AWAVS: An Engineering Simulator for Design of Visual Flight Training Simulators

W. S. Chambers*
Naval Training Equipment Center, Orlando, Fla.

The Navy AWAVS program is designed to improve visual system technology and define hardware performance requirements for training. A description is given of the visual system hardware capabilities being developed for the initial carrier takeoff and landing configuration of AWAVS. The display system provides a composite image of two TV channels. The background TV channel is a low-resolution wide-angle display of sky and seascape. The target TV channel's narrow field of view presents a high-resolution carrier image for insertion into the displayed background channel. Each channel includes high-performance perspective image generation, distortion correction, and visibility effects. In addition to establishing system feasibility, the system's variability will permit investigation of the effects of visual system parameters on pilot performance in a specific task environment.

Introduction

THE Navy's Aviation Wide Angle Visual System (AWAVS) is keyed to the concept that special equipment configurations are required to investigate fully the many complex pilot training tasks. This approach results from the recognition that no single wide-angle visual system concept exists which promises to be cost effective and satisfy currently projected visual training cue requirements. It is planned that the AWAVS program will investigate the effectiveness of new visual system capabilities and determine required levels of visual fidelity for effective training. The location of the AWAVS facility near engineering and research shop facilities at the Naval Training Equipment Center provides the means to efficiently implement this equipment reconfiguration concept. Two major hardware systems are being acquired for AWAVS. These are the Conventional Takeoff and Landing (CTOL) and Vertical Takeoff and Landing (VTOL) simulators, each consisting of a flight simulator, visual display, and image generation subsystems. Also, a computer image generation subsystem will be added to the facility. The various image generation subsystems can be configured with either the CTOL or VTOL display systems for experiments. The CTOL simulator currently is being developed by Singer, Simulation Products Division, and will be installed at the Naval Training Equipment Center in 1977.

The CTOL visual system characteristics are described in this paper in their initial equipment configuration, optimized for carrier approach and landing tasks. It should be understood that the performance levels of some visual subsystems for this training research simulator may be different than required in a given training simulator. The AWAVS simulator, to achieve its research mission, must have a wide range of visual parameter control and repeatability of these parameters (e.g., brightness, contrast, resolution, etc.). In addition, comprehensive performance measures and data recording techniques are necessary to assure discriminative assessment of pilot performance. Figure 1 shows the general arrangement of the installed CTOL simulator.

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*Project Manager. Member AIAA.

CTOL Simulator

The CTOL simulator is composed of the visual system and the flight simulator, with six-degree-of-freedom synergistic motion base and cockpit, *g*-seat, computer system, and experimenter's console. The visual system is the principal topic of this paper, and only a brief description is given of the other subsystems. Figure 2 gives a general block diagram of the CTOL simulator. The blocked lines show control paths, single lines show video paths, and the dashed lines give optical paths. The display system is discussed first followed by details on the two major TV channels, the Fresnel Lens Optical Landing System (FLOLS), projector, and the supporting subsystems.

Visual Display System

The CTOL display is a wide-angle real image presented on a 10-ft-radius spherical screen. The entire display system, consisting of screen, two TV projectors, and FLOLS projector, is mounted on the six-degree-of-freedom motion base. The screen covers a $\pm 120°$ horizontal and $+90°$, $-30°$ vertical field of view (FOV). The background display of 160° horizontal by 80° vertical FOV can be positioned statically anywhere within the screen's FOV. A typical arrangement would center the display on the aircraft axis covering $\pm 80°$ horizontal and $+50°$, $-30°$ vertical FOV. An alternate for left-hand circling approach patterns would displace the display center 40° left of the aircraft axis. The target display presents the carrier image, which can be superimposed upon a background seascape image or set into it. The carrier image can be dynamically positioned anywhere within the screen FOV. The 60° FOV target projector's optics contains a 10:1 zoom lens to increase simulated range to the carrier without degrading resolution. The composite display presents a sky/seascape scene of moderate resolution (15-30 min of arc) with a carrier image of high resolution. The carrier resolution is a function of zoom, which provides 1.5 min of arc at long ranges (> 10,000 ft), reducing to 12 min of arc at close range (< 1,000 ft). Full six-degree-of-freedom visual dynamic cues are presented in both TV channels. A FLOLS image is optically combined with the target projection optics to provide a very high resolution bright FLOLS display for long range visibility to match real world viewing ranges.

The display system geometry is shown in Fig. 3, identifying the exit pupil location of each projector and the pilot's eyepoint. All image shape compensations for distortions (e.g., off-axis projection keystoneing, spherical screen curvature,

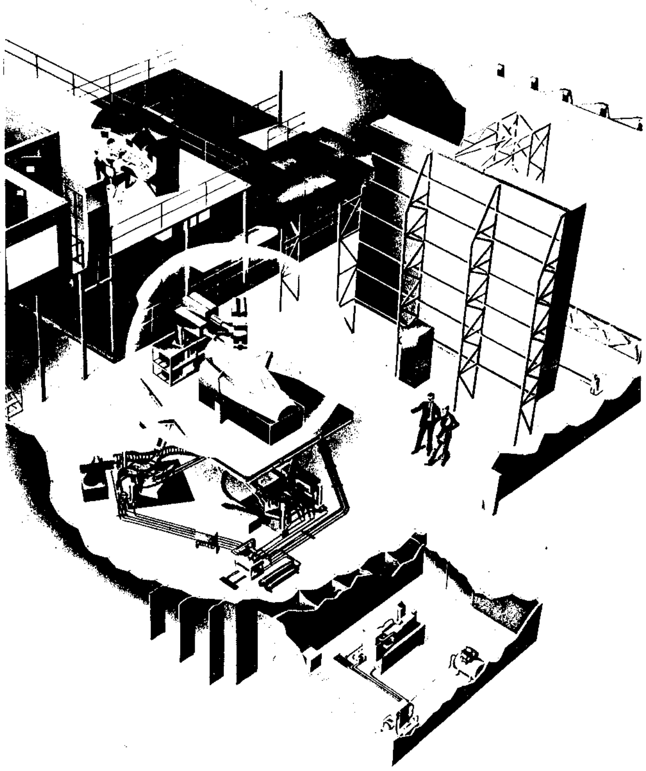

Fig. 1 CTOL simulator installation.

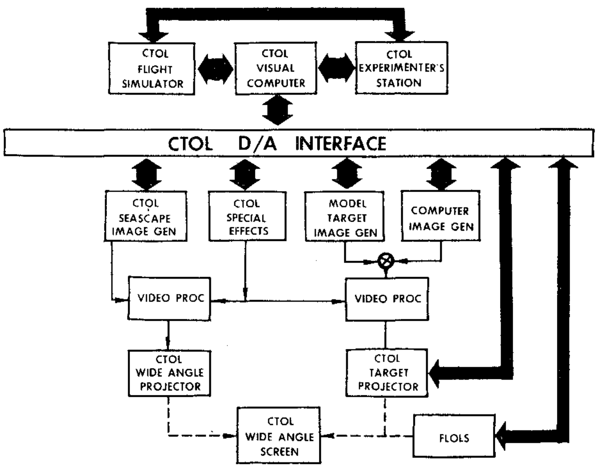

Fig. 2 CTOL simulator block diagram.

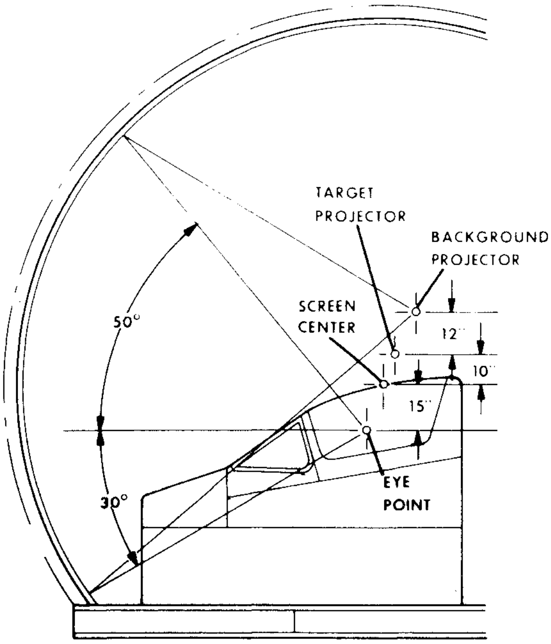

Fig. 3 Display system geometry.

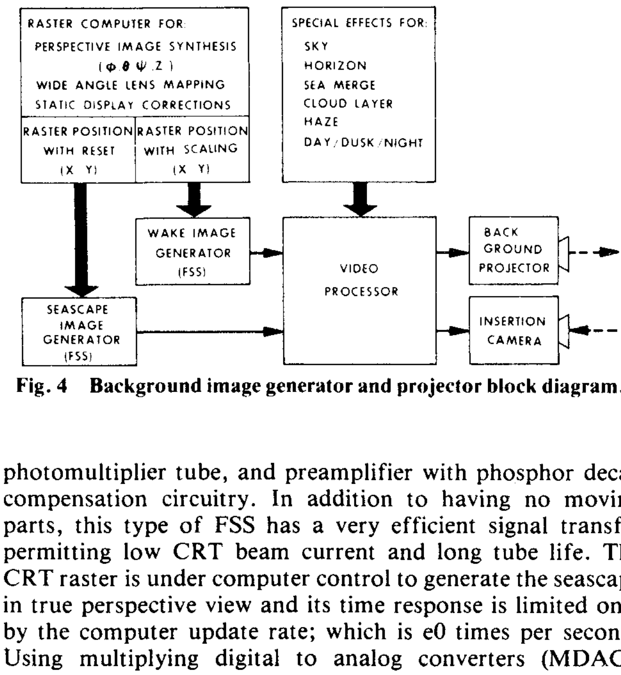

Fig. 4 Background image generator and projector block diagram.

lens mapping, etc.) are performed in the image generation subsystems to provide true perspective display images. The screen will have a specular reflective surface of a moderate gain (~ 3) to provide 6-ft-L highlight brightness and minimize crossscreen reflections. The use of a wide-angle screen with gain is possible due to the location of the pilot eyepoint and both projectors near the shperical screen's center. Table 1 gives a summary of the display system characteristics.

Background Channel

The background channel is an all electronic subsystem, which produces a monochrome TV composite scene of seascape, carrier wake, sky, horizon, special effects, and a void for insertion of the carrier image by the target channel. Figure 4 shows the functional location of these components in the background system.

The seascape generator is a flying spot scanner (FSS), consisting of a fiber-optic faceplate CRT, a seascape photographic transparency in direct contact with the CRT, photomultiplier tube, and preamplifier with phosphor decay compensation circuitry. In addition to having no moving parts, this type of FSS has a very efficient signal transfer permitting low CRT beam current and long tube life. The CRT raster is under computer control to generate the seascape in true perspective view and its time response is limited only by the computer update rate; which is e0 times per second. Using multiplying digital to analog converters (MDAC), computer commands are converted and processed to generate deflection voltages for raster shaping. The final raster shape reflects simulator roll, pitch, yaw, altitude, wide-angle projection lens mapping, and display distortion mapping to compensate for the off-axis position of the projection lens and pilot viewpoint. The raster then is moved across the CRT faceplate to simulate airspeed and heading, defined by simulator X and Y commands. As the raster reaches the edge of the CRT faceplate, it is reset to the opposite side during the TV vertical retrace period. This technique is used, because of the repetitive nature of the seascape imagery, to permit a continuous translation cue over the waves.

The wake image generator is identical to the seascape image generator, except that a photographic transparency of a carrier wake is substituted for the seascape transparency and there is no raster reset feature. The X, Y position commands are processed to place the wake in proper position relative to the carrier image. The wake video, which is primarily white or high-level video, is added to the seascape video in the video processor.

Table 1 Summary of display system characteristics

CHARACTERISTIC	BACKGROUND CHANNEL	TARGET CHANNEL
FOV (MAX)	160°H x 80°V	60°H x 40°V
(MIN)	....	6.6°H x 4.2°V
RESOLUTION:		
CENTER	15 ARC MIN/LP	12 ARC MIN/LP
EDGE	30 ARC MIN/LP	15 ARC MIN/LP
MAX ZOOM	....	1.5 ARC MIN/LP
BRIGHTNESS (HIGHLIGHT)	6 FOOT LAMBERTS	6 FOOT LAMBERTS
GRAY SCALE SHADES	10	7 (INSERT)
DISTORTION (STATIC)	±4%	±3%
TV LINE RATE VARIABLE	825 525 - 1023	825 525 - 1023
TV BANDWITH VARIABLE	20 MHz 4 - 30 MHz	20 MHz 4 - 30 MHz

The special effects generator provides video for sky, distinct horizon, and a seamerge, which blends the video level from horizon to seascape video to simulate aerial perspective. Other special effects features include cloud effects (above, in, or below), haze, and day, dusk, or night settings. The video processor combines these video scenes for presentation to the projector. This final video is modified by blanking of the scene area occupied by the carrier image. This video blanking control signal is generated by the insertion camera.

The background projector is the new high-brightness light valve General Electric Company Model 7150 which produces a 1000-to 1200-lm output light flux. Because of the projector's small aperture (approximately 1 in.), special thermal design features had to be incorporated to make this projector practical. A new wide-angle lens attachment for the projector will provide a 160° diagonal field-of-view. A spectral filter is added to the light path to eliminate the deep red and near infrared spectrum, leaving a blue-green projected output for the sky and seascape.

The insertion camera uses a high-sensitivity isocon TV tube and a 160° wide-angle lens which matches the projector lens. The camera deflection circuitry scans synchronously with the background projector. A spectral filter in the camera optics rejects the background projector's blue-green wavelengths and generates video only from the displayed carrier image (from the target projector), which contains the red and near infrared spectrum. This insertion camera video is used to blank the background projector video. This prevents the background seascape from being visible through the carrier image, thus enhancing the carrier image contrast.

Target Channel

The target channel is an electromechanical and electro-optical subsystem which produces the high-resolution monochrome TV image of the carrier. The quality of the carrier image is very important, since it provides nearly all of the pilot's visual cues for the critical final approach and touchdown. Also, a carrier's runway length is less than 10 % of a typical airfield, and the seascape, except for the carrier wake, provides no supporting line-up or turn cues. Figure 5 shows the functional relationship of the target channel components and the complexity which has been incorporated to assure the necessary image quality.

The carrier is a three-dimensional model of the Forrestal CVA-59 at a 370-to-1 scale. It is 33-in. long, highly detailed, and includes all runway, centerline (with and without strobe), deck, and drop lights. The FLOLS is not included on the carrier model, but its position is marked by a small HeNe laser. The laser is located away from the model, and its light is brought to the carrier's FLOLS location by a light pipe and is dispersed to cover the same FOV produced by the FLOLS lights. The carrier model is servo driven in pitch, roll, and heave to simulate various seastates. It is mounted on a typical vertical model board frame and illuminated by thirty-two 1000-W metal halide lamps.

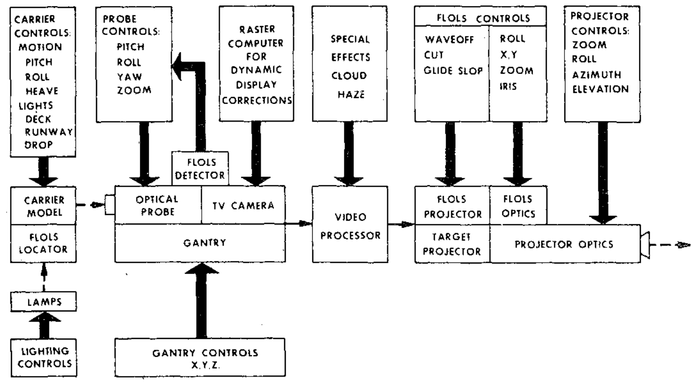

Fig. 5 Target image generator and projector block diagram.

A three-axis servo-driven gantry transports the optical probe and TV camera in response to *X*, *Y*, and *Z* computer commands. The *X* and *Y* servo drives cover an 11-ft radius about the carrier for a scaled range of 4070 ft. Longer ranges, out to 6 miles, are simulated by projector and camera zoom lenses. Smooth acceleration of the gantry is maintained by providing a transition region between full gantry movement and full zoom movement in the computer control equations for range simulation. The *Z* axis servo travel of 2.7 ft simulates an altitude range of 0 to 1000 ft, with normal carrier touchdown deck height at 62 ft.

The four-axis, servo-driven optical probe responds to roll, pitch, yaw, and zoom computer commands. The roll and yaw servos are continuous, and pitch travel is +45° and −135°. The 4-to-1 zoom is used at ranges beyond 1000 ft from the carrier to reduce the FOV gradually from 60° to 16.4°, to maintain a large number of TV lines across the carrier image, improving carrier image quality. The probe zoom, in combination with the projector zoom, causes the carrier broadside image to cover at least 90% of the camera raster width, and the carrier's standard stern approach view causes it to cover 18% of the raster width throughout the critical approach region, within 2 miles of the carrier. The optical probe includes a spectrally selective beam splitter to separate the LASER FLOLS position indicator from the camera optical path, directing it to a diode array detector. The detectors provide an error correction signal to accurately point the optical probe at the carrier and prevent drift of the FLOLS projected image with respect to the carrier projected image.

The TV camera uses a Westinghouse WX-31836/WX5168 2-in. vidicon with image intensifier. The camera design is similar to the luminance channel of a camera previously fabricated by Singer, SPD.[1] The newer Westinghouse tubes exhibit lower-third TV field lags of 17% rather than 25% reported for the earlier camera. Since the camera system is operated in the area-of-interest mode, dynamic rate of movement of the image across the faceplate is low, and the lower lag response of tubes, such as the plumbicon, is not required. Therefore, the high sensitivity of this image intensified vidicon can be applied effectively. The camera deflection circuitry is driven dynamically by the computer to compensate for display geometry raster shape distortions. The close placement of the target projector exit pupil to the pilot eyepoint has reduced these distortions to a worst-case raster size change of only 15%. This small correction, when applied, will not have a significant impact on display resolution, which often is the case in off-axis wide-angle display systems.

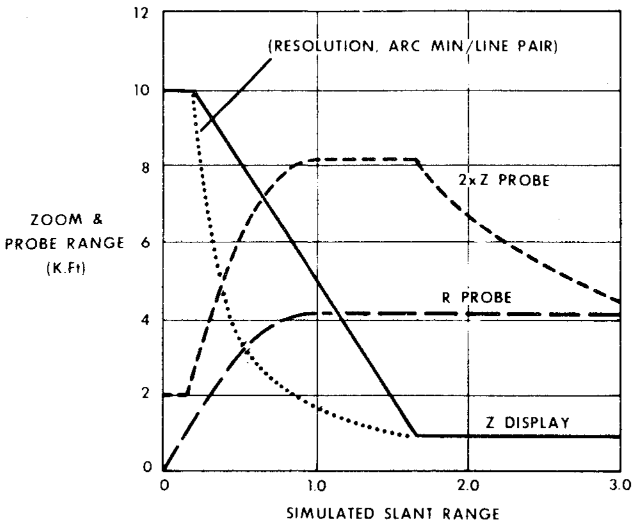

Fig. 6 Probe slant range and zoom ratios vs simulated slant range.

The special effects generator is a simplified version of that used in the background channel, since the range to carrier is considered a single value. This simplifies the haze simulation by making it uniform over the entire carrier. This haze function, and the cloud-layer thickness and height, are computer-controlled and variable by the experimenter. The special effects functions are combined with the carrier video in the video processor, which presents the final composite image to the target projector.

The target TV projector is identical to the background TV projector, but has complex projection optics to achieve the area-of-interest function. A 10-to-1 zoom lens, derotation prism, azimuth prism, and elevation prism are servo-controlled. The zoom function is used over the simulated range of 1000 to 10,000 ft from the carrier. Simulation of longer ranges, between 5840 and 10,000 ft, is performed solely by this zoom lens, whereas the close-in range simulation from 1000 to 5840 ft is a function of this projector zoom, the optical probe zoom, and gantry movement, as shown in Fig. 6. The azimuth and elevation prisms comprise the pointing optics to implement the area-of-interest projection of the carrier image. These small prisms simplify the high dynamic rate servos required in the display. The roll prism performs an image derotation function to counter an induced image roll from the azimuth and elevation prisms. A beam splitter combines the FLOLS image with the carrier image prior to the target projectors zoom lens, so that both images pass through the same optical transformations and no tracking error is introduced between the two images by the target projection optics.

The FLOLS projector produces a high-brightness color optical projection of the FLOLS landing aids systems. Its displayed brightness of 30 ft-L provides good daytime contrast with the 6-ft-L carrier image. The FLOLS two-dimensional model is a light pattern formed by the ends of small fiber light pipes, which are illuminated by a Xenon arc lamp. The model includes the FLOLS datum lights, waveoff and cut lights, and meatball, each in its appropriate color. A zoom lens provides for range simulation from 1000 ft from the carrier to touchdown, since the target projector zoom is fixed in this region. The iris is servo-driven to maintain proper brightness with range, and turns off the FLOLS when the pilot is out of the viewing cone. The roll prism is servo-controlled by the computer, since the target projector roll prism is used only for derotation and not for flight simulator roll. Displacement of the FLOLS image relative to the target projector optical axis is provided for, but is not required by the current control system math model, which centers the optical probe FOV and the FLOLS carrier model location during final approach.

An additional capability to be acquired early in the AWAVS program is a computer image generation (CIG) system. It will be interfaced with the flight simulator, and will provide CIG video to the video processor of the target channel. A CIG carrier image can be inset into the background display channel for direct comparison with the substituted 3-D carrier model. All other parameters can be held constant (e.g., brightness, contrast, resolution, and system control characteristics). General capabilities of the real-time CIG system includes variable TV line rate, picture capacity of 2000 edges at 525 line rate, edge smoothing, and surface shading.

Flight Simulator

The flight simulator is a Navy T2C twin-engine jet trainer. It is similar to Navy Training Device 2F101. Major differences are the inclusion of a *g*-seat in the cockpit, a more powerful computer system, and an experimenter station. The *g*-seat is similar to current experimental designs.[2] The computer system has been upgraded from a 16-bit PDP 11/45 to a 32-bit SEL 32/50. All flight dynamics and motion base equations are solved 30 times/sec. A second SEL 32/50 computer for visual system control is synchronized with the flight simulator computer. The schedule of computations in the two computers allows complete processing of flight dynamics, motion, and visual equations each thirtieth of a second. This is done to reduce computer throughput time to 33 msec maximum. Additional small time lags will result from sampling of pilot stick inputs and execution of computer output commands by the servos. Selection of this higher performance computer system was required in order to achieve this processing speed, and still have capacity for real-time performance data computations and recording, and leave spare capacity for future training task software.

The inclusion of device 2F101 flight simulator in the CTOL system provides a good starting point in obtaining a valid simulator baseline from which to monitor pilot performance. The extensive effort by the Naval Air Test Center to validate device 2F101 will be continued in establishing a baseline for the CTOL simulator.[3]

Conclusions

The AWAVS CTOL simulator will provide a research capability to investigate real image wide-angle visual technology and define visual system criteria for future training simulators. Probably its most outstanding characteristic is the display of very high resolution object images in a wide-angle background scene, with a minimum of dynamic time lag. The system's flexibility to simulate complex or simplified equipment configurations, along with parameter variability, will be invaluable in achieving the program objective. The problem still remains of how much fidelity is required of visual cues, and what their interaction should be with other cues for effective pilot training.

References

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