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AFWAL-TR-84-3036

PICTORIAL FORMAT DISPLAY EVALUATION

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May 1984

Final Report for Period September 1981 to September 1982

Approved for public release; distribution unlimited

FLIGHT DYNAMICS LABORATORY
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	AFWAL-TR-84-3036
2. GOVT ACCESSION NO.	AD-A149252
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	PICTORIAL FORMAT DISPLAY EVALUATION
5. TYPE OF REPORT & PERIOD COVERED	Final Technical Report September 1981 to Sept. 1983
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	T. C. Way, M. E. Hornsby, J. D. Gilmour, R. E. Edwards, and R. E. Hobbs
8. CONTRACT OR GRANT NUMBER(s)	F33615-81-C-3610
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Boeing Military Airplane Company P.O. Box 3707 Seattle, WA 98124
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	P.E. 62201F Project 2403-04-40
11. CONTROLLING OFFICE NAME AND ADDRESS	Air Force Wright Aeronautical Laboratory (AFWAL/FIGR) Wright-Patterson Air Force Base, OH 45413
12. REPORT DATE	May 1984
13. NUMBER OF PAGES	182
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)	Approved for public release; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)	
18. SUPPLEMENTARY NOTES	

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cockpits	Flight Displays	Engine Displays
Displays	Situation Displays,	Airplane System Displays
Pictorial Formats	Threat Warning,	Advisory Displays
Simulation	Stores Management Displays	Human Factors,

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two sequential simulation studies were conducted to evaluate the usability and acceptability of pictorial format displays for fighter aircraft; to determine whether usability and acceptability were affected by display mode -- color or monochrome; and to recommend format changes based on the simulations.

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Government-furnished formats were modified for dynamic display on CRTs in a simulator cockpit to support a representative mission scenario with surface and air threats. Objective performance data, subjective pilot ratings and comments were collected, and the formats were revised on the basis of this data.

In the Basic Pictorial Display Evaluation study, pictorial formats were implemented and evaluated for flight, tactical situation, system status, engine, stores management and emergency status displays. In the Threat Warning Study, the number of threats, and the amount and type of threat information were increased.

A total of thirty USAF and Navy pilots in the two studies flew mission simulations with color and monochrome versions of the displays. In general, the pilots found the pictorial format displays, and the specific implementations used in these studies quite acceptable, and preferred the color over the monochrome versions. A number of improvements were suggested for particular format elements, and were incorporated into revised formats.

PREFACE

This report covers work performed during the period September 1981 to September 1983 for the Air Force Wright Aeronautical Laboratories Flight Dynamics Laboratory (AFWAL/FIGR) under Contract No. F33615-81-C-3610. Dr. John M. Reising served as Project Manager with Capt. Carole Jean Kopala and, later, Major James S. Hawkins as Project Engineers. The authors thank Dr. Reising, Capt. Kopala and Major Hawkins, all of AFWAL/FIGR, as well as Lt. Andy Kraska of AFATL/DLJA, Dr. Julie Hopson of NADC and Richard Bacca of AFWAL/AAWD for their support and guidance during this effort.

Special acknowledgement is made of the operational Air Force and Navy flight crews who served as evaluator pilots during this program. The participation of the 318th Fighter-Interceptor Squadron, McChord AFB, and several organizations at NAS-Whidbey Island materially contributed to program objectives.

The work was performed by the Crew Systems Technology Group of the Boeing Military Airplane Company (BMAC), J. D. Gilmour, Manager. The simulation was conducted in BMAC's Flight Simulation Laboratory, R. A. Becker, Manager.

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1.0 INTRODUCTION

1.1 Background

The increasing complexities of modern weapon systems and missions are placing demands on pilots and aircrews that often exceed their ability to perform in the traditional manner. Advanced avionics and supporting ground systems are capable of collecting, processing and distributing unprecedented amounts of operating data, much of which is essential in order to cope with current and projected mission requirements and threat situations. At the same time, the air vehicle, subsystems, and weapons are themselves becoming more sophisticated in order to support performance goals and extended operating conditions. As a result, pilots are being faced with vastly more information to interpret, more complex instructions to give their onboard systems, and considerably less time to perform these functions. Desired performance gains associated with new and "improved" weapon systems may not be achieved if these requirements exceed the aircrew's ability to perform.

Historically, pilots have been able to function successfully at an "operator" level, exercising direct monitoring and control over many of the individual components and subsystems that comprise the total weapon system. In this capacity, the pilot effectively performed the integration function in real-time. Using essentially raw data, he was required to search, monitor, interpret, transform, integrate, and evaluate multiple readouts in order to arrive at the alternatives, decisions and control actions needed to manage his aircraft and mission. Raw data for this purpose was most typically obtained from dedicated electromechanical instrumentation in alpha-numeric form. In the current complex environment this approach is no longer feasible; it has become clear that the information processing capacity of man can severely limit the overall performance of the system. Modern efforts toward cockpit integration are dramatically enhancing the role of the crew, allowing him to more effectively exercise appropriate aircraft and mission control functions at a "management" level.

Technologies that have resulted in increased complexity have, at the same time, created some of the advances needed to solve the problem. Rapid advances in computing and data processing technology have made it possible to automate many of the raw data functions previously performed manually, thus offering the pilot processed decision-level information tailored to "management" responsibilities. Mass storage and high speed processing also provide the potential for more and better systems and mission information available to the pilot than he could hope to achieve manually, as well as the means to help determine what information is needed and when. Multifunction electro-optical displays and controls have given the crewstation designer and the pilot vastly increased levels of flexibility in the cockpit. The flexible programming offered by these devices allows for the true integration of information and control functions according to the needs of the pilot, and for the rapid reconfiguration of the cockpit based on changing mission and system conditions. The numerous readouts of alpha-numeric raw data once used by the pilot can thus be replaced by integrated, mission-oriented displays formatted for ease of interpretation, heightened situational awareness, and rapid decision-aiding.

Until recently, the advantages of programmable electro-optical displays and controls, including the use of color and graphic or pictorial information, have only been partially exploited. Although the flexibility exists, there has only infrequently been a re-examination of pilot information needs together with the formats and symbology best able to convey this information. Instead, there has been a tendency to mimic the information and formats characteristic of the older electro-mechanical devices. The goal of the present Pictorial Format Displays program has been to extensively explore the concept of replacing the alpha-numeric data typically used in the past with integrated graphic and pictorial display formats. In the phases of the program reported here, representative electronic pictorial displays were developed, based on format concepts provided by the Government, and these displays were then evaluated in a real-time, full-mission piloted simulation.

Sponsorship of this work was provided by the Crew Systems Development Branch of the Air Force Flight Dynamics Laboratory (AFWAL/FIGR), the ECM Advanced Development Branch of the Air Force Avionics Laboratory (AFWAL/AAWD), the Air Force Armament Laboratory (AFATL/DLJA), and the Naval Air Development Center. Both services are conducting a comprehensive interrelated program to develop the advanced integrated crewstation technologies needed for future aircraft. This work represents a contributing part of these efforts.

1.2 The Two Simulation Studies

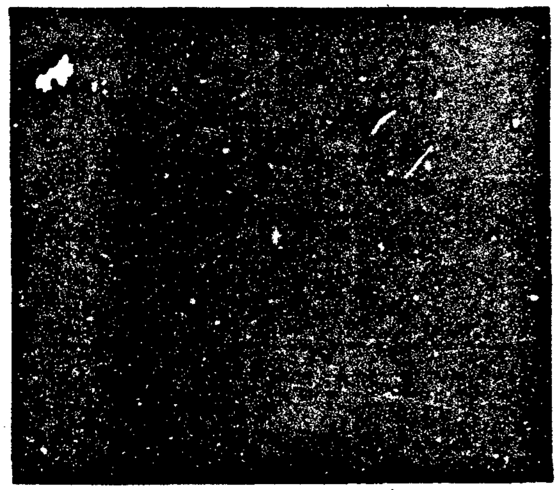
The program reported here consisted of two sequential studies. The basic study was a general evaluation of the concept of pictorial format displays, while the second used the same basic displays but concentrated on threat warning formats of the sort which might be employed in future tactical aircraft. Sections 2 through 5 and Appendices A and B of this report cover the basic study. Sections 6 through 10 and Appendices C and D cover the threat warning study. Section 11 includes the combined conclusions and recommended format changes.

1.3 Test Objectives - Basic Study

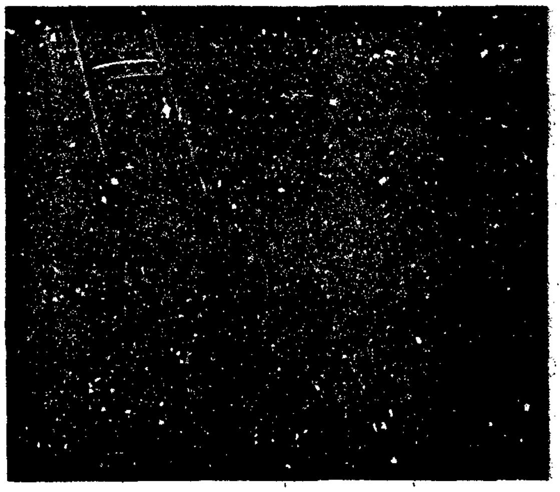
The basic study had three primary objectives. One of these was to evaluate usability and pilot acceptance of a set of service-provided pictorial format concepts for electro-optical displays. The second objective was to determine whether the degree of usability and pilot acceptance of the pictorial formats is a function of three basic display presentation modes: monochromatic, color line, and color fill. The third objective was to revise the formats based on the data collected. All pictorial elements in the monochromatic formats were composed of black and white lines and surfaces. Pictorial representations in the color line formats were depicted by simple outlines, but several different colors were used to define elements within the formats. In the color fill formats, surfaces enclosed by line segments were also colored.

Realistic man-in-the-loop simulation was used to evaluate the display formats. USAF and Navy aircrews evaluated pictorial formats for seven basic types of displays: head-up flight displays, head-down flight displays, navigation/tactical situation displays, system status displays (fuel, electrical, hydraulic), engine displays, stores management displays, and emergency procedures displays. Data collected from these studies were used to refine the original formats, where appropriate, and the results are documented in this report. Figures 1.3-1 and 1.3-2 show examples of the formats. Section 3 discusses each in detail.

HEAD-UP FORMAT

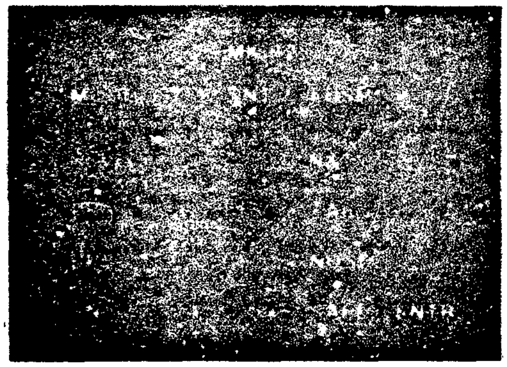


VERTICAL SITUATION FORMAT

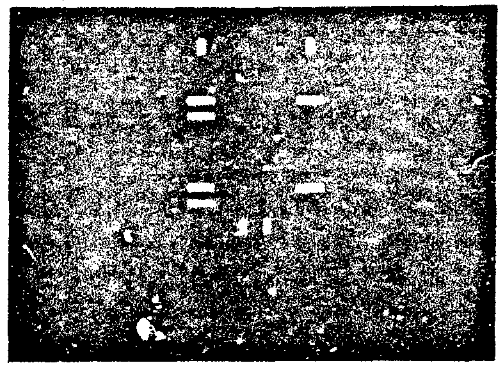


HORIZONTAL SITUATION FORMAT

Figure 1.3-1. Flight and Navigation/Tactical Situation Format Examples

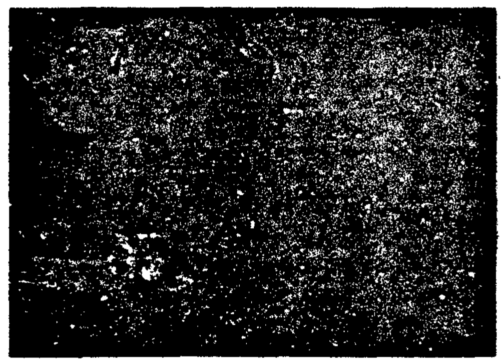


STORES MANAGEMENT

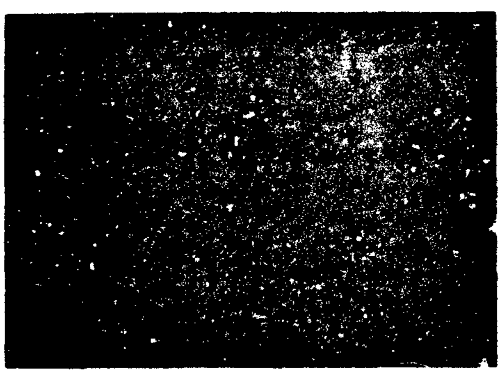


ENGINE STATUS

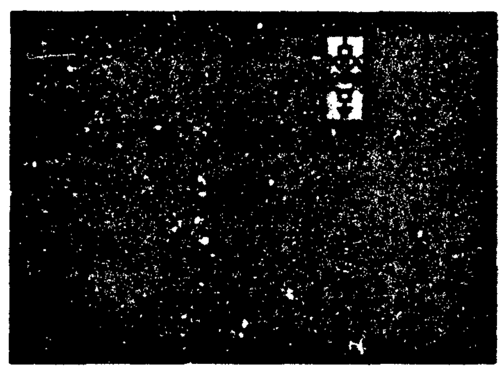
HYDRAULIC ADVISORY



HYDRAULIC STATUS



ELECTRICAL ADVISORY



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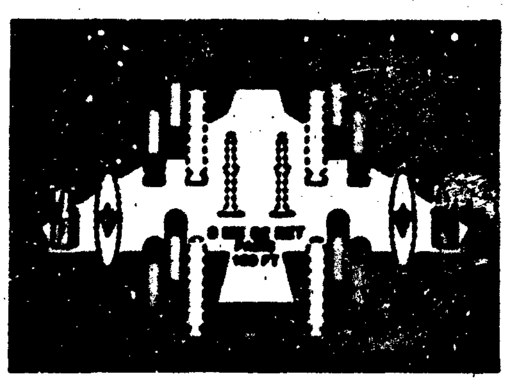
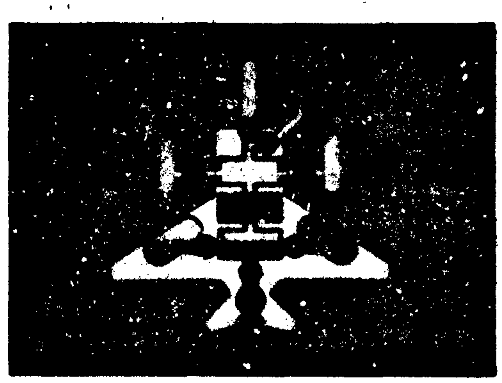


STORES STATUS



FUEL STATUS

Figure 1.3-2. System Advisory and Status Format Examples

2.0 TEST EQUIPMENT AND FACILITIES - BASIC STUDY

The simulation hardware configuration which supported the basic Pictorial Format Display Evaluation study is shown in Figure 2.0-1. For discussion, the equipment can be divided into four groups: simulation host computing and bus communication; digital graphics system; crew station with displays; and supporting elements, including data recording units.

2.1 Simulation Host Computers and Bus Communication

An advanced tactical fighter model and a navigation cell with real world coordinates were used as a baseline for both the manual and autopilot flight modes. Three Varian V-76 computers and one Floating Point Systems AP-120B array processor provided for airplane modeling, navigation cells, simulation operating systems, instruction sets and airplane derivatives for graphics assembly, and on-line data recording. This part of the simulation was recomputed each 42 milliseconds. All available data (bidirectional) were transmitted within two computer frame times of less than 84 milliseconds. Digital data was passed from V-76 computer No. 5 through a MIL-STD-1553B digital data bus composed of one bus control interface unit, two base band fiber optic modem sets and two bus interface adapter units to the crew station I/O and to the graphics generators. This was a 1 Mhz, bidirectional data bus. Programs were written in FORTRAN and assembly languages. Assembly language (about 20 percent of total software) was used for the crewstation I/O, special switch routines, recording devices, and the airplane equations of motion.

2.2 Digital Graphics System

The digital graphics system was supported by a dedicated SEL 32/2750 computer which had a 300 megabyte (MB) memory disc, 800/1600 bpi 1/2 inch magnetic tape unit, high speed line printer, and several line terminals. Two high speed devices served as parallel interfaces between the SEL 32/2750 computer and two graphics generators.

One Megatek 7250 color raster graphics generator provided RGB video outputs for both the HUD and the VSD displays. Both display channels had 512 by 512 pixels

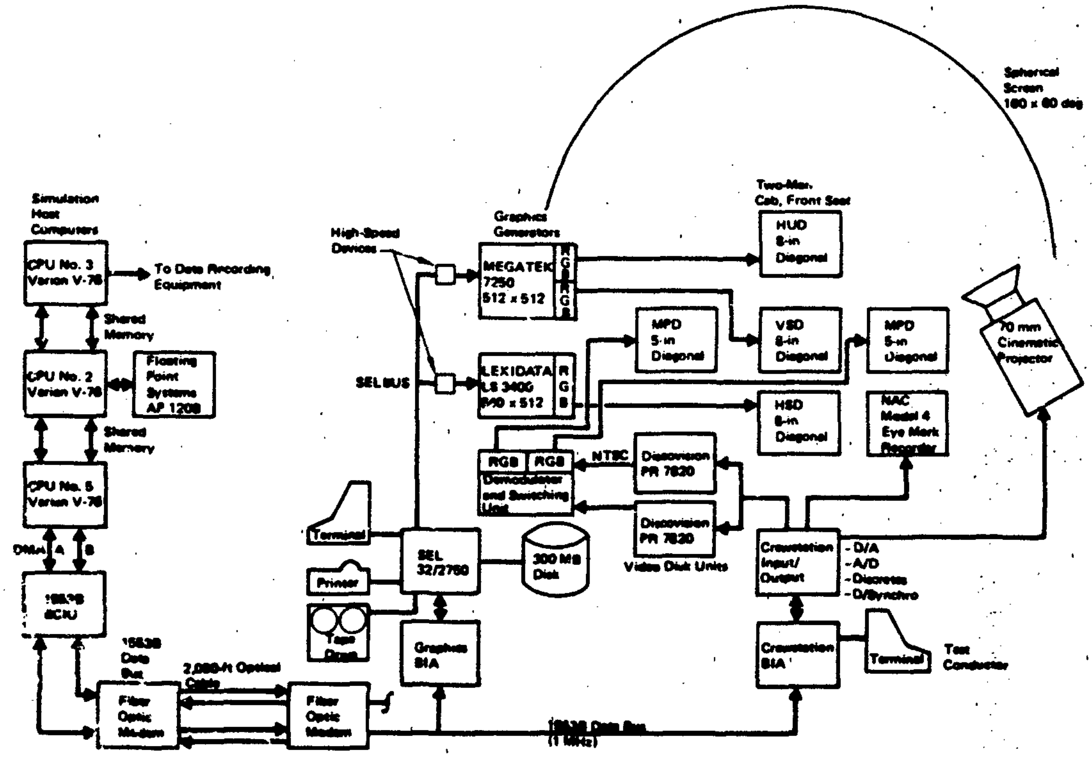


Figure 2.0-1. Simulation Configuration

resolution updated at 30 frames per second interlaced. With the 32 bit parallel interface to the Selbus, (3 MB/sec), speeds were 1.75 microseconds per vector and 160 nanoseconds per pixel average writing time. Internal hardware architecture allowed for color block fill, vectoring, and 2D/3D transformations. The 32 bit wide bus allowed up to two vectors to be processed with a single memory access, thus minimizing processing time and maximizing throughput to the vector generator and raster displays. The hardware transformation modules scaled, rotated, and translated each vector and then clipped the result to the specified viewport. This transformation was performed on each refresh cycle, providing the fastest frame update rate possible. The Megatek 7250 was supported by WAND 7200, a modular software package following guidelines derived from the latest efforts in computer graphics standardization. Call-up routines resided in the SEL 32/2750.

One Lexidata 3400 color raster graphics generator provided RGB video output for the HSD. Line resolution was 640 by 512 pixels updated at 30 frames per second interlaced. It was interfaced through a 16 bit parallel bus to the SEL computer. Burst data transfer rates of up to 1 megaword per second (16 bit words) were typical.

Normal operating speeds were 2 microseconds per pixel update and 3 microseconds per vector with a 13 microsecond vector set-up time. Image control and manipulation features consisted of high speed color look-up tables, zoom control with magnifications from 1 to 16 power in integer increments, pan controllers, multiple overlays, blink and circle controllers. Image manipulation subroutines were stored in the Lexidata 3400 either in PROM or user programmed RAM and called from FORTRAN library programs residing in the SEL 32/2750.

Two Discovision Model PR-7820-3 video disk units provided 525 line, 30 frame per second, NTSC video through two Lenco PCD-363 demodulator color units to the two MPDs. The Lenco decoders received composite color video from the disk players, demodulated color and stripped RGB and sync from the signal. This allowed RGB displays and monitors to be used. The MPD units had limiting resolution of approximately 300 TVL. The PR-7820-3 is an optical laser video disk player with a storage capacity of up to 54,000 frames (1 image list per frame) per side. Direct random access to any frame out of 54,000 is possible within 2.5 seconds. Access speeds of 60-120 milliseconds were realized by selective programming of the image lists onto the disk. The disk units were interfaced through two RS-232 ports of the crew station I/O bus. Digital instructions directed the disk units for freeze frame, search, frame-by-frame, forward, reverse, and frame by number operations.

2.3 Crew Station and Displays

The front seat of the multimission two-man tandem crew station was modified and used in support of this program as represented in Figure 2.3-1 and pictured in Figure 2.3-2. The crew station was interfaced through a MIL-STD-1553B bus interface adapter to the 1553B 1Mhz data bus. Bidirectional digital data was converted in the crew station I/O into discrete in and out, analog to digital, digital to analog, and digital to synchro data. A local Motorola 68000 microprocessor, connected to the I/O 16 bit parallel bus, provided for local intelligence (i.e, instrument scaling, diagnostics, test routines, and demonstration capability).

Five color CRT monitors were installed in the cockpit for this simulation. The HUD, VSD and HSD were eight-inch diagonal, modified NEC narrow shadow mask monitors. They had approximately 480 lines of vertical resolution. The HUD was designed for a 23-degree horizontal by 17-degree vertical field of view and was focused at near

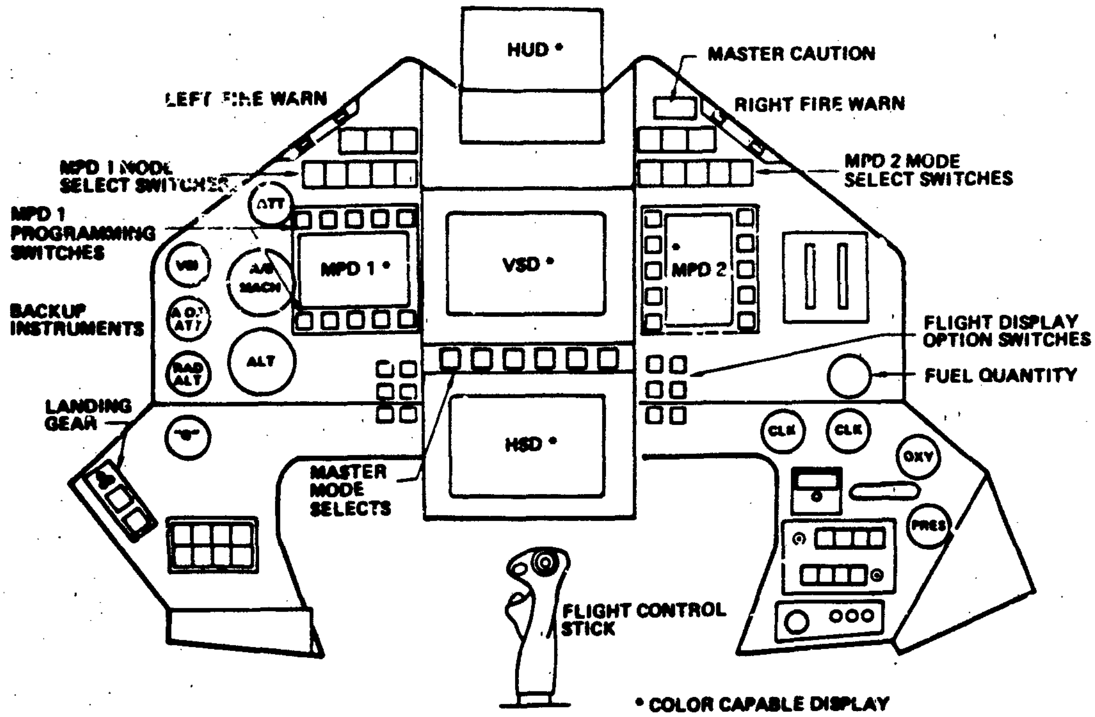


Figure 2.3-1. Front Instrument Panel With Pictorial Displays and Switches

infinity. The VSD monitor was underscanned to provide a square format. The HSD had a horizontally oriented 4 by 3 aspect ratio.

The MPD's were five-inch diagonal modified Hitachi monitors. The active display area was 3-1/4 by 4-1/4 inches with 200 by 280 color triads. The left MPD was oriented and scanned horizontally and the right MPD was oriented and scanned vertically.

In addition to the full color CRT displays, a flight control stick, dual throttles, an altimeter, accelerometer, attitude indicator, vertical speed indicator, angle-of-attack, and Mach-airspeed instruments were installed and available for use. An autopilot comprising heading hold, nav steer, altitude hold, and speed hold were available as well as a selection of controllers, multifunction switches, and subsystem control panels.

2.4 Supporting Elements

The simulator crew station was placed before a 60 degree vertical x 160 degree horizontal spherical section screen. The screen had a radius of 15 feet with a high

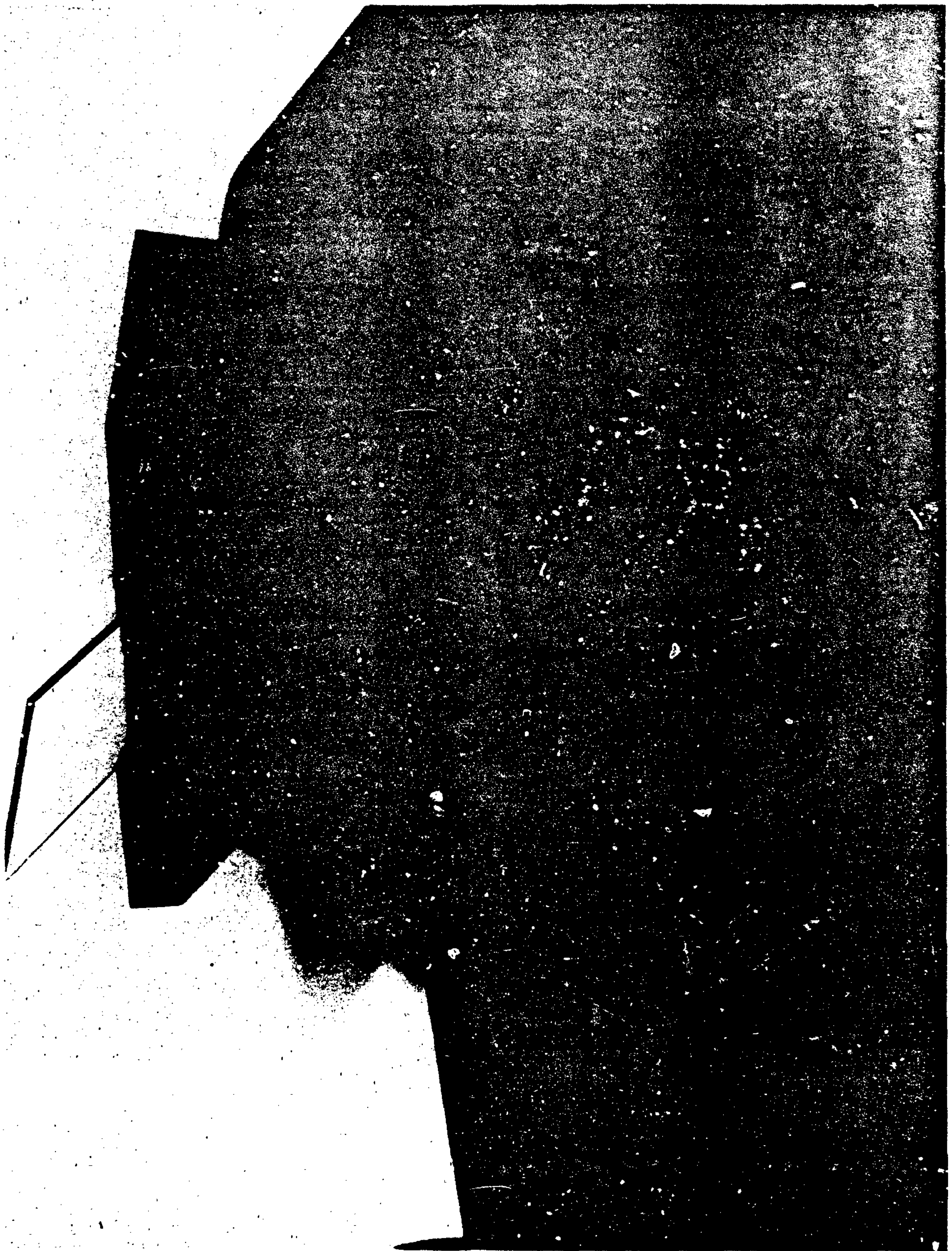


Figure 2.3-2. Cockpit Overall View

gain coating. A 70 millimeter, variable speed motion picture projector operating in coincidence with the air-to-ground simulation scenario presented the out-of-cockpit scene. Symbology on the HUD was superimposed on, and tracked, the out-of-cockpit scene, thus providing a basis for color observation evaluations.

Oculometer data was obtained with an NAC Model 4 eye mark recorder, a device that enables the point of visual regard to be monitored. It was lightweight (14.4 oz), required minimal time to set up and calibrate, and allowed freedom of head movement. A V-shaped reticle was superimposed on a visual image of the cockpit over a range of approximately 60 degrees horizontally by 40 degrees vertically. The reticle and image were conveyed via a fiber optic link to a Dage-650 silicon intensified tube (SIT) 525 line video camera. The combined image was then recorded on a JVC model CR 6600U video tape recorder. For runs when the eye mark recorder was not used, a second Dage camera was employed to record pilot cockpit activity. A Portac Model DS-1 time and window generator were used to key and mix digital clock time and frame number information on each frame of the imagery. This allowed rapid access to specific frames of interest. The video mixing unit clock was activated by a command from the Varian V-76 host computer at the start of the simulation and then ran in parallel with the computer clock. The maximum discrepancy between times recorded on the video imagery and event times recorded in the V-76 simulation computer was approximately 50 milliseconds over the course of a 30-minute simulation. A monochrome TV monitor was on-line to continuously monitor the final video being recorded on the JVC video recorder. The pilot's verbal reports were recorded on the recorder audio channel.

A test conductor's console was positioned just aft and above the crew station. The test conductor had access to the host computer controls. He monitored the simulation run variables via a TV repeater from the V-76 computer console. He was in constant communication with the subject as well as with other personnel operating the simulation equipment.

3.0 TEST FORMATS - BASIC STUDY

All the formats tested in this evaluation - the Head-Up Display (HUD), the Vertical Situation Display (VSD), the Horizontal Situation Display (HSD) and the systems formats - were created in three versions or display presentation modes. The color fill mode represented a color hybrid or raster display system. Formats were created with either lines or filled areas of color. The color line mode represented a color stroke or calligraphic display system. The formats were created from colored lines. In the monochrome mode, lines and filled areas were used but in white-on-black, with no color.

Many of the format concepts tested in this evaluation were initially developed in an earlier program, and were reported in Reference 1. A number of formats were changed only as necessary to implement them in this simulation. In all cases, the salient features of the earlier conceptual formats were retained.

Considerable effort was expended designing and detailing the formats of Reference 1 for dynamic display on CRT's in a simulator cockpit and further tailoring them to support a representative mission scenario. All the displays were responsive to both the mission and the pilots' actions. The HUD, VSD and HSD were programmed to fly the mission with real-time updates at an acceptable rate. They were, literally, computer-generated imagery. The formats which appeared on the MPD's were individually static, but enough of them (834) were created to represent all the conditions and system states required by the mission. The stores programming format was a new development, created to provide control necessary to exercise the stores status format.

3.1 Head-up Display

The head-up display (HUD), shown in Figure 3.1-1, featured a pathway-in-the-sky flight director, an airplane symbol, synthetic terrain information and data boxes with digital airspeed, heading and altitude. It was the primary flight display, and symbology was true-scale with the outside world. The HUD field of view was 23 degrees across

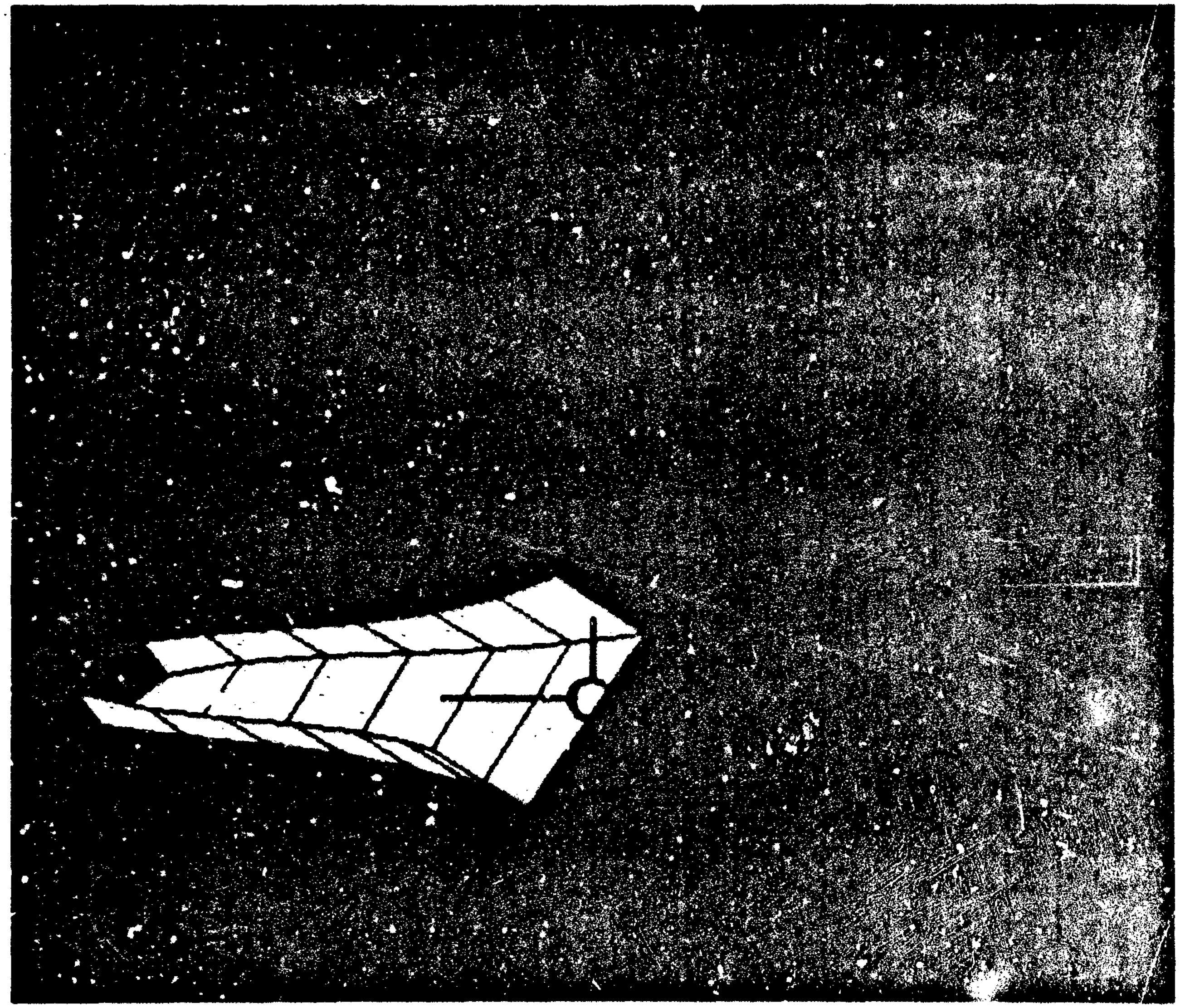


Figure 3.1-1. HUD Display TF/TA Format

by 17 degrees high. Artificial terrain, the horizon and the pathway were ground-stabilized.

The pathway represented the desired flight path. The entrance gate represented an area 300 feet wide by 150 feet high. It was 6000 feet long, tapered in perspective toward the far end, and had a single line extension 20,000 feet long. There were internal lines on the floor and sides of the pathway at 1000 foot intervals. Numbered flags on the side of the pathway represented waypoints or ground targets.

At high altitude, the terrain was replaced by an artificial horizon line. During flight, a caution or warning condition was indicated by color change (to yellow or red, respectively) of the airplane symbol and data blocks. The symbology flashed to indicate caution or warning in the monochrome mode. A red (or white for monochrome) "X" symbol appeared in the center of the airplane symbol for both air-to-air and air-to-ground weapon delivery. It came on solid to indicate entry into the delivery envelope, flashed when the pilot pressed his weapon delivery handoff button and disappeared when the weapon was released or the envelope had passed.

In the color fill mode, mountains on the HUD were green, the ground plane was a darker green, the channel was white with black markings and the airplane symbol was blue. In color line mode, the terrain shapes were outlined in green and the channel was outlined in white. In the monochrome mode, the terrain shapes and channel were black with white outline. In both color line and monochrome modes, radial lines on the ground plane, originating at the center of the horizon, provided sky-ground differentiation.

3.2 Vertical Situation Display

At high altitude, the vertical situation display (VSD) had conventional attitude director indicator symbology. Below an arbitrarily selected 10,000 feet, the low altitude or terrain-following/terrain avoidance VSD format was available.

The low altitude VSD format (Figure 3.2-1) gave a perspective view of the aircraft, the desired flight path, the terrain and surface threats. A 90-degree wide by 67-degree high field of view was shown from a viewpoint 6000 feet behind and 1000 feet

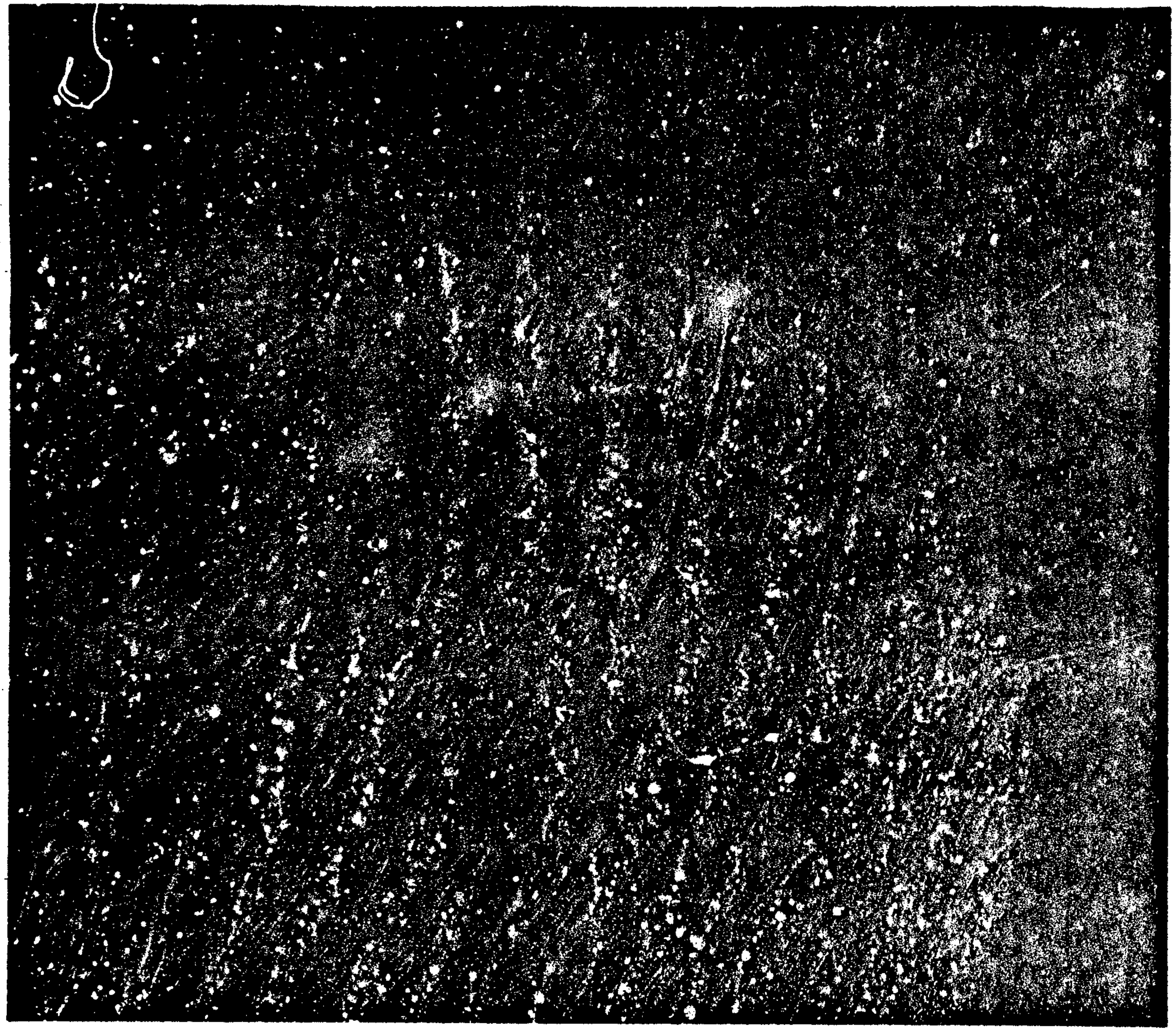


Figure 3.2-1. VSD Display TF/TA Format - Color Fill

above the aircraft. The desired flight path was portrayed as a five mile long ribbon beginning 1000 feet ahead of the aircraft symbol and ending 20,000 feet ahead. It was roughly comparable to the floor of the HUD pathway. Like the HUD pathway, the VSD ribbon had numbered flags representing waypoints and targets.

Terrain, in the low-altitude VSD, was represented as three dimensional mountain shapes, brown above current aircraft altitude and green below. A grid on the ground plane helped create the perspective effect. Rivers, roads, targets and the Forward Edge of the Battle Area (FEBA) were shown on the ground plane.

Surface-to-air missile (SAM) and anti-aircraft artillery (AAA) threats were shown on the VSD as three dimensional shapes, colored yellow and red to indicate degree of lethality. The SAMs were roughly conical with apex downward and axis inclined slightly toward the planned flight route. The outer volume of each SAM shape was yellow and the inside red. Whenever two SAM volumes intersected, lethality was considered to be high and the intersection was red. AAA sites were shorter truncated cones (base down) with uniformly high lethality, and thus were solid red.

In color line mode (Figure 3.2-2), the mountains and threats on the VSD were outlined with the appropriate color—brown or green for mountains and yellow or red for threats. In monochrome mode (Figure 3.2-3), mountains above current altitude and the high lethality portions of threat shapes were solid white with the remainder of mountains and the threats outlined in white.

3.3 Horizontal Situation Display

The horizontal situation display (HSD) was a plan view projection of situation and tactical information. It was a track-up format centered on the airplane symbol as shown in Figure 3.3-1. Information on the HSD included the planned flight route with numbered waypoints and targets, mountains, threats, rivers, roads and the FEBA.

In the low altitude mode, available below 10,000 feet, these features were shown against a green background. As in the VSD, mountains were brown above current aircraft altitude. SAM and AAA threats were shown as current altitude slices through

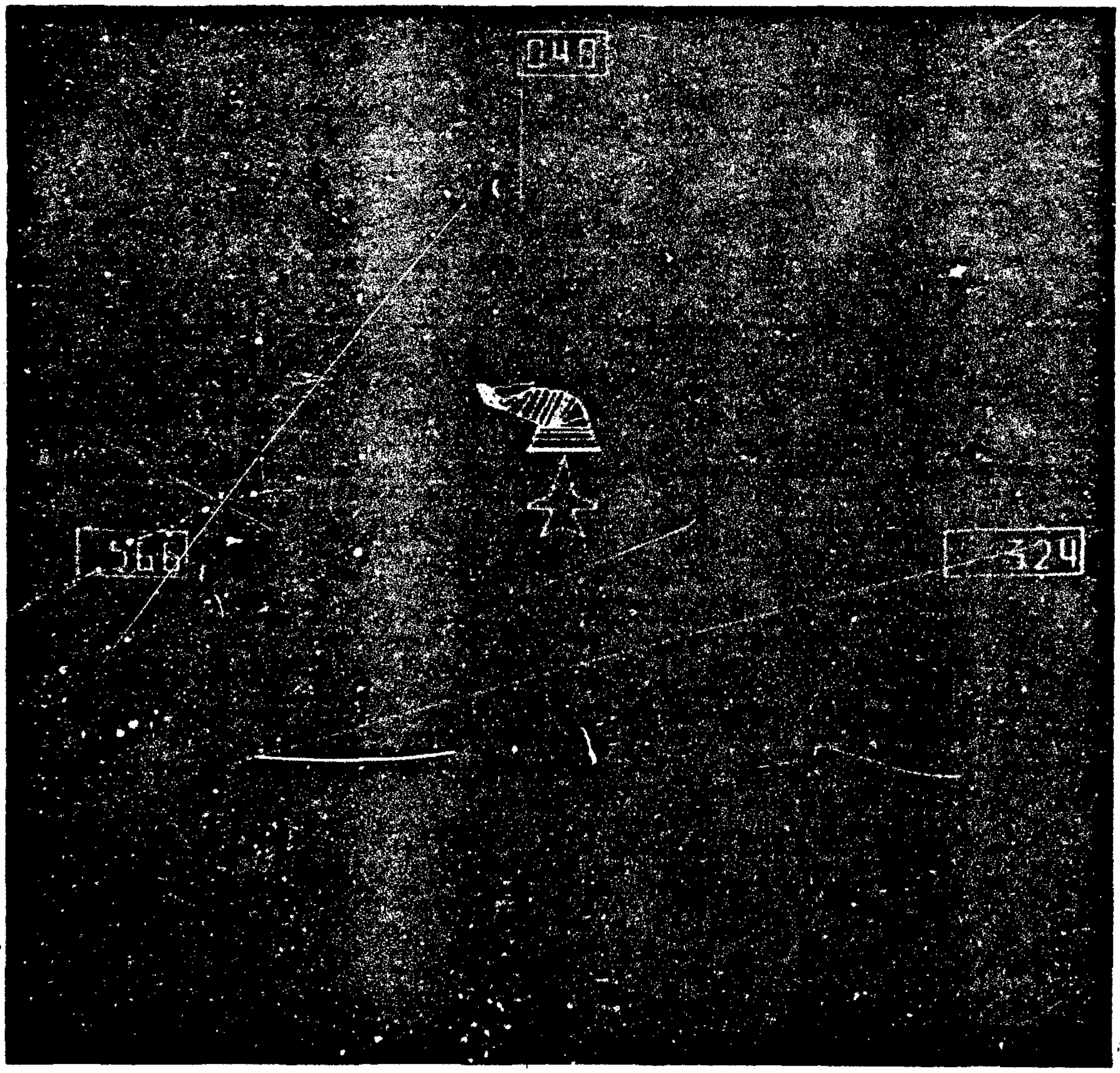


Figure 3.2-2. VSD Display TF/TA Format - Color Line

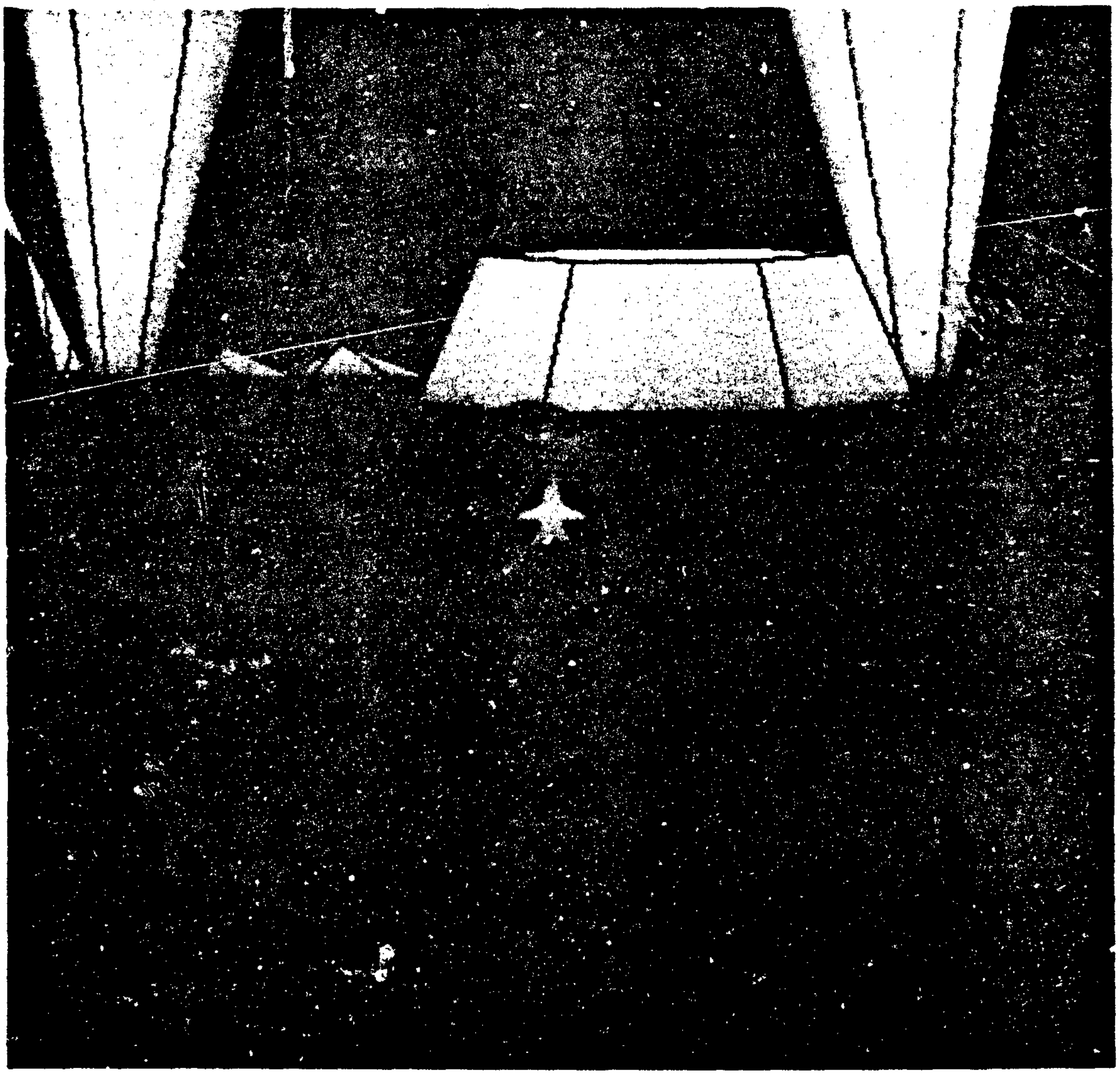


Figure 3.2-3. VSD Display TF/TA Format - Monochrome

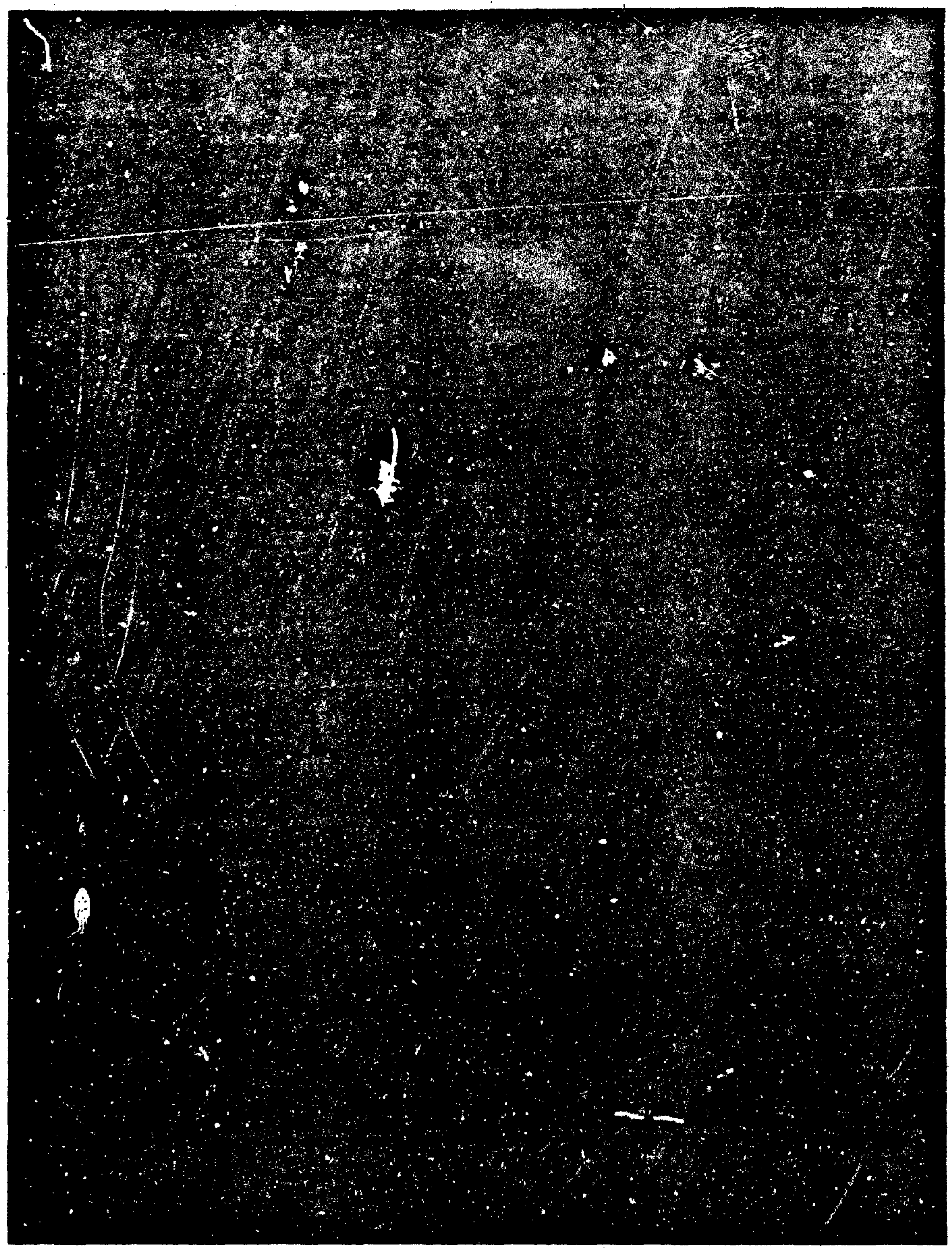


Figure 3.3-1. HSD Display TF/TA Format With Target Inset

the red and yellow lethality shapes described above. Digital heading was given in a box at the top center of the display.

The high altitude HSD showed all the above information except threats and mountains. The background was black. In air-to-air mode, the HSD contained only the symbology shown in Figure 3.3-2. The sector shapes represented low (outer) and high (inner) probability of kill areas for both own and adversary aircraft. In this simulation, only the 80-mile scale was available for air-to-air mode and the range rings had 20 and 40 nautical mile radii.

A number of option switches were available for the HSD. "Range Increase" and "Range Decrease" allowed the pilot to select amoung 40, 80, 160 and 320 nautical mile along-track display ranges. The selected range was given in a box in the lower left corner of the HSD. "Fuel Range" allowed the pilot to select or deselect two range rings. They represented normal and extended fuel range limits. "Target" put an expanded inset of the target area on the right side of the display. A line led from this target inset to the actual target location. Three other buttons allowed the pilot to display digital time and distance to the home base, the next target or the next waypoint. This information, when selected, was displayed at the lower center and right of the HSD.

3.4 Multipurpose Displays

Formats on the multipurpose displays pictorially represented airplane systems: engines, stores, electrical, hydraulic and fuel. Each of these systems had a status display. Several (engines, electrical and hydraulic) had associated advisory displays, and there was also a programming display for the stores system. The engine status, electrical status and hydraulic status formats were assigned to the right MPD. The two stores formats, the fuel status format and the advisory formats were on the left MPD. Each of these formats is discussed in more detail below.

Like the flight and situation displays, these systems formats each had three versions, following the rules for color fill, color line and monochrome described in paragraph 3.0.

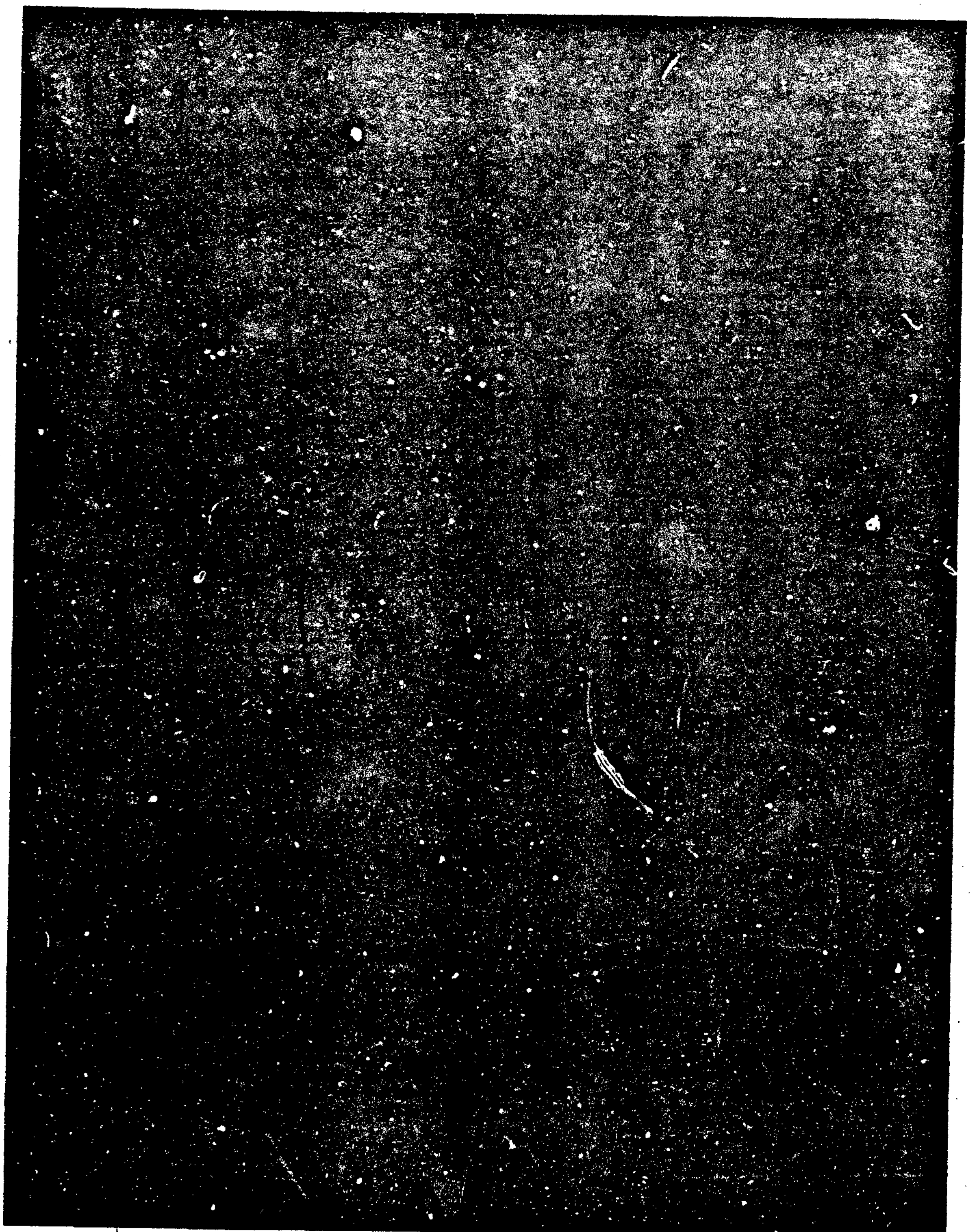


Figure 3.3-2. HSD Display Air-to-Air Format

3.4.1 Engine Formats

Figure 3.4.1-1 shows the engine status format for a two-engine airplane. Engine body outlines were given with important engine parameters depicted symbolically. The articulating inlet and exhaust doors were shown. Turbine inlet temperature (TIT) and exhaust gas temperature (EGT) were shown as thermometers with safety limits represented by horizontal bars. Compressor speed (N1) and turbine speed (N2) were shown as vertical bars with limits. Fuel flow (FF) to each engine was shown as an arrow with moving bubbles and a bar for fuel cut-off. The size of the arrows represented rate of fuel flow. The flame at the rear of each engine changed color and moved outside the burner section to indicate afterburner operation. Figure 3.4.1-2 shows a series of engine advisory formats directing the pilot through remedial steps after an engine fire. The pilot was advised by these formats to (a) bring the throttle of the affected engine to idle, (b) cut off the fuel to that engine, (c) release the fire extinguishing agent and, (d) with the fire extinguished, land as soon as possible.

3.4.2 Stores Formats

The Stores Status format showed presence or absence of each store on the aircraft and the state of the stores selection and stores programming options. Figure 3.4.2-1 is an example of one configuration of the stores status format. Represented are two ECM pods on the wing tips, two napalm canisters, twelve Mark 82 bombs, and two air-to-air missiles. The weapons shown in dashed outline are on board but not selected. Eight of the bombs are selected with nose and tail colored green to indicate programmed fusing. The center sections of the selected bombs are yellow. These would appear green if the Master Arm switch were turned on and the bombs were completely ready to drop. The triangles near the forward two bombs indicate that they will be the first two to drop. If any store had already been expended, that position would be vacant.

The wingtip ECM pods were represented to have only three states—off, standby and on. When off, they appeared with dashed outline. In standby, the ECM pod symbol turned yellow and had a solid outline. When the ECM was turned on, the symbol turned blue and yellow lighting bolts appeared forward of the pod symbol. ECM functioned separately from dropable stores, and could be selected in combination with any of the weapons options.

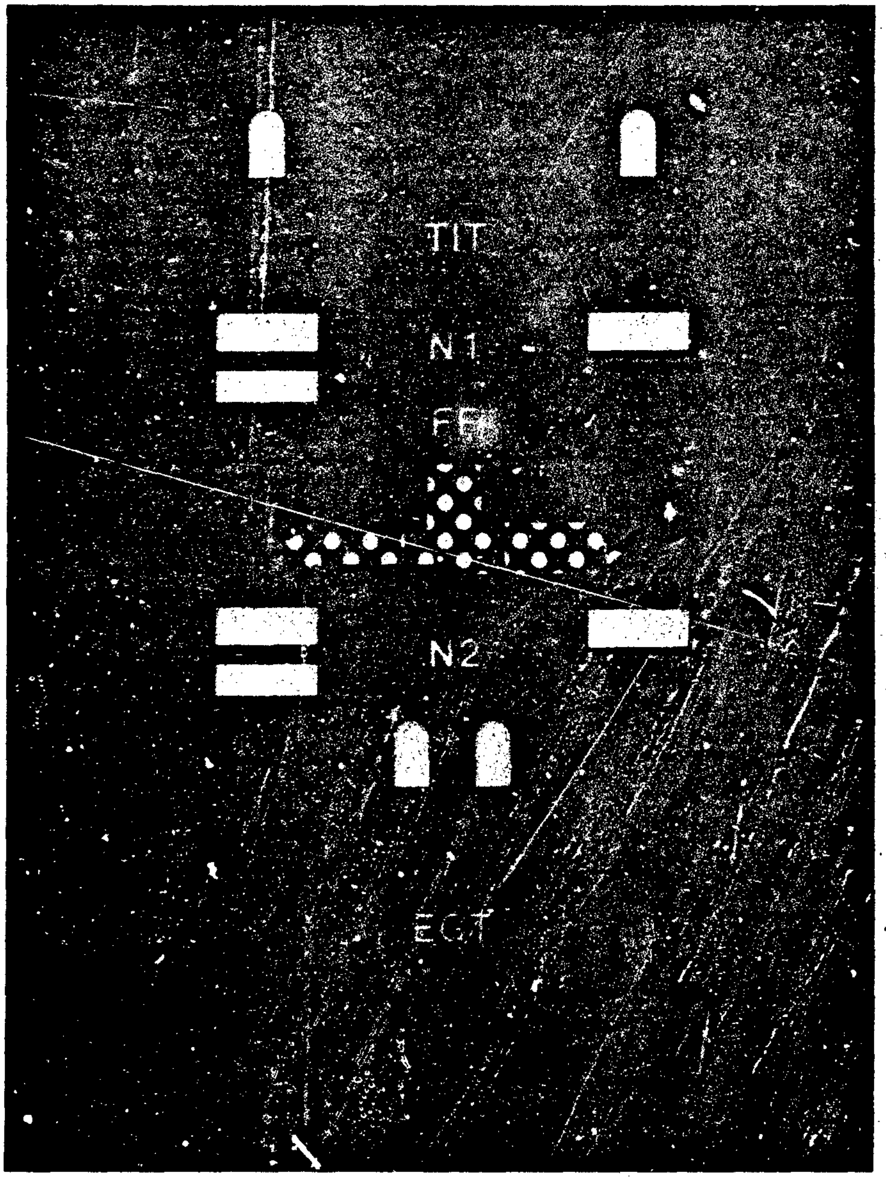
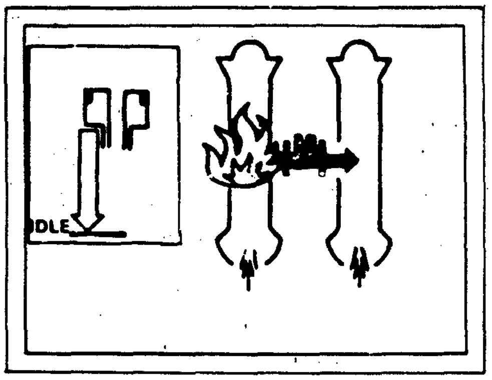
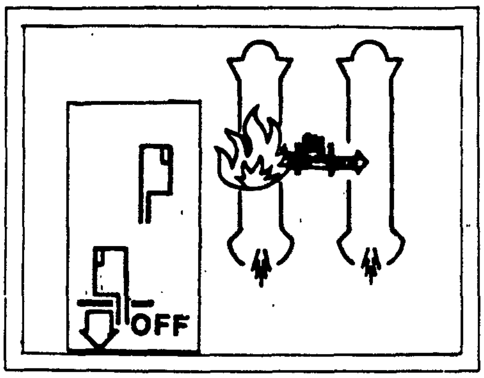


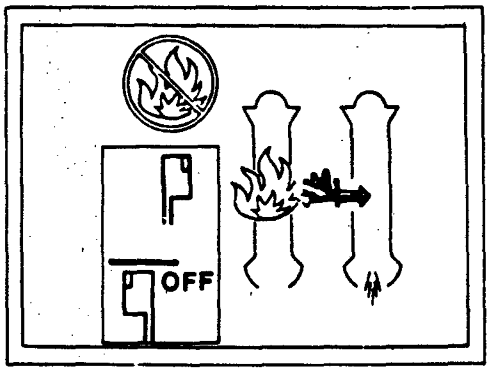
Figure 3.4.1-1. Engine Status Display



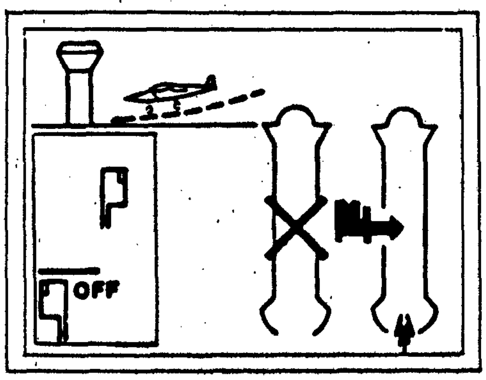
A. BRING THROTTLE TO IDLE



B. CUT OFF FUEL



C. RELEASE EXTINGUISHING AGENT



D. FIRE OUT. LAND AS SOON AS POSSIBLE

Figure 3.4.1-2. Engine Fire Advisory Series

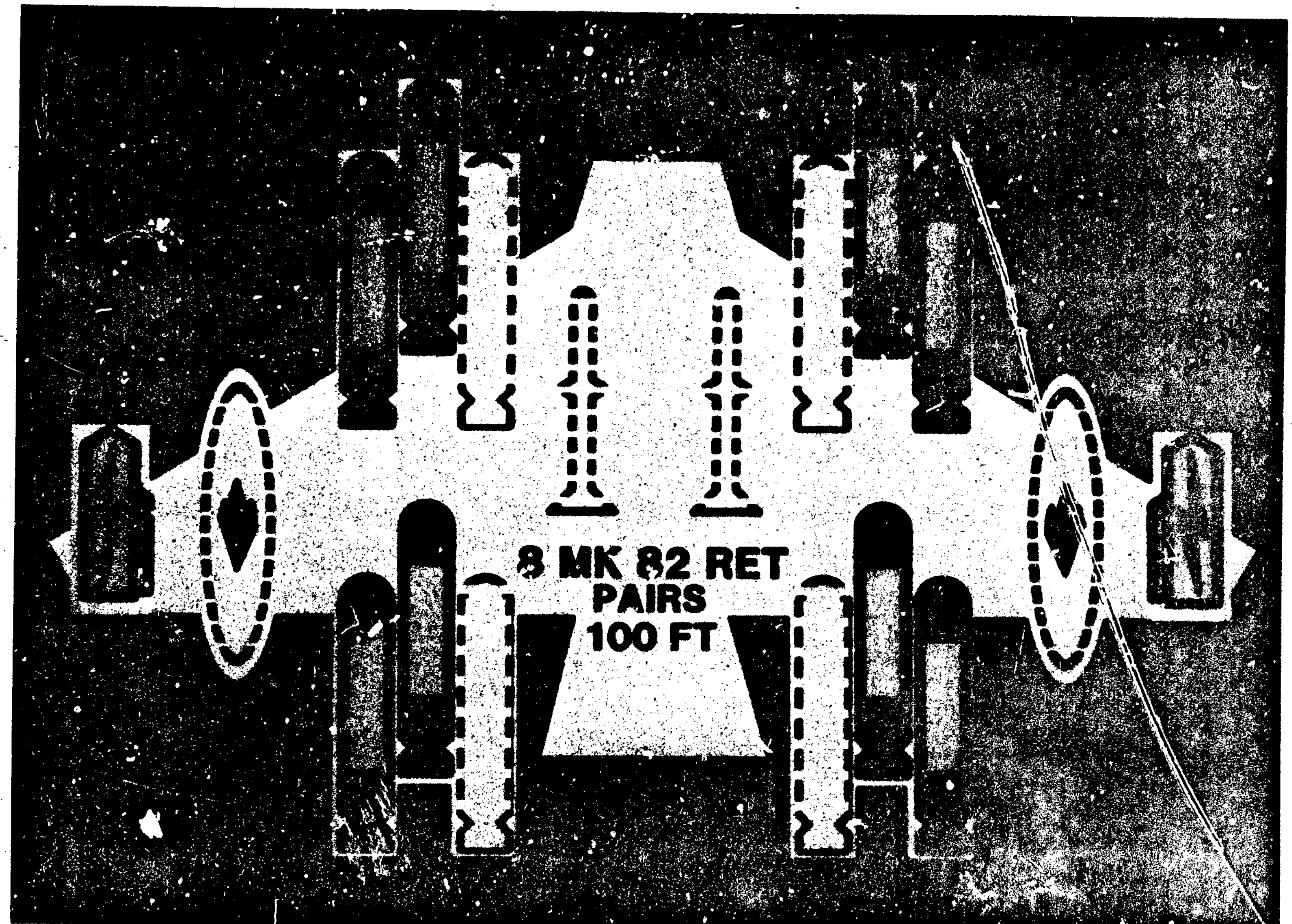


Figure 3.4.2-1. Stores Status Format

The only malfunction in the stores system was a single hung bomb after the bomb drop. When that happened, the format was bordered in red, the remaining (hung) bomb turned red and the word "HUNG" was written alongside the bomb. When the pilot safed the fuses, the nose and tail of the bombs went to outline red. When he turned the master arm switch off, the belly went to outline red and when he deselected bombs, the border turned from red to yellow.

For programming the stores, pilots in this evaluation used alphanumeric menu lists. One such list was available for each type of store and contained all the available options for the selected store. Figure 3.4.2-2 is an example of the Stores Program format. In this example, eight Mark 82 bombs were selected, to be delivered in pairs at 150 foot intervals with nose and tail fused. The pilot could reprogram any store using the select and program buttons located just above and below the Stores Program format.

3.4.3 Electrical Formats

The electrical system was represented by two formats. One, the Electrical Status format shown in Figure 3.4.3-1 was a simplified schematic of the system. If some element of the electrical system failed, a red (for permanent failure) or a yellow (for temporary failure) border appeared around the format and the picture of the failed element changed character. The failed element was shown against a white background and a red X was drawn through it, closed for permanent failure and open for temporary. The Electrical Advisory format showed required actions in pictorial form. Figure 3.4.3-2 indicates an example of a permanent failure of the right generator. The advisory is to turn the right generator switch off and to land as soon as possible.

3.4.4 Hydraulic Formats

The Hydraulic Status format, an example of which is shown in Figure 3.4.4-1, followed a non-schematic pictorial philosophy. The format was a matrix of system (1A, 1B, 2A, 2B) by status (normal, temporary failure, permanent failure). In case of failure, the symbol representing the failed element moved to the second column (temporary failure) or the third column (permanent failure). In addition, a yellow border appeared around both the whole format and the failed element for permanent failure. It was

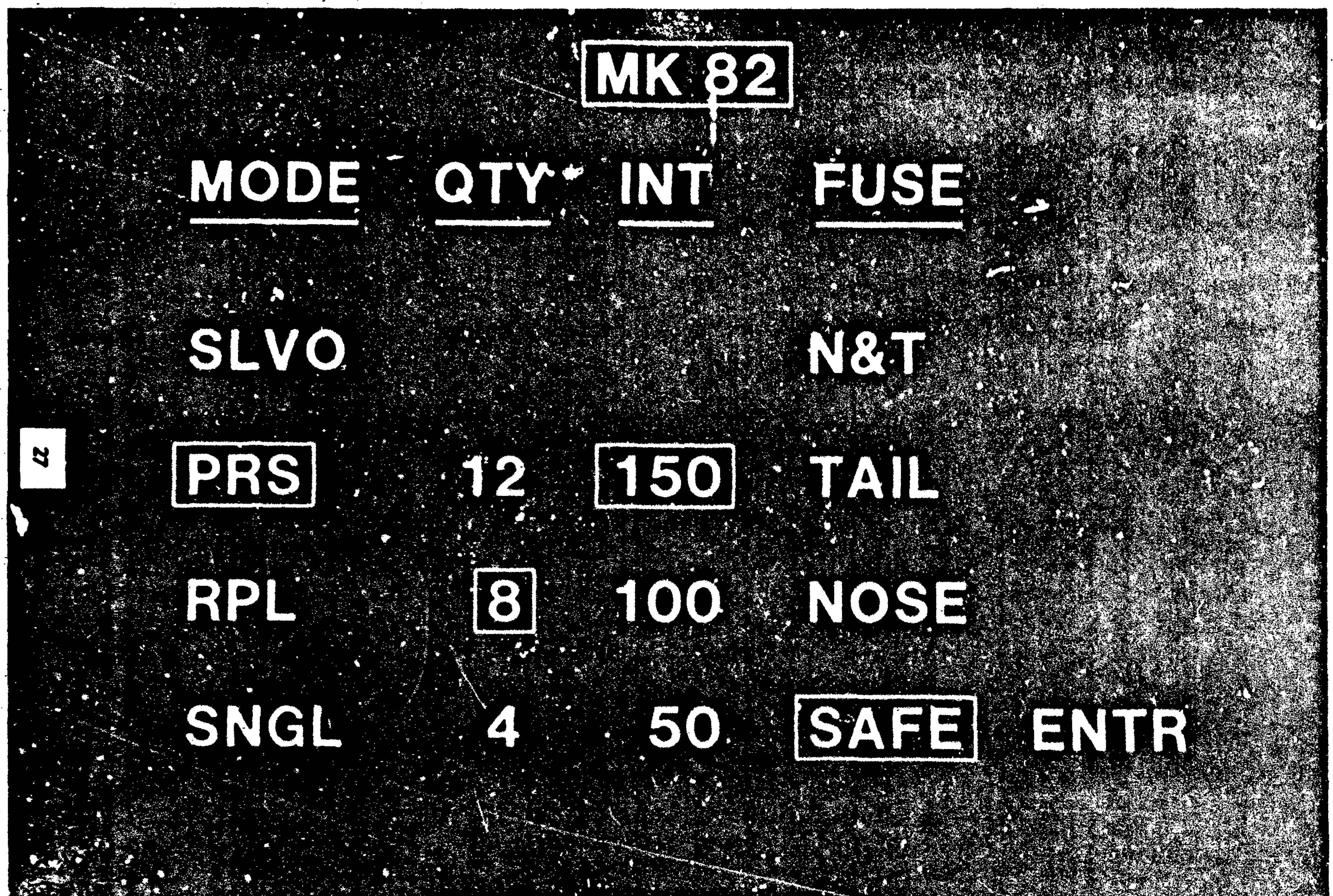


Figure 3.4.2-2. Stores Programming Format

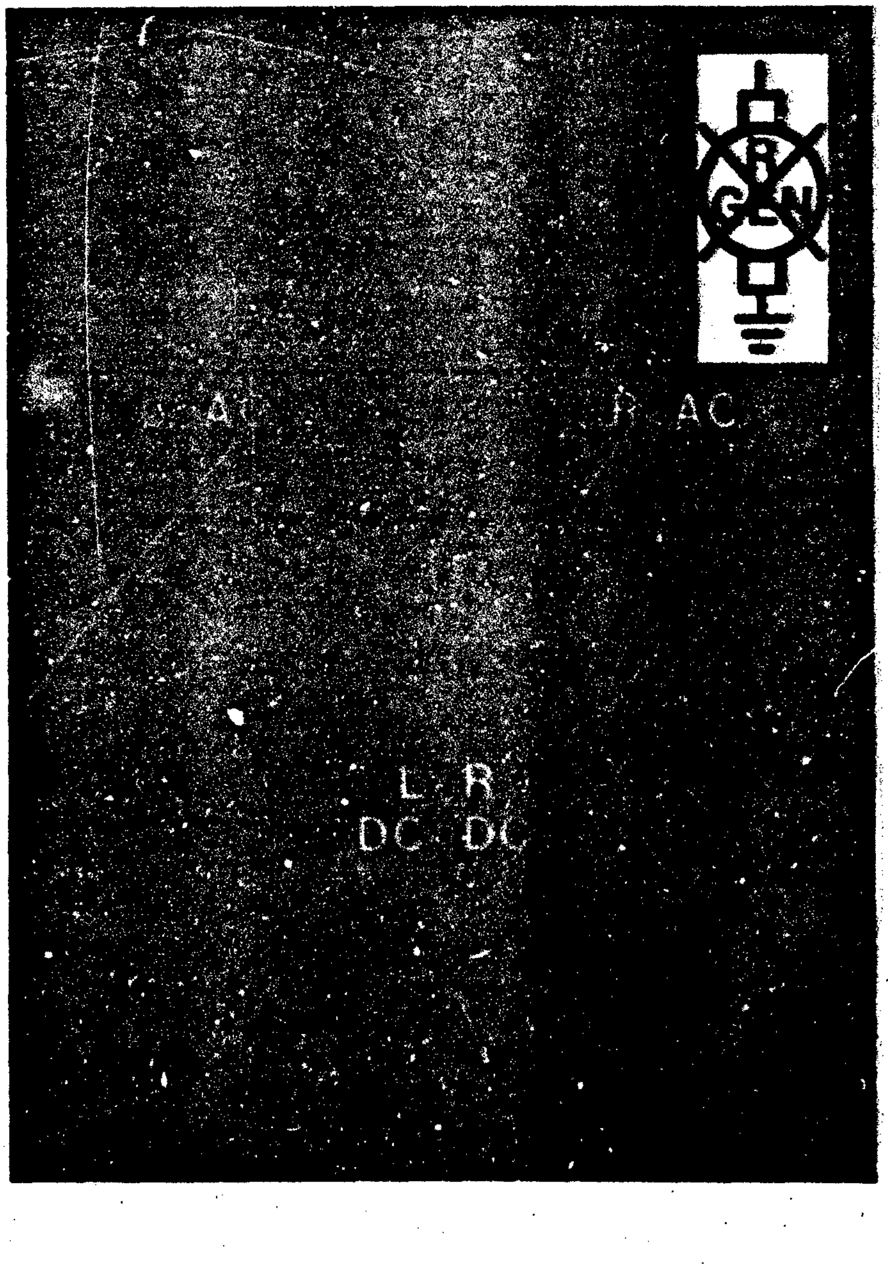


Figure 3.4.3-1. Electrical System Status Format

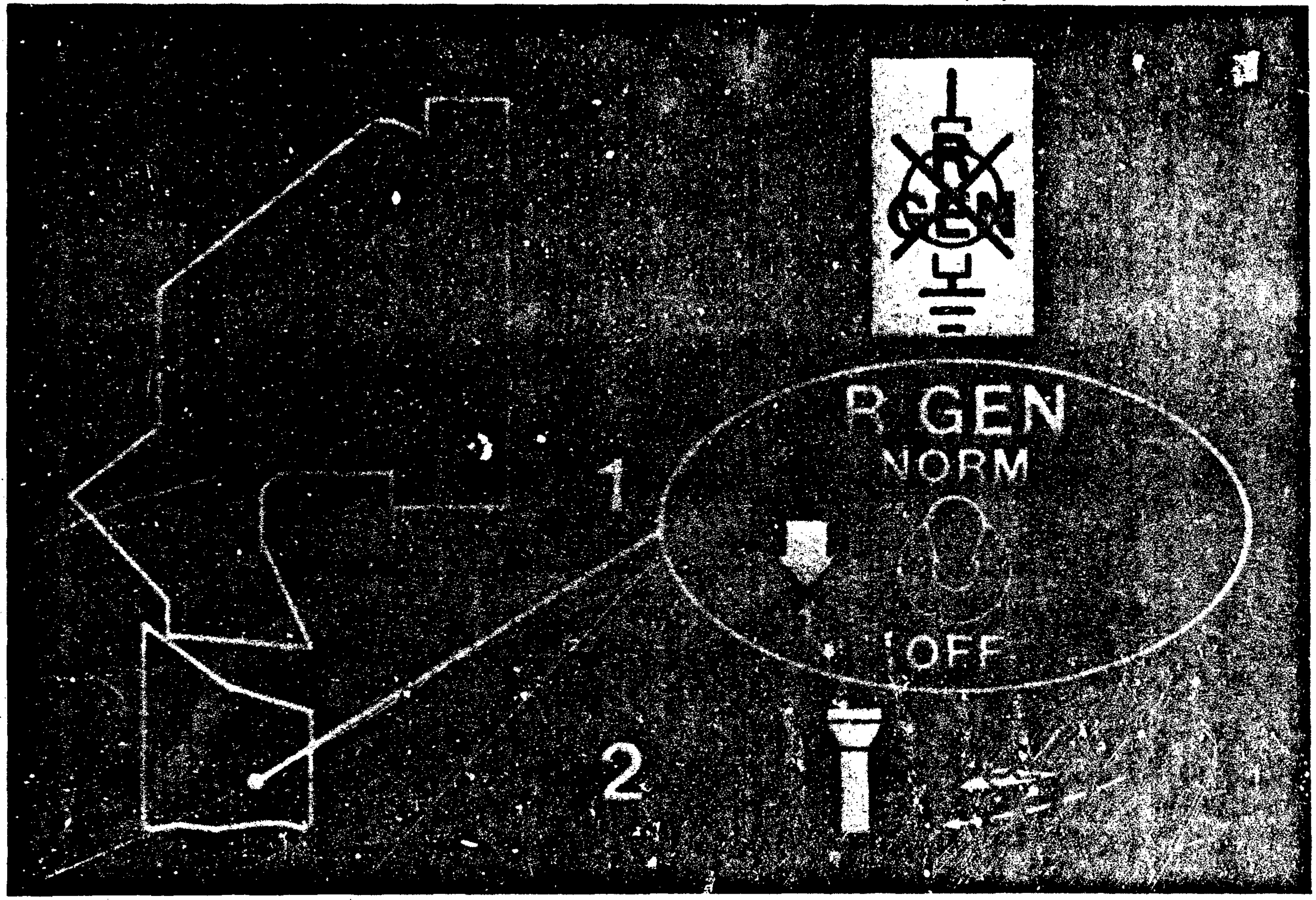


Figure 3.4.3-2. Electrical System Advisory Format

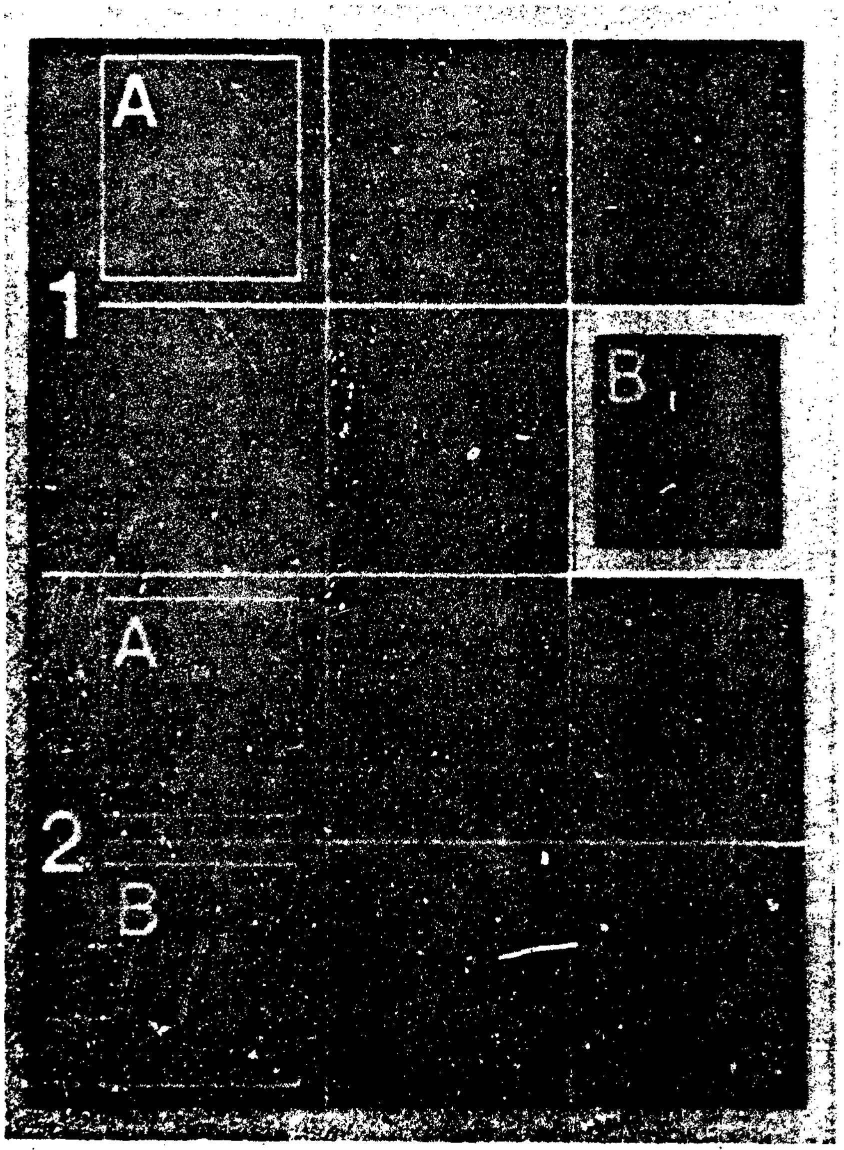


Figure 3.4.4-1. Hydraulic System Status Format

assumed that the hydraulic system had enough redundancy that a temporary failure did not warrant caution status.

The Hydraulic Advisory formats did not portray remedial action, but instead indicated the affected airplane system. Figure 3.4.4-2 shows the example of a permanent failure of the 1B hydraulic system and indicates that the port side control surfaces are affected.

3.4.5 Fuel System Format

The fuel system was shown against an airplane outline in the Fuel Status format. A five-tank system was shown with valves, crossfeed, a refueling probe and a single boost pump. It was assumed that additional details would be provided on an advisory display as needed. The level of fuel in each tank, the state of each valve and the boost pump were represented. Figure 3.4.5-1 shows roughly 35 percent of the fuel remaining and a closed valve on the right wing tank resulting in a fuel imbalance.

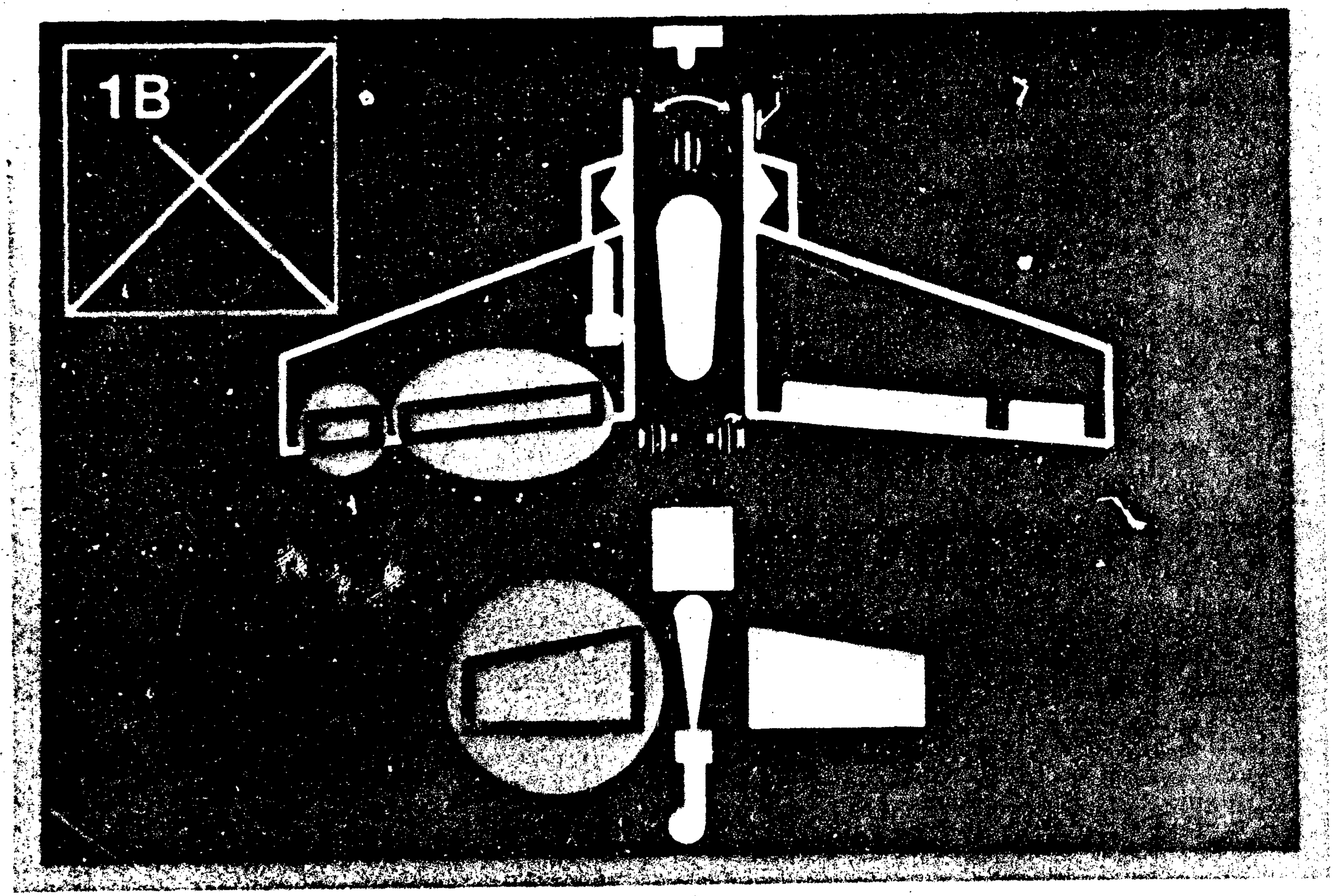


Figure 3.4.4-2. Hydraulic System Advisory Format

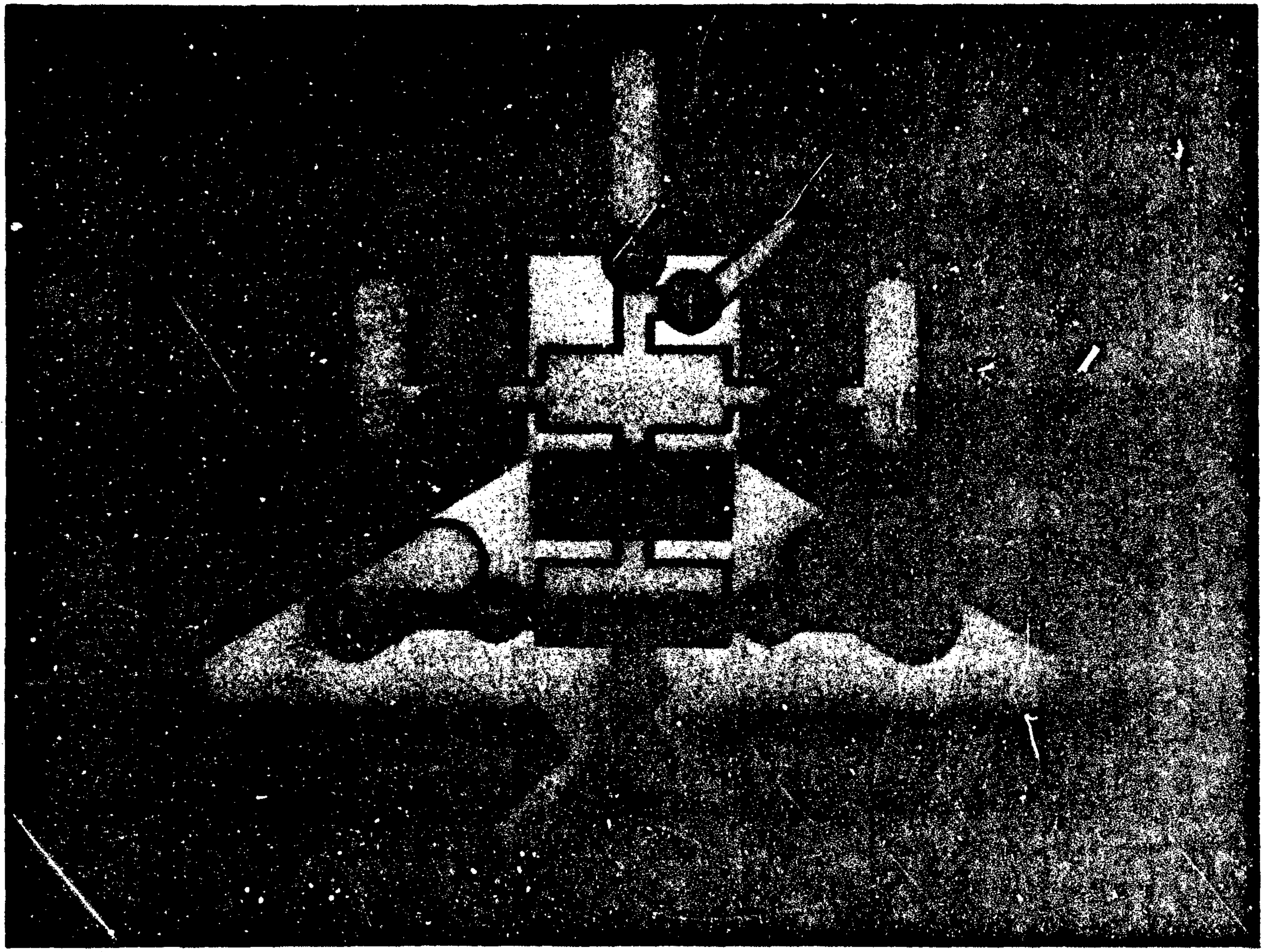


Figure 3.4.5-1. Fuel System Status Format

4.0 TEST PLAN - BASIC STUDY

The test plan for the basic study was derived from the prime objectives. They were to evaluate the usability and pilot acceptance of these pictorial formats; determine whether usability and pilot acceptance are a function of presentation mode - monochrome, color line and color fill; and revise the formats based on study results.

The intent was to provide an operationally valid evaluation under conditions of moderate experimental control. To this end, current military fighter or attack pilots were recruited as evaluators and a within-subjects factorial design was selected. The test procedure provided an intensive training and practice period before testing began. The test scenario exposed the salient features of the formats. Data were collected to support responses to the program objectives.

4.1 Test Subjects

A total of eighteen (18) pilots served as subjects in the study. Nine pilots each were obtained from McChord AFB and from Whidbey Island NAS. The Air Defense Command pilots from McChord were current in the F-106 airplane or the T-33 while the tactical fighter pilots from Whidbey were current in either the A-6 or the A-7. The special qualifications of the pilots are listed in Table 4.1-1. The pilots had an average age of 29 years and an average of 1,510 flying hours in a variety of jet aircraft. Two additional pilots, one from each command, served as check-out pilots. They flew the same schedule as the other pilots. The simulation, but not the formats, changed in significant ways after their participation. For this reason, their performance data are not included but their responses to the usability questionnaire and the general questions are included.

Names, telephone numbers, and home organizations for all participating pilots were made available to Boeing approximately two weeks prior to the scheduled test date. A training package (Reference 2), designed to familiarize subjects with the test objectives, conditions of test and the simulation facility, was forwarded to all pilots for review prior to the simulation.

Table 4.1-1. Pilot Qualifications

	Mean	Range
Age:	29	24 - 38 yrs
Total jet hours:	1,510	350 - 3,800 hrs
Year of pilot rating:	1977	1968 - 1982

Operational experience:

Pilot no.	Branch	Type of aircraft
1	N	A-7, A-4, T-2
2	AF	T-38, T-37, T-33
3	N	A-6, A-4, AF-111, F-4, T-38
4	AF	T-38, T-37, T-33
5	AF	F-106, T-38, T-37, T-33
6	N	A-6, A-4, T-38, T-2
7	N	A-6, EA-6B, T-38
8	AF	F-106, T-38, T-37, T-33
9	AF	F-106, T-37, T-38
10	N	A-6, A-4, T-2
11	AF	F-106, T-38, T-37, T-33
12	N	A-6, A-4, T-28, T-2
13	N	A-6, A-4, T-34B, T-2
14	AF	T-38, T-37, T-33
15	AF	T-38, T-37, T-33
16	N	A-6, TA-4, T-2
17	N	A-6, A-6B, TA-4, T-2
18	AF	T-38, T-37, T-33

4.2 Test Design

The experimental design selected for this study was determined, to a large extent, by two important considerations. The most significant consideration was the requirement to use experienced pilots as subjects. Using experienced pilots offers the advantage of reducing the amount of training required and also maximizes generalization of simulation results to the large population of operational pilots. On the other hand, use of experienced pilots imposes a serious restriction on the number of subjects available for participation in the study. Therefore, the experimental design selected for this study had to be inherently economical in terms of subject utilization.

A second consideration involved the magnitude of the error variance components in the performance measures. In some experimental designs (independent-groups designs), as the number of test subjects decreases, there is an increasing risk that individual differences between subjects may contribute to performance differences between two or more treatment conditions. Since the number of subjects available for this study was quite small, it was decided to select a within-subjects experimental design that would minimize effects due to individual differences.

A block diagram of the test design for the proposed study is shown in Figure 4.2-1. As can be seen, there were two independent variables: display presentation mode, and eye movement recorder. The display presentation mode variable had three levels: monochromatic, color line, and color fill. Display presentation mode was selected as an independent variable in order to determine whether the use of more expensive color displays would be justified by increased usability and pilot acceptance.

The eye movement recorder variable had two levels: present and absent. This device was used to obtain information about the nature of the pilots' scan patterns over the advanced display formats. It was selected as an independent variable because the eye movement recorder is an obtrusive measurement device. Whenever such devices are introduced into a realistic working environment, it is possible that the subjects may modify their typical behavior. A comparison of operator performance with and without the device was made in order to determine if the device, in and of itself, altered the subjects' normal behavior.

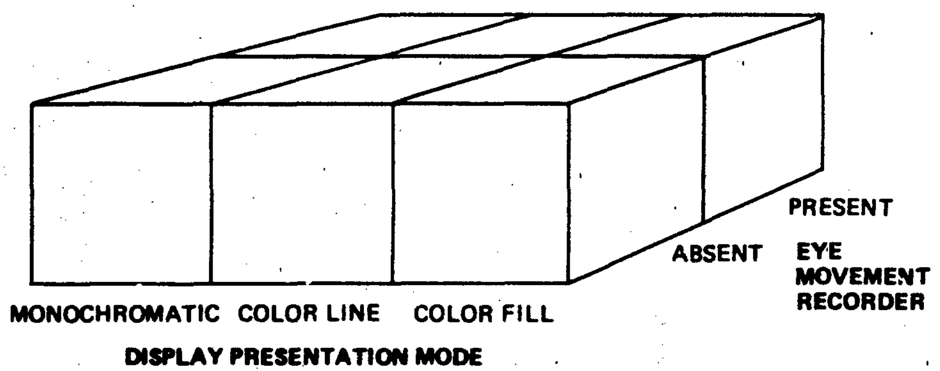


Figure 4.2-1. Experimental Design

The six cells in Figure 4.2-1 represent a 3 by 2 factorial design with repeated measures. Each subject was tested in all treatment conditions of the experiment. Therefore, error variability due to individual differences between groups of subjects did not differentially affect the performance measures. This design also minimized the number of subjects required and provided more data per subject than any other design. Training requirements were minimized since skills learned under initial training trials transferred to all subsequent conditions.

4.3 Test Procedure

Before reporting, pilots had access to, and were asked to study, a "flight manual" (Reference 2) which described the simulator cockpit, the formats to be evaluated and the missions to be flown. The test subjects reported to the Kent Space Center in pairs. Most pairs consisted of one Navy and one Air Force pilot. Two days were required to process each pair of subjects through the entire training and test sequence. The daily test schedule shown in Figure 4.3-1 presents the sequence of events for the first two pilots. The same basic sequence of events was used for all subsequent test days except that the order of the treatment conditions was varied.

Each test day began by bringing the simulator on-line and checking to see that all equipment was operating properly. Any detected deficiencies were corrected before the first practice or test trial began.

On the first day, pilots were given an introduction to the multimission simulator while the cab was being initialized for the first practice trial. Following the introduction, the pilots were briefed on the general cockpit layout, the formats to be evaluated, the

	DAY 1
0730-1000	Bring simulator on line and checkout
0800-0930	Introduction to facility and pre-flight briefing
0930-1000	Cockpit familiarization
1000-1040	Practice trial, color fill, autopilot, no eye recorder, no visual scene, subject 1
1040-1120	Practice trial, color fill, autopilot, no eye recorder, no visual scene, subject 2
1120-1200	Practice trial, color fill, no eye recorder, no visual scene, subject 1
1200-1300	Lunch Break
1300-1340	Practice trial, color fill, no eye recorder, no visual scene, subject 2
1340-1420	Practice trial, color line, no eye recorder, visual scene, subject 1
1420-1500	Practice trial, color line, no eye recorder, visual scene, subject 2
1500-1540	Practice trial, monochrome, eye recorder, no visual scene, subject 1
1540-1620	Practice trial, monochrome, eye recorder, no visual scene, subject 2
1620-1700	Test trial, monochrome, eye recorder, subject 1
1700-1740	Test trial, monochrome, no eye recorder, subject 2
	DAY 2
0730-0830	Bring simulator on line and checkout
0830-0910	Test trial, color line, eye recorder, subject 1
0910-0950	Test trial, color line, no eye recorder, subject 2
0950-1030	Test trial, color fill, eye recorder, subject 1
1030-1110	Test trial, color fill, no eye recorder, subject 2
1110-1150	Test trial, monochrome, no eye recorder, subject 1
1150-1300	Lunch Break
1300-1340	Test trial, monochrome, eye recorder, subject 2
1340-1420	Test trial, color line, no eye recorder, subject 1
1420-1500	Test trial, color line, eye recorder, subject 2
1500-1540	Test trial, color fill, no eye recorder, subject 1
1540-1620	Test trial, color fill, eye recorder, subject 2
1540-1700	Post-flight debriefing

Figure 4.3-1. Daily Test Schedule

operational procedures to be used, and the flight plan for the simulated mission. A one-half scale foamcore mock-up of the simulator cab was used during the cockpit layout briefing. Static pictorial representations on film transparencies were used to introduce display formats that would be encountered during the practice and test trials. The briefing was conducted in a room removed from the simulator cockpit. Then the pilots were taken to the simulator cab for familiarization with the operation of required cockpit controls and to calibrate the eye movement recorder.

Each pilot flew one familiarization trial and three practice trials, one with each of the three presentation modes. Familiarization and practice trials included the same basic misson profile and flight duration used in the test trials. At the beginning of each practice and test trial, the pilot completed the preflight checklist given in Figure 4.3-2. The eye movement recorder was worn on one practice trial to familiarize the subjects with its characteristics prior to data collection. The VMC flight segment was also presented during one of the practice trials. After the practice trials, each pilot flew two twenty-four minute test trials with each display presentation mode, one with the eye movement recorder and one without. Half of the subjects were tested with the eye movement recorder present on the first set of trials. The remaining half were tested with the eye movement recorder absent on the first set of trials. The presentation order for levels of the display mode and eye movement variables is shown in Table 4.3-1. As can be seen, the levels of these variables were counterbalanced over the eighteen subjects.

The pilots wore a set of headphones and a microphone during all trials. They were asked for verbal system status reports and for verbal confirmation of the presence and meaning of emergency conditions. These responses were recorded on the audio channel of the eye movement video tape for subsequent analysis. When the eye movement recorder was not worn by the pilot, a video camera recorded an image of the front panel.

Fuel Crossfeed – CLOSED
Fuel Transfer Switches – OFF
Flaps – UP, Sweep 25 degrees
Engine and Fuel Master – ON
Throttles to MILITARY Power (in detent)
Electrical – LH and RH Generators ON
Gear – UP
Standby Altimeter Setting – 29.92
Program Stores: (left MPD)
  Select:
  ECM – Standby
  BLU – Ripple, Qty 2, 50 feet
  MK 82 – Ripple, Qty 12: Interval 100 feet; nose and tail fused
  AAM – Single
  Select BLU
Master Arm – OFF
HSD – Select 320 nm Scale
Master Mode Control – Select NAV Mode
Engine Status – ON (right MPD)
Adjust Seat and Rudder Pedals
Autopilot – AUTOPILOT ENGAGED
Hydraulic Control – T-bar OFF
Engage RUN on Simulator Control Panel When Ready

Figure 4.3-2. Pre-Flight Checklist

Table 4.3-1. Sequence of Conditions for Test Trials

Branch	Subject	Eye recorder present			Eye recorder absent		
		Monochrome	Color line	Color fill	Monochrome	Color line	Color fill
Navy	1	1	2	3	4	5	6
Air Force	2	4	5	6	1	2	3
Navy	3	3	1	2	6	4	5
Air Force	4	6	4	5	3	1	2
Air Force	5	2	3	1	5	6	4
Navy	6	5	6	4	2	3	1
Navy	7	4	5	6	1	2	3
Air Force	8	1	2	3	4	5	6
Air Force	9	6	4	5	3	1	2
Navy	10	3	1	2	6	4	5
Air Force	11	5	6	4	2	3	1
Navy	12	2	3	1	5	6	4
Navy	13	1	2	3	4	5	6
Air Force	14	4	5	6	1	2	3
Air Force	15	3	1	2	6	4	5
Navy	16	6	4	5	3	1	2
Navy	17	2	3	1	5	6	4
Air Force	18	5	6	4	2	3	1

Forty minutes were reserved in the daily test schedule to complete each practice and test trial. This included a sixteen-minute period to reconfigure the simulator, rotate subjects, and calibrate the eye movement recorder for a subsequent trial.

Control of the simulation facility was turned over to the test conductor only after the facility had been initialized by the laboratory personnel. Following each test run, control of the facility was returned to the laboratory personnel to allow them to re-initialize the equipment for the next test condition. During the re-initialization period, the eye movement recorder was recalibrated as required and data acquisition was verified.

4.4 Mission Scenarios

The navigation track for the simulated mission is shown in Figure 4.4-1. Table 4.4-1 defines pertinent aircraft conditions and mission events for each leg of the flight plan. The mission covered approximately 240 nautical miles. During each trial the pilot experienced both Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC), manual and coupled flight, air-to-air and air-to-ground weapon deliveries, degraded flight conditions, and airspeeds from 500 knots to Mach 1.6.

Leg A

The mission began with the aircraft on autopilot holding altitude at 20,000 feet and heading at 330 degrees. The power was set to 500 knots for cruise to the Forward Edge of the Battle Area (FEBA). The aircraft had just completed aerial refueling and was proceeding inbound to the pre-assigned target area, a petroleum dump located at a railroad switching yard.

Shortly after initiation of the mission, the pilot received a communication from an advanced C^3 aircraft informing him that two enemy aircraft were proceeding outbound from the FEBA on an intercept course. The pilot set the ECM pods to ON, selected missiles as the active weapons option, activated the master arm switch, and selected the air-to-air master mode in preparation for the aerial engagement.

Two enemy aircraft appeared at the top of the HSD. Shortly after the missile lock-on appeared on the HUD, the pilot launched a missile and one of the enemy aircraft was destroyed. The second enemy aircraft was beyond range for missile lock-on so the aerial engagement was terminated. At this time the pilot set the ECM pods to standby, selected napalm as the active weapons option, turned the master arm switch off, and selected the navigation master mode.

A "systems status" message was presented over the pilot's headset as a cue to call up the subsystem status formats by depressing the appropriate MPD mode select switches. As each switch was depressed, the appropriate subsystem format appeared on one of the MPDs. Both normal and degraded system status formats were presented.

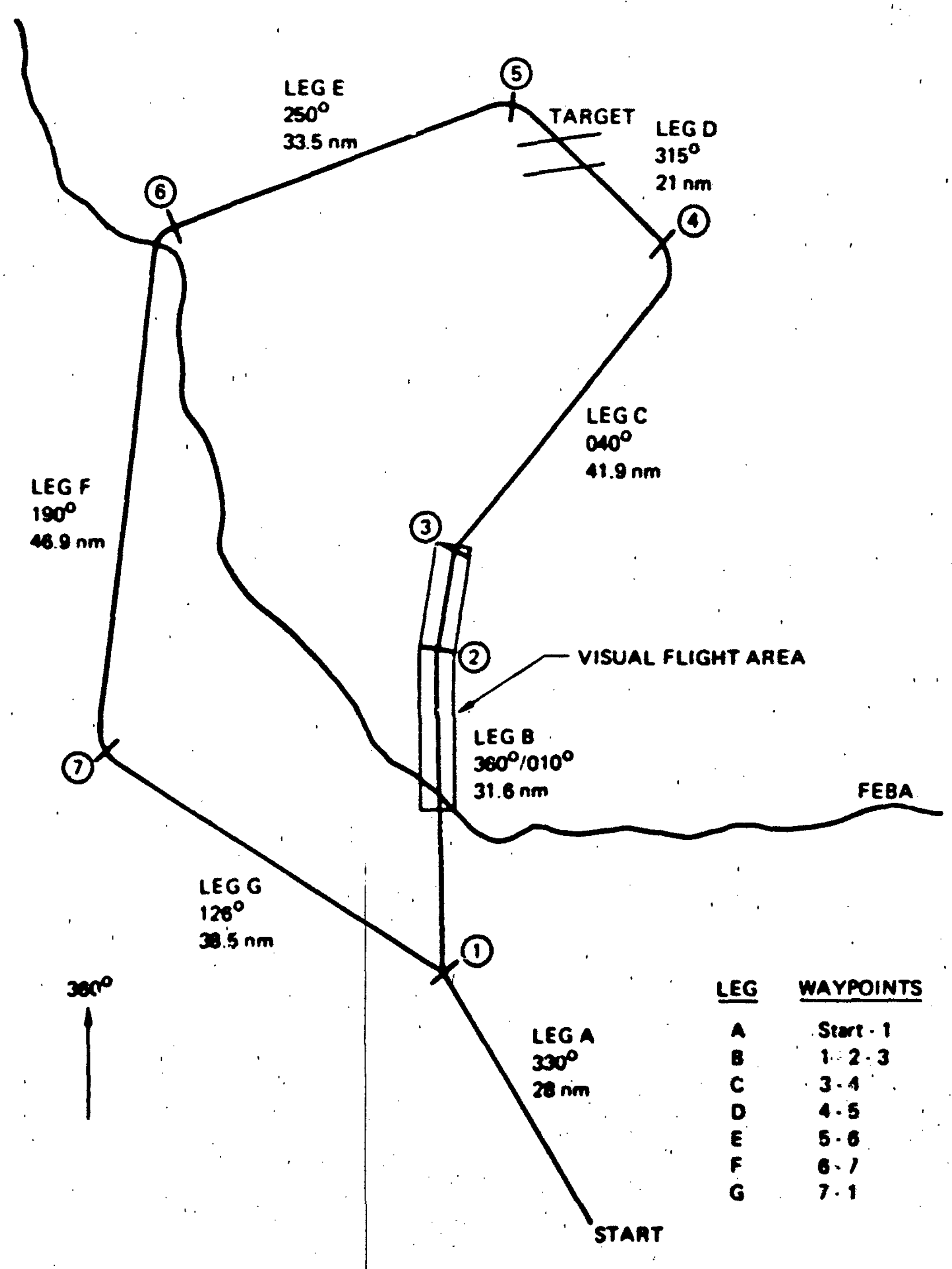


Figure 4.4-1. Navigation Track

Table 4.4-1. Flight Plan Events

Leg	Weather	Control	Altitude (AGL)	Airspeed	Distance	Time	Events
A Approach FEBA	IMC	Autopilot	20K ft	500 kts	28 nmi	3.4 min	Program weapons, air-to-air encounter, report systems status
B Penetration	IMC/VMC	Autopilot	20K-200 ft	500 kts	31.8 nmi	3.8 min	Failure, report systems status, HUD evaluation
C Approach IP	IMC	Autopilot	200 ft	500/585 kts	41.9 nmi	4.6 min	Failure, report systems status, popup threat
D Target	IMC	Manual	200 ft	580 kts	21 nmi	2.3 min	Deliver stores, hung bomb
E Withdrawal	IMC	Manual	200 ft	600 kts	33.5 nmi	3.4 min	Failure, avoid threats, popup threats
F Escape	IMC	Autopilot	200-20K ft	Mach 1.6	46.8 nmi	2.6 min	Failure, report systems status
G Return	IMC	Autopilot	20K ft	600 kts	38.5 nmi	3.8 min	Failure, report systems status
					241.4 nmi	23.9 min	

The pilot verbally identified each subsystem as it was selected and reported "normal" or "degraded" as appropriate. If a degraded format was presented, the pilot also provided a brief verbal description of the nature of the problem and performed the appropriate corrective action, if required.

Leg B

The aircraft descended from 20,000 feet to minimum terrain following altitude immediately after the air-to-air engagement. During descent, the pilot performed another systems status check and received a message informing him that the petroleum dump had been destroyed, and directing him to bomb the switching yard. Upon receipt of this message, the pilot selected bombs as the active weapons option. As the aircraft passed through 10,000 feet, the pilot selected TF/TA on the master mode panel and the low altitude displays appeared.

The aircraft encountered VMC shortly after reaching terrain following altitude. The total VMC simulation period lasted approximately three minutes. The VMC period was used to evaluate the degree of visual interference between HUD symbology and a dynamic color background, particularly in the color presentations.

Leg C

The aircraft autopilot captured a heading of 040 degrees at the beginning of Leg C. The aircraft returned to IMC and remained in that condition for the rest of the flight. Another systems status check was performed. The VSD and Horizontal Situation Display (HSD) formats were used to observe the position of enemy ground threats during the approach to the target area.

Leg D

The aircraft autopilot captured a heading of 315 degrees at the beginning of Leg D and the pilot assumed manual control of the airplane. The target area, a railroad switching yard, was highlighted on the HSD as the aircraft approached the weapon release point. All twelve MK 82 bombs were delivered from a wings-level attitude on a single pass at 550 knots. Weapon delivery was cued by the appearance of a weapon release symbol on the Head-Up Display (HUD). Following weapon release, the pilot maintained minimum terrain-following altitude for withdrawal from the target area.

A single hung bomb remained following weapon delivery on selected trials. When this occurred, the pilot deactivated the master arm switch, deselected bombs as the active weapons option, and defused the hung bomb.

Leg E

The aircraft was flown manually to a heading of 250 degrees at waypoint 5 and speed was increased to 600 knots. The pilot's primary task during this leg was to use the VSD and HSD formats to minimize exposure to enemy ground threats. Displayed ground threats included both prebriefed and pop-up threats. Prebriefed threats remained on the displays as long as they were within the selected range. Pop-up threats appeared suddenly as an addition to the prebriefed threats. When a pop-up threat appeared, the pilot activated a navigation update switch that fed the new threat data to the navigation computer so that the flight channel could be modified based on computer-aided analysis of the best evasive tactic. Thirty seconds were required to generate a new flight channel following the pilot's input to the navigation system. Therefore, a control input to update the navigation system had to be made at least 30 seconds prior to intercepting the pop-up threat if it was to be effective. All pop-up threats were presented from 7 to 12 miles away from the aircraft. At an airspeed of 600 knots, the pilot had a maximum of 12 seconds to detect and respond to a pop-up threat that was 7 miles away and a maximum of 42 seconds to detect and respond to a pop-up threat that was 12 miles away. Navigation-update commands at other times in the mission were assumed to be assimilated by the navigation system, but did not actually result in alterations to the flight channel. When evasion tactics were employed, the flight channel was programmed to reintercept the mission leg once the threat had been avoided.

Leg F

The autopilot was engaged at waypoint 6 after crossing the FEBA outbound. The aircraft captured a heading of 190 degrees and the afterburner was used during a Mach 1.6 dash to cruising altitude of 20,000 feet. Power was reduced to 600 knots at top of climb and a systems status check was performed.

Leg G

The aircraft autopilot captured a heading of 126 degrees at the beginning of Leg G. During the return to home base, the pilot exercised the fuel range ring feature of the HSD. A final systems status check was performed in Leg G.

4.5 Emergency Conditions and System Status Reports

Emergency conditions were presented on selected trials in Legs B, C, D, E, F, and G. Warning symbology appeared in the HUD, the master caution light came on and selector buttons blinked for the appropriate status and advisory displays. When this occurred, the pilot selected the proper displays, verbally identified the nature of the problem and performed the appropriate corrective action, if required. Formats for the following emergency conditions were presented:

- Left generator failure - temporary*
- Left generator failure - permanent*
- Right generator failure - temporary*
- Right generator failure - permanent*
- Hydraulic circuit failure - 1B
- Hydraulic circit failure - 2A

- Fuel boost pump failure
- Hung bomb*
- Left engine out*
- Left engine overtemp*
- Left engine fire*
- Right engine out*
- Right engine fire*

Some of the emergency conditions required the pilot to take immediate corrective action. An asterisk (*) has been used to indicate all such conditions in the above list. No emergency, with the exception of the hung bomb, occurred more than once in the same mission leg over the six trials for a given pilot. The top half of Table 4.5-1 shows the assignment of specific failures to mission legs for each of the six trials. A dashed line in the body of the table signifies that no emergency format was presented for a particular leg on a particular trial. The trial numbers in the left column correspond to the numbers in the body of Table 4.3-1, Sequence of Test Conditions.

System status reports were requested during Legs A, B, C, F, and G. In addition to normal systems status, verbal reports of the following degraded conditions were required:

- Fuel boost pump failure
- Closed valve right wing fuel tank - temporary*
- Closed valve left wing fuel tank - temporary*
- Right transformer rectifier failure - permanent
- Left transformer rectifier failure - permanent
- Right generator failure - permanent
- Left generator failure - permanent
- Hydraulic circuit 1B - temporary
- Hydraulic circuit 2A - temporary
- Hydraulic circuit 1B - permanent
- Hydraulic circuit 2A - permanent
- Hung Bomb
- Left engine out
- Right engine out

Two fuel conditions required the pilot to take immediate corrective action, as indicated by asterisks. The bottom half of Table 4.5-1 shows the assignment of specific status formats to mission legs for each of the six trials. No routine status reports were requested during Legs D and E when the pilot was flying manually. The letters F, H, and E adjacent to the trial numbers in the left column stand for the fuel, hydraulic, and electrical subsystems, respectively. Status formats were determined, in some cases, by previously presented emergency conditions. If, for example, an emergency format was presented for a permanent right generator failure, all subsequent electrical status formats indicated a permanent right generator failure. The number of degraded system status formats increased from Leg A to Leg G because each permanent failure remained on all subsequent legs after its initial presentation. Stores status and normal fuel range were added to the Leg F status request. Stores status, engine status and extended fuel range were added to the Leg G status request.

After each pilot had been exposed to all of the test conditions, a questionnaire and a structured interview were administered to elicit constructive comments about the pictorial formats and obtain comparative judgments about the usefulness of the three display presentation modes. The debriefing emphasized the identification of problem areas and suggestions for improvements to the display formats. The test conductor was present during the debriefing period to answer any questions the subjects might have and to ensure that all questionnaire items were answered completely.

4.6 Test Data Collection

It is not uncommon to obtain conflicting results when objective and subjective data collection techniques are used. Differences between pilot performance and pilot opinion may suggest differential sensitivity between the two measurement techniques. Therefore, both sorts of data were collected in this study.

4.6.1 Pilot Performance Measures

Eight measures of pilot performance were recorded. These measures provided quantitative data with regard to the pilots' ability to use pictorial information in the three display presentation modes to accomplish: a) flight path control, b) threat detection and avoidance, c) weapon delivery, d) identification and resolution of

Table 4.5-1. Sequence of Emergency and Systems Status Formats

Trial No.	Emergency formats and pop-up threats						
	Leg A	Leg B	Leg C	Leg D	Leg E	Leg F	Leg G
1	—	—	Pop-up 1 L. generator–temporary	Hung bomb	Pop-up 2 Hydraulic circuit 2A–permanent	—	Fuel boost pump
2	—	Right engine out	Hydraulic circuit 1B–permanent	—	Pop-up 2, 3	R. generator–permanent	—
3	—	Hydraulic circuit 2A–permanent	Pop-up 1	Hung bomb	Pop-up 3 L. generator–permanent		L. engine fire
4	—	—	Pop-up 1	—	Pop-up 3 L. generator temporary	Hydraulic circuit 1B–permanent	R. generator–temporary
5	—	R. generator–temporary	R. generator permanent	Hung bomb	Pop-up 2, 3	Hydraulic circuit 2A–permanent	
6	—	L. engine out	Pop-up 1	—	Pop-up 2	L. engine–overtemp	R. engine fire
	Systems status formats						
1 F H E	Normal Normal Normal	Normal 2A–temporary Normal	Normal Normal Normal	— — —	—	R. valve closed 2A–permanent Normal S–hung bomb	Fuel boost pump 2A–permanent Normal S–hung bomb Engine–normal
2 F H E	Normal Normal Normal	Normal Normal Normal	Normal 1B–permanent Normal	— — —	— — —	Normal 1B–permanent R. generator S–normal	Normal 1B–permanent R. generator S–normal Engine–normal
3 F H E	Normal 2A–temporary Normal	Normal 2A–permanent Normal	Normal 2A–permanent Normal	— — —	— — —	L. valve closed 2A–permanent L. generator S–hung bomb	Normal 2A–permanent L. generator S–hung bomb Engine–L.engine out
4 F H E	Normal 1B–temporary Normal	Normal Normal Normal	Normal Normal R. XFMR RECT	— — —	— — —	Normal 1B–permanent R. XFMR RECT S–normal	Normal 1B–permanent L. XFMR RECT S–normal Engine–normal
5 F H E	Normal 2B–temporary Normal	Normal Normal Normal	Normal 2A–temporary R. generator	— — —	— — —	R. valve closed 2A–permanent R. generator S–hung bomb	Normal 2A–permanent R. generator S–hung bomb Engine–normal
6 F H E	Normal Normal Normal	Normal 1B–temporary Normal	Normal 1B–temporary L. XFMR RECT	— — —	— — —	Normal Normal L. XFMR RECT S–normal	Normal Normal R. XFMR RECT S–normal Engine–normal

degraded system status, and e) identification and resolution of emergency conditions. It was assumed that deviations from the flight path channel, problems in threat detection and avoidance, errors in weapon delivery, and difficulty in the identification and resolution of degraded or emergency conditions would be greater for display presentation modes that were more difficult to use.

Percent of Time Airplane Symbol Within Flight Path Channel

Accuracy of flight path control was measured during Legs D and E when the pilots were flying manually. The magnitude of vertical and lateral excursions from the center of the flight path channel were recorded at a rate of one sample per second. Data collection began when the pilot deselected the autopilot at the beginning of Leg D and ended when the pilot was instructed to engage the autopilot at the end of Leg E.

Latency of Response to Pop-up Threats

Response latency to presentation of pop-up threats was measured in Legs C and E. Response latency was defined as the interval from the appearance of the pop-up threat on the HSD to the pilot's control input to update the navigation system.

Latency of Response to Missile Lock-on Cue

Response latency to presentation of the missile lock-on cue was measured in Leg A. Response latency was defined as the interval from the appearance of the lock-on cue on the HUD to the pilot's control input to fire a missile.

Latency of Response to Bomb Release Cue

Response latency to presentation of the bomb release cue was measured in Leg D. Response latency was defined as the interval from the appearance of the bomb release cue on the HUD to the pilot's control input for weapon release.

Latency of Response and Proportion of Errors in Responding to System Status Formats

Response latency and error data for system status formats was measured in Legs A, B, C, F, and G. Response latency was defined as the interval from the end of the status request to beginning of the response. An error was defined as an incorrect status report ("normal" when actually degraded or "degraded" when actually normal) or a failure to perform the appropriate corrective action.

Latency of Response and Proportion of Errors in Responding to Emergency Formats

Response latency and error data for emergency formats was measured in Legs B, C, D, E, F, and G. Response latency was defined as the interval from the appearance of the emergency format to the beginning of the pilot's verbal response identifying the nature of the problem. All engine, electrical, and stores emergency formats required one or more overt motor responses by the pilot. An error was defined as an inappropriate control input, an omission of a specified control input, or as an incorrect verbal analysis of the problem.

4.6.2 Eye Fixations and Movements

A continuous record of eye fixations and eye movements within the cockpit was recorded for all pilots in each of the display presentation modes. Performance measures included:

- Median dwell time on each display
- Proportion of time spent fixating each display
- Proportion of fixations on each display
- Fixation rate on each display
- Transitional probabilities from one display to another

This data was recorded on video tape for subsequent reduction and analysis. Although care must be taken in interpretating such data, the pattern of eye movements, in conjunction with other performance measures such as response latencies, may reveal display-format deficiencies.

4.6.3 Pilot Opinion Measures

A comprehensive questionnaire was administered after all simulation test trials were completed. The questionnaire was composed of three parts. The first part was designed to examine the pilots' opinions regarding the relative usefulness of the three presentation modes and to evaluate the extent to which the individual formats were integrated into a coherent and comprehensive information presentation system. The second part was designed to examine the pilots' general level of acceptance of pictorial displays and to compare their relative usefulness with conventional aircraft displays. The third, and final, part of the questionnaire was designed to obtain critical comments regarding display dynamics and specific features within display formats. The questionnaire addressed differences between high and low altitude versions of the primary flight and navigation displays. Topics receiving special attention included:

- Flight path channel on the HUD during IMC versus VMC
- Terrain presentation on the HUD during IMC versus VMC
- Terrain and threat presentation on the VSD
- Perspective flight path on the VSD
- Terrain and threat presentation on the HSD
- Target expanded inset, and fuel range ring options on the HSD
- Stores formats
- Engine formats
- Air-to-air format on the HSD
- All system status formats
- All emergency condition formats

5.0 RESULTS - BASIC STUDY

5.1 Performance Data and Multivariate Analysis of Variance

An on-line data acquisition system recorded the time of selected discrete events. Output from the on-line system contained the computer clock time for the following events:

- When the pilot deselected autopilot at the beginning of leg D
- When the pilot selected autopilot at the end of leg E
- When a pop-up threat was presented
- When the pilot activated the navigation update switch
- When the missile lock-on cue was presented on the HUD
- When the bomb release cue was presented on the HUD
- When the pilot released a missile
- When the pilot released bombs
- When the pilot activated the air-to-air master mode switch
- When the pilot activated the MPD mode select switches
- When an emergency format was presented
- When the right or left generator switches were turned on or off
- When the right or left throttle was moved to the idle or off position
- When the pilot activated the engine restart switch
- When the pilot received each pre-recorded message

In addition, the output contained RMS errors for lateral and vertical deviations from the flight channel as well as total time and percent of time that the airplane symbol was within the flight path channel during manual flight. This information was generated at the end of each trial.

Error data and response latency data for pilot's system status reports and responses to emergency conditions were extracted from the audio and the video channels of the video tapes. The error data were obtained by monitoring the pilot's verbal and motor responses and recording whether they were correct or incorrect. Response latencies for system status reports were obtained by searching for successive requests for system status information on the audio channel. For each such request, the digital clock time at the beginning of the pilot's response was recorded. The difference between the message presentation time and the beginning of the pilot's response defined the latency of response measure.

Response latencies for emergency conditions were obtained by locating successive emergencies on the video channel. For each emergency condition, the digital clock time was recorded at the beginning of the pilot's verbal response. The difference between the emergency onset and the beginning of the pilot's response defined the latency measure for emergency conditions.

A preliminary multivariate analysis of variance (MANOVA) was performed to determine if the presence of eye movement recorder had an appreciable effect on the performance measures. The independent variables in this analysis were eye mark recorder with two levels (present or absent) and display presentation mode with three levels (monochrome, color line or color fill). The dependent measures included: percent of time in 150 by 300 foot flight channel, root mean square vertical deviation from flight channel, root mean square lateral deviation from flight channel, latency of response to pop-up threats, latency of response to missile lock-on cue, latency of response to bomb release cue, and latency of response to system status requests. The MANOVA summary table for this analysis is shown in Table 5.1-1. No significant main or interaction effects involving the eye movement recoder variable were found.

Since the eye movement recorder did not differentially affect the other performance measures, these measures were averaged over the eye mark and no eye mark conditions and a second, one-way MANOVA was performed. The independent variable in this analysis was display presentation mode with three levels (monochrome, color line, or color fill). The same seven dependent measures were used in this analysis. The MANOVA summary table for this analysis is shown in Table 5.1-2. Results of the MANOVA indicated no significant difference among the three display presentation modes for the set of seven performance measures.

Table 5.1-3 shows the mean and standard deviation for each performance measure in the three display presentation conditions. As can be seen, three of the seven performance measures (RMS vertical deviation, RMS lateral deviation, and latency to

Table 5.1-1. Two-Factor Repeated Measures MANOVA

MANOVA for pictorial format display evaluation
Effect . . eyemark
Multivariate tests of significance (S = 1, M = 2½, N = 4½)

Test name	Value	Approximate F	Hypothesis DF	Error DF	Significance of F
Pillais	.57759	2.14870	7.00	11.00	.124
Hotellings	1.36735	2.14870	7.00	11.00	.124
Wilks	.42241	2.14870	7.00	11.00	.124
Roys	.57759				

MANOVA for pictorial format display evaluation
Effect . . display
Multivariate tests of significance (S = 1, M = 6, N = 1)

Test name	Value	Approximate F	Hypothesis DF	Error DF	Significance of F
Pillais	.76368	.92331	14.00	4.00	.598
Hotellings	3.23157	.92331	14.00	4.00	.598
Wilks	.23632	.92331	14.00	4.00	.598
Roys	.76368				

MANOVA for pictorial format display evaluation
Effect . . eyemark by display
Multivariate tests of significance (S = 1, M = 6, N = 1)

Test name	Value	Approximate F	Hypothesis DF	Error DF	Significance of F
Pillais	.87741	2.04489	14.00	4.00	.256
Hotellings	7.15711	2.04489	14.00	4.00	.256
Wilks	.12259	2.04489	14.00	4.00	.256
Roys	.87741				

Table 5.1-2. One-Factor Repeated Measures MANOVA

MANOVA for pictorial format presentation mode

Effect .. display

Multivariate tests of significance (S = 1, M = 6, N = 1)

Test name	Value	Approximate F	Hypothesis DF	Error DF	Significance of F
Pillais	.70337	.67748	14.00	4.00	.738
Hotellings	3.37116	.67748	14.00	4.00	.738
Wilks	.29663	.67748	14.00	4.00	.738
Roys	.70337				

Table 5.1-3. Mean and Standard Deviation for Seven Performance Measures

Performance measure	Monochrome		Color line		Color fill	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
% time in 150 x 300 ft channel	76.0	7.5	74.4	9.4	77.6	10.3
RMS vertical deviation	141.3	75.2	132.7	39.8	121.8	65.9
RMS lateral deviation	279.3	157.3	257.3	135.5	249.5	143.2
Latency to popup threats	17.7	6.5	15.5	6.0	13.6	6.8
Latency to missile lock-on	3.1	3.4	2.1	1.2	3.0	3.7
Latency to bomb release cue	2.7	2.0	2.6	2.0	3.6	2.6
Latency to system status request	13.0	3.1	12.6	1.4	12.4	1.5

pop-up threats) showed a consistent improvement from the monochrome condition to the color fill condition. In all cases, however, the variability of scores within each condition was much greater than the differences in mean performance between the conditions. Much of this variability was caused by the high task demands that were intentionally built into the simulation. For example, on selected trials, a pop-up threat was presented shortly after releasing bombs. In addition, a hung bomb condition occurred following bomb release on selected trials. A problem with the bomb release task could precipitate subsequent problems in dealing with the hung bomb or in identification of the pop-up threat. Thus, a pure test of the three display presentation conditions for each performance measure was not possible because of the interdependence of task demands. While the simulation scenario introduced a considerable amount of error variability into the data, it also enabled the test subjects to evaluate a large number of display concepts in a realistic mission-oriented environment. The demonstration of these new pictorial display concepts was considered an important aspect of this study.

5.2 Eye Mark Recorder Data

A frame-by-frame analysis of the eye movement data during manual flight was conducted to transform each video record into a digital format. A video control unit with single frame advance capability was used to obtain the start time for each eye fixation. The following procedure was used to complete the manual translation effort. The cockpit was divided into seven zones for data reduction purposes. These zones were identified as follows:

Zone	Display
1	Head-Up Display
2	Vertical Situation Display
3	Horizontal Situation Display
4	Left Multipurpose Display
5	Right Multipurpose Display
6	Other (caret visible but not on one of the above)
7	Unknown (caret not visible)

The data were recorded using a format that included the display number and the time and frame number at which the eye movement caret first appeared on a display for each fixation. For example, the code 03013425 denotes a fixation on display 3 (Horizontal Situation Display) beginning at 1 minute, 34 seconds and 25 frames into the simulation.

Approximately 30 hours were required to translate 1 hour of video data into a digital format. The video records of eye movements and eye fixations occuring in Legs D and E were analyzed for all pilots in each of the three presentation modes. These legs were chosen for analysis because of the high workload imposed by manual flight, weapon delivery and threat avoidance tasks.

The translated eye data was processed through a screening program that flagged specific data input errors. The raw data were edited to remove all identified errors prior to data analysis. Then, a second computer program was used to generate descriptive statistics for the eye movement data. Table 5.2-1 shows mean performance for the eighteen subjects on four eye-movement variables: median dwell time in seconds, percent of flight time spent fixating on a display, percent of total

Table 5.2-1. Eye Movement Data for Display by Presentation Mode Combinations

Variable	Monochrome					Color line					Color fill				
	HUD	VSD	HSD	MPD1	MPD2	HUD	VSD	HSD	MPD1	MPD2	HUD	VSD	HSD	MPD1	MPD2
Median dwell (sec)	3.4	0.7	0.8	0.6	0.3	3.3	0.7	0.7	0.8	0.6	3.1	0.8	0.8	0.4	0.3
% of total time	82.0	4.2	2.2	0.8	0.3	83.0	3.9	1.6	1.0	0.5	85.1	3.5	1.4	0.7	0.2
% of total fixations	42.6	14.7	7.6	3.1	1.4	43.0	14.8	5.7	3.5	1.5	43.7	12.8	5.3	3.1	1.5
Fixation rate/min	8.1	2.7	1.3	0.5	0.2	8.2	2.8	0.9	0.6	0.2	7.7	2.3	0.8	0.5	0.2

fixations devoted to a display, and fixation rate. As can be seen, eye movements and fixations were dominated by the HUD. Over 80 percent of the manual flight time was spent fixating the HUD. Median dwell times were much longer for the HUD and fixation rates were much higher for the HUD. Pilot eye movements and fixations did not vary as a function of display presentation mode. Indeed, a display by display comparison between presentation modes reveals nearly identical values for all of the eye movement variables.

The remainder of the eye movement analysis was done on data from pilot 10, mission 2, color fill. Table 5.2-2 summarizes relevant parameters for that flight segment and each display. By inspection these data are similar to those of Table 5.2-1 which were averaged across pilots. Number and percent of fixations, total and percent of dwell time and length of fixation are all considerably greater for the HUD.

Table 5.2-3 shows the probability of transition from each display represented by the rows of the matrix to each display represented by the columns. Examination of column one clearly shows that the majority of transitions from all other displays was to the HUD. The transition probability from the HUD was highest when going to the VSD. It should be noted that the probability of transition from the HUD to the OTHER and UNKNOWN categories was higher than to all other displays except the VSD. Because of this, the percent of total time and the percent of total fixations for these two categories were typically higher than for the HSD and the two MPDs. The relatively high percentage of time for the OTHER and UNKNOWN categories resulted from the unique interaction between the cockpit geometry and the NAC Model IV eye mark recorder. Considerable head rotation was required, when wearing the eye mark

Table 5.2-2. Summary of Eye Movement Data for One Flight

	Number of fixations	Percent of fixations	Total dwell time	Percent of time	Median dwell time	Mean dwell time	S. dev dwell time
HUD	34	46.5	240.7	85.1	4.0	7.3	6.8
VSD	14	19.2	18.9	6.7	1.0	1.4	1.1
HSD	4	5.5	4.7	1.6	1.1	1.2	0.3
Left MPD	4	5.5	3.3	1.1	0.8	0.8	0.3
Right MPD	1	1.4	0.9	0.3	0.9	0.9	–
Other	9	12.3	9.1	3.1	0.9	1.0	0.6
Unknown	7	9.6	5.4	1.9	1.0	0.8	0.4

Pilot 10, Mission 2, color fill

Table 5.2-3. Eye Movement Transition Probability Matrix

From \ To	HUD	VSD	HSD	Left MPD	Right MPD	Other	Unknown
HUD	–	.364	.030	.121	.030	.242	.212
VSD	.929	–	0	0	0	.071	0
HSD	.750	.250	–	0	0	0	0
Left MPD	1.000	0	0	–	0	0	0
Right MPD	1.000	0	0	0	–	0	0
Other	.889	.111	0	0	0	–	0
Unknown	.571	0	.429	0	0	0	–

Pilot 10, Mission 2, color fill

recorder, for the pilot to monitor the vertically oriented HUD, VSD and HSD displays. It was possible, however, for the pilots to reduce some of this head movement by deflecting their eyes downward. When this happened the eye mark caret would leave the half silvered mirror and disappear from the video image. Despite considerable effort to acquaint the pilots with this problem, they all tended to revert to the eye deflection habit. Over all subjects and conditions, the percent of total time attributed to the OTHER and UNKNOWN categories ranged from 1.7% to 26.3% with a mean of

9.3%. Over all subjects and conditions, the percent of total fixations on the OTHER and UNKNOWN categories ranged from 5.2% to 50.6% with a mean of 31.4%.

Figure 5.2-1 shows a frequency distribution of dwell times for the HUD. As can be seen, there are a number of very long fixations. The very long HUD fixations in conjunction with the restricted scan pattern suggests that the manual flight control task with the HUD display was very difficult. Another reason for pilot concentration on the HUD is probably that the HUD format contained most of the information the pilot needed, so fewer excursions from that display were required.

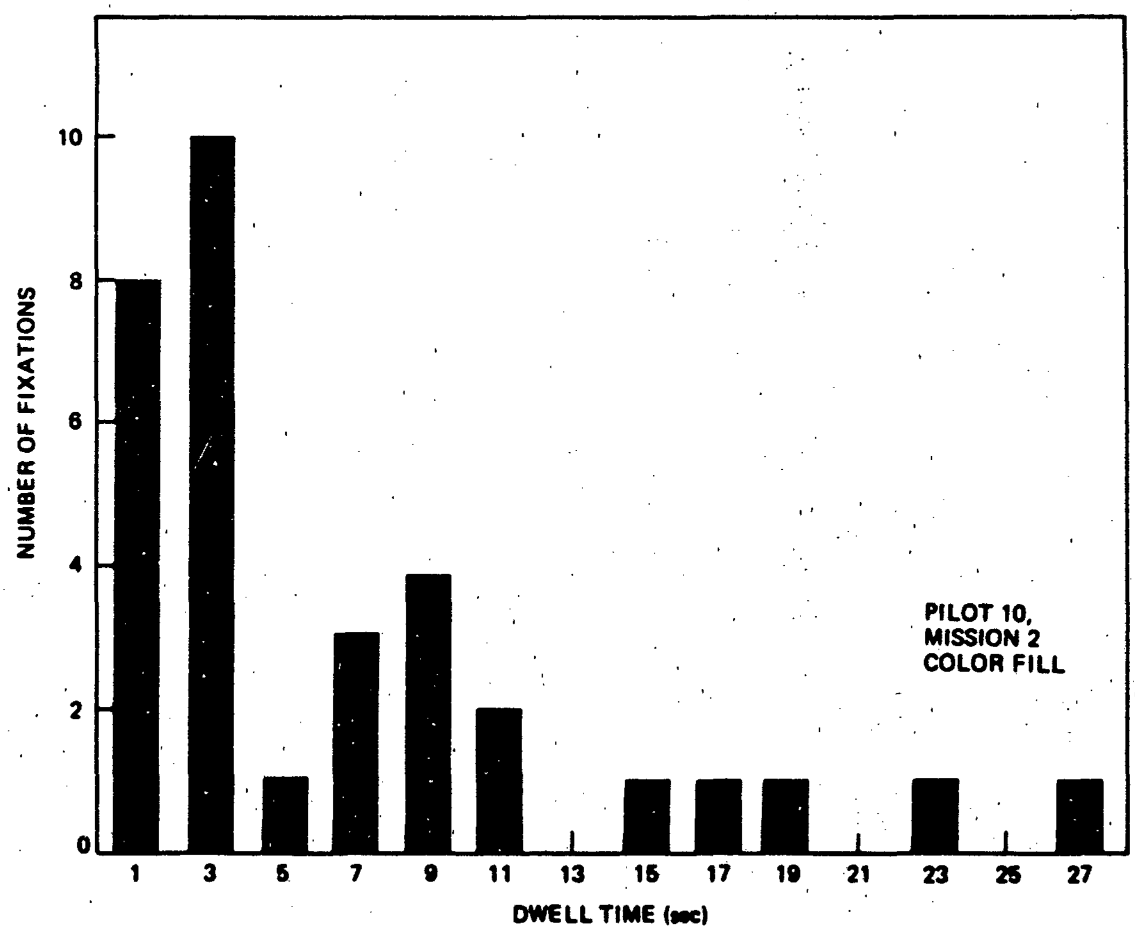


Figure 5.2-1. HUD Eye Dwell Time Frequency Distribution

5.3 System Status Reports, Emergency Condition Responses, and Pop-up Responses

Across pilots and conditions, 2160 individual status report items were requested. Of these, only 44 were omitted or incorrectly reported. Table 5.3-1 shows the distribution by reports and conditions. Eleven of these were in monochrome display mode, 20 in color line and 13 in color fill. Nineteen were committed by pilots when wearing the eye mark recorder and 25 with no eye mark recorder. By Chi-square test, neither of these effects were significant.

On the other hand, two conditions were more frequently reported incorrectly than the others. The "fuel valve closed" report was omitted or was incorrect 21 times ($p < .001$). Fuel range was omitted or incorrect 10 times ($p < .01$).

Across pilots and conditions, there were 378 programmed emergency conditions. Of these, 65 responses or corrective actions were omitted or improper. Table 5.3-2 gives the distribution by system and condition. Twenty of these were in monochrome display mode, 21 in color line and 24 in color fill. Thirty-seven were commited by pilots when wearing the eye mark recorder and 28 when not wearing the eye mark recorder. Again, neither the display mode nor eye mark effects were significant. The problem-type effect was significant. Compared with other response errors, there were significantly more ($p < .01$) missed hung bomb reports (25 of 54 occasions) and significantly more ($p < .001$) missed engine overtemperature reports (11 of 18 occasions).

On each flight, there were two pop-up threats. These were shown as unique shapes on the VSD and HSD. As discussed earlier, appropriate pilot response was to press the Navigation Update button. If this was done soon enough, an evasion course would be calculated and displayed. If not, the flight path continued on through the threat volume. Despite that motivation, a significant number of pop-up threats were missed as shown in Table 5.3-3. By Chi-square test, the difference between eye-mark and no eye-mark was significant ($p < .02$). The presentation mode effect was only suggestive.

5.4 Opinion Data

The formal questionnaires and the list of questions for open-ended responses are given in Appendix A.

Table 5.3-1. Errors or Omissions in System Status Reports

Systems status	Monochrome		Color line		Color fill		Total errors	Total reports
	EM*	No EM	EM	No EM	EM	No EM		
Fuel—normal	0	0	1	0	0	0	1	468
Fuel—boost pump	1	0	0	0	0	1	2	18
Fuel—valve closed	3	2	4	8	1	3	21	54
Hydraulic—all	0	0	1	0	0	4	5	540
Electrical—all	0	0	0	0	0	0	0	540
Stores—all	1	0	1	0	0	0	2	216
Engines—all	1	1	0	0	0	1	3	108
Fuel range	0	2	2	3	3	0	10	216
Total	6	5	9	11	4	9	44	2,160

*Eye mark recorder

Table 5.3-2. Errors or Omitted Responses to Programmed Emergencies

Programmed emergency	Monochrome		Color line		Color fill		Total errors	Total occasions
	EM*	No EM	EM	No EM	EM	No EM		
Generator—temporary	0	0	8	3	2	4	17	72
Generator—permanent	1	0	0	0	0	1	2	54
Hydraulic	0	0	0	0	1	0	1	90
Hung bomb	2	4	3	5	7	4	25	54
Fuel	1	0	0	0	0	0	1	18
Engine—out	0	0	0	0	0	0	0	36
Engine—fire	4	3	0	0	1	0	8	36
Engine—overtemp	3	2	1	1	3	1	11	18
Total	11	9	12	9	14	10	65	378

*Eye mark recorder

Table 5.3-3. Missed Pop-Up Threats

	Monochrome	Color line	Color fill
Eye mark	38.8%	30.5%	27.7%
No eye mark	22.2%	16.6%	8.3%

36 threats per cell

In one part of the questionnaire, pilots were asked to use a score of 100 for color line as a standard and rate monochrome and color fill for usability against a number of detailed questions. This is the method of magnitude estimation described in Reference 3. The Friedman two-way analysis of variance by ranks (Reference 4) was applied to the responses to each question. The mean ratings are profiled in Figure 5.4-1. The results indicate a clear preference for color line over monochrome, and color fill over color line, except for the HUD. Of the four questions on the HUD, pilots preferred color line in the two VMC cases, though the effects were not statistically significant.

In the second part of the questionnaire, pilots rated the pictorial formats used here against the display of comparable information in "conventional aircraft." The results of these ratings are profiled in Figure 5.4-2. In general, the pictorial formats were well accepted. Median response was at least "moderately easier" for all but the HUD, engine status and hydraulic status formats.

The general trends of pilot opinion elicited by the formal questionnaire were detailed in responses to a set of open-ended questions. Responses to those questions reinforced the other questionnaire responses. Except for the HUD, color fill was perferred, with color line next and monochrome last. Except for the HUD under VMC conditions, the pictorial formats were generally well accepted.

The formal questionnaire with average responses, and a synopsis of responses to the open-ended questions, are given in Appendices A and B, respectively.

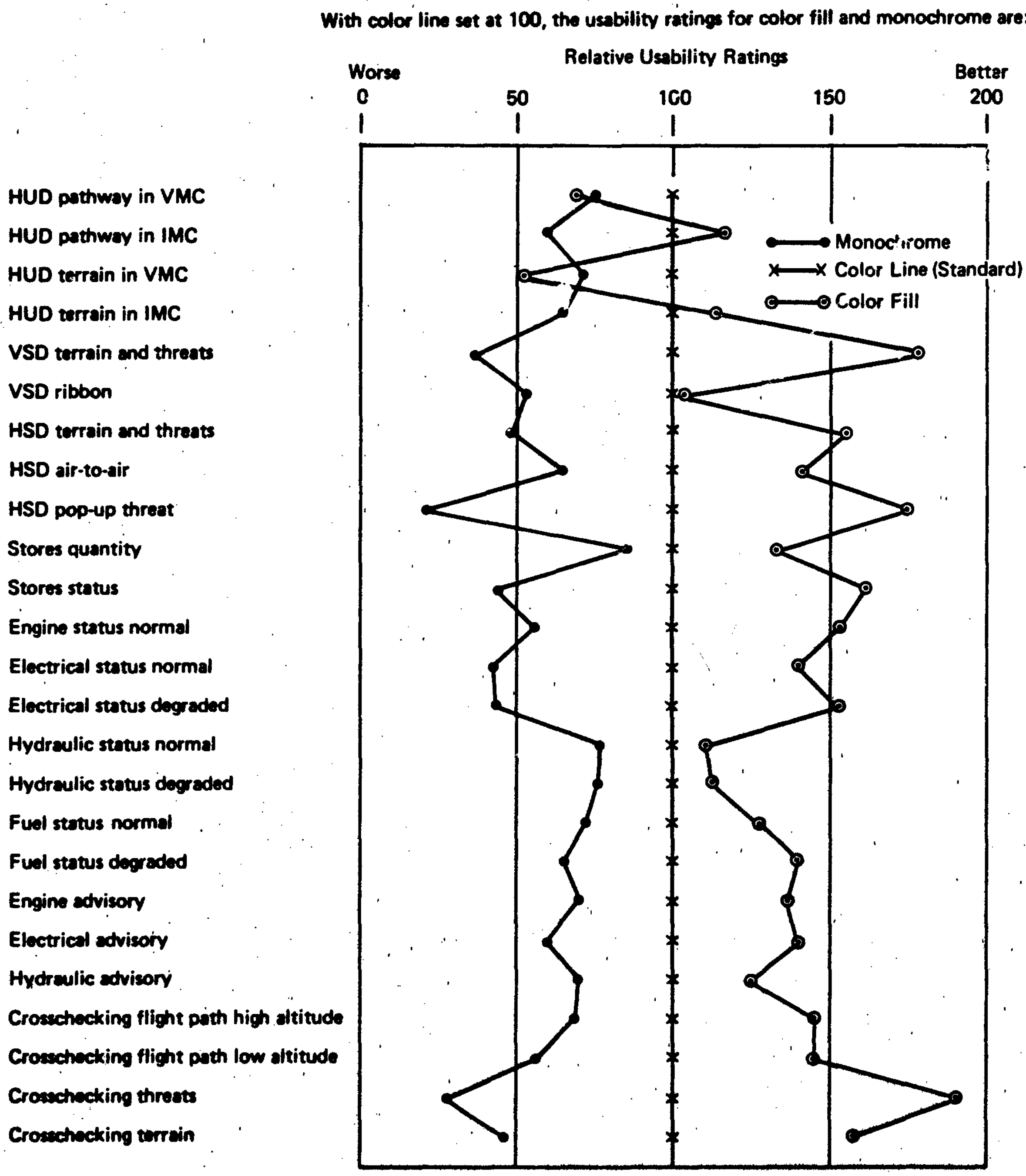


Figure 5.4-1. Profiles of Scaled Comparisons Among Presentation Modes

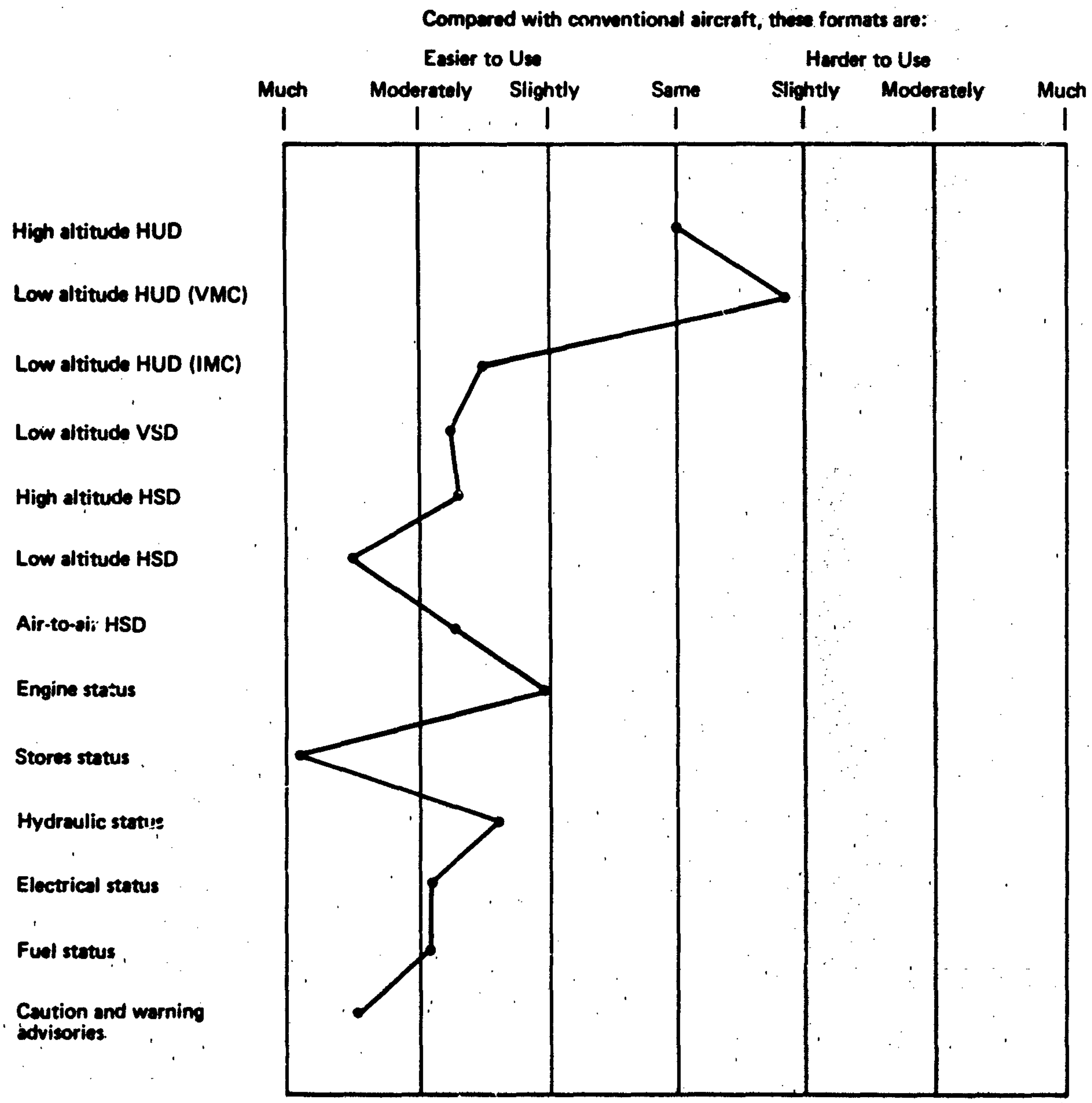


Figure 5.4-2. Profile of Median Comparative Usability Ratings

6.0 INTRODUCTION - THREAT WARNING STUDY

This section and the next four report the threat warning study of the Pictorial Display Formats Evaluation program. This second study was an extension of the effort carried out in the first study. Display formats used earlier were enhanced by adding threat information, while retaining as much of the supporting software and hardware as possible. The display formats of primary interest in the threat warning study were those which depicted threat-related information. These included the low altitude mode of the vertical situation display, which gave a perspective view of the airplane with surrounding terrain and threat information, from a viewpoint behind and above the aircraft. The low altitude mode of the horizontal situation display (HSD) gave much of the same information but in a map-like plan view. The air-to-air mode of the HSD provided information about air-to-air threats. Finally, in the threat warning study, the HUD provided threat alert cues.

The threat warning study had three primary objectives. The first was to develop a candidate concept for pictorial threat displays. The candidate display formats were applicable to both air-to-air and air-to-ground situations, and were compatible with advanced threat warning systems. The second objective was to evaluate the usability and acceptability of the candidate threat warning formats. The third objective was to determine if the degree of usability and acceptability of the candidate display concept was a function of two basic display presentation modes: color and monochromatic.

7.0 TEST EQUIPMENT AND FACILITIES - THREAT WARNING STUDY

The simulation hardware configuration was retained from the first study to the second with very few exceptions. First, the eye-mark recorder and the 70-mm motion picture projector were not used. Second, a push-button switch on the flight control stick and an indicator labeled "EVADE" in the bank of switches between the VSD and the HSD were activated. This switch was used by the pilot to indicate that a short-term maneuver should be flown to evade an incoming missile. With these two exceptions, the configuration described in Section 2 applies.

8.0 TEST FORMATS - THREAT WARNING STUDY

As in the basic study, primary flight and threat information was presented on three displays: a Horizontal Situation Display (HSD) and Vertical Situation Display (VSD) located in the center of the front instrument panel; and a Head Up Display (HUD) located just above the VSD. HSD and VSD information was presented on two eight-inch (diagonal) Cathode Ray Tube (CRT) displays. HUD symbology was projected onto a color-capable combiner designed especially for this simulation. The system status displays from the basic study were available and some were used in the threat warning study.

Each of the pictorial formats on these displays was presented in two versions, or presentation types: color and monochrome. In the monochrome formats, all symbology was composed of black and white lines and surfaces. The color formats consisted of colored outlines and surfaces. Each simulator flight utilized one of the two versions.

Several types of threat-related information were represented in the primary flight displays: threat location, threat type, threat lethality, threat mode (inactive, search, track or launch), and countermeasures effectiveness. Not all information was presented in all three displays, but wherever possible the coding of threat information was similar across displays and for both surface-to-air (S/A) and air-to-air (A/A) threats.

8.1 Primary Flight Displays

The three primary flight displays presented flight information from three different viewpoints, updated in real time. The Head-Up Display (HUD) presented a pilot's eye view of the outside world, with terrain outlines, threat alert information, "own" airplane symbol and the desired flight path superimposed on the visual scene (Figure 8.1-1a). The HUD field of view was 23° (horizontal) by 17° (vertical).

The Vertical Situation Display (VSD) displayed much of the same information, but from a viewpoint 6,000 ft. behind and 1,000 feet above the aircraft, and with a wider field of view (90° horizontal). From this viewpoint, one looked down and forward at the current aircraft position. In addition to terrain outlines, airplane position and the desired flight path, threat, and some terrain altitude information were presented (Figure 8.1-1b). The VSD was truly a situation display, using a remote viewpoint to include one's own aircraft. Aircraft maneuvers initiated by the pilot were reflected by the movement of the ribbon and orientation of the aircraft symbol in the display; the remainder of the display was airplane stabilized.

The Horizontal Situation Display (HSD) gave a view looking straight down from a point directly above the airplane. It showed a plan view of the terrain (including some terrain altitude information) and threat information, along with the flight path and "own" airplane position (Figure 8.1-1c).

It is important to note that for each of the three primary displays, the airplane symbol showed the airplane in the same position relative to the terrain (the plane's current position); only the viewpoints differed. Figures 8.1-1a, b, and c show the viewpoints represented by the HUD, VSD and HSD for a given airplane position.

The VSD and HSD had two modes: navigation (NAV), and Terrain Following/Terrain Avoidance (TF/TA). In addition, the HSD had an Air to Air (A/A) Mode. These modes were selected using the master mode switches located between the VSD and HSD. Pressing the NAV or TF/TA mode switches put the selected format on both the VSD and HSD. The A/A mode switch was "press-on, press-off" and affected the HSD only. Pressing it on caused the A/A HSD mode (160 mile range) to be displayed. Pressing it off returned the HSD to the previously selected mode and scale. The range selection switches for the HSD operated in all three modes.

8.1.1 Head-Up Display (HUD)

An example of the Head Up Display (HUD) TF/TA format is shown in Figure 8.1-2. Outlines of terrain features (mountains) and the horizon were projected on the HUD. In addition, a segmented flight channel (pathway in the sky) defined the desired flight path. The entry gate to the flight channel was 300 feet wide and 150 feet high. The flight channel started 4,000 feet in front of the plane and extended 6,000 feet. Lines on the floor of the "pathway" represented 1000 foot distances along the desired flight

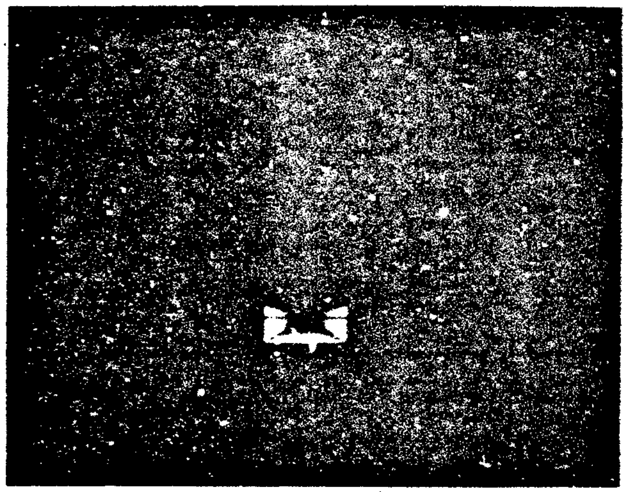


Figure 8.1-1a. Example HUD Display Format

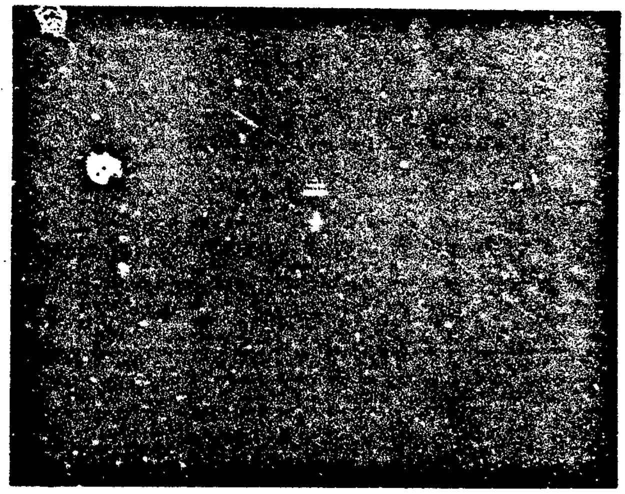


Figure 8.1-1b. Example VSD Display Format

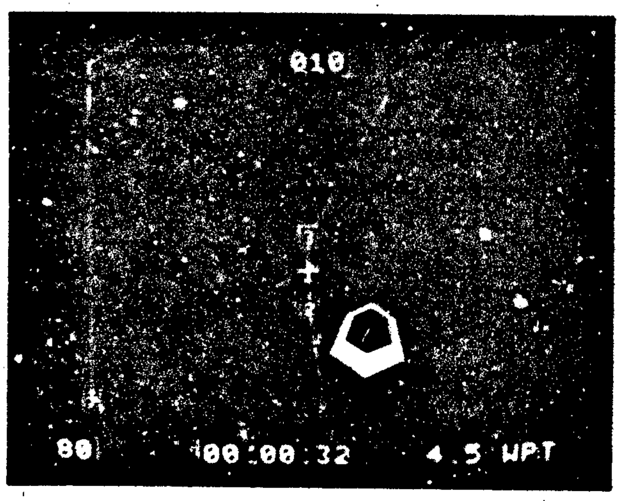


Figure 8.1-1c. Example HSD Display Format

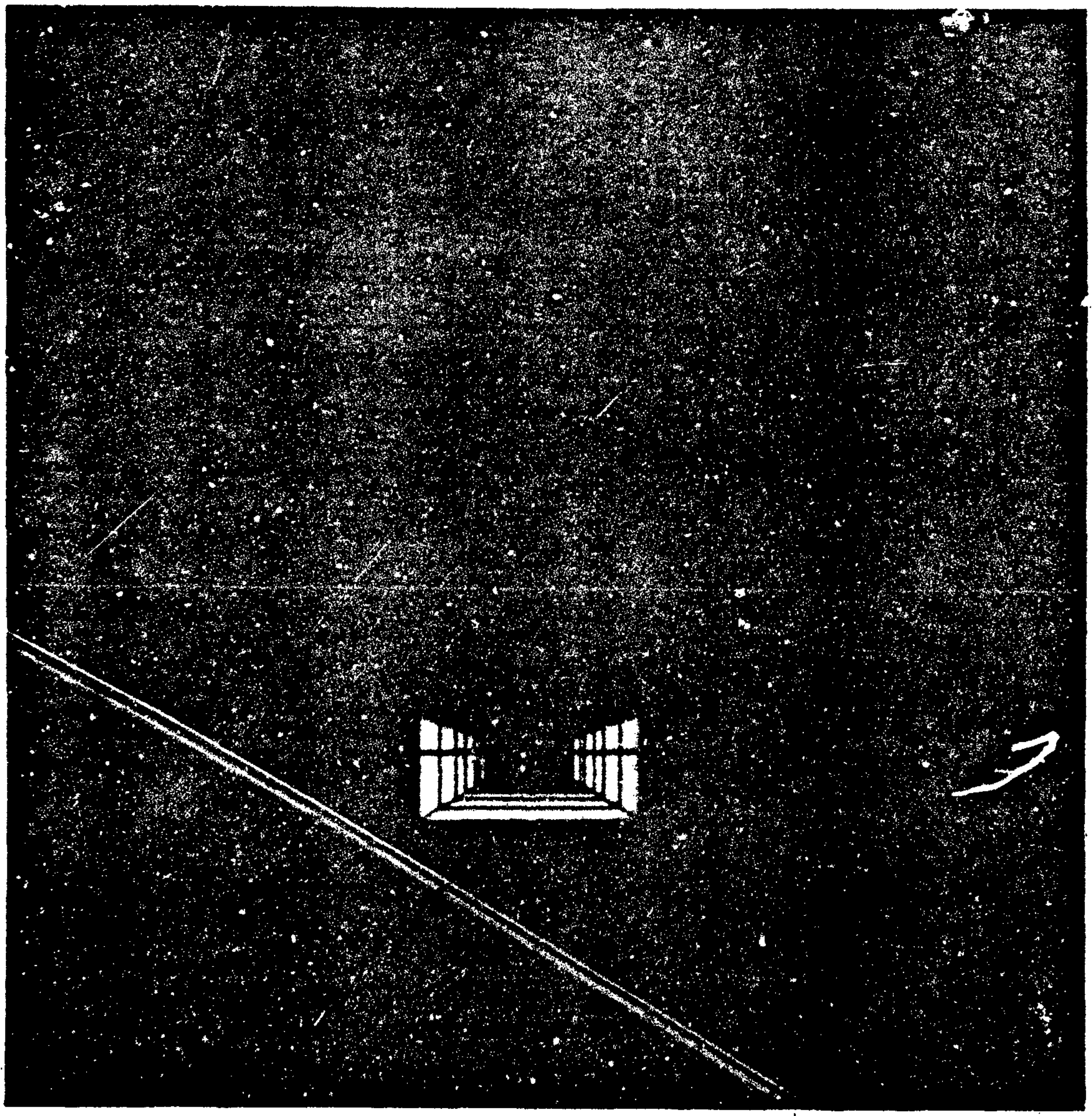


Figure 8.1-2. Head-Up Display (HUD) TF/TA Format

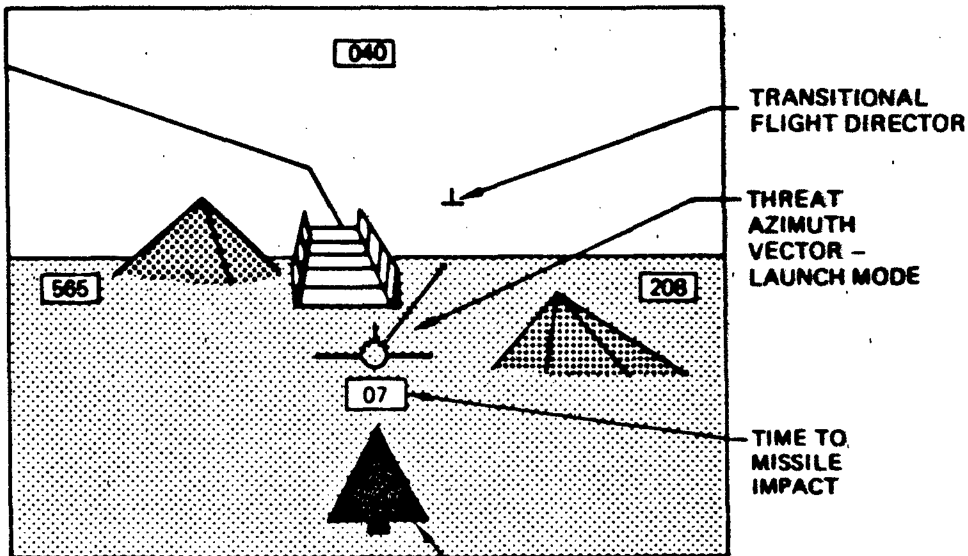
path. If the desired flight path was maintained accurately, the aircraft symbol was positioned in the middle of the "pathway" entry gate, and its "wings" were lined up evenly with the lines that extended outward from the middle of the sides of the flight channel.

If the desired flight path was not maintained, the pathway moved relative to the aircraft symbol, which remained fixed. The entrance of the flight channel in Figure 8.1-2 is displaced slightly below the airplane symbol. This indicates that the pilot should descend slightly to regain the desired flight path. If the aircraft deviated far enough from the desired course, the pathway moved out of the theoretical field of view of the HUD. It did not disappear from the HUD, however, instead it was pegged to the side of the HUD in the direction of its current position. When the pathway was pegged to the side, a transitional flight director symbol (an inverted "T") appeared (shown in Figure 8.1-3) to aid in regaining the correct course. The transitional flight director disappeared once the aircraft was within five degrees of the entry gate of the pathway.

A line which extended from the end of the pathway indicated the desired flight path past the 6,000 foot pathway limit. Other symbology included square waypoint "flags" and triangular target "flags" which indicated the locations of these points relative to the desired flight path. Boxed readouts of airspeed and altitude appeared to the left and right of the aircraft symbol; heading was shown at the top center.

Threat alert information (detailed in Figure 8.1-3) was also provided on the HUD. An airplane- or a missile-shaped "threat alert symbol" represented air-to-air or surface-to-air threats, respectively. The appropriate symbol appeared for six seconds when a threat became active (went into search mode). When a threat went into track mode, the same symbol flashed for six seconds. In launch mode, a vector that gave the relative azimuth of the missile or threat site appeared, along with the flashing threat alert symbol. In addition, a boxed readout of "time to impact" appeared above the threat alert symbol.

The navigation (NAV) HUD format was identical to the low altitude format, except that terrain outlines were reduced to a single artificial horizon.



Information	Levels	Coding in Threat Warning Study
Threat Alert	Search-mode	Air-to-air – airplane symbol; Surface-to-air – missile symbol } 6 seconds
	"Track Mode" threat	Air-to-air – flashing airplane symbol; Surface-to-air – flashing missile symbol } 6 seconds
	"Launch Mode" threat	Same as track mode, but remains for duration of missile launch
Missile Azimuth	0- to 360-deg	Vector to threat or missile azimuth (A/A and S/A) – launch mode only
Missile "Time to Impact"	0 to x secs	Boxed readout of time to missile impact in seconds – launch mode only

Figure 8.1-3. HUD Threat Information Coding

For weapon delivery, an "X" was added to the circle of the airplane symbol when the aircraft entered the weapon release envelope. When the pilot pressed the weapon release button on the control stick to hand the weapon off to the automatic weapon fire control system, the "X" flashed. The "X" then disappeared when the weapon was launched.

Figure 8.1-2 shows the solid "ground" shading of the color presentation mode. In the monochrome version, where such shading was not possible, radials extended from a vanishing point on the horizon in the "ground" portion of the display to distinguish it from the "sky".

8.1.2 Vertical Situation Display (VSD)

An example of the low altitude Vertical Situation Display (VSD) is shown in Figure 8.1-4. As previously discussed, the viewpoint of this display (6,000 feet behind and 1000 feet above the airplane) differed from the pilot's eye viewpoint of the HUD. The VSD field of view (90° horizontal) was significantly wider than the HUD field of view (23°). Much of the basic VSD symbology, however, was similar to HUD symbology. The desired flight path was depicted as a "ribbon in the sky", similar to the "floor" of the HUD "pathway". The ribbon started 1,000 feet in front of the airplane, and extended to 20,000 feet ahead. The lines across the ribbon represented a distance of 2,000 feet. Square flags marked the location of waypoints and a triangular flag marked the location of the ground target.

Airspeed, heading, and altitude readouts, in boxes at the top and sides of the VSD, were identical to those on the HUD. Terrain information on the VSD was similar to terrain information on the HUD, with additional three-dimensional perspective information available. The same basic terrain features were depicted, but terrain above current airplane altitude was colored brown to distinguish it from terrain currently below airplane altitude, which was colored green. In the monochrome version, "above altitude" terrain was solid white, "below altitude" terrain was black. The "ground" area of the display, in both presentation types, included a grid composed of radials extending from a vanishing point on the horizon, crossed by horizontal parallel lines which got progressively closer together towards the horizon. This grid helped to give a perspective to the VSD. The VSD also included other selected terrain

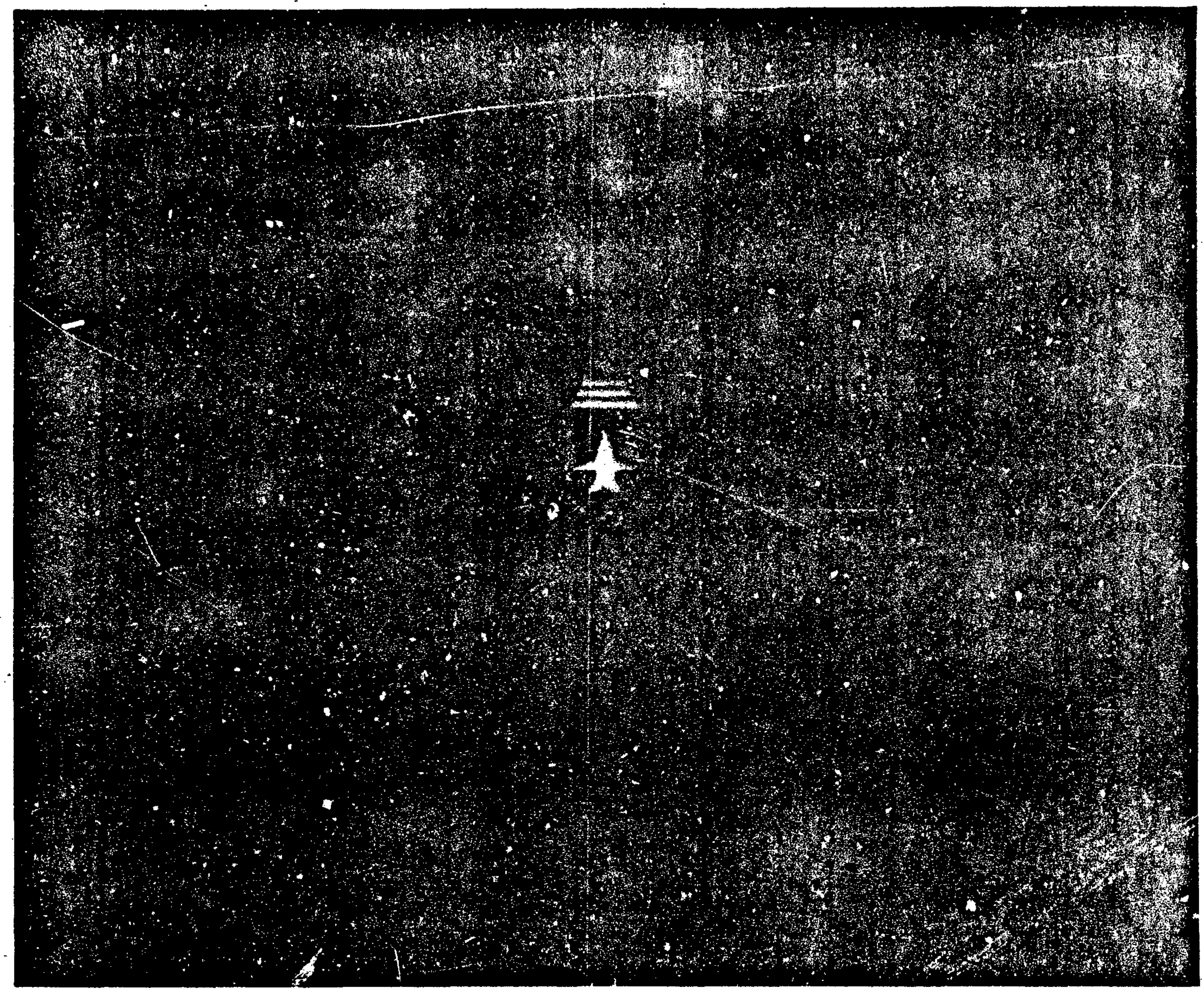


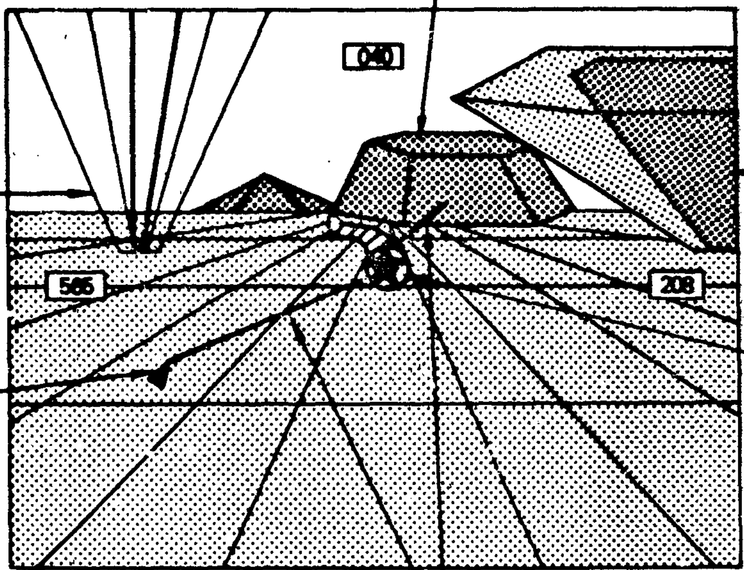
Figure 8.1-4. Vertical Situation Display

and cultural features such as rivers and roads, target, city, and the FEBA (Forward Edge of the Battle Area).

Information about threats was presented pictorially on the VSD as detailed in Figure 8.1-5. The lethality zones of SAM-type threats were depicted as six-sided cone-like objects with their bases up. Their position was shown relative to terrain features and the desired flight path. There were two generic types of SAM's represented: high-altitude and low-altitude, which differed primarily in the height and radii of their lethality zones. Anti-aircraft artillery threats (AAA's) were represented by truncated cone figures, base downward, that were much shorter than the SAM's.

Threat modes (inactive, search, track, launch) were coded as follows. Inactive threats (those known only through intelligence data) were shown in a transparent, outline form. When sensor data indicated an active threat in search mode, the threat was depicted in solid color: SAM's had an inner red (high lethality) area surrounded by a yellow (lower lethality) area. In the monochrome version, the high lethality area was solid white, while the surrounding lower lethality area was black with white outlines. AAA's were solid red, or solid white in the monochrome version. The location (but not the lethality areas) of air-to-air threats was represented by a red triangle.

For threats in track mode, a "tractor beam" was added that connected the threat to a circle around the own aircraft symbol. In launch mode (possible only after the aircraft had entered a threat lethality envelope) the threat lethality envelope symbology disappeared and was replaced by a small "jewel light" at the threat site. (For air-to-air threats, the threat location triangle remained the same for track and launch modes.) A flashing tractor beam connected the circled aircraft symbol to the "jewel light" for as long as the threat remained in launch mode. Even if the site of the threat passed out of the VSD field of view, the flashing tractor beam remained, and the "jewel light" was pegged to the side of the display at the end of the flashing tractor beam. For both track and search modes, the circle around the aircraft symbol was color coded to reflect the status of countermeasures: yellow for effective, red for ineffective or depleted. In the monochrome version, white outline represented effective countermeasures, and solid white represented ineffective or depleted countermeasures.



Information	Levels	Coding in Threat Warning Study
Threat Type		
Surface-to-air	SAM A	"High altitude" SAM – tall core
	SAM B	"Low altitude" SAM – shorter, wider cone
	AAA	Inverted, truncated cone
Air-to-air	—	Triangle (red/white)
Threat Lethality		
Surface-to-air	Low	Yellow/white outline
	High	Red/white
Threat Mode		
Air-to-air, surface-to-air	Inactive (prebriefed)	Outline only
	Search	Outline plus color/white fill
	Track	Tractor beam connects aircraft symbol (plus circle) to threat
	Launch	Flashing tractor beam connects aircraft symbol to "jewel light" at threat site (S/A) ; or to A/A threat position
Countermeasures Status		Aircraft circle:
Surface-to-air	Effective	Yellow fill/white outline
	Not effective	Red fill/white fill

Note: Slash marks separate coding for color/monochrome versions

Figure 8.1-5. VSD Threat Information Coding

The NAV mode of the VSD was a conventional EADI format. It included an airplane symbol, horizon, pitch ladder, and roll indicator, as well as the airspeed, heading and altitude boxes found on the TF/TA (low altitude) version.

8.1.3 Horizontal Situation Display (HSD)

The low altitude Horizontal Situation Display (HSD) gave a plan view of the plane's position and desired flight path relative to terrain features and threats, as shown in Figure 8.1-6. Terrain above aircraft altitude was colored brown: mountain "peaks" were four- or six-sided brown ("above altitude") figures against a green background (in the color fill version). Threats had a red (high lethality) zone surrounded by a yellow (lower lethality) zone. The flight route was represented by a line that connected numbered waypoint boxes. The airplane was always in the center of the display, track up. The airplane symbol remained stationary and the other symbology moved relative to it. The current track was given at the top. The pilot-selectable range was given at the lower left (40, 80, 160 or 320 NM from the top to the bottom of the display). Optional time and distance information to the next waypoint, to the next target, or to home base was displayed at the bottom when selected by the pilot. Other terrain and cultural features were also represented.

Threat information was presented in plan view on the HSD with coding similar to that used on the VSD. Inactive threats were shown in outline form. Threats in search mode were in solid color (or white) and a tractor beam was added for track-mode threats. Unlike coding on the VSD, tractor beam did not flash in launch mode. Instead, a moving circle marked the current position of the missile. HSD threat coding details are summarized in Figure 8.1-7.

The high altitude NAV mode of the HSD showed the flight path, waypoints, and other cultural and terrain features, but the above altitude/below altitude terrain distinction was no longer relevant; the background was black.

The pilot could select among four ranges (40, 80, 160 or 320 NM) for the NAV mode of the HSD, using the switches to the left of the HSD. Time and distance information could also be selected, along with optional fuel range rings, using the same group of switches. The fuel range rings showed the flight distance available with the remaining

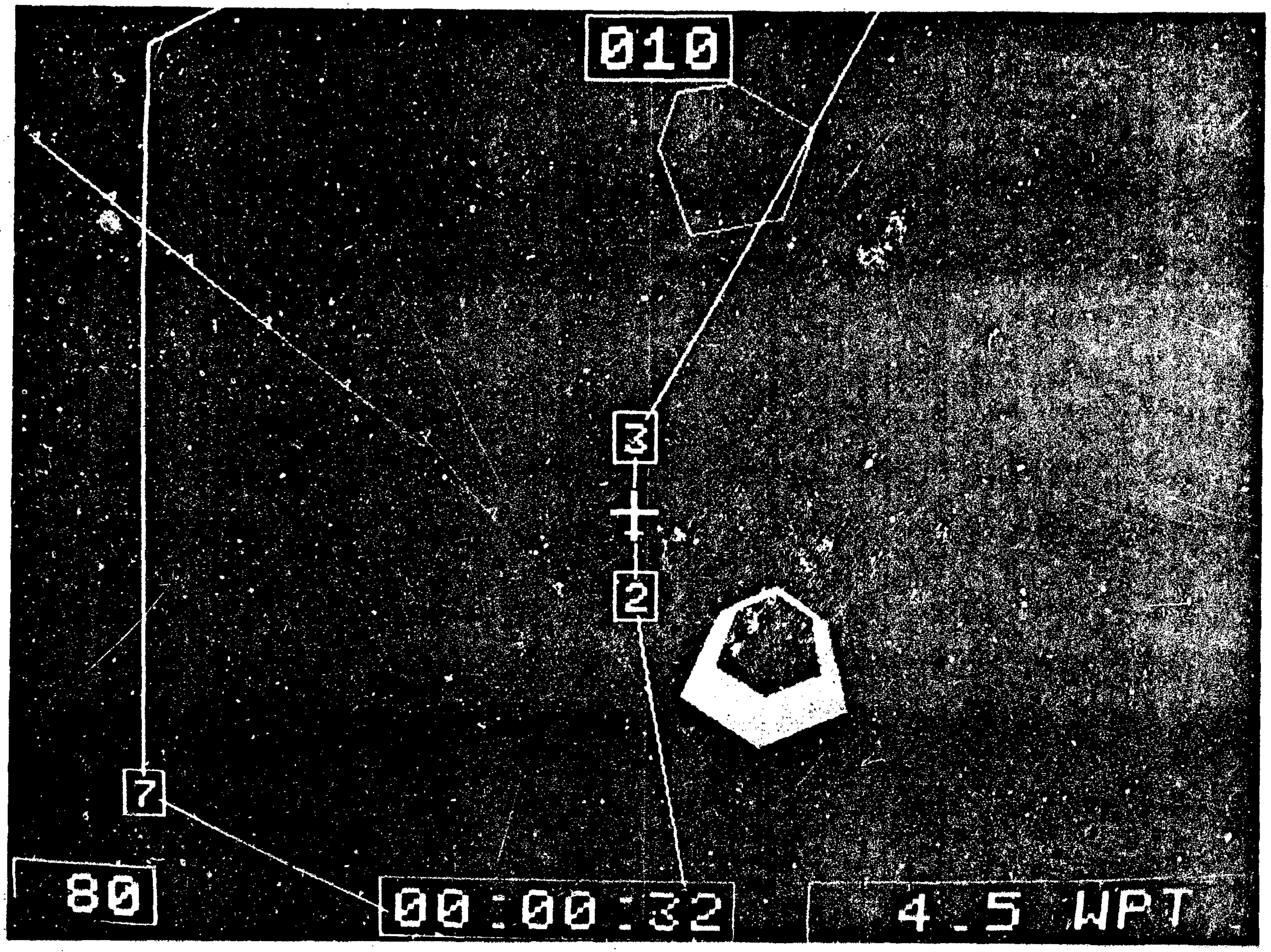
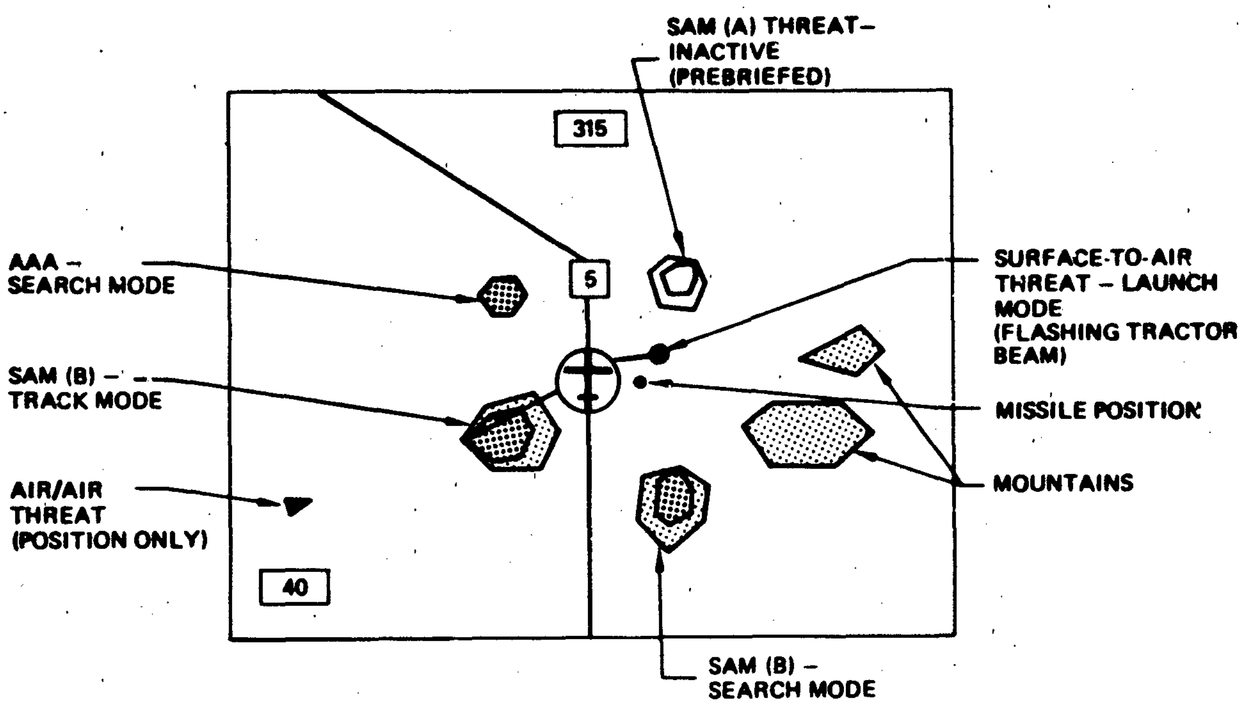


Figure 8.1-6. Horizontal Situation Display



Information	Levels	Coding in Threat Warning Study
Threat Type		
Surface-to-air	SAM A SAM B	Double symmetrical hexagon
	AAA	Regular hexagon
Air-to-air	–	Isoceles triangle
Threat Lethality		
Surface-to-air	Low	Yellow/white outline
	High	Red/white
Threat Mode		
Surface-to-air	Inactive (prebriefed)	Outline only
	Search	Color fill/outline plus fill
	Track	Tractor beam connects aircraft symbol to threat
	Launch	Tractor beam con[illegible] aircraft symbol to "jewel light" at th[illegible] site (threat plan view disappears)

Note: Slash marks separate coding for color/monochrome ve[illegible]ions

Figure 8.1-7. HSD Surface-to-Air Threat Information Coding fuel, for both present configuration (inner ring) and maximum range configuration (outer ring).

8.1.4 Horizontal Situation Display - Air-to-Air Mode

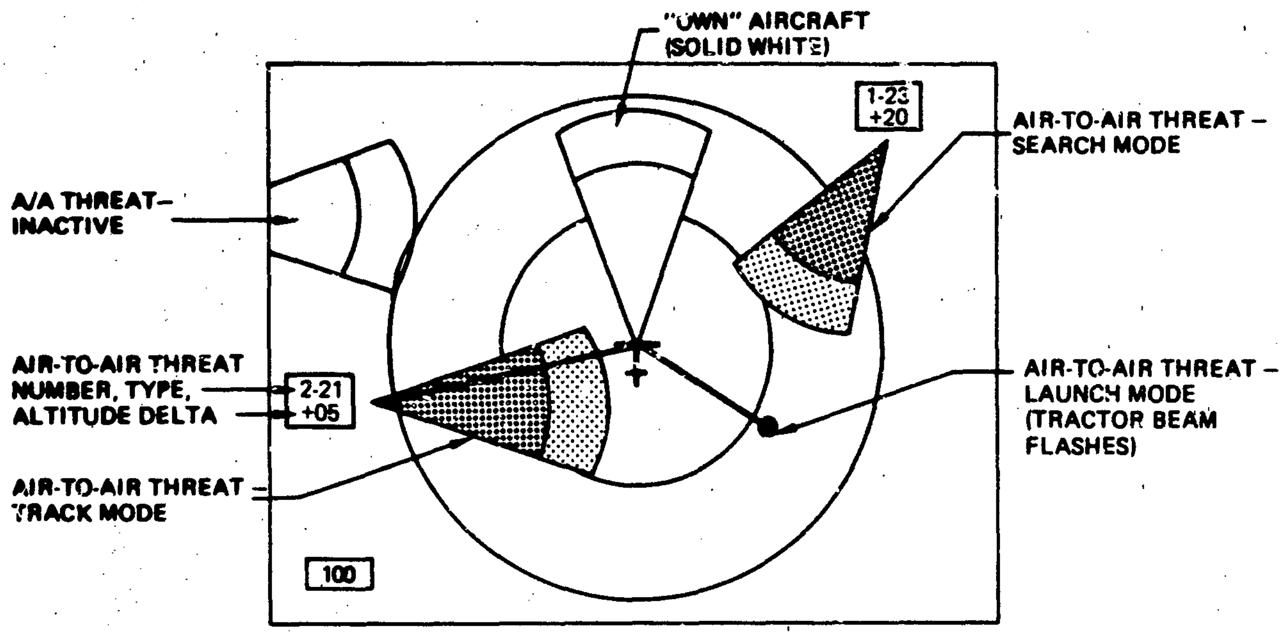
Figure 8.1-8 shows the Air to Air (A/A) mode of the HSD. Each sector represented the missile "lock on" range for an airplane located at the apex, and flying in the direction of the long axis of the wedge. "Own" aircraft sector was white; those of "enemy" aircraft was red and yellow. The inner (red) and outer (yellow) portions of the sectors represented high and lower probability of kill areas. As in the other HSD modes, the display was always track up for "own" aircraft, with a heading box at the top. Range rings represented distances of 40 and 80 miles, and the FEBA was depicted when it was within the display range. The pilot-selectable range (40, 80, 160 or 320 NM) was displayed in the lower left corner.

Air-to-air threat type, number, lethality (p_K) zones and mode information were also presented as detailed in Figure 8.1-9. Air-to-air threat modes were analogous to air-to-ground threat modes: outline, fill, connecting tractor beam, and tractor beam to jewel light at threat location (with missile position indicated by a moving circle) represented inactive (prebriefed), search, track and launch modes, respectively. The number, type and altitude difference (from "own" aircraft, in thousands of feet) were given in alphanumerics in a box at the apex of the air-to-air threat sector. Abbreviated air-to-air threat coding was also given in the other modes of the HSD (NAV and TF/TA). In these formats, an air-to-air threat was represented by an isoceles triangle pointing in the direction of the "bogie's" flight.

8.2 System Status and System Advisory Displays

The Multipurpose Displays (MPDs), located on either side of the HSD, were used to display engine and system status information and to program and display stores options. MPD mode selection switches were located in a group above each MPD. The left MPD, used primarily for stores programming and status, was oriented with its long axis horizontal. Display programming switches were located along the top and bottom of this MPD. The right MPD, used for engine and system status information, had its long axis oriented vertically, with display programming switches on either side (not

Figure 8.1-8. HSD - Air-to-Air Mode



Levels	Information	Coding in Threat Warning Study
Threat Type		
Air-to-air	Mig 21	"21" at apex of sector
	Mig 23	"23" at apex of sector
Threat Number		
Air-to-air	1,2	Number at apex of sector (2 - 21)
Threat Altitude Delta		
Air-to-air	±(x) thousand feet	± x at apex of sector, below number, type
Threat Lethality		
(P_K zones)	Low	Yellow/white outline
	High	Red/white
Threat Mode		
Air-to-air	Inactive	Outline only
	Search	Color fill/outline plus fill
	Track	Tractor beam connects aircraft symbol threat
	Launch	Tractor beam connects aircraft symbol to "jewel light" at threat position – Missile location shown by moving circle

Note: Slash marks separate coding for color/monochrome versions

Figure 8.1- HSD Air-to-Air Threat Information Coding

used during this simulation). The MPD formats used in the threat warning study were unaltered from those in the basic study, described in Section 3.4.

During the course of a mission, the pilot would typically have the engine status format displayed on the right MPD, and the currently selected stores option on the left MPD (initially programmed before the flight began). The other MPD formats, while available, were not exercised in the threat warning study.

9.0 TEST PLAN - THREAT WARNING STUDY

The test plan for the threat warning study was derived from the prime objectives for Phase D. They were to develop a candidate concept for pictorial threat displays, both air-to-air and surface-to-air; evaluate the usability and acceptability of the candidate threat warning formats; and determine if the degree of usability and acceptability of the candidate display concept is a function of the two basic display presentation modes: color and monochromatic.

The intent was to provide an operationally valid evaluation under conditions of moderate experimental control. To this end, current military fighter or attack pilots were recruited as evaluators and a within-subjects factorial design was selected. The test procedure provided an intensive training and practice period before testing began. The test scenario exposed the salient features of the formats. Data were collected to support responses to the program objectives.

9.1 Test Subjects

A total of twelve (12) pilots served as subjects in the study. Five pilots were from McChord AFB and seven from Whidbey Island NAS. The Air Defense Command pilots from McChord were current in the F-106 airplane, T-33 or F-4 while the pilots from Whidbey were current in either the A-6, EA-6B or the P-3. The special qualifications of the pilots are listed in Table 9.1-1. The pilots had an average age of 30 years and an average of 1,524 flying hours in a variety of jet aircraft. The pilots with F-4 and F-106 experience had used HUD's. Those with F-4, or A-6 experience had used threat warning devices. The A-6E pilots had used a cathode ray tube VDI. None of the pilots who served as subjects in the threat warning study had participated in the basic study.

Names, telephone numbers, and home organizations for all participating pilots were made available to Boeing approximately two weeks prior to the scheduled test date. A training package, designed to familiarize subjects with the test objectives, the test conditions, and the simulation facility, was forwarded to all pilots for review prior to the simulation.

Table 9.1-1: Pilot Qualifications

	Mean	Range
Age:	30	24-36 yrs.
Total Jet Hours:	1,524	465-2,600 hrs.

OPERATIONAL EXPERIENCE:

			Ever Used ?		
Pilot No.	Branch	Type of Aircraft	HUD	Threat Warning	CRT
1	AF	F-4, T-38, T-37	F-4 F-15 (Sim)	F-4	No
2	N	P-3, S-2, A-4, F-4, T-28	No	F-4	No
3	N	A-6E, KA-6D, TA-4J, T-2C T-34C	No	A-6E	A-6E
4	N	A-6E, A-4, T-2	No	A-6E	A-6E
5	AF	T-33, T-38, T-37	No	No	No
6	AF	F-106, T-33, T-38, T-37	F-106	T-33	No
7	N	A-6, A-4, T-2, F-14	A-7 (Sim)	A-6	A-6
8	N	A-6, A-4, T-2, T-28, T-39	No	A-6	A-6
9	AF	F-106,T-38, T-33, T-37	F-106	No	No
10	AF	F-106,T-33, T-38, T-37	F-106	No	No
11	N	EA-6B, TA-4J, T-2, T-28	No	EA-6B	No
12	N	EA-6B, A-4, T-2, T-34	No	EA-6B	No

9.2 Test Design

The experimental design selected for this study was determined, as in the basic study, by the desire for economical use of the operational evaluator pilots and by a requirement to minimize the effect of individual differences. For these reasons, a within-subjects design was used in this threat warning study, as in the basic study. There was one independent variable: display presentation mode. It had two levels: monochromatic and color. Display presentation mode was selected as an independent variable in order to determine whether the use of more expensive color displays would be justified by increased usability and pilot acceptance. Each subject was tested in both treatment conditions of the experiment. Therefore, error variability due to individual differences between groups of subjects did not differentially affect the performance measures. This design also minimized the number of subjects required and provided more data per subject than any other design. Training requirements were reduced since skills learned under initial training trials transferred to all subsequent conditions.

9.3 Test Procedures

Before reporting, pilots had access to and were asked to study a "flight manual" (Reference 5) which described the simulator cockpit, the formats to be evaluated and the missions to be flown. The test subjects reported to the Kent Space Center in pairs. Two days were required to process each pair of subjects through the entire training and test sequence. The daily test schedule shown in Table 9.3-1 presents the sequence of events for the first two pilots. The same basic sequence of events was used for all subsequent test days except that the order of the treatment conditions was varied.

Each test day began by bringing the simulator on-line and checking to see that all equipment was operating properly. Any detected deficiencies were corrected before the first practice or test trial began.

On the first day, pilots were given an introduction to the multimission simulator while the cab was being initialized for the first practice trial. Following the introduction, the pilots were briefed on the general cockpit layout, the formats to be evaluated, the operational procedures to be used, and the flight plan for the simulated mission. Static pictorial representations on film transparencies were used to introduce display formats that would be encountered during the practice and test trials. The basic features of each display and the mission profile were described to the subjects. Then the pilots were taken to the simulator cab for familiarization and training.

Each pilot flew four practice trials using a training mission with the same basic mission profile and flight duration used in the test missions. The training mission was flown twice with color and twice with monochrome displays. At the beginning of each practice and test trial, the pilot completed the same preflight checklist used in the basic study. After the practice trials, each pilot flew six twenty-four minute test trials, three with each display presentation mode. The presentation order for levels of the display mode and mission is shown in Table 9.3-2. Entries in the body of the table are the ordinal numbers of each subject's trials. As can be seen, the orders of display mode and mission number were counterbalanced over the twelve subjects.

The pilots wore a headset with microphone during all trials. They were asked for verbal reports of changes in threat status. These responses were recorded on the audio channel of the video tape for subsequent analysis. Required switch hit responses were recorded automatically by computer on magnetic tape and printed out at the end of each days run. Both the videotape and the computer recorded data had clock data (hours, minutes, seconds, video frame, and date) recorded.

Table 9.3-1. Typical Daily Test Schedule

DAY 1	
0730-1000	Bring simulator on line and checkout
0800-0930	Introduction to facility and pre-flight briefing
0930-1020	Cockpit familiarization
1020-1055	Practice trial, color, subject 1
1055-1130	Practice trial, color, subject 2
1130-1230	Lunch Break
1230-1305	Practice trial, color, subject 1
1305-1340	Practice trial, color, subject 2
1340-1415	Practice trial, monochrome, subject 1
1415-1450	Practice trial, monochrome, subject 2
1450-1525	Practice trial, monochrome, subject 1
1525-1600	Practice trial, monochrome, subject 2
1600-1635	Test trial, color, subject 1
1635-1710	Test trial, color, subject 2
DAY 2	
0730-0830	Bring simulator on line and checkout
0830-0905	Test trial, monochrome, subject 1
0905-0940	Test trial, monochrome, subject 2
0940-1015	Test trial, color, subject 1
1015-1050	Test trial, color, subject 2
1050-1125	Test trial, monochrome, subject 1
1125-1225	Lunch Break
1225-1300	Test trial, monochrome, subject 2
1300-1325	Test trial, color, subject 1
1325-1410	Test trial, color, subject 2
1410-1445	Test trial, monochrome, subject 1
1445-1520	Test trial, monochrome, subject 2
1520-1720	Debriefing, questionnaire and taped interview

Table 9.3-2. Sequence Of Conditions For Test Trials

	Color			Monochrome		
Subject	Mission 1	Mission 2	Mission 3	Mission 1	Mission 2	Mission 3
1	1	5	3	4	2	6
2	5	3	1	2	6	4
3	3	1	5	6	4	2
4	4	2	6	1	5	3
5	2	6	4	5	3	1
6	6	4	2	3	1	5
7	1	5	3	4	2	6
8	5	3	1	2	6	4
9	3	1	5	6	4	2
10	4	2	6	1	5	3
11	2	6	4	5	3	1
12	6	4	2	3	1	5

9.4 Mission Scenario

The flight plan for the simulated mission is shown in Figures 9.4-1 and 9.4-2. Table 9.4-1 defines pertinent aircraft conditions and mission events for each leg of the flight plan. The mission covered approximately 240 nautical miles. During each trial the pilot experienced manual and coupled flight, air-to-air and air-to-ground weapon deliveries, and airspeeds from 500 knots to Mach 1.6 under Instrument Meteorological Conditions (IMC).

Table 9.4-1. Flight Plan

Leg	Weather	Control	Altitude (AGL)	Airspeed	Distance	Time
A - Approach FEBA	IMC	Autopilot	20K ft	500 Kts	28 nm	3.35 min
B - Penetration	IMC	Autopilot	20K ft - 200 ft	500 Kts	31.5 nm	3.79 min
C - Approach IP	IMC	Manual	200 ft	500/565 Kts	42 nm	4.59 min
D - Target	IMC	Manual	200 ft	560 Kts	21 nm	2.29 min
E - Withdrawal	IMC	Manual	200 ft	600 Kts	33.5 nm	3.35 min
F - Escape	IMC	Autopilot	200 ft - 20 Kft	Mach 1.6	46.9 nm	2.61 min
G - Return	IMC	Autopilot	20K ft	600 Kts	38.5 nm	3.85 min
					241.40 nm	23.93 min

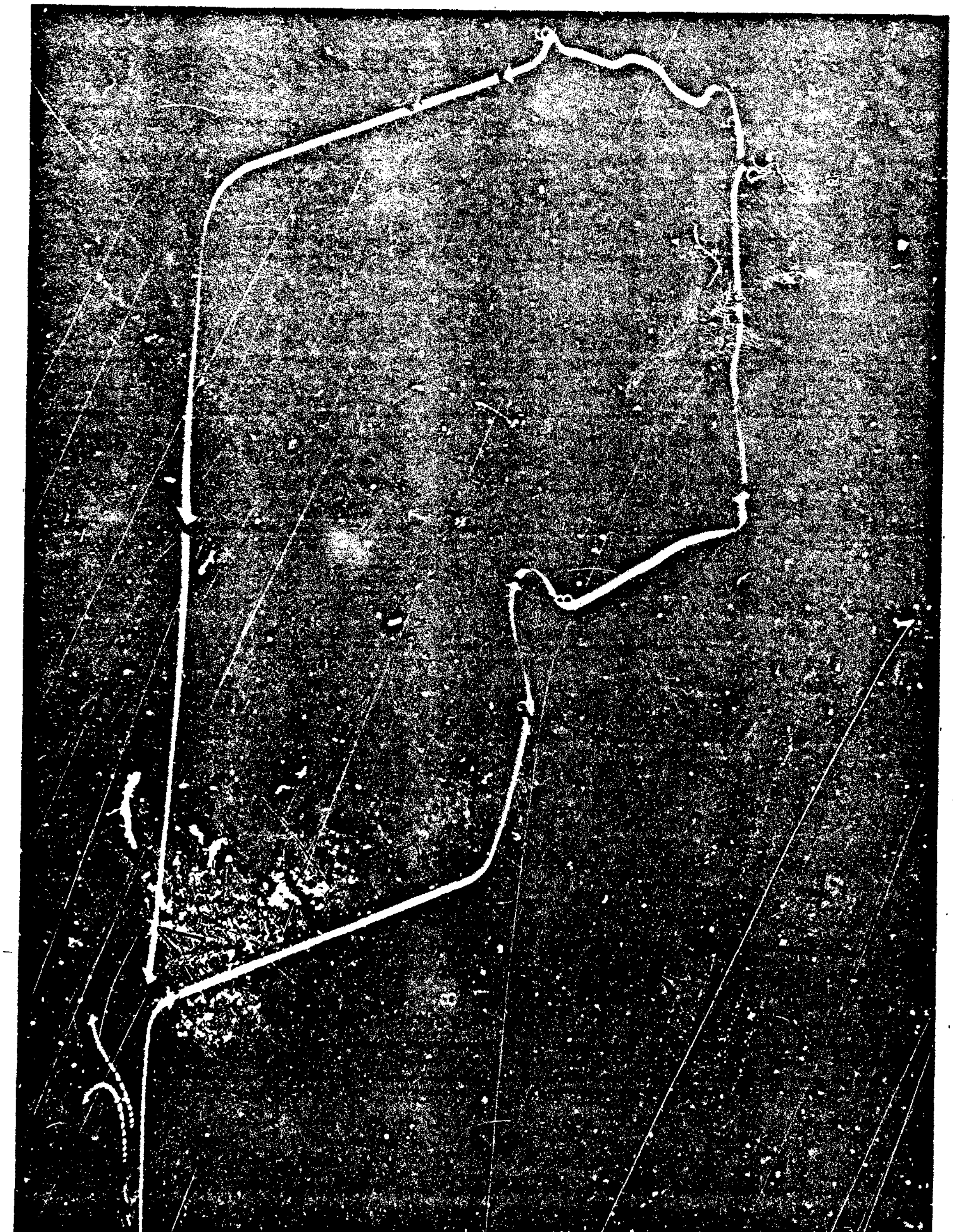


Figure 9.4-1. Mission Scenario

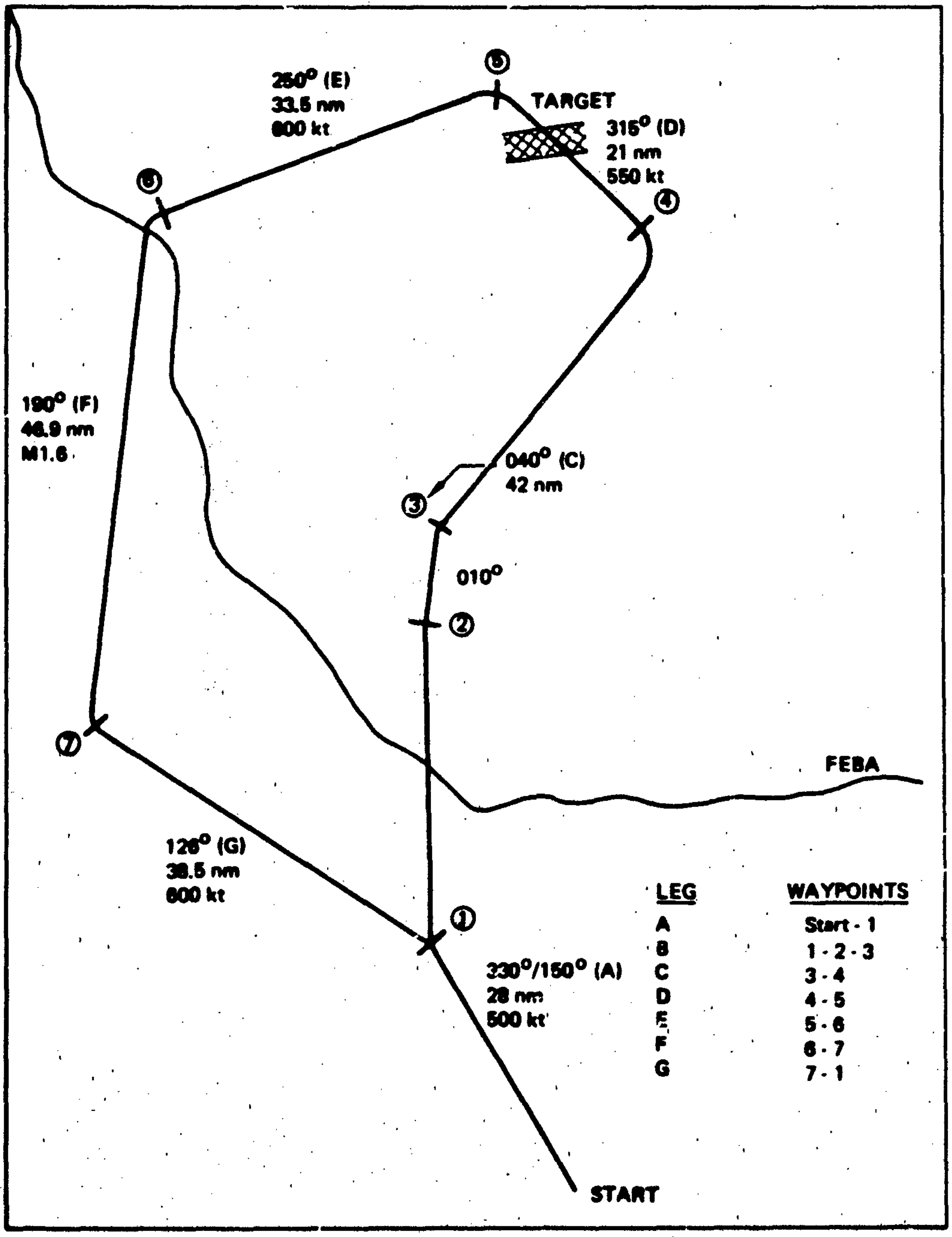


Figure 9.4-2. Navigation Track

Leg A

Just prior to initiating the mission, the pilot exercised the preflight checklist. He used the left Multi-Purpose Display (MPD) to program the weapons options. The initial weapons format showed all stores in the inventory (2 ECM pods, 2 napalm canisters, 2 air-to-air missiles, 12 MK 82 bombs), but nothing was selected or fused.

The missions began with the aircraft on autopilot at 20,000 feet and on a heading of 330 degrees. Cruise speed was 500 knots to the Forward Edge of the Battle Area (FEBA). The aircraft had just completed aerial refueling and was proceeding inbound to the pre-assigned target area, a railroad switching yard.

The pilot encountered enemy aircraft proceeding outbound from the FEBA on an intercept course. The pilot set the ECM pods to ON, selected air-to-air missiles as the active weapon option and turned the master arm on.

The air-to-air format was automatically displayed on the HSD when the enemy aircraft was detected. The enemy aircraft appeared at the top of the HSD Air/Air mode format. An "X" appeared in the middle of the HUD airplane symbol when an enemy aircraft was within radar range. At this point, the pilot could press the weapon release trigger to hand the missile off to the automatic weapon fire control system, and the "X" then flashed. A missile was launched and the enemy aircraft destroyed. When the missile was fired, the flashing "X" disappeared. At this time the pilot set the ECM pods to standby and selected MK 82 bombs as the active weapons option.

Leg B

The aircraft descended from 20,000 feet to 200 feet above terrain immediately after the air-to-air engagement.

During this leg, the pilot was sometimes alerted to a heat seeking missile fired from behind. The pilot was required to activate an "evade" switch during an appropriate time window, 3-5 seconds from missile impact, to simulate initiation of an appropriate evasive maneuver.

Leg C

The autopilot established a heading of 040 degrees at the beginning of Leg C. After this heading was captured, the pilot disengaged the autopilot and flew manually, adjusting the power to maintain approximately 550 knots. The VSD and HSD formats were used to observe the position of enemy ground threats during the approach to the target area.

The pilot's primary task during legs C through F was to use the VSD and HSD formats to minimize exposure to enemy ground threats. Displayed ground threats included both inactive and active threats. On the VSD, inactive, search, and track mode threats remained on the displays as long as they were within the field of view. On the HSD, active and inactive threats were displayed whenever they were within the selected range. When a threat was in track mode, and countermeasures were ineffective or depleted (as indicated by the color of the circle around the airplane symbol), the pilot activated a navigation update switch that fed the new threat data to the navigation computer so that the flight track and the displayed flight channel could be offset to take the best evasive action. When a threat was in launch mode, and the countermeasures were ineffective or depleted, the pilot activated an evade switch (located on the control stick) to simulate initiation of a "jink" evasive maneuver.

Leg D

The pilot manually turned onto a heading of 315 degrees at the beginning of Leg D. The pilot could optionally highlight the target area, a railroad switching yard, as the aircraft approached the weapon release point. All MK 82 bombs were delivered on a single pass over the target. Entry into the weapon delivery envelope was cued by the appearance of an "X" on the Head-Up Display (HUD).

Leg E

The aircraft was flown manually to a heading of 250 degrees at waypoint 5 and speed was increased to 600 knots.

Leg F

The autopilot was engaged at waypoint 6 after crossing the FEBA outbound. The aircraft captured a heading of 190 degrees and the afterburner was used during a Mach 1.6 escape to cruising altitude of 20,000 feet. Speed was reduced to 600 knots at top of climb. On some flights, the pilot was alerted to a heat seeking missile from behind, and responded by activating the "evade" switch. In some missions, an enemy aircraft approached for an engagement in this leg. The pilot disengaged the autopilot and engaged the enemy in manual flight.

Leg G

The aircraft autopilot captured a heading of 126 degrees at the beginning of Leg G. A final enemy air-to-air engagement sometimes occurred in this leg, if one had not occurred in Leg F. The mission ended as soon as the final air-to-air engagement was completed.

9.5 Threat and Mission Variations

Four missions were developed for this study, one for pilot practice and three for testing. These missions varied only in the location and behavior of the air-to-air and surface-to-air threats. Figures 9.5-1 through 9.5-4 show the threat beddown locations for the four missions. In those figures, the circles around the surface threat locations represent maximum launch range at ground level. For air-to-air threats, the bogies' location and the location of our aircraft at the start of the engagement are shown.

The threat encounters for each mission were drawn from a catalog of twenty-four surface threats and twelve air threats. Among the surface threats, seven were anti-aircraft artillery sites, eight were low altitude SAM's and nine were high altitude SAM's. The air threats included four which closed and could be fired upon without maneuvering, four which closed but required maneuvering to hit, and four incoming air-launched missiles which had to be evaded.

Table 9.5-1 shows the threat composition of each of the four missions. Each mission used sixteen of the twenty-four threats, chosen so that each threat was used a total of

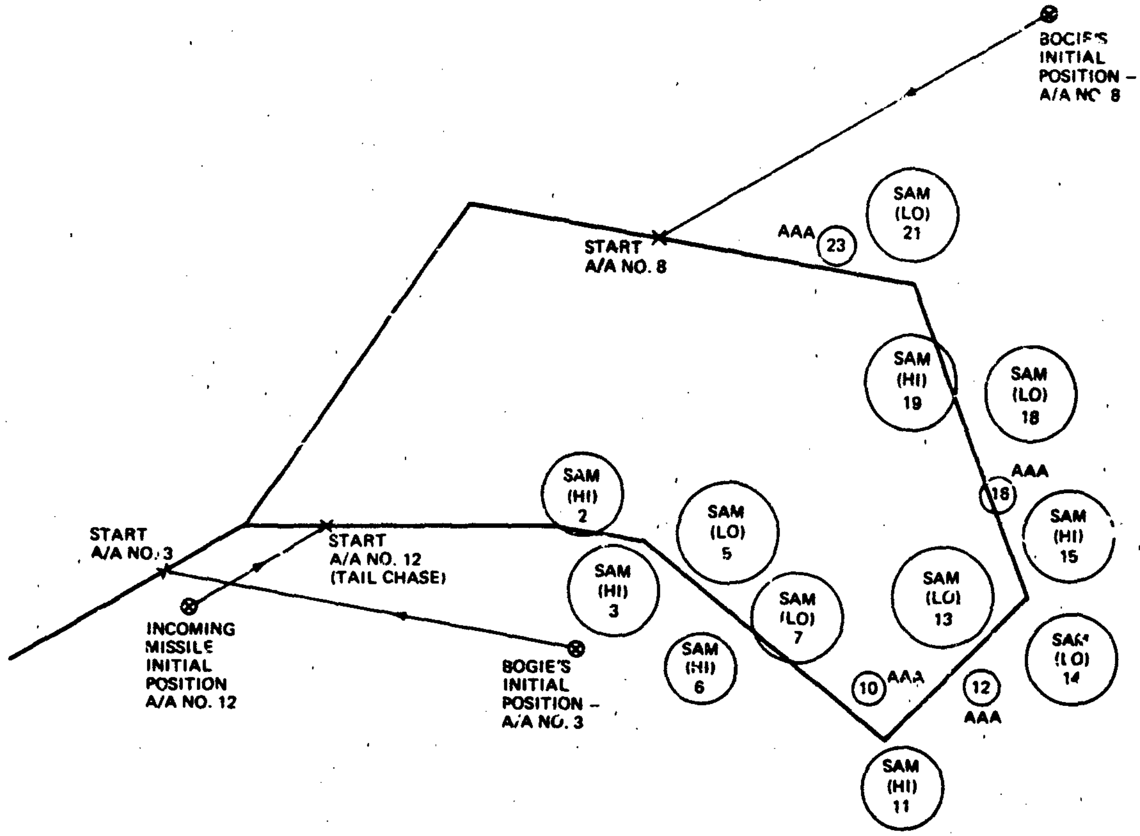


Figure 9.5-1. Threat Locations for the Practice Mission

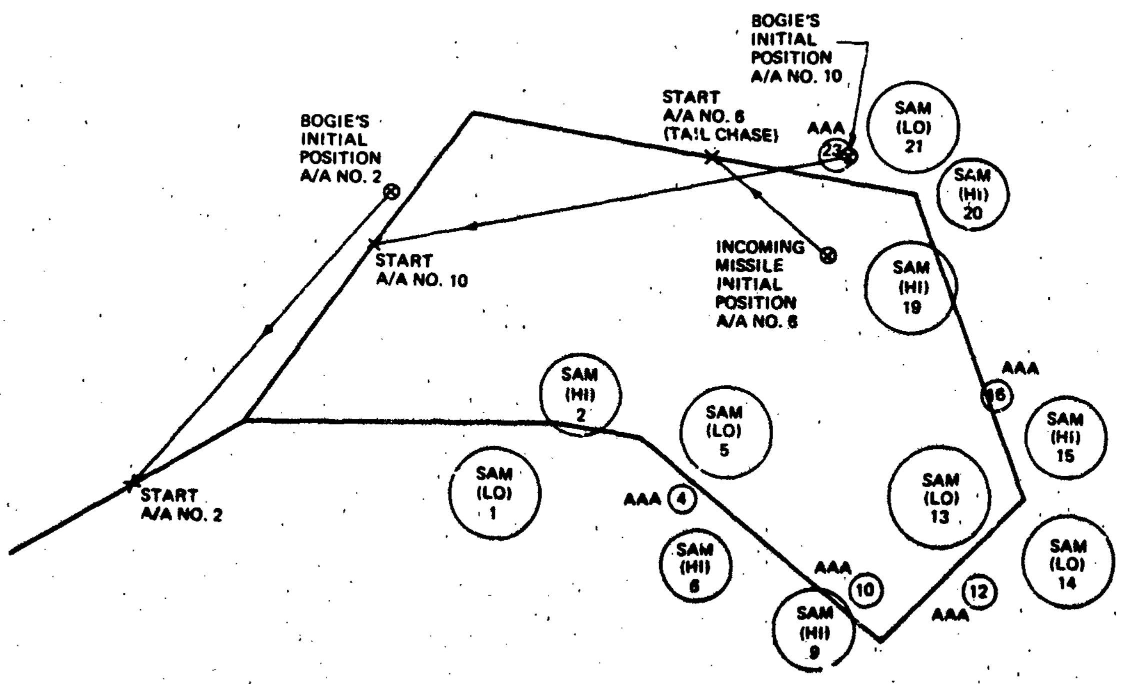


Figure 9.5-2. Threat Locations for Test Mission No. 1

9.6 Test Data Collection

As in the basic study, both objective performance and subjective opinion data were collected. These data addressed the questions of overall suitability of the pictorial format display concepts, the selection between color and monochrome implementations of those concepts, and identification of particular format weaknesses which could be corrected in revised formats.

Ten measures of pilot performance were collected. These measures provided quantitative data on the pilot's ability to use the pictorial formats in the two presentation modes to accomplish flight path control, threat detection and avoidance, and weapon delivery.

9.6.1 Flight Path Control Performance Measures

During three manual legs of the mission, one of the pilot's tasks was to use the flight displays, primarily the HUD, to maintain the desired flight path. Airplane position was sampled at one-second intervals from the time that the pilot, on cue, selected manual flight until the time he, on cue, resumed automatic flight. Four measures were derived from these samples:

- RMS vertical deviation - RMS (root mean squared) error in the vertical or altitude dimension
- RMS lateral deviation - RMS (root mean squared) error in the lateral or cross-track dimension
- Percent of time in flight path channel (150 feet high by 300 feet wide)
- Percent of time in tight channel (75 feet high by 150 feet wide)

9.6.2 Verbal Reports

Throughout the missions, whenever a threat went into an active mode (search, track or launch) or upgraded from one active mode to another more threatening mode, a threat alert symbol appeared on the HUD. The pilots were instructed to report these events immediately with several items of information available from one or more of the three major displays as discussed in Section 8.1. Required verbal responses are given in Table 9.6-1. Three measures were taken of these verbal responses.

- Latency of verbal response - Elapsed time from appearance of threat alert symbol to beginning of verbal response

- Duration of verbal response - Elapsed time from beginning to end of verbal response

- Correctness of verbal response - Was response correct and complete or not?

Table 9.6-1. Required Verbal Responses

Event		Response items (and alternatives)
Threat	Mode	
Air	Search	Threat Type (MIG 21 or MIG 23) Mode (Search, track or launch) Clock position (1 o'clock through 12 o'clock)
Surface	Search	Threat Type (SAM or AAA) Mode (Search, track or launch)
Air or surface	Track or launch	Threat Type (MIG 21, MIG 23, SAM, or AAA) Mode (Search, track or launch) Clock position (1 o'clock through 12 o'clock) Countermeasures effectiveness (Yes or no)

9.6.3 Motor Responses (Switch Hits)

When a threat went into track or launch mode and countermeasures were not effective, the pilots were instructed to respond with an appropriate evasive action. When a surface threat went into track mode, and countermeasures were not effective, he was to press the "Nav Update" switch. If done in time, this would cause the computer to calculate, the displays to show, and the airplane to fly, a safe route around the threat and back to the original flight plan. As soon as any threat launched, and countermeasures were not effective, the pilot was to press the "Evade" switch. For AAA threats, this was to be done immediately, and for missiles (SAM or AAM) this was to be done from three-to-five seconds before projected missile impact. The measures taken on these responses were:

- Latency of "Nav Update" response - Elapsed time from threat going into track mode to switch hit

- Switch hit errors - Inappropriate or missed "Nav Update" or "Evade" switch hit

9.6.4 Weapon Release Measures

The objective of these missions was a bomb drop on a target. The pilots were instructed to press the weapon delivery switch as soon as the HUD weapon release symbol indicated entry into the bomb drop window. They were also instructed to press the weapon delivery switch in air-to-air engagements (two opportunities per mission) as soon as the adversary entered the AAM delivery envelope and the HUD weapon release symbol was displayed. Response latencies to these weapon release situations were measured.

9.6.5 Pilot Opinion Measures

A questionnaire (Appendix C) was administered after the simulation trials were completed. It was divided into three parts. In the first part, ten attributes or characteristics of display symbology were defined. Then the pilots were asked to rate individual elements of the HUD, VSD and HSD symbology on a seven point scale, from "very good" to "very poor", against those attributes. The attributes are listed and defined below.

Usability in Color. How usable was this display element in the color display mode?

Conspicuousness in Color. How easy was it to see this display element in the color mode?

Usability in Monochrome. How usable was this display element in the monochrome display mode?

Conspicuousness in Monochrome. How easy was it to see this display element in the monochrome display mode?

Location. Is this format element in the right place and on the right display (HUD, VSD, HSD)?

Meaning. How clear or obvious is the meaning of this format element?

Precision. Does this format element convey its information with the appropriate level of precision?

Timeliness. Is this format element available to you at the right time and for the right duration?

Training. How easily could this format element be learned?

Workload. Does this format element contribute to workload or relieve it?

In the second part of the questionnaire, pilots were asked to rate the usability of monochromatic and color presentation modes for particular aspects of the HUD, VSD and HSD, and for crosschecking certain information. Again a seven point scale was used, this time from "very easy" to "very difficult".

The third part of the questionnaire was a list of ten open-ended questions. The pilots spoke their responses into a tape recorder and the resulting records were transcribed for analysis.

10.0 RESULTS - THREAT WARNING STUDY

10.1 Pilot Performance Data

Table 10.1-1 summarizes the ten objective measures of pilot performance that were collected in the threat warning study. The data shown are all mean values taken across the twelve subjects and the three missions, repeated once for color and again for the monochrome display version. Although only two of these measures (RMS vertical error and percent correct verbal reports) were statistically significant, all ten showed an advantage for the color display version. The individual response measures are discussed in the paragraphs which follow.

10.1.1 Flight Path Control

Table 10.1-2 gives means for each pilot across the three missions on each of the four measures of flight path control. At the bottom of the table the means and standard deviations across pilots are given as are the four paired measures t-tests. With 11 degrees-of-freedom, the .05 level criterion for significance of a one-tailed test is 2.202. With this criterion, only the difference between color and monochrome presentation modes for RMS vertical error was significant. All four differences, however, are in the expected direction with color better than monochrome.

Table 10.1-1. Objective Performance Summary

	Color	Monochrome
RMS vertical error (feet)	257.1	343.6
RMS lateral error (feet)	1222.4	1696.8
Percent time in 150 foot by 300 foot window	67.7	64.2
Percent time in 75 foot by 150 foot window	44.7	42.1
Verbal report latency (seconds)	2.28	2.35
Verbal report duration (seconds)	3.83	3.94
Percent correct verbal reports	88.47	86.69
Navigation update latency (seconds)	7.17	7.66
Percent correct switch hits	88.83	85.83
Weapon release latency (seconds)	2.52	2.64

Table 10.1-2. Flight Path Control Summary Data

Pilot	RMS (ft) Vertical error		RMS (ft) Lateral error		Percent time in 150 x 300 ft window		Percent time in 75 x 150 ft window	
	Color	Monochrome	Color	Monochrome	Color	Monochrome	Color	Monochrome
1	148.2	197.1	816.8	830.8	81.4	80.1	57.3	56.2
2	287.8	427.3	987.8	913.0	63.1	64.1	37.3	37.5
3	323.0	314.3	2607.2	3025.1	67.5	67.6	49.9	45.4
4	478.3	398.0	1892.0	2382.1	47.5	54.6	24.8	29.7
5	310.6	389.9	772.6	1188.2	47.7	52.4	20.4	24.4
6	375.4	742.6	811.5	983.1	66.5	35.5	40.2	33.9
7	289.2	140.9	1937.2	671.0	70.7	73.9	40.8	48.9
8	117.8	381.5	657.2	3423.6	77.7	62.9	54.7	40.0
9	152.7	407.1	696.1	1047.1	80.3	78.1	65.1	60.3
10	113.7	271.5	677.6	1579.0	78.7	75.3	55.5	45.4
11	303.1	277.2	1704.5	1629.2	58.2	59.4	37.6	35.4
12	185.0	175.4	1108.7	2689.2	73.3	66.0	52.9	48.2
Mean	257.1	343.6	1222.4	1696.8	67.7	64.2	44.7	42.1
S.D.	113.7	159.0	647.1	945.1	11.8	12.6	13.5	10.0
t	-1.943*		-1.673		1.183		1.408	

* Significant, $p < .05$

10.1.2 Verbal Reports

Table 10.1-3 gives the mean latency and duration of verbal reports for each pilot. To make the values as comparable as possible, the subject means include only those cases for each pilot where the particular reports were complete and correct for both color and monochrome display versions. While the mean difference across subjects was not significantly different for either latency or duration, both measures showed the color display version to be slightly better.

Table 10.1-4 gives percent correct verbal reports and the breakdown of incorrect reports into corrected errors, uncorrected errors, and omitted or incomplete reports. By Chi-square test, the difference in frequencies of correct reports between color and monochrome display versions was significant at the .05 level. Again, a slight performance improvement was found with the color formats. The most common errors in these verbal reports were incomplete or omitted reports. Among these, the difference in frequencies of incomplete or omitted reports between color and monochrome display versions was significant by Chi-square at the .05 level.

Table 10.1-3. Verbal Report Latency And Duration (Seconds)

	Verbal Report Latency		Verbal Report Duration	
Pilot	Color	Mono	Color	Mono
1	2.23	2.05	3.51	3.22
2	1.91	1.64	6.69	6.59
3	2.21	2.42	3.12	3.16
4	2.39	2.74	3.38	3.27
5	2.01	2.49	5.27	5.53
6	2.96	3.18	2.68	2.88
7	2.08	1.90	4.29	4.39
8	2.75	2.84	3.88	4.02
9	2.03	2.23	3.82	3.27
10	2.21	1.87	4.12	4.69
11	2.24	2.69	2.17	2.74
12	2.37	2.16	2.99	3.46
Mean	2.28	2.35	3.83	3.94
S.D.	0.31	0.46	1.21	1.17
t	-.794		-1.101	

Table 10.1-4. Percent Correct and Incorrect Verbal Reports

	Correct	Corrected errors	Uncorrected errors	Omitted responses
Color	88.47	2.30	3.93	5.30
Monochrome	86.69	2.62	3.97	6.73
χ^2, df = 1	4.13*			4.71*

*Significant, $p < .05$

10.1.3 Motor Responses and Weapon Release

Table 10.1-5 gives the mean latencies for navigation update and weapon release switch hits. As with the verbal report latencies, the means for each subject include latencies only for events for which the responses were correct in both the color and monochrome display versions. This was an attempt to avoid contamination of the latency data by incorrect responses. For both these measures, the mean latency was slightly shorter for color formats, but neither was statistically significant.

Table 10.1-6 gives percent correct "navigation update" and "evade" switch hit responses. Incorrect responses are broken down into corrected errors, uncorrected errors and omitted responses. By Chi-square test, the difference in correct responses between colored and monochrome display versions was not significant at the .05 level.

Table 10.1-5. Navigation Update and Weapon Release Latencies (Seconds)

Pilot	Navigation update latency		Weapon release latency	
	Color	Monochrome	Color	Monochrome
1	7.33	6.65	1.74	2.84
2	8.92	6.23	5.88	2.11
3	6.59	6.32	1.32	2.48
4	9.13	7.85	1.96	2.17
5	6.33	10.91	4.27	2.80
6	6.58	8.54	2.37	2.90
7	4.87	6.85	4.61	2.09
8	8.39	9.09	2.23	5.73
9	8.63	7.26	1.47	1.41
10	5.85	6.89	1.24	1.72
11	5.22	5.71	2.07	3.13
12	8.19	9.57	1.07	2.31
Mean	7.17	7.66	2.52	2.64
S.D.	1.47	1.57	1.54	1.09
t	-.875		-.218	

Table 10.1-6. Percent Correct and Incorrect Switch Hits

	Correct	Corrected errors	Uncorrected errors	Omitted or incomplete
Color	88.83	1.06	1.33	8.78
Monochrome	85.83	1.67	2.50	10.0

10.2 Opinion Data

Appendix A contains a copy of the questionnaire with mean responses for the rating questions. In general, the responses were fairly tightly grouped and quite favorable.

In Figure 10.2-1, ratings of HUD symbology elements for usability in color and usability in monochrome are plotted as profiles. With the exception of waypoint/target flags, where the ratings are tied, color was judged slightly better than monochrome for all the symbology elements covered. The profiles also show that, except for the transitional flight director, the elements were judged from slightly good to very good. This was the first time the transitional flight director was included in the display, and its implementation was incomplete at the time of the threat warning study.

Table 10.2-1 shows a correlation matrix, across subjects and symbology elements, of attribute ratings for the HUD. For both color and monochrome, rated usability was most highly correlated with precision, timeliness, training and workload. Caution should be exercised in interpreting this correlation matrix and the others to be presented. The characteristics of the response scale and the tight grouping of responses may violate some of the assumptions for the Pearson product-moment correlation coefficient. However, at this level, that statistic provides a valid indication of relatedness.

Figure 10.2-2 profiles the color and monochrome usability ratings for the VSD. For each of the symbology elements, color was rated better than monochrome. Even in the monochromatic mode, only altitude terrain coding was rated as low as neutral.

The correlation matrix for the VSD, Table 10.2-2, shows that for the colored symbols, usability was most closely correlated with conspicuousness, training, workload and precision. For the monochromatic symbols, training, conspicuousness, precision and timeliness were most closely correlated with usability.

As Figure 10.2-3 shows, the profiles of rated usability for color and monochrome in the HSD are parallel and quite close. The two items for which mean ratings were tied, bogie number and type and bogie altitude, are both numeric rather than symbolic elements. All elements in both display modes had mean ratings better than neutral.

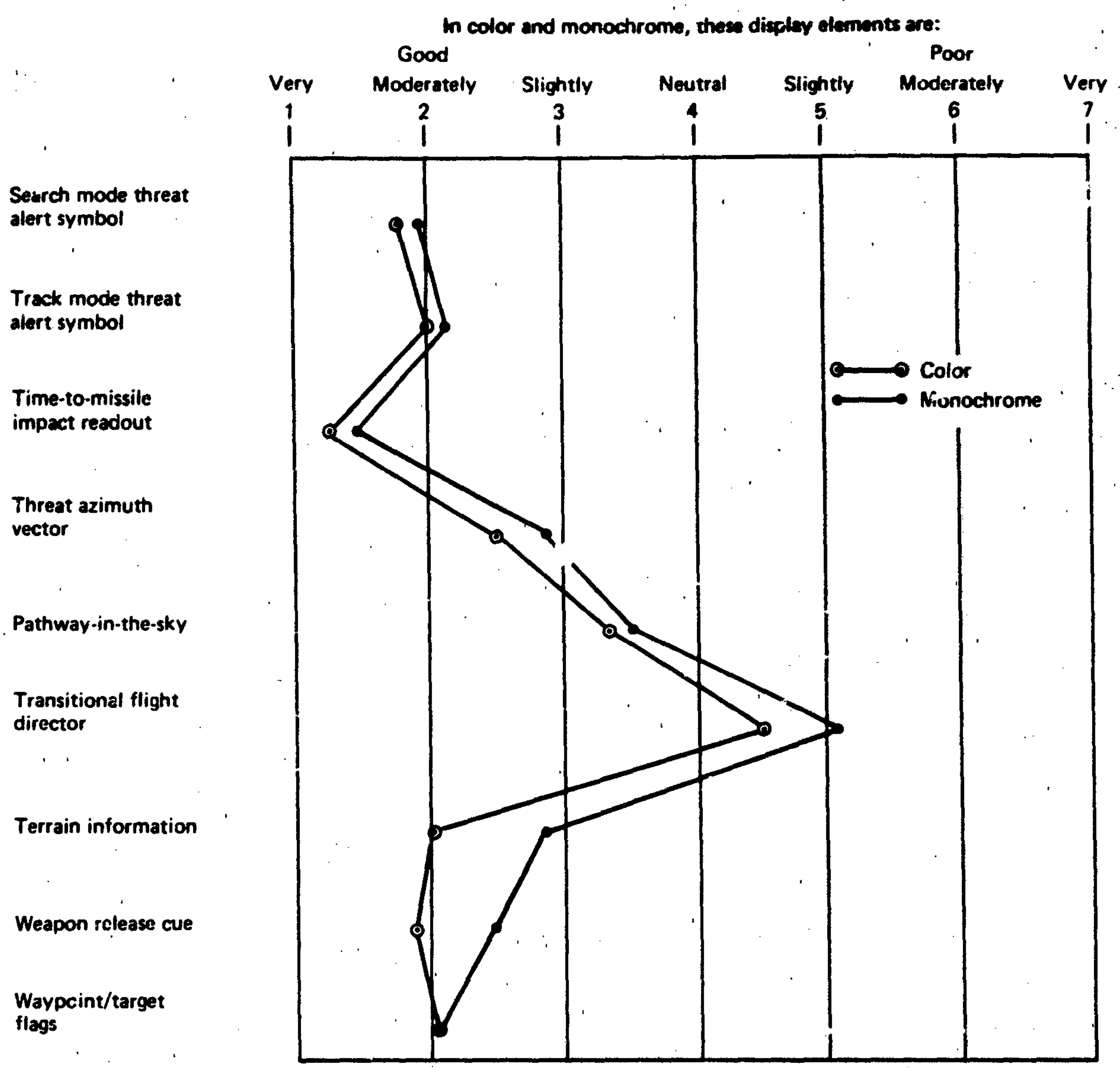


Figure 10.2-1. Usability Ratings for HUD in Color and Monochrome

The correlation matrix shown in Table 10.2-3 shows that for both color and monochrome, usability was most closely correlated with conspicuousness, training, meaning and precision. The HSD correlations are generally higher than comparable correlations for the other displays.

The results of the second part of the questionnaire are plotted in Figure 10.2-4. The pilots were asked specifically to rate the two display modes for difficulty in extracting or crosschecking specific information. The familiar pattern appears - all items were rated neutral or better, with color slightly better than monochrome. The tie was for threat type in the air-to-air HSD mode, which was presented digitally.

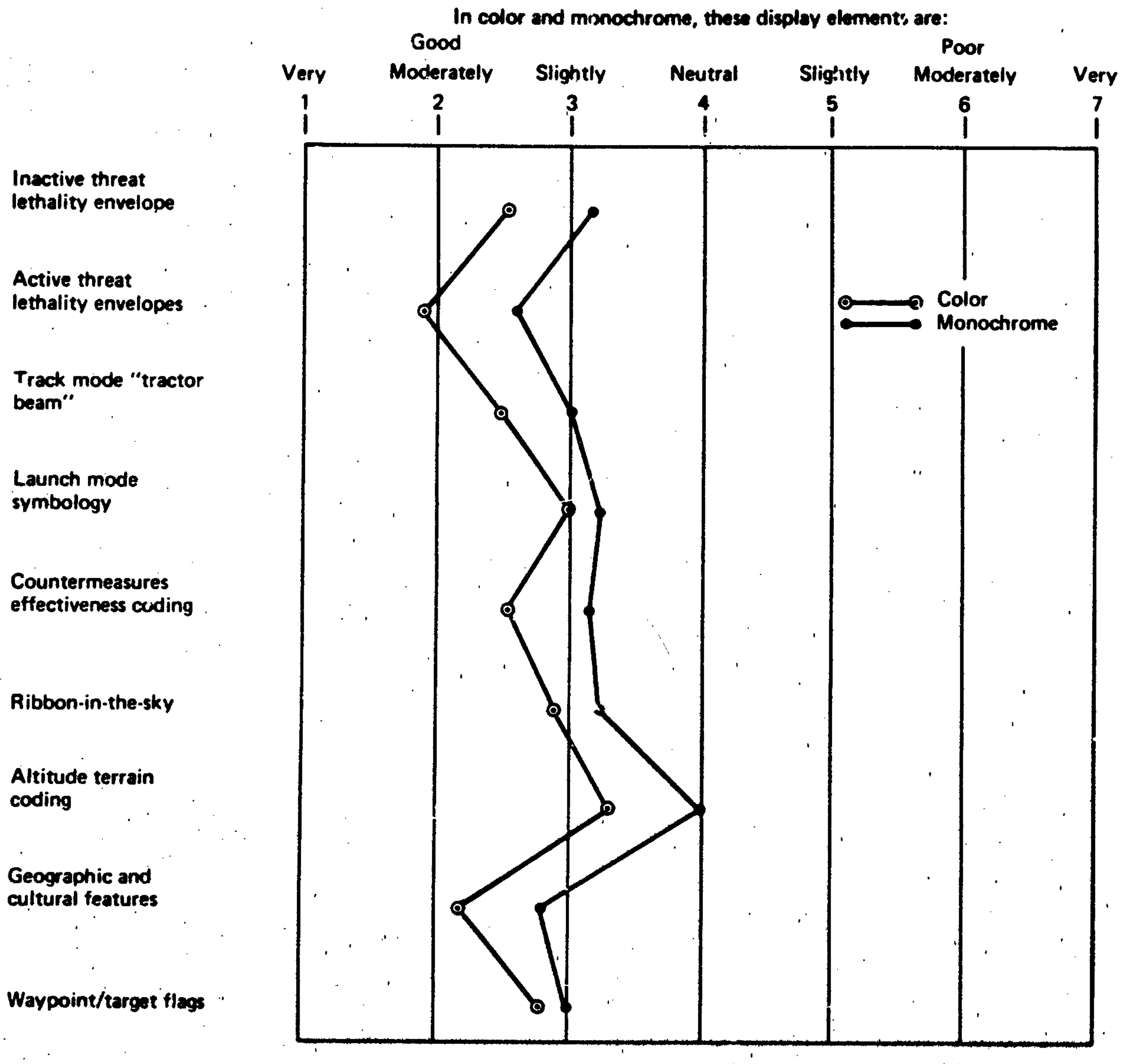


Figure 10.2-2. Usability Ratings for VSD in Color and Monochrome

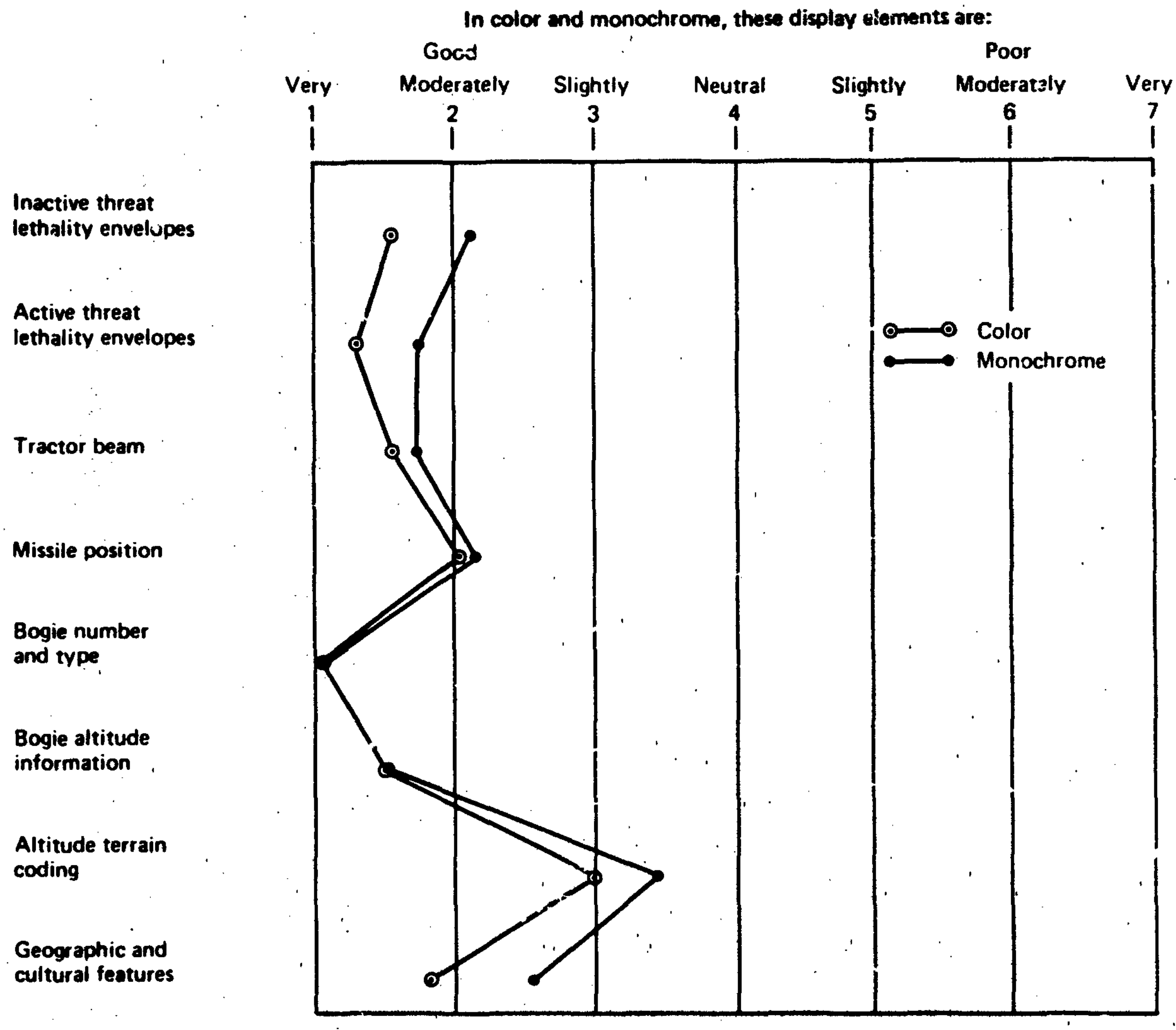


Figure 10.2-3. Usability Ratings for HSD in Color and Monochrome

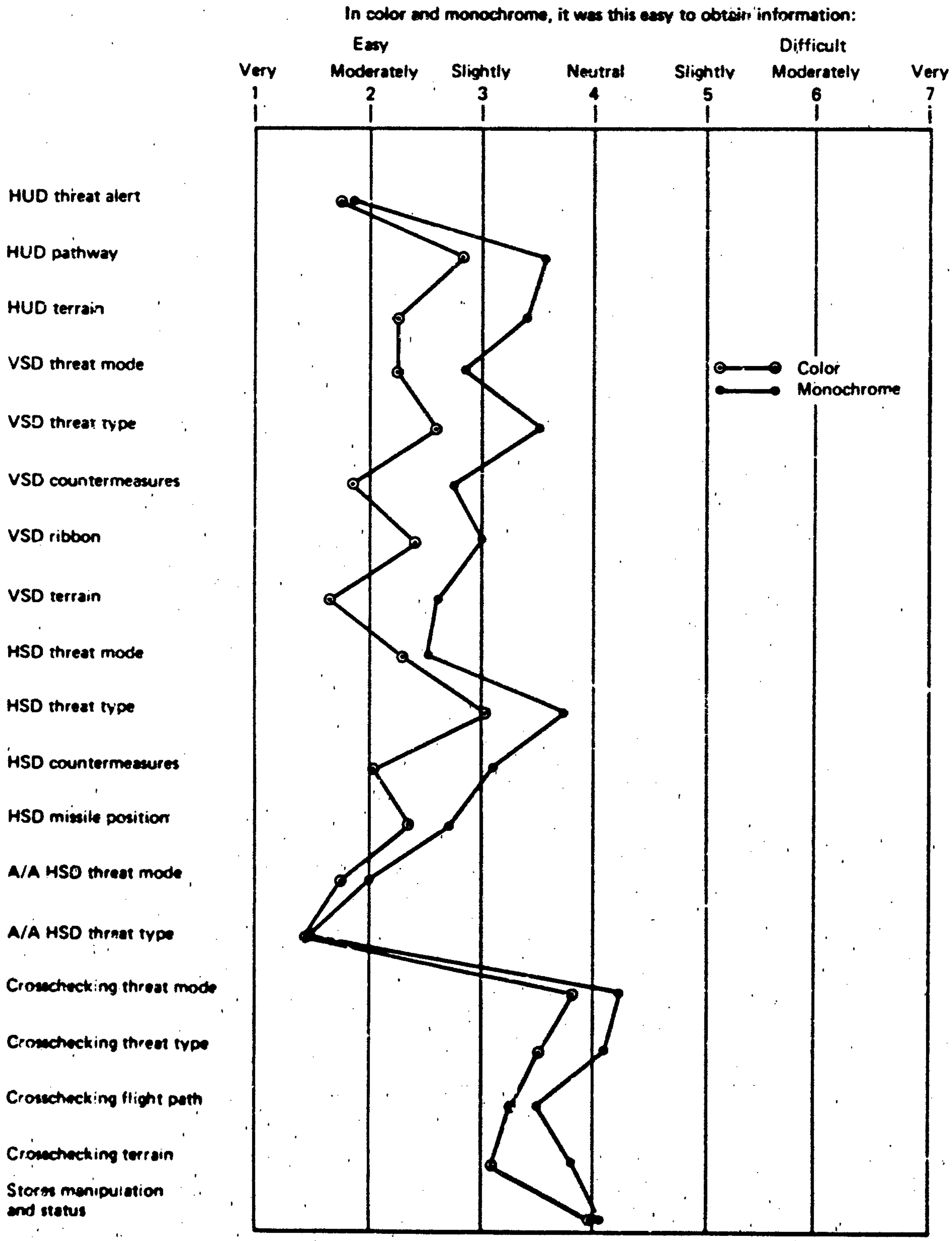


Figure 10.2-4. Ease of Use Judgments for Color and Monochrome

Table 10.2-1. Head Up Display – Correlation Matrix of Ratings

Symbology attributes	B	C	D	E	F	G	H	I	J
A. Usability in color	.68	.97	.55	.66	.75	.93	.93	.94	.89
B. Conspicuousness in color		.75	.94	.98	.43	.60	.59	.77	.52
C. Usability in monochrome			.65	.71	.74	.94	.92	.95	.82
D. Conspicuousness in monochrome				.91	.18	.42	.41	.57	.30
E. Location					.41	.56	.56	.75	.54
F. Meaning						.90	.80	.85	.87
G. Precision							.95	.96	.87
H. Timeliness								.95	.87
I. Training									.90
J. Workload									

Table 10.2-2. Vertical Situation Display – Correlation Matrix of Ratings

Symbology attributes	B	C	D	E	F	G	H	I	J
A. Usability in color	.66	.88	.27	.32	.22	.43	.26	.54	.44
B. Conspicuousness in color		.67	.86	.44	.24	.08	-.11	-.05	-.26
C. Usability in monochrome			.43	.21	.31	.43	.36	.58	.32
D. Conspicuousness in monochrome				.22	.22	-.06	-.17	-.28	-.61
E. Location					-.41	.27	.16	.07	.27
F. Meaning						.25	.14	.28	-.07
G. Precision							.92	.81	.81
H. Timeliness								.88	.66
I. Training									.84
J. Workload									

Table 10.2-3. Horizontal Situation Display – Correlation Matrix of Ratings

Symbology attributes	B	C	D	E	F	G	H	I	J
A. Usability in color	.96	.96	.92	.81	.94	.93	.87	.97	.91
B. Conspicuousness in color		.88	.92	.73	.86	.91	.82	.92	.91
C. Usability in monochrome			.96	.70	.96	.97	.81	.90	.80
D. Conspicuousness in monochrome				.56	.87	.99	.73	.84	.81
E. Location					.80	.59	.86	.86	.77
F. Meaning						.91	.82	.91	.82
G. Precision							.74	.86	.86
H. Timeliness								.94	.75
I. Training									.84
J. Workload									

11.0 CONCLUSIONS AND FORMAT REVISIONS

The basic study was general in the sense that formats were developed and tested for the HUD, the VSD, the HSD, and airplane systems formats on the two MPDs. Some of the format improvements from the basic study were implemented in the threat warning study. In that second study, more threat information was added to the HUD, VSD and HSD formats and the emphasis in testing was on the added threat information. Since there was some format evolution between the two studies and since the objective and methodology of the two studies were similar, conclusions and recommended format changes are combined and presented in this final section. The revised figures for the HUD, the VSD, and the HSD formats represent composites. As such, they include examples of specific symbology which may not all appear simultaneously in actual use.

11.1 General Conclusions

The first objective was to determine whether these formats are usable by, and acceptable to, operational military fighter and attack pilots. Both the opinion and performance data indicate that the concept of pictorial formats and the particular formats studied were usable and accepted by the subject pilots.

The second objective was to determine whether the acceptability and usability of these formats was a function of display mode - color fill, color line or monochrome in the basic study, and color or monochrome in the threat warning study. In both studies, the pilots clearly preferred the color format versions and their performance was slightly better with color.

The final objective was to identify format improvements. From pilot opinion and weak spots in performance, a number of improvements have been identified and are discussed in the subsections which follow.

This is not to say that the work on pictorial format displays is completed with these revised formats. Each specific application will bring its own set of requirements which must be met, some with more empirical study. Since crew information needs in the tactical environment may change considerably with different mission situations and operating conditions, the flexibility offered by electronic displays and information processing should be fully utilized to accommodate changing requirements. Thus, the particular group of graphic formats evaluated in this study should only be considered a representative subset, subject to refinement and revision as needs change.

Also, blending of pictorial format work with other on-going advanced crew station technology will provide additional opportunities for controlled evolution of pictorial format displays. Activity in such areas as flight management, mission management, sensor development for target acquisition and flight path selection, target classification, and weapon delivery all require crew station integration with pictorial format displays to help achieve the transition of air crews from system operators to mission managers, as discussed in Paragraph 1.1.

Finally, the present program has raised a number of new issues. Some general ideas are presented here, and those which are format-specific are discussed under the specific displays.

Both the basic study and the threat warning study were aimed at simulating and evaluating candidate concepts for pictorial flight, situation, systems, stores and threat warning displays. As such, the displays used in the simulation represented a first attempt to integrate and portray a wide range of information in a pictorial, rather than alphanumeric or strictly analog format. In order to progress from "concept" displays used in laboratory simulations, to displays that can be used as an integral part of an aircraft cockpit, numerous issues must be resolved. These factors range from psychophysical, perception-related parameters to questions of information structure and priority, and include such questions as the following:

- Display field of view
- Optimum size, color, duration, brightness, and flash rates (where necessary) for symbology
- Optimum display size and placement
- Range limits for terrain and threat information

- Algorithms for threat display decisions in high threat density situations, based on mode, range and time factors
- Pilot-selectable declutter options and format changes based on mission segments
- Role of voice commands in entering and requesting information, and of voice annunciation or aural warnings for threats or other warning information

11.2 Head-Up Display

The HUD display format, as tested in the basic study, was not a unanimous success. Pilots tended to have difficulty with it initially, and even after a significant amount of practice this format would have to be considered a high workload contributor. Overall, nearly one-third of the pilot ratings of this display suggested that it was the same or more difficult to use than information in conventional aircraft. The usability of the HUD received a lower rating than any of the formats tested.

Several factors likely contributed to this result. The three-dimensional flight director pathway, including the dynamics of flight path commands and "airplane" handling qualities, were all unfamiliar to the evaluators. The concern with color fill obscuration of the outside scene during VMC was the major source of lower ratings. As the primary flight display, and as the only source of this type of information during low altitude mission segments, the HUD would be expected to command a high percentage of the pilot's attention. This was further accentuated by the degree of precision in flight control elicited by the flight director channel during manual flight. The dimensions, sensitivity and dynamics of this symbology can undoubtedly be improved upon. Moreover, the precise flight path control called for during particular segments of TF/TA and weapon delivery should probably be relaxed at times when requirements are less severe.

Nevertheless, a large number of improvements were suggested for the HUD format and have been incorporated in the revision. A simple steering symbol has been added. This symbol would appear any time that the entry gate of the pathway is at the peripheral limits of the HUD display, and would provide the pilot with director information to smoothly re-intercept the desired pathway. At the pilot's option, steering symbol dynamics and geometry could be coupled with a cursor in the HSD that allows pilot selection of the re-interception point. This has the further advantage of allowing close-in manual threat and missile avoidance maneuvering with easy return to the preferred flight route at any desired point.

Indicators have been added for air-to-air and surface-to-air threats. These symbols would appear for a specified period whenever the onboard threat warning system detects pop-up threats not previously known to the system, and would serve principally to alert the pilot to new threat information appearing on the situation displays.

An optional vertical velocity indication has been added, primarily to assist the pilot with precision altitude control and pitch trimming functions. To eliminate any ambiguity in viewing the three-dimensional flight pathway, particularly during maneuvering turns where the channel may overlap itself, the 1000-foot segment lines have been eliminated from the outside and used only on the inside of the pathway.

For medium and high altitude flight, a pilot selectable pitch ladder and roll index are recommended. This could be accompanied by some damping of the flight director channel to allow greater latitude in flight path control. Abbreviated pitch and roll indices could also be considered for low altitude segements where terrain portrayed in the HUD field-of-view may not always provide a reliable horizontal reference. For transparency, the color line HUD format is preferred under VMC conditions, but may lack the information needed in a primary flight display during low-altitude IMC operations.

For the threat warning study, the transitional flight director symbol, and the threat alert symbol suggested above were added to the HUD as described in paragraph 8.1.1.

In the threat warning study, the HUD display format in general, and the threat alerting symbology in particular, were fairly well accepted by the pilots, although they made many suggestions for specific coding changes. Usability of most of the threat symbology was rated moderately good to very good; the only exception was the threat azimuth vector, which was difficult to see under some conditions. Many of the pilot suggestions for change were requests for more (or more differentiated) threat-related information to be presented on the HUD. Specific suggestions, and their impact on the revised formats are described below.

The only HUD symbology that received a usability rating poorer than "neutral" was the transitional flight director. As discussed previously, this symbology was included for the first time in the threat warning study, and its implementation was incomplete. Pilot comments supported the concept of a flight director, but not its execution in this simulation.

The HUD alert symbology consisted of an air-to-air alert symbol (shaped like a fighter) or a surface-to-air symbol (a missile) that appeared solid for six seconds for search-mode threats; flashed for six seconds for track-mode threats; or flashed for launch duration, accompanied by a time-to-missile-impact readout and threat azimuth vector, for launch-mode threats. Most of the pilots considered the HUD threat symbology adequate for alerting them to change in the threat environment; and also rated it moderately- to very usable, especially in color. Half the pilots, however, suggested that a separate alert symbol be used for AAA's, to distinguish them from SAMs. Figure 11.2-1 shows the revised HUD format, which incorporates an AAA alert symbol, a gun-type silhouette at bottom right.

Some pilots also commented that it was sometimes difficult to distinguish between track- and launch-mode alert symbology, which differed only in duration and in the presence or absence of the time-to-impact readout and threat azimuth vector. In the revised HUD format, search mode threats would be represented by solid (non-flashing) yellow symbols (SAM, AAA or A/A, as appropriate); track-mode threats by solid red symbols; and launch mode threats by flashing red symbols. This coding would make the distinction between threat modes more explicit. In addition, since threat azimuth symbology would not be tied directly to launch mode threats, it could be added, as several pilots suggested, to track mode threat alerts, or eliminated where inappropriate. The time-to-missile-impact readout could be deleted for AAA's, for example, to increase the distinction between them and SAM's, as suggested by two pilots. Table 11.2-1 summarizes the revised HUD threat alert coding.

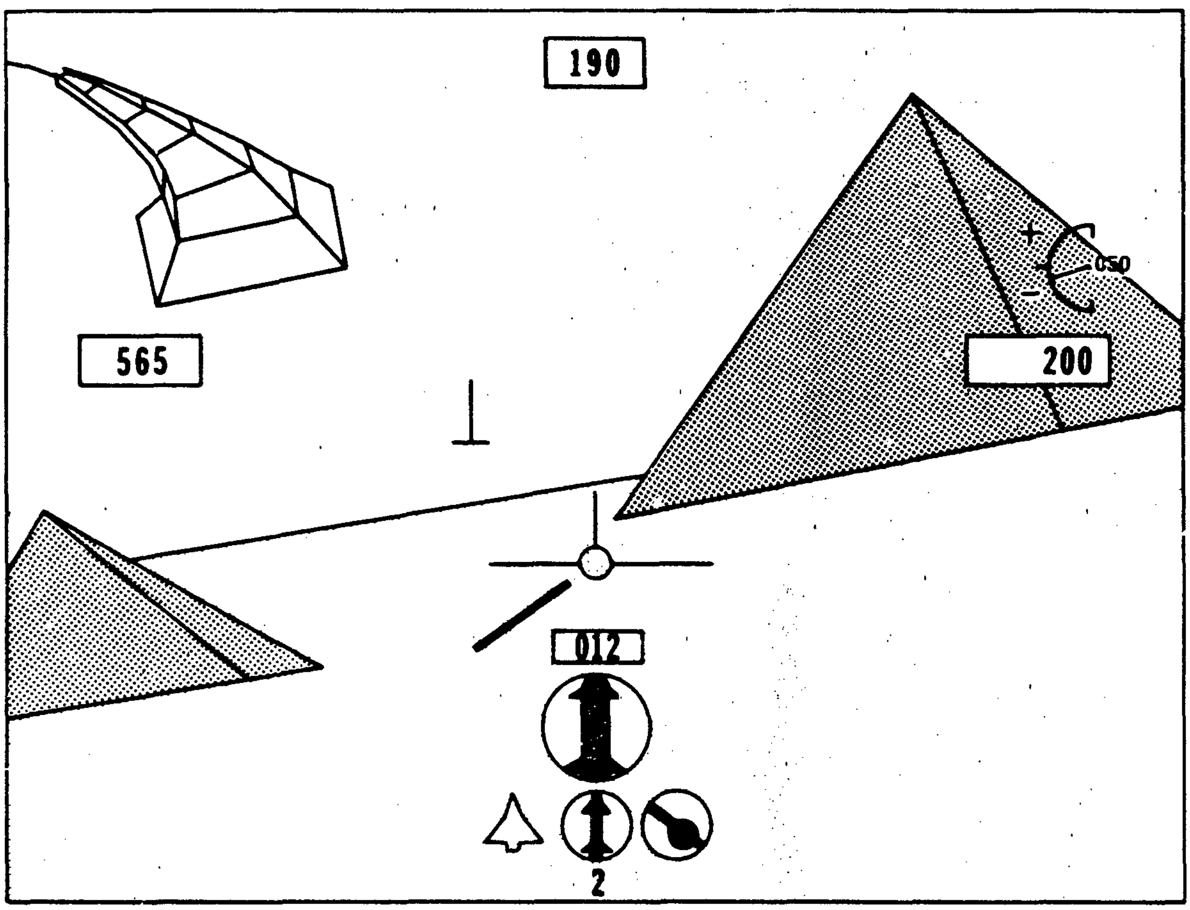


Figure 11.2-1. Revised Head-Up Display (HUD) — Composite

Some pilots requested more continuous threat information (for search and track mode threats) in addition to the alerts for new threats. One possible way of providing longer and more inclusive information about the overall "active threat situation" is shown in Figure 11.2-1. Threat alert symbology similar to that in the threat warning study, but with the modifications described above, would continue to appear below the aircraft symbol for all new or upgraded mode threats, to alert the pilot to changes in the threat environment. In addition, similar symbology, but reduced in size, would appear for all currently active threats in a row below the threat alert symbology, at the bottom of the screen. The symbol for a given type of threat (A/A, SAM or AAA) would always appear, if a threat of that type was active, in the same relative position: left, center, or right. The "currently active" threat symbols would be coded in the same way as the "threat alert" symbology: yellow, red, or flashing red for search, track, or launch modes. If more than one threat of a given type were active, the number of those active could be given below the appropriate symbol, which would be coded to represent the most severe mode of the threats of that type. Figure 11.2-1

Table 11.2-1. Proposed Threat Information Coding for Head-Up Display Format

Information	Scope or restrictions	Levels	Coding
Threat status	–	• "Alert" • "Active"	• Large threat symbol just below "own" aircraft symbol, 6 seconds • Smaller threat symbols below alert threat symbol, duration of active mode
Threat type	• Alert or active threats	• Air-to-air • SAM • AAA	• Fighter symbol • Missile symbol • Gun symbol
Threat mode	• Alert or Active threats • A/A, SAM or AAA Highest priority threat of given status, type	• Search • Track • Launch	• Yellow threat symbol • Red threat symbol • Flashing red threat symbol
Countermeasures status	• Alert or Active threats • A/A, SAM or AAA Most severe status for given status, type • Track or Launch mode only	• Effective • Not effective or depleted	• Yellow circle • Red circle
Missile azimuth	• Alert threat • A/A or SAM • Launch mode only	0- to 360-deg	Vector to missile azimuth
Missile "Time-to-Impact"	• Alert threat • A/A or SAM • Launch mode only	0 to x secs	Boxed readout of time to missile impact
Number of threats	• Active threats • A/A, SAM or AAA	2 to x	Default is 1; pilot's option to select "all active threats" number, or restrict to track and launch mode total

also shows possible coding for the countermeasures status of "active" or "alert" threats, using a yellow (effective) or red (not effective) circle around the appropriate symbol (for track or launch modes threats, analogous to the coding used on the Vertical or Horizontal Situation Displays). Four pilots suggested that countermeasures information be added to the HUD.

The additional symbology for "active" threats and countermeasures status information outlined above and shown in Figure 11.2-1 is only one possible approach. The feasibility of adding such information as well as its size, location, range limits, and availability (in a pilot-selectable mode, for example) would need to be investigated in further research.

Two other changes have been incorporated into the revised HUD symbology in response to pilot comments: the threat azimuth has been made longer and thicker, and the time-to-missile-impact readout has been enlarged to make it more conspicuous.

The revisions discussed above for the HUD are related to threat-warning symbology. As in the basic study, some of the pilots suggested that a pitch ladder and better flight direction information be added to the HUD. Changes in the sensitivity of the flight channel are appropriate for different mission segments and requirements. The addition of an abbreviated pitch ladder, pilot-adjustable sensitivity for the flight channel symbology, and a fully implemented flight director for recapturing the flight channel when necessary, would improve the usability and pilot acceptability of the HUD format.

11.3 Vertical Situation Display

The low-altitude VSD format was a true situation display that portrayed, in aircraft stabilized form, the interaction of one's own aircraft with terrain, threats, targets, cultural features, and future intended flight path. At high altitude the VSD reverted to a standard, ground-stabilized electronic attitude director indicator (EADI) format. Generally, the unique features of the low altitude VSD were well accepted; it provided a concise overview of the mission situation with a minimum requirement to process and integrate information from different sources. Overall, three-fourths of the pilot evaluators rated this concept as easier to use than conventional aircraft information.

Much of the criticism of the vertical situation display in the basic study followed the form, "I liked it, particularly for threat display, but otherwise it was redundant." In part, this stemmed from lack of understanding or acceptance of the distinction between flight and situation display. The low altitude VSD was intended to be a situation display showing more about the threat and terrain environment and less about the mechanics of flight. The latter information was contained in the HUD.

If the HUD had been optimized and if the vertical situation display had remained a situation display at high altitude, the pilots would likely have been quite satisfied with the VSD. The low altitude VSD changes are shown in Figure 11.3-1. The ground grid should have meaningful linear dimensions (1 mile squares) and be fixed at the nadir or point directly below the aircraft. This would help in determination of range to terrain and threats and also give a coarse indication of aircraft altitude. There was some feeling that a heading tape or compass rose was needed somewhere as an azimuth reference for terrain, threats and targets and one suggestion was the VSD. That is probably appropriate since it has a wider field of view than the HUD. If necessary, a more complete compass rose could be added to the HSD.

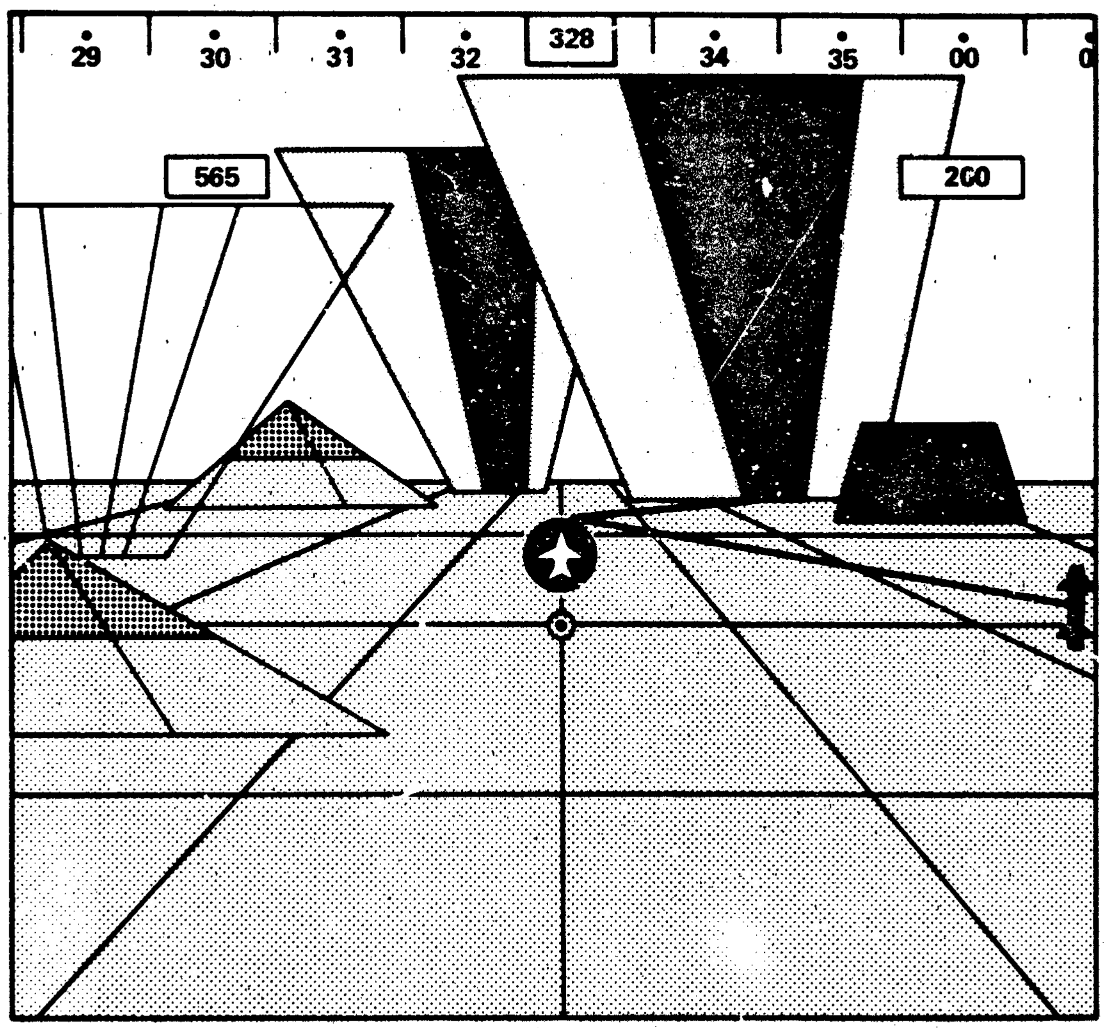


Figure 11.3-1. Revised Low Altitude Vertical Situation Display (VSD) — Composite

At high altitude, the VSD should not dramatically change character from an aircraft-stabilized situation display to a ground-stabilized attitude director display. Even if the aircraft is above terrain, the threat information may still apply. The ground grid could be retained, with each square representing five or ten miles to reduce clutter. The VSD could still be a back-up location for the HUD format in case of HUD system failure.

With one exception (altitude terrain coding), the color version of the VSD received ratings of slightly good, or better, in the threat warning study. However, in general, the VSD was the lowest rated display and the least used source of threat information. In part, this result was an artifact of the response measures, and the relatively narrow field of view of the VSD, combined with an anomaly in the threat mode coding for the VSD. Moreover, it was likely influenced by the design of the VSD format as a "situational" display, rather than one intended to give discrete threat data uniquely tailored for response purposes.

In the threat warning study, the pilots were required to give the type and mode of all threats flagged by a HUD threat alert symbol. Sometimes such threats were out of the field of view of the VSD, or hidden behind a mountain or another threat. Information for such threats could be reliably obtained only be referring to the HSD. This was especially true for threats in track mode. Once they went out of the field of view of the VSD, their lethality envelope, tractor beam, and the concommitant countermeasures status coding circle disappeared; this was not true for the HSD. An important revision proposed for the VSD is that the tractor beam and countermeasures information for track mode threats remain on the VSD even if the threat goes outside the field of view (with the caveat that some range limits might have to be enforced for all three displays, especially in a high density threat environment).

Another difficulty with the VSD (one it shared with the HSD) was the "jewel" light symbology used to replace the lethality envelopes of threats in launch mode. Pilot comments (and performance data) indicated that the jewel light was easily confused with the AAA threat lethality envelope. Moreover, once the jewel light had replaced the threat lethality envelope, there was only minimal information as to the type of threat that was in launch mode (i.e., the presence or absence of the missile position symbol on the HSD, and the difference in time-to-missile-impact readout on the HUD).

Table 11.3-1. Proposed Threat Mode Coding for Low Altitude Vertical Situation Display and Low Altitude Horizontal Situation Display Formats

Threat site location, mode \ Aircraft location		Within threat lethality envelope	Outside threat lethality envelope
Within VSD field-of-view or HSD display range	Search mode	Yellow threat-site symbol	Threat lethality envelope
	Track mode	Red threat-site symbol Tractor beam Countermeasures circle	Threat lethality envelope Tractor beam Countermeasures circle
	Launch mode	Flashing red threat-site symbol Flashing tractor beam Countermeasures circle	Threat lethality envelope Flashing tractor beam Countermeasures circle
Outside VSD field-of-view or HSD display range	Search mode	No coding*	No coding*
	Track mode	Red threat-site symbol pegged to side at correct azimuth Tractor beam to symbol Countermeasures circle	Tractor beam to side at correct azimuth Countermeasures circle
	Launch mode	Flashing red threat-site symbol pegged to side Flashing tractor beam to symbol Countermeasures circle	Flashing tractor beam to side at correct azimuth Countermeasures circle

* An increase in the selected HSD range would bring the threat site within the HSD display range

Finally, there was a more general problem with the way the jewel light was implemented in the threat warning simulation. Although the substitution of the jewel light was initially intended to indicate that a threat lethality envelope had been penetrated, there was also a requirement that the jewel light remain as long as the threat was in launch mode. Thus, threat mode status and lethality envelope penetration were not clearly differentiated. To keep the coding and briefing straightforward, the jewel light was defined as a part of the code for launch mode status rather than lethality envelope penetration. One possible solution for the drawbacks associated with jewel light as it was used in the threat warning study is shown in the revised VSD and HSD formats, Figures 11.3-1 and 11.4-1, and the proposed threat coding for the two formats, Table 11.3-1.

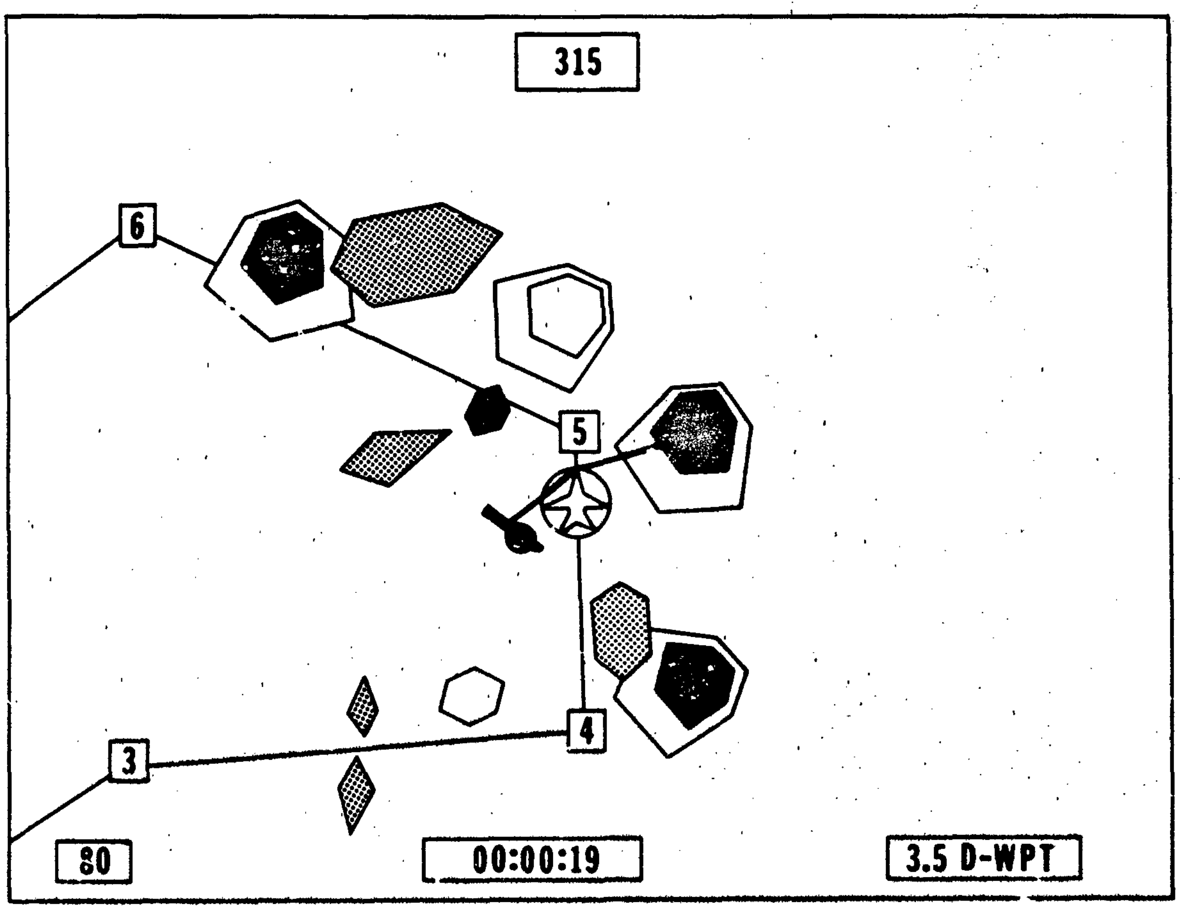


Figure 11.4-1. Revised Horizontal Situation Display (HSD) – Composite

Figure 11.3-1 shows the jewel light replaced by a "threat site symbol" similar to the threat symbology used in the HUD. This symbology, with a unique symbol for AAA's, SAM's and A/A threats would allow threat type to be identified even after the threat lethality envelope disappeared. In addition, Table 11.3-1 shows how all combinations of threat mode (search, track and launch), threat envelope penetration (inside or outside envelope) and VSD field of view (inside or outside field of view) could be represented.

With this coding, the appropriate threat site symbol would replace a lethality envelope only if the envelope had been penetrated. The threat site symbol would then reflect the current mode of that threat: the symbol would be yellow, red, or flashing red for threats in search, track, or launch mode (with the latter modes more probable). Threat site symbols would appear only for threats within the VSD field of view; for track and launch mode threats outside the field of view, the appropriate tractor beam (solid or flashing to correct azimuth) and countermeasures status circle (yellow or red) would remain. The width of the tractor beam would be increased to make it more conspicuous, and the optimum flash rate would be determined. Similar coding would be used on the HSD. This proposed coding is only one possible approach, but it has the dual advantages of presenting and distinguishing threat envelope penetration and threat mode information, as well as increasing the consistency and commonality of coding across displays. This would have the added result of making the VSD a much more reliable and complete source of threat information, increasing its usability as a true situational display.

11.4 Air-to-Surface Horizontal Situation Display

The basic HSD is an electronic moving-map display. It contains some unique features which should be retained. The idea of showing threat envelope and mountain sizes at current altitude is good and would probably be even more valuable with denser threats and more manual evasive maneuvers than were simulated here. The target inset was well accepted by most of the pilots.

Several optional features should be added. If numeric fuel-range is important, then its numeric value should be added to the fuel-range rings. The selectable time and distance boxes should have a "direct" option as well as "via flight plan". Other important ground features such as prime and alternate landing fields and radio aids to navigators should be considered as pilot options. An offset option should be added to put the airplane symbol at the bottom of the display. This would, for a given scale selection, almost double the look-ahead range. A pilot-selectable cursor is suggested that would allow the pilot to make minor course changes in near real-time, and would facilitate return to the preplanned route following manual maneuvering.

An optional trend vector should be added. This would give 30, 60 and 90-second predictions based on current configuration and speed. In other applications, this feature has proven to be a valuable aid to manual flight. Display range (scale) should be stated as distance from the airplane symbol to the top of the display.

In the threat warning study, the horizontal situation display received the highest usability ratings of the three displays. This result may have been partly an artifact of the response structure and some anomalies in the VSD threat coding, as discussed earlier. The revisions to the HSD air-to-surface format, shown in Figure 11.4-1 and described in Table 11.3-1, are analogous to those made on the VSD. The primary proposed change is the substitution of a threat site symbol (which also codes threat mode status) for threats within the HSD display range whose lethality envelopes have been penetrated. As with the VSD, the tractor beam (for track or launch modes) would be made thicker and more conspicuous, and it would flash for launch mode to increase consistency across displays.

Because the plan view of the HSD contains no information on the height of the lethality envelopes, the pilots had more difficulty distinguishing SAM's from AAA's, and threats (especially AAA's and jewel lights) from terrain. One reason for this was a less discriminable difference between the red (of threats) and the brown (of above-altitude terrain) on the CRT used in this simulation for the HSD. But this may be only one example of the more general problem of distinguishing threats from terrain when more realistic depictions are used (so that threats and terrain cannot be classified by their distinctive regular shapes), or when a more dense threat and mountain environment occurs. Although it was not incorporated in the revised HSD format shown in Figure 11.4-1, one possible solution would be to use a more distinctive coding, such as a striped (stroke or partial fill raster) format for terrain. This would increase the discriminability of the two types of information, and would also allow the terrain information to be presented in a high density environment without occluding important threat information. This is only an attempt to define a possible approach to a solution, since no work has been done to test the effects of this coding in the laboratory.

One final pilot suggestion should be noted: three pilots wanted some indication on the HSD about which threat was associated with the threat alert symbol currently on the HUD. This was undoubtedly influenced by the requirement to identify the clock position of the threat for a given HUD alert, but this request could be easily accommodated by changing the color of the entire threat envelope for the duration of the HUD alert symbol (e.g., magenta threat envelope for six seconds). The feasibility of this suggestion would depend on threat density and the timing of threat mode changes.

11.5 Air-to-Air Horizontal Situation Display

The air-to-air format of the HSD was well received. The revised format, shown in Figure 11.5-1, reflects two major changes. First, in keeping with the changes made to the air-to-surface HSD, and the VSD, a "threat site" symbol replaces the lethality envelope of the threat (the sector shape) once it has been penetrated.

Second, the location of the threat number, type, and altitude difference information has been changed. Some pilots noted that, for some ranges, this information was out of the HSD field of view. To provide more timely information, these data have been moved inside the threat envelopes. Threat number might also be coded pictorially, as shown in Figure 11.5-1. This coding gives a clearer picture of the relative position of formation aircraft, transitions more easily when a change in formation occurs, and reduces the alphanumeric readouts to two numbers that can fit in the body of the threat envelope (even if the envelope rotates) under all usable scale conditions.

11.6 Multipurpose Displays

The status and advisory formats, which were shown on the two multipurpose displays, were generally well received. Some of them do not warrant revision at this time. Others require extensive work.

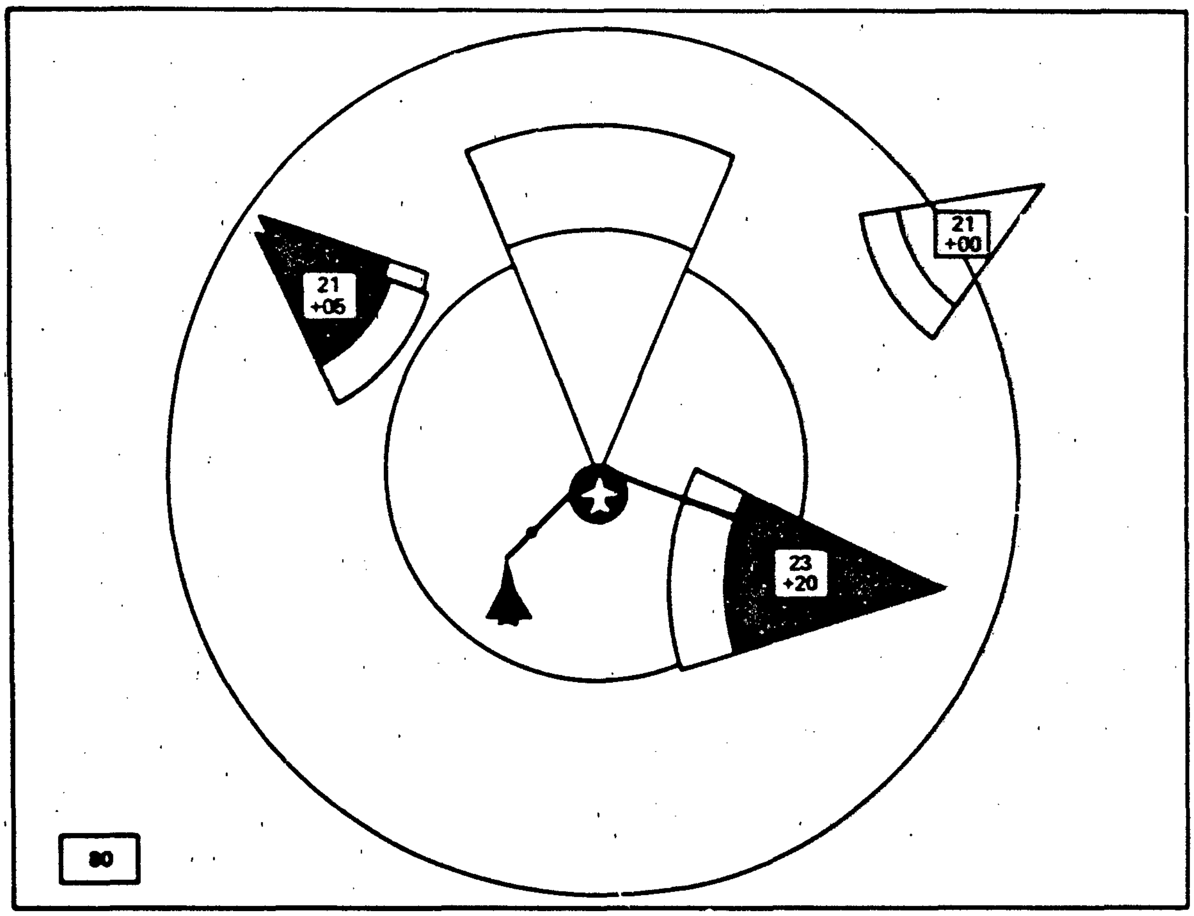


Figure 11.5-1. Revised Air-to-Air Horizontal Situation Display (HSD) – Composite

11.6.1 Engine Formats

The pilots wanted two things from engine displays. They required good thrust setting information and they were concerned about engine health. The test version of the engine format covered both of these concerns - but not well. There was not sufficient resolution in the thrust parameters (N1, N2, fuel flow) to set thrust level. The engine health parameters (turbine inlet temperatures, exhaust gas temperature) were lost among the other display elements; engine oil quantity and pressure were not shown. The engine status display was criticized for being too cluttered.

The design response to these criticisms is shown in Figure 11.6.1-1. Turbine inlet temperature and compressor speed have been eliminated. Fuel flow has been simplified and "bubble" movement removed. If numeric fuel flow is required, it could

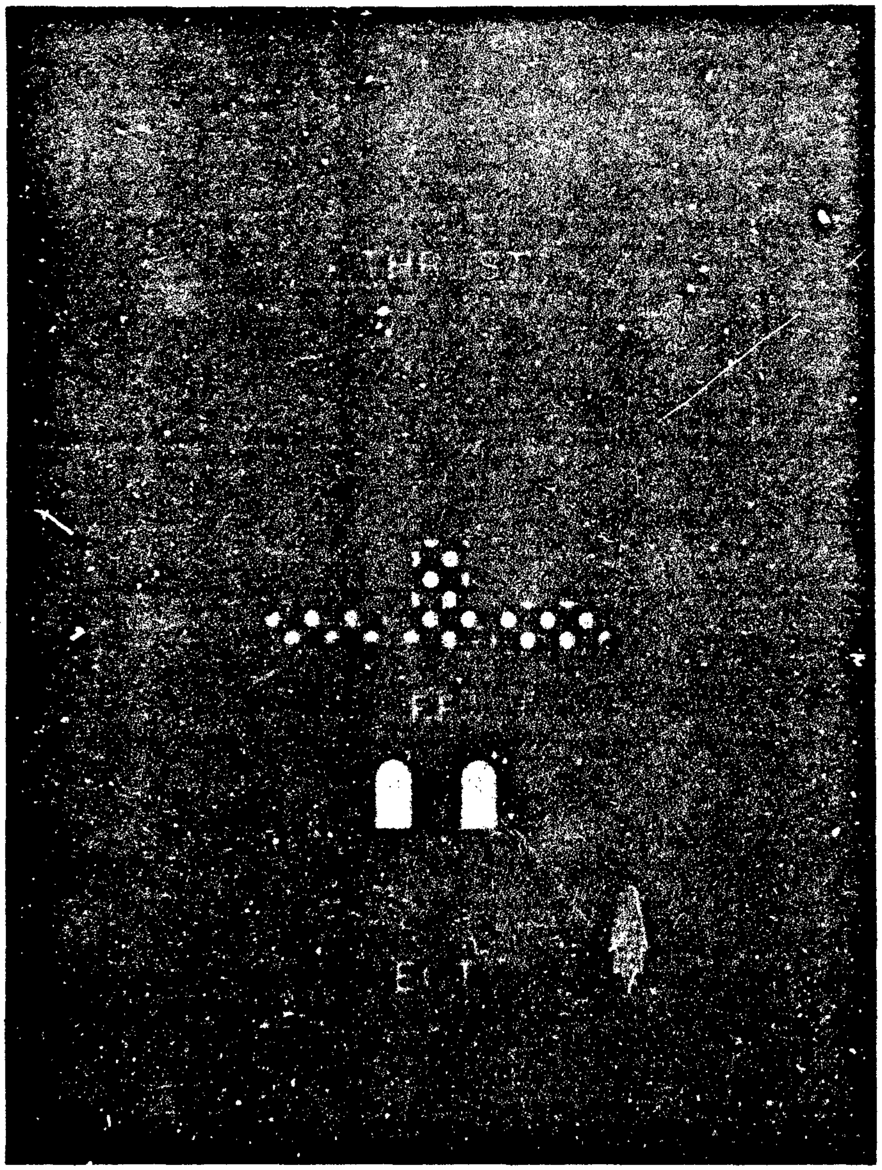


Figure 11.6.1-1. Engine Status Format

be added at the ends of the fuel flow arrows. Characters should be the same size as the letters on this format. A composite thrust parameter is suggested and displayed as shown in a tape-like display with desired thrust shown, derived from autopilot or manually set desired airspeed. Actual thrust is shown along with throttle position. This way, the thrust goal is known and displayed. The pilot can set his throttles quickly to match that goal and attend to other duties while engine thrust comes up (or down) to match the setting or goal. The procedure obviates the continual monitoring and successive approximation frequently required with current engine display systems.

The engine advisory formats were successful. They cued the pilots though the steps necessary to deal with engine problems. No change is suggested to the existing formats. An engine health format should be added to display the health parameters of concern.

11.6.2 Stores Formats

The stores status and stores program formats were very successful - they were well accepted and pilots performed well with them. Neither the status nor the program formats require revision at this stage. Both would be tailored for specific applications. Pilot errors in dealing with the hung bomb problem indicate that stores problems should bring up either verbal or pictorial checklists like those used here for engine and electrical problems.

11.6.3 Electrical Formats

The electrical status format requires only modest change. The distinction between permanent and temporary failure of an electrical system element was subtle - filled vs. open X. If the distinction is important, it should be more clearly indicated. Figure 11.6.3-1 is the modified electrical status format, showing a temporary failure of the left generator. A permanently failed element would have an X through it, as well.

The electrical advisory format was an example of a pictorial checklist showing required actions. Some pilots would have preferred verbal checklists and were critical of the cartoons. If verbal checklists are used, they should be interactive and have a recall feature. In this way, completed checklist items would be automatically indicated and actions not completed would be available for later recall.

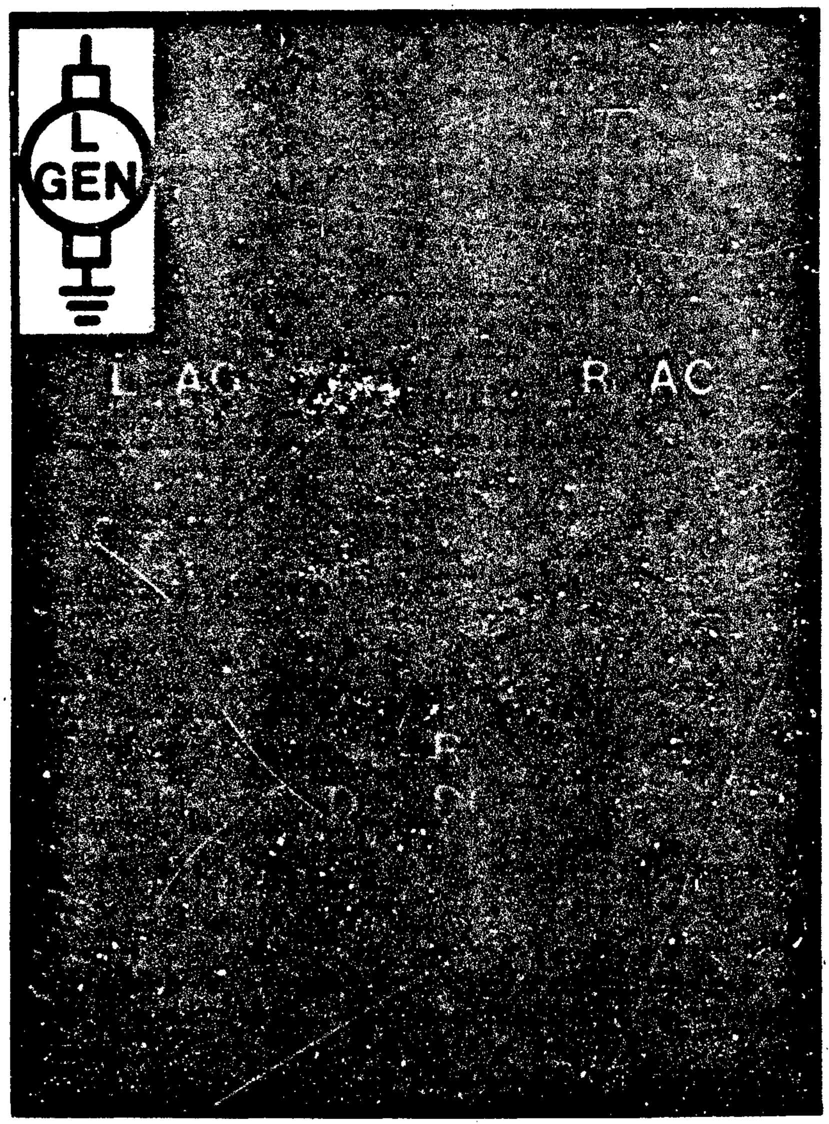


Figure 11.6.3-1. Electrical Status Format

If pictorial checklists are used, they should be simple, clear and have a fairly uniform format across systems. Required actions should be clearly separated, perhaps to the point of having separate pictures for each action. This would have precluded the relatively common error of forgetting to turn the generator back on after a temporary failure. In pictorial checklists, condition and action should be clear. Showing cockpit location of switches is not as important and could be excluded.

11.6.4 Hydraulic Formats

The hydraulic status format was well received and easily understood. However, a number of pilots indicated the need for numeric information. Pending the sort of analysis that accompanies a specific application, no revision is recommended.

The hydraulic advisory format showed results of a system failure but did not indicate any action required. The pilots read the display quickly and accurately. No revision is recommended.

11.6.5 Fuel System Format

The fuel status format was judged to be good, but pilots had to refer to a conventional gauge to report amount of remaining fuel. Figure 11.6.5-1 shows a version which adds numeric fuel quantity to the format. In some aircraft, fuel flow is used as an indication of thrust. A number of pilots requested display of fuel flow. This has been discussed in the revised engine status format.

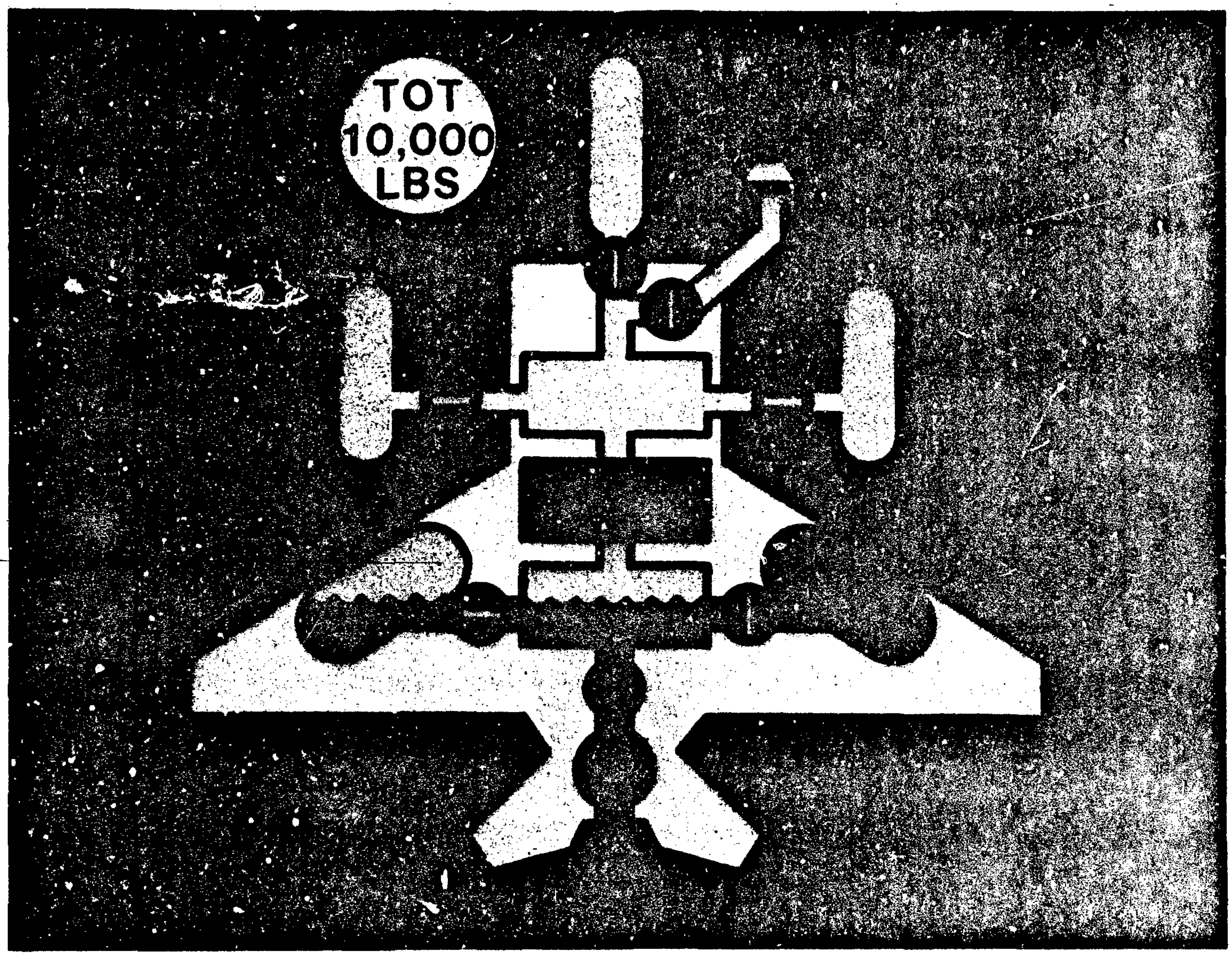


Figure 11.6.5-1. Fuel Status Format

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APPENDIX A

PILOTS' QUESTIONNAIRE - BASIC STUDY

This appendix is a copy of the questionnaire completed by the pilots in the basic study. As described in paragraph 5.4 of the main body of this report, the first part of the questionnaire was analyzed by the method of magnitude estimation. The numbers written in under "Color Fill" and "Monochrome" are the geometric mean responses. Questions marked with asterisks had significant differences ($p < .05$) by Friedman two-way analysis of variance.

In the second part of the questionnaire, pilots were asked to compare these formats with conventional aircraft displays. The boxes in that part of this appendix contain the number of pilots making that response and the asterisks indicate the median response.

NAME ______________________________ DATE ____________

SERVICE BRANCH ______________________________________

AGE ____________________ TOTAL JET HOURS ____________

EXPERIENCE BY AIRCRAFT TYPE

AIRCRAFT ______________________ HOURS ____________

AIRCRAFT ______________________ HOURS ____________

AIRCRAFT ______________________ HOURS ____________

AIRCRAFT ______________________ HOURS ____________

AIRCRAFT ______________________ HOURS ____________

YEAR OF PILOT RATING ____________ CURRENT RANK ____________

This part of the questionnaire is designed to obtain your opinions regarding the relative usability of the three presentation modes for the pictorial formats: monochromatic, color line, and color fill. Please indicate the usability of presentation modes by placing a number on each line under the display mode column headings adjacent to each question. To give you a standard reference for your judgments, a value of 100 has been assigned to the color line presentation mode. Please assign a number to the other two presentation modes which represents their relative usability with respect to the color line standard. The values you assign to the monochrome and color fill presentation modes should be proportional to the relative usability of the standard. For example, if you feel a display presentation mode is twice as usable as the standard, it would be given a number twice as large as the standard (e.g. 200). If, on the other hand, you feel it is one-fifth as usable, it would be given a value of 20.

SYSTEM STATUS FORMATS (CONT.)	COLOR FILL	COLOR LINE	MONOCHROMATIC
* 5. Interpretation of electrical status information for degraded operational conditions was:	156.4	100	42.8
6. Interpretation of hydraulic status information for normal operational conditions was:	112.3	100	78.4
7. Interpretation of hydraulic status information for degraded operational conditions was:	114.8	100	77.2
* 8. Interpretation of fuel status information for normal operational conditions was:	129.1	100	72.4
* 9. Interpretation of fuel status information for degraded operational conditions was:	139.9	100	67.7
EMERGENCY CONDITION FORMATS			
* 1. Interpretation of engine advisory formats was:	137.2	100	70.7
* 2. Interpretation of electrical advisory formats was:	140.2	100	63.3
* 3. Interpretation of hydraulic advisory formats was:	125.6	100	73.5

This part of the questionnaire is designed to obtain your opinions regarding the relative usability of the three presentation modes for the pictorial formats: monochromatic, color line, and color fill. Please indicate the usability of presentation modes by placing a number on each line under the display mode column headings adjacent to each question. To give you a standard reference for your judgments, a value of 100 has been assigned to the color line presentation mode. Please assign a number to the other two presentation modes which represents their relative usability with respect to the color line standard. The values you assign to the monochrome and color fill presentation modes should be proportional to the relative usability of the standard. For example, if you feel a display presentation mode is twice as usable as the standard, it would be given a number twice as large as the standard (e.g. 200). If, on the other hand, you feel it is one-fifth as usable, it would be given a value of 20.

HORIZONTAL SITUATION DISPLAY	COLOR FILL	COLOR LINE	MONOCHROMATIC
* 1. Interpretation of HSD terrain and threat information during low altitude flight was:	158.5	100	48.6
* 2. Interpretation of HSD position and threat level information for enemy aircraft during the Air-to-Air mode was:	141.3	100	64.6
* 3. Detection of HSD pop-up threat information during low altitude flight was:	175.1	100	20.4
SYSTEM STATUS FORMATS			
* 1. Interpretation of the quantity of on-board stores was:	136.3	100	85.8
* 2. Interpretation of the state of on-board stores was:	163.6	100	43.5
* 3. Interpretation of engine status information for normal operational conditions was:	154.2	100	54.7
* 4. Interpretation of electrical status information for normal operational conditions was:	142.6	100	42.7

This part of the questionnaire is designed to obtain your opinions regarding the relative usability of the three presentation modes for the pictorial formats: monochromatic, color line, and color fill. Please indicate the usability of presentation modes by placing a number on each line under the display mode column headings adjacent to each question. To give you a standard reference for your judgments, a value of 100 has been assigned to the color line presentation mode. Please assign a number to the other two presentation modes which represents their relative usability with respect to the color line standard. The values you assign to the monochrome and color fill presentation modes should be proportional to the relative usability of the standard. For example, if you feel a display presentation mode is twice as usable as the standard, it would be given a number twice as large as the standard (e.g. 200). If, on the other hand, you feel it is one-fifth as usable, it would be given a value of 20.

HEAD-UP DISPLAY	COLOR FILL	COLOR LINE	MONOCHROMATIC
1. Interpretation of HUD pathway-in-the-sky commands during low altitude VMC was:	73.4	100	78.1
* 2. Interpretation of HUD pathway-in-the-sky commands during low altitude IMC was:	118.7	100	59.8
3. Interpretation of HUD terrain profiles during low altitude VMC was:	52.7	100	72.5
* 4. Interpretation of HUD terrain profiles during low altitude IMC was:	115.6	100	64.8
VERTICAL SITUATION DISPLAY			
* 1. Interpretation of VSD terrain and threat information during low altitude flight was:	178.1	100	35.5
* 2. Interpretation of the VSD ribbon-in-the-sky during low altitude flight was:	105.7	100	52.2

This part of the questionnaire is designed to obtain your opinions regarding the relative usability of the three presentation modes for the pictorial formats: monochromatic, color line, and color fill. Please indicate the usability of presentation modes by placing a number on each line under the display mode column headings adjacent to each question. To give you a standard reference for your judgments, a value of 100 has been assigned to the color line presentation mode. Please assign a number to the other two presentation modes which represents their relative usability with respect to the color line standard. The values you assign to the monochrome and color fill presentation modes should be proportional to the relative usability of the standard. For example, if you feel a display presentation mode is twice as usable as the standard, it would be given a number twice as large as the standard (e.g. 200). If, on the other hand, you feel it is one-fifth as usable, it would be given a value of 20.

CREWSTATION INTEGRATION	COLOR FILL	COLOR LINE	MONOCHROMATIC
* 1. Crosschecking flight path information on the HUD, VSD, and HSD during high altitude flight was:	145.7	100	72.7
* 2. Crosschecking flight path information on the HUD, VSD, and HSD during low altitude flight was:	145.5	100	58.6
* 3. Crosschecking threat information on the VSD and HSD during low altitude flight was:	190.6	100	29.0
* 4. Crosschecking terrain information on the HUD, VSD, and HSD during low altitude flight was:	157.8	100	49.8

This part of the questionnaire is designed to obtain your opinion with regard to the usability of the pictorial display formats that were presented in the simulated mission. On each of the following scales, you are requested to indicate the relative usability of a specific pictorial format by comparing it to comparable information available in conventional aircraft. Please place an X inside one of the boxes on each scale that best describes the relative usability of the specified format.

Using conventional aircraft as a reference	Easier to use: Much	Easier to use: Moderately	Easier to use: Slightly	Same as conventional	Harder to use: Slightly	Harder to use: Moderately	Harder to use: Much
1. How do our rate the usability of the high altitude HUD pictorial format?		4	4	2*2	6	2	
2. How do you rate the usability of the low-altitude HUD format during VMC?	1	3	4		2*4	5	1
3. How do you rate the usability of the low-altitude HUD format during IMC?	8	2	*4		6		
4. How do you rate the usability of the low-altitude VSD pictorial format?	5	5*3	2	3		2	
5. How do you rate the usability of the high-altitude HSD pictorial format?	6	4*1	3	4	2		
6. How do you rate the usability of the low altitude HSD pictorial format?	10	*6	3	1			
7. How do you rate the usability of the air-to-air HSD pictorial format?	8	2*7	3				

Using conventional aircraft as a reference	Easier to use				Harder to use		
	Much	Moderately	Slightly	Same as conventional	Slightly	Moderately	Much
8. How do you rate the usability of the engine status pictorial formats?	2	6	2*2		3	2	3
9. How do you rate the usability of the stores status pictorial formats?	10*1	7	1	1			
10. How do you rate the usability of the hydraulic status pictorial formats?	4	5	1*5	2	1	1	1
11. How do you rate the usability of the electrical status pictorial formats?	6	4*3	4		2	1	
12. How do you rate the usability of the fuel status pictorial formats?	6	4*3	2	1	3	1	
13. How do you rate the usability of the advisory pictorial formats for emergency conditions?	10	*2	6	1	1		

APPENDIX B

SYNOPSIS OF TWENTY RESPONSES TO EACH OF NINETEEN GENERAL QUESTIONS

BASIC STUDY

It was hoped that providing each pilot a list of general questions and a tape recorder would elicit ideas not otherwise available - a sort of directed free association. The technique worked well. Transcripts of the tapes from individual pilots were recordered by question and are summarized in the pages following. The richness of the raw data made summarizing difficult but an attempt was made to represent all the ideas presented. Both convergences and divergences appear. There were a few comments on the simulation as opposed to the formats under evaluation; these were excluded from the summaries.

Question 1. What is your general feeling with regard to the use of CRT displays in the cockpit?

Good (19 pilots).
Systems displays especially good (5 pilots).
Some too complicated (4 pilots).
Make thrust setting information better (2 pilots).
VSD and HSD don't give quick information (1 pilot).
Quick and easy crosscheck (1 pilot).
Color fill best (1 pilot).

Question 2. What is your general opinion of the low altitude Vertical Situation Display?

Good, particularly threat display (18 pilots).
Good for situational awareness (2 pilots).
Used it mostly for threats (5 pilots).
Ribbon questionable (3 pilots).
Put threat warning in HUD, as well (3 pilots).
Perspective confusing (2 pilots).
Want better steering and attitude information (2 pilots).
Tie to radar for real terrain (2 pilots).
Monochrome best (1 pilot).
Color line best (1 pilot).
Color fill best (1 pilot).

Question 3. Does the HUD provide sufficient information for flight path control during low altitude flight? If not, what would you add?

Yes, the HUD provides sufficient information for flight path control in low altitude flight (8 pilots).
No, it doesn't (12 pilots).
Add better flight director or steering information (10 pilots).

Pathway difficult to return to from extreme deviations (7 pilots).
Add clear attitude information (6 pilots).
Get rid of background fill, especially in VMC (5 pilots).
Add threat indication (5 pilots).
Add vertical velocity (5 pilots).
Heading, airspeed and altitude boxes should be moved in (2 pilots).
Add forward-looking sensor overlay (2 pilots).
Add pitch ladder (2 pilots).
Too cluttered (2 pilots).
Add angle-of-attack (1 pilot).
Ridge lines too cluttered (1 pilot).
Add low altitude alert (1 pilot).
Use velocity vector (1 pilot).
Prefer standard ADI (1 pilot).

Question 4. In this simulation, the HUD presentation was airplane stabilized and the Vertical Situation Display was ground stabilized. Is this acceptable? If not, what would you change?

Acceptable (19 pilots).
Not acceptable (1 pilot).
Add attitude to HUD and better steering display on VSD (1 pilot).
Establish back-up director mode for VSD if HUD fails (1 pilot).

Question 5. What do you think of the terrain shading on the low altitude color fill HUD format?

Fine as it was (8 pilots).
Alright for IMC, but clear up for VMC (6 pilots).
Masked too much, color line better (5 pilots).
Attitude and steering not well displayed (2 pilots).

Add range information to the mountains (1 pilot).
Need declutter capability (1 pilot).
Color fill excellent on VSD and HSD (1 pilot).
Terrain avoidance information is better on the A6 (1 pilot).

Question 6. Did you have difficulty interpreting HUD flight path information due to the lag between the airplane symbol and the pathway-in-the-sky when flying with autopilot engaged?

No difficulty on autopilot (13 pilots).
Problems in manual flight (6 pilots).
Turns hard to interpret (3 pilots).
Experience may help (3 pilots).
Monochrome hard to interpret (2 pilots).
Hard to get back to course (1 pilot).
Too much information when in autopilot (1 pilot).
A6 format better (1 pilot).

Question 7. Did you ever refer to the electromechanical standby instruments in the cockpit? If so, about how many times and for what purpose?

Rarely (6 pilots).
Sometimes, particularly on early flights (5 pilots).
Yes, but more out of habit (5 pilots).
Yes, primarily for cross check (3 pilots).
Altimeter (8 pilots).
Used vertical speed indicator (5 pilots).
Mach/airspeed (5 pilots).
Needed analog heading information (2 pilots).
Looked for attitude because it wasn't clear on the HUD (1 pilot).
Looked for angle of attack (1 pilot).
Would like to see Navy format angle of attack on HUD (1 pilot).

Note: Despite all the emphasis here on pictorial formats, heading, airspeed and altitude were presented digitally. Pilots used the standby instruments for analog presentations of those parameters.

Question 8. Did the flight path channel ever completely disappear from the HUD? If so, did you find it difficult to recapture proper position with respect to the flight path?

Note: When the path disappeared from the HUD, it was due to extreme deviation from the flight path. In that case, the entry gate remained, pegged at the display periphery.

Yes, it did but recovery was not difficult (5 pilots).
Yes, and add steering symbology to get back (5 pilots).
Yes, HSD helped recovery (3 pilots).
No, but steering cues would help (4 pilots).
No, it did not disappear (3 pilots).

Question 9. Was the blinking velocity vector on the HUD a useful indication of abnormal and emergency conditions in the monochromatic presentation?

Yes, it was fine (11 pilots).
No, easy to miss (4 pilots).
Other indications (master caution, fire light or blinking display selector) were more effective (5 pilots).

Question 10. Was a change in color of the velocity vector on the HUD a useful indication of abnormal and emergency conditions in the color format presentations? If not, how would you indicate this information on the HUD?

Yes, it was adequate (8 pilots).
No, blink it, too (6 pilots).

No, add something else (6 pilots).

Do not need heading in all three displays (1 pilot).

Question 11. Do you think the waypoint and target flags on the HUD and on the Vertical Situation Display are useful cues? Were these cues useful in crosschecking flight progress on the Horizontal Situation Display?

Yes, they are useful (16 pilots).

Good on VSD, but not HUD (2 pilots).

No, unless they were real sensor input (1 pilot).

No, HSD indication is enough (1 pilot).

Question 12. What is your general feeling about the river and highway presentations on the low altitude Vertical Situation Display?

Not useful (9 pilots).

Might be useful in low altitude VMC navigation (5 pilots).

Good (3 pilots). Good but not in monochromatic VSD (2 pilots).

Question 13. What is your general feeling about the usefulness of the target expansion feature on the map display?

Useful (14 pilots).

Not useful (2 pilots).

Better if it were real sensor imagery (4 pilots).

"...greatest feature in the whole system" (1 pilot).

"...one of the less important features" (1 pilot).

Question 14. What is your general feeling about the usefulness of the fuel range rings on the map display?

Good (7 pilots).
Good but add fixed range rings or something to improve estimation (7 pilots).
Good but add digital range (5 pilots).
Add fuel flow gauge (2 pilots).
Good, but might be hard to implement (1 pilot).

Question 15. What is your general feeling about the usefulness of the air-to-air pictorial format on the horizontal situation display?

Good (9 pilots).
Good but makes assumptions about adversary's ordinance (5 pilots).
Good but add target designator box on HUD (2 pilots).
Good but may need to be reduced for multiplane engagements (1 pilot).
Good, but need more range (1 pilot).
No opinion (2 pilots).

Question 16. What did you like most about the pictorial formats that were presented in this simulation?

Speed of understanding malfunctions and corrective actions with pictorial checklists (10 pilots).
HSD (5 pilots).
Threat and terrain depiction (4 pilots).
Color fill (2 pilots).
Use of color (2 pilots).
Stores formats (2 pilots).
Versatility of format creation (1 pilot).
Emergency indication on HUD (1 pilot).

Clear, sharp pictures (1 pilot).
Fuel format (1 pilot).
VSD and HSD (1 pilot).
Air-to-air mode (1 pilot).

Question 17. What did you dislike most about the pictorial formats that were presented in this simulation?

Fuel and engine displays (2 pilots).
HUD too cluttered (2 pilots).
HUD terrain presentation (1 pilot).
HUD pathway (1 pilot).
VSD - the information should be on the HUD (1 pilot).
Flying the pathway and getting used to it (1 pilot).
Too much non-useful information (1 pilot).
Difficulty of seeing trends in status displays (1 pilot).
Cartoon advisories. Should have actions memorized (1 pilot).
Need accurate thrust setting information on engine format (1 pilot).
Fuel, engine and electrical status displays (1 pilot).
Fuel display (1 pilot).
Want North-up HSD (1 pilot).
Color fill on HUD (1 pilot).
Color line and monochrome display modes (1 pilot).
Monochrome mode (1 pilot).

Question 18. Would you modify the content or layout of any of the pictorial formats used in this simulation? If so, what would you change?

Head Up Display

Add steering symbology back to pathway and for turns (7 pilots).
Cut out clutter in low attitude HUD (5 pilots).

Add threat indication to HUD (4 pilots).

Replace channel with fly-to symbol and single line (2 pilots).

Add better artificial horizon (2 pilots).

Add pitch ladder and roll indicator (2 pilots).

Need better altitude information (2 pilots).

Eliminate artificial terrain (2 pilots).

Integrate nose camera video (1 pilot).

Add vertical speed (1 pilot).

Add air-to-air threat information (1 pilot).

Make it like A7E HUD (1 pilot).

Add declutter capability (1 pilot).

Make heading, airspeed and attitude boxes larger (1 pilot).

Need range information to terrain features (1 pilot).

Need low altitude warning (1 pilot).

Make lock-on X larger in monochrome (1 pilot).

What would weather look like (1 pilot)?

Good as is (1 pilot).

Color line best (1 pilot).

Monochrome worst (1 pilot).

Monochrome best (1 pilot).

Vertical Situation Display

Good as is (8 pilots).

VSD redundant except for threats (4 pilots).

Make low altitude VSD available full time (1 pilot).

Make high altitude version like A6 VDI (1 pilot).

High altitude - make roll index bigger (1 pilot).

Needs roll, attitude and steering information (1 pilot).

Add radar terrain imagery (1 pilot).

Simple heading tape better than single box (1 pilot).

Move ground texture to indicate ground motion (1 pilot).
What would weather look like (1 pilot)?
Exchange locations of VSD and HSD (1 pilot).
Use color fill (2 pilots).
Use color line (1 pilot).
Monochrome worst (2 pilots).

Horizontal Situation Display

Good (3 pilots).
Wish I had it in A6 (1 pilot).
Air-to-air makes assumptions about adversary's characteristics (2 pilots).
Provide declutter for air-to-air (1 pilot).
Air-to-air range should be selectable (1 pilot).
Add velocity, identification and probable armament load to air-to-air mode (1 pilot).
Add offset-to-bottom option (2 pilots).
Add real imagery (1 pilot).
State range as radius rather than display height (1 pilot).
Add heading on each leg (1 pilot).
Add range rings (1 pilot).
Add North-up option (1 pilot).
HSD should not have time critical information (1 pilot).
What would weather look like (1 pilot)?
Color fill best (3 pilots).
Color versions better (2 pilots).

Stores Status and Stores Program MPD Formats

Good (15 pilots).
Master arm switch is a problem (3 pilots).
Programming easy but eliminate entry key (1 pilot).

Color fill best (4 pilots).
Color line and color fill better (2 pilots).

Engine Status MPD Format

Good (4 pilots).
Throw it out (1 pilot).
Too cluttered (3 pilots).
Too simple (1 pilot).
Too much of a cartoon (1 pilot).
Improve power setting readings (9 pilots).
Add numeric RPM (8 pilots).
Add numeric EGT (4 pilots).
Add numeric fuel flow (3 pilots).
Add oil pressure and quantity (1 pilot).
Color fill best (1 pilot).
Color line best (1 pilot).

Hydraulic Status MPD Format

Good (9 pilots).
Terrible (1 pilot).
Could replace with gauge (5 pilots).
Need numerical information (3 pilots).
Combine with engine format (1 pilot).
Need more detail (1 pilot).
Monochrome was all right (1 pilot).

Electrical Status MPD Format

Good (10 pilots).
Replace with gauges or annunciator (3 pilots).
Just tell me in words (1 pilot).
Hard to distinguish between temporary and permanent failure (1 pilot).
Color line best (1 pilot).
Monochrome worst (1 pilot).

Fuel Status MPD Format

Good (10 pilots).
Need numeric fuel flow somewhere (5 pilots).
Make valve indications clearer (2 pilots).
Add numeric total fuel to format (2 pilots).
Need more complete schematic (1 pilot).
Prefer digital indication by tank (1 pilot).
Boost pump failure indication should be clearer (1 pilot).
Replace with annunciators (1 pilot).
Monochromatic worst (1 pilot).

Emergency and Advisory MPD Formats

Good (9 pilots).
Prefer checklists (7 pilots).
Pilot should already know this information (4 pilots).
Saves memorization (1 pilot).
Add warning light on VSD (1 pilot).
Make each step a separate presentation (1 pilot).
Should come up automatically (1 pilot).
Airplane this smart should be able to fix these problems and just announce fix (1 pilot).
Borders too bright (1 pilot).
Monochrome worst (1 pilot).
Color made little difference (1 pilot).

Question 19. Do you have any suggestions for additional pictorial formats that might be developed?

No additional (3 pilots).
Geez, no (1 pilot)!

Communications and navigation (2 pilots).
Put VSD threat information in HUD (1 pilot).
Emergency pull-up indication in HUD (2 pilots).
VSI in HUD (1 pilot).
Integrate actual pictures in HUD (1 pilot).
Variable accuracy requirement in pathway to reflect operational requirement (1 pilot).
Better steering and attitude in HUD (1 pilot).
Make HUD altimeter a tape (1 pilot).
Bank scale on HUD and VSD (1 pilot).
Air-to-air display on VSD (1 pilot).
Sensor pictures on VSD (1 pilot).
Compass rose on VSD or HSD (1 pilot).
Format to steer for stern engagement - also useful for refuelling (1 pilot).
Straight course and distance for emergency return to base (1 pilot).
HSD scale should read radius (1 pilot).
Compass card with TACAN, ILS and flight director (1 pilot).
Offcenter airplane to bottom of HSD (1 pilot).
Pictorial evasion format, chaff, ECM, and maneuver (1 pilot).
Engine and hydraulic oil pressure and quantity (1 pilot).
Fuel flow (1 pilot).
More checklists (1 pilot).
RHAW display (1 pilot).
Include ground speed for low level, airspeed and Mach number at altitude (1 pilot).
Ordered single action pictures for advisories (1 pilot).
Clean up engine format (1 pilot).
Environmental system (1 pilot).
Voice actuated communications change (1 pilot).
Flash master caution (1 pilot).

Flashing light for pop up threats (1 pilot).

Vertical velocity (1 pilot).

Trim position indication (1 pilot).

Color change in colored displays not noticeable (1 pilot).

APPENDIX C

PILOTS' QUESTIONNAIRE - THREAT WARNING STUDY

The pages which follow contain a copy of the questionnaire each pilot filled out at the completion of their data taking flights in the simulator. The numbers in the cells are the mean responses across the twelve subjects.

Subject No. ________________

Name ______________________ Date ________________________

Rank/Branch ________________

Age ______________________ Total Jet Hours ________________

Experience by Aircraft Type

AIRCRAFT	HOURS	CURRENT (YES, NO)

Have you every used a HUD? ______. If yes, which aircraft ______________?

Have you ever used threat warning devices (RHAW, etc.)? ________. If yes, which aircraft? __________

Other than radar, have you ever used CRT cockpit displays? _______
If yes, what display(s) in which aircraft? _______

1. The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Threat warning elements are emphasized, but ratings are also requested for other display symbology. Defined below are attributes or characteristics of display symbology.

Usability in Color. How usable was this display element in the color display mode?

Conspicuousness in Color. How easy was it to see this display element in the color mode?

Usability in Monochrome. How usable was this display element in the monochrome display mode?

Conspicuousness in Monochrome. How easy was it to see this display element in the monochrome display mode?

Location. Is this format element in the right place and on the right display (HUD, VSD, HSD)?

Meaning. How clear or obvious is the meaning of this format element?

Precision. Does this format element convey its information with the appropriate level of precision?

Timeliness. Is this format element available to you at the right time and for the right duration?

Training. How easily could this format element be learned?

Workload. Does this format element contribute to workload or relieve it?

This symbology element is { 1 Very Good; 2 Moderately Good; 3 Slightly Good; 4 Neutral; 5 Slightly Poor; 6 Moderately Poor; 7 Very Poor } with respect to this attribute.

HUD SYMBOLOGY ELEMENTS	IN COLOR		IN MONOCHROME		MODE INDEPENDENT ATTRIBUTES					
	USABILITY	CONSPICUOUSNESS	USABILITY	CONSPICUOUSNESS	LOCATION	MEANING	PRECISION	TIMELINESS	TRAINING	WORKLOAD
Search mode threat alert symbol	1.75	1.33	1.91	1.50	1.42	2.41	2.25	1.75	1.67	2.27
Track mode threat alert symbol	2.00	1.42	2.08	1.58	1.33	2.67	2.33	1.75	1.83	3.18
Time-to-missile impact readout	1.25	1.67	1.42	2.00	1.42	1.58	1.42	1.67	1.33	1.45
Threat azimuth vector	2.5	3.27	2.83	4.36	2.67	2.17	2.25	2.00	2.50	3.09
Pathway in the sky	3.33	1.67	3.50	2.25	1.58	2.33	3.25	2.82	2.55	3.55
Transitional flight director	4.50	3.83	5.08	4.58	2.67	3.58	5.08	3.58	4.33	4.36
Terrain Information	2.00	2.08	2.83	3.08	1.67	2.42	2.75	1.91	1.91	2.09
Weapon release cue	1.83	2.33	2.42	4.00	1.83	1.33	1.67	1.50	1.42	1.55
Waypoint/target flags	2.08	1.83	2.08	2.50	1.58	1.63	1.58	1.25	1.27	1.82

This symbology element is

1. Very Good
2. Moderately Good
3. Slightly Good
4. Neutral
5. Slightly Poor
6. Moderately Poor
7. Very Poor

with respect to this attribute.

VSD SYMBOLOGY ELEMENTS	IN COLOR: USABILITY	IN COLOR: CONSPICUOUSNESS	IN MONO-CHROME: USABILITY	IN MONO-CHROME: CONSPICUOUSNESS	MODE INDEPENDENT ATTRIBUTE: LOCATION	MEANING	PRECISION	TIMELINESS	TRAINING	WORKLOAD
Inactive threat lethality envelopes (outlines only)	2.58	2.67	3.17	3.58	1.83	2.58	1.83	1.55	1.73	2.18
Active threat lethality envelopes	1.92	1.92	2.67	2.83	1.92	2.33	1.83	1.64	1.91	2.73
Track mode "tractor beam"	2.50	2.50	3.00	3.58	2.33	1.75	2.17	1.75	1.82	2.55
Launch mode flashing tractor beam and jewel light	3.00	2.92	3.25	3.83	2.38	2.58	2.13	1.67	2.09	2.73
Countermeasures effectiveness coding (circle around aircraft symbol)	2.58	2.67	3.17	3.42	2.50	1.83	1.71	1.58	1.82	2.95
Ribbon in the sky (VSD pathway)	2.92	2.17	3.25	2.50	2.17	2.25	2.50	2.00	3.27	4.18
Above and below altitude terrain coding	3.33	2.83	4.00	3.83	2.08	2.42	2.17	1.82	2.82	3.09
Geographic and cultural features	2.17	2.33	2.83	3.50	1.92	2.17	1.83	1.73	2.00	2.45
Waypoint/target flags	2.83	2.33	3.00	2.92	2.00	1.92	1.58	1.45	1.73	2.91

This symbology element is { 1 Very Good, 2 Moderately Good, 3 Slightly Good, 4 Neutral, 5 Slightly Poor, 6 Moderately Poor, 7 Very Poor } with respect to this attribute.

HSD SYMBOLOGY ELEMENTS	IN COLOR		IN MONOCHROME							
	USABILITY	CONSPICUOUSNESS	USABILITY	CONSPICUOUSNESS	LOCATION	MEANING	PRECISION	TIMELINESS	TRAINING	WORKLOAD
Inactive threat lethality envelopes (outline only)	1.58	1.67	2.17	2.58	1.83	2.00	1.75	1.67	1.64	2.00
Active threat lethality envelopes	1.33	1.25	1.75	2.00	1.58	1.42	1.50	1.33	1.45	1.64
Tractor beam	1.58	1.83	1.67	2.17	1.58	1.50	1.58	1.58	1.73	1.82
Missile Position	2.08	2.67	2.17	3.08	2.00	1.92	1.92	1.58	1.82	2.82
Bogie number and type information (A/A)	1.08	1.25	1.08	1.25	1.83	1.25	1.25	1.33	1.36	1.55
Bogie altitude difference information (A/A)	1.50	1.42	1.50	1.42	2.25	1.67	1.42	1.58	1.64	2.27
Above and below altitude terrain coding	3.00	3.30	3.40	3.80	3.10	3.40	2.20	2.10	2.60	3.00
Geographical and cultural features	2.08	2.17	2.58	3.00	1.92	2.67	2.00	1.50	1.82	2.45

2. This part of the questionnaire is designed to elicit your opinions on the relative usability of the two display presentation modes - monochromatic and color. Please place a number on each line to indicate, for monochromatic and for color, the degree of ease or difficulty of understanding the particular display information.

Easy				Difficult		
Very	Moderately	Slightly	Neutral	Slightly	Moderately	Very
1	2	3	4	5	6	7

	Monochrome	Color
1. Interpretation of threat alert symbology on the HUD was:	1.92	1.75
2. Interpretation of HUD pathway information was:	3.67	2.83
3. Interpretation of HUD terrain information was:	3.42	2.25
4. Interpretation of surface-to-air threat mode information on the VSD was:	2.83	2.25
5. Interpretation of surface-to-air threat type information on the VSD was:	3.50	2.67
6. Interpretation of countermeasures effectiveness information on the VSD was:	2.75	1.83
7. Interpretation of the VSD ribbon in the sky was:	3.00	2.42
8. Interpretation of VSD terrain information was:	2.67	1.67

Easy				Difficult		
Very	Moderately	Slightly	Neutral	Slightly	Moderately	Very
1	2	3	4	5	6	7

	Monochrome	Color
9. Interpretation of surface-to-air threat mode information on the HSD was:	2.58	2.33
10. Interpretation of surface-to-air threat type information on the HSD was:	3.75	3.08
11. Interpretation of countermeasures effectiveness information on the HSD was:	3.16	2.08
12. Interpretation of current missile position information on the HSD was:	2.75	2.41
13. Interpretation of A/A threat mode information on the HSD A/A format was:	2.00	1.75
14. Interpretation of A/A threat type information on the HSD A/A format was:	1.42	1.42
15. Crosschecking threat mode information on the VSD and HSD was:	4.25	3.83
16. Crosschecking threat type information on the VSD and HSD was:	4.17	3.58
17. Crosschecking flight path information on the HUD, VSD and HSD was:	3.50	3.33
18. Crosschecking terrain information on the HUD, VSD and HSD was:	3.83	3.08
19. Stores manipulation and status	4.17	4.08

APPENDIX D

SYNOPSIS OF TWELVE RESPONSES TO EACH OF TEN OPEN-ENDED QUESTIONS

THREAT WARNING STUDY

The pilots spoke their responses to the open-ended questions into a tape recorder. These responses were transcribed and are summarized in the pages which follow. As might be expected, there are some agreements and a number of differences. Several pilots went through the listed questions and found themselves will still more to say. These additional statements are summarized under "General Comments" at the end of this appendix. The revised formats include attempts to address plurality opinions.

Question 1. What is your general opinion of the threat alerting information on the HUD? Any suggestions for change?

Good (7 pilots).

Use different symbol for AAA and SAM (6 pilots).

Need countermeasures effectiveness information on HUD (4 pilots).

For AAA, put three A's instead of 3 O's in the countdown box (2 pilots).

Need continuous search or track information in HUD as well as alerts for new threats (2 pilots)

Keep alerting symbol up longer than 6 sec - perhaps reduce size (1 pilot).

Hard to see threat azimuth vector (2 pilots).

Put azimuth vector on alert symbol vs airplane symbol (1 pilot).

Didn't use threat azimuth on HUD (1 pilot).

Use different symbols or color as track and launch (2 pilots).

Use different flash rates for track and launch (1 pilot).

Turn flash rule around - flash for search, solid for track or launch (1 pilot).

Red alerting symbol especially good (1 pilot).

Repeat alert symbols on VSD (1 pilot).

Make launch indication (countdown box) more conspicuous (1 pilot).

Add information on adversary position for air-to-air in HUD (1 pilot).

Add aural warning for new threat (1 pilot).

Put G-meter in HUD (1 pilot).

Monochrome confusing (1 pilot).

Need better horizon in HUD (1 pilot).

Make HUD numbers larger (1 pilot).

Use heading tape in HUD (1 pilot).

Too much color fill in HUD obscures outside scene (1 pilot).

Question 2. What is your general opinion of the threat mode and type of information presented on the VSD? Any suggestion for changes?

Didn't use it much (6 pilots).

Good (3 pilots).

Good in color (1 pilot).

Bad on monochrome (2 pilots).

Put SAM vs AAA distinction on HUD then eliminate VSD (1 pilot).

Repeat HUD threat alert symbols on VSD (1 pilot).

Confused AAA site with launch "jewel light" (1 pilot).

Put all essential information in HUD-use VSD and HSD for backup details (1 pilot).

In two-seat aircraft, give HUD to pilot; VSD and HSD to back seater (1 pilot).

Change airplane symbol so it shows roll (1 pilot).

Put viewpoint in airplane and use to amplify and expand HUD data (1 pilot).

I liked high altitude mode (simple ADI) (1 pilot).

"I wouldn't want to go flying into a valley at night with that thing." (1 pilot).

Question 3. What is your general opinion of the threat mode and type information presented on the HSD? Any suggestions for changes?

Good (8 pilots).

Identify on HSD which new threat the HUD is alerting (3 pilots). Takes too long to distinguish SAM from AAA (3 pilots). Sometimes confused threats with mountains (3 pilots).

Consider eliminating terrain data (3 pilots).

Jewel light is worthless -- too much like AAA (1 pilot).

Countermeasures effectiveness hard in monochrome (1 pilot).

Monochrome tough (1 pilot).

Cluttered with all those threats (1 pilot).

Put in single button for each range rather than stepping through (1 pilot).

Question 4. Which display did you find most useful for threat information?

HUD (9 pilots).

HSD (6 pilots).

Air-to-Air HSD (2 pilots).

VSD good backup (4 pilots).

VSD of limited value (2 pilots).

Put more in HUD so I don't have to look down (3 pilots).

Consider mode buttons which would put VSD and HSD pictures on HUD (1 pilot)

Question 5. Was the threat symbology on the HUD adequate for alerting you to threat mode changes?

Yes (8 pilots).

Add countermeasures effectiveness information to HUD (3 pilots).

Retain alert symbol longer than 6 seconds. Shrink "old" ones to reset for "new" alerts (3 pilots).

Consider different flash rates for track and launch (3 pilots).

Add threat type and clear track/launch distinction to HUD (1 pilot).

Add audio tone for threat warning (2 pilots).

Add threat location vector to HUD for surface-to-air as well as air-to-air (1 pilot).

Need different symbols for SAM and AAA (1 pilot).

Question 6. Was the distribution of threat alert symbology across the HUD, VSD and HSD appropriate? What would you change?

The distribution was good (3 pilots).

Do not add more to HUD (1 pilot).

More in HUD (7 pilots).

Azimuth in HUD earlier than launch for surface-to-air as well as air-to-air (4 pilots).

SAM/AAA distinction in HUD (2 pilots).

Countermeasures effectiveness in HUD (2 pilots).

Track/launch distinction in HUD (1 pilot).

Maybe change scales to add more to HUD (1 pilot).

Repeat alert in VSD as it is in HUD (2 pilots).
Improve attitude information in VSD (1 pilot).

Question 7. Would you modify the layout or content of any of the pictorial formats used in this simulation? If so, what would you change?

Pitch 'der and better flight director in HUD (5 pilots).
Put mo. : information in the HUD (3 pilots).
Heading tape in HUD (2 pilots).
HUD weapon delivery X hard to see in monochrome (2 pilots).
Altitude tape in HUD (1 pilot).
Put selected weapon information in HUD (1 pilot).
In HUD, get rid of data boxes and make airspeed, heading and airspeed numbers larger (1 pilot).
Eliminate waypoint and target flags from HUD (1 pilot).
Remove sides from HUD pathway (1 pilot).
Put countermeasures effectiveness in HUD (1 pilot).
Put flight director and attitude information in VSD (1 pilot).
Didn't use VSD ribbon much (1 pilot).
Have VSD revert to ADI format at high bank angles (1 pilot).
Remove VSD and move HSD up (1 pilot).
Swap positions of HSD and VSD (1 pilot).
Improve stores management and status displays - like A-10 (2 pilots).
Hard to tell mountains from AAA sites (1 pilot).
Monochrome displays appeared to cluttered (2 pilots).
Put symbol dictionary on MFD - then you could make any symbol on other displays and look up its meaning (1 pilot).

Question 8. Do you have any suggestions for additional pictorial formats that might be developed? Specifics?

Good as they are (3 pilots).

Expand stores/attack symbology to include other tactics and delivery options (3 pilots).

Need good transitional flight director - and ability to chose its duration and mode (1 pilot).

Add accelerometer to HUD (1 pilot).

Use ribbon vs pathway in HUD (1 pilot).

Put desired as well as actual heading, airspeed and altitude in HUD (1 pilot).

Add threat position to HUD (1 pilot).

Add vertical speed to VSD (1 pilot).

Add angle-of-attack to VSD (1 pilot).

With more than 3 types of surface threats, you'll run out of symbols so use alphanumerics (1 pilot).

Unclutter displays in monochrome (1 pilot).

Keep it simple (1 pilot).

Question 9. How does the threat warning symbology used in this study compare with other threat warning systems you may have used or know about?

A lot more information here. This is much better (6 pilots).

No comment - not familiar with other systems (5 pilots).

Retain aural warning from older systems (1 pilot).

Question 10. How necessary are the various threat warning elements shown in this simulation? Are there some you could do without in a mission of the sort simulated?

Need it all (8 pilots).

Wouldn't trust countermeasures effectiveness (3 pilots).

Clear up AAA/SAM distinction on HUD (1 pilot).

Remove the VSD (2 pilots).

Need good ADI (1 pilot).

Weapons switchology too complicated (1 pilot).

Engine status poor (1 pilot).

Color much better -monochrome appears cluttered (1 pilot).

General Comments

Find way to integrate more threat information in HUD (3 pilots).

HUD inverted T difficult to use (1 pilot).

Put angle of attack on HUD and VSD (1 pilot).

Use something like Kaiser VDI in A-6 rather than this perspective pictorial VSD (1 pilot).

VSD airplane symbol should rotate about its center of gravity (1 pilot).

Give VSD and HSD to the back seater in a two-place airplane (1 pilot).

Bogie altitude notation in air-to-air HSD - hard to know units (1 pilot).

Color coding of countermeasures effectiveness was confusing (1 pilot).

Need transparent envelope notation for active threats for case when the threat is the target (1 pilot).

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