1960s, flight simulators used analog computation techniques; the development of high-speed, general-purpose digital computers led to the sophisticated devices that we know today. Similarly, the first visual systems were analog and used either a motion picture or a terrain model together with a closed-circuit television system. Today we have progressed to completely digital image generation, thus the gaming area restrictions imposed by the analog systems are eliminated.

Generically, visual systems consist of

1. An information store,
2. A means of scanning and extracting information from that store, and
3. A means of displaying the data.

The table below summarizes three types of visual systems, two analog and one digital.

Visual System	Store	Scanning and Extraction Method	Display
Photographic	Movie film	Movie projector	Projector and screen
Closed-circuit television	Model board	Television camera	Cathode-ray tube
Digital computer	Memory	Computer	Cathode-ray tube

For the photographic technique the data store takes the form of a reel of movie film, the projector is driven to illuminate the appropriate frame according to the simulated aircraft position, and an image is displayed to the pilot on a conventional screen.

VARIABLE ANAMORPHIC MOTION PICTURE SYSTEM

Flight simulators are used for training crews in all aspects of flight and handling procedures. For airlines in particular, the most-critical flight sectors are landing and take-off in all kinds of weather and for different aircraft conditions. During landing and take-off maneuvers, the main cues that the pilot uses are visual and are derived from out-of-the-window scenes. His or her visual sense provides position, direction, attitude, velocity, and rate-of-closure cues. Therefore, the visual simulation system must produce a realistic image of high quality. The choice of a film system to meet

these criteria is a natural one—we are all familiar with the high quality of pictures produced at the cinema and with home movie projectors. The variable anamorphic motion picture (VAMP) system uses movie film and functions in the following manner.

Film sequences are made by using a camera mounted in a helicopter that is flying along a nominal flight path for a series of take-offs and landings in a variety of weather conditions. When the film is projected to the pilot of the simulator, the speed and position of the simulated aircraft controls and determines the passage of the film through the projector by varying the projector running speed and selecting the correct frame for display. The pilot will not, of course, fly exactly the nominal flight path employed in making sure the movie and servo-driven distortion optics are used to accommodate a range of flight paths and attitudes around the nominal.

Although film-based systems have the inherent potential for providing images of high realism, the requirement of providing a maneuvering envelope around the nominal flight path led to their demise. A complex anamorphic lens system is required to correct for the flight path deviation and this leads to a reduction in the brightness and resolution of the displayed image. Although correction of eye point position and attitude is satisfactory, the image is distorted such that vertical objects depart from the true vertical and provide negative training cues.

CLOSED-CIRCUIT TELEVISION SYSTEMS

The second type of visual system listed in the preceding table uses a terrain model board as the data store. Models may be as large as 60 x 24 ft and scale factors of 100:1 to 20 000:1 have been employed. Figure 1 shows a typical system. A television camera views the model board through an optical probe and is mounted on a gantry system that allows the entrance pupil of the probe to be positioned at the scaled pilot's eye height above the model board. The gantry system provides translational motion in three axes in response to control signals from the flight simulator. The optical probe includes servo-optics that provide the three rotational degrees of freedom. Thus, at any particular instant in time, the simulated pilot's eye is driven to the correct scaled position and attitude by the flight simulator.

The model board is illuminated by the bank of high-intensity lamps seen to the left of Figure 1. An enormous amount of detail is included in the model board and, when a high resolution television camera (1000 lines) and display monitor are used, an image of high realism is obtained. The major disadvantages of the camera and model system are the high running costs associated with the lamp bank that consumes close to 200 kW of electrical power and the limited gaming area provided by a model board of practical scale and size. The scale factor determines not only the gaming area for a given model size but also the closeness of approach of the optical probe to the model board at minimum flight altitude. For a scale factor of 1000:1, a 60- x 24-ft model board provides a gaming area of 52 miles² and, if the minimum required eye height is 10 ft, then the probe must be able to operate as close to the model board as 1.18 in.

COMPUTER GENERATION OF IMAGES

Computer generation of images (CGI) is the term used to describe visual simulation systems in which the environment in which the simulated aircraft is flying is described by numbers or bit patterns and held in a digital memory. This numerical description of some part of the real or imaginary world is usually called a data base and is operated on by the digital computing complex to generate appropriate video signals to drive a display device that is being viewed by the pilot.

Figure 2 illustrates the elements of a CGI visual system. The environment model is stored on a rapid access disc file and may represent a gaming area, say of 100 x 100 miles, or the whole world. Bulk

storage devices are relatively inexpensive and the gaming area is really only limited by the cost of preparing the data base, which in turn is highly dependent on the amount of detail in the data base. The general-purpose computer reads into its high-speed memory that part of the data base that is within visual range of the simulated aircraft and, together with the special-purpose hardware, performs the perspective transformations necessary to generate the correct view of the objects in the data base. Occlusion of one object by another must be taken into account and, finally, information regarding color, intensity, and effects of atmospheric fading are added.

The major attraction of CGI in visual simulation is its flexibility. Apart from the multitude of environmental models that may be stored and displayed, a single system may also store and generate moving vehicles on the land or in the air. This is obviously important for military applications. Figures 3 and 4 are examples of the scenes generated by a Link digital image generator (DIG) system (the actual system is in full color).

COMPARISON OF THREE TYPES OF VISUAL SYSTEMS

The logical sequence that we follow in selecting a visual system for a training simulator is as follows:

1. Define the mission to be trained,
2. Determine the skills required to perform the mission, and
3. Establish the visual information required to train these skills.

When we simulate the behavior of a cockpit instrument, we do it by effectively duplicating the visual appearance and performance of that instrument. In fact, the instrument may well be an actual aircraft instrument and the simulation task reduces to one of merely providing the correct drive signals to that instrument. The human visual system has a processing capability well beyond the performance limits of currently available image generators and displays. Even the film system that we described earlier cannot match the human eye as far as field of view and resolution are concerned. When we follow the sequence for selecting a visual system as listed above, we usually have to make compromises because a single type of visual system can rarely supply all of the visual cues required for a complete training program.

Figure 1. Camera model system.

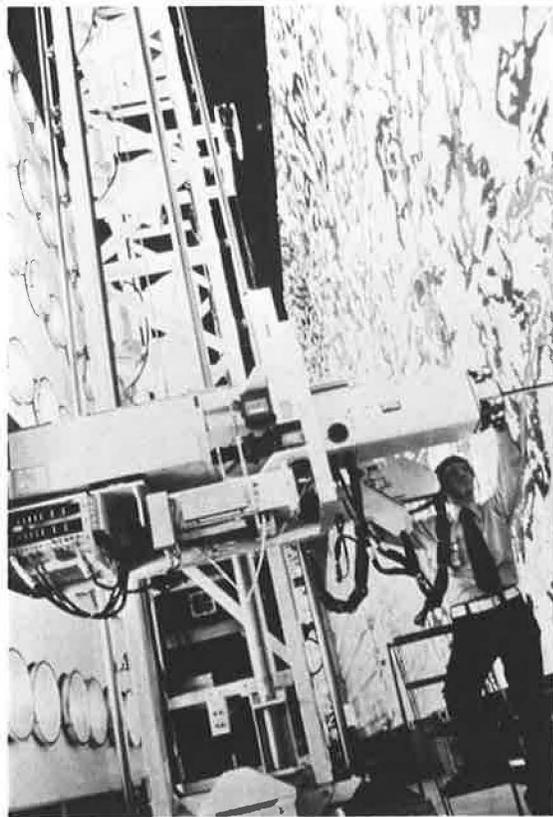


Figure 2. Elements of computer image generator.

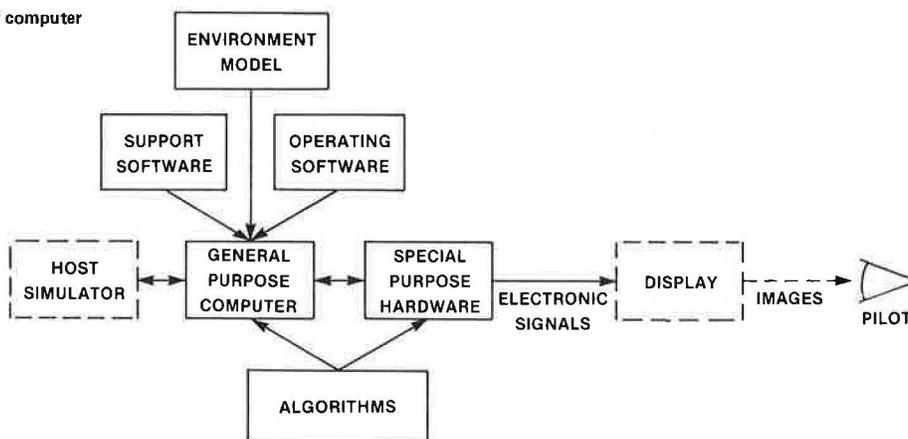


Figure 3. Example of DIG image.

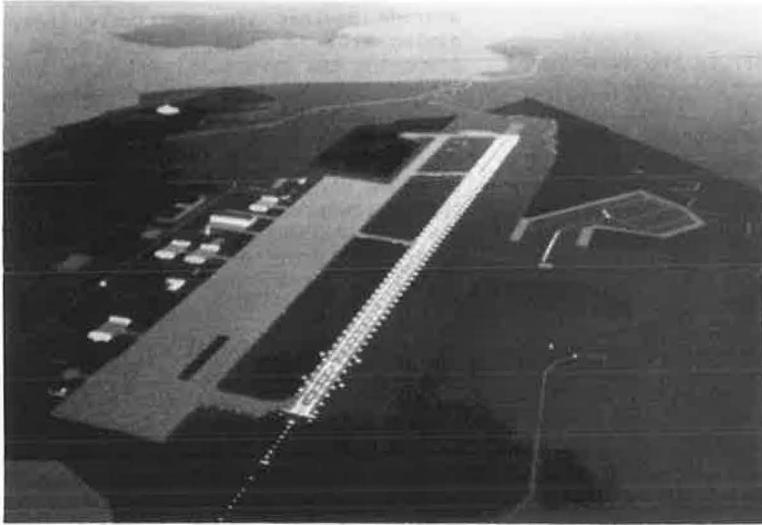
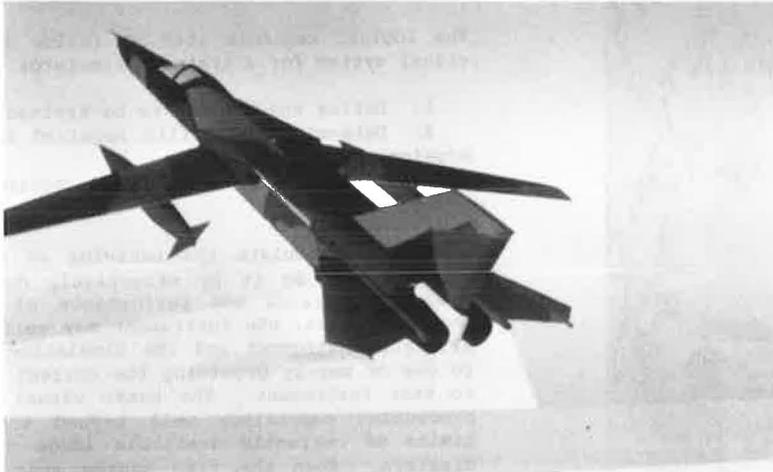


Figure 4. Example of DIG military application.



The table below presents a comparison of the three types of visual system we have discussed.

<u>Visual System</u>	<u>Advantage</u>	<u>Disadvantage</u>
VAMP	High resolution, real-world scenes	Limited maneuverability
Camera and model	High detail, real-world scenes	Limited gaming area
CGI	Flexibility	Computing power limits detail

At one end of the scale we have the film system that provides real-world scenes at relatively high resolution but requires that the simulator follows closely the path of the vehicle that provided the platform for making the original movie. For a locomotive simulator, this might be considered to be the ideal visual system, but it would be totally inappropriate for an air-to-air combat simulator. At the other end of the scale is the CGI system that enjoys the freedom of maneuverability of the real world but cannot reproduce real-world detailed scenes. If the total computing power of the CGI system may be devoted to a single inanimate object, however, it does an excellent job, as we saw in

Figure 4, which depicts an aircraft. For air-to-air combat, then, CGI would probably be the most-appropriate choice.

In between these two extremes of the film and the CGI, we have the closed-circuit television (CCTV) model board system. It generates high-detail, real-world scenes and faithfully reproduces the features included in the model. The model is relatively inexpensive to produce and is mainly an artistic rather than a scientific data base, like the movie film. The system does not have maneuverability limitations like the film system but approaches that of the CGI. The gaming area is severely limited by the size of the model board and scale factor, however. A 60-ft long model board at 1000:1 scale factor represents 11 miles of terrain. A high-speed fighter or attack aircraft would cover this territory in a little more than a minute during low-level flight, so this system is not suitable for training pilots in terrain following and avoidance flying.

For a relatively low-speed aircraft like a military helicopter, where the pilot stays close to the ground to avoid detection by the enemy, the CCTV system is considered to be a good compromise. The pilot requires high scene detail to perform a visual navigation task and to judge rates of closure and distances; the system can provide this detail with

sufficient fidelity. Missions can be planned that keep the simulated helicopter within the confines of the model board and have an elapsed time similar to the real-world scenario.

A number of these systems are currently being operated by the U.S. Army to provide training for the Chinook, Blackhawk, and Cobra helicopters. Due to the continually increasing cost of energy, Link has sought ways of reducing the running costs of these systems and, to this end, we have developed a laser image generation visual.

LASER IMAGE GENERATOR

The conventional camera and model system pictured in Figure 1 includes a television camera, an optical probe, and a high-intensity lighting bank. The system currently in use is the result of 20 years of development effort and employs the most-sophisticated television technology. Link developed a 1000-line, full-color television to achieve a substantially increased resolution capability over commercially available devices. The weaknesses of the existing systems are as follows:

1. Although the static resolution is excellent, the camera tubes exhibit a condition called dynamic lag. Briefly, this is concerned with the image-retention properties of the tube from one frame to the next and is evident to the viewer as a degradation of resolution or defocussing of the displayed picture under dynamic conditions.
2. High-resolution television calls for four camera tubes, one for each primary color and a fourth known as a luminance channel. This use of four tubes increases the registration and linearity problems and complicates the optical system.
3. The conventional camera and model system is operated in a highly unfavorable optical situation. We require a large field angle to give a good field of view and we require high f-number to achieve a good depth of focus. The optical probe must be small, however, to be able to function with a sensible model scale factor, and we find ourselves working with insufficient light input. Attempts to relieve the depth-of-field problem result in larger optical acceptance angles without any corresponding increase in field of view.
4. The lighting bank required to illuminate the model board consumes around 200 kW of electrical power. This high illumination level is required to compensate for light loss due to spectral separation filters and light loss due to scattering inefficiencies of the model itself.

We need to eliminate the television camera from the system if we are to overcome these difficulties and still retain the desirable qualities of the system.

The use of a scanning laser beam achieves this by reversing the conventional image-generation process. In Figure 5, in the conventional arrangement, we illuminate the object to be televised with an even, constant level of illumination and image the object through a lens system on to the television camera tubes. By scanning the pick-up tubes with an electron beam we are able to generate a raster format video signal that will drive a display that may be either a cathode-ray-tube (CRT) monitor or a television projector.

The laser concept is shown on the right of Figure 5. Instead of flooding the complete object with light, we illuminate only that part of the object to be televised. A laser beam is passed through an optical probe similar to that used in the conventional system and is caused to scan the appropriate part of the object to produce a raster pattern that may be likened to that described by the electron beam on the camera pick-up tube. The reflected laser light is collected by an array of sensitive photocells and a video signal is generated by synchronizing the processing of the electronic output of the photocells with the passage of the laser beam across the object. So, instead of illuminating the whole model board and producing an image of only one small portion of it at any instant in time, the laser image generator illuminates only that portion of the model that is within the visual field of view, on a television line-by-line basis.

An artist's conception of a completed system is shown in Figure 6. The terrain model board and gantry are identical to those in a conventional system, but instead of a television camera being carried and positioned over the model board, an optical laser scanning complex is located in the same position. In place of the lighting bank that was used to illuminate the model, we have an array of photomultiplier tubes arranged in groups of three. These triads receive the reflected light from the model board and the three photomultipliers in a triad each have a color filter placed in front of it to make it responsive to either red, green, or blue. We can thus compose a color video signal by summing together all of the triad outputs by color channel.

On the left of the artist's concept is shown the laser package that generates the pseudo-white light beam that is scanned over the model. The model and the gantry are contained in a light-tight room to avoid spurious light from falling on the photomultipliers.

An Argon laser provides the blue and green components and a Krypton laser provides red. A dye laser pumped by a portion of the green line generates a fourth color line in the orange sector of the spectrum. These four color lines are mixed together after being expanded to produce a 2-in diameter beam, the color spectrum of which has been selected

Figure 5. Comparison of television and laser systems.

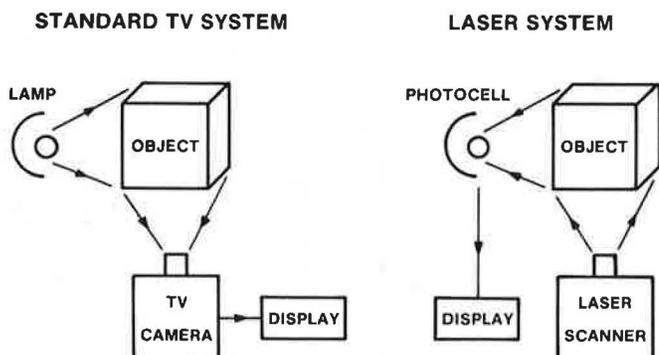


Figure 6. Artist's conception of laser image generator.

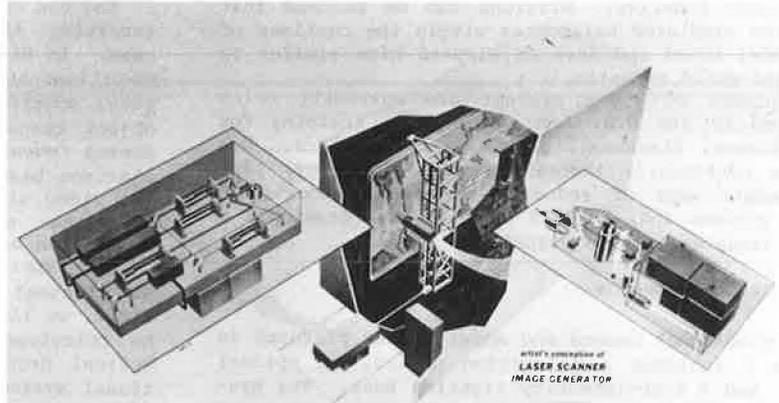
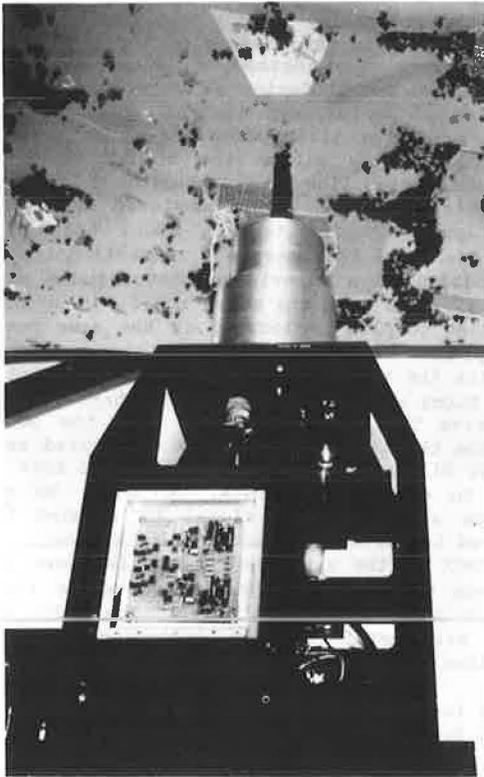


Figure 7. Scanning head.



to match the pigments in the paints on the model board. This beam is collected by a mirror located at the foot of the gantry and is directed toward the scanning head assembly, along the vertical axis of the gantry.

The laser beam was expanded to a 2-in diameter bundle for two reasons:

1. With the energy somewhat dispersed, it provides a measure of safety and
2. It is easier to track the larger diameter beam as the gantry travels along the model board.

When the beam arrives at the scanning head, it is reduced down to 0.04-in diameter and any beam-pointing errors are corrected by an optical servo system. The horizontal scanner that produces the horizontal scan lines of the television raster is a rotating mirror polygon that has 24 facets. It is

fabricated from a solid block of beryllium and rotates at 76 000 revolutions per minute. The laser beam is deflected by each of these mirror facets to produce 30 000 raster lines per second. That is 1000 lines per frame at 30 frames/s. From the horizontal scanner, the laser travels to the vertical scanner that is a simpler galvanometer, stepping at 1000 times per frame to provide the vertically scanned field of view. A 2:1 interface is employed and, in the prototype system, a field of view of 48 degrees horizontal by 36 degrees vertical is covered. The laser beam passes from the horizontal scanner through the optical probe that applies the simulated aircraft heading, pitch, and roll motions to the scanning raster format.

Figure 7 shows the scanning head illuminating the model board. The photograph in Figure 7 was made with the model board room lit, but under normal operating conditions the area of the model outside the scanned raster would be in darkness. For the prototype system, the images are displayed on a high-resolution CRT, and an example is shown in Figure 8.

The prototype system was completed in 1978 and proved the feasibility of the laser image generator concept and current development efforts are being directed toward extending the field of view up to 180° horizontal by 70° vertical.

LASER PROJECTOR

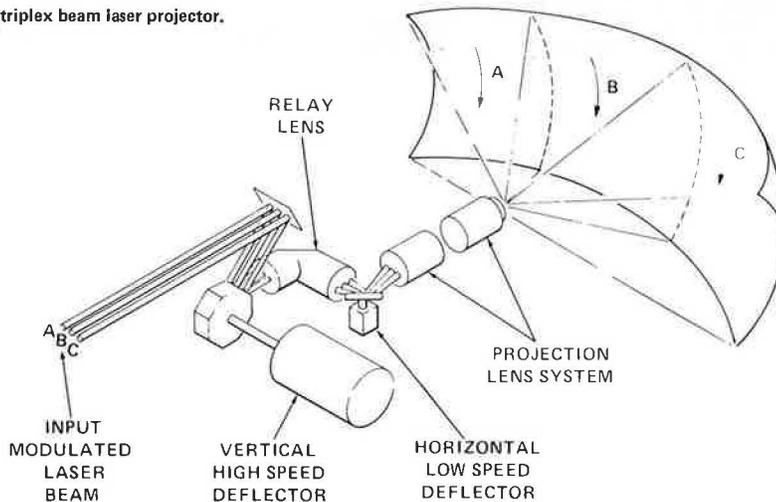
The simulator industry normally depends on the television equipment industry to provide monitors and projectors for our visual systems. As we are required to maintain a high-resolution image, there is a limit to the field of view we can generate from a single display device and this is typically 48°x36° with a 1000 raster line system. If we want to cover a larger field of view, then we have to use a matrix of CRTs or projectors mounted around the cockpit. This poses certain problems apart from those involving mechanical considerations. Juxtaposition of a number of CRTs to provide a continuous field of view is difficult in the horizontal direction and even more so in the vertical, and a similar problem exists for television projectors. It is also a maintenance problem to achieve constant color balance and brightness over a matrix of devices.

The direct writing laser projector offers a solution to these problems as it has the potential of covering a large field of view from a single device. A wide-angle laser projector is shown in Figure 9. This concept is a multichannel device for the following reason. If we are to maintain resolution and frame rate over the larger field of view, then the bandwidth of the system must increase. For the laser image generator this is no problem, but if

Figure 8. Laser image.



Figure 9. Principle of triplex beam laser projector.



the input video is derived from a CGI system, then for a given amount of image detail these systems are bandwidth limited. For practical purposes the 48°x36° field of view represents the upper limit for bandwidth and, if our computing power increases, we prefer to use it to include more detail in the image. Large fields of view for a CGI are therefore derived from a multiplicity of CGI channels, each channel being dedicated to a particular segment of the total field. Our laser projector, therefore, uses a number of scanning laser beams, each scanning a segment of the total field and driven by a CGI channel. If a laser image generator is the input device, then a single laser beam scans the whole field.

Figure 9 depicts a three-channel system. Three laser beams are generated by the laser package, each beam being modulated in intensity according to the video signal on the three video channels. These beams pass through a horizontal and vertical scanning system very similar to that described in the laser image generator. The probe on the latter is replaced by a projection lens and each composite laser beam scans a sector of a spherical screen.

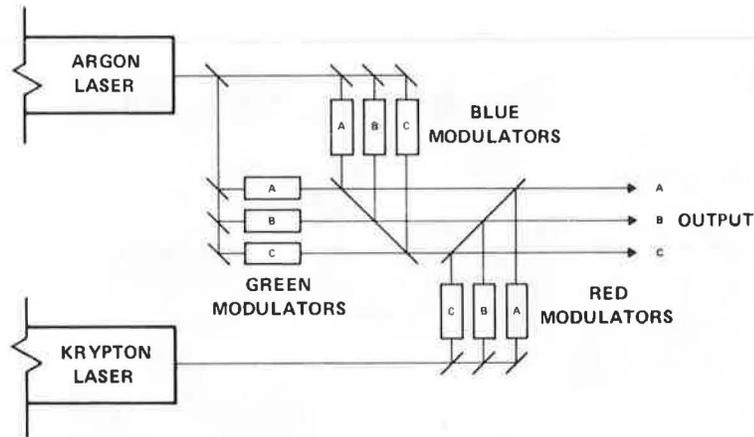
In order to create a laser beam whose color content is controlled by a video signal, we again start with an Argon and a Krypton laser, as shown in

Figure 10. The Argon laser provides both the blue and the green lines, and the Krypton provides the red. For our three-channel system, each of these lines is split into three separate channels: A, B, and C. Each color channel has in it an acousto-optic modulator that alternates the intensity of the laser beam according to the video signal on that particular color channel. The outputs of the modulators are summed together (red, blue, and green) to create a light beam for each channel that covers the spectrum from blue to red.

These three modulated laser beams travel together to the scanning package in a manner similar to that illustrated in Figure 9. The high-speed line scanner and the low-speed frame scanner are the same devices we used in the laser image generator except that now, with the increased vertical field of view, we are scanning the line in the vertical direction, each horizontal sector being 45°. The three laser beams are separated in the projection lens system to scan the three separate fields of view. To cover 180°, then, we would have four laser channels and we would require eight channels of CGI video to cover the total field of view.

A prototype of a single channel of this system has already been completed.

Figure 10. Laser package.



SUMMARY

Three different types of visual simulation systems have been described. Each excels in a particular training environment; the laser visual system offers a solution to helicopter low-level flight training.

A system that provides a large field of view is currently in development.

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