ARTICULATED WIDE-ANGLE OPTICAL PROBE FOR USE IN CONJUNCTION WITH VISUAL SYSTEMS FOR SIMULATION

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MANY papers have already been written which recognize or emphasize the importance of simulation. Papers have been written dealing with the value of simulation systems in evaluating engineering concepts; even more articles present the increasing utilization of simulation equipment for training purposes in lieu of using the actual, and in many cases revenue-producing, equipment.

THE TREND in simulation of providing the observer or trainee with realistic visual cues which he can evaluate, judge, and initiate action upon, has led to the presentation of many a discourse describing optical systems and their fundamental limitations especially when the view is generated from a model whose scale is significantly reduced as compared to the real-life object.

This paper, therefore, will not devote itself to a reiteration of these known, significant, basic optical parameters which prevent us from achieving with any visual system a performance level compatible with that of the human eye and brain.

Nevertheless, by recognizing and understanding these basic limitations, compromises can be made which make it possible to produce a useful visual system for simulation.

DALTO is one of the companies engaged in developing and producing useful visual systems.

The DALTO system is a real-time, random-access visual system capable of generating and displaying realistic visual cues useful for judging position, direction, speed, attitude, and altitude as may be applicable to space flight and air flight as well as surface travel simulation, utilizing a newly developed, high resolution Image Isocon camera and a complementary television projection system. The displayed image is viewed by the observer(s) through a lens system which assures an essentially uninterruped scene and provides essentially the same image at viewing points which are nominally 42" apart—as is the case in most cockpits of large commercial aircraft—without requiring an unreasonably large display system. Figure 1 illustrates such a system.

ONE OF THE MOST CRITICIZED aspects of visual systems for use in simulation has been the limited field of view which most systems provide. This "tunnel vision," as it is often called, especially with respect to the horizontal field of view, was considered by many experts to be one area where a significant improvement could be achieved.

DALTO is of the same opinion and has done considerable work in this area over the past five years.

AFTER careful evaluation and discussions with users of visual systems in conjunction with flight simulation training, it was concluded that as a first goal, a wide-angle display having a horizontal field of view of about 230° is required. The vertical field of view of 40°, which is common for most visual systems other than film systems, was considered satisfactory, but not necessarily the desired limit.

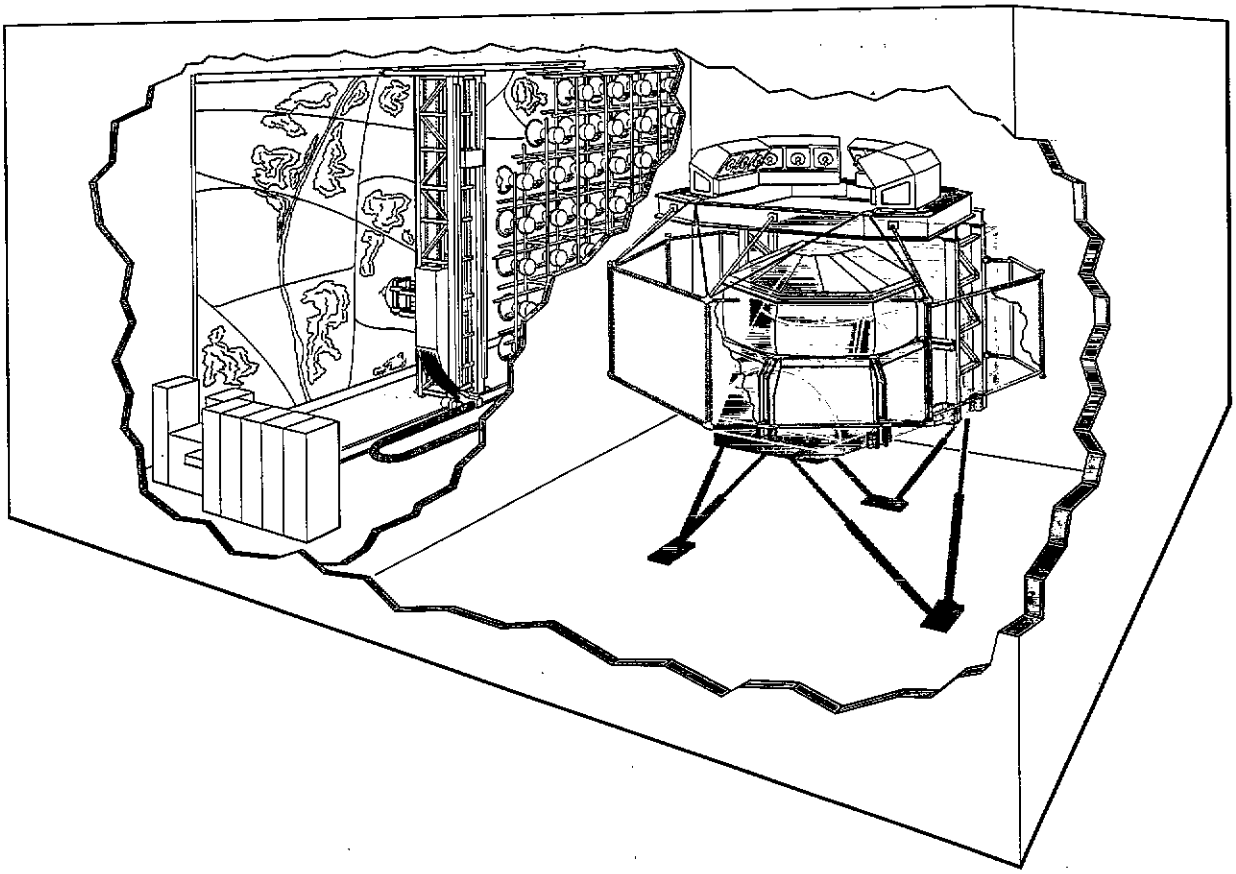

Figure 1. Dalto Wide Angle-Visual System for Simulation

Furthermore, it was agreed that the terrain model scale should be about 1:2000 to allow for sufficient terrain coverage, as required for certain maneuvers in flight training, with a reasonable model size.

HAVING REALIZED that the only known economically justifiable system for generating and displaying a realistic image in real time is a closed-circuit television system. DALTO has concentrated its efforts to evaluate means and ways of best utilizing television for such a wide-angle system, and to find an adequate device to pick up such a wide-angle image.

One of the first apparent limitations manifests itself in the development of a wide-angle television projector with such an aspect ratio, producing satisfactory image resolution and image brightness, since the development of using LASER to project large, bright television pictures, as an alternative to the cathode ray tube and its associated optics, has not yet left the laboratory.

This PROBLEM has been solved by appropriately dividing the total field considering the fact that the two observers are positioned nominally 42 inches apart, and displaying it with four properly positioned projectors upon display screens which are viewed through what is known as virtual image lenses.

By utilizing four projectors, each one displaying a given portion of the required total field, a corresponding image generation system has to be provided. Thus, four cameras are being used, one each for each projector so that the field of view displayed by each projector is also covered by the corresponding camera.

The NEXT STEP in generating this wide-angle visual system was the development of the image pickup device.

RECAPITULATING the parameters set forth for this system, and considering the findings outlined before, this image pickup device should provide:

—Horizontal field of view	230°
—Vertical field of view	40°
—Resolution and depth-of-field	At least as good as any presently available narrow or wide-angle optical system suitable for such an application, and which can be used in conjunction with terrain models having a scale factor of as high as 2000, whereby the entrace pupil (look-point) position relative to the model surface represents, for an "on-ground" condition, the position of the pilot's eye-point for a DC-8, Boeing 707 type aircraft so that proper perspective can be maintained.

—The image has to be relayed and the appropriate portion of the total field re-imaged upon each of the four camera tubes.

—The reproduced image of the field, as seen by the observer(s), shall be essentially distortion free and well corrected.

For the first two or three years of this development cycle, it was considered that the REVERSED TELEPHOTO OBJECTIVE LENS, also known as the fish-eye or wide-angle distorting sky lens, would give a satisfactory solution, but each solution to a problem introduced new difficulties which eventually led to a complete departure from a strictly refractive image pickup lens system to THE ARTICULATED, WIDE-ANGLE OPTICAL PROBE, as illustrated in figure 2.

In brief, this is how the articulated, wide-angle probe works. The model is viewed by the convex reflector which forms a virtual image of the model scene corresponding to a field of view of 232° horizontal and 42° vertical. Rays leaving the convex reflector are reflected by the flat Mirrors A and B so that the theoretical extension of the optical axis passes through the look-point of the convex reflector in a direction opposite to the direction of forward viewing and inclined to the plane of the model surface. This axis is referred to as "offset roll axis." The convex reflector, Mirrors A and B rotate about this offset roll axis, simulating roll motion. Because of the inclination of this axis, required to avoid interference of the probe body with the terrain due to the close proximity of the look-point to the model surface for "on-ground" conditions, this rotation will also cause a pitch and yaw motion of the convex reflector. The computations of the required motion about all three axes take this into consideration, so that when only a roll motion is required, cancelling rotations are applied to the other two axes to offset the undesired pitch and yaw motions.

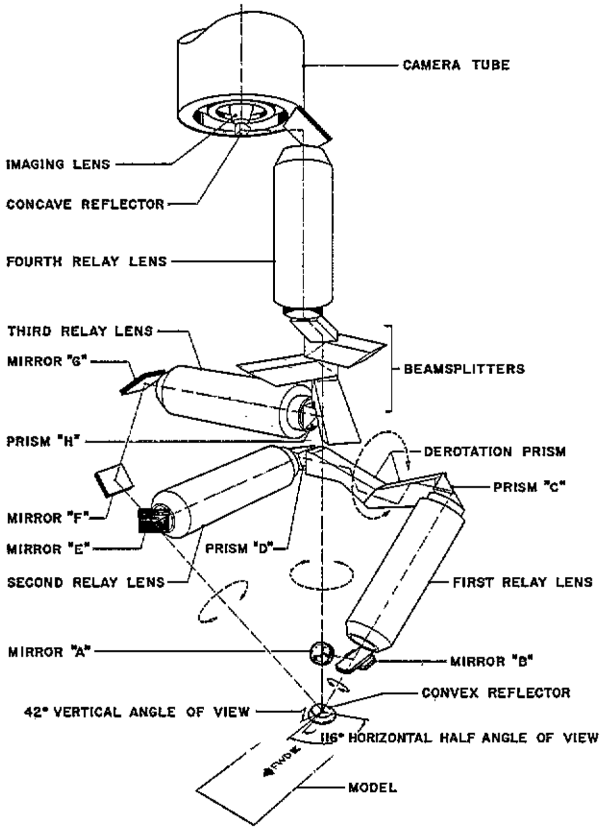

Figure 2. Articulated, Wide-Angle Optical Probe

Following Mirror B, the first relay lens is placed, emitting parallel light which is reflected by the prism C into the derotation prism. The rays emerging from the derotation prism are then reflected by prism D into the second relay lens, followed by Mirrors E and F which change the direction of the optical axis so that its theoretical extension passes again through the look-point of the convex reflector, but normal to the direction of forward viewing and inclined to the plane of the model surface. The required inclination of this axis follows the same reasoning outlined before.

This axis is referred to as the "offset pitch axis." All optical elements up to and including Mirror E rotate about this offset pitch axis. Again, the undesired roll and yaw motions are offset by cancelling rotations as described before.

The third relay lens is positioned so that the intermediate image formed by the second relay lens is coincidental with the focal surface of this, the third relay lens. Mirror G reflects the rays into the third relay lens.

Provisions are made for axial movement of the third relay lens, to permit the correction for an inclined object surface. Furthermore, the capability of installing a "focus-disc" in close proximity to the intermediate image (between Mirrors F and G) is provided.

The parallel rays emerging from the third relay lens are reflected by prism H so that the theoretical extension of the optical axis passes through the look point normal to the model surface. This axis produces true yaw motion. All optical elements up to and including prism H rotate about the yaw axis which is also referred to as the azimuth axis.

The parallel rays reflected by prism H are now split in four directions. The direction of each path is determined by the angle which corresponds essentially to each of the four projection axes previously mentioned.

From here on, all subsequent optical elements are repeated four times.

Following the beam splitters, the rays proceed to the fourth relay lens, which forms again an image of the first image (virtual) which was formed by the convex reflector.

THIS IMAGE, FORMED BY THE FOURTH RELAY LENS, IS OF THE SAME SIZE AND SHAPE AS SAID FIRST IMAGE, AND IS LOCATED RELATIVE TO THE FOLLOWING CONCAVE REFLECTOR IN A POSITION CORRESPONDING TO THE LOCATION OF THE FIRST IMAGE (VIRTUAL) RELATIVE TO THE CONVEX REFLECTOR.

The concave reflector is of the same size and geometry as the convex reflector, but cut in half in order to allow the reflected rays to exit.

Each of the four concave reflectors covers the appropriate part of the total field of view which is to be re-imaged and magnified upon the photocathode of the isocon camera tube.

This re-imaging and magnification is accomplished by a special imaging lens which is located between the concave reflector and the camera tube.

This describes the articulated, wide-angle optical probe developed and disclosed by DALTO, designed to produce a wide-angle picture presented by closed-circuit television, capable of relaying images to four television camera tubes, each displaying a given part of the field of view seen from a simulated vehicle through a common entrance pupil.

A tabulation of important parameters follows:

Field of view	Horizontal 232°; 116° each side Vertical 42°; 20° up, 22° down
Look-point elevation above terrain model	2.5 mm (minimum)
Diameter of convex reflector	19.2 mm
Entrance pupil (aperture) size	0.6 mm
Focal length of probe system	15 mm
Transmission through probe system	6% @ 4800 through 6200 Å
Aberrations and distortions	Essentially completely corrected

Relay lens pairs can be added or removed to lengthen or shorten the light path as required for other applications within the scope of the optical performance capability of this wide-angle probe.

The excursions attainable with this articulated, wide-angle optical probe are as follows:

Roll	$\pm 60^{\circ}$ maximum
Pitch	$\pm 30^{\circ}$ maximum
Yaw	360° continuous

The rates are nominal

$$1 \text{ radian sec}^{-1}$$

With respect to the interface of this articulated, wide-angle probe with a television system, the following parameters apply:

Camera raster	Rectangular raster, stationary in position. Nominal 1:2 aspect ratio for each of four camera tubes.
Image size on photocathode of camera tube	1.4 inches diagonal.
Camera registration requirements	Conventional static raster. All motions are in the optical system and common to all four (or fewer) camera tubes.
Projector raster	Stationary raster. nominal 1:2 aspect ratio for each projector tube.
Projector overscan	NONE required.