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## F-16 AND A-10 DIFFRACTION OPTICS HEAD UP DISPLAY (HUD) FLIGHT TEST EVALUATION

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## ABSTRACT

Advances in Avionic Systems and Display Technologies that provide a night attack capability require an approach to testing that is markedly different from the classical flight test approach. Improvements in computers, sensors and cockpit displays have dictated innovative test planning to insure that all integrated system performance requirements are fully addressed.

The introduction of Wide Field-of-View (WFOV) diffraction optics Head up Displays (HUDs) provide potentially more capability than has been previously available. A direct head-up, pilot-to-real-world interface via video raster and stroke written symbology permits low level maneuvering flight at night and provides at least a survivable capability. Integration of the WFOV HUD with the F-16 and A-10 aircraft provides a potentially useful capability that could make single seat night attack a realistic and effective alternative.

This paper examines the major planning activities and test results of the F-16 and A-10 HUD evaluations and provides a synopsis of relevant test procedures and test techniques applicable to HUD testing in general and night video raster testing in particular. The unique test requirements and safety aspects of night attack system testing are also addressed, and lessons learned are documented.

## INTRODUCTION

This paper presents the results of the flight tests to verify the performance usability and acceptability of the F-16 and A-10 Wide Field-of-View (WFOV) Head up Displays (HUDs) manufactured by Marconi Avionics Limited, Rochester, Kent, England. The tests were conducted at the Air Force Flight Test Center (AFFTC), Edwards Air Force Base, California, from 12 August 1982 through 17 January 1983 (for the F-16), and 5 November 1982 through 8 March 1983 (for the A-10). The F-16 test effort involved 107 test sorties for a total of 118.4 flight hours and the A-10 program encompassed 45 test sorties and 58.2 flight hours.

The primary objectives of the flight test programs were to verify that the WFOV HUDs were functionally equivalent to the production HUDs installed in the F-16A/B and A-10A aircraft. For the purposes of these evaluations, functional equivalency was defined as:

"The condition whereby the capabilities of the WFOV HUD, evaluated over all functional areas, are equal to or exceed the total capabilities of the current HUD."

Secondary objectives were to evaluate the capabilities of the WFOV HUDs to display a Forward Looking Infrared (FLIR) video source. These efforts included an evaluation of the pilot's ability to interface with the HUD and to qualitatively determine the performance of the HUDs in the video raster mode.

## BACKGROUND

In late 1980, Headquarters, Air Force Systems Command (AFSC) initiated a program to evaluate various avionic systems applicable to the night attack mission. The Quick Look Review of Night Attack Systems program, was designed to expose evaluation pilots to a wide spectrum of night attack systems, so as to permit them to make a comprehensive evaluation of the avionics requirements for the night attack mission. The quick look test effort provided an opportunity to consolidate Air Force experience with specific weapons system and extrapolate this information to a common viewpoint. This information was then made available to aid the Air Force in making critical decisions concerning avionics and workload trade-offs in the night attack arena.

The quick look evaluation encompassed the six different aircraft and seven simulators shown in Table 1. The program spanned the spectrum of night attack avionics and, in some cases, specific avionics systems were examined in several design schemes. The "hands-on" experience of the test team members was also supplemented by discussions with operators who routinely used the equipment in their night operations.

The results of the Quick Look evaluation verified the effectiveness of some specific night attack avionic systems and confirmed the importance of the Head up Display (HUD) in particular. The ability to overlay flight and weapons information on a wide angle electro-optical video presentations and provide that information to the pilot via a Head up Display was determined to provide a significant advantage for conducting effective night attack operations.

TABLE 1 SUMMARY OF QUICK LOOK REVIEW AIRCRAFT AND SIMULATORS

AIRCRAFT	CHARACTERISTICS	SIMULATORS	CHARACTERISTICS
YA-7E	BEST EXAMPLE OF SINGLE SEAT NIGHT ATTACK AVIONICS AND INTEGRATION	F-16 LOW ALTITUDE NAVIGATION AND TARGETING INFRARED FOR NIGHT (LANTIRN)	PROPOSED CONFIGURATION
AC-130	CURRENT NIGHT ATTACK AVIONICS	F-15 STRIKE EAGLE	POTENTIAL TWO SEAT ALL WEATHER
HH-53 PAVE LOW	AVIONICS USED IN NIGHT LOW ALTITUDE OPERATIONS (INCLUDES NIGHT VISION GOGGLES)	F/A-18 HORNET	NAVY SINGLE SEAT NIGHT ATTACK
RF-4C, ARN-101 PAVE TACK	SOPHISTICATED NAVIGATION SYSTEM INTEGRATED WITH RADAR AND FORWARD LOOKING INFRARED	MARTIN MARIETTA SYSTEM TEST LAB (STL)	MAJOR SOURCE OF PREVIOUS NIGHT ATTACK RESEARCH
F-111D	MULTI-FUNCTION DISPLAYS AND SOPHISTICATED NAVIGATION SYSTEM	CREW STATION DESIGN FACILITY (CSDF)	PROPOSED AIR FORCE SIMULATOR FOR LANTIRN
F-111F PAVE TACK	SOPHISTICATED NAVIGATION SYSTEM WITH INTEGRATED FORWARD LOOKING INFRARED	DIGITAL AVIONICS INFORMATION SYSTEM (DAIS)	RESEARCH VEHICLE FOR ADVANCED COMPUTER INTEGRATION
		HUMAN RESOURCE LABORATORY (HRL)	F-16/A-10 SIMULATOR WITH COMPUTER GENERATED SCENES

The F-16 and A-10 Wide Field-of-View Head up Displays (WFOV HUDs) (Figure 1), were specifically designed to provide these capabilities. Built by Marconi Avionics of Rochester, Kent, England, the WFOV HUDs incorporate diffraction optical techniques to provide a wide angle video raster image to the pilot that corresponds one-to-one with the normal daytime scene. Because the image seen by the pilot relates directly to what he is accustomed to seeing by day, he can continue to use his normal day low flying visual cues and techniques at night and thus increase safety while considerably reducing his workload.

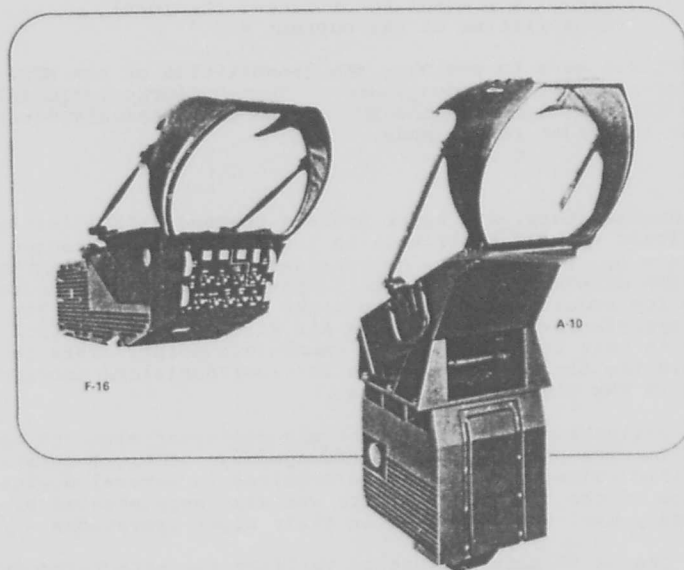


FIGURE 1 F-16 (LEFT) AND A-10 (RIGHT) WIDE FIELD-OF-VIEW HEAD UP DISPLAYS (HUDs).

F-16:

In Early 1980 the United States Air Force and General Dynamics initiated the F-16C/D, Block 25, Multinational Staged Improvement Program (MSIP). Divided into three stages (I, II, III), this program involves a series of changes to be integrated into the F-16 airframe and systems which would facilitate the introduction of various advanced avionics and systems.

Specifically, some of the additions to the F-16 as a result of these modifications include: The improved Westinghouse APG-66 radar; the modified AN/APN-22 Radar Altimeter; an increased capacity environmental control system; and expanded core avionics computer; and Advanced Central Interface Unit (ACIU); multi-function displays, upfront Communicatins, Navigation and Identification (CNI) equipment and the LANTIRN Navigation Pod, Targeting Pod and a Wide Field-of-View Head up Display.

The incorporation of the MSIP modifications essentially rebuilds the F-16 avionics suite and provides for a significant development potential for increasing the aircrafts multirole capabilities. The increased avionics capabilities are mirrored in the instrument presentations (Figure 2).

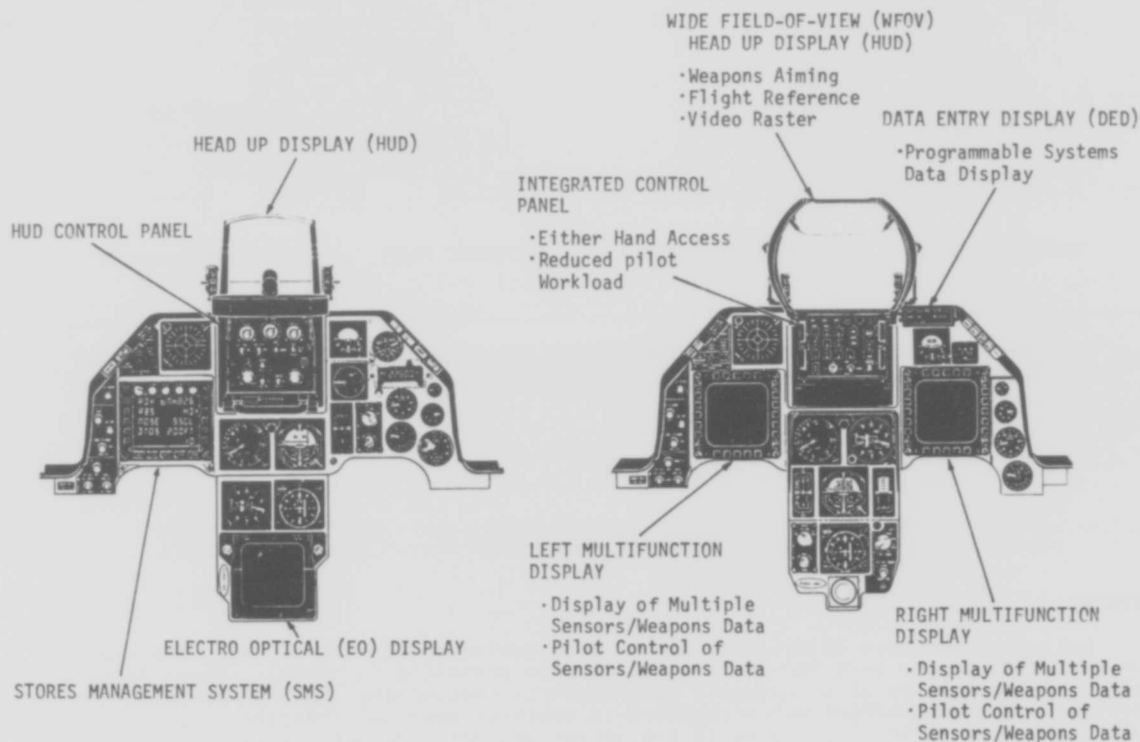


FIGURE 2 F-16 INSTRUMENT PANEL CONFIGURATION PRE- AND POST- MULTINATIONAL STAGED IMPROVEMENT PROGRAM (MSIP) INCORPORATION INCLUDING THE WIDE FIELD-OF-VIEW HEAD UP DISPLAY.

A-10:

The A-10 is also being upgraded to significantly increase the aircraft's effectiveness specifically in the night attack, first pass scenario. The total system is envisioned as utilizing pod capabilities to provide the necessary low level terrain following and target cueing aids that are not a part of the basic aircraft avionics. The A-10 Integrated Navigational System (INS) which utilizes digital multiplex techniques, provides the necessary interface system that allows for integration of Advanced Avionics with a minimum of aircraft modification.

As part of the A-10 capability upgrade, a noticeable change to the aircraft configuration is the addition of the WFOV HUD in the cockpit (Figure 3). Designed as a replacement for the production KAISER HUD, the WFOV HUD can provide the pilot with a video raster presentation as well as the necessary flight, navigation and targeting information for effective utilization of the aircraft in the night attack arena.

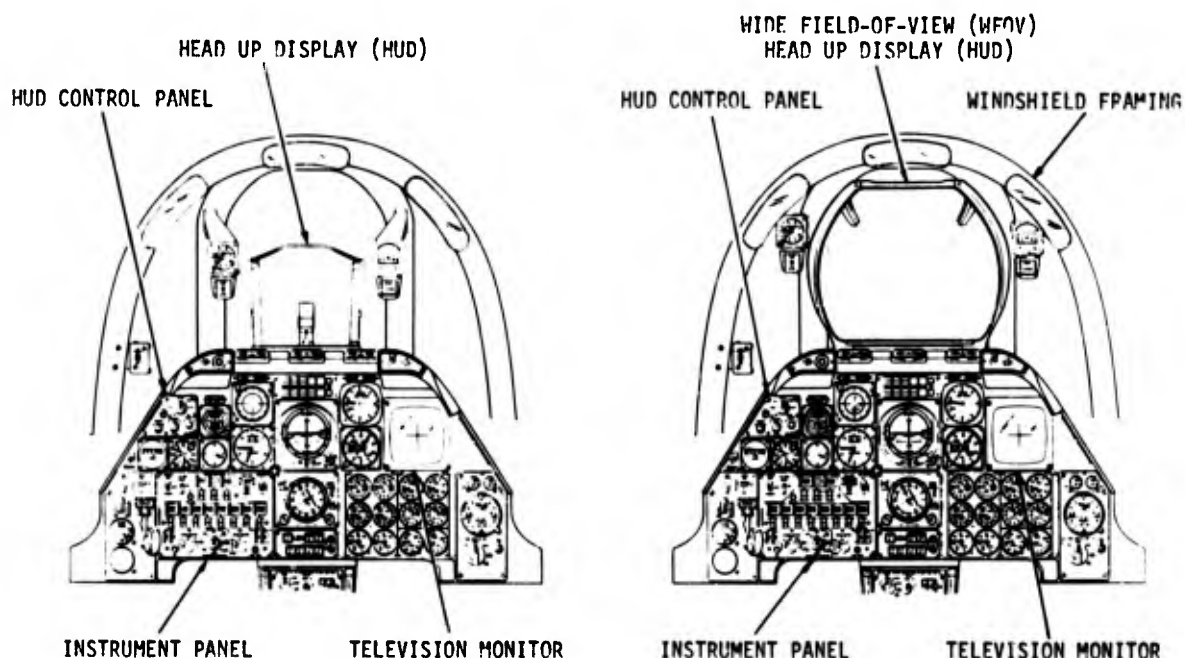


FIGURE 3 A-10 INSTRUMENT PANEL CONFIGURATION PRE- AND POST- LANTIRN SYSTEM INCORPORATION INCLUDING THE WIDE FIELD-OF-VIEW HEAD UP DISPLAY.

## TEST AND EVALUATION

### GENERAL

Following the test objectives, system description and method of test, the specific test results for each HUD (F-16 and A-10) are presented in detail. Human factors data and qualitative pilot comments together with engineering analysis are also included. The test effort was structured to evaluate each HUD independently. An integrated system level performance evaluation was not considered a part of these tests.

### TEST OBJECTIVES

The specific objectives of the Wide Field-of-View Head up Display (WFOV HUD) flight test programs were: 1) to verify that the WFOV HUDs were functionally equivalent to the production HUDs currently installed in the F-16 and A-10 aircraft and 2) to provide an early evaluation of the HUDs video raster capability.

### TEST LIMITATIONS

The F-16B aircraft used for the evaluation was a production Block 15 aircraft specifically modified for the test program. The Wide Field-of-View Head up Display, designed for the Block 25, Multinational Staged Improvement Program (MSIP) aircraft only, was modified to be compatible with this aircraft as shown in Figure 4.

A Texas Instruments/General Dynamics Forward Looking Infrared (FLIR) pod was used for the video raster evaluation. As implemented on the F-16, the interface between the aircraft and the pod was limited to a video raster display only without stroke-written symbology overlaid. In order to demonstrate the raster capability in time to support the production decision, these limitations were deemed acceptable and the flight tests were conducted with this configuration.

For the A-10 WFOV HUD evaluation, the Texas Instruments/General Dynamics FLIR pod was again used as the video raster source. Pod control functions (FLIR power, polarity, gain and level, etc.) were operated by using existing cockpit switches and controls.

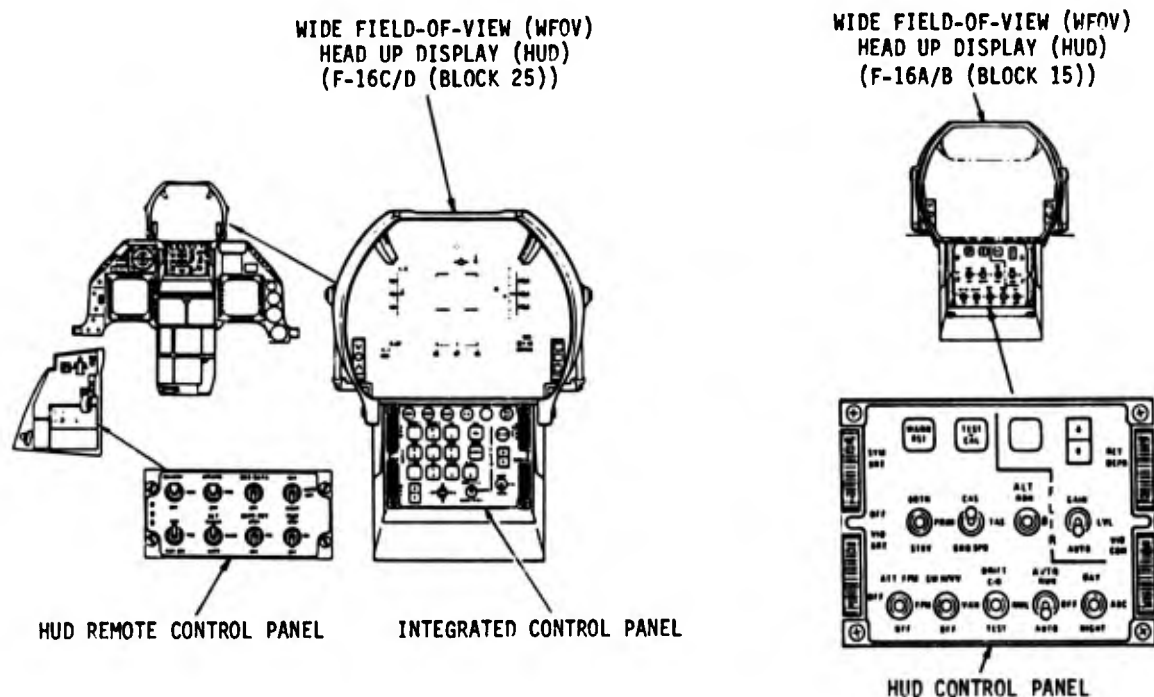


FIGURE 4 PROPOSED F-16 BLOCK 25 (MSIP) PRODUCTION CONFIGURATION (LEFT) AND THE TEST UNIQUE CONFIGURATION UTILIZED DURING THE FLIGHT TEST EVALUATION (RIGHT).

#### TEST ITEM DESCRIPTION

##### Aircraft:

##### F-16.

F-16B, USAF serial number 80-0635, was a production Block 15 aircraft modified with a reprogrammed Fire Control Computer (FCC), Central Interface Unit (CIU), and Fire Control Radar (FCR) computer. Additionally, the aircraft was modified to carry the Quick Reaction Instrumentation Package (QRIP) (for recording Mil-Std-1553B data traffic) and an Airborne Video Tape Recorder (AVTR) capable of providing two hours of video and audio recording.

##### A-10.

A-10A, USAF serial number 81-0945, was a production aircraft structurally and electronically modified to accept the WFOV HUD. The modification provided for the installation of the HUD in an aircraft equipped with an Inertial Navigation System (INS) and a Cockpit Television Sensor (CTVS)/Airborne Video Tape Recorder (AVTR).

##### Hud:

The F-16 and A-10 WFOV HUDs (Figure 5) were electronic and optical devices designed and built by Marconi Avionics, Rochester, Kent England. They processed data and projected weapons delivery and flight information in symbolic form on a combining glass assembly located in the pilot's forward field-of-view. The HUDs provided for stroke-written symbology for day and night operation, and a wide-angle video raster display for night operation. The raster display was compatible with RS-170 (MOD) standard video. The HUD's used diffraction optics techniques to obtain a wide angle field-of-view. The raster display and diffraction optics were the most significant differences from the production HUDs. The F-16 WFOV HUD consisted of two Line Replaceable Units (LRUs): the Display Unit (DU) and the Electronics Unit (EU). The A-10 WFOV HUD had a third LRU in the form of a remote control panel.

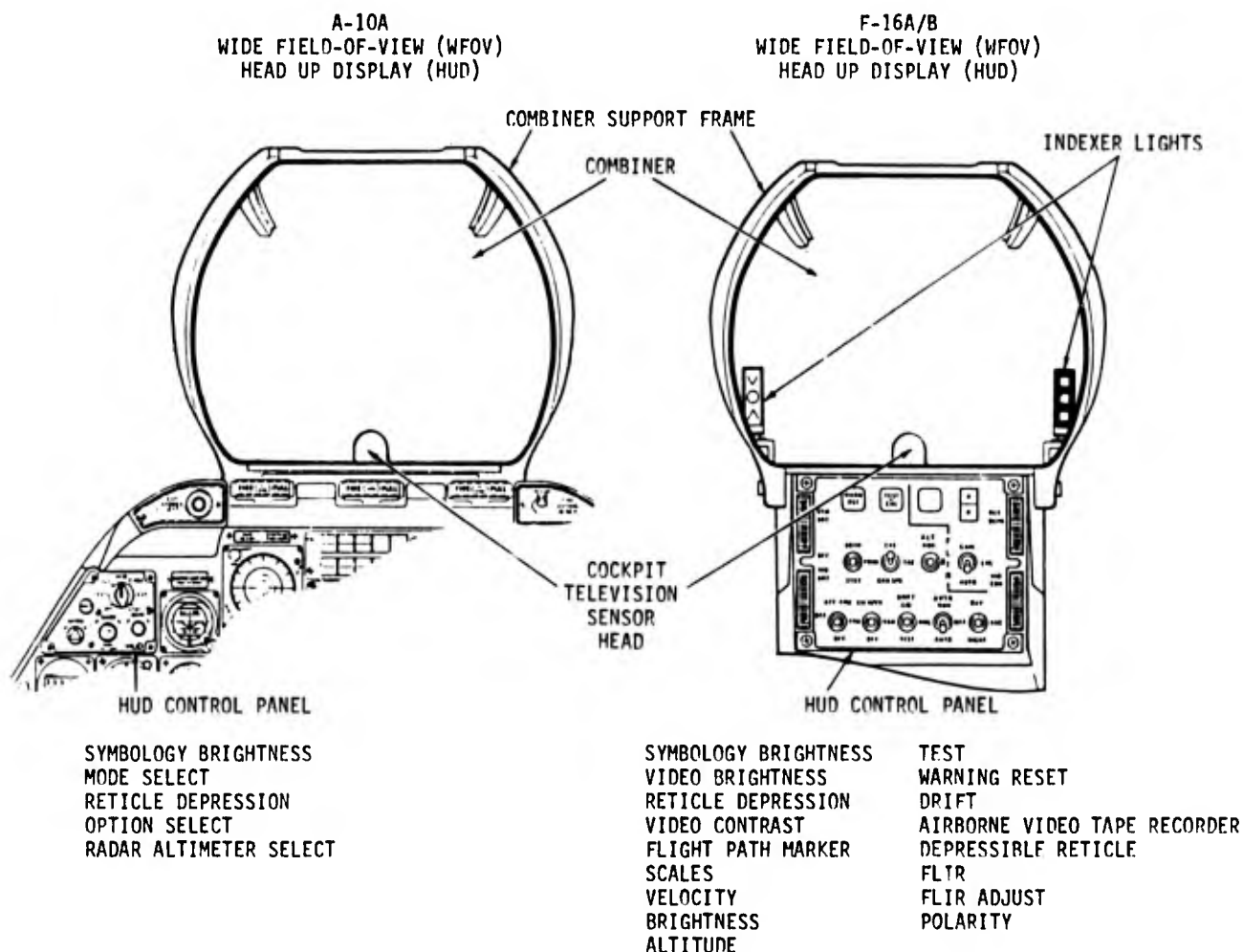


FIGURE 5 A-10 (LEFT) AND F-16 (RIGHT) WIDE FIELD-OF-VIEW HEAD UP DISPLAY

Display Unit (DU) (F-16 and A-10).

The Display Unit was mounted in the pilots forward Field-of-View above the glareshield. It contained a high brightness Cathode Ray Tube (CRT), an optical module, an automatic brightness sensor, associated electronics for signal interface compatibility, and a combining glass assembly with its associated support structure. It also contained a standby reticle generator to provide an independent standby sighting capability in case of total electronic unit failure. In the night environment, the DU could display video raster in addition to stroke symbology.

The F-16 HUD provided the pilot with an Instantaneous Field-of-View (IFOV), (i.e., seen by both eyes simultaneously) of 18.0 degrees vertical by 30.0 degrees horizontal (Figure 6). The Total Field-of-View (TFOV) was 20.0 degrees vertical by 30.0 degrees horizontal. This compares with an IFOV of 9.1 degrees vertical by 13.4 degrees horizontal and a TFOV of 20.0 degrees vertical by 20.0 degrees horizontal in the present production HUD.

The A-10 WFOV HUD provided the pilot with an IFOV of 19.0 degrees vertical by 30.0 degrees horizontal. This differs from the F-16 WFOV HUD (Figure 6) by being 1.0 degree larger in the vertical axis (from +3.0 degrees to -16.0 degrees from the horizontal datum) and the same in the horizontal axis. The TFOV of 20.0 degrees vertical by 30.0 degrees horizontal was the same as the F-16 WFOV HUD. These values are significantly larger than the 14.0 degrees vertical by 10.0 degrees horizontal TFOV in the A-10 production KAISER HUD.

Both the F-16 and A-10 HUDs contained mounting provisions for a cockpit television sensor (CTVS). The CTVS was a Charged Couple Device (CCD) electro optical imaging system which produced a composite video (television) output. It consisted of a video sensor head mounted forward of the combiner glass assembly pointed out over the nose of the aircraft and an electronic unit which was mounted in a remote location. The CTVS raster was electronically overlaid with symbology before being recorded by the AVTR.

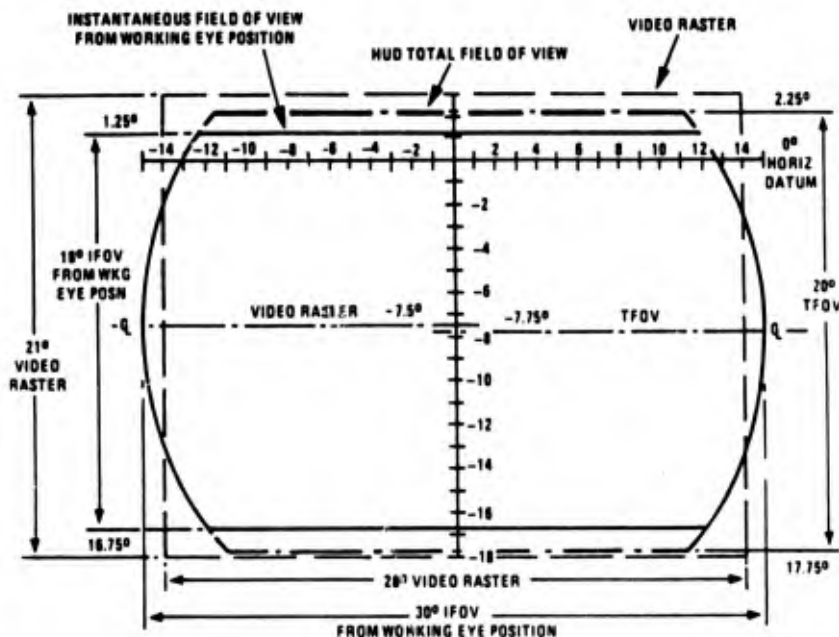


FIGURE 6 F-16 WIDE FIELD-OF-VIEW HEAD UP DISPLAY SPECIFICATION FIELDS-OF-VIEW.

Electronic Unit (EU) (F-16 and A-10).

The electronic units were located forward of the DU in the Electronics bay (F-16) or in the cockpit area (A-10). The EU contained the low voltage power supply, symbol generator, scan converter, digital computer and synchronization signals associated with the HUD interface requirements. Symbol generation, weapons aiming computations and parameter input scaling were performed by the dedicated digital computer. The symbology presented to the pilots was essentially the same as the symbology of the present HUDs. Figure 7 show typical F-16 and A-10 WFOV HUD symbology.

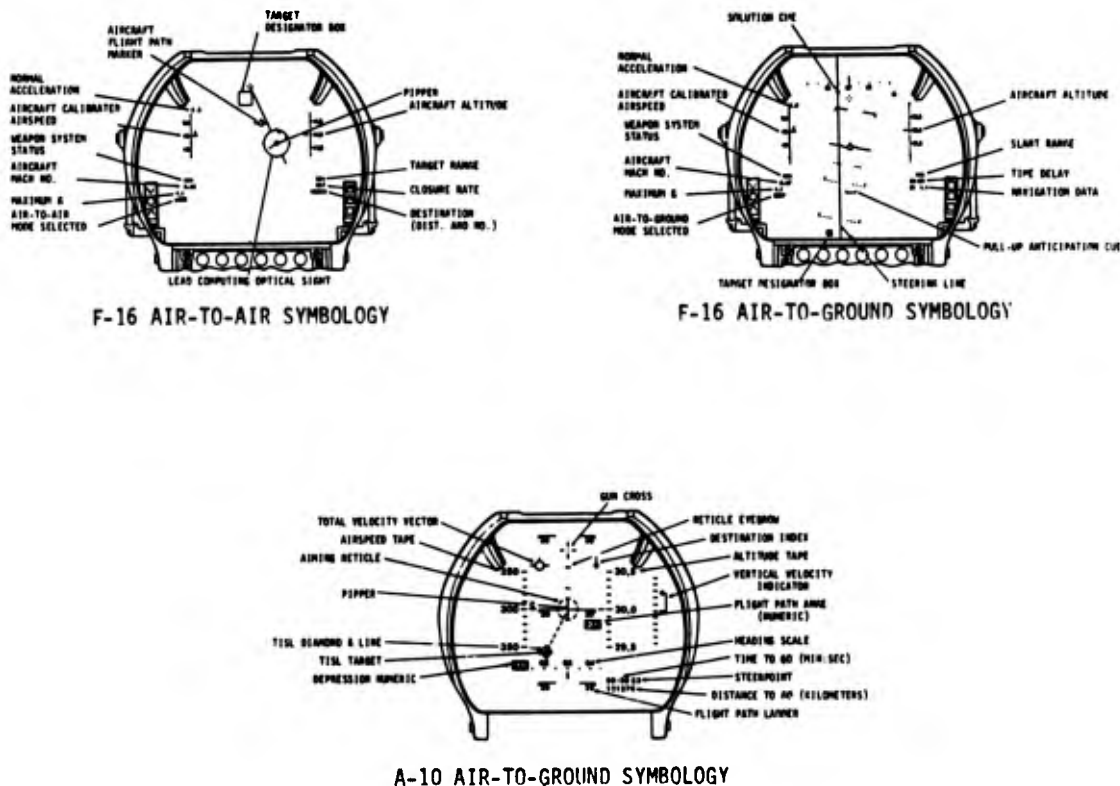


FIGURE 7 TYPICAL F-16 (TOP) AND A-10 (BOTTOM) HEAD UP DISPLAY SYMBOLOGY.

### Control Panel (A-10 only).

Unlike the F-16 where the HUD control panel was an integral part of the Display Unit, the A-10 control panel was a separate LRU. The panel (Figure 5) was mounted on the upper left control panel and provided the necessary controls for the operation of the HUD. There were five controls on the panel which operated symbol brightness, mode select, reticle depression, option select and a non-functional radar altimeter.

### Forward Looking Infrared (FLIR) Pod:

The General Dynamics/Texas Instruments FLIR Pod was used as the video source for the raster evaluations. The pod contained a modified Texas Instruments AN/AAQ-9 FLIR, which was repackaged into an existing pod and mounted on the left inlet station of the F-16 (Figure 8) and wing station number 4 of the A-10 for the tests. The optics for the FLIR were modified to provide a 21-degree vertical by 18-degree horizontal Field-of-View that was compatible with the HUD. The FLIR was a fixed installation and provided no look-into-turn or lead-into-turn features. The pod weighed 135 pounds (297.5 kg) and was 72 inches (182.8 cm) in length and 14 inches (35.6 cm) in diameter.

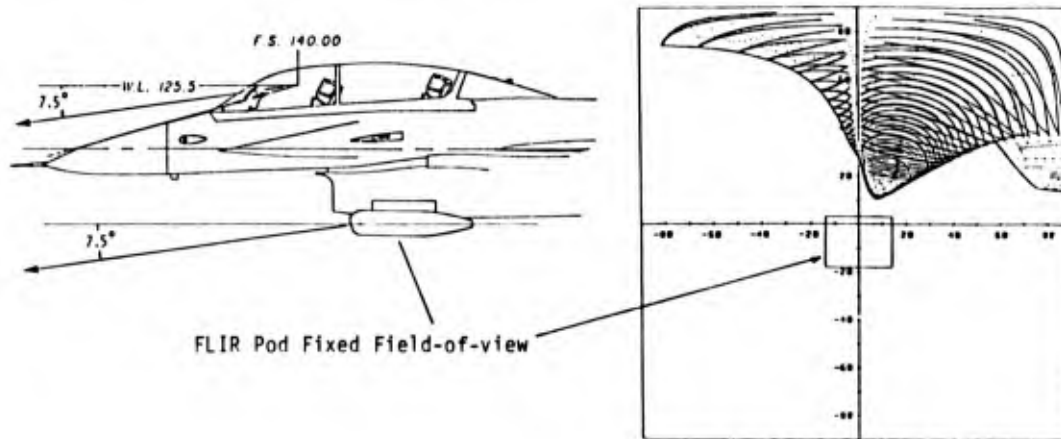


FIGURE 8 F-16 FORWARD LOOKING INFRARED (FLIR) POD FIELD-OF-VIEW.

### METHOD OF EVALUATION

The HUD evaluations were based on pilot debriefings and responses to questionnaires. The questionnaires were developed for the evaluation of the HUD's in the following areas:

1. Optical - included issues such as field-of-view, depth perception, distortion, color changes, transmissivity, head motion box, symbology brightness, reflections and sunspots. For the video raster flights, the additional areas evaluated included raster brightness, scene discrimination and real-world registration.
2. Mechanical - addressed such items as visibility, scene blockage and controls/switches.
3. Symbology - included symbol generation and mechanization.

Pilots flew the F-16 and A-10 aircraft under a variety of flight conditions for each set of tasks, e.g., navigation: day and night, overcast, bright sunlight. During post-flight debriefings, data were collected on each of the HUD characteristics for the particular conditions evaluated. The criteria for assigning these ratings and determining the performance of the WFOV HUDs is presented in Table 2.

Table 2 HUD EVALUATION CRITERIA

<u>Rating</u>	<u>Meaning</u>
Excellent	WFOV HUD enhances the baseline (F-16 or A-10) production HUD capability.
Satisfactory	Equivalent to baseline capability.
Marginal	Not equivalent to baseline capability, but acceptable.
Unsatisfactory	Not equivalent to baseline capability and unacceptable.

The potential acceptability of the F-16 WFOV HUD by the users was a significant concern during the evaluations. To provide as broad a spectrum of user inputs as possible, four

non-Air Force Systems Command F-16 pilots were invited to participate in the evaluation and provide their inputs covering all areas of the F-16 operational roles. The specific areas evaluated included: ground operations, take-off, Visual Flight Rules (VFR) navigation, weapons delivery, low level navigation, tactical weapon delivery, air-to-air weapons, air-to-air maneuvers, instrument approaches, VFR patterns, and landings.

In an attempt to quantify the results of these evaluations, a HUD rating scale (Figure 9) was developed to provide an objective indication of how the users perceived the F-16 WFOV HUD.

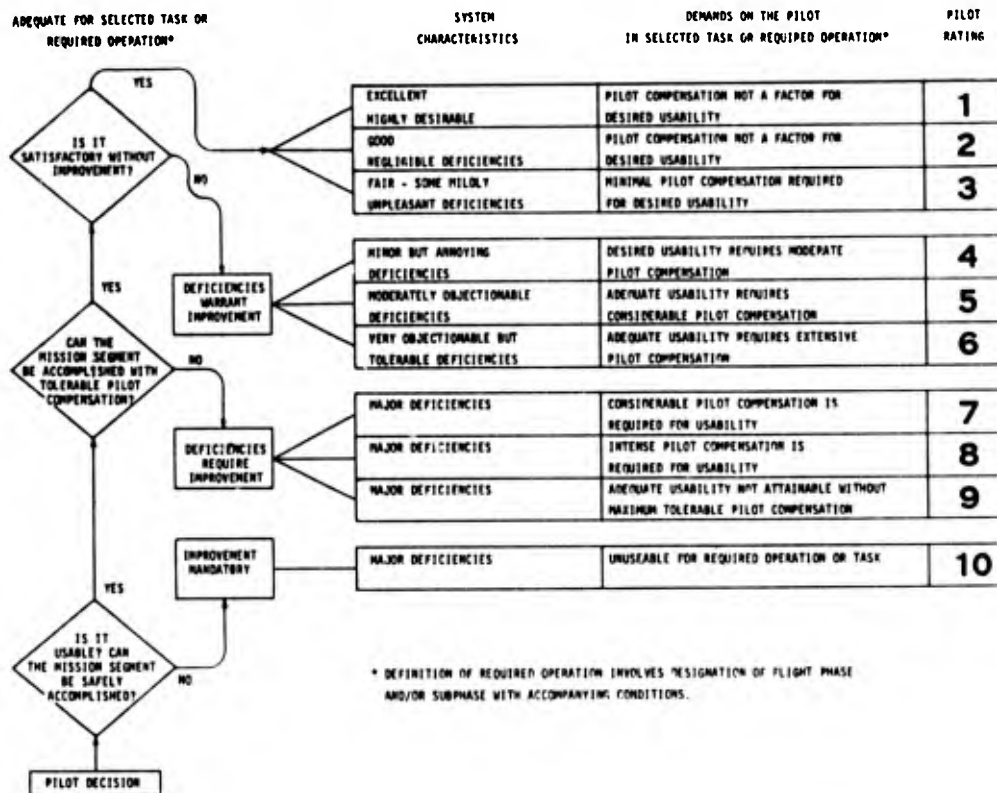


FIGURE 9 HEAD UP DISPLAY RATING SCALE.

Prior to commencing flight tests with the WFOV HUD, pilots were asked to rate the production HUD such that a performance baseline could be established. This baseline performance rating provided a direct production HUD to WFOV HUD comparison on which the functional equivalency evaluation was based.

#### TEST RESULTS

##### F-16:

##### Day Operations.

The greater Instantaneous and Total Fields-of-View (IFOV and TFOV) provided by the WFOV HUD, were favored by all the pilots who flew the aircraft. However, because of the deficiencies listed below, the advantages of the WFOV HUD were negated.

There were many pilot reports of a reduction in depth perception and other optical deficiencies. The magnitude and effect of these difficulties varied with the different canopy and HUD optical systems tested. The depth perception effects ranged from the HUD being reported unsafe for low level or weapons delivery events, to pilots touching down earlier than expected during landings.

Several pilots also reported was an apparent dual imaging anomaly. While focusing on the target, two sets of symbology were often viewed. Likewise, when focusing on the symbology, two targets were seen. This deficiency was particularly noted during simulated air-to-air combat and air-to-ground weapons deliveries.

The reduction of depth perception, early touchdowns and dual imaging were initially thought to be related to some HUD optical characteristic. An in-depth analysis of the F-16 canopy (both Block 15 and 25), the HUD, and the canopy/HUD combination was conducted in an attempt to pinpoint the primary cause and gain some insight into the HUD and canopy interactions. The participants in the analysis included Aeronautical Systems Division (ASD), Marconi Avionics, General Dynamics and AFFTC personnel. The findings indicated that the effects were caused by a canopy induced decollimation of the outside world which was noticeable primarily because of the large Binocular Instantaneous Field-of-View (BIFOV) of the WFOV HUD (20.0 degrees horizontal by 18 degrees vertical). Figure 10 graphically illustrates this effect. This situation existed with all of the limited number of F-16 canopies and WFOV HUDs tested.

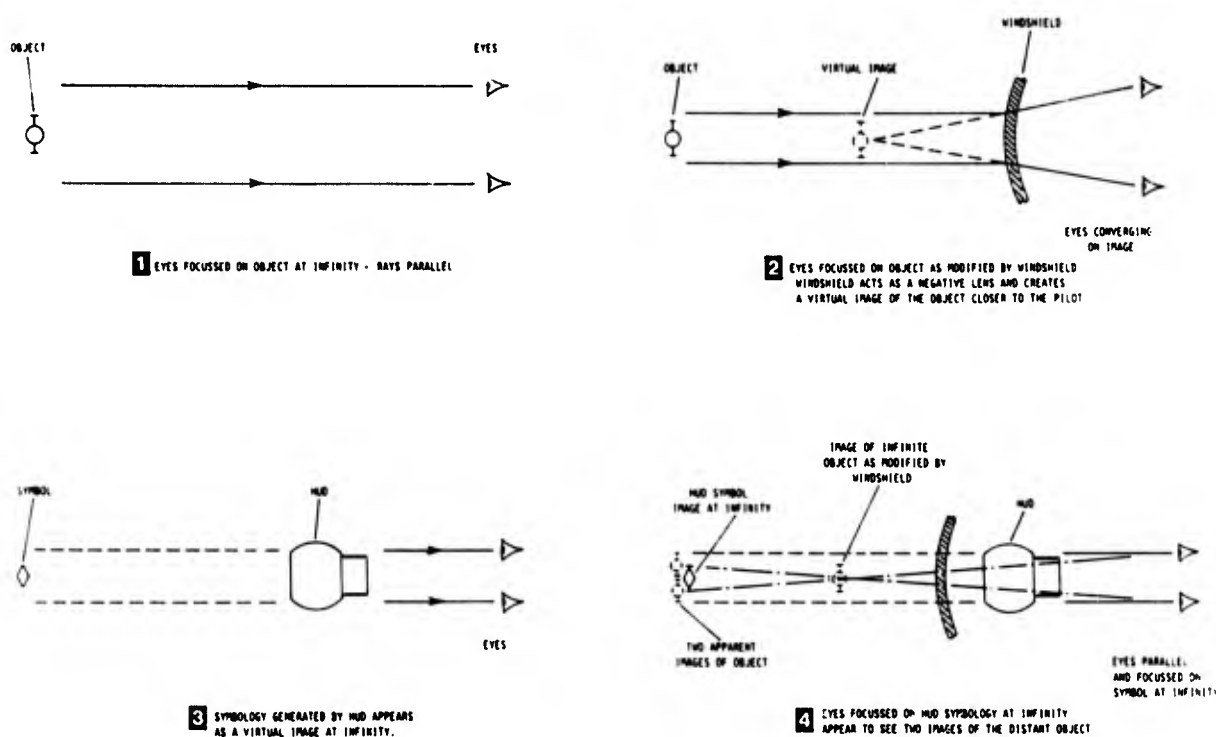


FIGURE 10 F-16 WIDE FIELD-OF-VIEW HEAD UP DISPLAY DECOLLIMATION EFFECT.

The narrow BIFOV of the production HUD (5.0 degrees horizontal, by 9.0 degrees vertical) was too small to make the decollimation effect readily apparent. It is expected that dual imaging and a reduction in depth perception will exist whenever a HUD with a large BIFOV is coupled with this type of canopy. The proposed Marconi Avionics fix involved determining the range of canopy decollimation over a large number of canopies and decollimating the HUD optics to a comparable mean value. This approach was never incorporated for the flight test evaluation.

The color changes and transmissivity of the HUD were rated marginal by the majority of the pilots. There were two or three colors present in the HUD at all times. In general, the bottom of the combiner had a pink shade with the top of the eyebrow area being a darker rose color. Light reflections, depending on their incident angle, often caused a green halo and green glare across the entire lower half of the combiner which was extremely distracting to the pilot.

Several pilots reported reduced transmissivity which caused an apparent reduction of visual acquisition ranges of airborne targets. Also noted when flying low level under overcast weather conditions, was an apparent darkening of the visual scene which made it difficult to distinguish detailed terrain features. The initial pilot response was to continually look around the HUD to monitor their flight path, terrain clearance, and to visually acquire targets. The dark appearance of the combining glass relative to background illumination gave the impression of having considerably reduced transmissivity. This anomaly was further exaggerated by the pink tint of the HUD which is a by-product of the diffraction grating technique on which the WFOV HUD optics are based.

Removing the gelatin from the upper one-third of the rear hologram to increase the overall transmissivity resulted in a cut-off line and added two more additional color changes to the HUD and was a further noticeable distraction to the pilots. In lieu of cutting the holographic gelatin, Marconi proposed leaving the gelatin but gradually fading the hologram toward the top of the combiner. This approach seemed workable but was never incorporated for flight testing.

The pink and rose-colored tints, the green halo, internal reflections, and the non-uniformity of the color changes tended to reduce the pilot's perception of the true world. With the Block 15 production HUD, pilots often tended to acquire targets outside of the HUD and then transfer to the HUD for weapons aiming and flight information. The WFOV HUD allowed tracking targets longer in the FOV but the apparent reduction in real-world transmissivity along with color mismatching and internal reflections caused a loss of visual acquisition range. Having to look through three combiner elements in the upper third of the HUD only exaggerated this deficiency and reduced the overall pilot acceptance of this HUD configuration.

The eye motion box was considered too restrictive by the pilots for several reasons and was rated unsatisfactory. The eye position stipulated in the HUD specification and for which the HUD optics were designed was not located at the eye position from which most pilots flew the aircraft. Figure 11 shows the allowable eye motion box and the design and working eye positions. The eye motion box defines the allowable head

movement permissible for viewing the symbology.

An eye position study was conducted on 33 pilots by ASD, Marconi Avionics, General Dynamics and AFMTC personnel. The data obtained during this study are presented in Figure 12. Eye positions were plotted while pilots seated themselves at their normal, relaxed aft, and alert forward positions. As shown by Figure 12, the average for all three positions was noticeably forward of the specification values.

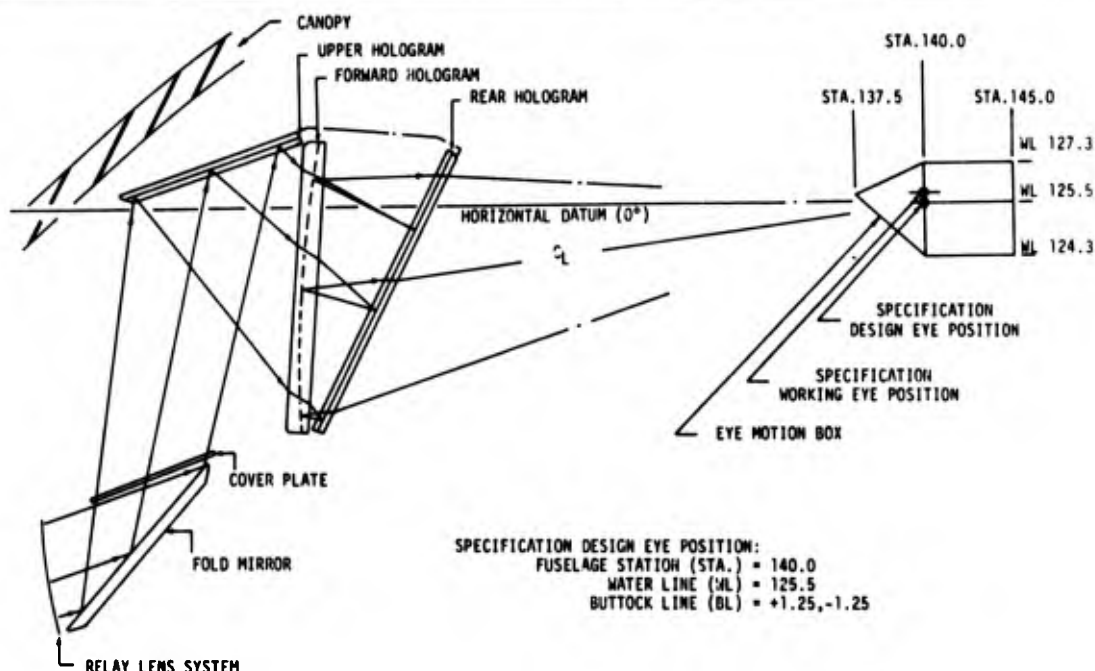


FIGURE 11 F-16 SPECIFICATION DESIGN EYE POSITION AND HEAD MOTION BOX.

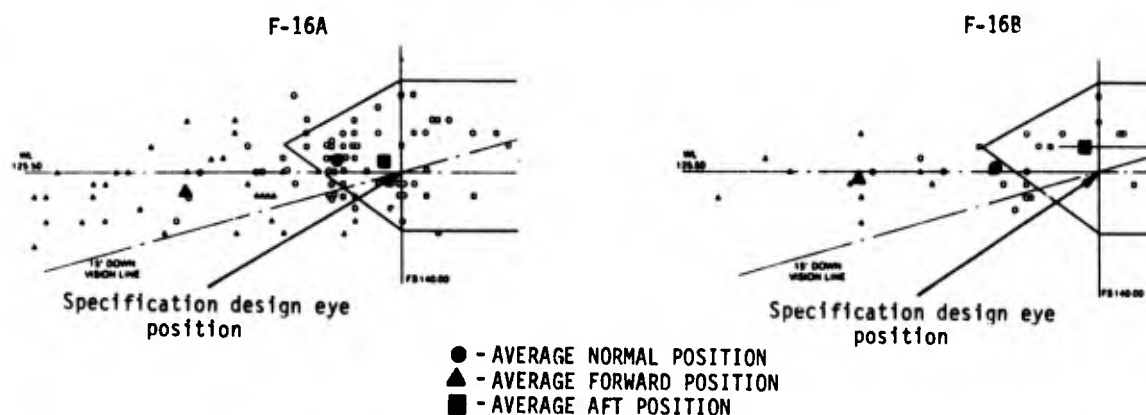


FIGURE 12 RESULTS OF F-16A (LEFT) AND F-16B (RIGHT) PILOT EYE POSITION STUDY.

An additional consequence of being outside and forward of the eye motion box resulted in the combiner halo, green glow and some of the internal HUD reflections previously discussed. Ground test verified that with proper eye positioning some, but not all, of those deficiencies could be alleviated.

The results of the eye motion box study was incorporated into the F-16 HUD Prime Item Development (PID) specification. Verification of the HUD design eye position proved to be of paramount importance during this HUD test and can have a significant effect on diffraction optic HUD flight test evaluations.

Symbology brightness was rated marginal. The symbology was controlled by an intensity control wheel as a function of two manual or one automatic brightness modes (DAY, NIGHT, and AUTO). When using the AUTO mode, the display brightness did not accurately compensate for changing ambient light or background conditions. The AUTO position also caused some fluctuations in symbology intensity under certain ambient light conditions. When operating the DAY mode, the range of brightness control was satisfactory; however, one setting was not adequate to maintain the symbology at a comfortable level. The intensity had to be continuously adjusted because of sun angle, clouds or terrain background brightness changes.

Reflections in the HUD originated from two sources. The most objectionable came from the pilot's flight cards, checklist and personnel equipment. Reflections of the cockpit area in front of the HUD combiner were also evident at various lighting conditions. These reflections included the CTVS sensor, canopy placards, and the depression area in front of the CTVS sensor head. Different colored flight cards were tried, but no color eliminated the reflections completely. Because the reflections caused significant pilot distractions during mission critical tasks, the HUD's performance was rated unsatisfactory.

Sunspots were observed on nearly all daytime flights when the sun was not totally obscured by clouds. The most distracting sunspots were collimated which caused extremely bright, circular images approximately 25 milradians (MR) in diameter. These types of sunspots washed out HUD symbology and made it difficult to see through the HUD. A second type of sunspot was caused by reflections of the sun from canopy, pilots' helmet visor, or other reflective surfaces into the HUD. These types were not nearly as intense as the collimated sunspots and were normally 10 to 15 MR in diameter. There were up to five such sunspots on the HUD at one time. The number and intensity of sunspots caused significant pilot distractions and the HUD was rated unsatisfactory for that reason.

Visibility, had the optical deficiencies not been present, was rated excellent. The HUD allowed a better view over the nose of the aircraft and the increased width was a significant improvement over the "porthole" effect of the production HUD.

The sides of the HUD and the upper combiner support arms (see Figure 5) caused some scene blockage which required significant pilot head movements during target acquisition and attack. As shown in Figure 5, the Angle of Attack (AOA) indexer and nosewheel steering/air refueling status lights caused some scene blockage. Pilots consistently found themselves moving their head around in an attempt to compensate for the bulky structure. This detracted from the overall HUD performance. The bulk of the combiner frame, the support arms, and the presence of the indexer lights contributed to the pilots' rating the HUD marginal with respect to scene blockage.

The controls and switches on the control panel were also rated marginal by most pilots. Control sensitivity, feel, sense, linearity and response degraded the ability of the pilots to operate the HUD. The thumbwheels were considered too flimsy with insufficient friction for optimum actuation and the symbology intensity control required approximately two-thirds total travel for any symbology to appear. During daytime operations, the symbology intensity was controllable by only the last one-third of the control movement.

The video raster control was located directly under the symbology control, and if the raster control was not on the OFF position, symbology could not be displayed. It was impossible to tell if the raster control was off unless it was physically checked. The stripe on the thumbwheel was misplaced and did not line up with the OFF label when it was off.

There were numerous deficiencies noted in the symbology. Improperly placed symbology, jitter, blanking, poorly defined or missing symbols, etc., were all deficiencies contributing to an unsatisfactory rating.

Due to high frequency noise, the symbology was often fuzzy and hard to distinguish. The Flight Path Marker (FPM) and pitch ladders jittered excessively, especially during ground operations. The symbology in the lower right portion of the HUD was also observed to jitter excessively and symbology often blanked intermittently in the top 10 percent of the FOV.

Those were but a few of the numerous software deficiencies documented during the test program. The software anomalies accounted for approximately 60 percent of the deficiencies identified and resulted in an unsatisfactory rating for symbology generation.

To verify symbology placement, a series of ground tests were scheduled. The composition of these tests was based on tests that were found valuable during similar efforts on other F-16, F-15, and A-10 programs. In particular, the F-16 canopy/WFOV HUD combination required that special attention be given to the canopy correction algorithms used to correct symbology placement relative to the outside world as seen by the pilot and the CTVS camera system.

Target displacement tests had previously been conducted at the General Dynamics, Ft Worth facility. Using a still photographic digitizing procedure, the General Dynamics tests provided the canopy eye position and CTVS correction coefficients which were used during the test program. The AFFTC ground tests, used a video digitizing process, and were intended to verify the coefficients and also to verify the algorithm.

The diffraction optical techniques used with the WFOV configuration precluded the use of a camera for direct viewing of the outside world. The CTVS sensor head was therefore required to be mounted forward of the HUD combiner and the symbology was then electronically interlaced with the forward field-of-view. Prior to interlacing the symbology, canopy corrections were applied to the symbology to compensate for outside world distortions.

The major areas of concern (lack of depth perception, reflections, scene blockage, etc.) overrode the ground test requirement and resulted in the design eye algorithm not being evaluated. The ground tests were originally scheduled prior to the start of flight testing and included a complete HUD and canopy optical evaluation. Lack of suitable test equipment and clearly defined test procedures at that time required postponing these tests to a later date where they were only partially accomplished. The availability of these data early in the test program would have saved considerable flight test time and would have provided substantiating data for some of the anomalies noted later in the program.

#### Night Operations.

The night evaluation did not expose any significant findings not already identified. FOV, depth perception, image distortion, transmissivity and eye motion box comments were very similar.

One color change deficiency not identified during the day operations was the pilot's inability to accurately judge glide slope information from the Visual Approach Slope Indicator (VASI) lights. When on the glide slope, the normal red-over-white VASI indicators appeared red-over-pink because of the HUD's pink tint. Loss of this important cue at night significantly increased the pilot's reliance on instruments and vision outside of the HUD's FOV.

The AUTO brightness mode was also unusable at night, being too bright and causing fluctuations in symbology intensity. The NIGHT mode was also deemed inadequate since the lowest intensity setting was too bright for night operations.

Reflections were less noticeable at night than during day operations. Some reflections of the cockpit console lights were noted on the left and right edges of the HUD but were not considered objectionable. During night air refuelings, pilots had no difficulty with reflections when in the contact position. However, when moving into or away from the contact position, reflections in the HUD from the KC-135 tanker lights were considered a distraction. Also when flying with a moon from one-half to full conditions, reflections or "moon spots" appeared just as sunspots had during day operations and the HUD was rated marginal.

The symbology also produced one deficiency not seen in the day. When symbols were at or near the edges of the FOV, they would often flash or sparkle at a greatly increased brightness level and were extremely distracting to the pilot. This flashing symbology made the HUD unsatisfactory at night.

A summary of the evaluation is presented in Table 3. The significant deficiencies included: a lack of depth perception/distortion, head motion box, reflections, sunspots, and symbology. A summary of the user evaluation is presented in Table 4.

TABLE 3 SUMMARY OF F-16 WFOV HUD FUNCTIONAL EQUIVALENCY EVALUATION

<u>CHARACTERISTICS</u>	<u>RATING</u>	
	<u>DAY</u>	<u>NIGHT</u>
OPTICAL:		
FIELD-OF-VIEW	EXCELLENT	EXCELLENT
DEPTH PERCEPTION/DISTORTION	UNSATISFACTORY	UNSATISFACTORY
COLOR CHANGES/TRANSMISSIVITY	MARGINAL	MARGINAL
HEAD MOTION BOX	UNSATISFACTORY	UNSATISFACTORY
SYMBOLGY BRIGHTNESS	MARGINAL	MARGINAL
REFLECTIONS	UNSATISFACTORY	MARGINAL
SUNSPOTS	UNSATISFACTORY	N/A
MECHANICAL:		
VISIBILITY	EXCELLENT	EXCELLENT
SCENE BLOCKAGE	MARGINAL	MARGINAL
CONTROLS/SWITCHES	MARGINAL	MARGINAL
SYMBOLGY:		
SYMBOL GENERATION	UNSATISFACTORY	UNSATISFACTORY
MECHANIZATION	SATISFACTORY	SATISFACTORY

TABLE 4 SUMMARY OF F-16 USER EVALUATION

MISSION FUNCTION	PILOT #												CONSENSUS		
	#1			#2			#3			#4			PRODUCTION	WFOV	
	PRODUCTION	WFOV		PRODUCTION	WFOV		PRODUCTION	WFOV		PRODUCTION	WFOV				
		DAY	NIGHT		DAY	NIGHT		DAY	NIGHT		DAY	NIGHT			
GROUND OPERATIONS	1	1	1	3	4	3	2	4	4	2	3	2	2	3	3
TAKE-OFF	2	3	1	4	4	4	2	5	4	2	3	1	2	4	3
VFR NAVIGATION	2	3	1	4	4	-	2	4	4	2	3	2	2	3	2
WEAPONS DELIVERY (BOX PATTERN)	3	6	2	3	5	5	2	10	10	3	4	4	3	6	5
LOW LEVEL NAVIGATION	2	4	-	4	5	5	4	5	10	2	6	2	3	5	5
TACTICAL WEAPONS DELIVERY	3	6	-	3	5	-	5	10	-	3	6	-	3	6	-
A/A WEAPONS	4	8	-	4	5	-	6	10	-	2	8	-	4	8	-
A/A MANEUVERS	3	3	-	3	6	-	4	8	-	2	8	-	3	7	-
INSTRUMENT APPROACHES	5	3	1	4	4	4	5	2	5	2	2	2	4	3	3
VFR PATTERNS	2	2	1	3	4	4	2	2	5	2	2	2	2	2	3
LANDING	4	2	1	3	4	4	2	2	2	2	2	2	3	2	2

NOTE: NUMERIC VALUES BASED ON HUD RATING SCALE

When compared to the production F-16 HUD within the criteria established, the WFOV HUD was determined not to be functionally equivalent. It was recommended to the program office that the WFOV HUD not be considered for fleetwide incorporation into the F-16 C/D aircraft in its present hardware and software configuration.

#### Video Raster.

Three night evaluation flights utilizing the WFOV HUD were flown. All of the flights were limited to FLIR video only with no symbology overlaid. Additionally, the FLIR was locked in the Automatic Contrast Enhancement (ACE) mode for a majority of the airborne evaluations allowing only a cursory look at the manual gain and level control functions.

Overall, the IFOV and TFOV provided by the HUD were impressive, and the HUD provided excellent FLIR video. Pilots found that with only slight head motions left and right, a complete view of the entire FLIR video picture could be obtained. None of the comments pertinent to previously described head motion box anomalies were observed during these flights. However, there was no symbology present on the video scene which the pilots could compare to daytime observations.

There were three distinct edges to the FLIR video (top, bottom and right side) but the left side had a green band along its entire length which 'bled' into the video approximately 3 to 5 degrees. There were also two wavy lines through the video which were present only during one of the flights. These two features were somewhat distracting to the pilots and detracted from the overall uniformity of the video display.

The HUD provided good apparent depth perception, especially over undulating terrain. Over relatively flat terrain with no distinctive vertical features, a definite degradation in depth perception was evident. Overall, a very realistic image of the real world was attainable.

There were no canopy/cockpit reflections from the FLIR video on the HUD, and no halo effect or reflections were observed by the pilot or by the rear cockpit observer looking forward.

The range of video brightness/contrast control appeared adequate to achieve an optimum FLIR picture. During low altitude acquisition runs on IR targets, detection ranges steadily increased with system familiarity and operator technique. Once the FLIR gain and level were set in manual, or when using the ACE mode, adjustments were required only to the video brightness to achieve a satisfactory FLIR video.

Real-world registration was rated satisfactory; however, two points are worthy of mention. Point light sources in a high ambient light environment appeared to show through the FLIR imagery and appeared to the pilot as add-ons, i.e., the lights were superimposed on the FLIR video. One pilot found viewing these lights through the HUD and canopy gave coincidental results while a second pilot felt there was some parallax error between real-world lights and FLIR imagery. Secondly, FLIR video over highly lighted areas was virtually invisible. The outside ground lights showed in the HUD as they were in the real world through the canopy but only small pieces of FLIR imagery were present. Overall, the outside light made for a significantly washed out FLIR presentation. This phenomena did not restrict pilot usability of the HUD, and on transitioning to an unlighted background, the pilot was again presented with a satisfactory FLIR picture.

All three evaluation pilots found the controls and switch operations to be satisfactory. In the ACE mode, the pilot was able to control brightness and contrast while maintaining good gray scale definition. In the manual mode, small adjustments of video brightness were easily accomplished.

System limitations did not permit an evaluation of FLIR video with HUD symbology overlaid. This is an area which requires extensive evaluation to ascertain the impact (if any) of HUD symbology on FLIR video quality and the effect on pilot interpretation. The FLIR video raster flights demonstrated the general raster capability of the HUD; however, further testing of the WFOV HUD with video raster and stroke written symbology was recommended to quantify and define the HUD's total system capabilities.

#### A-10:

##### Day Operations.

The greater field-of-view provided by the WFOV HUD was favored by all of the A-10 pilots on the test team. The wide field-of-view significantly improved forward visibility and reduced or completely eliminated any tendency of the pilots to look around the HUD. This feature was deemed an appreciable advantage over the present KAISER HUD.

Unlike the F-16, there were no depth perception or optical distortion difficulties reported. Depth perception was "normal" and comparable to the present HUD, with no obvious differences noted. There were no apparent distortions of the outside world when viewed through the WFOV HUD and the flat plate windshield. The visual scene and the symbology were reported as being clear, concise and in true perspective.

The head motion box, although rated satisfactory, was considered somewhat restrictive. As with the F-16, the eye position stipulated in the HUD specification was not located at the eye position from which most pilots flew the aircraft. Figure 13 shows the design and pilots eye positions and the head motion box. Most of the pilots flew the aircraft from a position which placed their eyes two to three inches forward of the design eye point. This situation was not as critical as the F-16 eye motion box due to a substantial portion of the A-10 head motion box being forward of the design eye position. Proper seat positioning and experience partially compensated for this limitation.

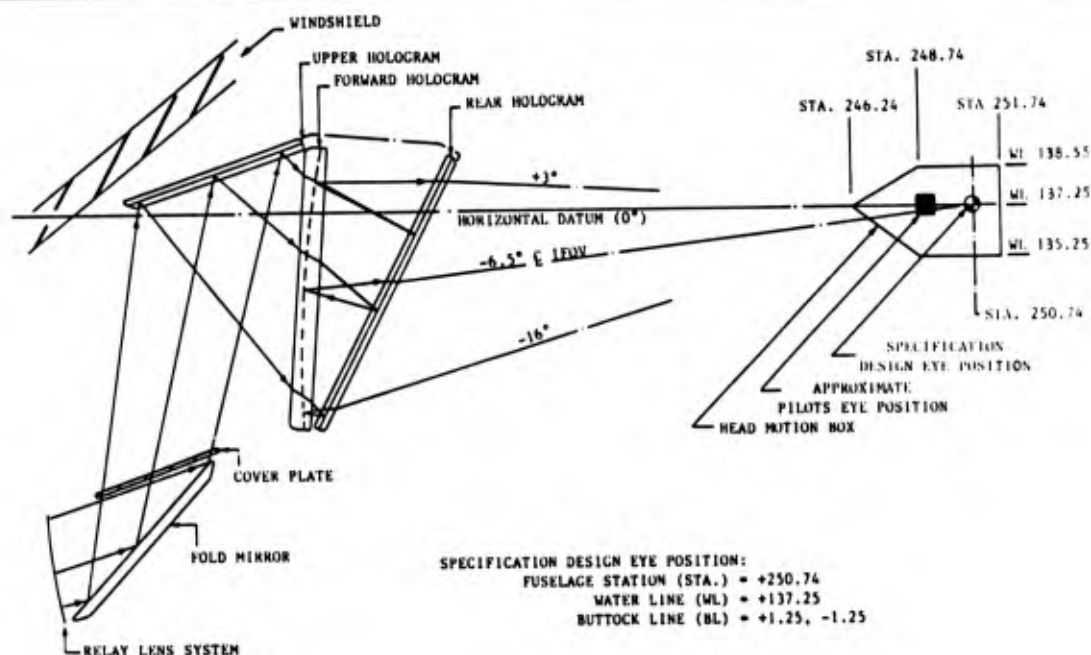


FIGURE 13 A-10 SPECIFICATION DESIGN EYE POSITION AND HEAD MOTION BOX.

The transmissivity of the HUD was rated satisfactory although there was a discernable difference in the amount of light transmitted through the WFOV HUD, the difference was not objectionable and the pilots felt that it did not affect their ability to acquire and maintain visual situation awareness.

The slight pink tint of the HUD in and of itself was not considered objectionable. Light reflections, depending on their incident angle, sometimes also caused a green tint along with the pink tint. These colorations were not noticed by the pilots during high gain tasks and pilots reported they could see through the combiner easily and not be distracted.

Symbology brightness was rated satisfactory. The symbology was controlled by a ganged knob which operated two manual and one automatic brightness modes (DAY, NIGHT, and AUTO). When utilizing the AUTO mode the display brightness did not accurately compensate for different aerial and terrain background. When operating in the DAY mode the range of brightness control was considered satisfactory. The overall rating for symbology brightness was based on the results obtained in the DAY mode.

Pilot reports on internal reflections in the HUD ranged from "no reflections seen" to "everything in the cockpit reflected on the HUD" with the majority of the pilots reporting reflections of flight cards and maps laying on their legs. In an effort to alleviate this problem, pink flight cards were used and pilots generally agreed that the pink cards were reflected less than the white but were still visible and annoying. The reflections were most evident when the cockpit was subjected to intense front lighting. When compared to the production HUD, the WFOV HUD's performance relative to reflections was rated marginal.

Sun reflections were also observed on a number of daytime flights. Again comments were wide ranging from "no sunspots noted" to "reflections of the sun in the HUD were persistent at all times". The consensus was that although there were some sunspots visible, they only appeared with the sun at high angles relative to the aircraft. The approximate sunspot "cone of occurrence" was observed when the sun was within 10 degrees of HUD vertical. This cone was slightly larger than the one existing in the present KAISER HUD. The sunspot effect degraded the WFOV HUD and therefore the pilots rated the HUD marginal in this area.

Visibility through the HUD and scene blockage were considered excellent and satisfactory respectively. Being considerably wider than the present HUD, the WFOV HUD allowed a better view over the nose of the aircraft and intruded less into the prime vision area. The combiner support was in line with the front windshield frame permitting an unbroken view through the front windshield. Pilots could occasionally produce some scene blockage but this required extreme pilot head movements.

Controls and switches on the HUD control panel were determined to be marginal from several aspects. Control sensitivity, feel, switch shape, arrangement, and spacing, were objectionable and resulted in a degraded ability to operate the HUD. The addition of steps on the rotary switches would have provided the necessary control feedback.

Various deficiencies in the symbology were noted. The display of non-specification symbols, jitter, poorly defined symbols, and some symbol blinking were often identified as problems or anomalies and resulted in an overall rating of unsatisfactory for symbology generation. The pilots were able to adapt to these deficiencies; however, time to read and understand the displays was increased and mission performance was degraded.

During the evaluation, pilots witnessed several cases of a momentary loss of symbology. This blanking was noted particularly during gun firing and multiple "G" pull-ups. The blanking did not persist for any significant length of time, was never predictable, and was not diagnosed. Symbology blinking was also observed on the Heading and altitude scale numerics. As heading or altitude scale numerics would enter or leave the scale, the numbers would often momentarily blink.

Deficiencies were also identified which resulted in the symbology mechanization being rated marginal. A particular problem in this area was the steering tadpole. On several occasions the steering symbol would seem to disappear from the HUD FOV. Actually, the symbol was still on the display; having only moved to the outer edge of the HUD where it was not easily seen. There were two reasons for this: 1) the symbol was horizon stabilized and was routinely limited on the display FOV during high positive or negative pitch angles, and 2) the range of movement for the symbol was too large and pilots would lose it at the extremes of travel. By moving the head around, the symbol could be located. This was considered unacceptable and increased the workload significantly. This deficiency could have been easily remedied by limiting this symbol's range of travel.

Display clutter, particularly in the gunnery and bombing modes, degraded the overall usability of the WFOV HUD. Symbology displayed when approaching a target was often cluttered by having the pipper, pitch line, flight path marker and symbols obscuring each other. Also, multiple images of the 0 degree pitch reference line, which appeared as three lines with the top line breaking away from the other two were reported. In one instance, the aiming pipper also appeared to be composed of multiple images. If the symbol brightness were turned down to an uncomfortable low level the

ghost images would disappear. These two observations, however, were not noted by the majority of pilots.

#### Nighttime Operations.

The night evaluation of the HUD did not expose any significant findings not already identified. Field-of-view, depth perception/distortion, color changes/transmissivity and head motion box comments remained unchanged.

One deficiency originally identified during the day evaluation produced a completely different characteristic at night. The AUTO brightness mode, which caused no significant symbology brightness change during the day, caused erratic brightness changes during the night flights which made this mode unusable. The NIGHT mode proved to be adequate and the DAY mode was usable at night although it was slightly too bright.

Reflections were significantly less noticeable at night compared to day operations. Reflections of interior cockpit panels, flight cards, etc., were observed but were considered less distracting than those observed during the day. The most conspicuous night reflections experienced were from the emergency (thunderstorm) flood light which greatly increased the interior cockpit illumination. The predominant reflections reported when using these lights include the arms, hands, aircraft console panels, and flight cards. During simulated attacks under aerial flares and ground illuminated targets, some reflections were observed but were not reported as being objectionable. During aerial refueling, the tail mounted flood lights on the KC-135 tanker illuminated the cockpit interior and caused some reflections on the HUD. However, the flood light was not required for in-flight refueling of the A-10 and, once extinguished, cockpit reflections during refueling were eliminated. Night reflections in the HUD were minimal and the HUD was rated satisfactory.

Several night flights were flown with the moon present at one half to near full conditions. Moon reflections were reported when the moon was at a high angle to the HUD, however, these moon reflections were weak and not objectionable.

The HUD control panel had an additional deficiency noted during the night operations. The control panel back-lighting was considered satisfactory but the knobs were not shape coded and did not provide sufficient tactile identification.

Data from the air-to-ground gunnery and bombing missions were analyzed to determine if there were any significant degradations to the accuracy of the A-10 by the addition of the WFOV HUD. The findings indicate that the existing air-to-ground capability of the A-10 was not degraded by the addition of the WFOV HUD. The HUD appeared to portray the correct aiming solutions for gunnery and bombing tasks but the results provided only an intuitive feel for the contribution of the HUD to the A-10's accuracy performance. Quantitative flight test of the WFOV HUD in the air-to-ground gunnery and bombing modes is yet to be conducted.

Table 5 tabulates the results of the functional equivalency evaluation. When compared to the production A-10 HUD within the criteria established, the WFOV HUD was determined to be functionally equivalent.

TABLE 5 SUMMARY OF A-10 WFOV HUD FUNCTIONAL EQUIVALENCY EVALUATION

<u>CHARACTERISTICS</u>	<u>RATING</u>	
	<u>DAY</u>	<u>NIGHT</u>
OPTICAL:		
FIELD-OF-VIEW	EXCELLENT	EXCELLENT
DEPTH PERCEPTION/DISTORTION	SATISFACTORY	SATISFACTORY
COLOR CHANGES/TRANSMISSIVITY	SATISFACTORY	SATISFACTORY
HEAD MOTION BOX	SATISFACTORY	SATISFACTORY
SYMBOLGY BRIGHTNESS	SATISFACTORY	SATISFACTORY
REFLECTIONS	MARGINAL	SATISFACTORY
SUNSPOTS	MARGINAL	N/A
MECHANICAL:		
VISIBILITY	EXCELLENT	EXCELLENT
SCENE BLOCKAGE	SATISFACTORY	SATISFACTORY
CONTROLS/SWITCHES	MARGINAL	MARGINAL
SYMBOLGY:		
SYMBOL GENERATION	UNSATISFACTORY	UNSATISFACTORY
MECHANIZATION	MARGINAL	MARGINAL

Video Raster:

The video raster capability of the WFOV HUD was demonstrated during two night flights with the General Dynamics/Texas Instruments FLIR pod. The flights were flown over a variety of terrain types and included several approaches and landings. Two WFOV HUD systems were flown to evaluate any differences as a result of different hardware/software combinations.

The greater FOV provided by the HUD enhanced the video raster capability. The improved FOV was very helpful in terrain avoidance. There was no hesitancy to maneuver the aircraft and the FOV was sufficient for low level terrain avoidance and terrain following tasks.

Recognition of objects seen on the display was marginal. While flying at 2,000 feet above ground level (AGL) pilots could barely discriminate large vehicles (trucks and buses) at very short slant ranges and smaller vehicles (cars) were reported as being difficult, if not impossible, to resolve. Terrain features (large trees, ridges, etc.), could be identified sufficiently to perform navigation tasks but ground attacks with the tested system were only marginally possible and thus the system was rated inadequate.

The simultaneous stroke written symbology and video raster presentation were very good. The display had some minor raster distortion around the edges but was reported to be insignificant and acceptable. The FLIR picture and real-world registration were estimated to be within two milliradians (mr) of each other. Problems of imaging, that of the real-world bleeding through the video raster picture, were not seen. There was no discernable mismatch when viewing the real-world through the HUD and there were no problems with any double images.

The prototype switches and non-operationally integrated system controls made FLIR adjustments very difficult. Pilots were required to look into the cockpit when making these adjustments. During high workload situations tuning the display, adjusting contrast, brightness and gain levels, was considered too time consuming and increased the likelihood of errors.

Display brightness and symbology were judged to be adequate. An adequate range of brightness was available and the symbology was clear and crisp. Since the symbology background was the FLIR picture, background intensity changes would occasionally require compensating symbol brightness changes. This was an annoyance which could be tolerated.

No reflections of cockpit lighting on the HUD were reported while video raster was being displayed. With the white cockpit lighting "on" and adjusted to a comfortable level, reflections were minimal. Approaches and landings to a brightly lighted runway produced no noticeable reflections.

There was no significant degradation of the FLIR video picture in banks up to 30 degrees. FLIR "blooming" (washout) in turns over 15 degrees had been looked for since the effect had been noted during the F-16 video evaluation. Modifications to the FLIR pod by Texas Instruments after the F-16 flights, apparently prevented a recurrence of this effect during the A-10 flights. This feature significantly improved the maneuvering capability of the aircraft.

Because of the altitudes at which these flights were conducted (2,000 feet AGL), no depth perception difficulties were expected or reported. During the approach and landing phases of the flights, no difficulties were experienced in judging range or altitude using the video raster presentation.

The A-10 FLIR video raster flights further demonstrated the raster capability of the WFOV HUD. Follow-on flight testing of the WFOV HUD with video raster was recommended to the program office to substantiate the HUD's capabilities and further define its characteristics.

## CONCLUSION

The results of these evaluations were briefed to the F-16 and A-10 program offices in January 1983 and March 1983 respectively. The failure of the WFOV HUD to demonstrate functional equivalency with the production F-16 HUD was an area that had significant ramifications to the F-16C/D (MSIP) production schedules. The final decisions relative to this program was two-fold: 1) The MSIP HUD reverted to a wide-angle conventional (WAC) optics HUD and 2) the WFOV HUD optical module was to be redesigned and further testing with this new configuration was to be continued.

The Marconi Avionics Wide Angle Conventional (WAC) HUD (Figure 14) has essentially the same form, fit and function as the WFOV HUD with the primary difference being in the optical module. Where the WFOV HUD used diffraction optical techniques for a wide field-of-view, the WAC HUD uses conventional optics to obtain a significantly larger field-of-view than the present production HUD. The HUD provides the pilot with an IFOV of 13.45 degrees vertical by 20.0 degrees horizontal. The TFOV of 25.0 degrees vertical and horizontal is the largest possible using this optical technique and given the F-16 cockpit configuration and sizing limitations. The first flight test articles are expected to be available in the April-May 1984 time frame.

The findings of the WFOV HUD test program identified various areas that were deficient with that particular HUD configuration. An improperly defined head motion box, a larger than desired optical combiner frame, transmissivity losses, canopy/HUD decollimation effects and internal HUD reflections were major areas that required correction before this HUD could be considered acceptable for incorporation into operational aircraft.

In early 1983, Marconi Avionics initiated work on a redesigned optical module for the WFOV HUD to correct these anomalies and substantially improve the overall acceptance of this HUD (Figure 14). The new configuration is designed to alleviate all of the previously identified anomalies including the canopy decollimation effect which is improved by decollimating the HUD to a mean value determined from a production canopy survey. The use of a single piece cast combiner frame in lieu of the three piece supported combiner is also expected to substantially reduce the scene blockage effect that was deemed unacceptable with the previous configuration.

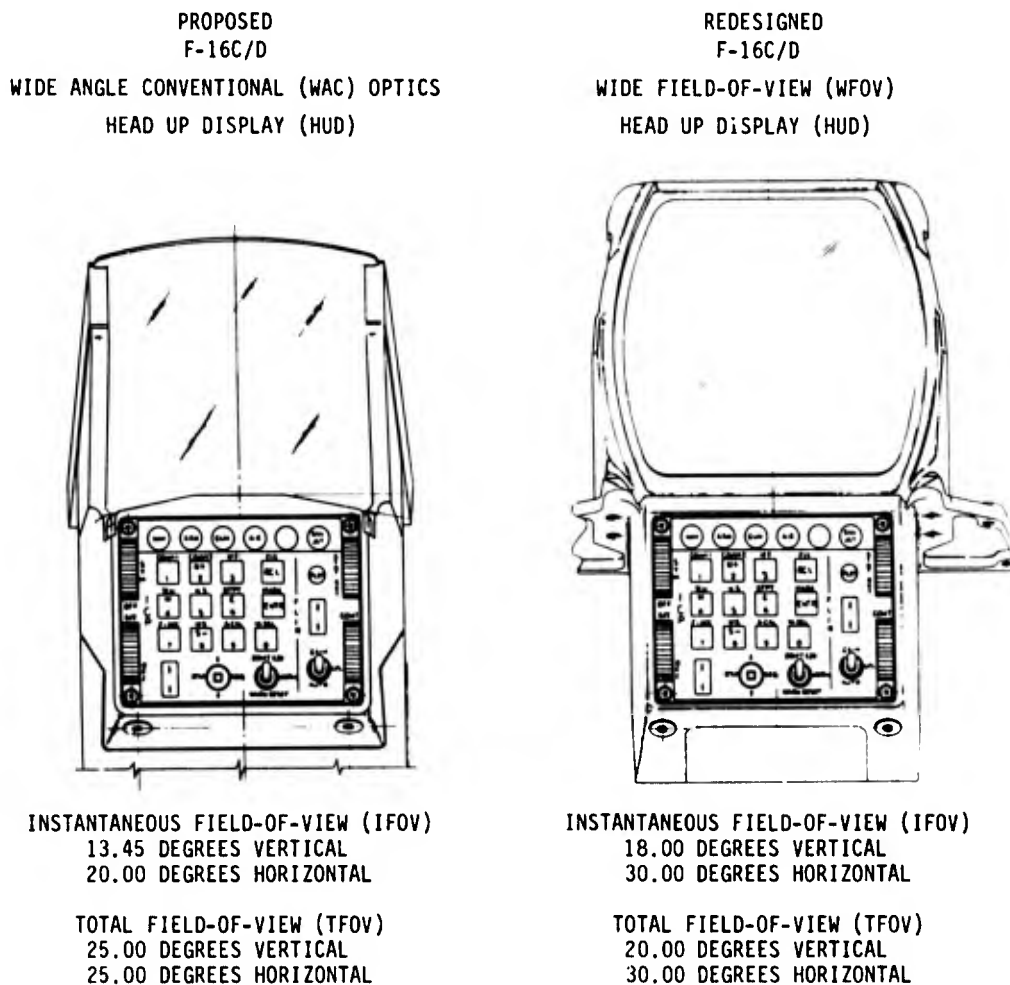


FIGURE 14 PROPOSED F-16C/D WIDE ANGLE CONVENTIONAL (WAC) OPTICS HEAD UP DISPLAY (LEFT) AND REDESIGNED WIDE FIELD-OF-VIEW HEAD UP DISPLAY (RIGHT).

Flight testing of this new configuration began in November 1983 and is on-going at this time. The availability of an MSIP configured F-16 for this test program also allows the reconfigured WFOV HUD to be tested in a fully integrated configuration and should result in a more meaningful test of the WFOV HUD.

The incorporation of the WFOV HUD into production A-10 aircraft is still undetermined. The decision to fit the A-10 with WFOV HUDs was not as critical as the F-16 decision since the HUD can be retrofitted to the aircraft and does not require the total integration as was the case for the F-16.

The development of the WFOV HUD has opened a new frontier in both design technology and test and evaluation techniques. As with any new state-of-the-art system, the initial technical application exhibited some undesirable characteristics that detracted from the overall performance. Much to the credit of both the contractor and Air Force Test and Evaluation community, most of the shortcomings have been identified and are being corrected during the current phase of the WFOV HUD development. The potential demonstrated by the WFOV HUD indicates it will have a major, favorable impact on the next generation of free world combat aircraft.