VISUAL SYSTEM OF THE F/A-18 WEAPONS TACTICS TRAINER

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ABSTRACT

Limitations in wide angle image generation and display technology historically have prevented dome simulators from portraying all of the visual cues required to train Air Combat Maneuvers (ACM). Dome simulators typically displayed trainee aircraft attitude but could not display other cues, such as altitude, position, translational velocity and vertical velocity, needed to prevent inadvertent collisions with the terrain. This paper will describe advanced Computer Image Generation (CIG) and wide angle projection techniques used in Device 2E7, the F/A-18 Weapons Tactics Trainer, to overcome these limitations.

The approach to be described achieves an unrestricted 360° field-of-view CIG scene that provides all of the sky/earth and target cues needed for ACM training. This approach features high-speed calligraphic image generators incorporating dome image predistortion algorithms to produce solid color sky/earth scenes and a CT-5 CIG to generate realistic air targets. The device 2E7 visual simulation also includes surface targets, and permits training in a wide range of air-to-ground weapons tasks in addition to the basic ACM capability. Moreover, the visual system may be upgraded in a straightforward manner to achieve greater air-to-ground and air-to-air capabilities, in order to support fully the broad mission of the F/A-18.

Introduction

Simulation of the full range of air-combat maneuvering (ACM) requires a 360° out-of-cockpit visual display containing high resolution target images. However, simultaneous display of high resolution imagery over the entire 360° field-of-view (FOV) is not necessary. Target images can be adequately represented with high resolution narrow FOV, "area-of-interest" displays, while remaining elements of the out-of-cockpit scene can be portrayed with low resolution, wide FOV displays.

Designs of early dome ACM simulators (such as NASA's DMS and Navy's Device 2E6) recognized this by featuring separate display systems for target and background images. High performance, slewable CRT projectors with restricted fields-of-view were used to display air targets, while servoed "shadow graph" transparency projectors were employed to simulate a sky/horizon/terrain scene over the full 360° FOV.

This approach was satisfactory for training ACM at high altitudes, but proved to have a number of significant shortcomings, among them:

1. The sky/horizon terrain projectors simulated aircraft motion in yaw, pitch and roll only. Translation, vertical velocity position and absolute altitude cues were lacking; consequently, trainees could not easily fly visually at low altitude without crashing.

2. The target simulation used a camera model system to generate aircraft images. This system had limited flexibility for portraying a wide variety of target types, and for simulating weather and weapons effects.

The goal of the Device 2E7 WTT visual system is to overcome these shortcomings by improving on the target-sky/earth concept of ACM simulation.

The basic approach of the Device 2E7 visual system is to employ Computer Image Generation (CIG) systems for target and sky/earth simulation instead of camera model or transparency image sources. This approach achieves all of the aircraft motion and position cues required for ACM, and provides a highly realistic, flexible target image simulation.

This paper will describe the different image generation and display components of the Device 2E7 visual system and will discuss the design philosophy and performance of each of the major visual subsystems.

The paper begins with an overall description of Device 2E7; next, the target image generation and projection subsystems are detailed, followed by a description of the sky/earth image generators and sky/earth projection devices. The paper concludes with a discussion of training experience gained with the Device 2E7 visual system, and concepts for future improvements.

Overview of Device 2E7

The initial training objectives of Device 2E7 F/A-18 WTT are to teach ACM, air-to-air weapons tasks, cockpit normal and emergency procedures, and limited air-to-surface weapons delivery. Eventually, it is intended that the WTT be enhanced to include expanded air-to-ground and avionics simulations.

Figure 1 shows the layout of the dual trainer system. Each trainee station consists of a replica of the F/A-18 cockpit located at the center of a 40 ft. diameter projection sphere that extends to -50° on the sides and to -40° in the front and rear. The cockpits use many of the actual controls and displays of the F/A-18 and feature hydraulic control loading, as well as a pneumatic seat g-cueing system. An audio simulation of engine noise, airstream effects and tactical tones is also provided.

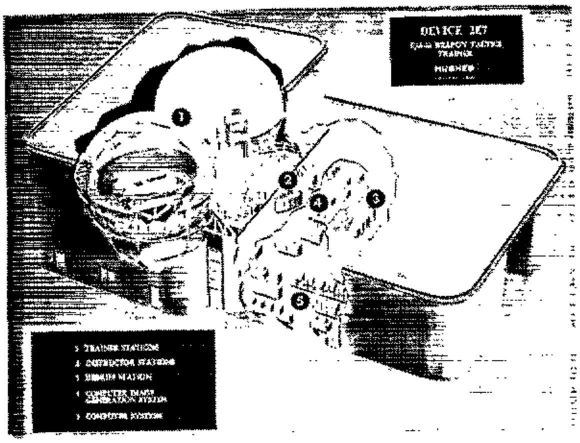

Figure 1. Dual Trainer System Layout

Sky/earth visual scenes are displayed on the dome screen from three projectors located on the dome periphery; four projectors placed on corners of the cockpit support platform display target imagery.

Each trainee station has an associated Instructor Operator Station, from which pilots can set up training sequences, monitor performance, and fly target aircraft against trainees.

A network of six minicomputers (SEL-32/77) perform the basic simulation computations for each trainee station assisted by F/A-18 mission computers and flight control computers, and special purpose processors to calculate airframe servo actuator responses.

Target images for both trainee stations are produced by a single Evans & Sutherland CT 5 CIG system, while separate graphics systems, based upon Interactive Machines Incorporated IMI-500 processors, are used to generate sky/earth scenery for each trainee station. Figure 2 shows a block diagram of the visual subsystem for one dome, and Figure 3 is a photograph of the visual scene as viewed from the cockpit. The sky/earth scene is a three color rendition of a light blue sky with dark ground texture against an earth-tone background. Two, independently driven target images are displayed in each dome in monochrome.

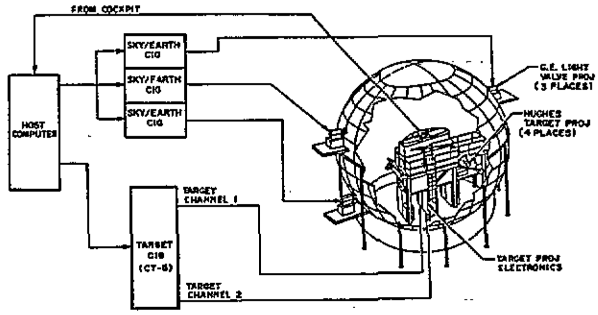

Figure 2. Device 2E7 Visual System Configuration

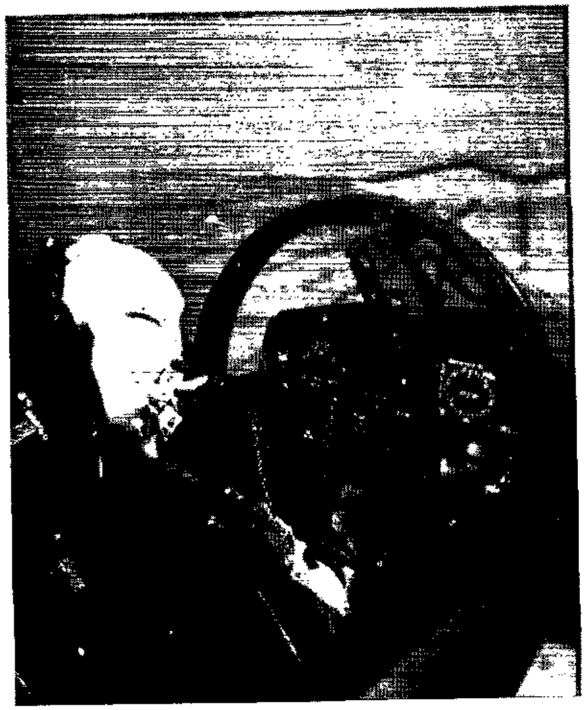

Figure 3. Out-of-Cockpit Scene of Device 2E7 Visual System

The trainer has several operating modes including:

1. Independent Mode - where Device 2E7 functions as two separate trainers. Trainees fly against the instructor, a computer driven target (Adaptive Maneuvering Logic), or surface targets.

2. Integrated Mode - in which the two halves of the trainer are linked to permit one vs. one, two vs. one and two vs. two engagements between instructors and trainees.

3. Demo-mode - which permits replay of pre-recorded sequences.

4. Test Mode - designed for system test, evaluation and checkout.

5. Instructor Training Mode - designed to walk prospective instructors through different functions of the trainer.

6. Debrief Mode - in which instructor pilots and trainees can review training mission performance.

Four WTTs have been ordered for use by NAVY and MARINE F/A-18 squadrons; the first of these was ready for training at Lemoore NAS in January 1984.

Target Simulation

Target System Overview

A block diagram of the target simulation system is shown in Figure 4. Target video is generated by the CT-5 based upon commands passed to the DEC11/44 from the visual host processor, and is routed through a video switch to the video electronics for the target projector CRTs. Special commands for control of the CRT raster and optical focus are sent directly from the visual host processor to the target projector video electronics unit. Resulting video and focus data are then relayed to the target projection head in the Trainee Station. This projector head has a two axis gimbaled mirror assembly whose azimuth and elevation servos receive pointing commands from the host processor via servo electronics units.

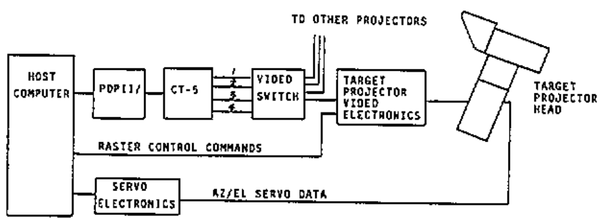

Figure 4. Target Simulation Block Diagram

As shown in Figure 2, target projectors are located on corners of the cockpit support structure, out of the trainee's line of sight. Projectors operate in pairs, such that each covers half of the 360° field-of-view.

Image Generator

A CIG approach was chosen over a camera model approach in order to achieve ease of changing targets and flexibility for programming an unlimited variety of air and surface target types.

The CIG configuration sought to achieve an optimum tradeoff between cost/size of the CIG and fidelity of target images. An additional goal was to start with a system that could easily be expanded to achieve full air-to-surface visual simulation.

The system configuration selected features a DEC11/44 front end processor with a CT-5 object manager (OM) and polygon manager (PM), a CT-5A geometric processor (GP) and two CT-5 display processors (DP).

The DEC11/44 communicates with the host processor from each half of the trainer via a high speed DMA interface. The host processor passes to the DEC11/44 aircraft eyepoint information and data for two independently controlled target images. The CT-5A GP, which normally calculates one view window, is specially programmed to compute four perspectively unique target images. From the GP, two target images are then passed to each DP. The DP's also have been specially modified to process multiple viewpoints using two of the three available color channels. Thus, each DP outputs two monochrome target images while the third color channel of the DP's is unused. Available pixel processing capacity of each DP (250K pixels) is divided equally between target images. DP output video is in a standard RS 170 format, so field extension for overload management is not provided.

The configuration described above produces high fidelity targets with a minimum of hardware (two and one-half racks for OM, PM, GP, and DP's). Extra GP's and DP's can be added to provide more visual or sensor channels.

The performance attained by the target CIG is 1000 visible polygons at a 60 Hz update rate. Smooth surface shading, antialiasing, articulating surfaces, atmospheric/meteorologic effects and weapons effects are also provided. Twenty air and surface targets are selectable in this baseline configuration.

Target Projectors

The target projector subsystem is composed of a video electronics subsystem, CRT subsystem, optical subsystem, and pointing subsystem. The video electronics and CRT subsystems (manufactured by SRL) have been described in detail elsewhere and will only be briefly summarized here. (1)

Video electronics for each pair of projectors are housed in several racks beneath the cockpit (see Figure 2). These racks contain four, linear deflection amplifiers (X and Y deflection for each projector) and an interface control unit that receives commands for movement of the CRT focus servo and for dynamic alteration of the size, shape, brightness, and rotation of the target raster. Alterations in these parameters are accomplished once per update field to correct changes in target image range, throw distance and distortion. In addition, separate assemblies are provided for video processor, focus amplifier and CRT high voltage.

The CRT subsystem is located in the target projector head (Figure 5). The CRT is a high brightness (20,000 ft.L) high resolution (0.003" spot) device with a 6" faceplate coated with a P43 phosphor. Mounted with the CRT are a video pre-amplifier and a servo system that moves the CRT longitudinally to keep the target image in focus on the dome screen as projection throw distance changes. The CRT faceplate is cooled with compressed air and the entire assembly is shielded to block X-irradiation.

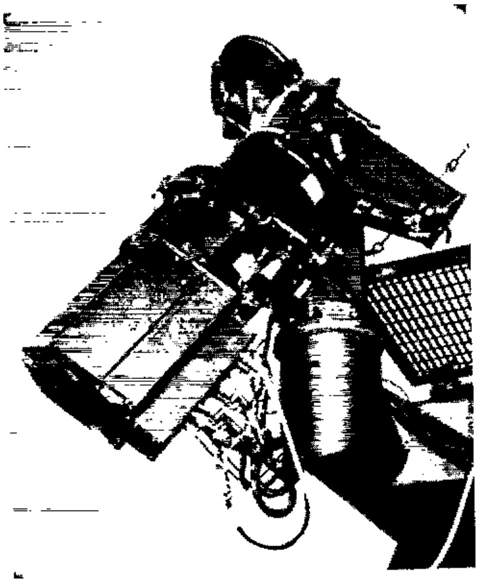

Figure 5. Target Projector of Device 2E7

A six-element lens is used to image the CRT faceplate on the dome screen. This lens has an effective field-of-view of 23° and achieves in excess of 70% transmission on-axis and 35% transmission at .8 field. MTF on-axis is greater than 20% at 1 arcmin/per optical line pair for nominal 240" projection and viewing distances.

A first-surface azimuth steering mirror is mounted between the second and third optical elements, and another mirror driven by the elevation steering servo is placed in front of the first optical element.

A 2 mw, HE NE laser is mounted parallel to the optical axis behind the azimuth steering mirror. It projects through a small hole at the optical axis in the azimuth mirror and is reflected off the elevation steering mirror onto the dome screen. The laser, which is attenuated by neutral density material for eye safety, is used for azimuth and elevation pointing servo calibration and for indicating target cannon fire.

The two-axis gimbaled pointing system theoretically permits projection at all angles except limited "dead zones" directly above and beneath the projectors' azimuth axes. The projectors are mounted at an angle to orient the pointing "dead zone" away from forward field-of-view. Each projector of a pair covers approximately one half of the trainee's field-of-view with a hand-off boundary defined roughly by the intersection with the dome screen of a plane bisecting the axis connecting the projectors.

The hand-off boundary is actually a zone, whose borders represent "on" and "off" margins for each projector. A three degree separation between the "on" and "off" boundary for each projector introduces a hysteresis that prevents rapid, repeated switching during target trajectories along the hand-off boundary. Forward boundaries are oriented to prevent target hand-off within the forward 80° cone of the trainee's field-of-view.

In order to attain desired dynamic response, both the azimuth and elevation servos were designed to achieve a .7 damped, 25 rad/sec, second-order model response.

Table 1 summarizes key performance parameters of the target projection system. Attainment of these performance levels provides an accurately positioned air target, of eye limiting resolution, for which aspect discriminations within $\pm 45°$ are possible out to a 25,000 ft. range. Furthermore, target image pointing performance adequately reproduces the demanding own-ship/target dynamics of air-combat.

Sky/Earth System

System Overview

The principal design goal of the sky/earth system was to visually induce motion in attitude, altitude and position over the full field-of-view available to the F/A-18. Because presentation of such motion cues does not require high fidelity reproduction of the outside world (motion induction is mediated by peripheral vision), it was possible to sacrifice scene detail in favor of wide display field-of-view.

In doing this, we sought to match the performance of each element of the sky/earth system in order to achieve the most cost-effective overall solution. For example, there was little benefit in generating a high fidelity sky/earth scene with a state-of-the-art CIG when the wide-field-of-view sky/earth projectors lacked the brightness and resolution to reproduce such high fidelity. Thus, a lower performance CIG was selected that generated only those cues that were required (and could be displayed).

A secondary design goal was to project sky/earth imagery in a manner that did not obstruct the trainee's field-of-view.

Figure 6 shows a block diagram of one channel of the sky/earth system.

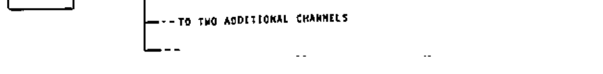

Figure 6. Sky/Earth System Block Diagram

The visual host processor passes eyepoint data and other information for special effects (described below) via a DMA interface to two IMI-500 calligraphic image generators. The stroke deflection signals from these processors are scan-converted to RS343, 1023 line format and combined into an R, G, B format by a specially designed video processor. From this processor R, G, B signals are routed through a video-switching matrix to a G.E. oil film light valve projector located outside the dome. Sky/earth scenes are pre-distorted prior to projection to correct for screen curvature, lens geometric distortion and offset of the projector from the design eye.

Sky/Earth Image Generator

The core of the sky/earth image generation system is the IMI-500. This processor is a high-speed, 3-D vector generator, which produces over 1650 visible vectors per 60 Hz update field. Outputs from two such processors are combined to generate a 180° X 180° field-of-view. The sky/earth data base processed by the IMI-500 consists of a 2-D grid and various 2-D and 3-D surface texture vectors. Data base management techniques such as area-level-of-detail are employed to equalize visual texture density at all altitudes.

The IMI-500 system also permits simulation of visibility effects, scud, g-dimming and in-flight missile smoke. New data bases can be programmed as required to simulate different gaming areas. The data base provided for the F/A-18 trainer covers 600 X 600 n.m.

The output of the IMI-500's is scan converted and processed to produce a three-color, solid surface scene, whose main textural cues are black vectors against a light blue sky and a tan background. Arbitrary colors for vectors, sky, and background are selectable.

Sky/Earth/Projector

Three G.E. oil film light valve color projectors (Figure 7) display the sky/earth scene in each dome. These projectors have 500 lumen output and are equipped with wide angle lenses that cover 90° projection cones. The optical axes of these lenses pass through the design eye. Each projection device is located immediately outside the dome with a nominal throw distance of 480." This yields an effective field-of-view of 180° from the design eye. Two of the projectors face each other at opposite ends of a diagonal in the longitudinal plane. The cockpit casts a shadow from the forward projector of this pair, so a third projector placed in front of the dome is used to fill this shadow. Thus, the entire visibility envelope of the F/A-18 is reproduced by three projectors.

Figure 7. Sky/Earth Projector of Device 2E7

The projection lenses and exit pupil are designed to prevent the trainee from seeing any direct illumination, and to permit projection of target and sky/earth images onto the screen area through which sky/earth projections pass.

The optical system incorporates a non-linear distortion feature that equalizes display pixel density across the entire FOV of each projector.

The boundaries of the different sky/earth displays overlap approximately 1°. Accurate matching of these boundaries is facilitated by precision adjustable projection pedestals (Figure 7) and by fiber optic fiducial points mounted in the dome screen at the sky/earth projection boundaries. Luminance discontinuities at the boundaries are minimized by countershading techniques.

Overall performance parameters achieved by the sky/earth display are shown in Table 2. Although the luminance (.1ftL) and resolution (36 arcmin/LP) are low, effective visual cueing is achieved because it is not necessary to represent small or sharply detailed objects in order to achieve the stated design goals.

Summary

The objective of the Device 2E7 visual system was to correct shortcomings of earlier dome ACM trainers by utilizing CIG systems to provide the full range of dynamic cues needed to simulate air-to-air maneuvers at all altitudes.

Based upon user feedback from the first operational WTT, this objective has been met. Pilots are able to pull out of steep dives at altitudes below 100 ft. using visual cues only, and experience "optical flow" from high-speed flight at low altitude. The presence of these important altitude and velocity cues greatly enhances the training capability of Device 2E7.

Recent experience also has shown that the visual system affords considerable air-to-ground weapons training capability. Using the target projectors to display ground-stabilized target scenes, pilots can practice maneuvers against twelve different surface targets.

The baseline visual system may be expanded in two important respects to provide added training capability.

First, the dome projection format lends itself to insetting additional displays having the increased resolution, contrast and brightness needed to simulate a broader range of air-to-surface tasks such as low-altitude penetration navigation.

Second, the CT-5 system can add up to seven channels for generating background scenes or sensor video for "smart bombs" or FLIR.

With such enhancement capability, the Device 2E7 visual system has the potential to simulate the full range of both fighter and strike missions of the F/A-18.

TARGET DISPLAY PERFORMANCE

PARAMETER	PERFORMANCE
FIELD-OF-REGARD (EACH PAIR)	360° HORIZ + 90° - 50° VERTICAL
FIELD-OF-VIEW (EACH PROJECTOR)	23°
SCAN FORMAT	525 LINE, 2:1 INTERLACE 30HZ FRAME, 60HZ FIELD
LUMINANCE	2.4 FTL FOR .75 INCH TARGET .6 FTL FOR 64 INCH TARGET
RESOLUTION	1 ARCMIN/LP FOR .75 INCH TARGET 8ARCMIN/LP FOR 64 INCH TARGET
COLOR	MONOCHROME
GREY SCALE	> 6 SHADES
DISTORTION	CORRECTED FOR SCREEN CURVATURE AND EYE/PROJECTOR OFFSET. 1:1 ASPECT RASTER TO WITHIN ± 2.5%
SIZE DYNAMIC RANGE	250:1
STATIC POINTING ACCURACY	± .15% OF SERVO EXCURSION
MAXIMUM SLEWING VELOCITY	AZ. SERVO - 10 RAD/SEC EL. SERVO - 10 RAD/SEC
MAXIMUM ACCELERATION	AZ. SERVO 20 RAD/SEC^2 EL. SERVO 40 RAD/SEC^2
SWITCHOVER ERROR BETWEEN PROJECTORS OF A PAIR	< 1°

TABLE 1

SKY/EARTH DISPLAY PERFORMANCE

PARAMETER	PERFORMANCE
FIELD-OF-VIEW	360° HORIZONTAL +90° TO -50° VERTICAL
LUMINANCE	.1 FTL
RESOLUTION	36 ARCMIN/LP
COLOR	R, G, B
SCAN FORMAT	1023 LINE, 2:1 INTERLACE 30HZ FRAME, 60HZ FIELD
DISPLAY APERTURE	NON-DISCERNABLE
MAPPING ERROR	< 1% OF DISPLAY HEIGHT
PROJECTION FIELD EDGE ALIGNMENT	< 1° MISMATCH

TABLE 2

References

1) Holmes, R.E., "Target TV Projector with Dynamic Raster Shaping for use in Dome Simulators." SPIE Proceedings, Aug. 24-28, 1981, San Diego, California.

ABOUT THE AUTHOR

Dr. Eric C. Haseltine is a Senior Project Engineer with the F/A-18 Weapons Tactics Trainer Program Office, Support Systems, Hughes Aircraft Company. A member of the staff responsible for visual systems in training simulators, Dr. Haseltine has had considerable experience in design and development of visual systems. His background at Hughes includes development of radar image processing algorithms, cockpit controls/displays, visually coupled FLIR systems and studies of integrated airborne multiple sensor systems. Prior to joining Hughes, he was engaged in post-doctoral research in visual neuroanatomy and psychophysics at Vanderbilt University. Dr. Haseltine holds a Ph.D. in Physiological/Sensory Psychology from Indiana University. He has published in the fields of neurophysiology, neuroanatomy, integrated sensor avionics, and visual simulation.