SIGNIFICANT FEATURES OF THE UNDERGRADUATE PILOT TRAINING - INSTRUMENT FLIGHT SIMULATOR (UPT-IFS) VISUAL/FLIGHT SYSTEM

THOMAS S. MELROSE
Aeronautical System Division
Wright-Patterson Air Force Base

INTRODUCTION

The USAF Undergraduate Pilot Training-Instrument Flight Simulator (UPT-IFS) System design combines several state-of-the-art improvements that promise to provide a highly realistic and effective training alternative to actual flight training. A significant part of the UPT-IFS system is its Visual Subsystem and its relationship to the total simulator complex. Limitations of previous visual systems dictated the need for establishing minimum image quality requirements and associated test procedures for the UPT-IFS system. These included the utilization of image detail criteria in terms of image contrast as a function of resolution levels of modulation transfer function (MIF), the employment of raster transformation to achieve the required low eye-height, the use of a high resolution color Cathode-Ray Tube (CRT) in an infinity image display, optimized terrain modeling, and depth-of-field criteria.

BASIC UPT-IFS PLAN

The basic plan for the UPT-IFS, as formulated from a study back in 1968, was to acquire a training system using technology of proven training capability and reliability. Accordingly, companion programs were established for the flight simulator system with Singer Simulation Products Division and the Visual System with American Airlines/Redifon.

The combined systems were to provide high-fidelity training for all phases of instrument flight, including visual simulation of takeoff, approach, and landing (or missed approach).

THE VISUAL SYSTEM

The visual system offers an enhanced training capability by providing extra-instrument training cues for approaches and transitions to landings under variable weather conditions. It consists of two color television (TV) probe/model image generators feeding four cockpit display crew stations with infinity image visual cues of the outside world.

These cues are critical in that they allow practice of the two-way transition from instrument indications to eye-contact with terrain patterns and textures, runway surface markings, lighting configurations, and signals. Because of this criticality, comprehensive steps were taken to quantify and qualify the parameters that provide these cues. To provide these critical cues, the TV probe/model system was selected as best suited for the requirement in terms of desired performance, necessary flexibility, proven training value and reliability. Basic performance advantages of this approach were: unprogrammed maneuverability, a relatively high level of detailed imagery of day as well as night scenes, and sufficient promise of providing the necessary visual cues in near-the-ground conditions.

In order to optimize the probe/model approach, past shortcomings were addressed and special steps were taken to effect improvements.

IMAGE QUALITY CRITERIA

One of the principal tasks was the adaptation of established criteria for assuring and objectively measuring the quality of the displayed image in terms of resolution and contrast transfer (or modulation transfer) characteristics. As applied to TV systems, resolution may be defined as the amount of distinguishable details in the display, normally expressed as the number of TV lines, observable in dimension, equal to the picture height. Traditional techniques of resolution verification have been mainly eyeball, or subjective determinations. In a study conducted by the Aerospace Medical Research Laboratories (AMRL) at Wright-Patterson Air Force Base, more objective-type measurement techniques were developed. These established a direct relationship between video signal risetime (relating to image-to-object contrast) and TV resolution capability.

If a TV system is required to reproduce a gross black-to-white transition, consisting of resolution bar patterns, the video signal waveform would take virtually no time to moveup from a minimum black reference level to the maximum white response level. A complete square-wave replica of the bar pattern results. As the bar pattern intervals are reduced (to higher resolution spatial frequencies), and given the TV system's timing constraints, the move-up time reaches its practical limit, at or before the given interval is traversed. This results in just reaching (peaking) the maximum white level (100% contrast/modulation) or partially reaching that level (percentage modulation). Partial or percentage modulation, then, is suitable as a valuable tool in measuring resolution.

In adapting this concept and technique, a typical probe/model candidate system was used in a series of measurements for performance comparisons against known standards. Measurements of the system camera's gray scale, geometric distortion, and contrast transfer characteristics were performed through analysis of the video output signals, correlating to standard and special optical test patterns, viewed by the camera. The special patterns consisted of resolution charts, representative of four levels in spatial frequencies of 5, 7, 10, and 15 arc-minutes. With the camera set up to view a wide black-to-white transition pattern, a reference amplitude reading representing the lowest resolution was obtained, using a linefinding oscilloscope or waveform monitor. For each resolution level, the peak-to-peak amplitudes of the video signal waveform were noted. These amplitude swings, taken as percentages of the reference amplitude swing, served to reflect the modulation characteristics of the system. Measurements were taken for each of the three color channels, at nine different points within the field of view, and at simulated ranges of a half-mile and seven miles.

After analyzing and normalizing, the resulting measured parameters, as shown in Table 1., were made the required inputs into a stipulated final display device (CRT Monitor) of known characteristics and performance. Thus, system picture quality was controlled through specification (and measurement) of both camera image quality and display monitor performance.

DEPTH-OF-FIELD (DOF) REQUIREMENTS

In addition to the emphasis on the resolution/MTF parameters, particular attention was directed to assuring adequate DOF characteristics, another critical cue requirement. The conventional optical pickup was favored as a minimum risk item, even though it tended to have DOF limitations. To ascertain its performance, arrangements were made for visual systems with conventional pickups to be demonstrated and evaluated prior to contract award. The results were considered favorable. Further, an objective, "Twice-the-Risetime" method, (adapted from the earlier mentioned AMRL study) was employed to determine and measure DOF as a function of video signal risetime. With this method, an appropriate chart is used to obtain an optimum probe focus setting, corresponding to sharpness in image resolution. The video signal risetime is taken at this setting. The chart is then repositioned at points nearer to and away from the probe. The repositioned points are those at which the focus is degraded to the extent that the signal risetime is not more than twice that at the optimum focus setting. These points mark the near and far field limits. A plot showing the relationship is depicted in Figures 1 and 2.

USE OF RASTER TRANSFORMATION

The optical probe is the controlling component in a TV probe/model visual system. As such, the probe's closest approach to the model determines the minimum model scale, commensurate with the minimum required pilot eye-height. State-of-the-art probe technology, at the time, enabled a minimum probe-to-model approach to be achieved, that was sufficient for the 7.66 feet needed for the T-38 application. But for the T-37, a lower 5-feet eye-height was required. The technique of TV raster transformation, or anamorphic compression, was employed for reducing the physical eye-height to an apparent 5 feet. The transformation of the TV raster is achieved by means of electronic circuitry, driven by computer generated height signals, to change the scanning pattern of the camera. The picture height, width, and vertical linearity are changed as needed to provide the necessary aspect ratio, without allowing unsatisfactory side effects, such as corner cutting, registration shift, or brightness changes. A critical aspect of the transformation technique is to assure that the relationship of apparent distance above the terrain to that of the actual distance, is always greater than a ratio of 0.6 to avoid unrealistic or unsatisfactory image degradation when the video scanning is modified.

TABLE 1.

RESOLUTION REQUIREMENTS FOR VIDEO INPUT TO MONITOR

	PERCENTAGE MODULATION							
	7 Miles				0.5 Mile			
Position within Field of View	5'	7'	10'	15'	5'	7'	10'	15'
C	15	35	90	95	15	30	90	95
CU	X	50	70	80	X	40	60	70
CD	10	50	80	85	10	40	70	80
LU, RU	X	15	40	50	X	15	40	60
LC, RC	10	25	60	75	10	25	60	75
LD, RD	10	20	45	55	10	15	40	60

NOTE:

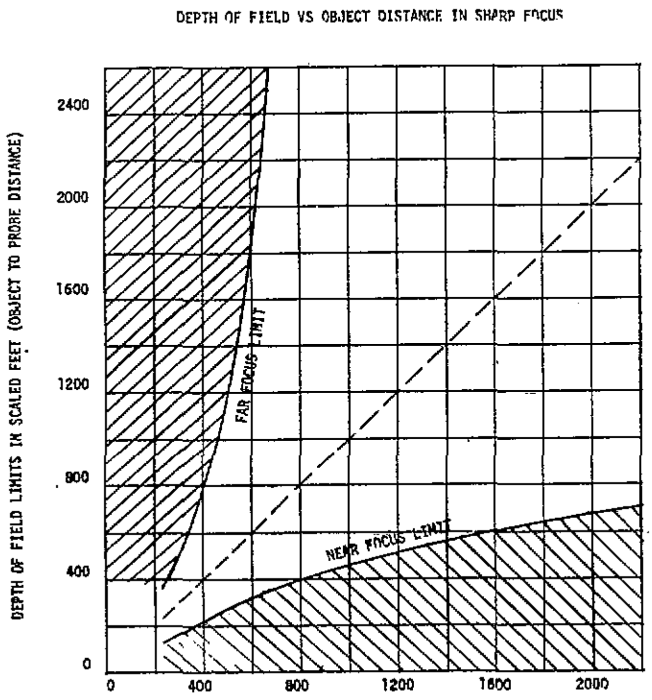
For a $36^{o} \times 48^{o}$ FOV on the display

5' corresponds to 432 TV lines per picture height resolution.

7' corresponds to 309 TV lines per picture height resolution.

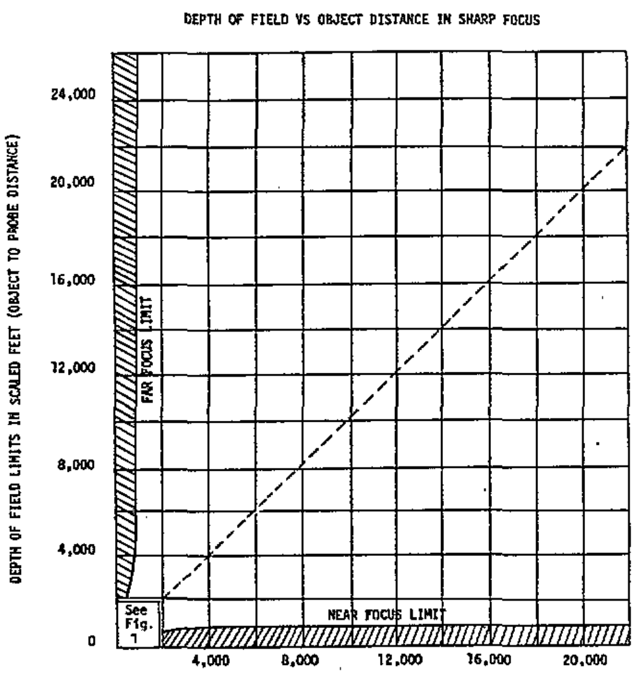
10' corresponds to 216 TV lines per picture height resolution.

15' corresponds to 144 TV lines per picture height resolution.



Probe to Object distance in sharp focus (scaled feet)
Focus servo limits for Probe and Camera
For 2:1 change in video rise time

Figure 1



Probe to Object distance in sharp focus (scaled feet)
Focus Servo Position
Limits for Probe and Camera for 2:1 change in video rise time

Figure 2

The rate of transformation into the height-above-the-model-terrain function must be introduced gradually and soon enough to avoid any noticeable transitioning.

HIGH RESOLUTION DISPLAY CATHODE-RAY TUBE

The next significant feature of the UPT-IFS visual system was the use of a high resolution, shadow mask type cathode-ray tube, which had been developed on an earlier program. The RCA developmental tube, originally designated Type C74957, is now a limited commercial production item listed as RCA 1908P22. The center resolution capability is given as approximately 900 lines with a white test pattern, having a brightness of 77-foot lamberts. Because of the prior favorable experience with this developmental component and an associated monitor chassis, this display tube was specified for use in the system. The advantages of using a CRT/monitor as image input into a mirror/beamsplitter design, are relatively low cost, high brightness, higher optical efficiency and less maintenance concerns, when compared with a projector type display package.

ON-AXIS INFINITY IMAGE SYSTEM

Yet another basic feature of the design, but representing significant advantages in realism, is the 60° diagonal field of view, on-axis *infinity or virtual image* display package. The infinity image is produced by placing the image input at the focal plane of the spherical mirror. The advantage, inherent with a virtual image display, is its ability to present a scene in a collimated fashion, such that the eye perceives the image as focused at infinite distances, as in the real world.

An earlier concern involved the operational maintenance aspects of using acrylic versus glass as the material for the collimating mirror. After considering long-range advantages associated with glass against the more obvious factors of less cost and weight for acrylic, the former was selected for use. The beamsplitter is also glass.

Indications point to a compatible matching of the curve surfaces of the high resolution CRT and the spherical mirror design.

MODELING ENHANCEMENTS

Finally, in keeping with the basic plan, existing terrain modeling design was optimized to best suit the UPT-IFS application. Major efforts centered around minimizing facility size and power requirements. Accordingly, a common model scaling (2000:1) was able to accommodate the two different gaming area (5 X 10 and 6 X 12 nautical miles) requirements. Two different, typical terrain-scapes and airfield runway configurations were fashioned to provide training flexibility and to avoid the cost and complexity of customized modeling. The modeling scheme followed was to place emphasis on realism through the entire optical and video chain as presented to the pilot, rather than on a realistic looking model board. Previous experience had shown that model detials, coloration, and contrasts, for example, when modeled as in the real world, appear to be unsatisfactory in the display to the pilot.

SPECIAL EFFECTS

The integral design of the visual system is enhanced by a special effects "fog box," which electronically generates variable visibility restrictions, cloud tops, and ceilings. This fog box generator also provides each of the four simulator cockpits with a capability to fly into or above the clouds, even when the probe/model images are not available. The above-the-clouds effects generate a blue sky above adjustable shades of white to dark gray cloud tops. The sky/cloud tops "horizon" reference in the visual scene is designed to be fully and accurately responsive to aircraft pitch, roll, and altitude changes.

VISUAL SYSTEM PERFORMANCE

The UPT-IFS visual system has recently undergone engineering verification testing. These tests were extensive and included tests on the probe/camera combination, the distribution amplifiers and the display system. The MTF of the probe/camera complied with the requirements for all but a few points. In many instances, MTF significantly exceeded the minimum required. The only performance area causing concern involves limitations in the on-runway DOF characteristics. The DOF pattern appears as a band of reasonably sharp imagery sandwiched between "softer" image details in the foreground and background. Further qualification tests are being conducted on the system, as integrated with its host flight simulator, to assess overall performance adequacy.

INTEGRATED UPT-IFS SYSTEM

With the integration of the visual system with the "flight" portion of the UPT-IFS complex, critical assessments will be made as to the total systems effectiveness as originally envisioned. The host flight simulator brings as its share, several equally unique, state-of-the-art features.

This system employs a six-degree-of-freedom motion system for each cockpit, on-board instructor stations, advanced digital computation systems, automatic demonstration and aural briefing facilities, a playback capability, and the ability to synthesize emergency conditions. These capabilities, combined with the out-the-window cues of the visual system, are expected to make a major contribution in providing high fidelity synthetic training in a cost-effective manner for the Undergraduate Pilot Training Program.

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ABOUT THE AUTHOR

MR. THOMAS S. MELROSE is a Senior Project Engineer with the Engineering Division of the Simulator System Program Office at Aeronautical Systems Division. He is primarily responsible for the UPT-IFS Visual Simulator System and its interfacing relationships with the host simulator complex and housing facility. He has been associated with several simulator programs, including the first Air Force probe/model visual simulator system. His professional affiliations include the IEEE and the Tau Beta Pi organizations. Mr. Melrose has a B.S. degree in electrical engineering, with additional studies at the Air Force Institute of Technology.