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AFWAL-TR-87-3047

MULTI-CREW PICTORIAL FORMAT DISPLAY EVALUATION

AD-A189 349

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February 1987

Final Report for Period May 1984 - January 1987

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FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS NONE
2a. SECURITY CLASSIFICATION AUTHORITY N/A 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S) F33615-83-C-3618	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFWAL-TR-87-3047
6a. NAME OF PERFORMING ORGANIZATION Boeing Military Airplane Co. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Crew Systems Development Branch
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 3707 Seattle, WA 98124-2207	7b. ADDRESS (City, State, and ZIP Code) AFWAL/FIGR Wright-Patterson AFB, OH 45433-6553
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Crew Systems Development Branch 8b. OFFICE SYMBOL (If applicable) AFWAL/FIGRB	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-83-C-3618
8c. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB, OH 45433-6553	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62201F; PROJECT NO. 2403; TASK NO. 04; WORK UNIT ACCESSION NO. 57

11. TITLE (Include Security Classification)
Multi-Crew Pictorial Format Display Evaluation

12. PERSONAL AUTHOR(S)
T.C. Way, R.L. Martin, J.D. Gilmour, M.E. Hornsby, R.E. Edwards

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM May 84 TO Jan 87	March 1987	214

16. SUPPLEMENTARY NOTATION
None

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
0508		
0505		

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Pictorial Format, Engine Status Format, Color Symbology, Multi-Function Display, Head-Up Display, Human Factors Engineering (Continued over)

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

The Multi-Crew Format evaluation was designed to evaluate pictorial formats in a two-seat fighter, to determine their usabiltiy as a function of color, and determine their acceptability. The study consisted of designing the formats, evaluation of formats in part-task, part-mission, and full-mission simulation, and redesigning formats based on air crew feedback if needed.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL 2Lt. James E. McClain	22b. TELEPHONE (Include Area Code) (513) 255-8269 22c. OFFICE SYMBOL AFWAL/FIGRB

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Block #18 Con't - Tactical Situation Display
Horizontal Situation Display
Perspective Situation Format
Close Look Format

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LIST OF ACRONYMS

AAA	Anti-Aircraft Artillery
A/A	Air-to-Air
A/C	Aircraft
ADI	Attitude Direction Indicator
AF	Air Force
AFCS	Automatic Flight Control System
AFWAL/AAAT	Air Force Wright Aeronautical Laboratories, Information Processing Technology Branch
AFWAL/FIGR	Air Force Wright Aeronautical Laboratories, Crew Systems Development Branch
A/G	Air-to-Ground
AGL	Above Ground Level
AIM	Air Intercept Missile
AIR	Air Mode
AN/ALE 40	A countermeasures dispensing set
ANOVA	Analysis of Variance
ATT	Attack
BMAC	Boeing Military Airplane Company
BNB	Busy-Not Busy
BVR	Beyond Visual Range Mission Segment
CDRL	Contract Data Requirements List
C/L	Center Line
CLF	Close Look Format
CRT	Cathode Ray Tube
DARPA	Defense Advanced Research Project Agency
DEF	Defense
ECM	Electronic Countermeasures
EGT	Exhaust Gas Temperature
FEBA	Forward Edge of the Battle Area
FL	Flight Level
FLOT	Forward Line of Troops
GND	Ground Mode
HOTAS	Hands On Throttle and Stick
HSF	Horizontal Situation Format
HUD	Head-Up Display
ID	Identification
IFFN	Identification, Friend, Foe, Neutral
ILS	Instrument Landing System
I/O	Input/Output
IRST	Infared Search and Track
KTAS	Knots True Air Speed
LLP	Low Level Penetration Mission Segment
MANOVA	Multivariate Analysis of Variance
MCPFD	Multi-Crew Pictorial Format Display
MLE	Missile Launch Envelope

MPD	Multi-Purpose Display
N	Navy
N	Number of cases
NM	Nautical Miles
PFDE	Pictorial Format Display Evaluation
PSF	Perspective Situation Format
RMS	Root Mean Square
SAM	Surface-to-Air Missile
SH	System Health Mission Segment
SWAT	Subjective Workload Assessment Technique
WSO	Weapon System Officer

PREFACE

This report covers work performed during the period May 1984 through January 1987 for the Air Force Wright Aeronautical Laboratories Flight Dynamics Laboratory (AFWAL/FIGR) under contract F33615-83-C-3618. Dr. John M. Reising was Project Manager with Capt. Gretchen Lizza, and later, Lt. James E. McClain as Project Engineers. The authors wish to thank Dr. Reising, Lt. McClain, and especially, Capt. Lizza for their guidance and support during this project.

Special acknowledgement is made of the contributions by the operational Air Force and Navy flight crews who evaluated these formats. These professional pilots and "guys in back" served as very effective measuring instruments for the pictorial formats.

The work was performed by the Crew Systems Technology Group of the Boeing Military Airplane Company in Seattle. J. D. Gilmour was the Program Manager. T. C. Way was the Principle Investigator and designed the simulation. Members of the staff participated in all phases of the effort but R. E. Edwards was primarily responsible for the test design and M. E. Hornsby was responsible for much of the format development. R. L. Martin organized the disc formats, and led the simulation integration, checkout and data collection phases.

The simulation was conducted in BMAC's Flight Simulation Laboratory, R. A. Becker, Manager. Programmers, engineers and technicians who worked on the project included Craig Betzina, Bob Coyle, Lee Emerson, Lou Hough, John Kay, Tom Krogel, Harmon Law, Kevin McMahon, Eric Miyamoto, Jake Schemnitzer, Steve Wagner and Mike Warden. Their skill and dedication in creating and operating the simulation contributed strongly to the program.

EXECUTIVE SUMMARY

OBJECTIVES: A simulator study was conducted to evaluate the usability and acceptability of pictorial format displays for two-seat fighter-attack aircraft; to determine whether usability and acceptability were affected by display mode -- color or monochrome; and to recommend format changes based on the results of the simulation.

BACKGROUND: The missions, complexity, and capability of modern aircraft are approaching the point where they are beyond capability of aircrews to operate. Integration and automation techniques are being applied to address this problem. The present study brings to bear recent advances in cockpit display technology which now allow pictorial representation of flight, situation, and airplane system information. The goal is to present the information the aircrew needs, when they need it, and in a form that is most useful.

APPROACH: Pictorial formats were developed for a head-up display (HUD), a perspective situation format (PSF), and a horizontal situation format (HSF). Two close look formats (CLFs) were developed to show an expanded view of aircraft in selected small areas during an air engagement. Additional formats were developed to represent status of the propulsion, fuel, hydraulics, electrical, stores, countermeasures, and passive sensor systems. Stores programming, countermeasures programming, and advisory checklists were also represented. All these formats had both color and monochrome versions.

A simulation was assembled to evaluate these formats under realistic flight conditions. A two seat cab was constructed with four cathode ray tubes, multi-purpose displays in each seat plus a HUD in the front. Controls and switches were added to support the procedures necessary for an operational mission. System malfunction, low level penetration, and beyond-visual-range air-to-air mission segments together with full high-low-high missions were planned and created in digital simulation.

Sixteen operation two-man USAF or USN aircrews each spent three days learning the formats and the simulated aircraft, then flying the missions and evaluating the monochrome and color versions of the formats. Pilot opinion, workload, and performance data were collected.

RESULTS AND CONCLUSIONS: In their critiques, the pilots and WSOs clearly preferred the color formats. They indicated general approval of the pictorial format concept and provided detailed criticism of specific formats. Subjective workload assessments did not show a significant difference between color and monochrome formats. However, there was an apparent learning effect favoring the color formats. The performance data did not show significant color/monochrome differences. There were weaknesses in aircrew performance which could be identified with particular formats.

The crew critiques and performance data were applied to recommended revisions. The PSF in air mode and the CLF received the most extensive revision. Minor changes were recommended to other formats.

1.0 INTRODUCTION

This is the final report of a program designed to further the development of pictorial formats for fighter and attack aircraft. In this program, pictorial formats were evaluated in a two-seat fighter. The intent of pictorial formats was to present information in a native, intuitive way which minimizes mental processing.

1.1 Background

Until quite recently, the primary medium for cockpit information display was electro-mechanical -- tapes, gages, flags, and dials assembled into indicators. The limited degrees of freedom in these electro-mechanical indicators required that they be dedicated and single purpose, that they show raw data, and that there be many of them. There was a time when this was sufficient. Aircraft, aircraft systems, and missions were simpler.

Since then however, aircraft, systems, and missions have all become more complex. As the mission requirements became more demanding, technology advanced to meet those requirements, providing more capable aircraft and systems. However, these technological advances created a cockpit information overflow. Aircrews in modern fighter attack aircraft are inundated with information, most of it important and much of it critical some time in some missions. Ideally, aircrews would be provided the information they need, when they need it, and in a form which can be easily understood and assimilated into an overall awareness of their current situation.

This problem is being attacked on a number of fronts. More efficient uses of the voice and auditory channels are being explored for pilot control inputs and airplane information outputs. New display media, including helmet-mounted displays, are being developed. Advanced sensors, fusion of information, better guidance schemes, and advanced automation through artificial intelligence are all in development.

The present series of studies is investigating ways to exploit the degrees of freedom available in electro-optical displays. Specifically, pictorial formats have been developed to portray information needed by the aircrew in a native, intuitive manner to maintain a clear general awareness of the airplane and mission situation and specific awareness of conditions which require immediate and reliable aircrew input.

1.2 Previous Work

The Multi-Crew Pictorial Format Display Evaluation Program is the third in a series of contracted efforts, sponsored primarily by the Air Force Flight Dynamics Laboratory, Crew Systems Development Branch, (AFWAL/FIGR). In the first of these efforts, conceptual displays were developed for six primary fighter crew station functions: primary flight, tactical situation, stores management, systems status, engine status, and emergency procedures (Jauer and Quinn, 1982).

In the second contract, Pictorial Format Display Evaluation (PFDE), the Boeing Military Airplane Company continued the development beyond the paper formats of the earlier program and implemented the results in a piloted simulation. Two simulation studies were conducted to evaluate the usability and acceptability of pictorial format displays for single-seat 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. In the first of the two PFDE studies, pictorial formats were implemented and evaluated for flight, tactical situation, system status, engine status, stores management, and emergency status displays. The second PFDE study concentrated on the depiction of threat data. The number of threats and the amount and type of threat information were increased. Both PFDE studies were reported in Way, Hornsby, Gilmour, Edwards and Hobbs, 1984.

A total of thirty USAF and USN pilots in the two studies flew mission simulations with color and monochrome versions of the displays. Objective performance data, subjective pilot ratings, and comments were collected. In general, the pilots found the pictorial format displays, and the specific implementations used in these studies to be quite acceptable. They preferred color over monochrome versions. A number of improvements were suggested for particular format elements, and were incorporated into revised formats.

1.3 Objectives

The present study had two primary objectives. One of these was to evaluate usability and acceptability to two-seat tactical air crews of a set of service-provided pictorial formats for electro-optical displays. The second objective was to determine whether the degree of usability and acceptability of the pictorial formats was a function of two basic display presentation modes: monochrome and color. A further objective was to refine the formats based on information gathered during the simulation.

The program was intended to support the services in their efforts to provide a firm technology base in the area of aircraft crewstations, displays, and controls. In addition, the work supports the Air Force Armament and Avionics Laboratories in their respective goals of developing integrated stores management and avionic systems which are compatible with advanced crew interface concepts and workload requirements. These service goals are being pursued through a number of exploratory and advanced development programs that include the demonstrated feasibility of cockpit electro-optical displays driven by high-speed digital computers. The Multi-Crew Pictorial Format Display Program has furthered these objectives by simulating and evaluating a representative set of electro-optical display formats designed to significantly reduce the information processing demands placed upon flight crews. This reduction in mental workload will allow flight crews to more efficiently extract information from the cockpit.

1.4 Organization of the Program and of this Report

The majority of the formats evaluated here were largely derived from recommendations at the end of the PFDE program. Others were developed locally and still others were added by the contracting agency, AFWAL/FIGR. The formats were subjected to an iterative development process with four evaluations.

1.4.1 Static Format Evaluation

Early, after the formats were fairly mature, but before they were committed or programmed, they were evaluated by pilots of the 318th Fighter-Interceptor Squadron stationed at McChord AFB. The static format evaluation is described more fully in Section 2.

1.4.2 Format and Simulation Development

Simulation development and further format development followed the static format evaluation. Section 3 describes the simulation facilities. Section 4 describes the simulated aircraft, its systems and the pictorial formats which support them.

1.4.3 Demonstration One

After the format and simulation development for the MCPFD program were well underway, it was decided to use these formats and parts of this simulation for a demonstration of artificial intelligence. The objective of Demonstration One was to show feasibility and potential of an expert systems approach to pilot decision aiding. This objective was met by adding symbolic processing to elements of the MCPFD simulation. The result highlighted expert systems at work in a high quality, pilot-in-the-loop simulation. The demonstration itself was a one-time event presented in January 1986. It was sponsored by the Defense Advanced Research Projects Agency (DARPA) and administered jointly by AFWAL/FIGR and AFWAL/AAAT. This simulation of expert systems was documented in a full color, narrated, video tape (Boeing Military Airplane Company, 1986a), in a technical operating report (Boeing Military Airplane Company, 1986b) and in a final report (Pohlmann, Shelnutt, Stenerson, Payne and Marks, 1986).

1.4.4 Dynamic Comparisons

After the formats and simulation were completed, but before data was collected in the final two stages, a session was conducted to select from among alternate versions of the dynamic formats for primary flight, tactical situation, and navigation displays. Information obtained from this evaluation was used to determine the specific versions of the dynamic formats which were to be tested in the mission segment and composite mission simulation evaluations. The dynamic comparisons stage is reported in more detail in Section 5.

1.4.5 Mission Segments and Composite Missions

Sixteen two-man aircrews each participated in a three-day program to learn, use, and evaluate the formats. Each crew flew both mission segment and composite mission pictorial format evaluations. Their program is detailed in Section 6 and the results of their evaluation are documented in Section 7.

1.4.6 Conclusions and Revised Formats

The conclusions and revised formats are given in Section 8. This is done as an application of performance, opinion, and workload data to the original intention of each format.

2.0 STATIC FORMAT EVALUATION

Modifications to existing formats, and the development of new formats, were based on data obtained in earlier evaluation efforts and on analyses of crew responsibilities and information requirements in a two-seat aircraft. Because the translation of display format concepts into a functional simulation environment is a long and iterative process, it was decided to involve operational crews in the development and evaluation process at the earliest possible stage. The purpose of the static format evaluation was to allow operational crews to critique proposed formats and to use their inputs in further modifications of the formats to be specified for the full simulation.

2.1 Formats

Seventeen format examples were submitted for evaluation: HUD, HUD with Missile Launch Envelope (MLE) symbology, air and ground mode Perspective Situation Format (PSF), air and ground mode Horizontal Situation Format (HSF), Target Formation, Engine Status and Engine Advisory, Electrical Status and Electrical Advisory, Hydraulic Status, Fuel Status, Stores Status, Countermeasures Status, and Passive Sensor Status. Two versions were developed for each format example: color and monochrome. Each format was generated as a high resolution color or monochrome transparency using a computer-based graphics system. In some cases composite examples were used to illustrate a wider variety of display symbology than would appear at any given instant on the cockpit display. A description was written for each format example to guide the evaluator briefing and ensure that all important display symbology was covered.

2.2 Evaluation

Evaluators in the static format evaluation were operational crews from the 318th Tactical Fighter Squadron, stationed at McChord Air Force Base in Washington. A total of twelve pilots participated in the evaluation. By rank, they were one Major, eight Captains, one U. S. Navy Lieutenant and two First Lieutenants. They reported 305 to 3000 flight hours with a mean of 1776 hours. Eleven of the pilots had flown F-15, nine T-38, seven T-37, four F-106, three T-33, three AT-38B and one each F-4, F-111A, KC-135, T-28, T-39 and T-43.

The briefing began with an explanation of the purpose of the static format evaluation, some background on the concept of pictorial formats, and an explanation of the questionnaire. Each format was presented first in its color version, with an oral briefing about its purpose and symbology. Then the monochrome version of the same format was presented with an explanation of the monochrome coding. Finally, each evaluator completed a questionnaire for a given format before the next format was presented. Both versions of the format were presented on overhead projectors along with the questionnaires, and questions were encouraged during the briefings.

The first page of the questionnaire requested data about the evaluator. Each of the remaining pages solicited responses about one of the formats under evaluation, and was labelled with the format name at the top. Except for this label, all questionnaire pages were identical.

For each format, the first four questions required rating the format on five point scales. Evaluators rated each format on how useful it was for its intended purpose (from "not at all useful" to "very useful"); how easy it was to interpret (from "not easy" to "very easy"); how appropriate the symbology was (from "not at all appropriate" to "very appropriate"); and how the use of color affected interpretability (from "makes interpretation more difficult" to "makes interpretation much easier"). Two additional questions asked what necessary, but currently missing, information should be added to the format, and what unnecessary information should be removed from the format. The final questionnaire item allowed the evaluators to make general comments about the format.

2.3 Results

Appendix A summarizes the pilot's general comments and those comments which specifically referred to the information content of the formats. Average ratings for each format are shown as profiles in Figure 2.3-1. Responses along each of the labelled, unnumbered scales were converted to ratings of 1 to 5, where 1 was the least favorable rating (e.g., "not at all useful"), and were then averaged. With a few exceptions, the ratings obtained from the operational crews were closely grouped and favorable. Results for each of the rating questions are discussed in the following paragraphs.

2.3.1 Usefulness

The alphanumeric Electrical and Engine Advisory displays received the highest average ratings of usefulness, followed closely by the ground mode HSF and PSF, air mode HSF, Stores Status, and Passive Sensor Status formats.

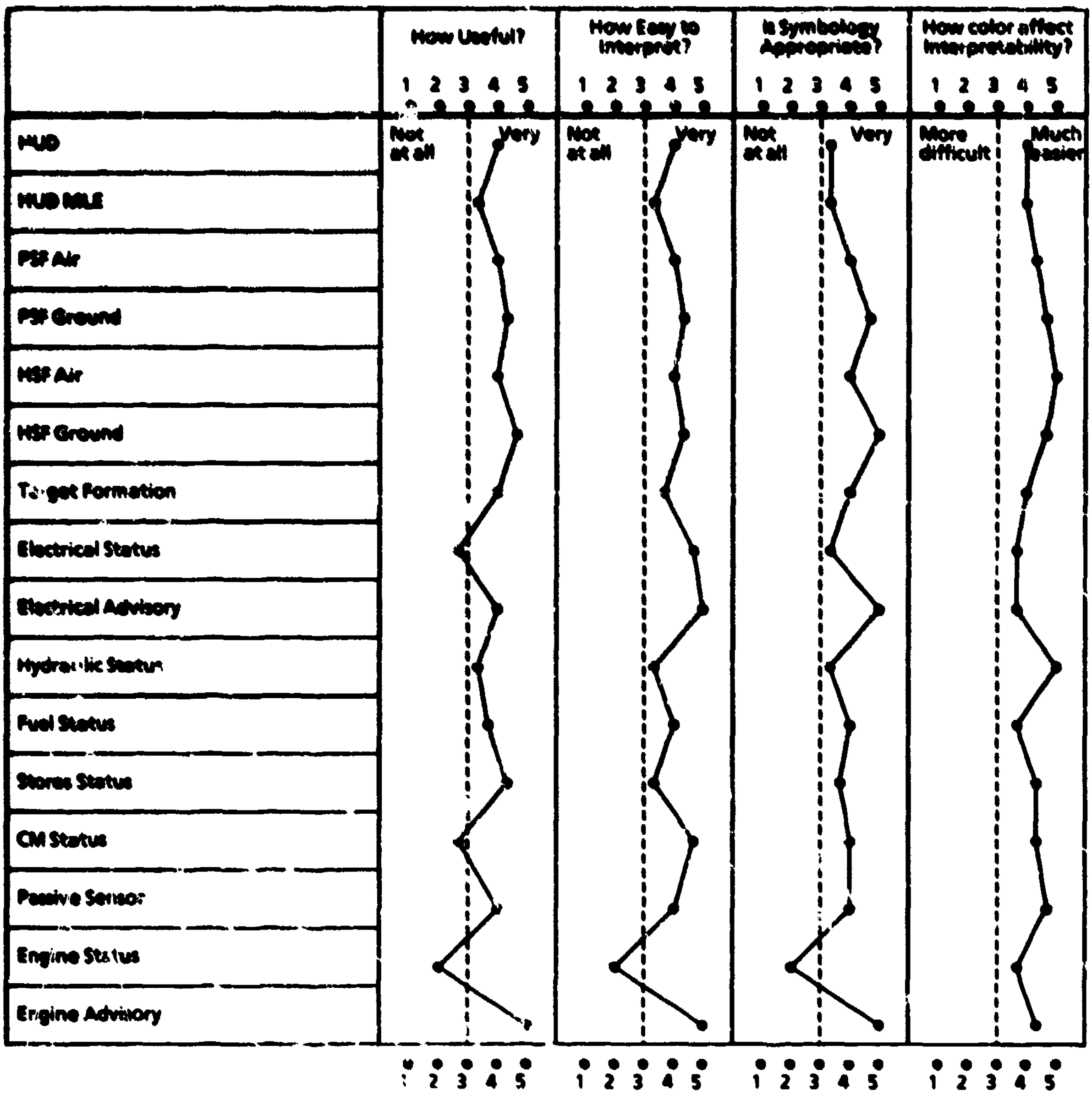

Figure 2.3-1. Static Format Evaluation Profiles

All these formats received average ratings higher than 4.0. Only three of the sixteen formats received average ratings of less than 3.0 ("somewhat useful") on this question. These formats were the Electrical Status, Engine Status, and Countermeasures Status. Review of the comments made about these formats suggests some of the reasons for the low usefulness rating. Several evaluators said that the Electrical System Status format was no better than the currently used telelight panel. Similarly, many evaluators preferred standard round dial or gauge displays to the Engine Status format. Some evaluators also emphasized that standard engine instruments and a telelight panel for systems problems display information continuously, which is an advantage over the time-shared pictorial formats.

2.3.2 Ease of Interpretation

Ratings of interpretability, with a couple of exceptions, were similar to the ratings for usefulness. Ten of the formats received average ratings greater than 4.0; these included the advisory formats, most of the dynamic situation displays, and in contrast to the usefulness ratings, the Countermeasures Status and Electrical System Status formats. Only the Engine Status format received an average rating lower than 3.0 ("somewhat easy to interpret"). Comments suggest that the Engine Status format was rated low due to a preference for round dial instruments and the lack of numeric readouts.

2.3.3 Appropriateness of Symbology

As expected, ratings of symbology appropriateness closely paralleled the ratings for ease of interpretation. The advisory formats were among nine formats that had average ratings higher than 4.0; others were the air and ground mode versions of the HSF and PSF, the Passive Sensor, Fuel, and Countermeasures Status formats. Again, only the Engine Status format received an average rating lower than 3.0 ("somewhat appropriate"). Again, the low rating was probably due to a preference for the conventional instruments.

2.3.4 Use of Color and Interpretability

Evaluators generally agreed that the use of color made the formats easier to interpret. All sixteen formats received average ratings of 3.0 ("color has no effect") or better, and fifteen of the sixteen had average ratings greater than 4.0. The average ratings on this question were highest for the complex situation displays; the air and ground mode PSF and HSF, and Target Formation display, and for the detailed Hydraulic Status and Passive Sensor Status Displays. Color may be particularly useful in complex or detailed displays where it may help the viewer to sort out the various types of information or quickly identify a problem area.

2.3.5 Information to be Added or Deleted

Evaluator's suggestions about information to be added to or deleted from the formats and additional comments are summarized in Appendix A. In the table, each suggestion or comment is followed by the number of evaluators who made that response. The evaluators had specific suggestions for changes to most of the formats. Many of these suggestions were implemented in the format revisions discussed in the next section. Other suggestions were not implemented because they did not represent sufficient concensus among the evaluators; because they were antithetical or irrelevant to the objectives of the program; or because they were imprecisely defined.

2.4 Application of Results

The static format evaluation proved to be of significant value in the development and evaluation of the formats used in the MCPFD simulation. The first, and perhaps not so obvious, benefit was the early development and production of high-quality, computer-generated versions of all proposed formats. This process allowed the rapid generation of alternate symbology and coding, and was a powerful and accurate tool for assessing format concepts in the design and revision process before, during, and after the static format evaluation.

The static format evaluation itself allowed the early and effective participation of operational crews in the format development process, and resulted in the confirmation of the validity of the pictorial display concept, especially as it applied to multi-crew aircraft. Valuable comments by the crews led to the incorporation of a variety of changes to improve the proposed formats.

On the HUD, options to select a filled or unfilled version of the pathway, and to add a pitch ladder were added, along with identification of weapon(s) selected. On the air mode PSF, optional readouts of target airspeed, closing rate, and range were included and relative altitude symbology was deleted. For the hydraulic status format, the symbology for normal systems was changed from white outline to green fill; this change made the hydraulic system coding more similar to the electrical system coding. Numeric readouts of fuel flow in pounds per hour and percent of available thrust were added to the Engine Status Format.

In one case, comments from the operational crews in the static evaluation, in combination with an analysis of a single-threat Beyond-Visual-Range (BVR) air-to-air mission scenario, resulted in the development of a new format. Evaluators requested readouts of target altitude and airspeed for the Target Formation Display. A second, tabular version of the Target Formation display was developed to display more detailed information about the selected targets. These two versions of the Target Formation Display became the Formation and Detail Close Look Formats.

3.0 TEST EQUIPMENT AND FACILITIES

The Multi-Crew Pictorial Format Display simulation was conducted in BMAC's Flight Simulation Laboratories in Kent, Washington. Three of the laboratories were used in this simulation, interconnected by a Pronet 10 MHz communications bus system. Figure 3.0-1 shows the major elements of this simulation and their arrangement. Figure 3.0-2 is a photograph of the two-seat simulator cab. The following paragraphs describe the cockpit arrangements in the two seats and the configuration of hardware elements which were employed in the simulation.

3.1 Layout of the Two-Place Fighter Cab

The arrangement of display and control elements in the front seat is shown is Figure 3.1-1. As a naming convention throughout this program, the CRTs were called "displays" and the pictures shown on those displays were called "formats". Thus, the front seat had a head-up display (HUD) as well as left, center, right, and lower multi-purpose displays (MPDs). The HUD and all the MPDs were eight-inch diagonal, narrow shadow mask, color CRTs. The HUD combiner was removed for this study. The MPDs each had five unlabelled push button switches on each side and seven labelled push button switches below. The unlabelled switches were used in conjunction with some of the formats. The labelled switches under the left and right MPDs were used to select the time-shared formats and those under the center and lower MPDs controlled options on the PSF and HSF, respectively. These switch applications are detailed in the format discussions of Section 4.

The panel above the left MPD contained switches for air mode - ground mode selection and for selection of several HUD options. The panel above the right MPD contained switches for stores and countermeasures selection. Small panels to the left and right of the lower MPD had switches for navigation functions and cursor definition. The thrust handles were located on the pilot's left side console as were panels for the fuel, engines, and electrical systems.

Both seats were equipped with side-arm controllers. For the pilot, this controller was used as the primary flight controller. Each of the grips for these controllers had a two way trim switch, a trigger, three auxiliary switches, and a thumb operated isometric X/Y controller which was used to position the cursor on the horizontal situation format. Except for the HUD, the major front seat forward panel displays and controls were duplicated in the rear seat, as shown in Figure 3.1-2.

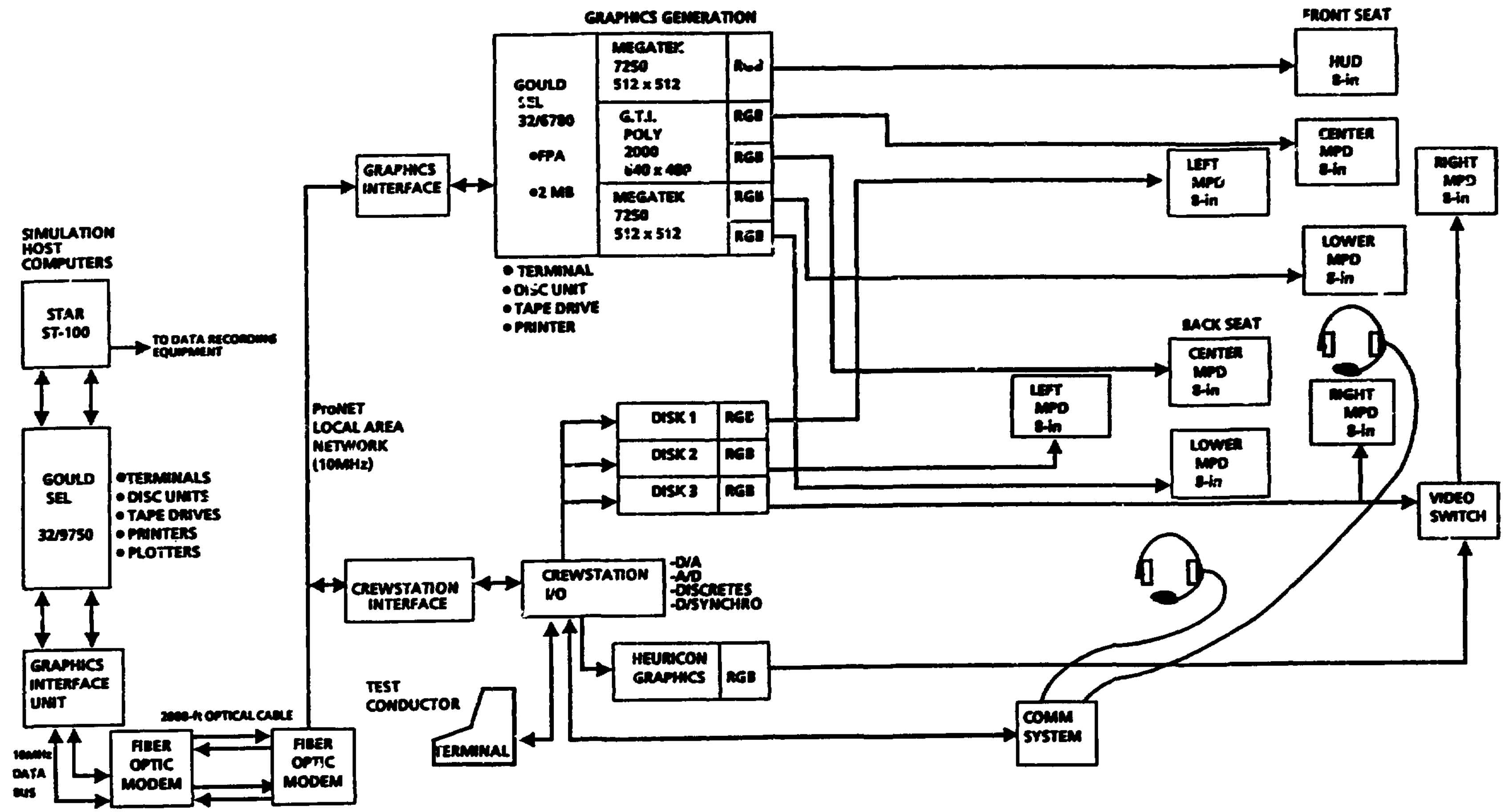

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Figure 3.0-1 Schematic Diagram of Major Simulation Elements

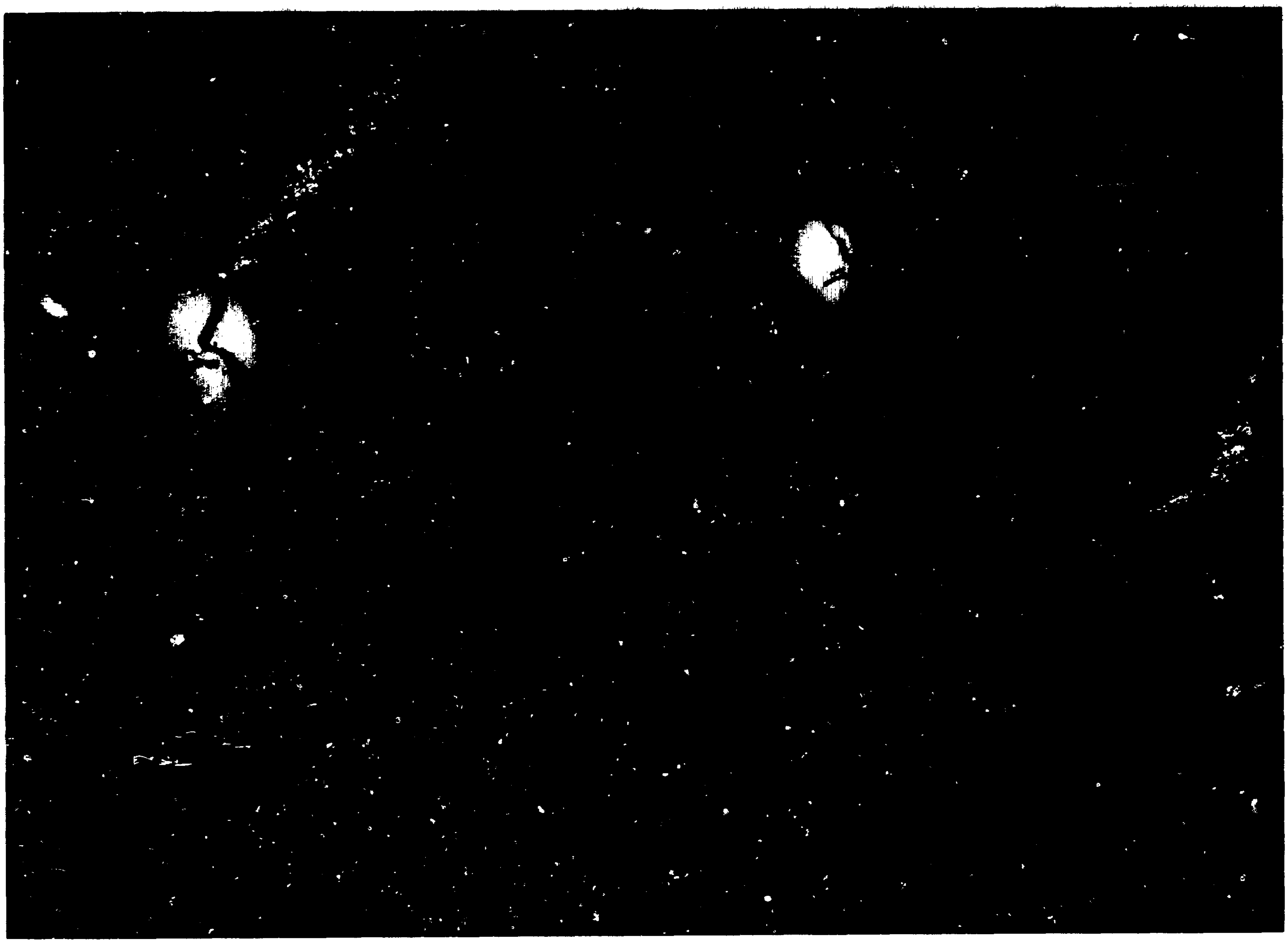


Figure 3.0-2. Two-seat Simulator Cab

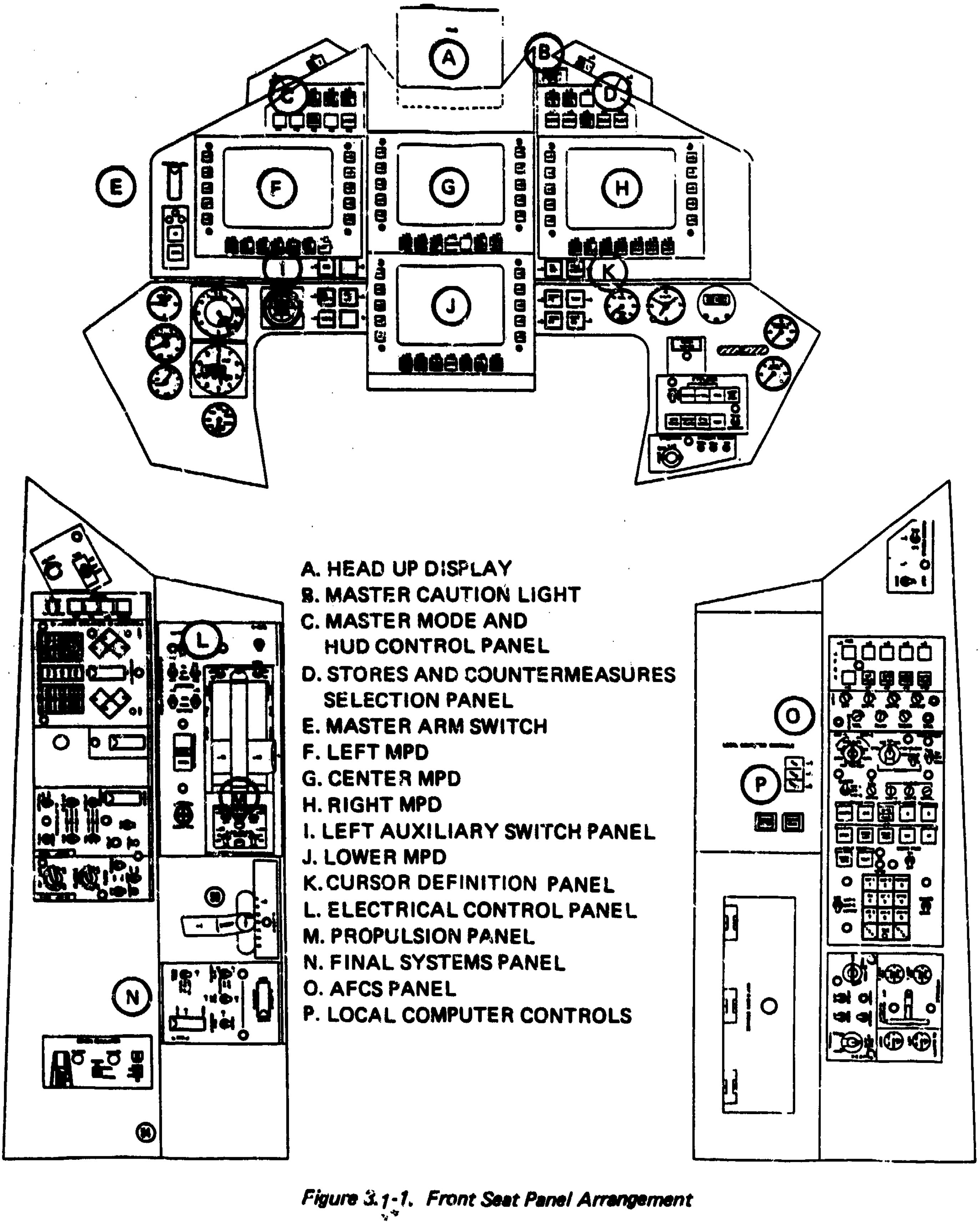
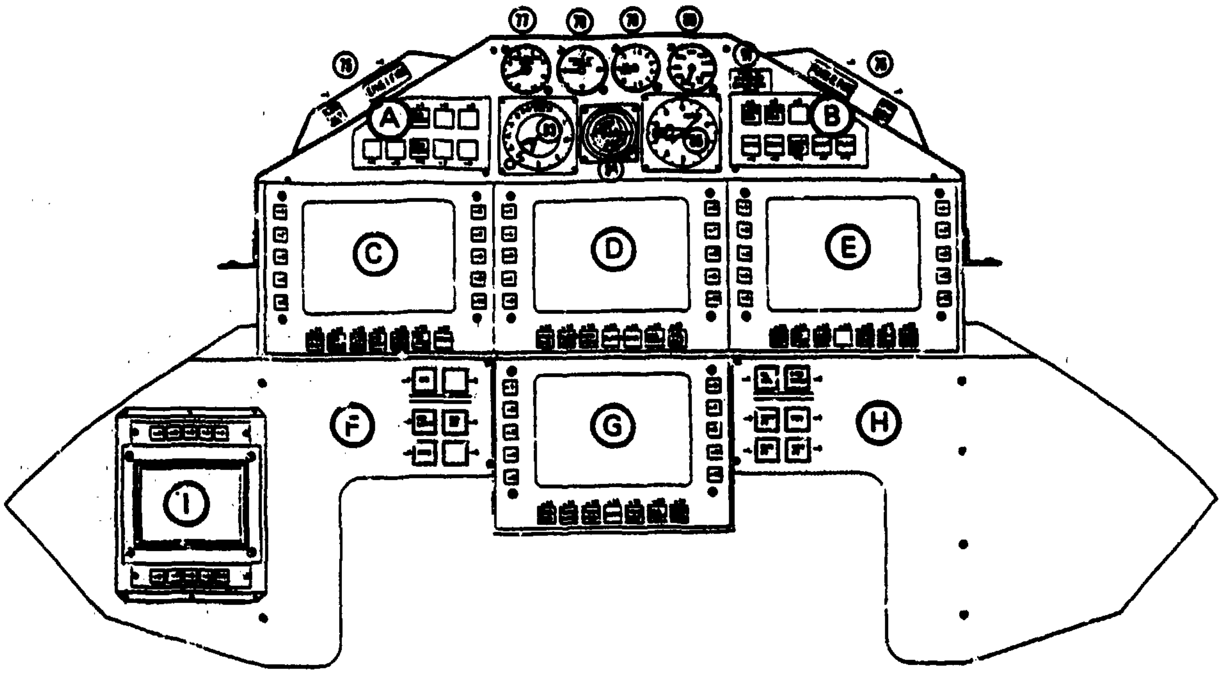


Figure 3.1-1. Front Seat Panel Arrangement



MAJOR PANELS AND DISPLAYS

A. MASTER MODE PANEL
B. STORES AND COUNTERMEASURES SELECTION PANEL
C. LEFT MPD
D. CENTER MPD
E. RIGHT MPD
F. LEFT AUXILIARY SWITCHES PANEL
G. LOWER MPD
H. CURSOR DEFINITION PANEL
i. LOWER LEFT MPD

Figure 3.1-2. Rear Seat Panel Arrangement

A test engineers' station was located above and behind the cockpit. From the station the test engineers had a direct view of crew activities during a simulation run, equipment for on-line data monitoring and recording, simulation control, and communications.

3.2 Simulation Host Computers and Bus Communications

A Gould SEL 32/97 computer and a Star Technologies ST-100 array processor in the Visual Flight Simulator Lab performed real time modeling of airframes, navigation cells, and control systems. In addition, they supplied graphics subsystem data and provided on line data recording. An F-15 tactical fighter model, a real world coordinate navigation cell, and a flight display control program provided both closed-loop and automatic flight mode. Adversary aircraft and all airborne missiles were also modeled in the host computers. Total simulation frame time was less than 30 msec after the addition of study unique graphic control logic, mission profiles, event sequencing, and on line data recording. The specific frame time for any given display format depended on its complexity (scene or symbology content) and required update rate (30 Hz for flight critical and 1.0 to 30 Hz for non-critical information).

The digital simulation data was passed through a 10 MHz serial Pronet digital data bus comprised of one bus controller connected via an HSD interface to the Gould SEL 32/97 computer, two fiber optic modem units which transparently interconnected the wire busses in each facility, and two bus interface controllers connected via memory buffers to the crewstation I/O system, and the Gould SEL 32/67 graphics generation computer.

3.3 Graphics System

Supported by a dedicated Gould SEL 32/6780, the graphics generators accepted data from the host computers, generated the display formats for the HUD, and for the center and lower multipurpose displays and updated them to reflect crew input and progress of the mission.

A single channel, Megatek 7250 color graphics generator with 512 by 512 pixel resolution was used for generation of the HUD. Two of the three channels of a GTI Poly 2000, 640 by 480 RGB color raster generator provided the Close Look formats and the three-dimensional Perspective Situation Formats on the center MPDs in the front and rear seats. The Megatek 7250, dual channel 512 by 512 RGB color raster generator drove the Horizontal Situation Formats in the front and rear seat lower MPDs, thus minimizing data handling while permitting totally independent front/rear seat display manipulations. The Megatek's display list buffer was doubled to permit more complex horizontal situation formats.

Three Pioneer laser video disk units contained the formats for the front and rear seat multi-purpose displays. The engine format, which time-shared the right front MPD, was programmed onto a dedicated Heuricon Graphics board-level generator.

4.0 PICTORIAL FORMATS AND SIMULATED SYSTEMS

This section details the specific aircraft systems and the formats which serve them. Some of the systems have no associated formats and some are represented in integrated formats. In a deliberate inversion of system development logic, the airplane sub-systems were developed to support format concepts, rather than the other way around. All of these will be discussed in turn.

4.1 Flight Control System and AFCS

Flight controls operated in the conventional manner. Hydraulically actuated surfaces controlled the aircraft in three axes. The in-flight speed brakes were available and controlled by a switch on the inboard thrust handle. The control stick and its active switches are shown in Figure 4.1-1. Pitch and roll were controlled by the front seat stick. Pitch and roll trim were controlled by the trim switch on the front seat stick. Trim did not relocate stick center. Yaw was hydraulically controlled with the rudder pedals. The flight control stick in the rear seat served only as a site for the switches mounted on it.

The aircraft had a unitary, all axis autopilot that included autothrust. It was selected with the autopilot button on the right side panel and deselected with either that button or the autopilot disconnect switch on the stick.

4.2 Primary Display System

Display formats were distributed across five CRT displays in the front seat and four CRT displays in the rear. The formats themselves are discussed later in this section. The HUD was unique to the front seat and was the primary flight display. Each seat had four multipurpose displays, called the left, center, right, and lower MPDs. The Perspective Situation Format (PSF) and the Close Look Formats (CLFs) time shared the center MPD. The lower MPD was the site for the Horizontal Situation Format (HSF).

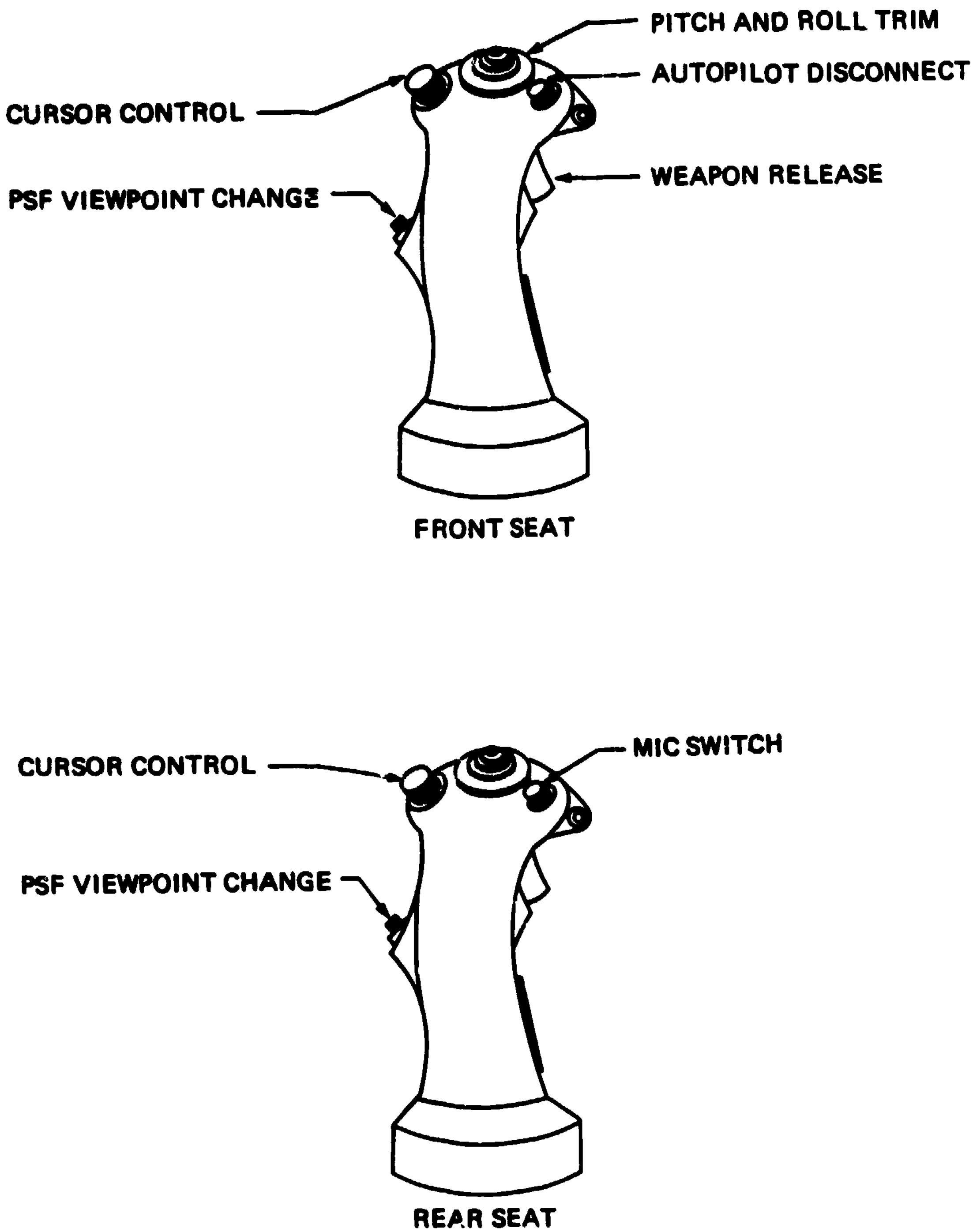


Figure 4.1-1. Flight Control Sticks

A number of system related formats shared the left and right MPDs. The Stores, Countermeasures, and Fuel Status formats were available on the left MPD. Formats to program stores and countermeasures, and advisory formats for systems health problems were also available on the left MPD.

The Stores, Countermeasures, and Fuel Status Formats were available on the right MPD as well. In addition, Electrical and Hydraulic Status Formats could be called up on the right MPD as could, in the front seat only, the Engine Status Format.

Lighted push button switches operated with many of the formats. These switches had three states: bright for "on", green for "option available", and off for "option not available". Function availability was determined by scenario and the state of other mode and sub-mode selections.

4.2.1 Head-Up Display Format

The Head-Up Display (HUD) was the primary flight instrument. Basic flight path guidance information was provided by the pathway symbology and the ownship symbol. The pathway, composed of solid white segments, served as the directive element of the display providing information based on the planned route. The wings forming the entry gate of the pathway functioned as the flight director and the ownship symbol served as the velocity vector, providing heading and attitude information. Therefore, it was the relationship between the ownship symbol and the entry gate of the pathway which provided flight guidance. When on course, the pathway was centered about the ownship symbol and the wings of the ownship were aligned with the wings of the pathway. However, once ownship deviated from the planned route far enough that the pathway fell outside the HUD field of view, the pathway entry gate remained at the edge of the display. To provide the pilot with steering (pitch and bank) commands to recapture the planned route, a transitional flight director (a white inverted T) which moved relative to a reference marker (a small white square centered within the display) was added to the display. The transitional flight director and reference marker remained within the display until the ownship symbol returned to the planned route with the correct heading.

In addition to the pathway and ownship symbol, Figure 4.2-1 includes features displayed on the HUD when they were within the field of view - a ground plane, a zero pitch reference line, and terrain. Generally, the terrain and pathway moved relative to the ownship symbol. Airspeed, heading, and altitude were presented as boxed digital readouts at the left, top, and right of the display, respectively. A required change from the

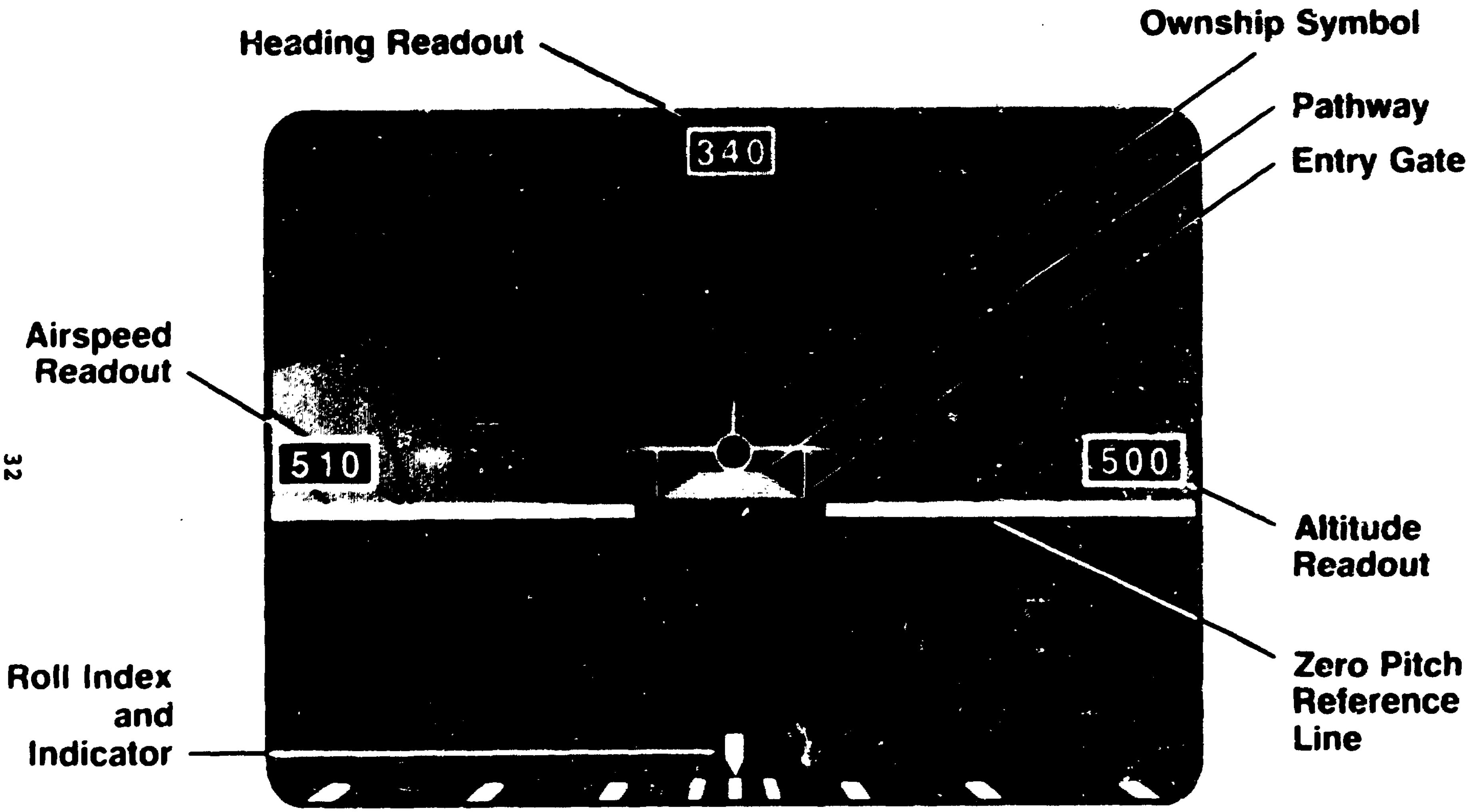


Figure 4.2-1. Basic HUD Symbology

current value in one of these three parameters was shown graphically and numerically as an attached solid arrow indicating direction of change to a displayed value. The roll index and indicator were located along the lower edge of the display.

HUD options available to the pilot included the pitch ladder, pathway fill, and a vertical velocity indicator. The pitch ladder, upon selection, was added to the pathway and the ownship symbol. Pathway fill replaced the solid pathway with an outline version, rendering the pathway transparent. The vertical velocity indicator as added to the display included a digital readout. For the HUD, selection of a Master Mode defined airspeed in knots when in ground mode or in Mach when in air mode.

The HUD threat alert and summary information was shown directly beneath the ownship symbol. When an airborne threat, surface-to-air missile site (SAM), or anti-aircraft artillary (AAA) site began to track ownship, an aircraft, missile, or gun symbol appeared in an alert position just below the ownship symbol for six seconds and then shifted into the summary line. The summary line showed the threat type and number of threats tracking at any point in time. When a threat launched or fired, a symbol returned to the alert position and flashed for the duration of missile flight or the firing of a AAA. Threat site azimuth was indicated by the clock position of a flashing vector radiating from the ownship symbol. For an inbound missile, a time to impact and missile type readout was included with the alert symbol.

For airborne threats and targets, missile launch envelope (MLE) information was presented when ownship or a target was tracked or launched upon. The attack arrow showed the capability of ownship's selected weapon against a targeted aircraft. Conversely, the defensive arrow displayed the assumed capability of the adversary's weapons against ownship. Each of the MLE arrows was divided into four sections based on such factors as airspeed, relative geometry, aspect angle, and maneuvering capability, in addition to range. The top section of each arrow represented a zone outside the weapon's maximum range. The next section, a zone within maximum range was followed by the no-escape zone. The no-escape zone was defined as within the effective range of the weapon, such that a target could not escape the weapon with a maximum maneuver. The bottom section of each arrow was a zone less than the minimum arming and launching range of the selected weapon. A particular target or threat was identified with a numbered caret where position and movement of the caret along the MLE arrow was indicative of status.

Figure 4.2-2 illustrates the MLEs and the threat alert and summary information positioned beneath the ownship symbol. The threat summary line indicates two aircraft are currently tracking ownship, as does the identified carets of the defensive arrow. However, ownship remains beyond the maximum range of the threat's weapons as shown by the position of the carets along the defensive arrow. The threats currently tracked by ownship have been identified as Aircraft 1, 2, 5, and 6, are within maximum range along the attack arrow, and have been targeted with the long AIM's.

Once a weapon (air-to-air or air-to-ground) was targeted, a weapon type and number readout was displayed on the HUD. A system generated cue (an X within the ownship symbol) appeared at the optimal weapon release point. As the pilot handed the weapon off, using the trigger on the flight control stick, the X began to flash, then vanishing when the weapon was released.

The coding or color coding of a particular symbol as described in the preceding refers to both the color and monochrome HUD. The two versions of the format were constructed to be equivalent. Table 4.2-1 outlines the coding of the basic elements.

Table 4.2-1
Coding of HUD Symbology

HUD Element	Color Coding	Monochrome Coding
Pathway	White	Light Grey
Entry Gate	Cyan	White
Ownship	Cyan	White
Ground Plane	Dark Green	Dark Grey
Terrain	Light Green	Light Grey
Threat Symbology	Red	White
Attack MLE Arrow		
Within-Maximum-Range	White	Medium Grey
No-Escape	Green	White
Defensive MLE Arrow		
Within-Maximum-Range	Amber	Medium Grey
No-Escape	Red	White
Weapon Release Cue	Cyan	White

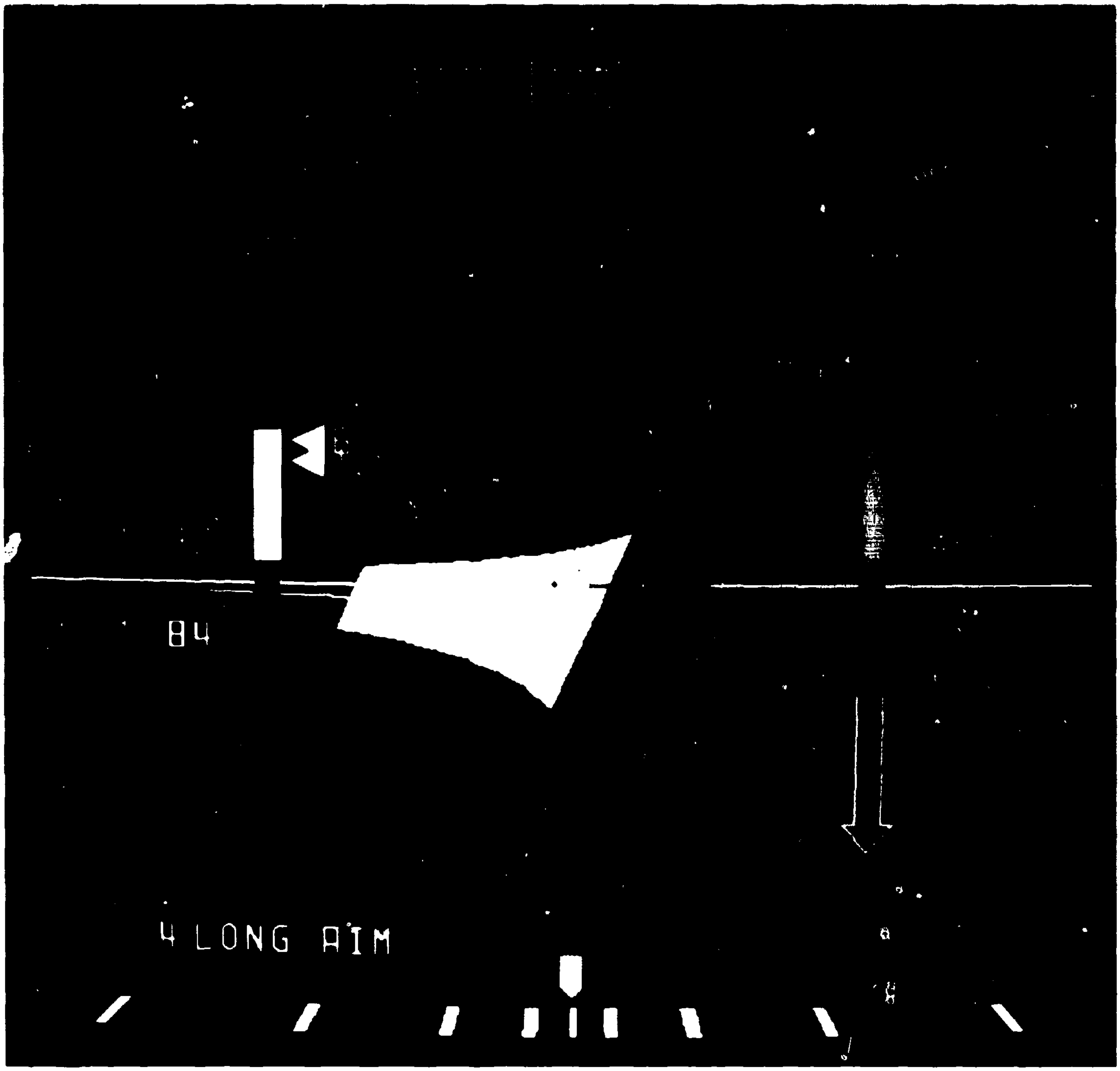


Figure 4.2-2. HUD Air Mode

4.2.2 Perspective Situation Format

The Perspective Situation Format (PSF) displayed the planned flight path, terrain, and the threat environment from a point 6,000 feet behind and 1,000 feet above ownship. The basic elements of the PSF are shown in Figure 4.2-3. The planned flight path consisted of a series of white triangles which pointed in the direction of flight. The ownship symbol was centered within the display, and a pyramid symbol on the ground plane showed the point directly below ownship. The ground plane, overlaid with grid lines converging on the horizon and the three-dimensional surfaces of the terrain were constructed to lend a perception of depth to the display. Terrain above ownship's altitude was differentially coded from terrain below ownship's altitude. As in the HUD, airspeed, heading, and altitude readouts were located at the left, top, and right of the display.

In ground mode, active surface-to-air threats were depicted as three-dimensional lethality volumes, while airborne threat symbols were presented in an abbreviated form (without threat envelope information). AAA sites were depicted as single volumes of uniform lethality, and SAM sites consisted of outer volumes of moderate missile lethality surrounding inner volumes of high lethality. As ownship entered these volumes, the outer surfaces of the envelope folded down to reveal the inner volume or the footprint representing actual ground coverage and a threat site symbol. Once a ground threat began to track ownship, a lock-on circle enclosed the ownship symbol and a tractor beam connected the threat site to ownship. If a threat launched or fired, the tractor beam began to flash, and for missiles in flight, a round missile symbol absorbed the tractor beam as it approached ownship.

Distinguishing SAM sites from AAA sites, coding of threat lethality envelopes, and terrain above and below current ownship altitude required the differential use of color and shades of grey. Table 4.2-2 summarizes the coding of monochrome format elements and color format elements.

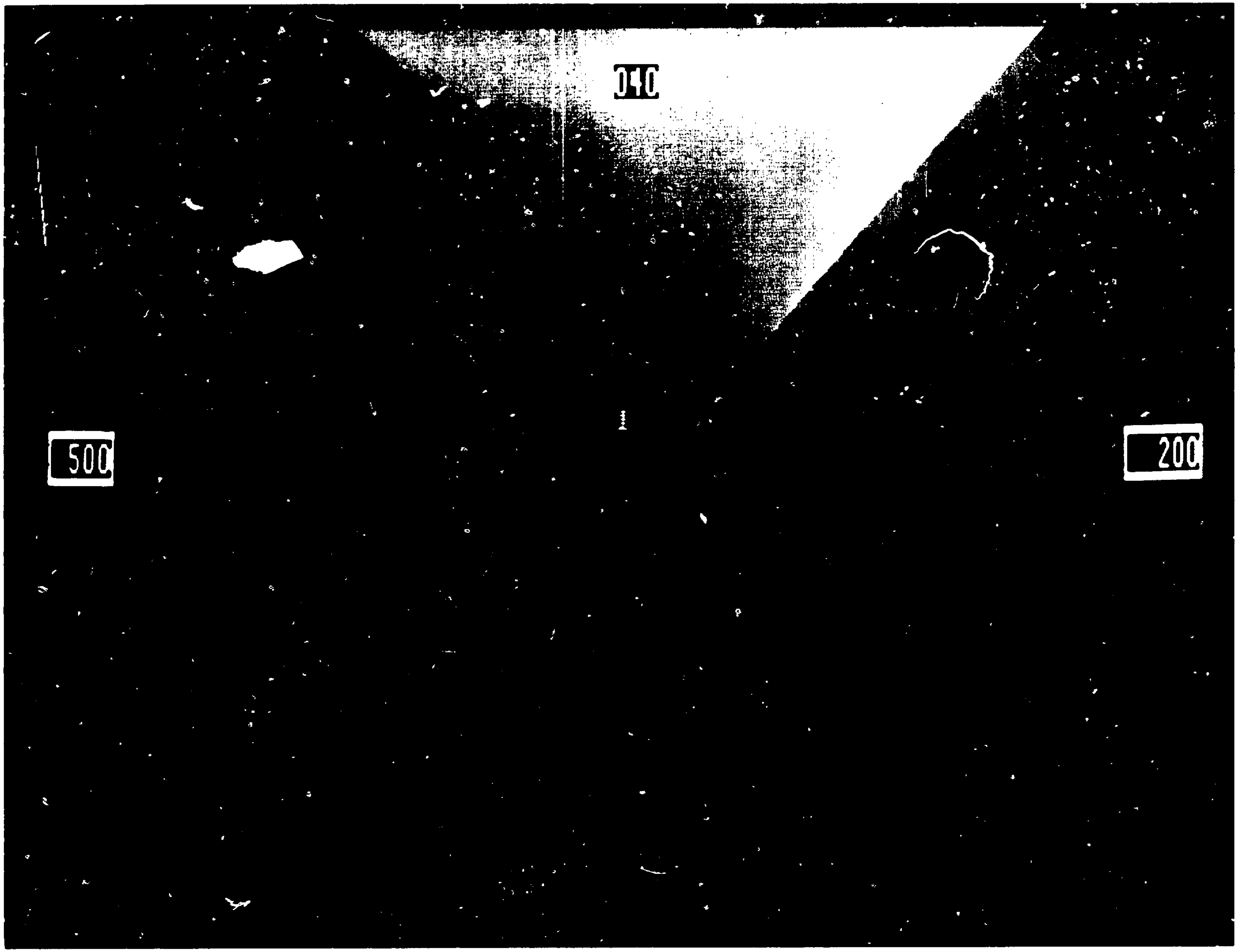


Figure 4.2-3. PSF Ground Mode

Table 4.2-2
Coding of PSF Symbology

PSF Element	Color Coding	Monochrome Coding
Pathway	White	White
Ownship and Ground Point Pyramid	Cyan	White
Ground Plane	Green With Black Grid	Black With Light Grey Grid
Terrain		
Above Aircraft Altitude	Brown	Dark Grey
Below Aircraft Altitude	Green	White
Sky	Blue	Black
SAM Site		
Inner Volume	Red	White
Outer Volume	Amber	Medium Grey
AAA Site	Red	White
Tractor Beam	Red	Light Grey
Lock On Circle	Amber	Medium Grey

The PSF air mode symbology of Figure 4.2-4 provided information concerning gross aspect angle and aircraft azimuth and elevation relative to ownship. In air mode surface-to-air threats were represented only by the site symbols. Aircraft detected by ownship sensors, were shown as three-dimensional airplanes color coded as friendly, unknown, or enemy. When they were in search mode, radar coverage sectors directed toward ownship were added to the nose of the aircraft. For an aircraft tracked by the Close Look Format, readouts of radar range, closing velocity, and altitude difference were displayed in the lower left readout. Airborne threat, track, and launch symbology was identical to that of the surface threats.

A number of optional features allowed each crew member to tailor his own PSF. The new view option allowed for independent viewpoint selection. With a constant slant range, the viewpoint could be slewed in an arc from a nautical mile directly behind ownship (horizontal view) to a nautical mile directly above (looking down in a vertical view). When the slave option was selected, the current PSF configuration was replaced by an exact duplicate from the other crew member's display. An all-threats option produced threat envelope information for both surface and airborne threats regardless of the Master Mode selected. A preview option was also available in conjunction with the HSF, as described in paragraph 4.2.5.

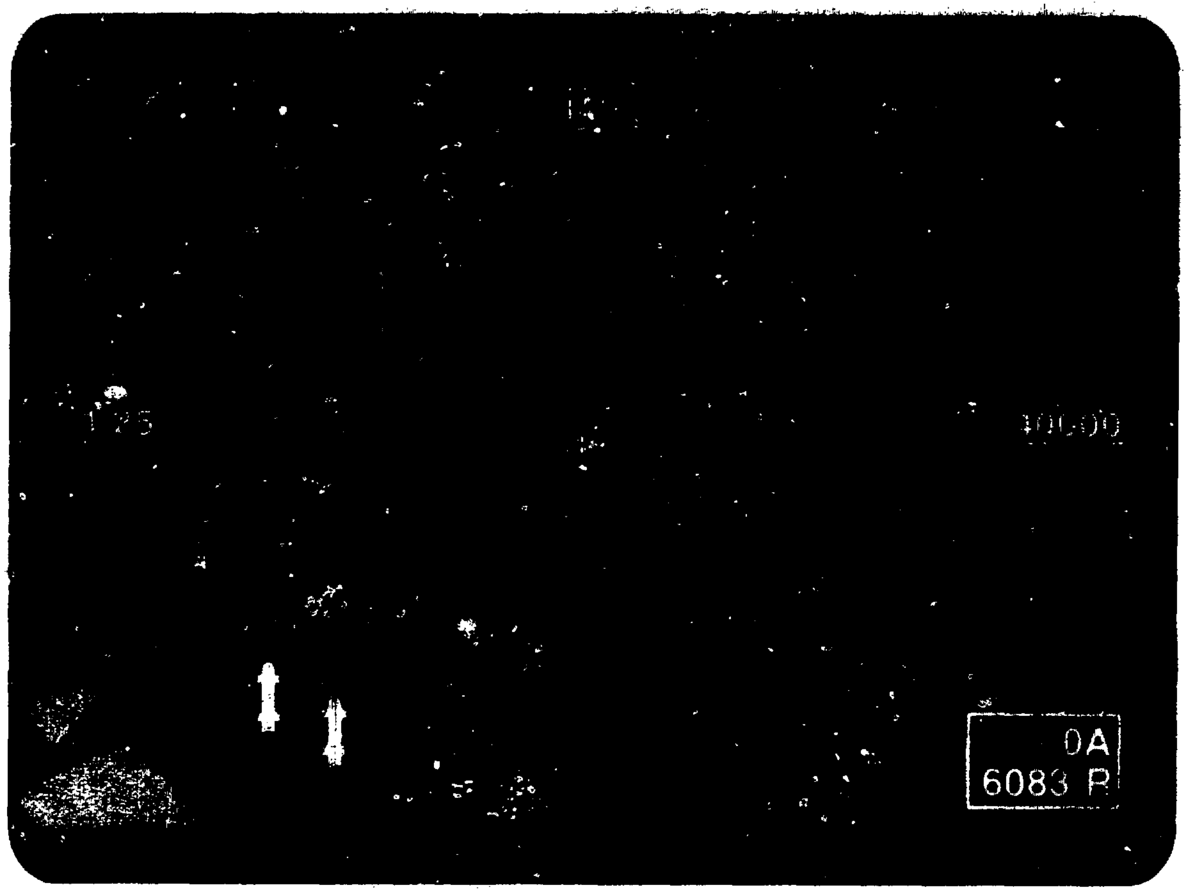


Figure 4.2-4. PSF Air Mode

4.2.3 Horizontal Situation Format

The basic Horizontal Situation Format (HSF) was a plan view display consisting of the planned flight route, terrain above current ownship altitude, and threat information. The ownship aircraft symbol was centered within the display; heading was shown as a digital readout at the top of the display.

The forward line of troops (FLOT) was a line with attached triangles pointing toward enemy territory. Ground targets appeared as white triangles and waypoints as white squares. Symbology options available included the capability to change displayed range in five steps from 20 to 320 NM; the capability to add or delete range rings and fuel rings; and the capability to move ownship's position to the bottom of the display. When displayed, the range rings marked a distance equal to one quarter and one half of the selected display range.

The fuel range rings marked normal and extended fuel range. Time and distance to the next waypoint, next target, or home could be optionally selected. As in the PSF, complete symbology for all airborne traffic and ground threats could be displayed regardless of the master mode selected. Figure 4.2-5 shows the symbology displayed while in ground mode: the FLOT, the ownship symbol, range rings, the planned flight route, terrain above current ownship altitude, and for surface-to-air threats, complete threat symbology. In ground mode, surface-to-air threat lethality envelopes were depicted as cross sections (at current ownship altitude) of the same three dimensional volumes shown on the PSF. AAA sites consisted of a single lethality envelope and SAM sites composed of a core of high lethality surrounded by a lower lethality envelope. As shown in Figure 4.2-6, four threat states were depicted for surface-to-air threats: prebriefed, active, track, and launch. Prebriefed threats - inactive threats known only through reported data - were displayed in the outline form as opposed to the solid form of active threats. As in the PSF, once a threat began to track ownship, a tractor beam connected the threat site to the ownship symbol. For launching or firing threats, the tractor beam flashed, and for SAMs, missile type (Infrared or Radar) was indicated by the round symbol which absorbed the tractor beam as it approached ownship. While in ground mode, reported and detected aircraft were represented by triangles pointing in the direction of flight. Outline triangles were used for reported aircraft and solid triangles for those detected by ownship's sensors. In air mode, radar coverage as well as track and launch symbology was added to the aircraft symbols. Complete threat coding for surface threats was replaced with abbreviated symbols.

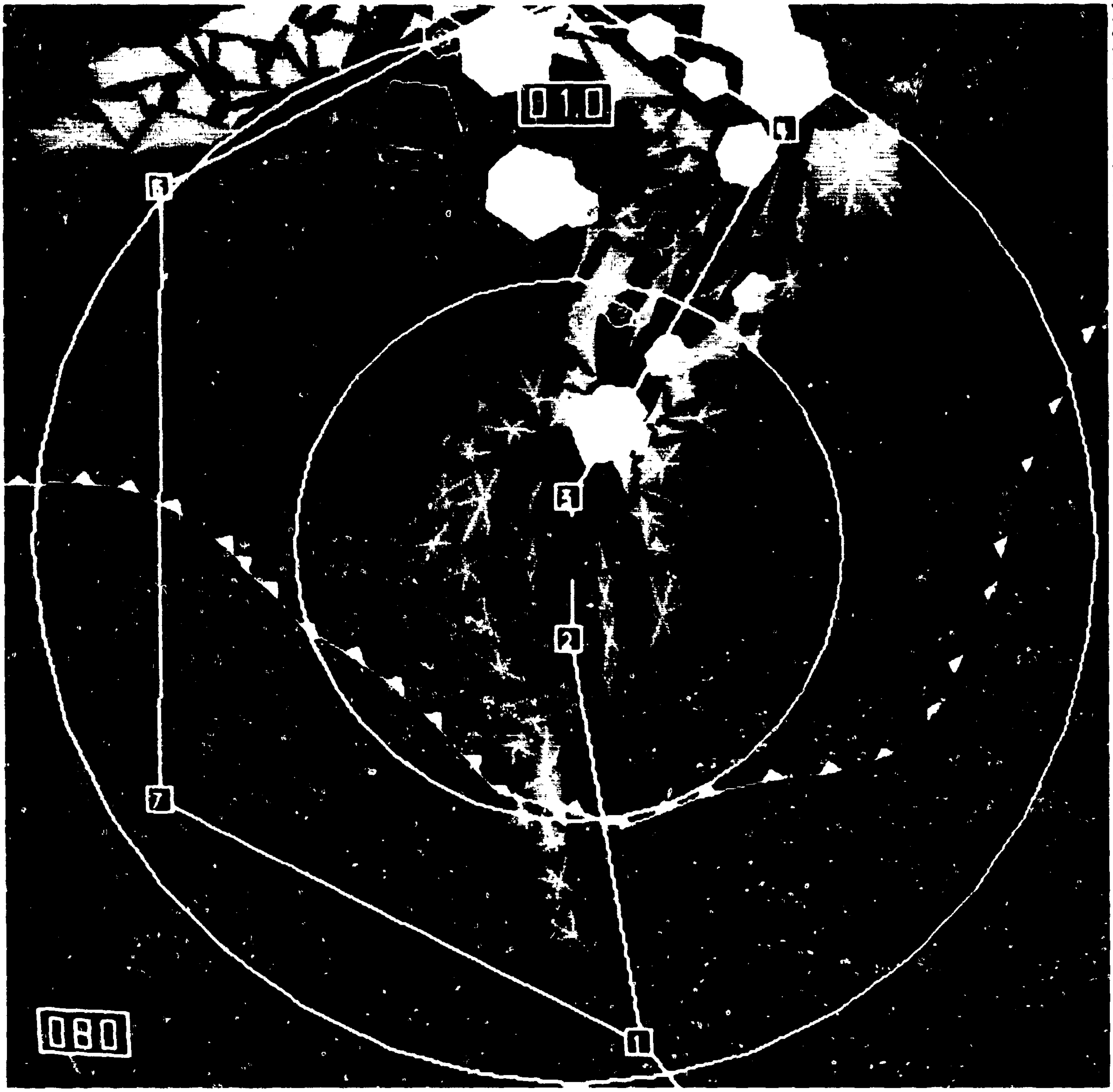


Figure 4.2-5 HSF Ground Mode

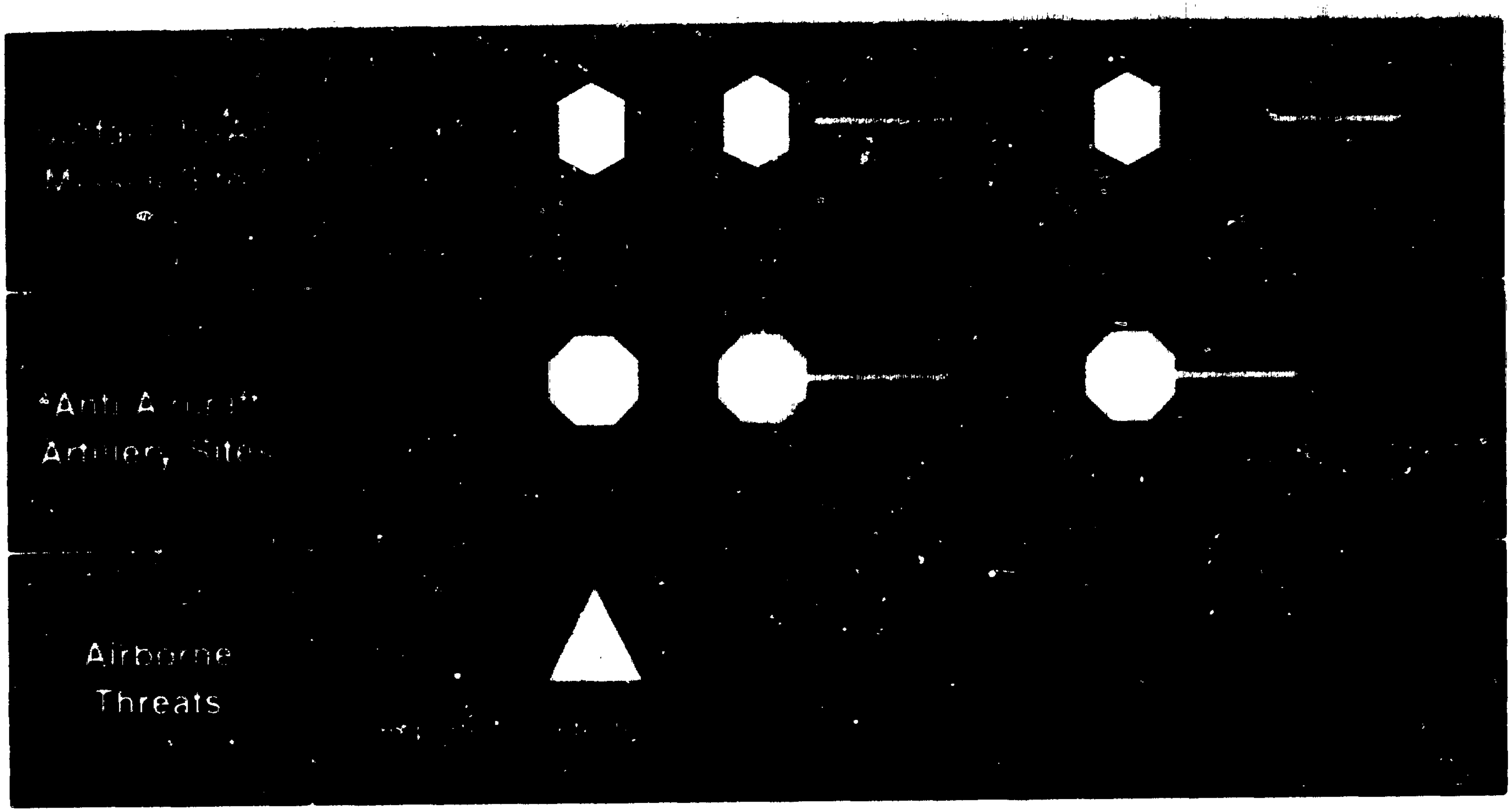


Figure 4.2-6. HSF Ground Mode - Threat Symbology

Ownship was assumed to be equipped with an advanced multimode sensor system, operating automatically to acquire necessary information while minimizing radiation. Infrared Search and Track (IRST) was used for initial detection and early tracking; radar was used only when precision was required. An IRST return was displayed as a dashed line which extended from the nose of ownship along the azimuth of the return. Once the detected aircraft's range was adequately refined, the IRST return line vanished; only the detected aircraft symbol remained. When in air mode, ownship radar coverage was always displayed in some form. If ownship's radar was off, the potential radar coverage area (120°) was shown as a dashed line; if ownship's radar was on, the radar coverage area was shown as a solid line. As ownship began to track an aircraft, a tractor beam was added to the radar coverage area. Placed along the tractor beam were the within-maximum-range and no-escape boundary arcs (as in the HUD attack MLE). Weapon status information was shown in the form of a halo enclosing the aircraft when targeted, differentially coded when the weapon was within range.

Upon detection by ownship IRST or radar, an unknown or an enemy aircraft was displayed as a solid symbol with 120° of potential radar coverage. For an airborne threat whose radar was searching, potential radar coverage was reduced to a ten degree sector of actual radar coverage, pivoting from the aircraft's nose toward ownship. When an aircraft began to track, radar symbology was replaced with the tractor beam and the lock-on circle enclosed ownship. Two MLE boundary arcs on the tractor beam defined the within-maximum-range and the no-escape zones, as in the HUD defensive MLE. With missile launch, the tractor beam flashed, the MLE boundary arcs vanished, and a round missile symbol absorbed the tractor beam as it approached ownship.

Figure 4.2-7 shows the HSF symbology displayed in air mode. Ownship, with radar on, is currently tracking a hostile aircraft (bearing 015°, enclosed by a pair of white box corners). The hostile aircraft is shown as detected by the solid symbol with its associated potential radar coverage area. The position of the target aircraft between the MLE boundary arcs along the tractor beam and the coding of the halo indicates that the target is within the maximum range of the weapon assigned by ownship. (For a more detailed list of the coding conventions used in monochrome formats and color formats refer to Table 4.2-3.) However, a second hostile aircraft (bearing 340°, enclosed by a set of four cyan box corners) is tracking ownship, evidenced by the tractor beam and lock on circle. The position of the defensive MLE boundary arcs indicates that ownship remains outside the hostile weapons maximum range.

Figure 4.2-7. HSF Air Mode

Table 4.2-3
Coding of HSF Symbology

PSF Element	Color Coding	Monochrome Coding
Ownship	Cyan	Dark Grey
Planned Flight Route	White	White
Ground Plane	Dark Green	Black
Terrain	Brown	Light Grey
SAM Sites		
Inner Volume	Red	White
Outer Volume	Amber	Medium Grey
AAA Sites	Red	White
IRST and Radar Symbology	Cyan	Dark Grey
Airborne Traffic		
Friendly	Green	Dark Grey
Unknown	Amber	Medium Grey
Hostile	Red	White
Lock On Circle	Amber	Medium Grey
Tractor Beam	Red	White
Attack MLE Boundary Arcs		
Within-maximum-range	Green	Medium Grey
No- escape zone	White	White
Defensive MLE Boundary Arcs		
Within-maximum-range	Amber	Medium Grey
No-escape zone	Red	White
Weapon Status Halos		
Targeted	Amber	Medium Grey
Within Range	Green	White

4.2.4 Close Look Formats

In air mode, when the aircrew required more detailed information on air traffic than was available on the HSF and PSF, the Close Look Formats (CLF) were selected. The Formation CLF was an expansion of the area selected from the HSF and the Detail CLF was a tabular arrangement of Identification Friend, Foe, or Neutral (IFFN) and targeting information on aircraft of interest. To display an aircraft or aircraft formation, a crew member engaged the HSF cursor, placed the cursor on the appropriate symbol, and selected the close look option. The Detail CLF was then available for display on the center MPD, replacing the PSF air mode upon selection of the appropriate switch.

Once selected, the tabular format of the Detail CLF displayed the IFFN data as it accumulated. Aircraft were classified with distinct symbols: enemy aircraft as diamonds, unknowns as squares, and friendlies as circles. Within the appropriate symbol, multiple aircraft were represented with an "M" until more precise raid count information was available. As the IFFN process neared completion and individual aircraft were identified, specific aircraft type was noted within each symbol. Direction of an aircraft's flight was indicated by a vector attached to the symbol while an airspeed or relative altitude readout (crew selectable) was displayed above each symbol. Each symbol had a nominal identification (ID) readout beneath it; the same ID number appearing beside a switch alongside the display. A given ID switch was used to target a weapon to an aircraft or in conjuction with the track function of the Formation CLF. The ownship heading readout was located at the center top of the display. A switch was used to select between the Detail CLF and the Formation CLF.

Using the same nominally identified aircraft and the basic symbology, the Formation CLF reflected the true geometric relationships among aircraft. While lacking some specific information concerning individual aircraft, the Formation CLF reflected the behavior of the formation in flight. The flight vectors remained attached to the symbol, while specific type data within a symbol and the peripheral readouts were deleted. An ownship bearing vector was attached to the edge of the display and the ID numbers for each aircraft appeared within the symbol. With the initial selection of the Formation CLF, the display tracked (or centered about) a single aircraft of the formation; other aircraft moving relative to the tracked aircraft. The option to select a different aircraft for the display to center about was accomplished by engaging the track switch, then pressing an ID switch corresponding to the aircraft ID number. Another option allowed the size of the close look window to vary.

Figure 4.2-8 shows the information available from the Formation or Detail CLFs as the IFFN process nears completion. The formation of aircraft selected for display on the Detail CLF consists of three confirmed hostile F-39 fighters with an airspeed of Mach 1.8. The same nominally identified aircraft appear in the Formation CLF. The positions of aircraft "2" and "3" are displaced relative to aircraft "1", the tracked aircraft of the display.

As the BVR engagement developed, additional coding was added to the symbols of both the Detail and Formation CLF. The additional coding (summarized in Table 4.2-4) reflected system generated target assignments and subsequently, the status of targeted weapons. System generated target assignments for both wingman and ownship were indicated by the coded rings added to an aircraft symbol. With selection of the appropriate ID switch, effectively targetting the selected air-to-air weapon, a solid halo was inserted between the target assignment ring and the aircraft symbol. A readout indicating the type and number of weapons targetted was added to the lower edge of the display. A target within range of the weapon was shown by the differential coding of the halo. With weapon release, the target assignment ring vanished while the weapon status halos were reduced to a thin outline. The Formation Close Look Formats of Figure 4.2-9 illustrate the coding of the symbology as target assignments are executed and weapons released.

Table 4.2-4
Close Look Formats - Coding of Weapon Information

CLF Symbology	Color Coding	Monochrome Coding
Target Assignment Ring		
Ownship	Cyan	White
Wingman	White	Dark Grey
Weapon Targeted Halo	Amber	Medium Grey
Weapon Within Range Halo	Green	White
Weapon Release Outline	Green	White

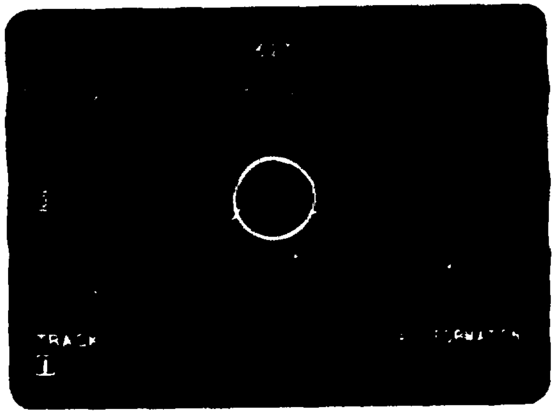
4.2.5 Cursor Functions

A number of cursor options were independently available to either crew member. The general procedure involved selection of the cursor switch from beneath the HSF, placement of the general

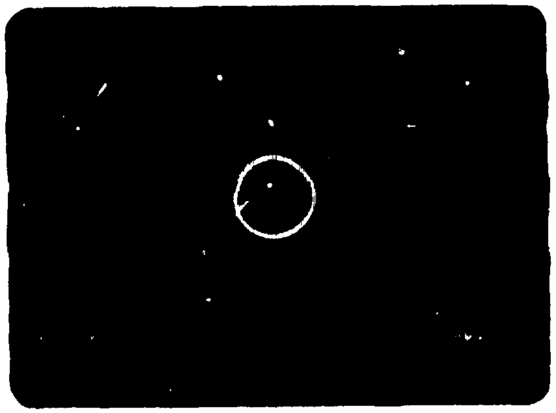
Detail CLF

Formation CLF

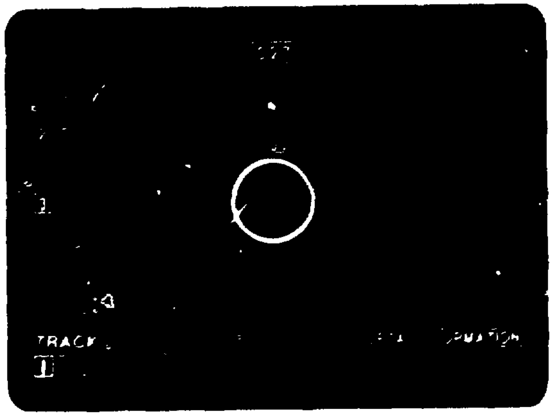
Figure 4.2-8. Close Look Formats



Target Assignment



Weapon Targeted



Weapon Within Range

Weapon Release

Figure 4.2-9. CFL Coding of Target Assignments and Weapon Status symbol, followed by the selection of an option from the cursor definition panel. It was from the cursor definition panel one accessed the Close Look Formats, executed the route segment or climb profile preview function, and designated targets for the air-to-ground weapons. The options available at any given point in a mission were a function of the current state of the HSF. Selection of an option defined the cursor function and replaced the general cursor symbol with the functional symbology (refer to Figure 4.2-10).

While in ground mode, weapons available included antiradiation missiles, bombs, and mines. The antiradiation missile was used as a defensive weapon to counter SAM and AAA sites. Once the general cursor was placed over the ground threat (as displayed on the HSF) and the target designated, the antiradiation missile assignment was accomplished and an unnumbered target symbol was inserted within the threat site. In range of the weapon, the symbol was differentially coded and the weapon delivery cue was added to the ownship symbol of the HUD. Bomb and mine targets were designated by using the cursor to mark one of the preselected target locations.

The route segment preview function allowed either crew member to preview any portion of the planned flight path in order to assess the threat beddown during low level flight. Once the preview option was engaged, the functional symbology within the HSF and the PSF flew the planned flight path at faster-than-real time until the preview switch was selected a second time to stop the process. The displays then reverted to normal real time presentation. In a similiar manner, the climb profile preview function allowed either crew member to view the ground threat environment as ownship ascended to high altitude from one of several points. The climb profile preview function was available only during a specified portion of a BVR mission segment when a set of system generated start of climb points were displayed on the HSF. The general cursor was then placed on a start of climb point, the preview function engaged, and the functional symbology flew the climb profile at faster-than-real-time. Upon reaching the top of climb, the symbology ceased to move, and the cursor could be selected to begin the procedure again for preview of a second or third profile. Alternatively, selection of the waypoint (WAY PT) from the cursor definition panel was used to insert a climb profile into the flight plan.

The close look selection cursor option was available once air mode had been selected and the HSF indicated that an aircraft had been detected (solid symbology). Once selected, the generalized cursor symbol was replaced by a set of four box corners representing the area displayed on the CLF. A pair of box corners was used to indicate the other crew member's close look selection. The Detail CLF was then available for display on the center MPD, replacing the PSF air mode upon selection of the appropriate switch.

CURSOR OPTIONS	FUNCTIONAL SYMBOLOGY	AFFECTED DISPLAYS
CL SEL. CLOSE LOOK		HSF
PREVIEW Route Segment Climb Profile		[illegible] AND PSF
WAY PT WAYPOINT		[illegible] AND PSF
TGT TARGET Predesignated Opportunity		HSF

Figure 4.2-10. Cursor Functions Symbology

4.3 Stores System

The stores carried by the aircraft supported its dual mission with both air-to-air and air-to-ground weapons. While similar to existing weapons, the weapons had features not in the current inventory. All were guided and "launch-and-leave" in the sense that, once fired, no further input was required, nor was there a requirement to continue to illuminate or track the target.

Four long range air intercept missiles (AIMs), with active homing guidance systems, were carried for the air-to-air engagements. Two short range AIMs and a gun were also carried but not used in the mission scenarios. The two defensive antiradiation missiles used their own broad band seekers for in flight guidance. The crews were briefed to employ the antiradiation missiles against unavoidable threats in active or track modes. The aircraft carried two powered homing glide bombs to be delivered from low altitude. Bomb guidance, control, and propulsion features allowed deployment against a variety of targets in a relatively large area around the launch point. The bombs had an automatic guidance mode in which they accepted and attacked targets at coordinates established with the target cursor option. Operation of the aircraft's two mine canisters was identical to that of the bombs.

Bombs and mines, as part of the preflight procedure, required programming for method of delivery, guidance, and for mines, burst height. From the stores programming menu, available on the left MPD in either seat, the bomb programming menu and the mine programming menu were accessed. Selections were made by pressing the switches beside the available options. Once a satisfactory selection had been made, selection of any other format entered the requested options into the system.

The Stores Status Format (Figure 4.3-1) showed an aircraft plan view with the inventory, status, and location of onboard weapons. One short range AIM was located at each wing tip, followed by an antiradiation missile, a mine canister (aft), and a glide bomb (forward). Located along the centerline were the four long range AIMS and in the nose, the gun.

The number and type of weapon(s) selected and if appropriate, additional release information and the master arm off indicator were included within the format. Examples of the Stores Status Format and the color coding used to reflect the state of the master arm and the selection and targeting of a weapon is shown in Figure 4.3-2. As a weapon was selected, the body of the weapon was color coded and an outline halo was added to the nose of the weapon. The weapon body color coding represented the status of the master arm; the color coding of the halo was indicative of weapon status. Once the weapon was targeted, the

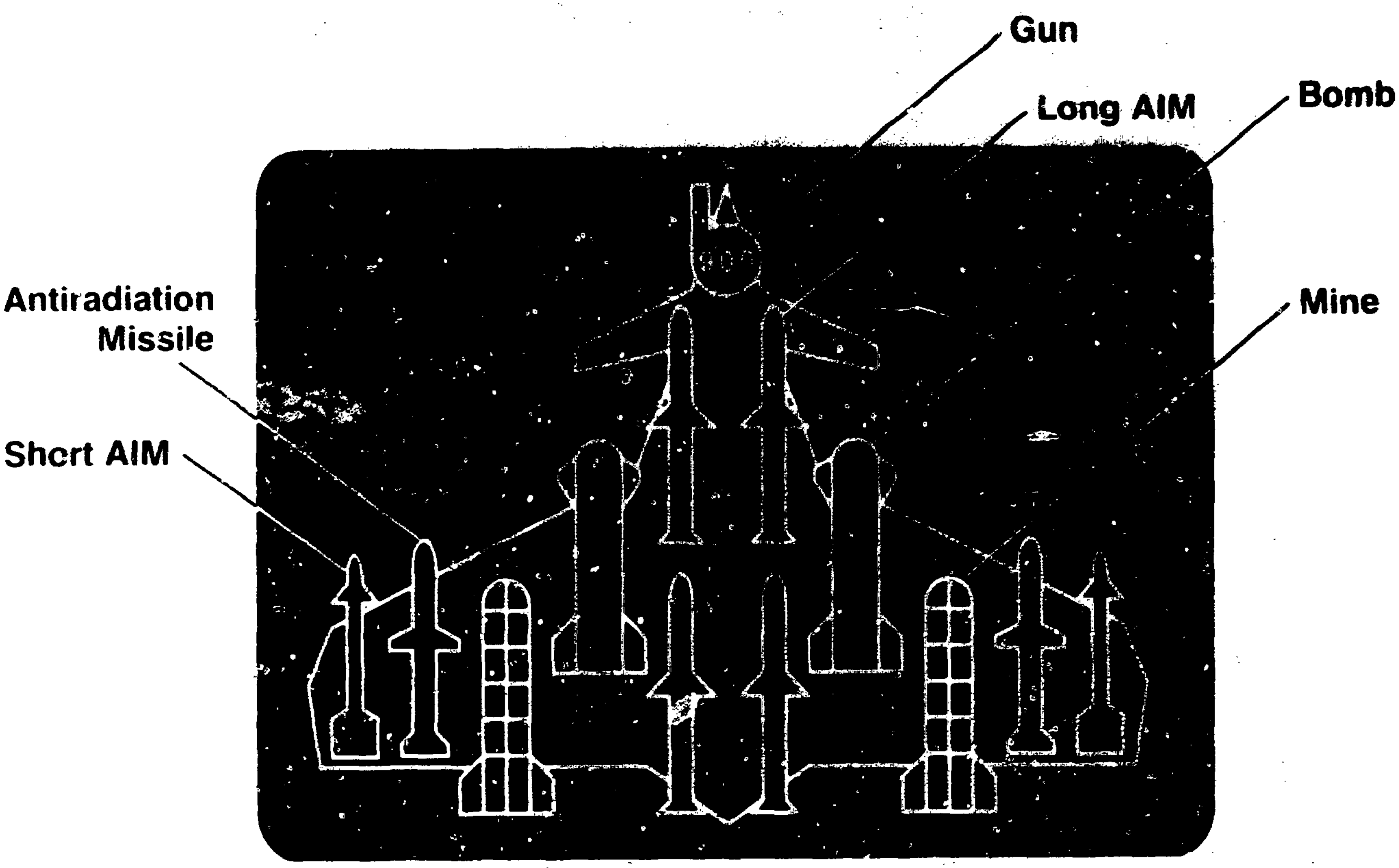
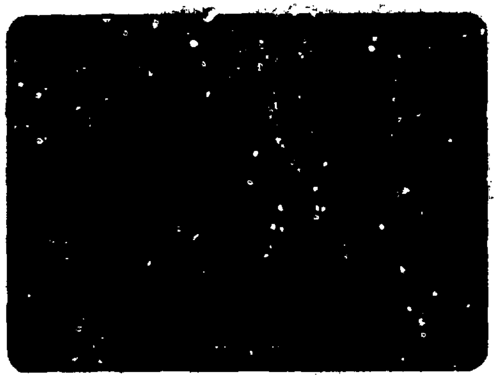
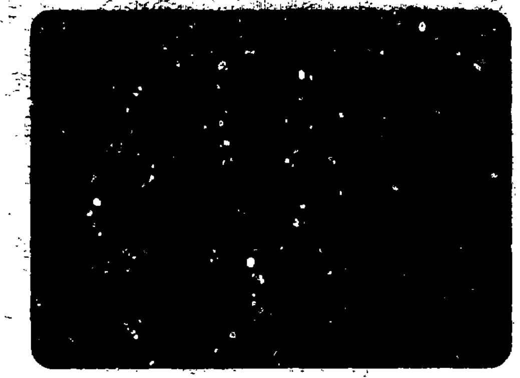


Figure 4.3-1. Stores Status Format



1 Long AIM Selected
Master Arm Off



1 Long AIM Selected
Master Arm On

1 Long AIM Targeted
1 Long AIM Selected
Master Arm On

1 Long AIM in Range
1 Long AIM Selected
Master Arm On

Figure 4.3-2. Stores Status Format - Selection and Targeting of a Weapon

halo was shown in the solid form. When all release parameters had been satisified, e.g., required range and master arm on, both the halo and the weapon body coding reflected the launch condition. Table 4.3-1 summarizes the coding used in the color and monochrome versions of the Stores Status Format.

Table 4.3-1
Stores Status Coding

Status	Weapon Body Coding		Halo Coding
On Board Not Selected	Color	Outline	None
	Monochrome	Outline	None
Master Arm Off Selected	Color	Amber	Outline
	Monochrome	Grey	Outline
Master Arm On Selected	Color	Green	Outline
	Monochrome	White	Outline
Master Arm Off Targeted	Color	Amber	Amber
	Monochrome	Grey	Grey
Master Arm On Targeted	Color	Green	Amber
	Monochrome	White	Grey
Master Arm On Within Range	Color	Green	Green
	Monochrome	White	White

In addition to the status and programming formats available to either crew member, control of the stores system was managed from the stores selection panel in conjunction with the Close Look Formats and the HSF. However, only the pilot had access to the master arm switch and only the pilot's trigger released stores. As previously discussed, stores programming was accomplished with the format on the left MPD, later specific stores were selected for delivery from the panel above the right MPD. Long range air intercept missiles were targeted with the Close Look Formats on the center MPD, while ground targets were designated on the HSF using the target cursor option.

4.4 Countermeasures System

The countermeasures system consisted of a radio frequency jammer, chaff, and flares. The jammer operated automatically, going active in response to its analysis of threat states. Chaff and flares were programmed and dispensed by a system similiar to the current AN/ALE 40.

In the simulation, the aircrew was required to execute the countermeasures programming tasks as part of the preflight procedure. The countermeasures information and control menu was accessible to either crew member. As shown in Figure 4.4-1, the jammer control page, the chaff and flare control page, the flare information page, and the chaff information page were accessed from the information and control menu. The options available from each page were presented as a row of selections with each row aligned with one of the side switches of the display; the current state of each option was shown by a box enclosing one selection in each row.

In the Countermeasures Status Format (Figure 4.4-2), the basic system was pictorially presented as a single internally mounted jammer, a stack of chaff bundles, and a stack of flares superimposed on an ownship planview. With chaff and flares at levels above twenty-five percent, the expendables were automatically released as required. In the simulation, the automatic maximum release quantity occurred with the expenditure of two flares or four chaff bundles. At expendable levels below twenty-five percent, release occurred manually at a reduced rate (one flare or two chaff bundles).

The jammer was coded to represent three states: in the off state, the pod and bolt were in the outline form, while in standby the bolt was shown in the solid form, and when on, a pair of small lightning bolts appeared outside the pod. Once the jammer was programmed in standby, it radiated automatically as threats began to track ownship, reverting to standby as appropriate.

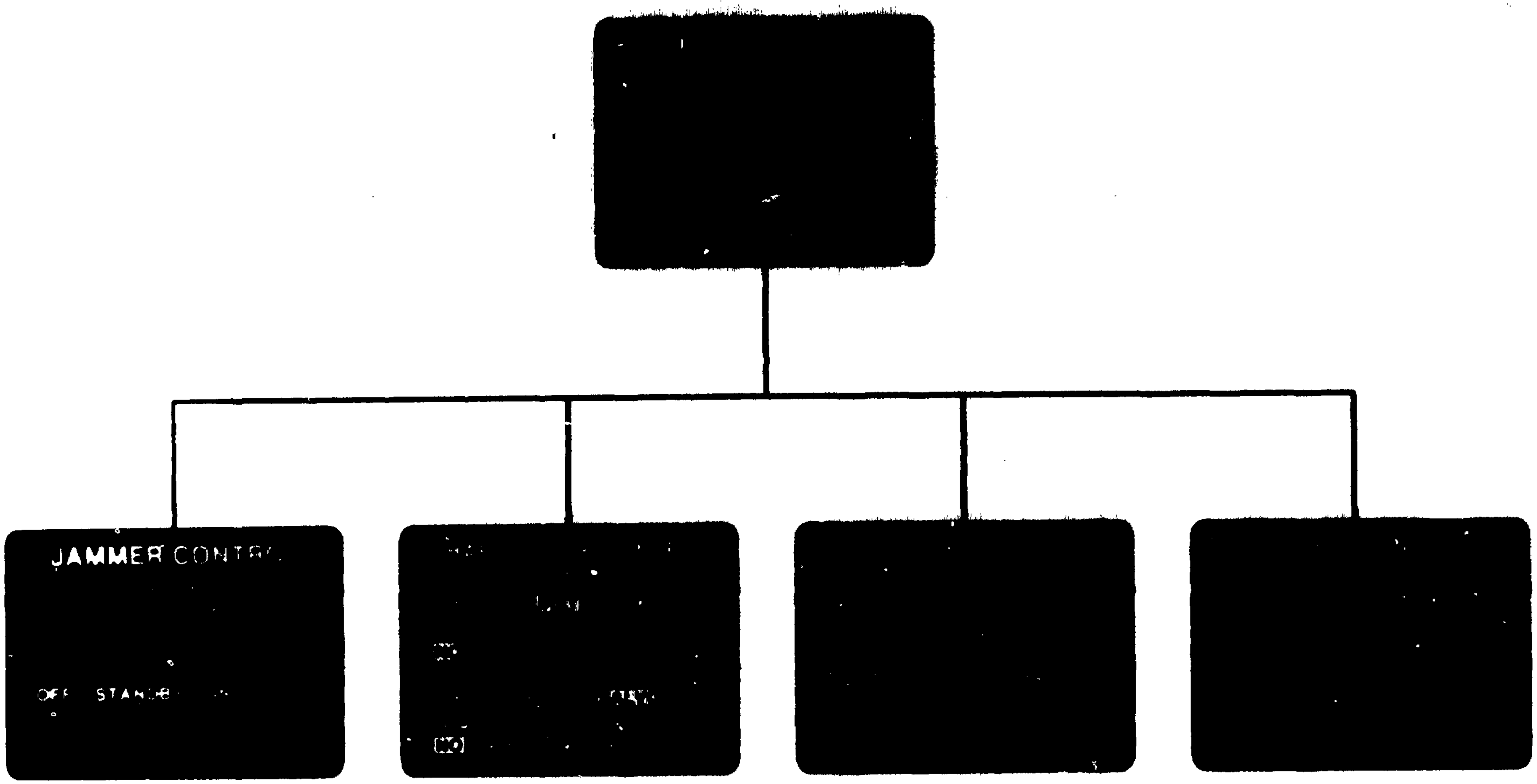


Figure 4.4-1. Countermeasures Programming Formats

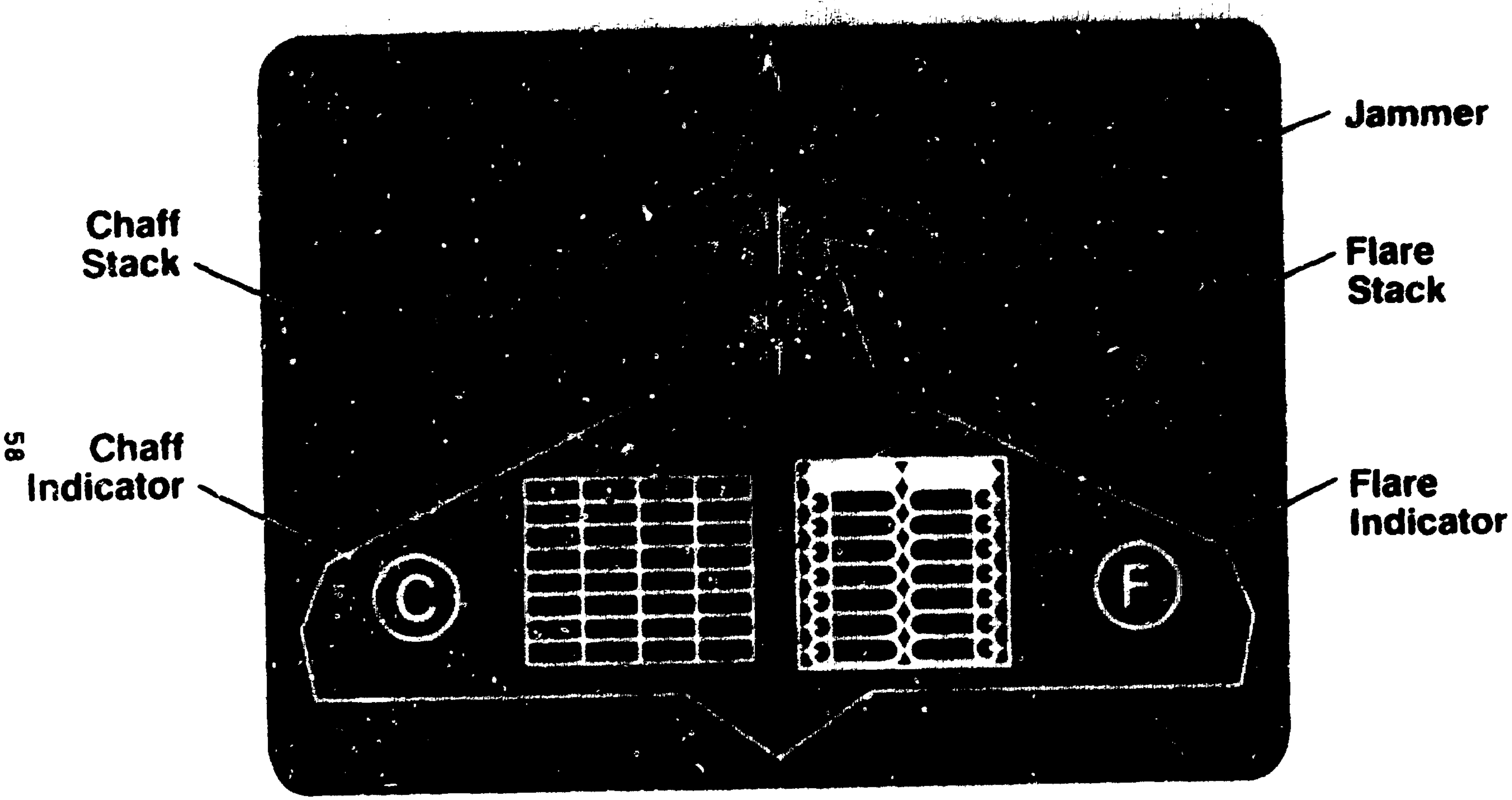


Figure 4.4-2. Countermeasures Status Format

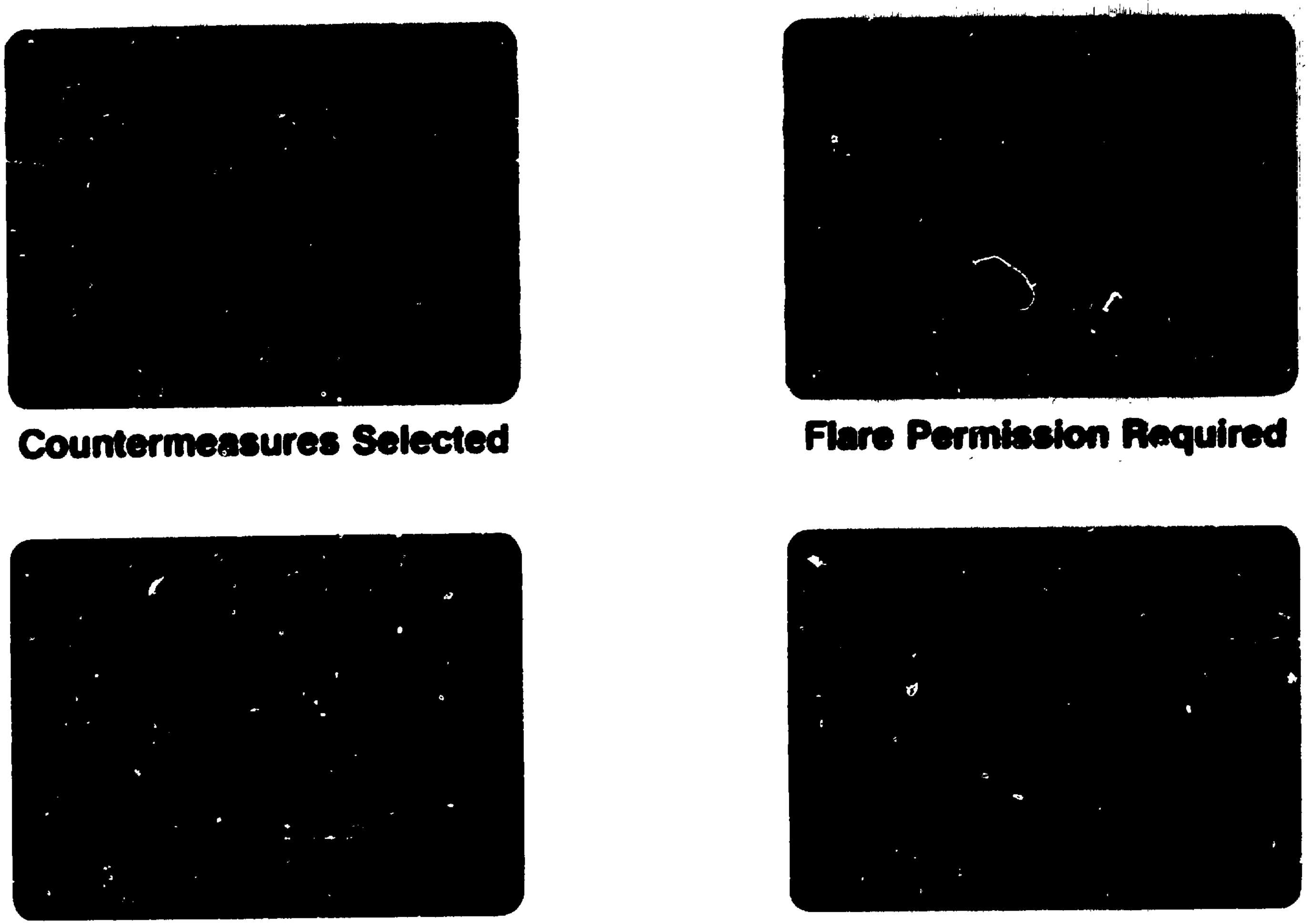
The status formats reflected the release of expendable countermeasures as previously programmed. At levels above twenty-five percent, flares were automatically released in a burst of two and bundles of chaff were expended in a salvo of four. The burst of flares and the salvo of chaff bundles each comprised one row within their respective stacks. In the normal status format sequence, a row of chaff bundles and a row of flares was designated as "selected" by the inclusion of a small dot within each symbol. When the countermeasures system determined that release was appropriate, either the "released" row of flares or the "released" row of chaff bundles was coded as a row of solid symbols. Once "expended", that particular row of countermeasures was absent from subsequent formats and the next row was again designated as "selected".

In the simulation, when expendables remaining on board dropped below the twenty-five percent level, the system automatically downselected, limiting the release of countermeasures to two chaff bundles (or one flare). The low quantity situation was indicated by illumination of the master caution lights, followed by flashing of the countermeasures status switch. Figure 4.4-3 illustrates the release sequence coding that occurred within the Countermeasures Status Format subsequent to the low quantity situation. Thereafter, each time threats launched upon ownship the "selected" countermeasure was color coded to indicate "permission required". The WSO was required to select the chaff or flare switch in order for the expendable countermeasures to be "released".

4.5 Propulsion System

The Engine Status Format, available only to the pilot on the right MPD, displayed propulsion information for setting thrust and monitoring engine health. The format consisted of two plan view engine sections, each with percent thrust shown both numerically and graphically. In addition, for each engine, oil pressure and quanity, exhaust gas temperature (EGT), afterburner operation, fuel flow, and state of the fuel valves were displayed. The basic Engine Status Format and its major elements are shown in Figure 4.5-1.

Within each engine body, throttle position and actual thrust formed a vertical bar alongside which required thrust was indicated. Throttle position was represented by the inner twenty percent of the thrust bar. Actual thrust was represented by the remainder of the bar. Thrust was scaled as an integrated measure which considered all relevant engine and environmental parameters. Thrust, shown numerically in the nose of the engine body, was registered from 0 to 100%. Afterburner and 100% thrust levels occurred at the lower (amber) and upper (red) indicating



Countermeasures Selected

Flare Permission Required

Flare Release

Flare Expended, Countermeasures Selected

Figure 4.4-3. Release Sequence Coding of Expendable Countermeasures

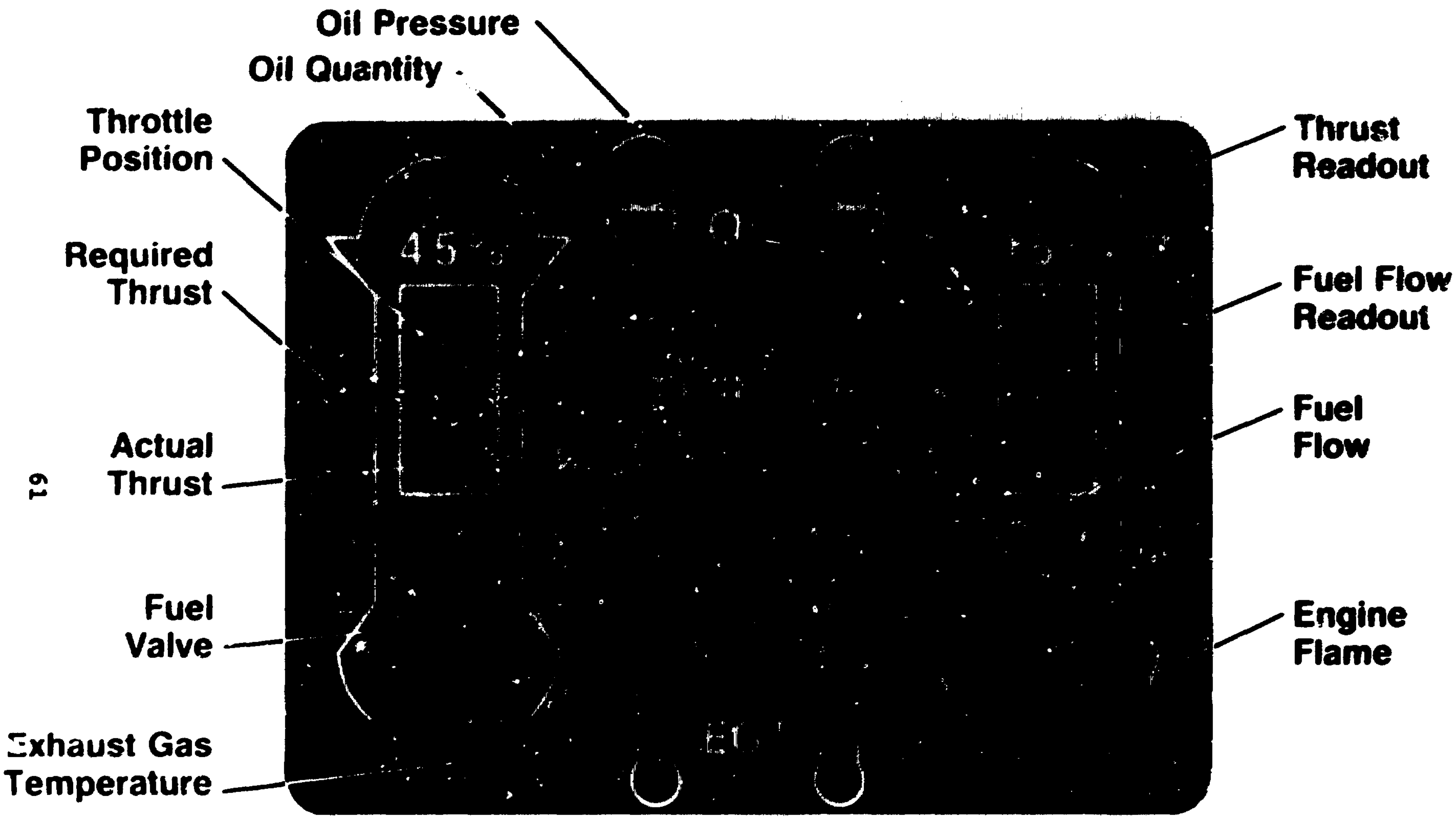


Figure 4.5-1. Engine Status Format

lines, respectively. As thrust reached the afterburner or 100% indicating lines, the thrust bar was appropriately color coded. Required thrust, calculated as a function of required speed, was represented by a pair of triangular pointers which moved vertically along the thrust bar. In operation, as a new speed was required by the flight plan, the triangular pointers indicated the requirement along the thrust bar. The engine in the first diagram of Figure 4.5-2 is at thirty-five percent thrust, but the triangular pointers show that more thrust is required. The pilot then moved the throttle such that the inner bar was level with the position of the pointers as shown in the second diagram. As engine thrust spooled up or down, the actual thrust bar rose or fell to match the throttle position and the required thrust pointers. In the third diagram, the engine has spooled up and actual thrust has increased to match throttle position and required thrust.

The symbology used to present the various states of oil pressure, oil quantity, and EGT is shown in Figure 4.5-3. Oil pressure for each engine was shown as a pressure gauge, the arrow within the gauge pointing up for good pressure. At caution level and warning level underpressures, the arrow pointed left and down, repectively. Oil quantity was shown as a reservoir with two horizontal lines defining caution and warning low quantity levels. EGT was represented with a thermometer of vertical bars, the lower afterburner level line, and the upper overtemperature line. For the purpose of the simulation, EGT had four discrete states per engine: with an engine off, the thermometer was empty; normal operation occurred below the afterburner level line; with afterburner operation, the level of fill rose above the line; overtemperature was indicated with the filled thermometer and radiating lines. A flame at the rear of each engine showed the state of the engines, a small flame symbol represented normal operations. When the engine was in afterburner, a large flame enclosed the existing symbol. Fuel flow was represented by the open arrows entering the engine body shapes. Amount of fuel flow was shown pictorially by the level of fill within the arrows and numerically (thousands of pounds per hour). Within the fuel valves, the open state was indicated with the vertical lines; in the closed state, the horizontal lines were differentially color coded. Valve position was changed with the fuel cut-off switches located on the aft side of the throttle quadrant.

Malfunctions of an engine were indicated by the illumination of the master caution lights followed by the blinking of the engine status switch. The status format indicated the nature of the problem. All actions required to reduce the impact of the condition were included within the advisory format. With an engine flame out, the small flame symbol vanished, actual thrust

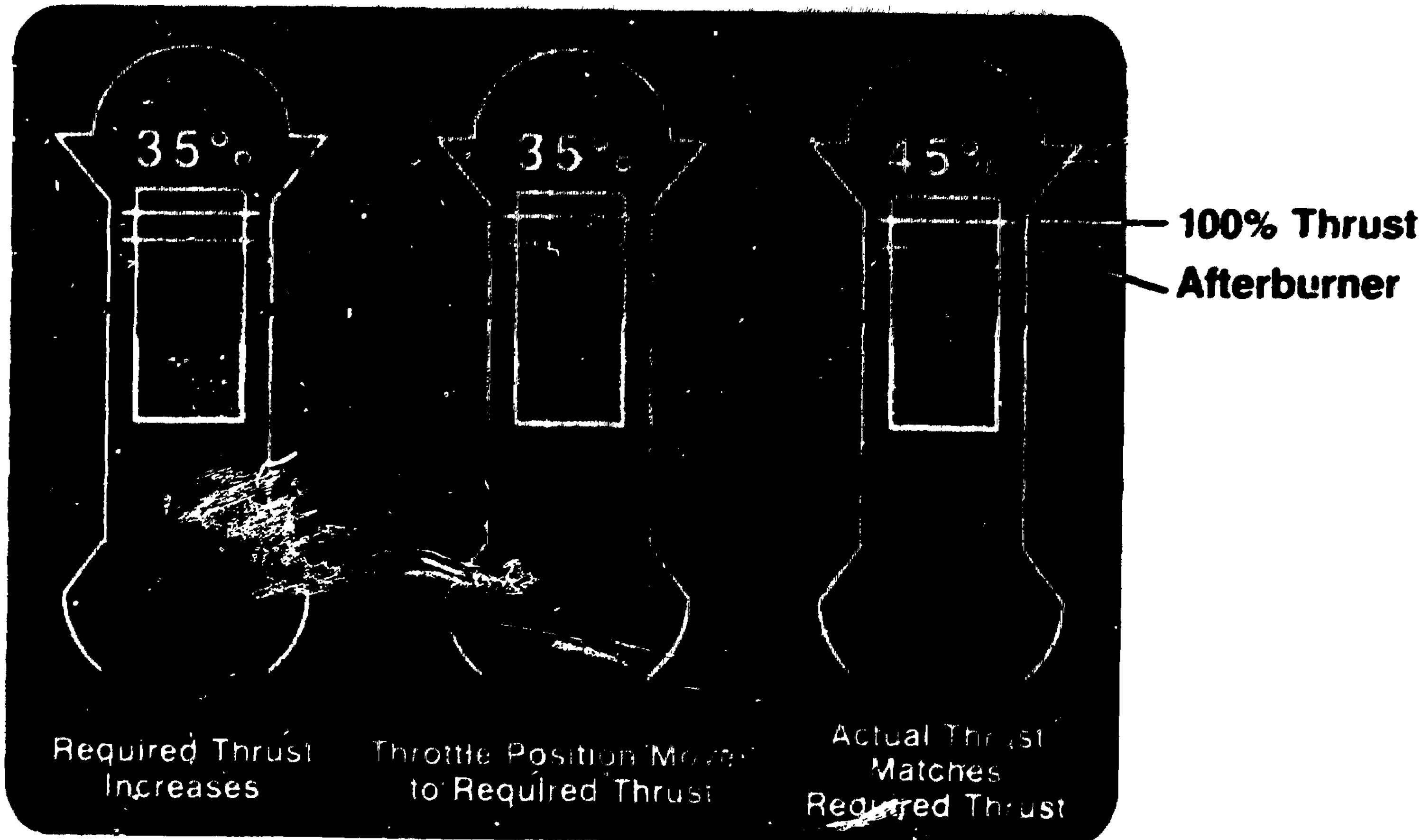


Figure 4.5-2. Required Thrust, Throttle Position, and Actual Thrust

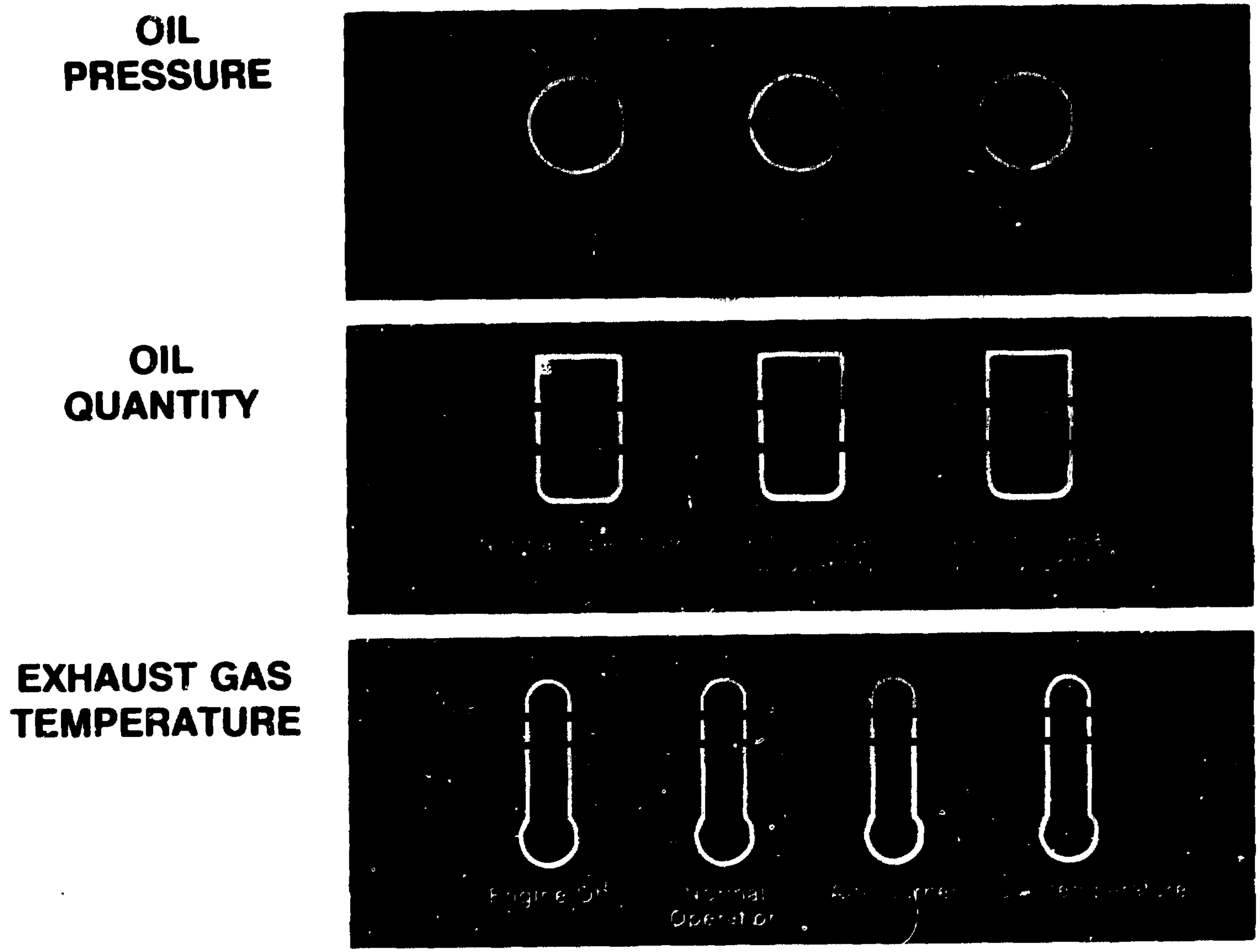


Figure 4.5-3. Oil Pressure, Oil Quantity, and EGT

dropped to zero, the appropriate EGT thermometer showed empty, and a solid warning border was added to the format. With engine damage, EGT temperature was elevated, and a pair of warning level markers along the thrust bar, a highlighted nozzle, and a striped caution border were added to the format. The advisory format associated with engine damage instructed the pilot in the required actions and cautioned against exceeding afterburner limits indicated by the markers. With an engine fire, a fire light was illuminated, requiring a response by the pilot to extinguish the light. Within the status format a larger fire flame was added to the affected engine, the EGT symbol indicated an overtemperature condition, actual thrust gradually fell to idle, and a solid warning border was added to the format.

4.6 Aircraft Systems

4.6.1 Fuel System

Fuel status information was available at any point during the simulation with selection of the fuel status switch beneath the left or right MPD. The basic fuel system was pictorially presented as seven tanks (two wing tanks, two inboard tanks, and three centerline tanks) and the associated fuel lines, superimposed on an ownship plan view (Figure 4.6-1). The solid portions of a tank were representative of fuel on board; empty portions of a fuel tank are in the outline form. Consumption of fuel occurred as the solid portion of a tank was gradually reduced. An alphanumeric readout was used to indicate total amount of fuel remaining. Simultaneously, the two wing tanks were the first to be depleted, followed by the two inboard tanks and the centerline tanks. Fuel flow to the engines was maintained through a series of valves, transfer pumps, and boost pumps. The valves were represented by a small circle, bisected with a fuel line. When a tank was depleted and there was no longer a functional requirement for a valve, the valve was rotated 90° and the associated fuel line was represented in the outline form. The boost pumps, the two large triangles, fed the engines. Two of the transfer pumps, the smaller triangles, were located within the two inboard tanks; the remaining two within the centerline tanks Similiarly, when there was no longer a functional requirement for a transfer pump, it was absent from the format.

Located in the forward seat only, left side panel, were the fuel controls, employed primarily as system malfunctions occurred. Failure of an element within the fuel system may have resulted from aircraft damage, therefore the following symbology occurred in a number of combinations. When one of the four transfer pumps failed (due to damage or a system malfunction), a striped warning border appeared within the status format and the pump symbol was differentially coded. Corrective measures included closing the associated pump valve or activation of the crossfeed

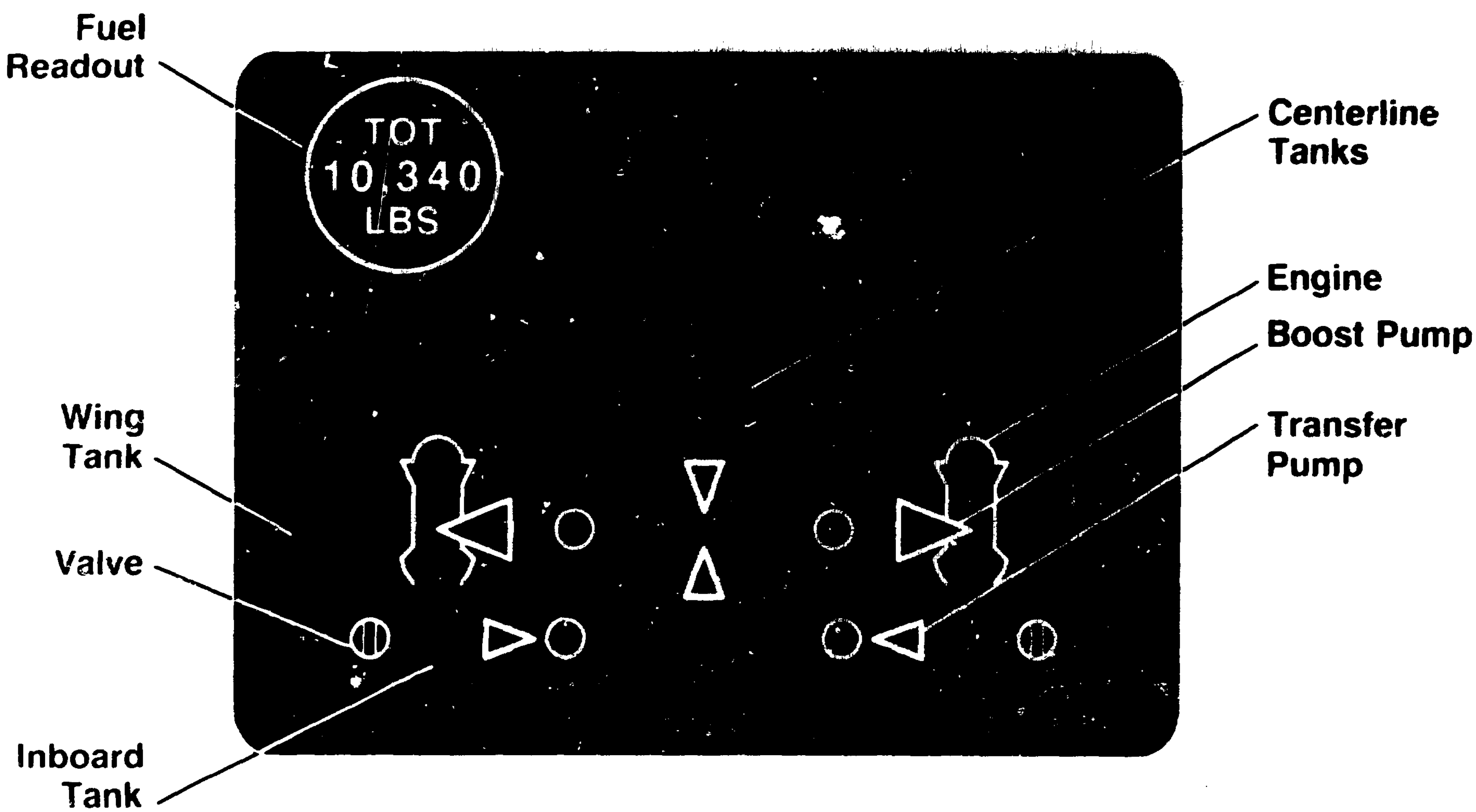


Figure 4.6-1. Fuel Status Format

fuel system. In the event of a boost pump failure, the failed pump was coded and the automatic emergency boost pump (which until required did not appear in the format) was activated by the system. The status format then included symbology representative of the emergency boost pump and the alternate fuel flow lines. A ruptured tank was indicated with the symbology superimposed over the affected tank. Depending on a tank's location, damage often required the closure of the fuel tanks associated valves, effectively isolating the damage. The numeric total indicator within the status format was highlighted with color as the fuel dropped to a predetermined critical level (bingo fuel), indicating to the crew the requirement to egress to a refueling point.

4.6.2 Hydraulic System

The Hydraulic Status Format (Figure 4.6-2) showed major elements of the system. Supported by four subsystems, the aircraft provided redundancy for the flight critical elements, i.e., the canards, leading edge flaps, rudders, elevons, and thrust nozzle doors. Non-flight critical elements, i.e., the canopy release, gun drive, nose wheel, nose wheel steering, main landing gear, and aerial refueling probe were not shown as redundant. A specific hydraulic sybsystem (1A, 1B, 2A, or 2B), functioning out of the normal range of operations was noted with an indicator, while the individual elements were appropriately coded. A failure of a non-redundant, non-flight critical element was coded as a solid cautionary symbol. A redundant element reduced to single thread operation continued to function normally. However, to distinguish the degraded condition of a redundant system element, a cautionary stripe was added to the symbol.

4.6.3 Electrical System

The Electrical Status Format was presented as a high level schematic of the primary elements: the buses, generators, transformer rectifiers, batteries, and major loads. Each element was abbreviated within the format and distinguished by shape. Electrical system health problems were indicated by illumination of the master caution lights, followed by flashing of the electrical status switch. Within the status format, a failed element was coded at the caution level and the appropriate relay switch was displaced, if appropriate.

4.6.4 Passive Sensor System

The aircraft was equipped with a passive sensor system which provided information about the battle environment around the aircraft. The Passive Sensor Status Format pictorially represented the system as a wire sphere composed of six sections:

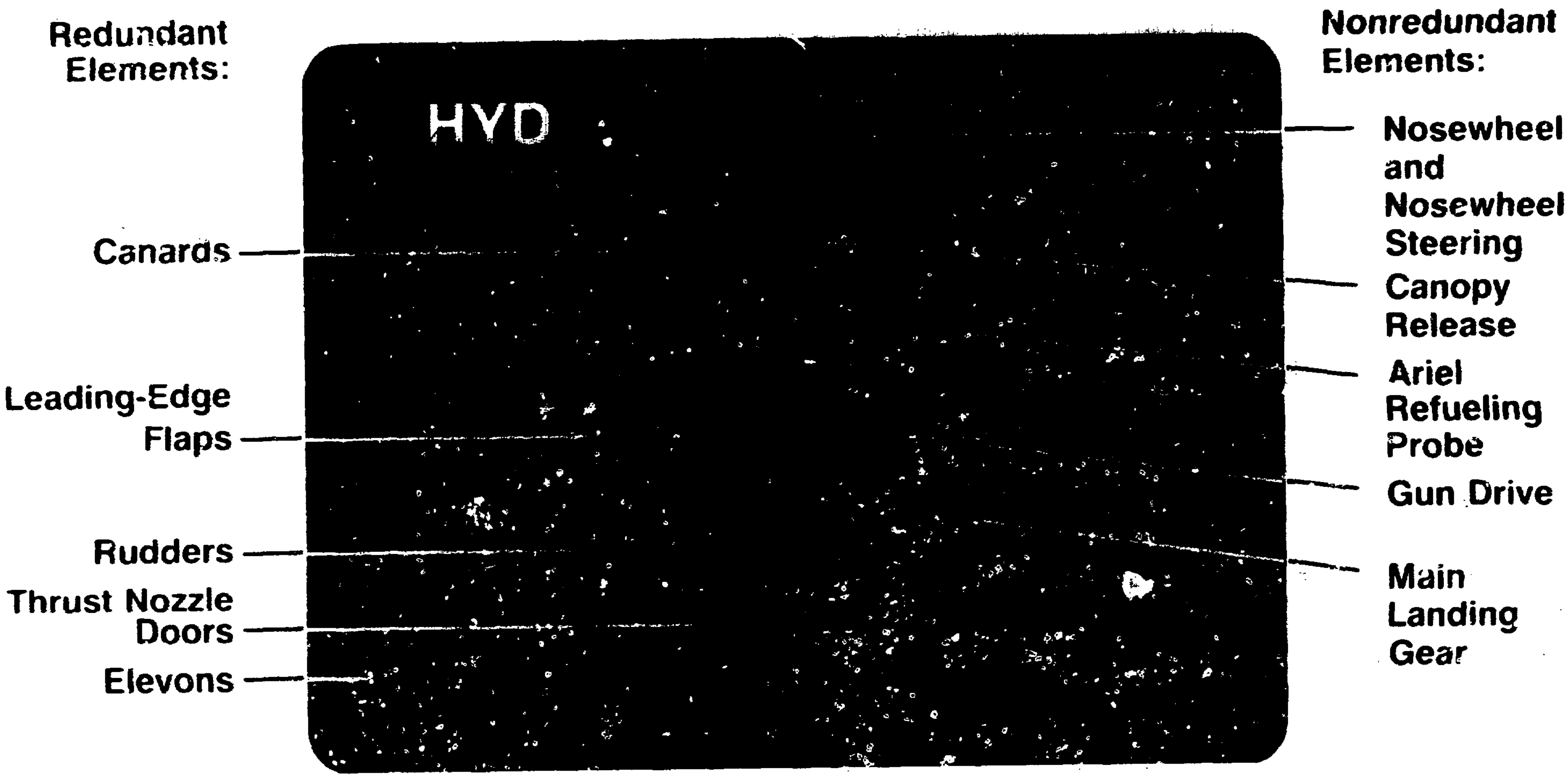


Figure 4.6-2. Hydraulic Status Format

top and bottom, each possessing a forward section, a near side section, and a far side section. If one or more of the sensors were degraded or failed, the area of coverage lost was coded at the caution level and connected to the aircraft. The caution coded areas represented zones from which the aircraft was not receiving complete passive sensor information.

4.7 Advisories, Cautions, and Warnings

The advisories, cautions, and warnings in this simulation were designed to exercise the system status formats with their attention and directive features. Thus, the procedures required more crew activity than would probably be the case in a new generation aircraft. While the formats and display controls from the front seat were duplicated in the rear, the airplane system controls were located in the front seat only. For this reason, all of the crew actions associated with system health problems were executed by the pilot. When a system malfunctioned or was damaged, the front and rear seat master caution lights were illuminated.

There were four levels of malfunction, with increasing levels of criticality. Level I was advisory, bringing to the crew's attention conditions which had minimal impact. As shown in the first pair of status formats in Figure 4.7-1, the advisory conditions were highlighted by the coded indicators. Levels II and III were cautions (also shown in Figure 4.7-1) indicating that the system health problem had the potential to adversely affect the aircraft or mission. As seen in the second and third pairs of status formats of Figure 4.7-1, the formats included a striped border. The difference between these two levels was that the required response was automated in Level II, but crew intervention was required in Level III problems. Level IV was the warning level where the status formats included a solid border as in the last pair of formats of Figure 4.7-1. Immediate crew action was required for these flight critical events. Table 4.7-1 summarizes the system health events, in terms of level of criticality, the coding of the indicators, and the malfunctions or damage. Each time the master caution lights were illuminated, the speed, heading, and altitude readouts and the ownship symbol on the HUD were color coded at the caution or warning level.

A uniform procedure was executed in response to master caution lights for system health problems. The pilot action was to press the master caution light, extinguishing it, select the ar[illegible]iate status format, and report the problem on the radio li[illegible]. At Levels III and IV, once the basic response procedure was executed, the pilot was cued to the available advisory format. The pilot selected the appropriate advisory format, followed its checklist, and reported the outcome.

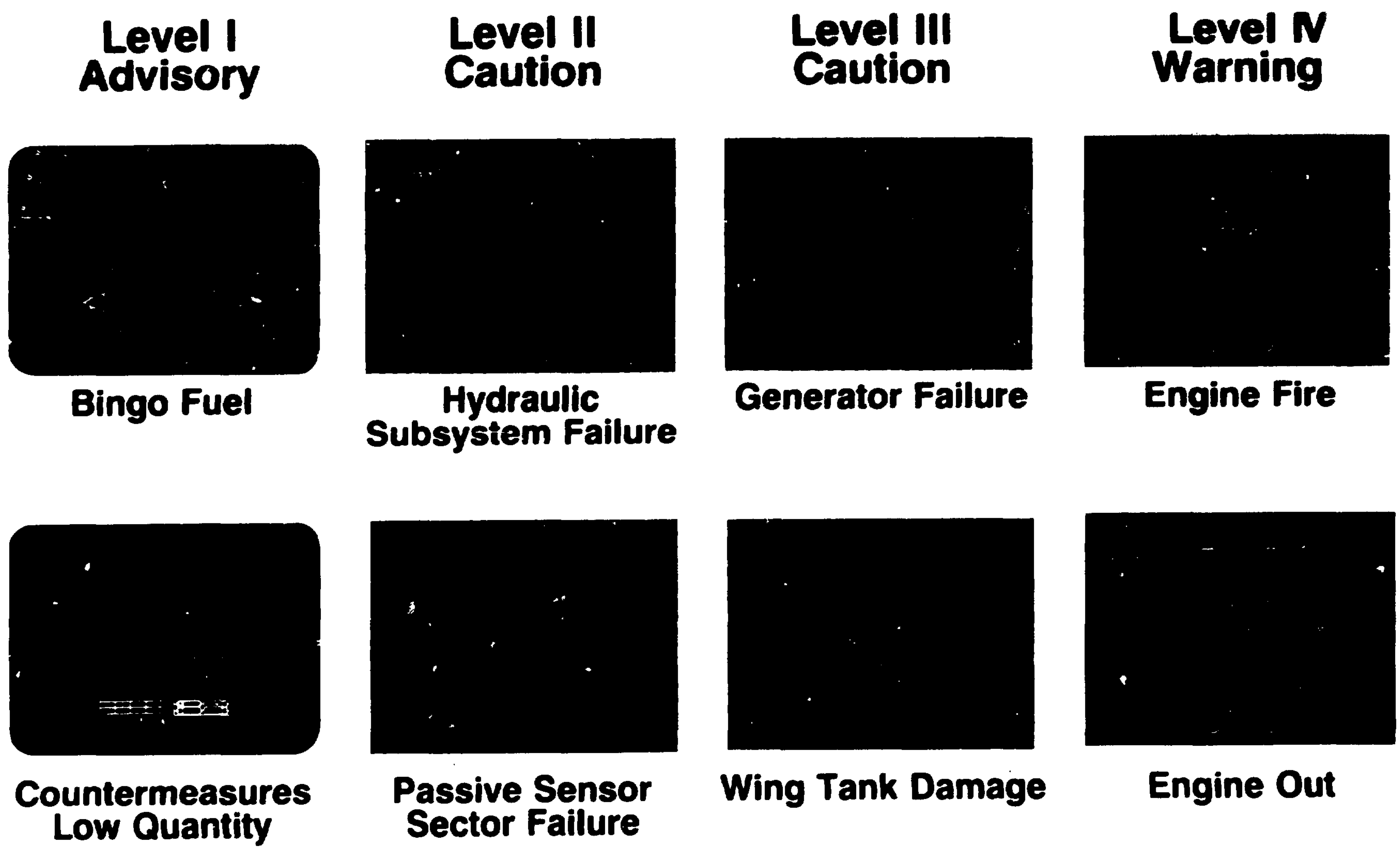


Figure 4.7-1. Advisory, Caution, and Warning System Status Formats

Table 4.7-1
Levels of System Health Problems

Level	HUD Symbols		Border	Advisory	Examples
I Advisory Minimal Impact	Color Monochrome	Amber Reverse Video	None None	No	Countermeasures Low Quantity Bingo Fuel
II Caution Potential Impact Automatic Reconfiguration	Color Monochrome	Amber Reverse Video	Striped Amber Striped Grey	No	C/L Fuel Tank Damage Boast Pump Failures Transformer Rectifier Failures Battery Failures Hydraulic Subsystem Failures Passive Sensor Sector Failures
III Caution Potential Impact Crew Action Required	Color Monochrome	Amber Reverse Video	Striped Amber Striped Grey	Yes	Engine Damage Fuel Transfer Pump Failures Fuel Wing Tank Damage Generator Failures
IV Warning Flight Critical Immediate Crew Action Required	Color Monochrome	Red Reverse Video	Solid Red Solid White	Yes	Engine Fire Engine Out

5.0 DYNAMIC COMPARISONS

The second planned format iteration ended with the dynamic comparison evaluation. It was conducted after the formats were completed and the simulation ready, but before data was collected in the final phases. AFWAL/FIGR personnel and three Air Force pilots were briefed on the simulation and formats, then the pilots flew the simulation repeatedly, selecting from among the offered format alternatives. The alternatives, issues and selections are summarized in this section.

5.1 Head Up-Display Dynamic Comparisons

For a detailed discussion of the HUD format, please see paragraph 4.2.1. The first issue on the HUD was arrangement of the missile launch arrows in the air mode. This is illustrated in Figure 5.1-1. The attack (ATT) arrow on the left side represented ownship's missile launch envelope against targetted aircraft. The logic for the ATT arrow seemed to be well understood and accepted. The scale represented by the arrow included range, known capabilities of ownship and ownship's selected missile, hypothesized capabilities of the targetted aircraft and the dynamics of the evolving engagement. There were four zones in the arrow, representing from top (head) to bottom (tail): beyond range for the selected missile, in range, no-escape for the hypothesized capability of the targetted aircraft, and too close to fire the selected missile. The carets representing targetted aircraft usually started near the top (head) of the arrow and moved down.

The issue came about when that logic was inverted to create the complementary defensive (DEF) arrow, representing threat missile launch envelopes against ownship. In the standard version, the DEF arrow had the same four zones, representing threat aircraft and missiles against ownship. From top (tail) of the DEF arrow, they were: too far for the hypothesized threat to fire its hypothesized missile against ownship, in range, no-escape for ownship, and too close. The carets for threat aircraft usually started near the top (tail) of the arrow and moved down. This way, both outbound and inbound missiles moved in the direction of the arrows and, as the engagement closed, symbols representing targets on the ATT arrow and threats on the DEF arrow moved closer to ownship at the bottom of the arrows.

The offered variant for the HUD DEF arrow had the zones from the top (tail) to bottom, represent too close, no-escape, in range, and too far. This way, ownship was at the tail of both arrows and, as the engagement closed, both targets on the ATT arrow and threats on the DEF arrow moved from the head toward the tail of the arrows.

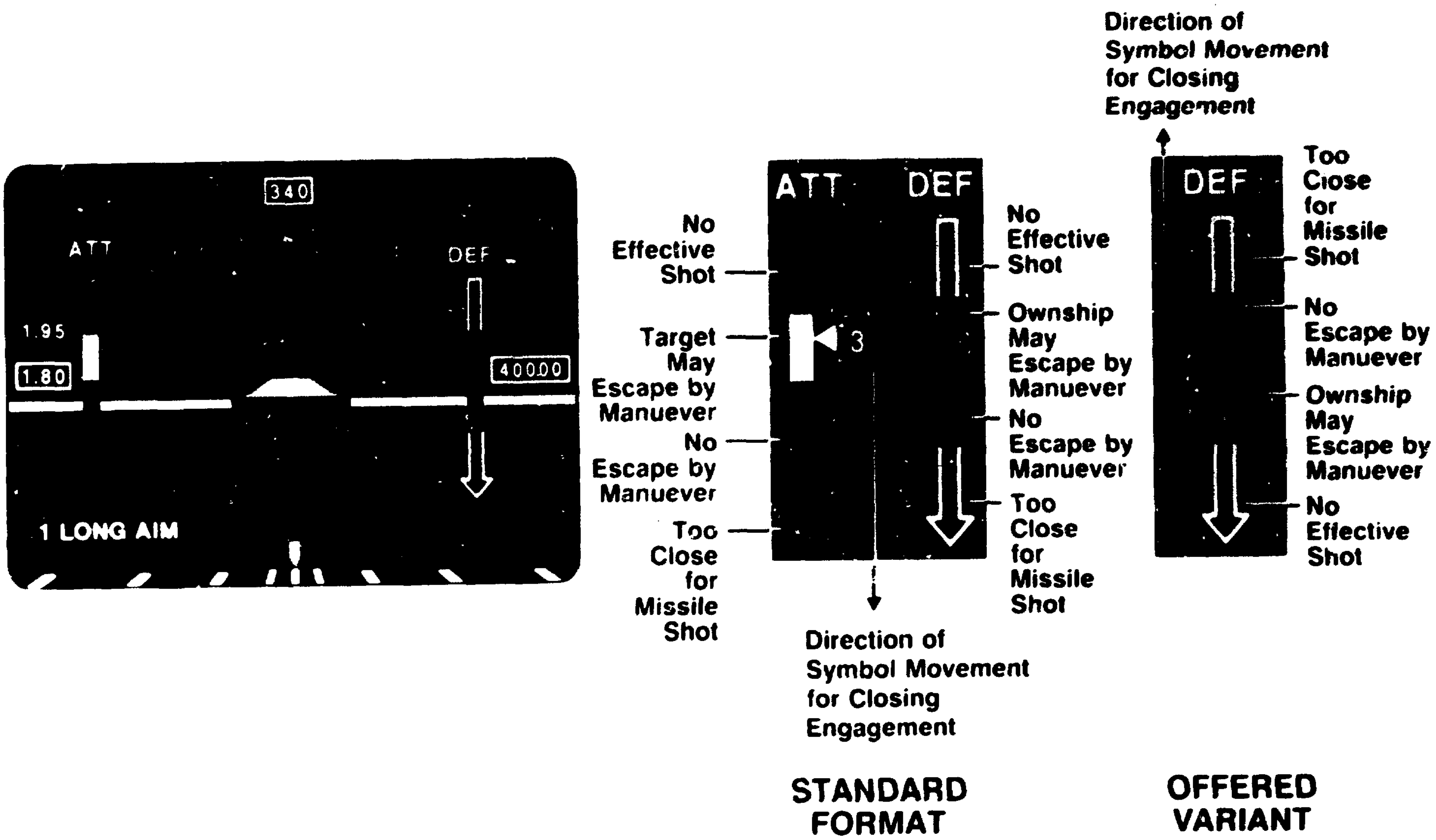


Figure 5.1-1. Alternative Missile Launch Envelope Definitions

The standard format was selected, on the logic that it would be more intuitive and more easily understood for the target and threat aircraft to move down the arrows as the engagement closed. The arrows both pointed in the direction of missile flight.

The second issue on the HUD was how much fill should be used in the format. On one hand, filled areas on a format may make those areas more easily understood. On the other hand, excessive use of fill consumes more energy, takes more time to draw a picture frame, and puts more light in the cockpit. In the HUD, fill covers the outside scene. Excessive use of color may reduce its attensity value for important symbology. In the standard HUD format, both mountains and the ground plane were filled, the mountains in green and the ground plane in half density green or full and half density gray, in monochrome. The offered variants allowed either the mountains or the ground plane, or both, to be left black framed in green or gray lines. It was decided to fill the ground plane with half density green, since this is an IMC simulation. In visual conditions, a declutter feature could be employed to remove the fill.

5.2 Perspective Situation Format Dynamic Comparisons

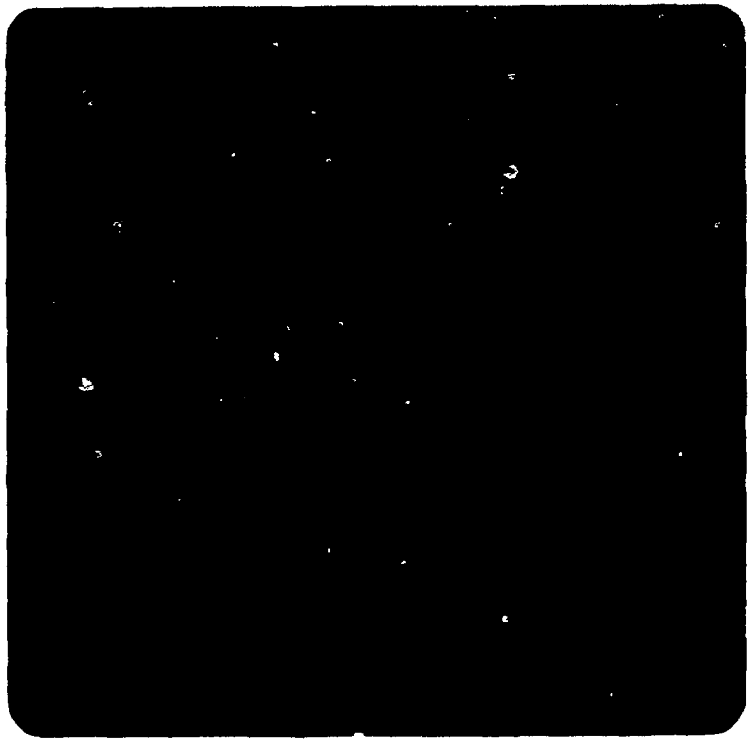
The perspective situation format is detailed in paragraph 4.2.2. The dynamic comparison issues again related to use of color. In the standard form, the sky was blue, the mountain tops were brown, the mountain bases with the ground plane were green. The ground grid was black. Offered variants had the sky black, the mountain tops white, the mountain bases light gray and the ground plane black with a green grid. The more colorful standard form was selected because the pilots felt that the full colors would be more meaningful to aircrews.

5.3 Horizontal Situation Format Dynamic Comparisons

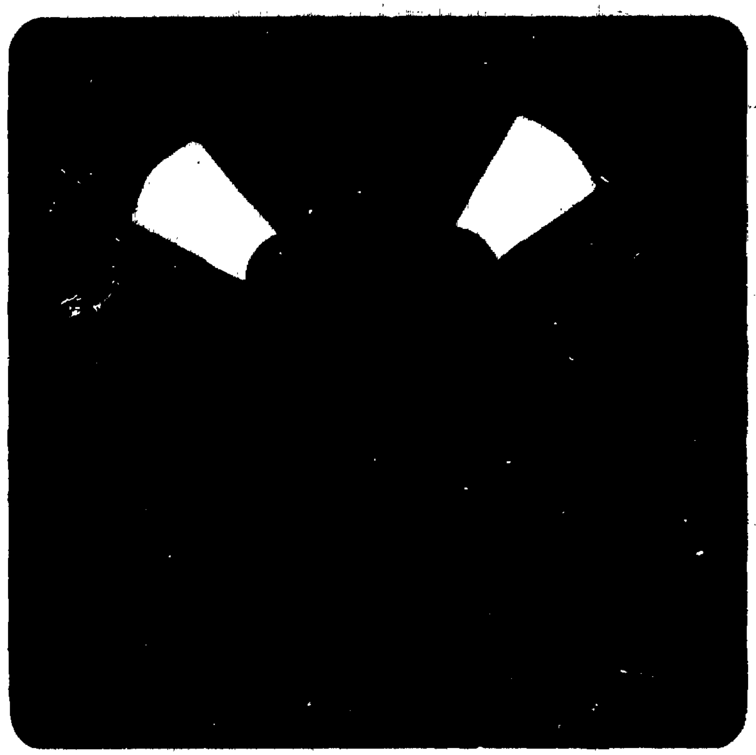
The first issue for dynamic comparison on the HSF again was related to use of color. In the standard form, the mountains above current altitude were colored brown against a green background. The variant had light gray mountains against a black background. The standard format with brown mountains and dark green background was selected. Some of the smaller symbols were made thicker to increase contrast against the colored background.

It was suggested that background color be changed as a function of display master mode, green for ground mode and black for air mode. This idea was not implemented in the simulator.

The second HSF issue concerned missile launch envelope symbology in air mode. This is illustrated in Figure 5.3-1. The missile launch envelope (MLE) for ownship and adversary aircraft could be shown with either reduced or full representation. Reduced representation would reduce clutter when there are several enemy aircraft in the engagement but full representation may be more easily understood. In the standard format both outbound MLEs from ownship to target aircraft and inbound MLEs from threat to ownship were composed of a line between aircraft with two arcs defining the maximum range and no-escape zones. The offered variant had MLEs with 10° sectors, color coded to correspond to MLE sectors in the HUD. The tractor beam representation was selected, based on the clutter argument. The pilots felt that, while the sectors were easier to see and understand, the probability of several of these sectors overlaying was high and information could be lost. The arcs at maximum range and no-escape range were made thicker to increase their prominence.



Standard Format
With Tractor Beam
and Arcs



Offered Variant
With Color
Sectors

Figure 5.3-1. Horizontal Situation Format Alternatives

6.0 CONDUCT OF THE MISSION SEGMENT AND COMPOSITE MISSION STUDY

The intent of the manned simulation was to apply the knowledge and skills of operational aircrews to assess the pictorial formats. In this sense, the aircrews acted as measuring instruments. This section describes what the aircrews experienced in their three days on site. Briefly, the program began with ground school, followed by hands-on training. The crews then flew mission segments where the emphasis was on collection of performance data in a variety of exercises or events. Finally, the aircrews flew composite missions with fairly compressed timelines and relatively high workload. The emphasis in the composite missions was on the aircrews' subjective assessment of the pictorial formats.

6.1 Test Subjects

AFWAL/FIGR arranged for sixteen, two-man, aircrews to serve as subjects in this study. All crew members were active duty military aviators and most were current in one or more combat aircraft. Each crew consisted of a pilot and a WSO. As Table 6.1-1 shows, the range of experience and aircraft flown was broad. Names and addresses of participating crew members were available to Boeing approximately two weeks before their scheduled test dates. A handbook (Martin, Way, and Hornsby, 1986), designed to introduce the program, the formats, and the agenda, was forwarded to all crew members two weeks prior to their arrival. All professed familiarity with the contents of the handbook.

6.2 Mission Segments

The purpose of the mission segment simulations was to compare usability and aircrew acceptability of color and monochrome versions of the pictorial formats under controlled conditions without the confounding of incompatible simultaneous task demands. To this end, aircrews flew three different sets of mission segments: low level penetration, system health, and beyond visual range (BVR) air-to-air engagement. Events and exercises peculiar to a given segment were separated in time so one activity was completed before beginning the next. There were both monochrome and color practice and test missions in each set. Appropriate performance measures were collected and, at the end of each set, crews were debriefed on the formats used in that set.

Table 6.1-1
Aircrew Qualifications

		Pilot		WSO	
Crew	Branch	Jet Hours	Aircraft	Jet Hours	Aircraft
1	AF	2850	T-38, F-15	1500	T-43, F-4 E/G
2	N	685	T-28, T-2, TA-4, EA-6B	900	EA-6B, TA-4J, F-4, T-39, T-2
3	N	2600	A-6, A-4, T-2, T-34	2300	A-4, A-6, T-2, T-34
4	AF	3155	T-37, T-38, F-4, F-16	3000	T-43, T-37, C-141, C-5
5	N	2030	EA-6B, trainers	875	T-2C, T-39, A-4M, EA-6B
6	N	1325	T-28B, T-2C, TA-4, A-6E, C-172, M-20C	2520	A-6, T-39, RA-5C
7	N	325	A-6E, TA-4, T-2C	200	A-6E, TA-4, T-47, T-39, T-2
8	N	1340	T-34, T-2C, TA-4, A-6	800	A-6, T-39, T-2, A-4, T-34, TC-4C, TA-7
9	N	3600	T-34, T-28, T-2, TA-4, A-4M, A-6, EA-6B	170	T-34C, T-2, T-39, TA-4, EA-6B
10	AF	2400	F-15 A/C, F-5 E/F, AT-38, T-37, T-38, F-4 C/D/E	1800	F-4, F-111
11	AF	4200	T-37, T-38, F-100, F-4, T-33, A-4, T-38 aggressors, F-5, F-15, YF-XX	1425	F-4, T-29
12	AF	3700	KC-135, T-39, F-100, F-4, F-104, F-16, F-111	2400	F-4, trainers
13	AF	2900	F-4, F-16	2500	T-38, A-10, F-16
14	N	2800	A-6E, T-2C, A-4	1300	A-6E, TA-4J, T-2C, T-39
15	N	1355	F-14, A-4, T-2, T-34	1400	F-14, F-4, F-18, F-16, A-6, S-3, P-3
16	N	2400	F-14, F-4, A-4, T-2, F-18	1650	F-14A, TA-4, TA-7, A-6, T-38, TF-18

Before each mission, the aircrew worked through a preflight checklist. This activity ensured proper initial conditions for the mission and served as a review for the crew of controls and information sources. Part of the checklist included programming of the stores and ECM options for the briefed mission.

6.2.1 Low Level Penetration Segments

The low level penetration mission segments began at terrain following altitude on the friendly side of the Forward Line of Troops (FLOT). Information in the ground threat file was relatively sparse at the start. A data link update occurred and new threats were then displayed along the flight path. The flight crew was to select a minimum exposure route at several branch points as the aircraft flew through the mountain passes. Crews were briefed to stay close to the selected flight path but to move laterally as necessary to minimize exposure to ground threats. The WSO was required to manually approve the release of chaff and flares for each threat that launched or fired upon the aircraft.

6.2.2 Systems Health Segments

The systems health mission segments began at terrain following altitude on the enemy side of the FLOT, enroute to the target area. The flight ended after weapon delivery and before transition to high altitude. As in the low level penetration segment, a limited ground threat file was updated and new threats were displayed along the flight path. As expendable countermeasures were also limited in this segment, the WSO had to manually approve the release of chaff and flares. Enroute, threats launched and the aircraft sustained battle damage precipitating various system health problems. Each segment contained examples of failures from several systems (e.g., engine, hydraulic, fuel, electrical, countermeasures) which required appropriate responses.

6.2.3 Beyond Visual Range Air-to-Air Segments

The BVR air-to-air mission segment began during low level flight and ended with either identification of friendlies or weapon delivery against a group of confirmed enemy aircraft. At some point in the flight the crew was directed to intercept a flight of aircraft whose number and identity were not known. The crew previewed three climbout profiles to determine a minimum exposure route for exiting the threat area. Ownship then flew from the start of climb point to the intercept point where the IFFN/raid count was presented and if appropriate, ownship engaged the enemy.

6.3 Composite Missions

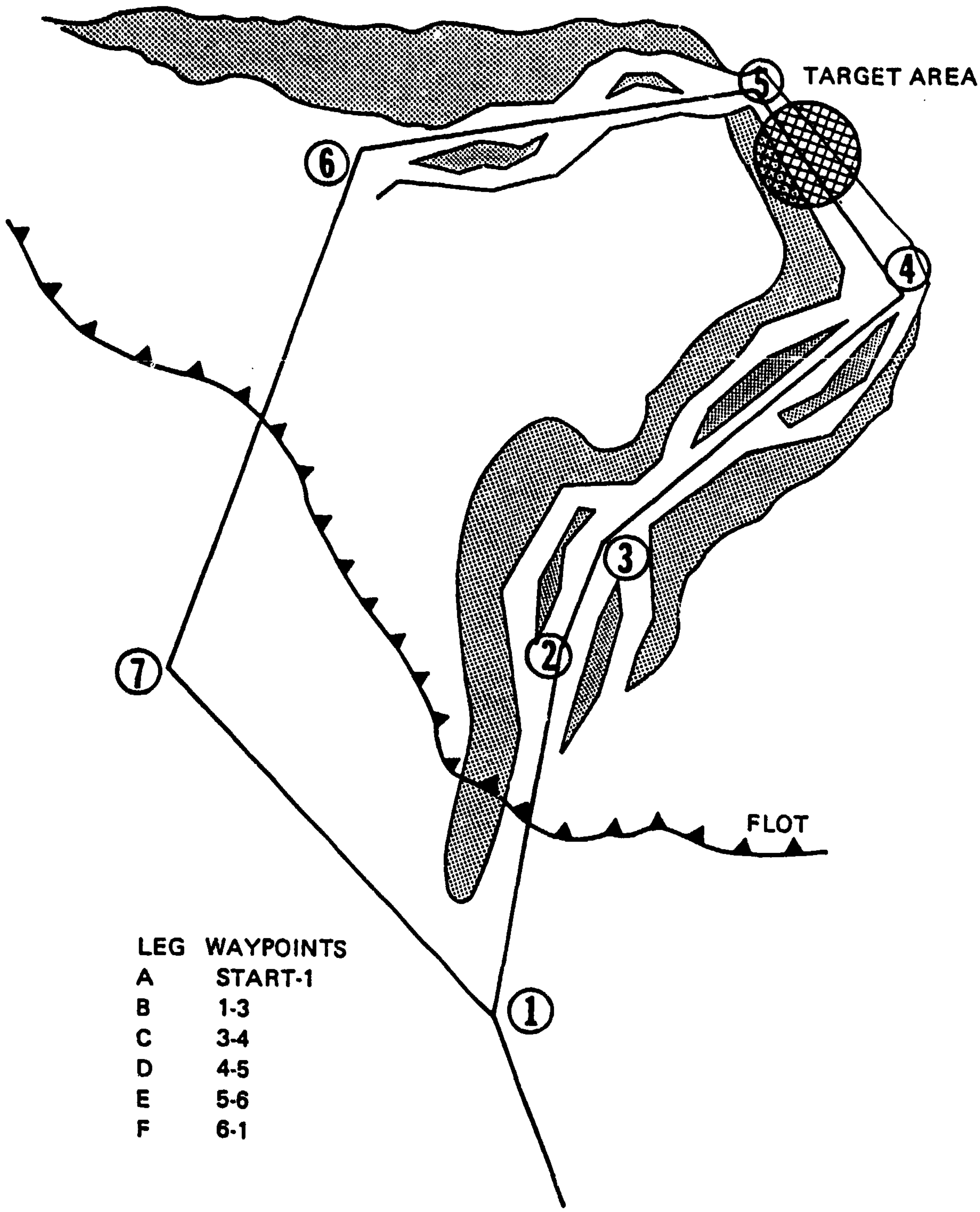
The navigation track for the composite missions is shown in Figure 6.3-1. It consisted of a high altitude approach, descent to terrain following altitude, penetration through a moderately defended area to an interdiction target, target acquisition, weapon delivery, withdrawal, climbout and return home. The aircrew encountered air and surface threats, and delivered air-to-ground and air-to-air weapons. The missions were flown at altitudes ranging from 200 to 35,000 feet AGL and airspeeds from 480 knots to Mach 2.2. The four composite missions all had the same structure. Threat beddowns, target assignments, system health events, and the final air-to-air engagement varied from mission to mission. A more detailed outline of the composite missions follows.

The first leg began just after aerial refueling enroute to WP1 at FL 200, airspeed 496 knots on a heading of 330 degrees. The crew had been briefed for a primary and a secondary ground target. After overflying WP1 , the aircraft descended to 200 feet AGL and entered terrain following/terrain avoidance mode to take advantage of the terrain masking opportunity offered by the high ground.

Entering leg B, the crew received a data link message, updating the location and activity of known ground threats. On some missions, there was a directed change to the secondary ground target. Speed was maintained at 496 knots and as the FLOT was crossed, the onboard passive sensors searched for enemy radar activity or other hostile threats.

There was an opportunity to select an alternate route, based on the updated threat situation. The aircrew made overt selections and the threats countered. The aircraft automatically employed countermeasures in self defense. Some battle damage occurred from near misses. This leg was heavily defended by SAM and AAA mobile units, some of which were located as indicated in the pre-flight briefing, while others popped up or were revealed by a data link update.

On leg C in some missions, a second data link message was received, again updating the threat situation. The aircrew again had alternative flight path choices and the aircraft sustained minor damage. Enroute to Waypoint 4, the crew was instructed to attack a ground threat site with an antiradiation missile. There was little terrain masking on the run to the ground weapon launch point, requiring the aircrew to be particularly alert to threats. The WSO targeted the weapon and the pilot released the air-to-ground ordnance.



LEG	WAYPOINTS
A	START-1
B	1-3
C	3-4
D	4-5
E	5-6
F	6-1

On some missions, the crew was informed of aircraft closing on their position. The direction was to climb, identify, and engage the new threat. As information on the aircraft accumulated, they were identified as friendlies or as adversaries. If the other aircraft were determined to be hostile, the mission ended with a BVR air-to-air engagement.

6.4 Schedule

The complexity of the aircraft being simulated, the novelty of the new formats being evaluated, and the amount of data to be collected together yielded three full days on site. Table 6.4-1 shows the aircrew agenda. The order of conditions changed from crew to crew.

The morning of the first day was devoted to ground school and cockpit familiarization. The first afternoon consisted of practice flights. On the morning of the second day there was a briefing, practice, and test trials on the first mission segment type, followed by debriefing on that segment type. That pattern was repeated the second afternoon and the third morning with the second and third segment types. The final afternoon consisted of flying the four composite missions and a post flight debriefing.

Table 6.4-1
Aircrew Agenda

First Day	Ground school Cockpit familiarization General flight and procedures training
Second Morning	First Mission Segment Briefing and demonstration Monochrome or color display condition Practice segments, one test segment Repeat with other display condition Debriefing
Second Afternoon	Second mission segment type Same pattern
Third Morning	Third mission segment type Same pattern
Third Afternoon	Four composite missions Two each in monochrome and color Final debriefing

The primary independent variable was format presentation - monochrome or color. In order to reduce bias introduced by differential learning, the odd-numbered crews flew practice and test segments in monochrome first, then in color. The even-numbered crews reversed the order. The order of segment sets was also varied systematically across crews.

The order of flying the four composite missions was also counterbalanced across crews. The odd-numbered crews flew their first two composite missions in monochrome and the second two in color. The order was reversed for the even-numbered crews.

6.5 Data Collection

Three types of data were collected during the manned simulations to assess the usability and acceptability of pictorial formats in color and monochrome. These data also helped improve both the content and depiction of aircraft, flight, and mission information. The three data types were questionnaire or opinion data, subjective workload assessment, and performance data.

6.5.1 Questionnaire Data

Among the three sets of mission segment flights, i.e., low level penetration, systems health, and BVR air-to-air engagement, all of the individual formats were exercised. After each set, aircrews was asked about the particular formats that supported specific events during that set. In the final debriefing, after all the mission segments and composite missions had been flown, aircrews responded to a questionaire on suites of formats. The emphasis here was on presentation and coordination of information across formats. Finally, each aircrew member was provided with a tape recorder, paper, and a list of general questions. It was found in the earlier studies in this series, that this technique worked well to elicit ideas not otherwise available - a directed free association. Experience has also shown that aircrew opinion, collected in this manner and collated, is extremely valuable in the assessment and improvement of display formats.

6.5.2 Subjective Workload Assessment Technique

One important goal in the design of these formats was to reduce, or at least contain, aircrew workload. The Air Force has had some success over the last several years measuring aircrew workload with a program called the Subjective Workload Assessment Technique (SWAT) (Reid, 1985). During the course of this study, aircrews were asked to use SWAT to quantify their mental workload required to complete the tasks. Mental workload refers to how hard the crew works to accomplish some task, group of tasks, or an entire job. The workload at any one time was assumed to consist of a combination of three dimensions which contribute to the subjective feeling of workload. SWAT defines these dimensions as (1) time load, (2) mental effort load, and (3) psychological stress load.

For purposes of subjective workload assessment, each of these three dimensions is divided into low, medium, and high levels. The SWAT theory assumes that each workload rater may have a different way of combining the three dimensions into subjective workload. For example, time load may be most important for one rater and psychological stress most important for another.

In order to be able to combine workload ratings across raters, it was necessary to calibrate the raters themselves. Cards were prepared, each containing one of the twenty-seven combinations of definitions of the three levels of the three dimensions. Decks of these cards were given to the individual aircrew members with instructions to sort the cards from low to high workload. Crewmen were asked to work independently and they took from twenty to thirty minutes to complete the task. The resulting orders were recorded and combined by a psychometric technique known as conjoint analysis.

During each mission segment flight, twelve tones were inserted at places intended to represent a wide range of workload conditions. Aircrew members were instructed to report workload each time they heard the signal tone. The pilot reported first, followed by the WSO.

6.5.3 Performance Data

A number of measures of crew performance were recorded during the mission segment simulations. Some of the performance measures reflected individual performance of the pilot or the WSO while others reflected the coordinated activity of both crew members. Collectively, these measures provided quantitative data on the crew's ability to use the pictorial information in color and in monochrome to accomplish: a) flight path control, b) threat detection and avoidance, and c) identification and resolution of degraded system status. It was assumed that deviations from the flight path channel, problems in threat detection and avoidance, and difficulty in the identification and resolution of degraded mode conditions would be greater for a display presentation mode that was more difficult to use.

7.0 RESULTS

In their questionnaire responses, pilots and WSOs clearly preferred the color formats. They indicated general approval of the pictorial format concept and provided detailed critiques of specific formats. Subjective workload assessments did not show a significant difference between the color and monochrome formats. However, there was an apparent learning effect favoring the color versions. The MANOVA performed on performance data did not show significant color/monochrome difference. However, there were weaknesses in aircrew performance which could be identified with particular formats.

7.1 Questionnaires

Appendix B contains profiles of usability for each of the formats plotted from mean judgements made by the aircrews. Appendix C contains the questionaires with mean judgements of usability and other attributes. Appendix D contains summaries of the aircrew responses to the open ended questions.

In this section, the formats are discussed in terms of aircrew ratings of usability and information interpretability. The individual formats are discussed in terms of aircrew ratings of usability and information interpretability. Usability ratings, were given on a seven point scale from 1 for "very good" to 7 for "very poor." All formats were rated for the color and monochrome cases. Two general observations are in order. First, in almost all cases, color format versions were rated better than the monochrome versions. Exceptions will be noted as they come up. Second, the data profiled in this section show that most of the color ratings fell between 2 ("moderately good") and 3 ("slightly good"). Symbology elements rated less than "slightly good" may be candidates for revision. Similarly, answers to information interpretation questions were given on a seven point scale from 1 for "very easy" to 7 for "very difficult." Elements or information rated low will be mentioned here and considered for revision in Section 8.

7.1.1 Head-Up Display

Usability ratings for HUD elements in the ground and air modes are profiled in Appendix B (B-2 and B-3). The threat alert symbols in both modes and MLE arrows in air mode were given high ratings. The MLE arrows also received strong support in the open ended questions. On the other hand, a number of HUD symbology elements were rated down and suggest revision.

The pathway, as implemented, was not well received. There was support for the concept of a pathway, but the present implementation requires a significant amount of work. The transitional flight director was rated less than "neutral" in both ground and air modes. The pilots were not happy with the addition of a different symbol, with different control rules, when they were off the pathway. In ground mode, the mean ratings for the pathway were slightly better in monochrome than in color. Several pilots pointed out that there was more contrast in the monochrome version. The airspeed and altitude readouts were acceptable, but the heading readout was less so. The roll index and the optional vertical velocity indicator were also not well received.

When pilots were asked to rate ease of information interpretation, the pathway, the vertical velocity indicator, the weapon release cue, and the relationship of ownship to terrain were judged to be less than "slightly easy" in both color and monochrome. Comments indicated that a nonlinear scaling would be better for the vertical velocity indicator, to yield more sensitivity at low vertical velocities. It was also pointed out that the weapon release symbol in the HUD should be more noticable and should probably not be an "X," which is usually considered to be a breakaway command. Even in color, interpretation of ownship's location relative to terrain was reported to be difficult.

7.1.2 Perspective Situation Format

Almost all of the elements of the PSF (Appendix B-4 and B-5) were rated better than "slightly good" in color, with the depiction of ground threat lethality volume particularly well received. In both air and ground mode, the preview symbol was less well accepted. Crews amplified this opinion in their comments, indicating that the preview option was not necessary. The ground grid and the ground point symbol were down rated in air mode. Essentially, they carried no information needed by the crews in air mode. The new view option - the ability to adjust viewpoint on the PSF - drew mixed comments. Some pilots and WSOs used the feature to set the viewpoint viewpoint for their individual preference or to meet their needs for a particular mission segment. Other pilots and WSOs did not use it or did not see the need for this feature. While speed and altitude readouts were fairly well accepted, in air mode the heading readout was rated worse than "slightly good."

For information interpretation, WSOs rated airborne threat mode and type information less than "slightly easy." Pilots rated airborne threat type and the numeric data on airborne threats less than "slightly easy."

Comparing ratings and opinions on the PSF in this study with those in the earlier pictorial format display evaluation (Way, et al, 1984), this is an improvement. The primary differences are that threat depiction was more complete in this study and the PSF in ground mode had a purpose here - simultaneous threat and terrain avoidance.

7.1.3 Horizontal Situation Format

Usability ratings of the HSF in ground and air modes are profiled in Appendix B (B-6 and B-7). With the exception of the fuel range rings, all the symbology elements in color were rated better than "slightly good." In amplifying comments, the aircrews questioned the utility of the fuel range rings.

The pilots rated the fuel range rings and ownship's proximity to mountains worse than "slightly easy" to interpret. The WSOs passed those but downrated enemy MLE boundary arcs on the HSF in air mode.

Despite these specific complaints, most of the pilots and WSOs reported that the HSF was an excellent format which provided a good awareness of the current and near future situation. When asked if the HSF background color should change as a function of master mode, e.g., black for air mode and green for ground mode, the clear majority said "No."

7.1.4 Close Look Formats

Crew ratings of the Detail and Formation versions of the Close Look Format are profiled in Appendix B (B-8). In color, all but one of the symbology elements were rated better than "slightly good." The one feature which was rated down was the range change feature of the Formation CLF. The utility of this feature, as implemented, was questioned. Crosschecks between the CLFs and HSF and between the CLF and Stores Status formats were rated "moderately easy" by the pilots and WSOs. Ability to interpret information on the CLFs was also rated "moderately easy." Although it does not appear in the formal data, a number of crewmen commented that having two Close Look Formats was awkward, leading to occasional confusion.

7.1.5 Stores and Countermeasures Formats

The Stores and Countermeasures Status and Programming Formats were rated better than "slightly good" in both color and monochrome as indicated in Appendix B (B-9). In their comments, crews indicated general satisfaction with these four formats.

7.1.6 Other Status Formats

Usability ratings for symbology elements in the Engine Status Format are profiled in Appendix B (B-10). In color, all the elements except the fuel flow arrows were rated "slightly good" or better. In their comments, pilots indicated that numeric fuel flow was sufficient and that the redundant fill level in the arrows was not necessary. They indicated that simplification of the format would make important information easier to find. The color versions of the Fuel, Electrical, and Hydraulic Formats and their elements were rated better than "slightly good" as shown in the usability ratings profile of Appendix B (B-11). Finally, usability ratings for elements in the Passive Sensor Status and System Advisory Formats are shown in Appendix B (B-12). The color versions of these were rated "slightly good" or better.

7.2 Workload

The Subjective Workload Assessment Technique (SWAT) was used as the measure of workload. SWAT measures require two stages of scale development and event scoring. Workload is defined as an aggregate of three factors: (1) time load, (2) mental effort load, and (3) psychological stress load.

Scale development began by having each of the thirty-two subjects (sixteen pilots and sixteen WSOs) sort a deck of cards to reflect their individual perception of how the three factors combine to determine workload. Each of the cards contained one of the twenty-seven combinations of three levels (low, moderate and high) of the three factors. This process typically took a subject about 20 to 30 minutes. The card order for each subject was recorded. A preliminary scale was derived using a statistical process known as conjoint analysis (Nygren, 1982). Kendall's Coefficient of Concordance (W) was calculated indicating a moderate level of agreement among the 32 subjects on that scale ($W = .72$). Following a procedural suggestion of Reid, Eggemeier & Nygren (1982), the individual subjects were prototyped or characterized as effort, stress or time responders, depending on their card sorts. New scales were derived based on those prototypes. Four of the subjects were characterized as effort responders ($W = .87$), five as time responders ($W = .94$) and the remaining twenty-three as stress responders ($W = .82$). A linear transformation was applied to yield a scale from 0 (no workload) to 100 (maximum workload).

The aircrews flew their six test missions - low level penetration, system health and beyond-visual-range air-to-air - each with monochrome and color formats. Twelve auditory tones were placed in each of the missions - six during busy times and six during less busy times. The crews were instructed to give a SWAT judgement when they heard a tone. Their judgement data was scaled, using the process just described and then subjected to an analysis of variance. Table 7.2-1 summarized that analysis. The independent variables were:

- Mission - low level penetration, system health or beyond-visual-range;
- Display - monochrome or color formats;
- Crewman - pilot or WSO;
- BNB - an independent division, by the experimenters, of the twelve SWAT occasions in each mission into the six busiest and the six least busy; and
- Sequence - a division of the sixteen aircrews into the eight who were tested on color before monochrome and the eight who were tested in the other order.

Table 7.2-1. SWAT Reports – Analysis of Variance Summary Table

Source	DF	Type I SS	F value
Mission	2	25841.88	26.53*
Display	1	540.92	1.11
Crewman	1	26896.25	55.22*
BNB	1	90967.97	186.75*
Sequence	1	100725.42	206.78*
Mission by display	2	2945.89	3.02*
Mission by crewman	2	16087.02	16.51*
Mission by BNB	2	1601.55	1.64
Mission by sequence	2	1299.45	1.33
Display by crewman	1	13.93	0.03
Display by BNB	1	70.90	0.15
Display by sequence	1	378.18	0.78
Crewman by BNB	1	2399.96	4.93*
Crewman by sequence	1	3770.79	7.74*
BNB by sequence	1	1[illegible]0.47	23.79*
Mission by display by crewman	2	1510.12	1.55
Mission by display by BNB	2	182.99	0.19
Mission by display by sequence	2	1735.92	1.78
Display by crewman by BNB	1	1.78	0.00
Display by crewman by sequence	1	317.36	0.65

* Significant, $p<.05$

Table 7.2-2 gives the mean SWAT scores for the main effects. The scores were significantly lower for system health missions than the other two, for the WSO's than the pilots; for the "not busy" occasions than the "busy" ones and for crews who were tested on color before monochrome than those who were tested in the other order. The small display difference was not significant. Significance was tested by the Bonferroni (Dunn) t-test within the SAS General Linear Models Procedure. A criterion of 0.05 was selected for the significance determination.

Table 7.2-2. SWAT Reports – Main Effect Means

Users	Levels	Mean SWAT Scores		
Mission	LLP, BVR, SH	25.7J	24.06	17.89
Display	Color, monochrome	22.89	21.88	
Crowman	Pilot, WSO	26.00	18.68	
BNB	Busy, not busy	29.41	15.74	
Sequence	Monochrome first, color first	29.57	15.26	

The significant sequence difference is particularly interesting. Crews who were trained and tested on color formats before monochrome formats reported overall mean workload 14.31 scale units lower than crews with the other order. This seems to indicate that, although the color - monochrome effect was not itself significant, it participated in an order or learning effect on all three segment types and with both pilots and WSO's.

Even after an intensive training program, the short time available caused the crews to be still learning as they were being tested. This supports the interpretation of order effects as learning. Apparently, the differential transfer from color formats to monochrome yielded lower overall perceived workload than the transfer from monochrome to color.

Figure 7.2-1 contains plots of the significant two-way interactions. With a significant mission main effect, but no significant display effect, the significant interaction appears to be a modest inversion of workload in the beyond-visual-range mission and functionally unimportant. Both crewman and mission main effects were significant. The significant interaction between them indicates that the pilots and WSO's perceived their mental workload to be almost the same in the BVR missions, but pilots reported higher workload than WSO's in the other missions.

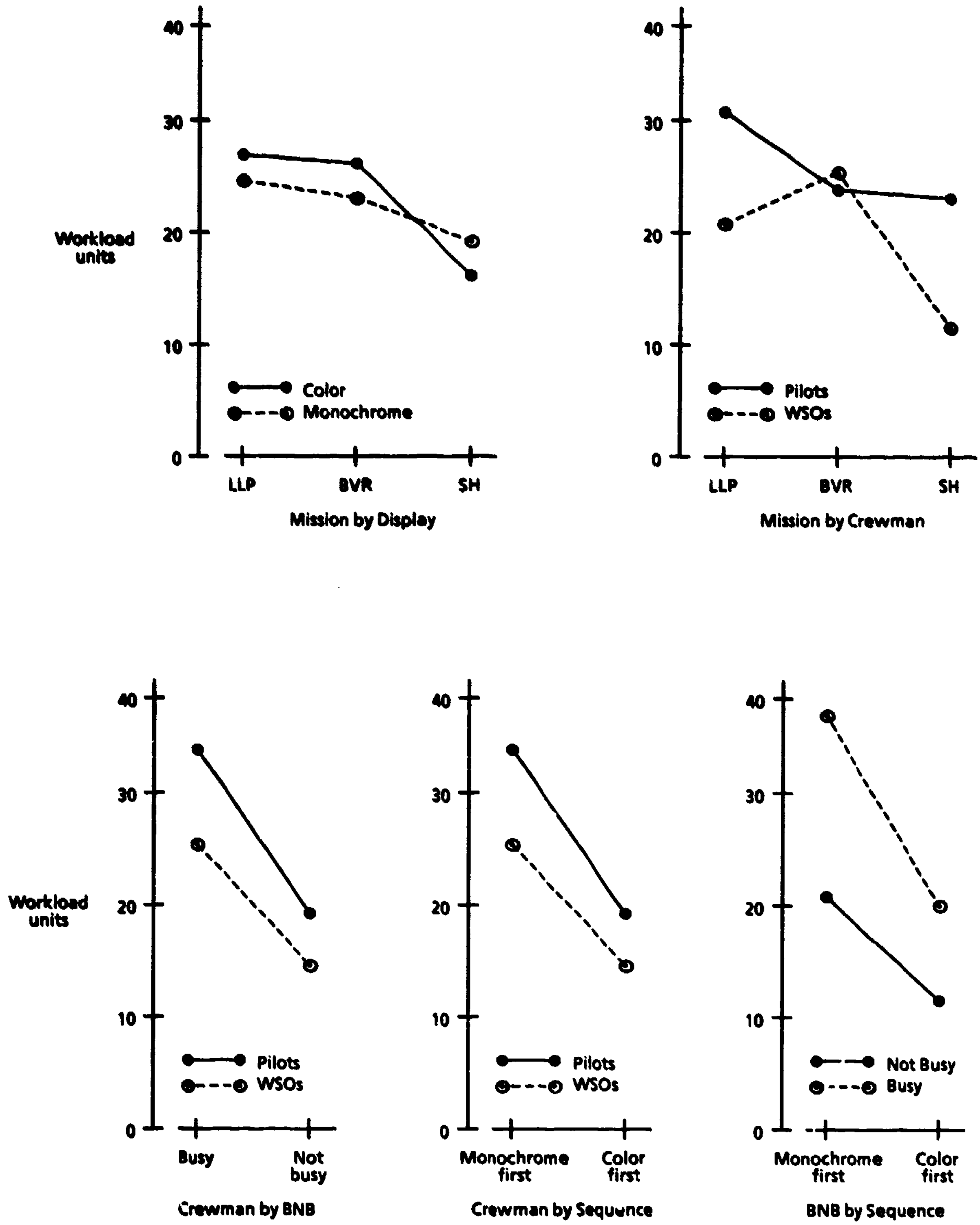


Figure 7.2-1. SWAT Reports - Significant Two-way Interactions

The three interactions in the lower row of Figure 7.2-1 have the same pattern and appear to support the same interpretation. In each case, the parameter with the lower score has a shallower slope. This appears to be a floor or scale-end effect where scores near the extremes of a closed-end scale tend back toward the center.

7.3 Performance

The performance measures collected in the low level penetration (LLP), system health (SH), and beyond visual range air-to-air (BVR) test segments can be broadly catagorized into three groups: flight path control data, latency of the required responses, and the frequency of response error. A subset of the three types of performance measures were appropriate in each of the three mission segments as indicated in Table 7.3-1.

Flight path control performance measures generated at the conclusion of each trial were defined as follows.

Root Mean Square (RMS) Error, Vertical: A cumulative measurement of the vertical deviation from the displayed flight path.

RMS Error, Lateral: A cumulative measurement of the horizontal deviation from the displayed flight path.

Percent Time in Pathway, Vertical: Percentage of time the flight path was flown within the vertical limits of the displayed pathway.

Percent Time in Pathway, Horizontal: Percentage of time the flight path was flown within the horizontal limits of the displayed pathway.

Percent Time in Both: Percentage of time the flight path was flown within the entry gate of the displayed pathway.

Exposure Score: The integrated time ownship was within the envelope of each threat, weighted by the relative lethality of each threat. The relative lethality of a threat is a function of type (AAA or SAM) and the state of that threat (prebriefed, search, track, or launch). Exposure score reflects the pilots' ability to deviate from the pathway as required to avoid threats.

Latencies of the required responses were derived from the data acquisition program which generated a detailed record of mission events. The time at which each event occurred and the time at which the crew responded were recorded to produce a latency report. For example, availability of an alternate route or a

Table 7.3-1. Performance Measures

Dependent Variables	Condition		
	LLP	SH	BVR
RMS Error, Vertical		●	●
RMS Error, Lateral		●	●
% Time in Pathway, Vertical		●	●
% Time in Pathway, Lateral		●	●
% Time in Path		●	●
Exposure Score	●		
Latency of Route Selection	●	●	
Correctness of Route Selection	●	●	
Latency of Climb Profile Section			●
Correctness of Climb Profile Selection			●
Latency of Countermeasures Release	●	●	●
Latency of Response to Pop-Up Threats	●	●	
Correctness of Pop-Up Threat Identification	●	●	
Latency of Damage Report		●	
Correctness of Damage Report		●	
Latency of Response to Target Assignments			●
Correctness of Reponse to Target Assignments			●
Latency of Response to Shoot Cue			●

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change in threat state was recorded as well as crew input in response to mission events, i.e., the selection of an alternate route or the release of expendable countermeasures. Latencies of the required responses were defined as follows.

Latency of Route Selection: Elapsed time from the presentation of the alternate route to the navigation update command.

Latency of Climb Profile Selection: Elapsed time from the presentation of alternate climb profiles to the designation of the start of climb point.

Latency of Countermeasures Release: Elapsed time from presentation of a threat launch cue within the display formats to the control input releasing the countermeasures.

Latency of Response to Pop-Up Threats: Elapsed time from the appearance of a pop-up threat within the display formats to the aircrews' verbal report of that threat.

Latency of Damage Report: Elapsed time from the selection of the appropriate status switch to aircrews' verbal report.

Latency of Response to Target Assignments: Elapsed time from the display of target assignments to the targeting of weapons.

Latency of Response to Shoot Cue: Elapsed time from the presentation of the shoot cue to the actuation of the trigger.

Frequency of response error was obtained from two sources. The required verbal responses - the aircrews climb profile selection, identification of pop-up threats (type and state), and the status reports of degraded aircraft systems - were obtained from the audio channel of the video tape flight records. The computer generated switch history indicated whether or not the optimal route alternatives were selected and the appropriate weapons targeted.

A multivariate analysis of variance (MANOVA) was performed to determine if display mode effected aircrew preformance. The independent variable was display presentation mode with two levels - color or monochrome. For the low level penetration mission segments the dependent measures included exposure score, latency of route selection, latency of countermeasures release, and latency of response to pop-up threats. The analysis, summarized in Table 7.3-2, indicated no significant difference between the two display presentation modes for the set of four performance measures.

Table 7.3-2. One-Factor Repeated Measures MANOVA

MANOVA for Low Level Penetration
Multivariate tests of significance (S = 1, M = 1.0, N = 2.5)

Test name	Value	F	Hypothesis DF	Error DF	Significance of F
Pillais	.7124	3.72 (approx.)	1	9	0.0746
Hotellings	2.477	3.72 (approx.)	1	9	0.0746
Wilks	.2176	3.72 (exact)	1	9	0.0746
Roys	2.477	3.72 (upper bound)	1	9	0.0746

MANOVA for System Health
Multivariate tests of significance (S = 1, M = 3.5, N = 1.5)

Test name	Value	F	Hypothesis DF	Error DF	Significance of F
Pillais	.4879	0.42 (approx.)	1	12	0.8692
Hotellings	.9529	0.42 (approx.)	1	12	0.8692
Wilks	.5121	0.42 (exact)	1	12	0.8692
Roys	.9529	0.42 (upper bound)	1	12	0.8692

MANOVA Beyond Visual Range
Multivariate tests of significance (S = 1, M = 3.5, N = 2.5)

Test name	Value	F	Hypothesis DF	Error DF	Significance of F
Pillais	.3517	0.36 (approx.)	1	14	0.9172
Hotellings	.5425	0.36 (approx.)	1	14	0.9172
Wilks	.6483	0.36 (exact)	1	14	0.9172
Roys	.5425	0.36 (upper bound)	1	14	0.9172

RMS error data, percentage of time within the pathway, latency of route selection, latency of countermeasures release, latency of response to pop-up threats, and latency of damage report were the dependent measures used to execute the MANOVA for the system health mission segments. The summary data (Table 7.3-2) revealed no significant performance difference between color and monochrome displays.

The beyond visual range dependent variables included: RMS error data, percentage of time within the pathway, latency of climb profile selection, latency of countermeasures release, latency of response to target assignments, and latency of response to shoot cue. The MANOVA (Table 7.3-2) failed to indicate a significant performance difference between the two presentation modes.

7.3.1 Low Level Penetration Performance

Exposure score and accuracy of flight within the displayed pathway and its entry gate were mutually exclusive flight path control measures. Therefore, in low level penetration segments, the exposure score reflected the pilots' ability to deviate from the pathway as required to avoid threats. With the color display suite, mean exposure score was 399.81; with the monochrome display suite, mean exposure score was 389.50.

Latency data for the required responses indicated no significant differences between the color or monochrome display presentation mode. As summarized in Table 7.3-3, mean response time for the release of countermeasures and selection of an alternate route and the standard deviations associated with the measurements generally remained consistant between display modes. However, in the monochrome condition slightly longer latencies together with substantial standard deviations were observed in the response to pop-up threats.

Table 7.3-3. LLP, Latency of Required Responses

	Mean	Standard Deviation	N
Latency of Route Selection			
Color	5.33	2.71	42
Monochrome	4.64	2.41	42
Latency of Countermeasures Release			
Color	2.15	0.82	27
Monochrome	2.17	0.72	23
Latency of Response to Pop-Up Threats			
Color	4.51	4.68	41
Monochrome	5.71	5.00	34

Frequency of error data were examined with respect to alternate route selection and identification of pop-up threats and their state (search, track, or launch). Summarized in Table 7.3-4, the data reveal no appreciable difference in performance between the monochrome and color displays.

Table 7.3-4. LLP, Frequency of Error

	Correct	Incorrect	Default	N
Alternate Route Selection				
Color	30	12	11	53
Monochrome	27	16	8	51
N	57	28	19	104
Response to Pop-Ups -Identification of Threat				
Color	36	2	9	47
Monochrome	32	1	14	47
N	68	3	23	94
Response to Pop-Ups -Identification of State				
Color	16	1	30	47
Monochrome	16	0	31	47
N	32	1	61	94

While the data reported above proved inconclusive in establishing a color/monochrome performance difference, the frequency of error data was useful in highlighting weak format areas common to the two display types. Of the pop-up threats that occurred across all low level penetration mission segments, aircrews failed to report twenty-four percent of those occasions. However, failures to report an identified pop-up's state were much higher - sixty-five percent. A decision to improve the distinction between threat states may reduce this high frequency of error.

7.3.2 System Health Performance

In the system health segments, aircrews were briefed to fly the displayed pathway within the entry gate regardless of the threat bedown. The flight path control measures of interest are summarized in Table 7.3-5.

Table 7.3-5. SH, Flight Path Control Data

	Color	Mono
RMS Error, Vertical	477.25	953.94
RMS Error, Lateral	639.14	1420.19
% Time in Pathway, Vertical	77.13	73.25
% Time in Pathway, Lateral	69.88	65.00
% Time in Both	65.19	59.75

Reported in Table 7.3-6 are the aircrew response latencies in the system health segments. Included are latencies for route selection, countermeasures release, response to pop-up threats, and latency of damage report. The data fail to indicate any performance difference as a function of display mode.

Table 7.3-6. SH, Latency of Required Responses

	Mean	Standard Deviation	N
Latency of Route Selection			
Color	6.28	3.36	54
Monochrome	6.02	2.92	55
Latency of Countermeasures Release			
Color	2.45	1.13	83
Monochrome	2.30	1.55	86
Latency of Response to Pop-Up Threats			
Color	3.00	2.58	54
Monochrome	3.68	5.41	47
Latency of Damage Report			
Color	7.58	3.49	92
Monchrome	8.25	3.65	84

Frequency of error, summarized in Table 7.3-7, reveals no substantial difference in performance between the monochrome and color displays. The high rate of failure (forty-two percent) to report the state of a pop-up threat is noteworthly, again indicating the necessity for improving the distinction between states.

Table 7.3-7. SH, Frequency of Error

	Correct	Incorrect	Default	N-
Alternate Route Selection				
Color	44	18	9	61
Monochrome	34	18	6	58
N	78	36	15	119
Response to Pop-Ups -Identification of Threat				
Color	49	2	13	64
Monochrome	46	2	15	63
N	95	4	28	127
Response to Pop-Ups -Identification of State				
Color	28	6	30	64
Monochrome	25	15	23	63
N	53	21	53	127
Report of Damage				
Color	75	17	0	92
Monochrome	59	24	0	83
N	134	41	0	175

The pilot's identification and brief description of the current malfunction or failure was useful in determining if an aircraft's subsystem could be displayed pictorially and interpreted correctly. The performance data provides no strong evidence for the modification of the generic system formats represented in the simulation.

7.3.3 Beyond Visual Range Performance

The flight path control performance data generated at the conclusion of the BVR test segments is summarized in Table 7.3-8. Latencies of climb profile selection, countermeasures release, response to the shoot cue, and response to the target assignments were recorded in the BVR engagements and are reported in Table 7.3-9. The frequency of error data (summarized in Table 7.3-10) was calculated for response to the shoot cue and target assignments.

Table 7.3-8. BVR, Flight Path Control Data

	Color	Mono
RMS Error, Vertical	1644.06	1358.44
RMS Error, Lateral	1492.81	1855.19
% Time in Pathway, Vertical	59.75	62.19
% Time in Pathway, Lateral	62.75	66.53
% Time in Both	49.12	53.44

Table 7.3-9. BVR, Latency of Required Responses

	Mean	Standard Deviation	N
Latency of Climb Profile Selection			
Color	42.03	10.13	16
Monochrome	43.54	9.74	16
Latency of Countermeasures Release			
Color	2.37	1.18	43
Monochrome	2.41	1.51	44
Latency of Response to Shoot Cue			
Color	6.65	9.43	31
Monochrome	7.77	11.43	31
Latency of Response to Target Assignments			
Color	19.47	18.27	97
Monochrome	22.54	21.61	95

Table 7.3-10. BVR, Frequency of Error

	Correct	Incorrect	No Response	Combination	N
Initial Target Assignments					
Color	26	0	2	4	32
Monochrome	28	0	3	1	32
N	54	0	5	5	64
Reassignment					
Color	10	0	0	6	16
Monochrome	10	0	0	6	16
N	20	0	0	12	32
Secondary Assignment					
Color	24	0	1	7	32
Monochrome	23	0	3	5	32
N	47	0	4	12	64

	Correct	Incorrect	No Response	N
Climb Profile Selection				
Color	11	4	1	16
Monochrome	14	1	1	16
N	25	5	2	32

The latency and error data fail to indicate a significant difference between the color and monochrome displays. However, the calculation of the frequency of error in response to targets assignments was unique. Examination of the detailed record of mission events and crew input revealed that while a few target assignments were incorrectly executed and a number omitted entirely, the vast majority of errors were the result of extraneous assignments in addition to the those displayed. The extraneous assignments are referred to as combination errors. The data indicate that as the mission progresses and the display complexity increases, errors increase. The example shown in Table 7.3-11, drawn from the record of mission events, serves to illustrate the two common combination errors. The failure to readily differentiate between ownship and wingman target assignment coding and to differentiate between target assignment coding and weapon release coding may be due to the use of closely related symbology.

Table 7.3-11. BVR, Target Assignment Response Example

Displayed target assignment	Crew input	Latency	Error
1. Initial assignments Target A/C 3 and 4	Target A/C 3 Target A/C 4	5 sec. 5 sec.	None None
2. Reassignment: Target A/C 1	Target A/C 1 Target A/C 2	27 sec. 71 sec.	None Extraneous weapon assigned to a wingman designated target
3. Secondary assignment: Target A/C 3 and 6	Target A/C 3 Target A/C 6 Target A/C 1	8 sec. 11 sec. 79 sec.	None None Extraneous weapon assigned to an A/C coded with 'Weapon Release' symbology

7.3.4 Repeated MANOVAs

The logic of multivariate analysis of variance allows for use of a correlation matrix to reduce the number of defendent variables to be examined. The reasoning is that if two variables have a large amount of common variance, the overall error variance will be reduced by eliminating one of the variables from the MANOVA. Three correlation matrices were computed, one for each of the mission types. A priori, it was decided that the threshold correlation of 0.7 would be applied. Thus, if two variables have 49 percent or more common variance, one of them would be eliminated.

Table 7.3-12 is the correlation matrix for the data used in the low level penetration MANOVA. The intercorrelations were quite low, none higher than 0.29 (8.4 percent common variance), so no dependent variable was eliminated by this process and the MANOVA was not repeated.

Table 7.3-12. LLP, Correlation Matrix

Exposure Score (ES)	1.00			
Pop-Up Latency (PL)	-0.19	1.00		
Countermeasures Latency (CL)	0.08	-0.19	1.00	
Route Selection Latency (RL)	-0.17	0.29	0.12	1.00
	ES	PL	CL	RL

Table 7.3-13 is the correlation matrix for the data used in the system health MANOVA. Based on these correlations, three dependent variables were eliminated for a repeat MANOVA. The two RMS error scores were correlated 0.89 (79 percent common variance). Lateral RMS error was eliminated because it also correlated higher than vertical RMS error with several of the other variates. The correlations among the three percent-time-in-pathway scores were all above 0.9. Percent-time-in-pathway (both) was retained because it logically contained the other two.

When the MANOVA was repeated on the reduced set of six dependent variables, F moved from the 0.42 reported in Table 7.3-2 to 0.66 and and the significance of that F moved from 0.8692 to .6840. The color versus monochrome difference was still not significant.

Table 7.3-13. SH, Correlation Matrix

RMS Error, Vertical (RMSV)	1.00								
RMS Error, Lateral (RMSL)	0.89	1.00							
Percent Time in Pathway, Vertical (PATHV)	-0.55	-0.61	1.00						
Percent Time in Pathway, Lateral (PATHL)	-0.60	-0.65	0.92	1.00					
Percent Time in Pathway, Both (PATHB)	-0.56	-0.62	0.94	0.99	1.00				
Damage Latency (DL)	0.09	0.10	-0.11	-0.13	-0.13	1.00			
Pop-Up Latency (PL)	0.01	0.11	-0.14	-0.13	-0.13	0.26	1.00		
Countermeasures Latency (CL)	-0.07	-0.05	0.03	-0.03	-0.03	-0.18	-0.28	1.00	
Route Selection Latency (RL)	0.47	0.45	0.30	-0.35	-0.31	-0.05	0.07	-0.07	1.00
	RMSV	RMSL	PATHV	PATHL	PATHB	DL	PL	CL	RL

Table 7.3-14 is the correlation matrix for the data used in the beyond visual range MANOVA. Based on these data, the same three dependent variables were eliminated as in system health. The two RMS error scores were correlated 0.81. Lateral RMS error was eliminated because it correlated higher than vertical RMS error with several of the other variates. Again the three percent-time-in-pathway scores correlated highly (all above 0.88); and again percent-time-in-pathway (both) was retained.

When the MANOVA was repeated on the reduced set of six dependent variables, F moved from 0.36 reported in Table 7.3-2 to 0.65 and the significance of that F moved from .9172 to .6901. Again the color versus monochrome difference remained non-significant.

Table 7.3-14. BVR, Correlation Matrix

RMS Error, Vertical (RMSV)	1.00								
RMS Error, Lateral (RMSL)	0.81	1.00							
Percent Time in Pathway, Vertical (PATHV)	-0.47	-0.64	1.00						
Percent Time in Pathway, Lateral (PATHL)	-0.50	-0.68	0.88	1.00					
Percent Time in Pathway, Both (PATHB)	-0.38	-0.61	0.92	0.97	1.00				
Climb Profile Latency (CPL)	-0.24	-0.12	0.06	0.14	0.01	1.00			
Countermeasures Latency (CL)	0.16	0.20	-0.41	-0.29	-0.33	0.07	1.00		
Shoot Latency (SL)	0.23	0.49	-0.61	-0.51	-0.53	-0.14	0.01	1.00	
Target Assignment Latency (TL)	0.10	0.26	-0.22	-0.23	-0.21	0.00	0.21	0.12	1.00
	RMSV	RMSL	PATHV	PATHL	PATHB	CPL	CL	SL	TL

8.0 CONCLUSIONS AND FORMAT REVISIONS

The intent of this program series has been to improve information flow to the aircrew by use of pictorial formats and to evaluate the extensive use of color formats. The program has established extremes in both of these areas - pictorial formats and color usage. From recorded and unrecorded aircrew comments, it appears appropriate to retain both color and pictorial formats, but to move away from the established extremes. Words and numbers should be used rather than symbolic or pictorial representation where they lead to more rapid and certain information flow. Similarly, color should be used with somewhat more restraint, to highlight particularly important information or to indicate relations across displays, but not to use color for its own sake. Taken together, these constraints would reduce apparent display clutter and increase aircrew awareness of critical information. Reising, Zenyuh, and Martin (1986) concluded that "A well constructed color pictorial format can include a number of coding strategies and yet concisely provide the essential data required to manage the aircraft and mission." The results of this study support this conclusion.

8.1 Usability and Acceptability of the Formats

The first objective of this program was to determine if the pictorial formats were usable and acceptable to two seat fighter crews. The objective was met and the clear answer is that the crews found these formats quite usable and acceptable. The aircrews provided significant feedback on particular formats. This information was addressed in the last section and, where consensus appeared, format revisions are suggested in paragraph 8.3.

The process of designing pictorial formats was addressed by Edwards, Way and Hornsby (1986). While this process is not unique, it is an effort which should be undertaken whenever displays are designed. The design process bears repeating here because a complete display suite was designed and evaluated in an environment free from some of the constraints of previous display efforts. For one thing, electronic displays provide clean slates upon which formats can be developed without the problems encountered in electromechanical instruments. For another, working with a complete display suite allows much more emphasis to be placed on compatibility among displays than if they were developed one at a time.

The display development process began with a preliminary definition of information requirements and then development of a point-of-departure display suite. This preliminary suite was then evaluated, refined, and evaluated again by operational air crews - all in the form of static pictures. Then a systems engineering exercise was undertaken by a team of human factors specialists, other engineers, and in-house pilots. A mission scenario was defined and decomposed to yield specific information-action requirements. Then the display requirements were assigned to elements of the preliminary display suite and static formats were drawn up for critical events during the scenario and laid out in an event-by-event and format-by-format storyboard. This cockpit wide analysis of the formats was useful in highlighting formatting inconsistencies among and within the formats and in identifying changes in information requirements at different points through the mission.

After the static development was complete, the formats were submitted for programming and integration into the dynamic simulation. Finally, they were evaluated twice more in crew-in-the-loop simulation with an operationally realistic mission.

8.2 Color versus Monochrome Formats

The second objective of the program was to develop and evaluate color and monochrome versions of each format. The results agree with many others, reviewed by Christ (1975) and Silverstein (1982), that whether or not color aided performance in an experimental task, it was preferred by the subjects. The pilots and WSOs in this program chose the color versions of these formats over the monochrome in almost every case.

Assuming that color is used, how should it be applied in electronic aircraft cockpit displays? The literature provides a number of lists of color applications. Krebs and Wolf (1979) give four uses for color in information displays; (1) as an aid in locating a specific symbol in a cluttered or information dense display; (2) as a cue or alerting signal to warn or inform an operator of change in some critical parameter; (3) as a method of grouping similar items or separating dissimilar items; and (4) as a method of increasing visibility of some information item by adding color contrast to brightness contrast.

Krebs and Wolf (1979) also warned that color may be inappropriately used and may distract the operator or reduce the effective rate of information flow. Examples of inappropriate use of color include: (1) color noted by the operator but which has no task oriented meaning; (2) symbols of the same color which are inappropriately grouped by the operator; (3) over use of color which interferes with its attention getting value.

8.3 Recommended Format Revisions

The third program objective was to use results from the simulation to recommend revision to the formats, where appropriate. Suggestions are made here for revisions to the HUD, the PSF, the HSF, the Close Look Format and the Engine Status format. No revisions are recommended to the other status formats, the advisory formats, or the programming formats. The aircrews found these acceptable and usable and they did not, with any consensus, suggest revision. These formats, in particular, are sensitive to particular applications and will reflect the systems and the missions of specific aircraft.

8.3.1 Head-Up Display

As the primary flight display, the pictorial format of the Head-Up Display proved to be adequate in most areas. It is suggested that the terrain and ground plane be retained in their present form. Readouts of airspeed, heading, and altitude could be used more effectively in a pilot's scan pattern if positioned closer to the center of the display. Adding a heading tape to the top of the display would facilitate heading change manuevers.

Aircrews were also critical of the roll indicator and index, arbitarily limited to 45°. It is recommended that the roll indicator and index be replaced with a horizontal reference line as shown in Figure 8.3-1. This line would provide the pilot with an immediate and intuitive indication of roll and limited pitch. The horizontal reference line indicates the aircraft's orientation relative to the earth at any attitude. At zero roll and zero pitch, the horizontal reference line appears as a pair of solid lines extending from either side of the ownship symbol. For pitch up the feet of the solid horizontal refesence line point down toward the horizon and for pitch down the feet of the dashed line point up toward the horizon. The artificial reference line overlays the horizon when it is in the field of view. At more extreme pitch angles, the horizontal reference line pegs at the top (for pitch down) or bottom (for pitch up), thereby continuing to provide roll information with an immediate indication of direction back to horizontal flight.

The minor adjustments suggested above are intended to improve the utility of the pathway. The segmented white pathway symbology appears to be acceptable as does the symbology of its associated elements - the pathway entry gate (flight director) and the ownship symbol (velocity vector). The conspicuousness of the entry gate and ownship symbol would be improved with heavier lines. The pathway was frequently found to be inadequate as a steering device and it was extremely difficult to recover using

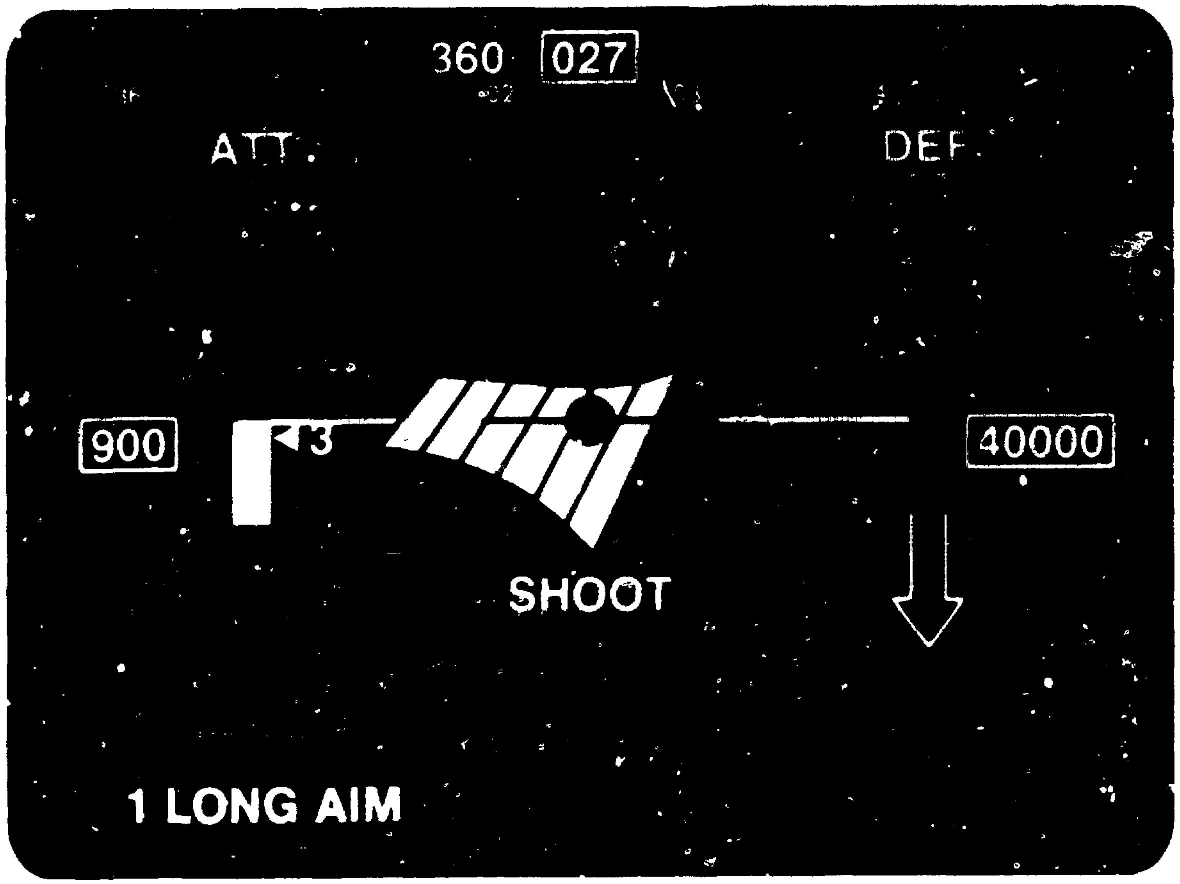

Figure 8.3-1. Revised Head-Up Display - Air Mode

the transitional flight director. The pathway in its current state of development appears to be best suited as a predictive element to be used when the pilot is adherring to a flight profile or when pathway guidance back to that flight profile can be generated.

The pitch ladder would not generally be used when on a predetermined flight profile. Yet in an air-to-air engagement or when executing threat avoidance maneuvers, it may not be possible or desirable to generate or display a pathway. In such cases the pitch ladder would be selected to replace the pathway. Later, when the pilot wished to return to the original flight profile, the pathway would be reselected to replace the pitch ladder. The pathway guiding the aircraft to the original flight profile may be differentially color coded until the return is complete. Using a pathway to return to aircraft to the original flight profile would eliminate the requirement for the clumsy transitional flight director.

In addition, as pilots have insisted, the HUD should include the capability to display an alternate pathway constructed with waypoints inserted by the aircrew using the HSF. In essence, the revised HUD seeks to explore mechanisms for implementing a pathway at differing levels such that the presence or absence of a pathway best suits a particular phase of flight.

Other minor modifications are suggested for the attack MLE and shoot cue. Throughout the display suite, the color coding green when used in conjunction with the targeting of a weapon has indicated the within range status of the weapon, except for the attack MLE. By simply reversing the white and green areas along the arrow, consistency across displays is acheived with green within range coding and white no-escape coding. The shoot cue, an X within the ownship symbol, was difficult to see and to many pilots it represents a break away indication. It is suggested that the word SHOOT replace the X as a shoot cue.

8.3.2 Perspective Situation Format

Modifications to the basic symbology of the Perspective Situation Format are minimal. A predictive flight vector has been attached to the ownship symbol to provide aircraft direction information based on current attitude. However a frequently cited problem was that the lock-on circle around ownship obscured other critical symbology. Transparency of the disk would be an ideal solution. However, without such a graphics capability, a lock-on ring would be sufficent to indicate the track condition. The track and launch conditions could be further differentiated with an amber tractor beam and lock-on ring indicating a tracking threat and a red tractor beam and lock-on ring indicating a launching threat.

Figure 8.3-2 is a revision of the PSF in air mode. It is intended to provide the aircrew with a quick look of the air battle situation, details of which are provided by the Close Look and Horizontal Situation Formats. In this revision, the perspective space is shown as a segment of a right circular cylinder bounded at the bottom by the ground plane and at the top by a horizontal plane through ownship's altitude. The radius of the cylinder and angular width of the segment are functions of ownship's radar coverage. The ground plane is ruled off in range arcs and ten degree relative bearing radials. The height of the segment can be inferred from ten thousand foot tick marks along the left and right sides of the radar coverage area.

Within the space thus defined, ownship is on the axis of the solid segment atop a stake running down to the origin of the figure. Other aircraft in the space are on stakes whose lengths represent altitude and origins on the ground plane represent range and bearing. Radar coverage sectors are attached to the nose of an aircraft in search mode. Airborne threat's track and launch symbology is identical to that of surface threats.

8.3.3 Horizontal Situation Format

The HSF remains essentially unchanged with only minor detailing in order to provide more precise information in selected areas. As with the PSF, a predictive flight vector has been attached to the ownship symbol.

Aircrews frequently critized the range ring implementation where the rings always represented ranges of one quarter and one half of the selected format range, but the ring interval was not explicit. Range may be better implemented as a series of rings where range is increased in specified steps from ownship, the size being that which best fits the display range in useful multiples. The recommended revision is to display ring interval with the selected format range, when range rings have been selected. Recommended range/ring interval combinations are: 20/5, 40/10, 80/20, 100/25, 150/25 and 300/50. Note that the available format ranges have also been changed to provide another intermediate range.

In Figure 8.3-3, a crew selectable compass rose has been added to the Horizontal Situation Format's heading readout. When both the range rings and the compass rose are selected, the compass rose forms the outermost range ring. The compass rose and the optional range rings are available to provide qualitative pictorial information concerning the global sitiuation. However, as the tactical situation develops, precise bearing and range information may be required. The cursor can be used to designate a given location for display of the numeric bearing and range. Similarly, time and distance to a particular point may be better implemented as a cursor function.

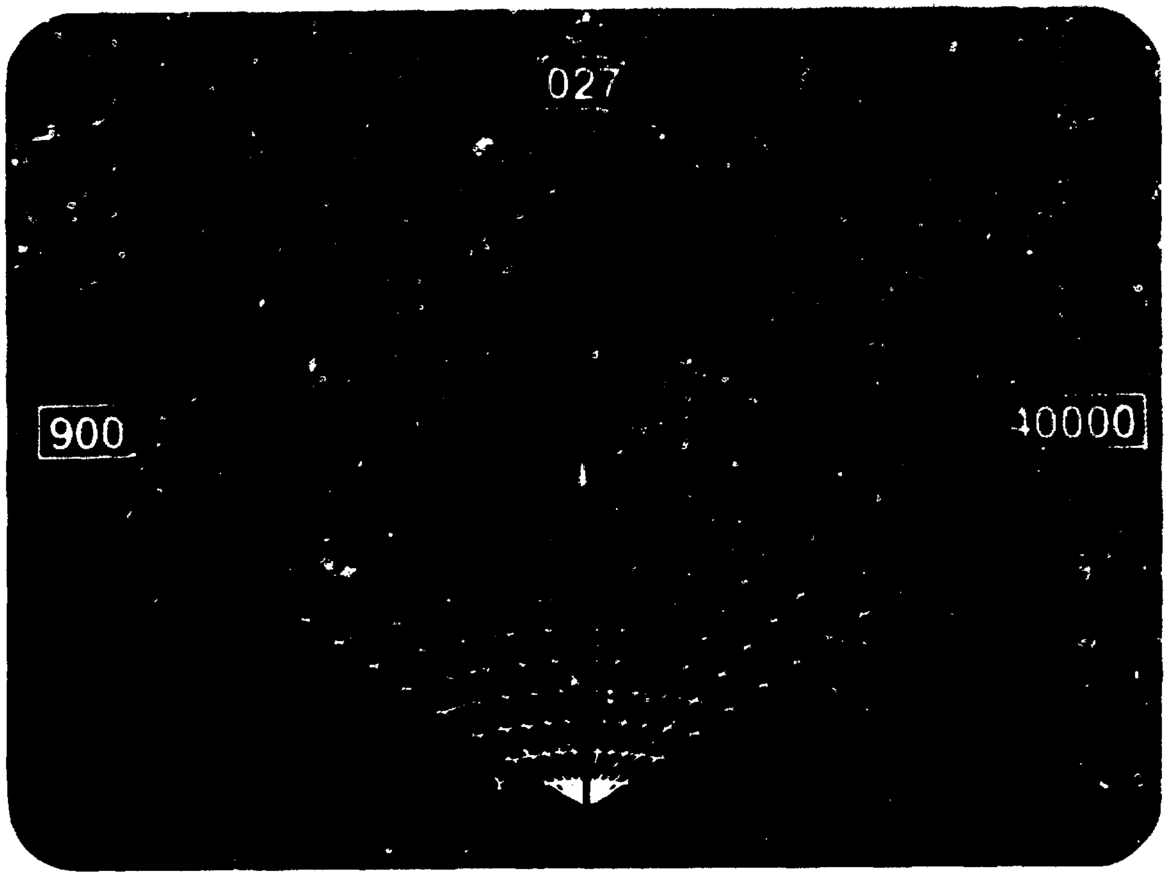

Figure 8.3-2. Revised Perspective Situation Format - Air Mode

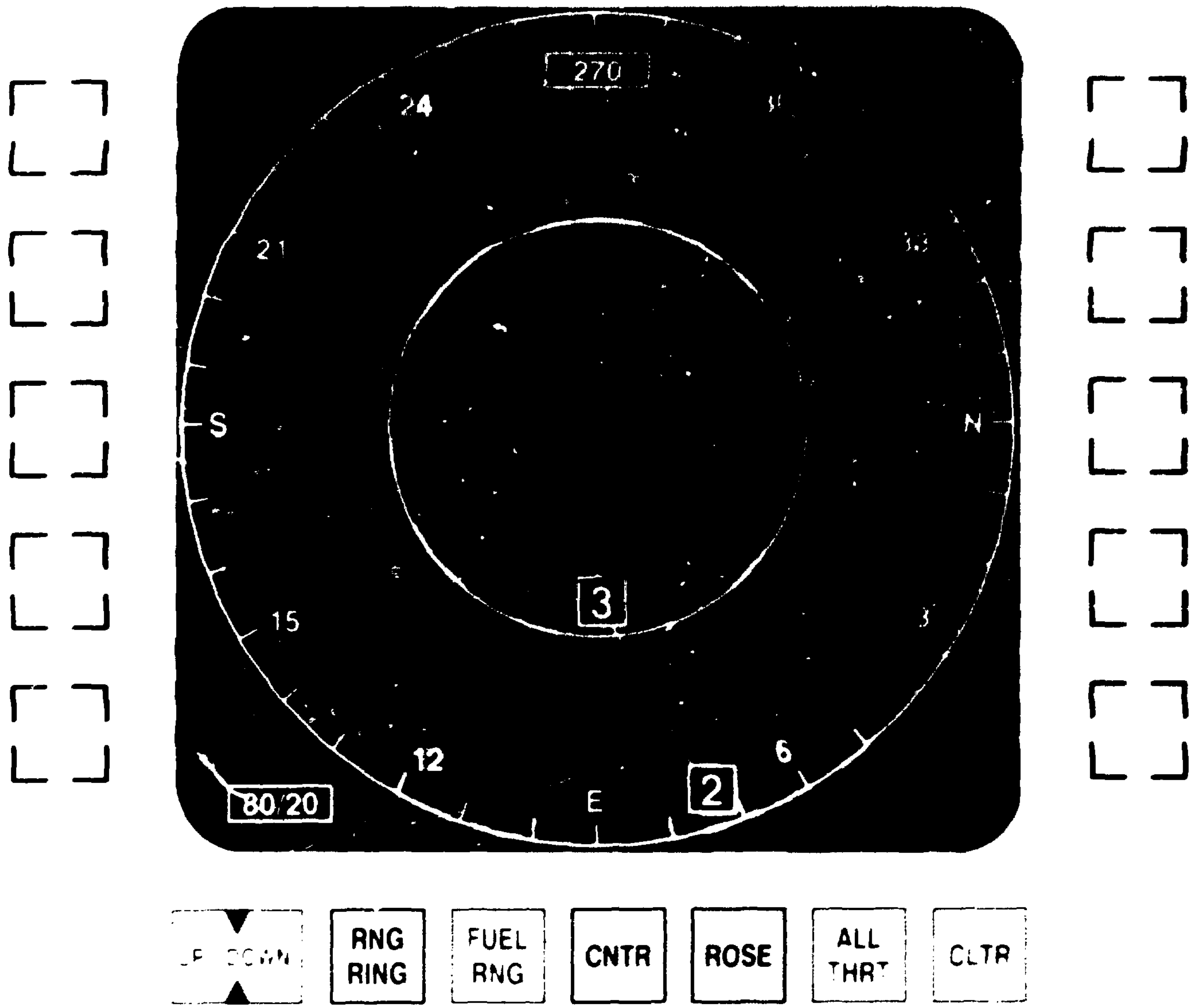

Figure 8.3-3. Revised Horizontal Situation Format - Ground Mode

One contributor to clutter on the HSF may be the use of abbreviated symbology for threats. In air mode, ground threats were shown as icons without the threat envelopes. The suggested change is to remove the icons and show only air threats in air mode and ground threats in ground mode. The all-threats feature would be retained to display, at crew option, both air and ground threat envelopes in either mode. Other declutter features are possible and could be added, depending on aircraft and mission application.

As with the PSF, the solid lock-on circle was reduced to a long-on ring to avoid obsuring other symbology. To better distinguish between the track and launch conditions, an amber tractor beam and lock-on ring indicates a tracking threat; a red tractor beam and lock-on ring indicates a launching threat.

In air mode, correlation between the HSF and CLF was weak with respect to aircraft identification and missile launch envelope depiction. From observation and informal discussion with the aircrews, execution of an engagement with two or more formations was difficult. To coordinate the symbology of the two displays, squares and circles with attached flight vectors should represent unknown and friendly aircraft or formations of aircraft on the HSF as they do on the CLF. To assist the aircrew in effectively using the HSF (in conjunction with the CLF), identification and access to each formation was simplified. Once selected for Close Look display an aircraft symbol would be enclosed by a set of four box corners and designated with an identifying letter. The identifying letter is then associated with one of the switches alongside the display. As subsequent formations are selected for Close Look display, sets of box corners and identification letters are added to each aircraft or formation of aircraft and to additional side switches. As shown in Figure 8.3-4 color coding may be used to differentiate that formation currently displayed on the CLF from those formations stored in the track file as a result of their initial designation. The identified side switches are then used to select the formation to be displayed on the CLF. Target assignment symbology will also be added to an HSF symbol as they appear within the formation should it be displayed on the CLF. An advantage to displaying a target assignment ring within the HSF is that it cues the pilot to select the appropriate formation on the CLF for targeting of weapons.

Figure 8.3-5 illustrates the threat and ownship symbology changes OSr the HSF in air mode. Few changes are recommended. The tractor beams which represent missile launch envelopes of threats and ownship appear as elongated "L" shapes and are more prominant. Graphics rules will preclude overlaying of the tractor beams. The order of colors on ownship's tractor beam has been reversed to match the HUD and the stores status format. Now, within range is green and within the no-escape zone is white.

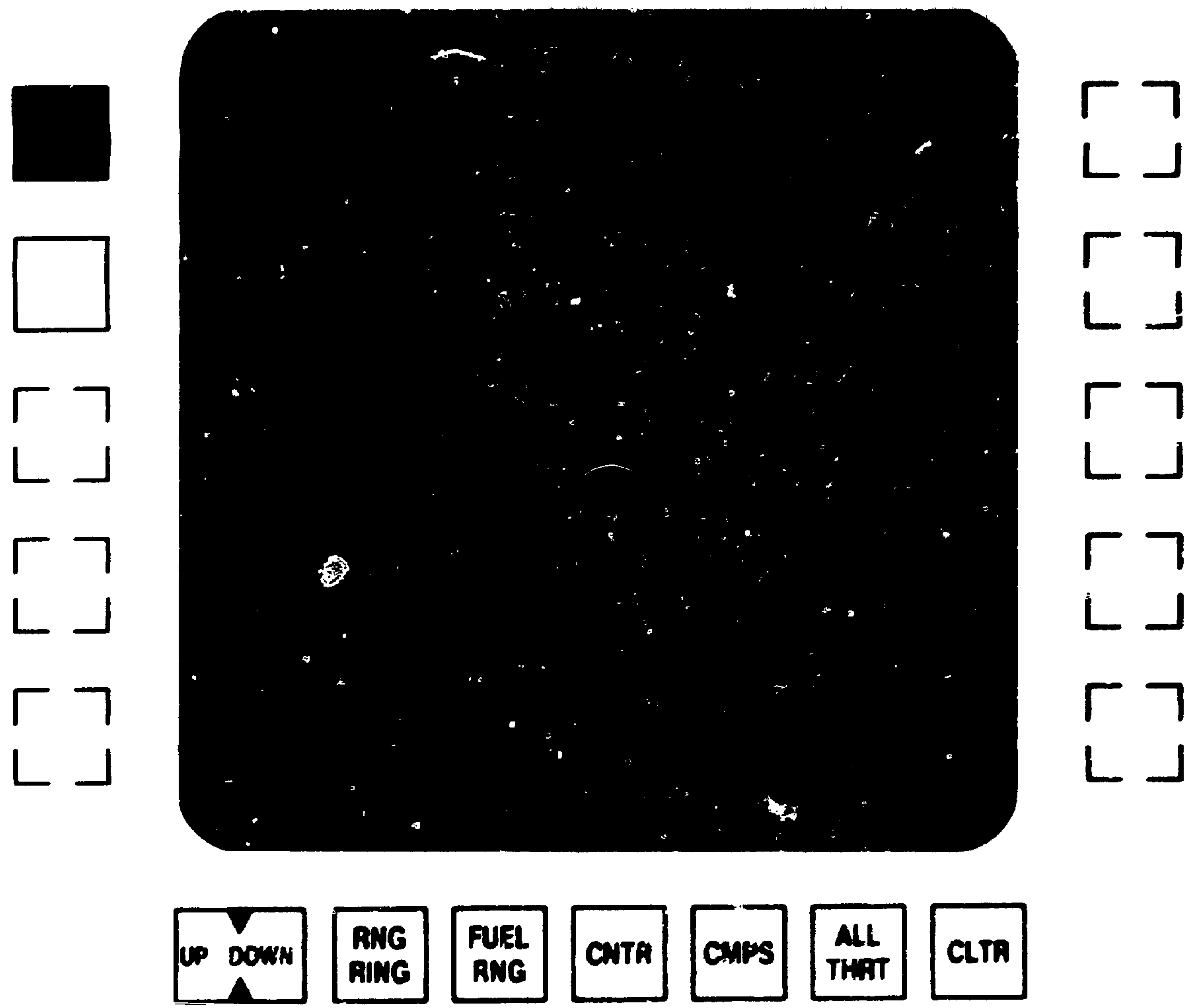

Figure 8.3-4. Revised Horizontal Situation Format - Air Mode

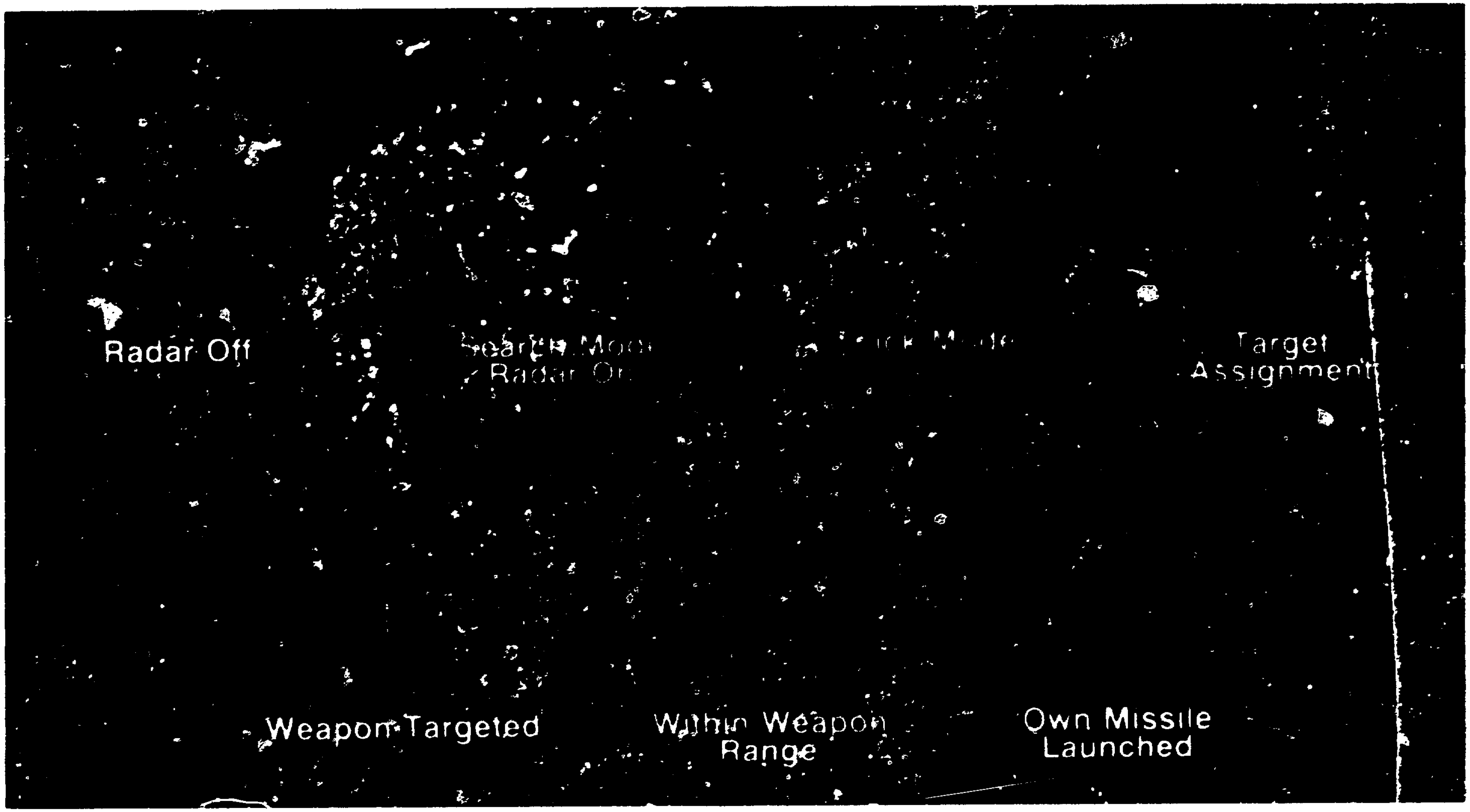

Figure 8.3-5. HSF Radar and Missile Launch Envelope Symbology - Air Mode

8.3.4 Close Look Format

Significant changes are recommended for the CLF to simplify its use with the HSF. The use of two Close Look Formats, each with a subset of the necessary information, required excessive display management and occasioned significant confusion. It is recommended that a single format be used which would display complete formations, selected from the HSF, as before. The CLF would center about the centroid of the formation (not necessarily a particular aircraft) and have one of four crew selectable ranges: 5nm, 10nm, 20nm, and 30nm. The size and number of ranges allows for an entire formation to be contained within a single format. The formation centroid is marked with a small white cross and is the point to which range and bearing are calculated.

The symbology identifying a multiple group of aircraft and those aircraft determined to be friendly and unknown remains unchanged. However, the diamond previously used in coding hostile aircraft is reduced to a triangle (as in the HSF). The three point scale identifying aircraft as hostile (red triangle), unknown (amber square), and friendly (green square) is sufficient, so the interpolated "probable hostile" and "probable friendly" symbols have been eliminated. The simplification is expected to reduce confusion. The flight vector is always attached to the nose of the aircraft symbol. A modification of the weapon status coding was required to assist the aircrew in distinguishing between target assignment coding (blue rings for ownship) and weapon release coding (thin green rings for ownship and wingman). Once a weapon has been fired, the target aircraft symbol and its coding are reduced in size.

As the Identification Friend, Foe, or Neutral process identifies aircraft type and model, that information is displayed within the symbol as previously. An identification number is included within each individual symbol; the same identification number is associated with a side switch for targeting. Readouts indicating heading (degrees), airspeed (knots), and altitude (in thousands of feet) for each aircraft are added to the display alongside the identified switches (Figure 8.3-6). An optional declutter feature is available to remove the aircraft information readouts on the sides of the format (but retain the aircraft identification number).

To map the formation selected from the HSF (indicated with a set of differentially coded box corners) for CLF display, a readout identifying the formation was added to the lower edge of the CLF display. The revised CLF also provides a mechanism to display aircraft in the event a formation breaks up and forms two distinct tactical groups. As the formation differentiates into

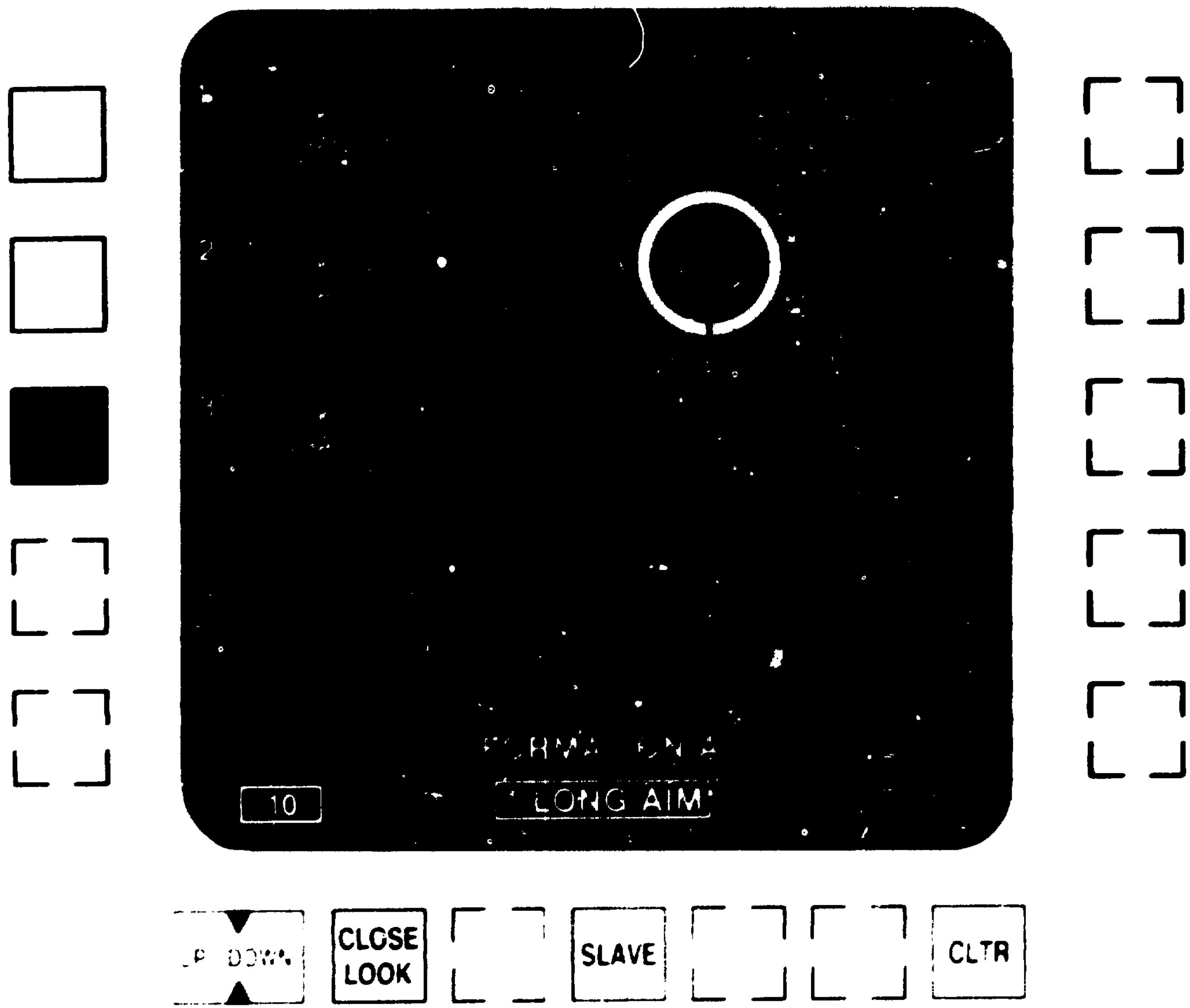

Figure 8.3-6. Revised Close Look Format

two, the addition of a new formation occurs automatically within the track file. The identification of the additional formation occurs in the MSF: the next available switch is identified and the appropriate symbol is enclosed within a new set of box corners.

8.3.5 Engine Status Format

The concepts depicted in the Engine Status Format were well received and worked well for the pilots. The notion of showing composite thrust directly, rather than the usual thrust correlates such as N1, N2, or EPR was well accepted. The criticisms and suggested revisions were in the direction of simplification and "display by exception." Figure 8.3-7 shows the recommended Engine Status Format revisions. The information between the two engine bodies has been removed and the engine bodies moved closer together to facilitate cross checks. The labels have been deleted and the numeric fuel flow readout has been moved into the fuel flow arrows. The engine oil pressure and temperature indications and EGT have been retained but will be displayed when needed, rather than full time. The resulting Engine Status Format retains the same information elements as before but is simpler, responsive to pilot feedback.

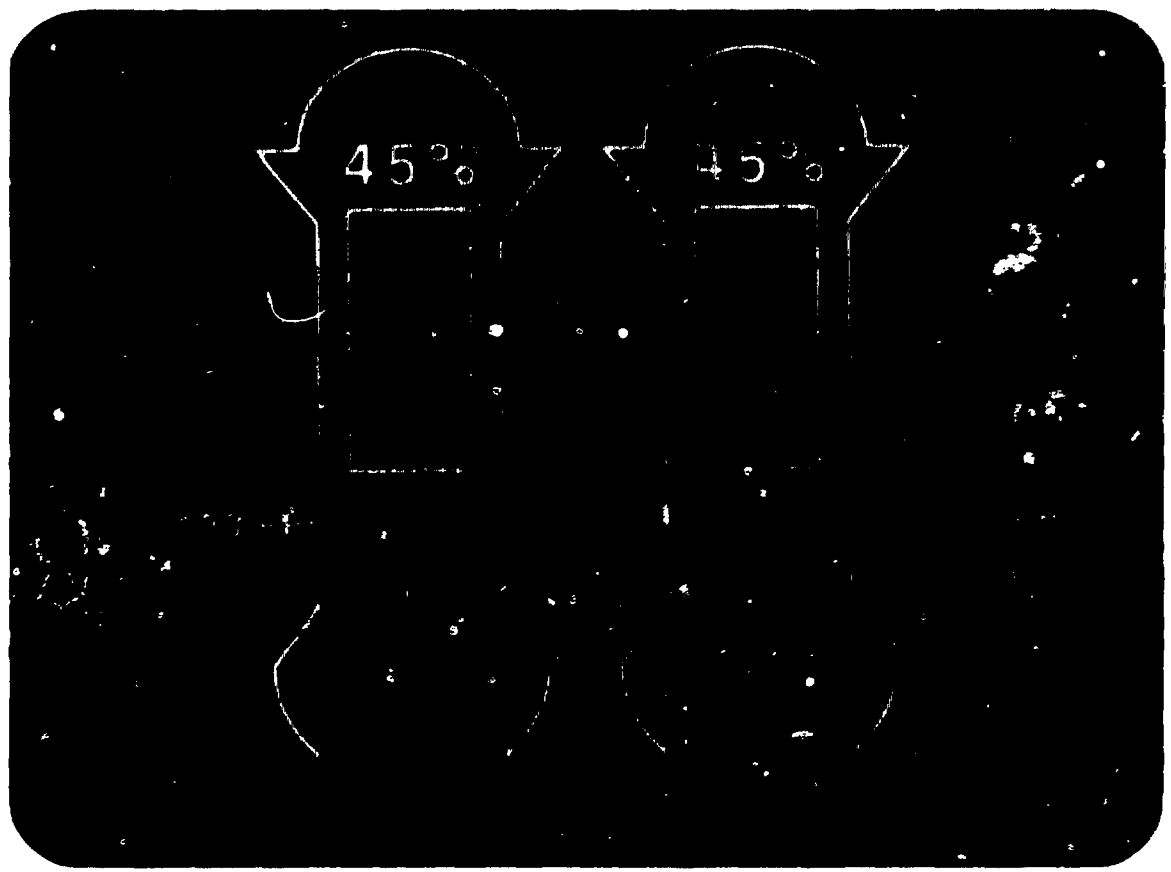

Figure 8.3-7. Revised Engine Status Format

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APPENDIX A

PILOT RESPONSES TO STATIC FORMAT EVALUATION QUESTIONNAIRES

The Static Format Evaluation is discussed in Section 2 of this report. Responses to the open-ended questions used in the static format evaluation are summarized in this appendix. Parenthetical numbers indicate frequency of the comment.

Head Up Display

Information to be added:

Pitch ladder (2)

Heading scale (2)

Reciprocal heading at bottom (1)

Target designator (1)

Weapon status, when Master arm on (1)

Range and time-to-go to target (1)

Bomb impact point (1)

A/A and A/G symbology (1)

Information to be deleted:

PITS fill (3)

PITS, in A/A mode (1)

1000-ft. markers on PITS (1)

Comments:

OK for air-to-ground; of little or doubtful use for air-to-air (2)

Makes PITS fill optional to avoid obscuring view (2)

Keep pitch ladder (1)

Terrain outlines good, but have declutter switch to delete unnecessary information (1)

Have a standard ADI for primary flight instrument (1)

Format good for navigation (1)

Missile Launch Envelope Symbology (HUD)

Information to be added:

Target designator box (3)

Steering cue (3)

Target type, range (2)

Weapons selected (2)

Weapons remaining (1)

Shoot cue (1)

Pitch ladder (1)

Missile launch parameters; cues to meet them (1)

Information to be deleted:

Flight path (3)

Terrain outlines (1)

Comments:

Don't need pathway; keep simpler (2)

Not bad, but prefer symbology in F-15 (better than F-16) (1)

Airspeed, not mach (1)

PSF, Ground Mode

Information to be added:	Information to be deleted:	Comments:
Attitude information (2)	(No responses)	Good (3)
Pitch information (2)		In monochrome, lock-on beam can be confused with grid lines (2)
ADI (1)		Need larger lock-on beam for active threats
Adjustable range scale (1)		
Specific probable threats (1)		

PSF, Air Mode

Information to be added:	Information to be deleted:	Comments:
Coding for highest priority threat - red or flashing (3)	Target altitude arrows (1)	Display absolute altitude, not relative altitude, for enemies (1)
Range to threats (2)		Flip relative altitude arrows. (1)
Threat altitude (2)		Not too useful (1)
Pitch ladder (1)		Difficult to interpret range and aspect of enemies (1)
Ground threat envelopes (1)		"New View" good for backseater (1)

HSF, Ground Mode

Information to be added:	Information to be deleted:	Comments:
Enemy altitude (2)	(No responses)	"New View" seems useful, but for WSO. (4)
Specific threat labels (1)		"New View" capability extremely favorable for survivability. (1)
Cardinal heading cues (1)		Good display (1)
Written launch warning (1)		Very busy to look out if fast and low. (1)
Option to display A/A threat envelopes, "friendlies" (1)		

HSF, Air Mode

Information to be added:	Information to be deleted:	Comments:
Range to target	(No responses)	Display too complicated/cluttered (2)
Type of missile launched (2)		Good concept (1)
Airspeed, altitude of aircraft (1)		Display absolute altitude, not relative altitude, for enemies (1)
Numbers of aircraft (1)		Delete threat envelopes for threats that aren't pointed at us (1)
Cardinal heading (1)		"New View" quite useful for A/G (1)
Ground threat status. (1)		Move airmode to HUD (1)

Target Formation Display

Information to be added:	Information to be deleted:	Comments:
Altitude information (3)	Diamond symbology. Just aircraft type (1)	Useful (2)
Selected vertical information (1)		Incorporate into HSF as range to target decreases (1)

Electrical Status

Information to be added:	Information to be deleted:	Comments:
Overall failure picture; what is lost by failure (1)	Status of all normal electrical components (1)	Not more useful than current telelight panel (4)
None (1)	None (1)	May lose information if there are problems with more than one system (2)
	Everything but problem identifier (1)	Display prioritized checklist (2)
		Prefer system lost/problem, then list what you would lose (1)

Electrical Status (Continued)

Information to be added:	Information to be deleted:	Comments:
		Use red only for critical action problems; flashing amber for non-critical failures (1)

Electrical Advisory

Information to be added:	Information to be deleted:	Comments:
None (1)	Unnecessary words (1)	Very good (2)
	None (1)	Good, but not necessary (2)
		Useful with telelight panel (2)
		Have pilot call this up on same CRT as Electrical Status (1)

Hydraulic Status

Information to be added:	Information to be deleted:	Comments:
None (1)	The whole format (1)	List degraded or failed systems (4)
	Everything but failed system ID (1)	Easy to interpret (1)
		Pictures easier than reading (1)
		Don't need (2)
		Limit information to operation-critical (1)
		Like amber for potential problems (1)
		Show normal systems in green (1)
		Flash symbology for new failures (1)

Fuel Status

Information to be added:	Information to be deleted:	Comments:
Fuel quantity in each tank (4)	(No responses)	A constant source of total fuel information is required (3)
Total fuel gauge, constantly available (3)		Prefer fuel gauge (3)
Wing fuel balance gauge (1)		Need more information about fuel in each tank (1)
Numeric readouts (1)		Has good potential as a supplement to fuel gauge (1)

Stores Status

Information to be added:	Information to be deleted:	Comments:
(No responses)	"Master Arm Off" except if format is brought up manually (1)	Display it automatically whenever Master Arm is on (4)
		Display it all the time (1)
		Display it automatically whenever a weapon status changes (1)
		Nice display (1)
		Not much better than current ACO (1)
		Need capability to look at 4 or 5 things with pressing buttons or using voice commands to change displays (1)

Countermeasures

Information to be added:	Information to be deleted:	Comments:
Actual number of chaff and flares (1)	(No responses)	OK for WSO (2)
		Only need to know if something is wrong (2)
		Prefer number of chaff/flares left (1)
		Only need low level warning light (1)
		ECM "lightning bolts" not required unless jamming is directional (1)
		Would be used only prior to FEBA (1)

Passive Sensor Status

Information to be added:	Information to be deleted:	Comments:
Move ownship symbol in globe to show current attitude (1)	(No responses)	Display it only upon failure or when called up (2)
		Would seldom be used (2)
		Good for WSO (2)
		Only for pre-FEBA or when time available (1)
		Integrate with other displays (1)
		Should be ownship relative (1)

Engine Status

Information to be added:	Information to be deleted:	Comments:
Numeric readouts (4)	Carets for suggested thrust/throttle position (1)	Prefer or need gauges/round dials (6)
Fuel flow in pounds per hour (2)	Actual versus selected thrust is not required (1)	Need numeric readouts (4)
	Afterburner flames, fuel flow arrows (1)	Must be displayed at all times (2)
		Prefer warnings or caution information, plus gauges (2)
		Include hydraulics (1)
		Oil display is excellent (1)

Engine Advisory

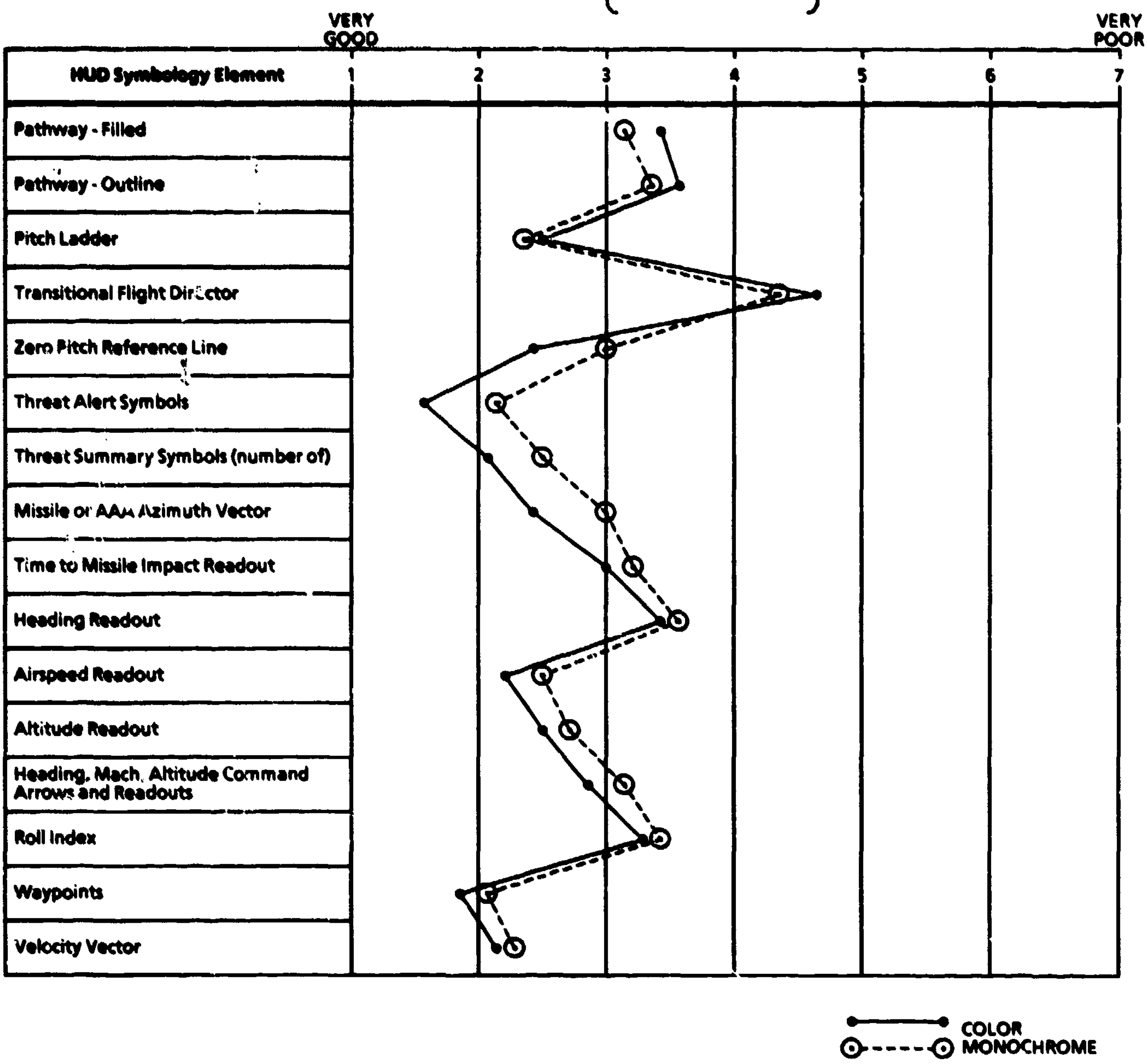
Information to be added:	Information to be deleted:	Comments:
(No responses)	(No responses)	Good, useful (3)
		Like checklist formats (1)
		Use round dials with warning lights and be able to call up this (1)
		Need both engine display and this at the same time (1)
		Monochrome reduces distraction (1)

APPENDIX B

AIRCREW QUESTIONNAIRES
MEAN USABILITY RATINGS OF FORMAT SYMBOLOGY ELEMENTS

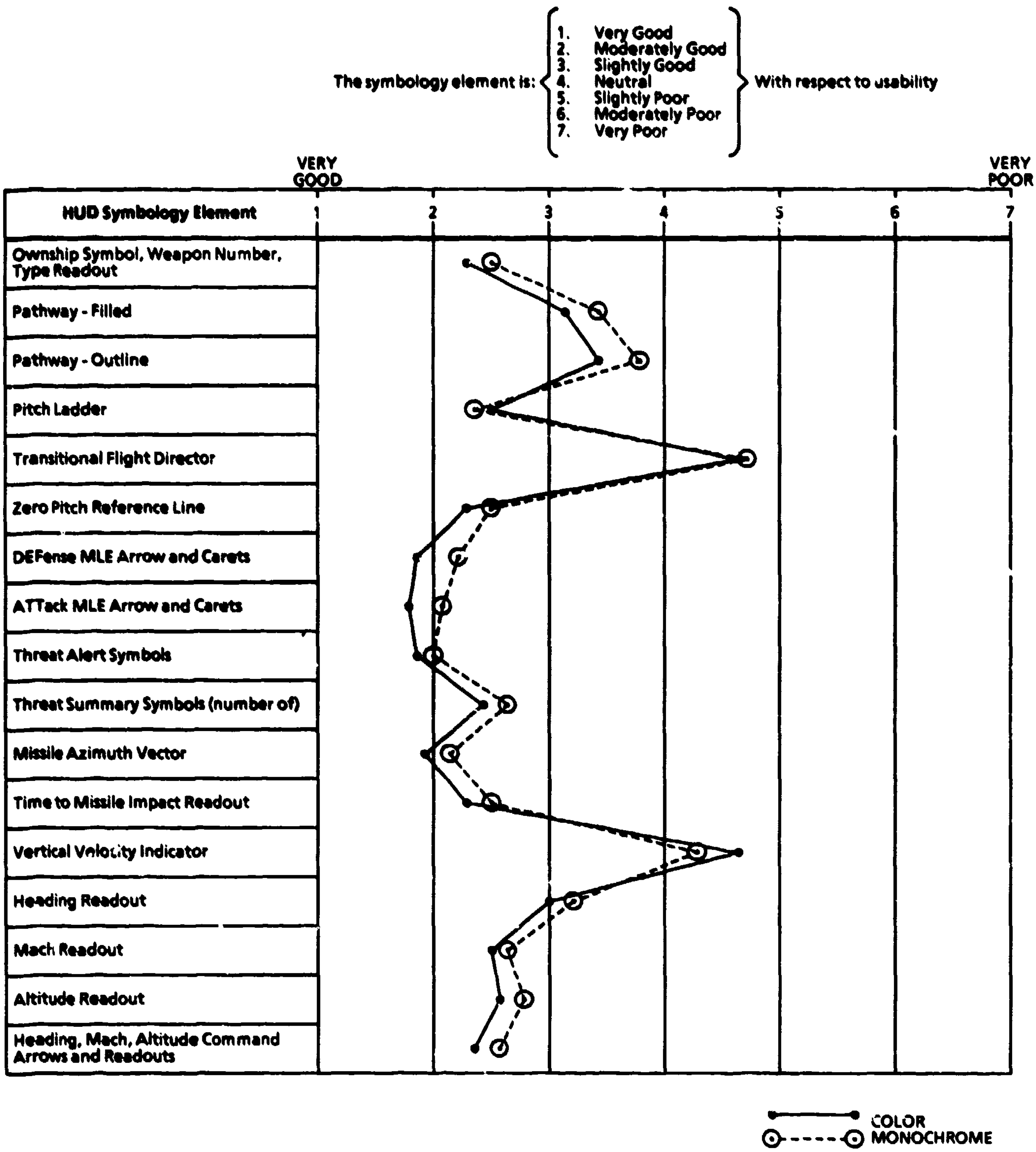
This appendix contains usability profiles of the formats and their symbology elements. These profiles were derived by plotting the mean usability ratings given by the aircrews in the questionnaires. The mean ratings for usability and other attributes are given in Appendix C.

The 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 usability



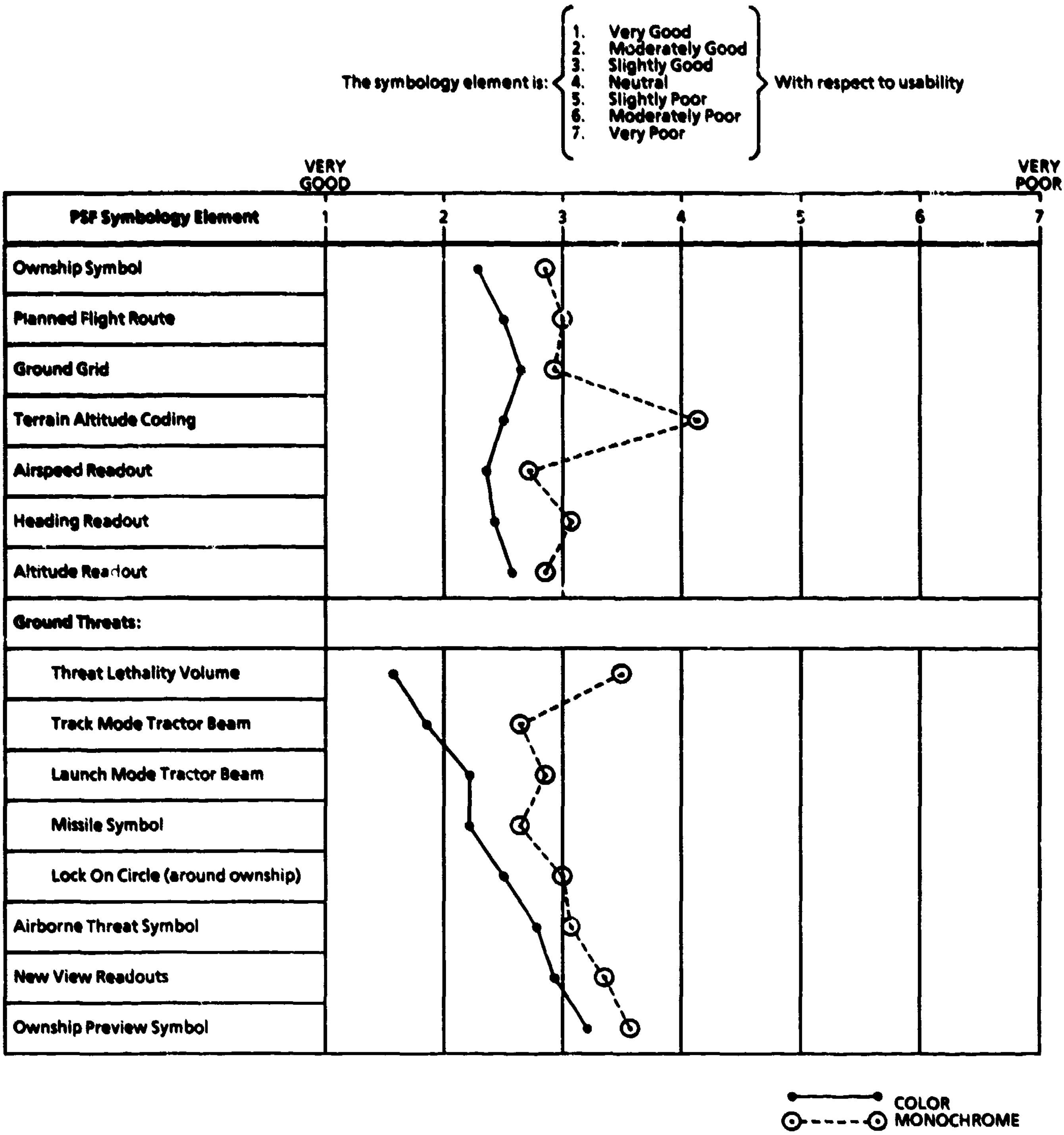
Usability Ratings of HUD Symbology Elements in Ground Mode (Mean of 16 Pilots)

SSS057/A/327-6

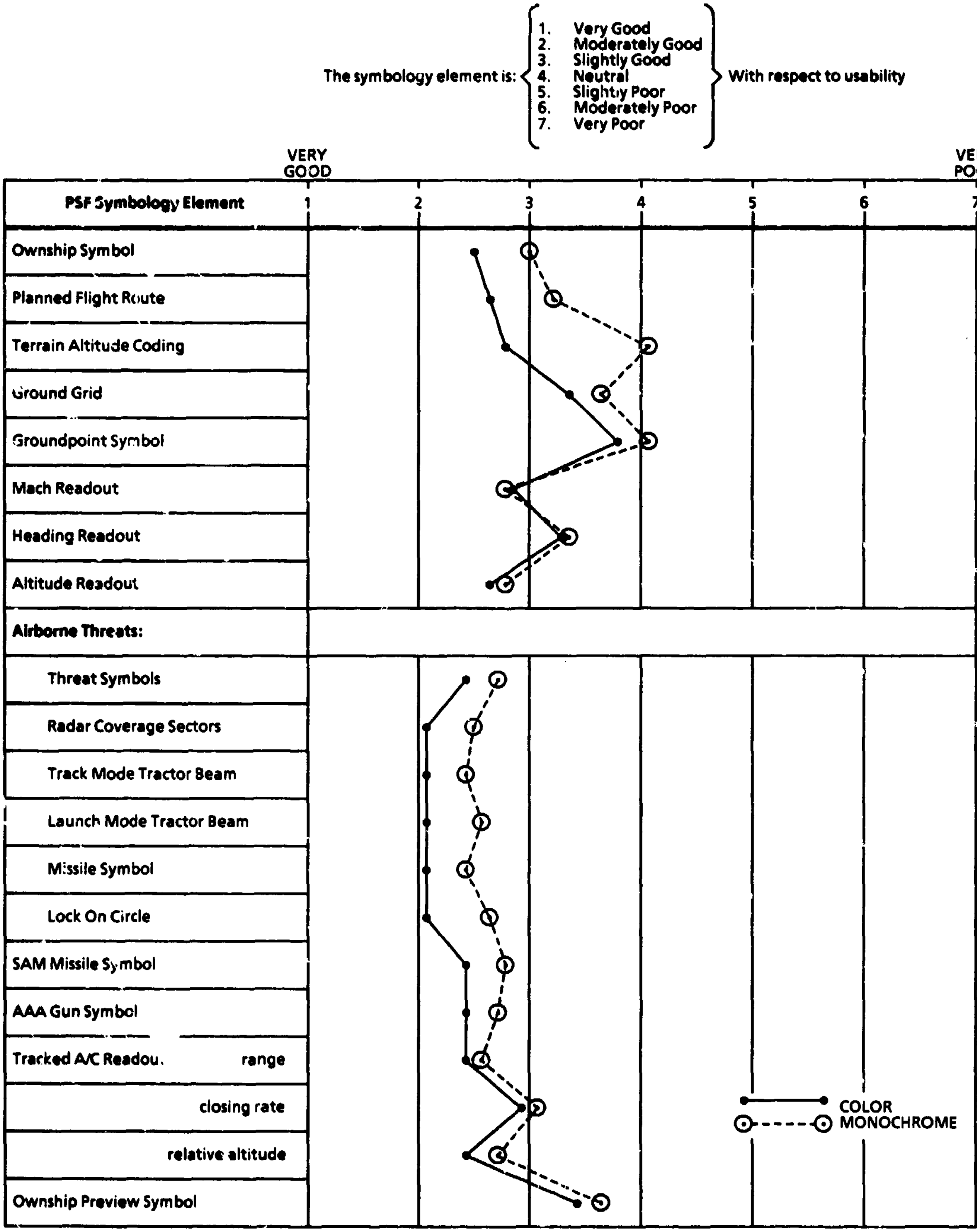


Usability Ratings of HUD Symbology Elements in Air Mode (Mean of 16 Pilots)

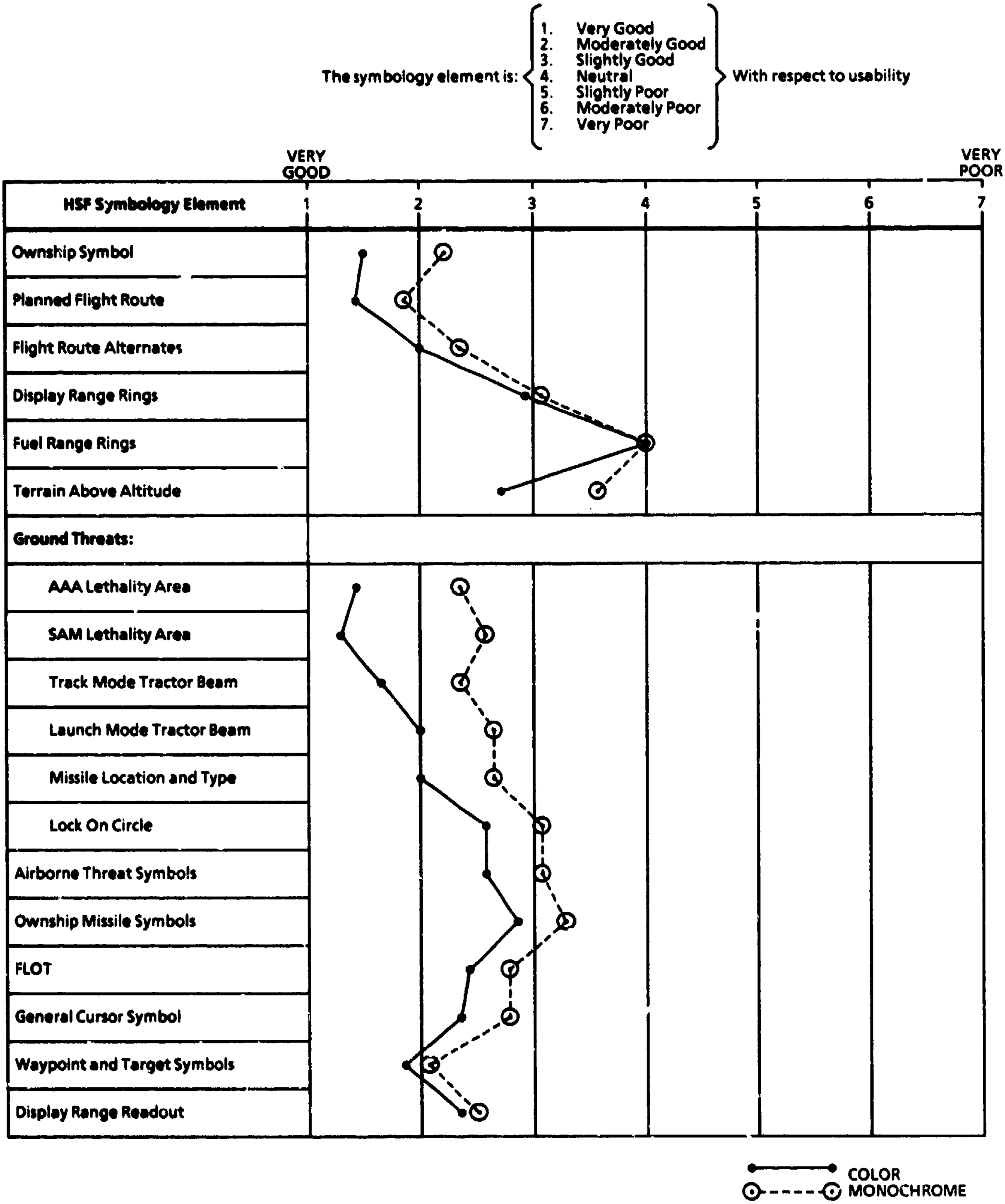
SS5057/B/327-6



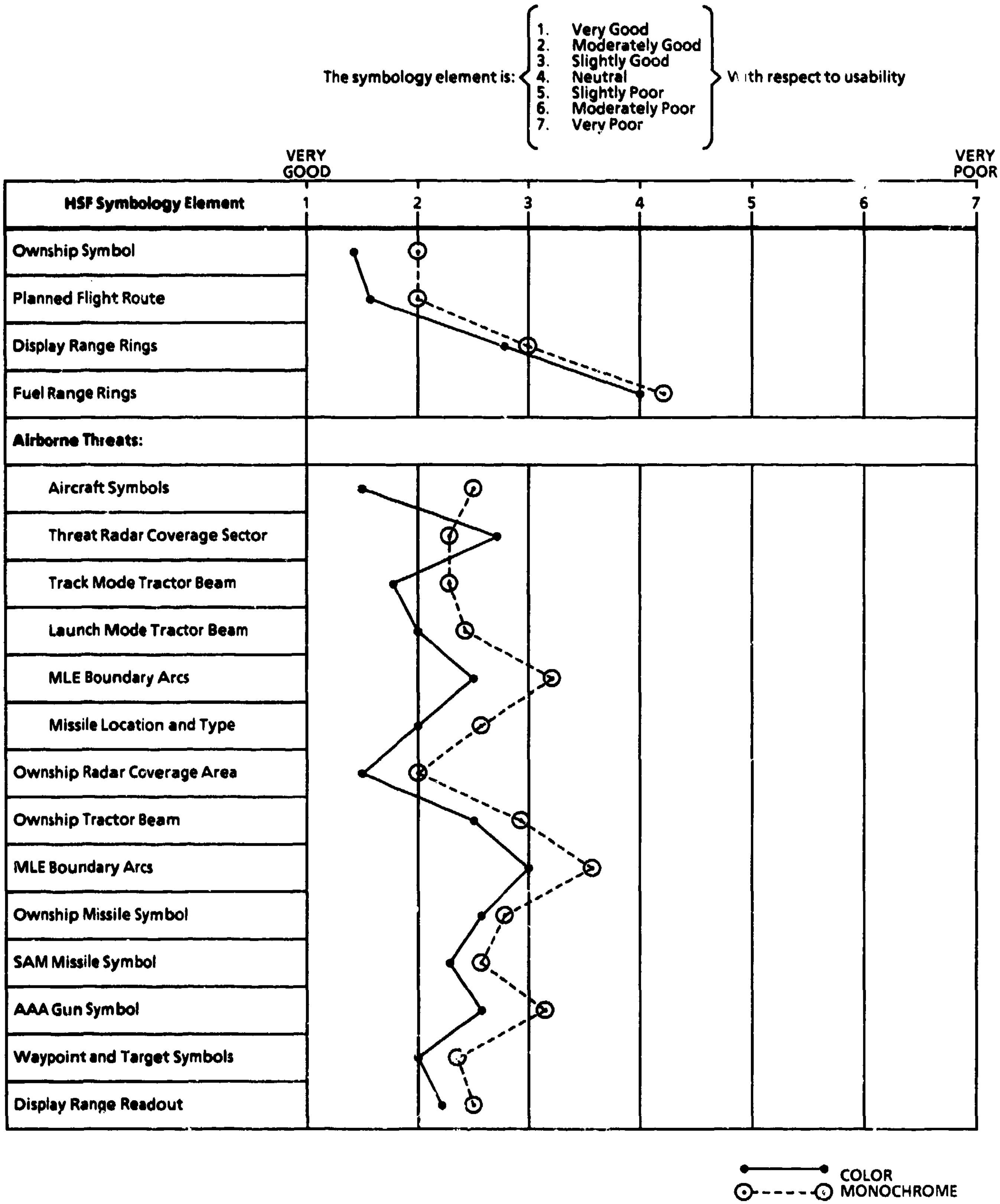
Usability Ratings of PSF Symbology in Ground Mode (Mean of 16 Pilots and 16 WSOs)



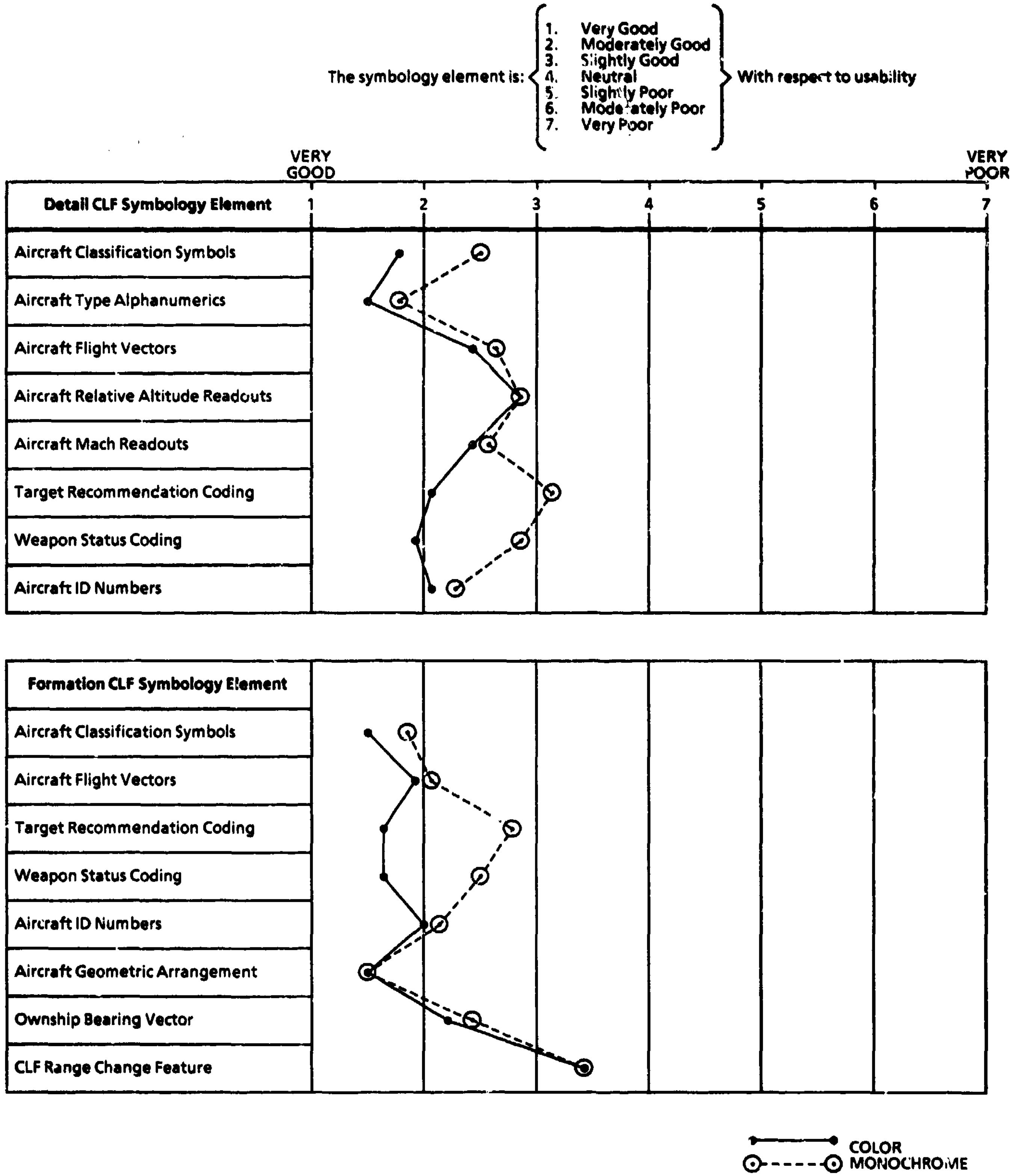
Usability Ratings of PSF Symbology in Air Mode (Mean of 16 Pilots and 16 WSOs)



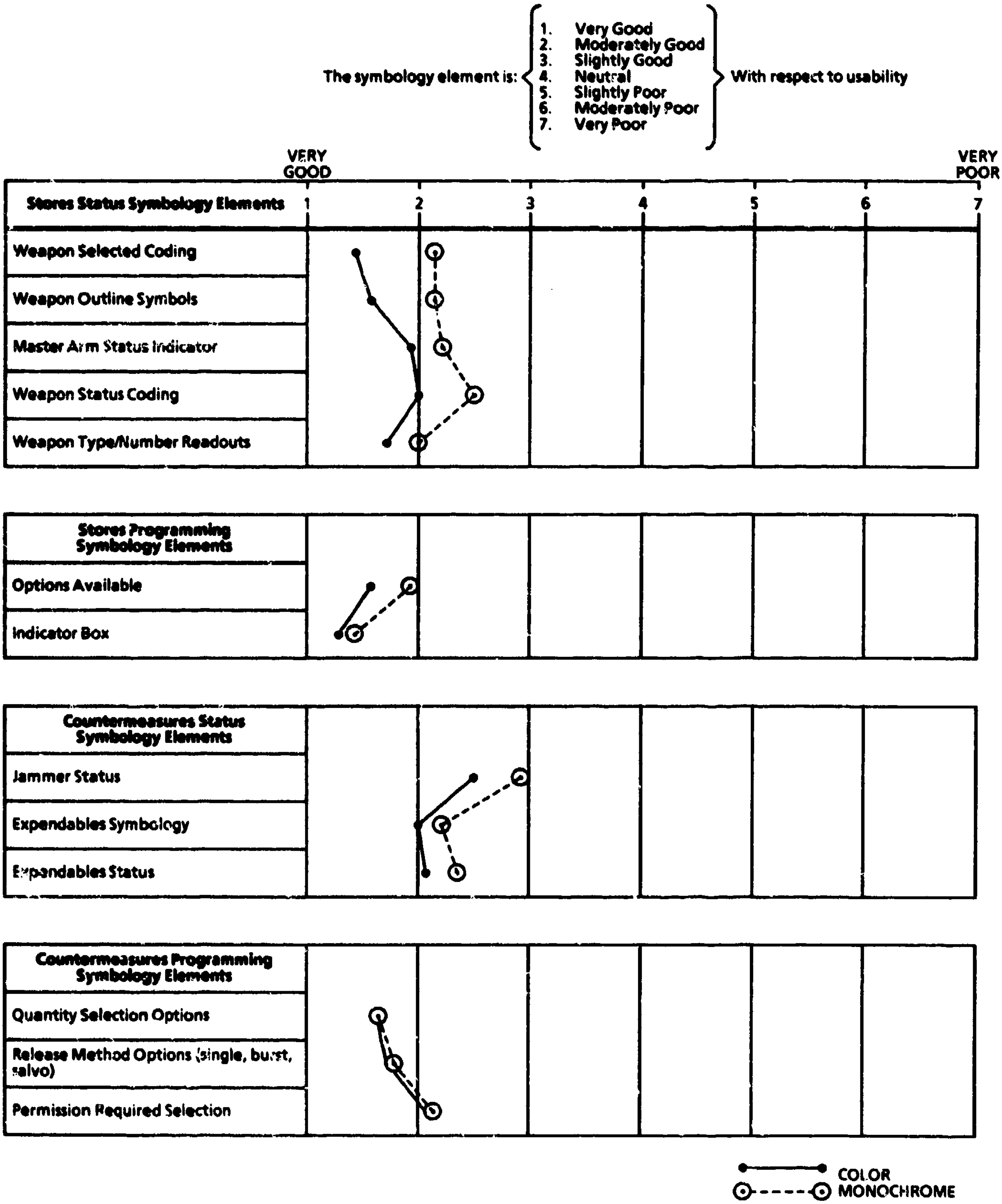
Usability Ratings of HSF in Ground Mode (Mean of 16 Pilots and 16 WSOs)



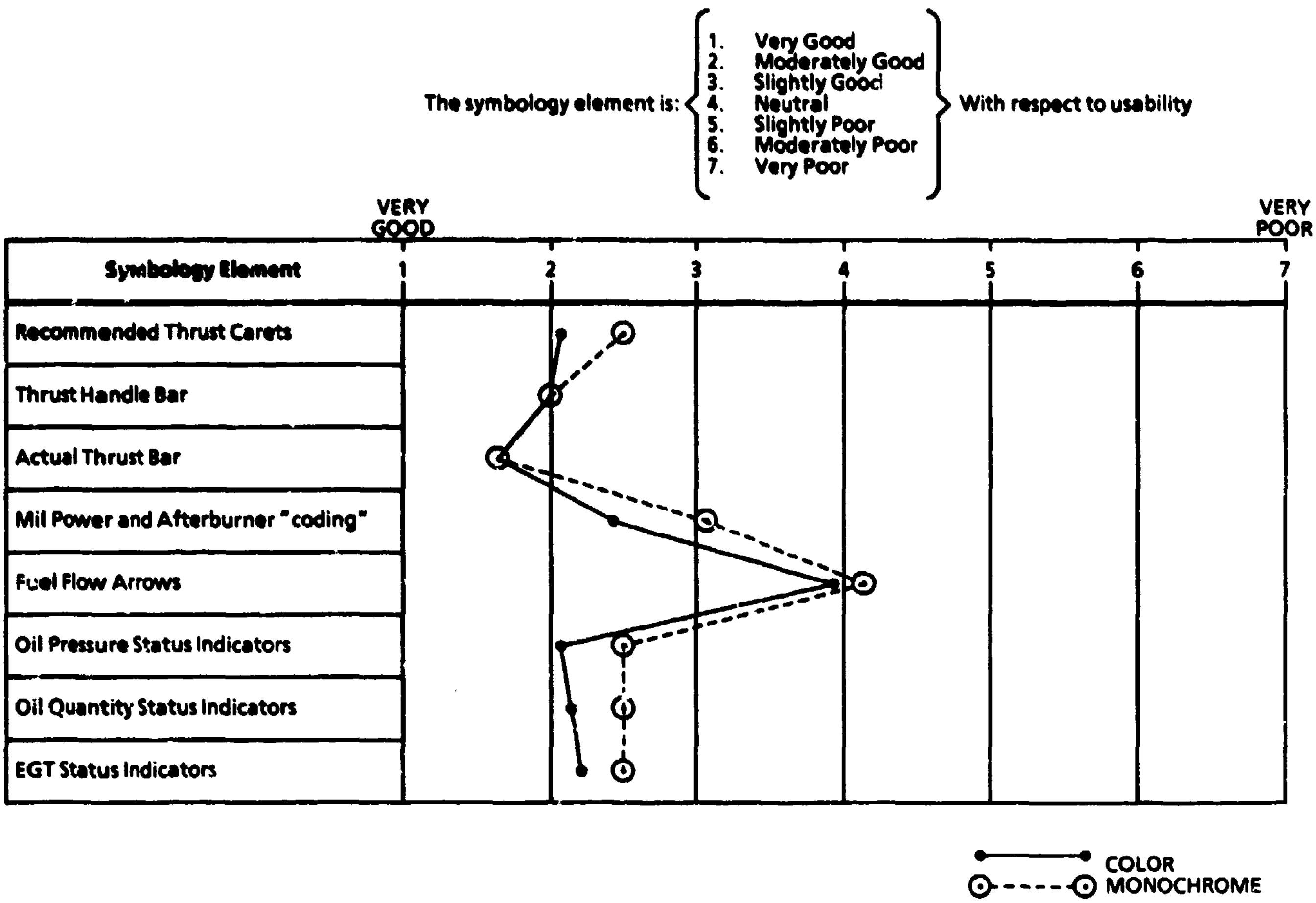
Usability Ratings of HSF in Air Mode (Mean of 16 Pilots and 16 WSOs)



Usability Ratings of Close Look Formats (Mean of 16 Pilots and 16 WSOs)

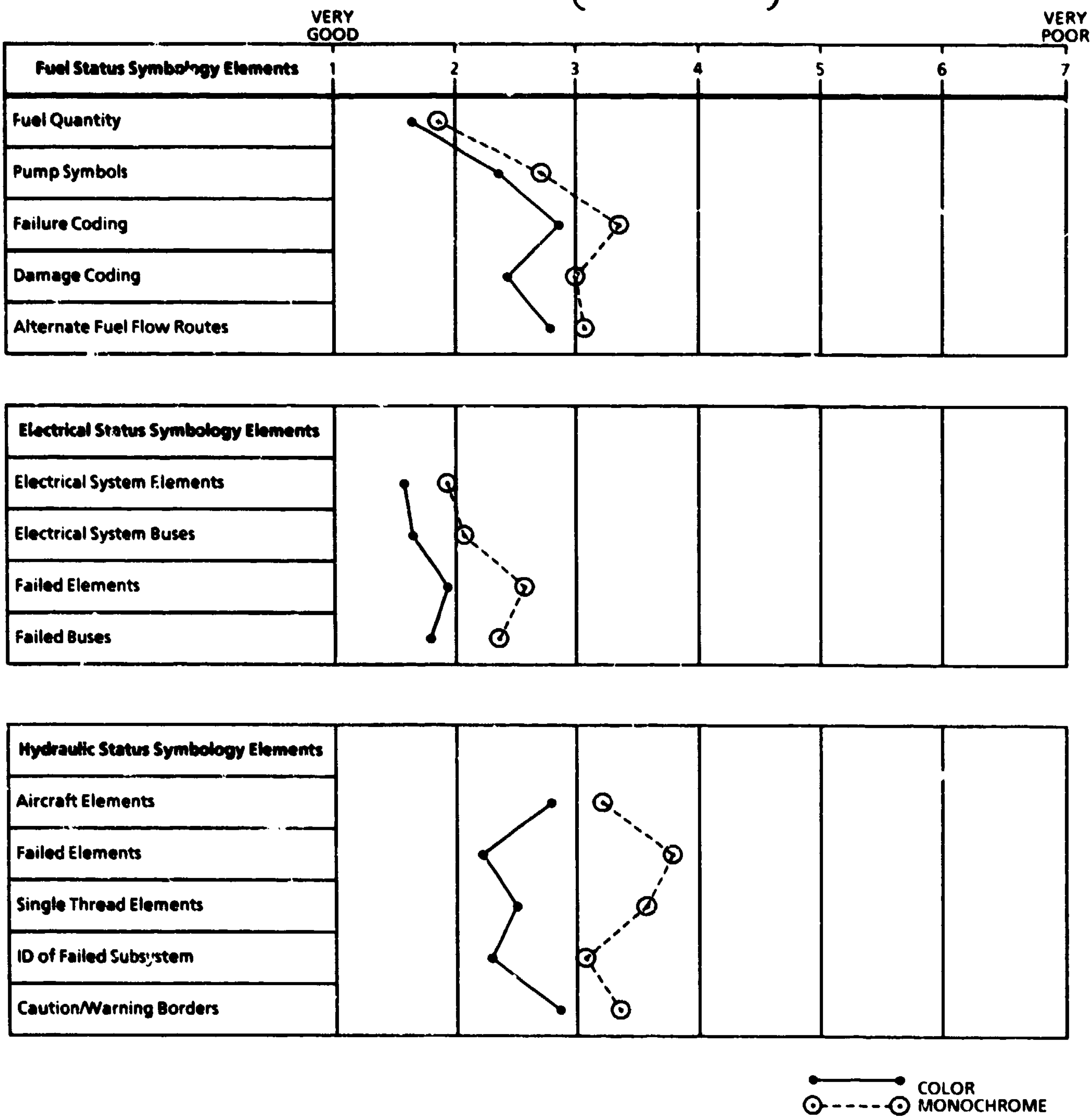


Usability Ratings of Stores Status, Stores Programming, Countermeasures Status and Countermeasures Programming Formats (Mean of 16 Pilots and 16 WSOs)

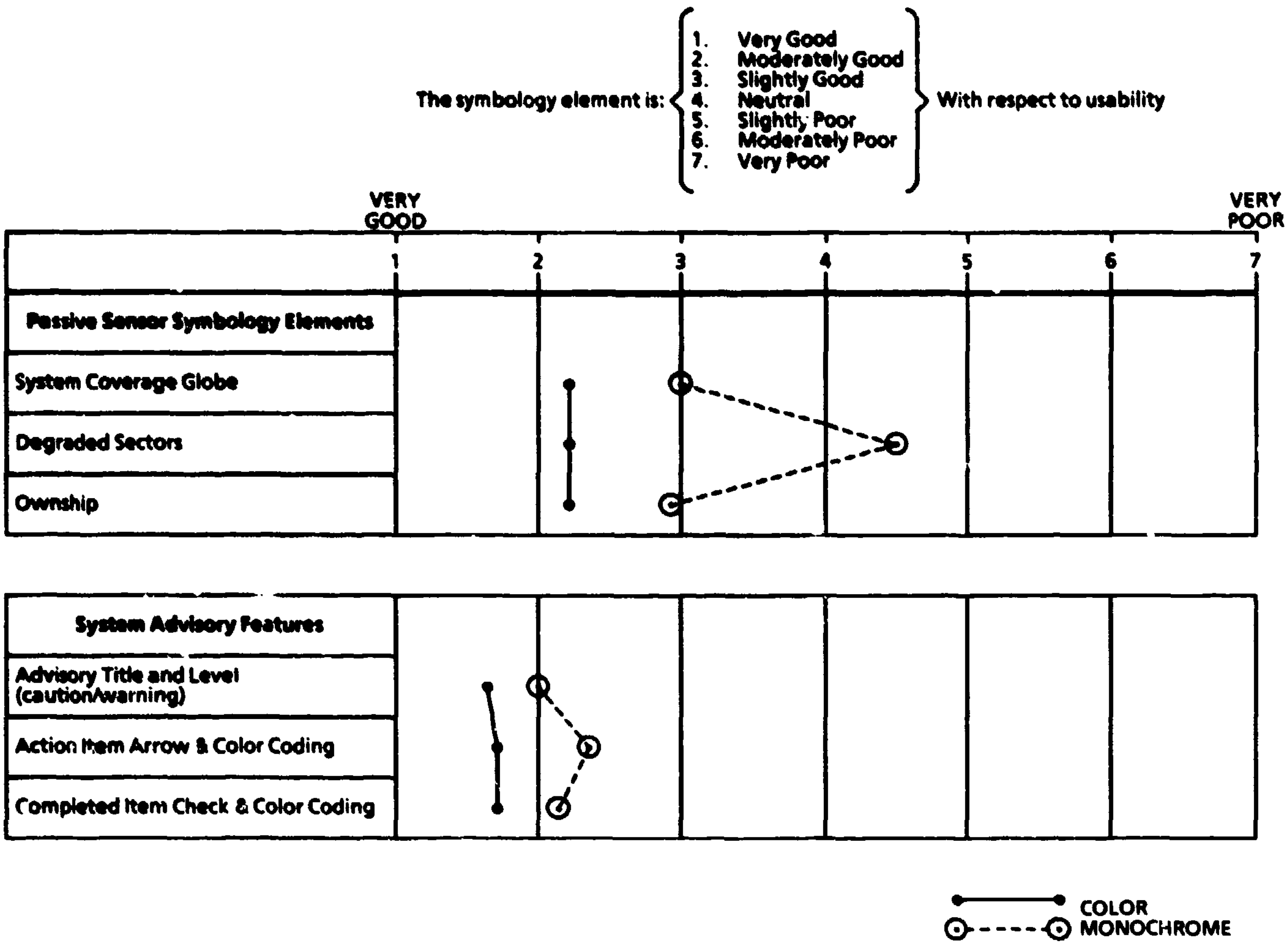


Usability Ratings of Engine Status Format (Mean of 16 Pilots)

The 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 usability



Usability Ratings of Fuel Status, Electrical Status, and Hydraulic Status Formats (Mean of 16 Pilots)



Usability Ratings of Passive Sensor Status (16 Pilots) and System Advisory Formats (16 Pilots)

APPENDIX C

AIRCREW QUESTIONNAIRES

MISSION SEGMENT AND COMPOSITE MISSIONS

At the completion of the test flights for each of the mission segments, the aircrews completed a questionnaire on the formats which were featured in that segment. The pilots completed one each time and the WSOs completed a questionnaire after the low level penetration and BVR air-to-air segments. In addition, both pilots and WSOs completed a broader questionnaire on information interpretation after the final full mission flight.

Appendix C contains in pages C-2 through C-17 mean pilot usability ratings of the display symbology for each of the three test segments. WSO mean usability ratings are reported in pages in C-25 through C-34. Information interpretation questionnaires and responses are given in pages C-18 through C-24 for pilots and C-35 through C-38 for WSOs. The WSOs had no HUD and were not responsible for system health responses so they were not questioned on the HUD or most of the system status formats.

PILOTS' RESPONSES TO

SYSTEM HEALTH SEGMENT QUESTIONS

The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Defined below are the attributes or characteristics that you will rate for each type of display symbology.

Usability in Color. How easy was it to make use of this display element in the color display mode?

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

Usability in Monochrome. How easy was it to make use of 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?

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?

The 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

Display: Engine Status	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Recommended Thrust Carets	2.1	2.1	2.5	3.0	2.1	2.3	2.0	2.4	2.0	2.2
Thrust Handle Bar	2.0	2.0	2.0	2.2	2.1	2.4	2.4	2.8	2.1	2.3
Actual Thrust Bar	1.8	1.9	1.8	2.0	2.0	1.9	2.6	2.3	1.8	1.9
Mil Power and Afterburner "coding"	2.6	2.9	3.1	3.4	2.5	2.5	2.4	2.6	2.3	2.6
Fuel Flow Arrows	3.9	3.9	4.1	4.3	3.7	3.7	4.1	3.9	3.9	3.5
Oil Pressure Status Indicators	2.1	2.4	2.5	3.0	2.5	2.4	2.3	2.6	2.4	2.5
Oil Quantity Status Indicators	2.1	2.3	2.4	2.9	2.5	2.3	2.3	2.6	2.3	2.5
EGT Status Indicators	2.2	2.6	2.4	3.3	2.5	2.3	2.6	2.6	2.3	2.3

Display: Fuel Status	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Fuel Quantity	1.8	1.8	1.9	2.2	2.9	2.3	2.3	3.3	2.2	2.6
Pump Symbols	2.3	2.2	2.6	2.7	2.6	2.8	2.4	2.7	2.5	2.8
Failure coding	2.8	2.6	3.4	3.6	3.1	3.1	2.6	3.3	3.2	3.1
Damage Coding	2.5	2.3	3.1	3.4	2.9	2.8	2.4	2.9	2.8	2.7
Alternate Fuel Flow Routes	2.8	2.7	3.1	3.6	3.1	2.8	2.7	2.9	2.9	2.7

The 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

Display: Electrical Status	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Electrical System Elements	1.6	1.6	1.9	2.4	1.8	1.9	1.6	2.3	2.1	2.0
Electrical System Buses	1.7	1.7	2.1	2.4	1.9	1.8	1.6	2.3	2.0	2.1
Failed Elements	1.9	1.6	2.6	2.9	1.9	2.5	2.2	2.3	2.1	2.2
Failed Buses	1.8	1.4	2.5	2.9	1.9	2.3	2.2	2.2	2.0	2.1

Display: Hydraulic Status	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Aircraft Elements	2.8	2.4	3.2	3.7	2.8	2.9	3.3	3.0	3.0	3.1
Failed Elements	2.3	2.3	3.7	4.3	2.9	3.1	3.1	2.9	3.1	2.9
Single Threat Elements	2.5	2.2	3.4	4.1	2.7	2.9	2.8	2.7	2.9	2.8
ID of Failed Subsystem	2.4	2.3	3.1	3.8	2.7	2.8	2.7	2.7	2.7	2.7
Caution/Warning Borders	2.9	2.6	3.4	3.6	2.9	2.6	2.9	2.8	2.8	2.8

The 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

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

Display: Passive Sensor System Status	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
System Coverage Globe	2.3	2.1	3.0	3.7	2.7	2.4	2.6	2.8	2.8	2.9
Degraded Sectors	2.3	2.6	4.4	5.7	2.9	3.0	3.1	2.9	2.9	3.1
Ownship	2.3	2.3	2.9	2.7	2.7	2.7	2.7	2.9	2.7	2.8

Display: Advisories

Advisory Title and Level (caution/warning)	1.7	1.8	2.0	2.3	2.3	2.2	2.3	2.0	2.2	2.2
Action Item Arrow & Color Coding	1.8	1.9	2.3	2.6	1.9	1.9	2.1	2.1	1.9	1.9
Completed Item Check & Color Coding	1.8	1.9	2.2	2.5	1.9	1.9	2.0	2.1	1.9	1.8

PILOTS' RESPONSES TO

LOW LEVEL PENETRATION SEGMENT QUESTIONS

The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Defined below are the attributes or characteristics that you will rate for each type of display symbology.

Usability in Color. How easy was it to make use of this display element in the color display mode?

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

Usability in Monochrome. How easy was it to make use of 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?

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?

The 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

Display: HUD GROUND MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Pathway - Filled	3.3	2.8	3.1	3.0	3.4	3.5	3.7	3.6	3.3	3.6
Pathway - Outline	3.5	3.2	3.4	3.4	3.1	3.3	3.4	3.5	3.1	3.5
Pitch Ladder	2.7	2.3	2.6	2.4	2.3	2.4	2.6	2.9	2.6	3.0
Transitional Flight Director	4.8	3.9	4.7	3.9	3.4	4.6	4.7	4.4	4.5	5.1
Zero Pitch Reference Line	2.6	2.7	3.0	3.2	2.4	2.5	2.5	2.3	2.3	2.6
Threat Alert Symbols	1.6	1.6	2.2	2.3	1.6	1.5	1.9	1.6	1.5	1.8
Threat Summary Symbols (number of)	2.0	2.1	2.5	2.8	2.4	2.1	2.2	2.1	2.1	2.3
Missile or AAA Azimuth Vector	2.4	2.4	3.0	3.3	2.3	2.2	2.1	2.0	2.1	2.1
Time to Missile Impact Readout	3.0	3.4	3.1	3.4	2.6	2.5	2.9	2.4	2.7	2.9
Heading Readout	3.3	3.3	3.4	3.4	2.4	2.4	2.6	2.3	2.3	3.0
Airspeed Readout	2.2	2.2	2.3	2.4	2.0	2.1	2.2	1.9	1.8	2.4
Altitude Readout	2.5	2.4	2.6	2.6	2.1	2.1	2.0	2.1	2.0	2.4
Heading, Mach, Altitude Command Arrows and Readouts	2.8	2.6	2.8	2.9	2.3	2.9	2.9	2.9	2.9	2.9
Roll Index	3.3	3.6	3.4	3.6	3.4	3.0	3.1	2.5	3.2	3.2
Waypoints	1.9	1.7	2.1	2.0	1.8	1.8	1.9	1.9	1.9	1.8
Ownship Symbol	2.1	2.4	2.2	2.3	1.8	2.3	2.4	2.0	1.9	2.0

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The 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

Display: PSF GROUND MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	2.3	2.8	2.8	3.4	2.0	1.6	2.1	1.8	2.3	2.1
Planned Flight Route	2.0	2.1	2.3	2.8	2.1	1.9	2.2	2.0	2.3	2.4
Ground Grid	2.5	1.9	2.7	2.3	1.8	2.2	2.4	2.2	2.2	2.2
Terrain Altitude Coding	2.8	2.8	4.4	5.1	2.9	3.3	4.1	3.6	3.4	3.6
Airspeed Readout	2.8	2.8	2.9	2.9	2.7	2.5	2.5	2.3	2.6	2.6
Heading Readout	3.1	2.8	3.1	2.9	2.6	2.7	2.6	2.6	2.8	2.8
Altitude Readout	3.0	2.8	3.1	2.9	2.9	2.7	2.6	2.6	2.8	2.8
Ground Threats:										
Threat Lethality Volume	1.5	1.4	3.1	3.9	1.5	1.4	1.4	1.7	2.0	1.8
Track Mode Tractor Beam	1.8	1.9	2.4	2.9	1.9	1.5	1.8	1.8	1.7	2.2
Launch Mode Tractor Beam	1.9	1.9	2.4	2.8	2.1	1.6	1.8	1.8	1.8	2.3
Missile Symbol	2.0	2.1	2.3	2.6	1.9	1.9	2.2	2.1	2.3	2.3
Lock On Circle (around ownship)	2.3	1.9	2.6	2.6	2.4	1.8	2.3	2.3	2.1	2.3
Airborne Threat Symbol	2.9	2.9	3.0	3.0	2.4	2.5	2.5	2.6	2.8	2.8
New View Readouts	3.2	3.2	3.6	3.7	2.9	2.9	2.9	2.9	3.0	3.0
Ownship Preview Symbol	3.0	3.1	3.1	3.2	3.0	3.0	2.8	2.8	2.9	3.0

The 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

Display: HSF GROUND MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship symbol	1.8	2.2	2.3	3.3	2.3	2.3	2.6	2.1	2.5	2.5
Planned Flight Route	1.4	1.6	1.6	2.1	1.6	1.4	1.6	1.6	1.6	1.6
Flight Route Alternates	1.8	1.7	1.9	2.5	1.7	1.3	1.5	2.4	2.3	2.5
Display Range Rings	2.6	2.4	2.6	2.5	2.5	2.3	2.3	2.3	2.5	2.7
Fuel Range Rings	3.9	3.5	3.9	3.8	3.6	3.3	3.9	3.5	3.7	3.8
Terrain Above Altitude	2.7	2.6	3.3	3.6	2.7	3.2	3.0	2.6	3.2	3.0
Ground Threats:										
AAA Lethality Area	1.3	1.1	2.3	3.3	1.4	1.3	1.6	1.7	1.8	1.8
SAM Lethality Area	1.2	1.1	2.4	3.4	1.4	1.3	1.6	1.7	1.8	1.8
Track Mode Tractor Beam	1.9	1.9	2.5	2.9	1.6	1.6	2.0	1.9	1.9	2.2
Launch Mode Tractor Beam	2.0	2.1	2.5	2.9	1.8	1.8	2.1	1.9	2.1	2.3
Missile Location and Type	2.0	2.3	2.3	2.8	1.8	1.6	2.1	2.0	2.0	2.3
Lock On Circle	2.4	2.1	2.8	2.5	2.8	2.0	2.1	2.5	2.1	2.6
Airborne Threat Symbols	2.6	2.6	3.0	3.3	2.8	2.8	2.6	2.6	2.8	3.0
Ownship Missile Symbol	3.2	3.2	3.5	3.9	3.0	2.9	2.9	3.5	3.2	3.3
FLOT	2.6	2.2	2.8	2.8	2.3	2.5	2.5	2.5	2.7	2.9
General Cursor Symbol	3.0	3.6	3.2	3.7	3.2	3.1	3.4	3.4	3.6	3.7
Waypoints Target Symbol	2.1	2.1	2.3	2.5	2.3	2.2	2.3	2.3	2.2	2.3
Display Range Readout	2.6	2.6	2.6	2.6	2.7	2.4	2.1	2.6	2.6	2.9

The 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

Display: Countermeasures Status	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Jammer Status	2.5	2.0	2.7	2.5	2.6	2.5	2.3	2.5	2.4	2.6
Expendables Symbology	2.1	2.1	2.1	2.5	2.4	2.3	2.3	2.5	2.3	2.5
Expendables Status	2.2	2.3	2.2	2.7	2.5	2.2	2.4	2.6	2.4	2.6

Display: Countermeasures Programming										
Quantity Selection Options	1.6	1.7	1.6	1.7	1.8	1.6	1.9	2.4	1.9	2.4
Release Method Options (single, burst, salvo)	1.7	1.6	1.7	1.6	1.7	1.5	1.9	2.1	1.7	2.1
Permission Required Selection	2.1	2.0	2.1	2.0	2.1	2.0	2.0	2.4	2.2	2.6

PILOTS' RESPONSES TO

AIR - TO - AIR BVR SEGMENT QUESTIONS

The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Defined below are the attributes or characteristics that you will rate for each type of display symbology.

Usability in Color. How easy was it to make use of this display element in the color display mode?

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

Usability in Monochrome. How easy was it to make use of 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?

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?

The 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

Display: HUD AIR MODE

	In Color		In Monochrome		Mode-independent Attributes					
Display Element:	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship symbol Weapon number, type readout	2.3	2.3	2.5	2.6	2.1	2.1	2.0	1.9	2.0	2.4
Pathway - Filled	3.1	2.8	3.3	3.2	2.6	2.3	3.8	3.6	3.3	3.6
Pathway - Outline	3.4	3.1	3.8	3.3	2.2	2.2	4.0	3.5	3.2	3.9
Pitch Ladder	2.4	2.1	2.4	2.2	1.9	1.7	2.4	2.5	2.4	2.4
Transitional Flight Director	4.8	4.0	4.8	4.0	4.1	4.4	5.1	5.3	4.9	5.3
Zero Pitch Reference	2.3	2.1	2.4	2.5	2.2	2.1	2.3	2.3	2.4	2.4
DEFense MLE Arrow and Carets	1.9	1.9	2.3	2.6	2.0	1.8	2.0	2.0	1.8	2.0
ATTack MLE Arrow and Carets	1.8	1.8	2.1	2.6	1.9	1.9	2.1	1.9	1.7	1.9
Threat Alert Symbols	1.8	1.9	1.9	2.1	1.7	1.6	1.9	1.8	1.9	1.9
Threat Summary Symbols (number of)	2.4	2.5	2.7	2.8	2.6	2.4	2.3	2.2	2.3	2.3
Missile Azimuth Vector	1.9	2.1	2.1	2.3	1.9	1.8	2.1	1.8	1.8	2.0
Time to Missile Impact Readout	2.3	2.5	2.5	2.7	2.3	1.9	2.3	2.1	1.9	2.3
Vertical Velocity Indicator	4.8	4.0	4.5	3.7	3.5	3.3	4.5	3.8	3.9	3.8
Heading Readout	3.0	2.6	3.1	2.8	2.4	2.6	2.8	2.7	2.8	2.8
Mach Readout	2.5	1.9	2.6	2.1	2.1	2.4	2.1	2.1	2.3	2.3
Altitude Readout	2.6	2.1	2.8	2.3	2.1	2.1	2.2	2.2	2.6	2.6
Heading, Mach, Altitude Command Arrows and Readouts	2.4	2.3	2.6	2.6	1.9	2.2	2.6	2.2	2.4	2.5

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The 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

Display: PSF AIR MODE

Display Element:	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	2.7	2.9	2.9	3.8	2.3	1.9	2.4	2.2	2.3	2.7
Planned Flight Route	2.4	2.8	2.8	3.3	2.2	2.0	2.5	2.0	2.6	2.6
Terrain Altitude Coding	3.1	3.0	4.0	3.9	3.1	3.1	3.3	3.4	3.3	3.3
Ground Grid	3.4	2.8	3.5	3.0	2.8	3.1	3.1	3.1	3.3	3.0
Groundpoint Symbol	3.3	3.7	3.7	4.3	3.1	3.1	3.1	3.2	3.2	3.4
Mach Readout	3.0	2.6	3.0	2.6	2.6	3.0	2.6	2.8	2.8	2.9
Heading Readout	3.2	2.8	3.3	2.9	2.6	2.8	2.9	2.9	2.9	2.9
Altitude Readout	3.1	2.7	3.1	2.8	2.7	2.9	2.9	2.9	3.0	3.1
Airborne Threats:										
Threat Symbols	2.5	2.6	2.9	3.3	2.4	2.4	2.9	2.2	2.4	2.8
Radar Coverage Sectors	2.1	1.9	2.5	2.8	2.2	1.9	2.5	2.3	2.2	2.2
Track Mode Tractor Beam	2.3	2.2	2.6	3.0	2.4	2.1	2.5	2.4	2.5	2.6
Launch Mode Tractor Beam	2.0	2.2	2.3	2.9	2.1	1.8	2.1	2.0	2.0	2.3
Missile Symbol	1.7	1.8	2.1	2.3	2.0	1.5	1.8	1.7	1.8	2.0
Lock On Circle	1.9	2.0	2.6	2.9	2.2	1.9	2.0	2.1	2.0	2.1
SAM Missile Symbol	2.4	2.1	2.7	2.7	2.3	2.3	2.3	2.2	2.1	2.2
AAA Gun Symbol	2.5	2.2	2.5	2.6	2.3	2.3	2.3	2.3	2.1	2.3
Tracked A/C Readouts range	2.9	3.0	3.0	3.1	3.1	2.9	2.8	2.9	2.9	2.9
closing rate	3.2	3.2	3.3	3.3	3.3	3.1	2.9	3.1	3.1	3.1
relative altitude	3.1	3.0	3.2	3.0	3.1	2.9	2.8	2.9	2.9	2.9
Ownship Preview Symbol	3.7	3.6	3.8	3.6	3.6	3.6	3.6	3.6	3.7	3.7

The 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

Display: HSF AIR MODE

Display Element:	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	1.5	1.5	2.3	2.6	1.7	1.3	1.6	1.6	1.5	1.8
Planned Flight Route	1.6	1.5	2.0	2.3	1.7	1.5	1.9	1.7	1.7	1.9
Display Range Rings	2.4	2.4	2.6	2.8	2.6	2.5	2.5	2.3	2.5	2.6
Fuel Range Rings	3.6	3.1	3.8	3.7	2.8	3.4	3.6	2.9	3.1	3.3
AirborneThreats:										
Aircraft Symbols	1.8	2.0	2.2	3.3	1.8	1.8	2.1	1.8	1.9	2.1
Threat Radar Coverage Sector	1.9	1.5	2.1	2.3	1.8	1.9	1.9	1.9	1.9	2.4
Track Mode Tractor Beam	2.2	2.0	2.5	2.9	2.0	2.0	1.9	1.9	2.2	2.1
Launch Mode Tractor Beam	2.2	2.0	2.5	2.9	2.3	2.3	2.1	2.0	2.5	2.5
MLE Boundary Arcs	2.8	3.1	3.3	3.9	2.6	2.6	2.4	2.3	2.8	2.9
Missile Location and Type	2.3	2.8	2.7	3.1	2.4	2.3	2.1	2.0	2.5	3.1
Ownship Radar Coverage Area	1.7	1.6	1.9	1.9	1.6	1.5	1.7	1.7	1.6	1.9
Ownship Tractor Beam	2.8	2.3	3.1	2.9	2.5	2.4	2.6	2.6	2.7	2.8
MLE Boundary Arcs	2.8	3.2	3.3	3.3	2.6	2.5	2.6	2.3	2.7	2.8
Ownship Missile Symbol	2.8	2.9	3.1	3.3	2.9	3.0	2.9	2.9	3.2	3.3
SAM Missile Symbol	2.3	2.3	2.5	2.9	2.4	2.3	2.3	2.2	2.5	2.2
AAA Gun Symbol	2.5	2.5	2.7	3.1	2.5	2.4	2.4	2.3	2.4	2.4
Waypoint Target Symbols	2.0	2.0	2.3	2.7	2.0	1.9	1.9	1.9	2.2	2.3
Display Range Readout	2.1	2.3	2.3	2.5	2.7	2.3	2.0	1.9	2.1	2.4

The 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

Display: CLF DETAIL Version

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Aircraft Classification Symbols	2.4	1.9	2.7	3.0	2.2	2.7	2.2	2.1	2.5	2.5
Aircraft Type Alphanumerics	1.8	1.8	1.9	2.0	2.1	2.0	1.9	1.9	1.8	1.9
Aircraft Flight Vectors	2.7	2.8	2.7	2.7	2.9	2.8	2.7	2.7	2.7	2.8
Aircraft Relative Altitude Readouts	2.8	2.9	2.8	2.9	2.9	2.8	2.5	2.6	2.8	3.2
Aircraft Mach Readouts	2.7	2.8	2.7	2.8	2.8	2.7	2.6	2.8	2.8	3.2
Target Recommendation Coding	2.0	1.9	2.9	3.7	2.3	2.8	2.1	2.2	3.0	3.2
Weapon Status Coding	2.1	2.4	2.5	3.4	2.3	2.3	2.1	2.1	2.9	2.8
Aircraft ID Numbers	2.2	1.7	2.3	1.9	2.3	2.4	1.9	1.9	2.2	2.3

The 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

Display: CLF FORMATION Version

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Aircraft Classification Symbols	1.9	1.9	1.5	2.3	1.9	1.9	1.6	1.5	1.6	1.8
Aircraft Flight Vectors	2.1	2.2	2.1	2.3	1.8	1.9	2.3	1.7	2.2	2.3
Target Recommendation Coding	1.8	1.9	2.4	3.4	1.7	2.2	1.8	1.8	2.0	2.5
Weapon Status Coding	1.9	2.0	2.2	2.8	1.8	2.1	1.7	1.8	2.5	2.5
Aircraft ID Numbers	2.1	1.9	2.1	1.9	2.0	2.4	1.8	1.8	1.9	2.3
Aircraft Geometric Arrangement	1.7	1.4	1.7	1.5	1.6	1.7	1.6	1.5	1.8	1.9
Ownship Bearing Vector	2.2	2.3	2.2	2.4	2.2	2.2	2.0	1.9	2.3	2.2
CLF Range Change Feature	3.0	3.1	3.0	3.2	3.0	2.8	2.7	2.6	3.2	3.1

The 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

	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Display: Stores Status										
Weapon Selected Coding	1.8	1.6	2.2	2.8	1.7	1.9	1.9	1.7	1.8	1.6
Weapon Outline Symbols	2.0	1.9	2.2	2.2	1.9	1.9	1.9	1.9	2.1	1.9
Master Arm Status Indicator	2.4	2.3	2.5	2.5	2.3	2.2	2.2	2.2	2.2	2.4
Weapon Status Coding	2.1	2.1	2.3	2.3	2.1	1.9	1.9	1.9	1.9	1.9
Weapon Type/Number Readouts	1.9	1.9	2.0	2.0	1.8	1.6	1.7	1.7	1.7	1.9
Display: Stores Programming										
Options Available	1.9	2.1	2.1	1.9	1.9	1.9	1.8	1.8	1.9	1.4
Indicator Box	1.4	1.4	1.5	1.6	1.5	1.5	1.5	1.4	1.4	1.4

PILOTS' RESPONSES TO

INFORMATION INTERPRETATION QUESTIONS

This part of the questionnaire is designed to elicit your opinions on the relative usability of the two display modes - monochrome and color. Place a number in each column to indicate, for the monochrome and color versions, the degree to which it is easy or difficult to understand the particular display information.

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

HUD

How easy or difficult is it to interpret the following information on HUD?

	Monochrome	Color
Pathway	3.4	3.1
Pitch Ladder	1.7	1.6
Threat Alert and Summary Information	2.5	2.3
DEF MLE Arrow	2.4	1.6
ATT MLE Arrow	2.4	1.6
Vertical Velocity Indicator	3.9	3.7
Ownship's Relationship to Terrain	4.6	4.6
Waypoint Locations	2.3	2.3
Weapon Release Cue	3.4	3.4

PSF

How easy or difficult is it to interpret the following information on PSF?

	Monochrome	Color
Planned Flight Route	3.3	2.4
Surface-to-air Threat Type (SAM,AAA)	2.7	1.3
Surface-to-air Threat Mode (search, track, launch)	2.9	1.6
Airborne Threat Type (enemy, unknown)	3.6	2.6
Airborne Threat Mode (search, track, launch)	2.8	2.2
Area of Airborne Threat Radar Coverage Area	2.6	2.0
Terrain	4.3	3.3
Location of Waypoints	2.1	1.7
Range, Closing rate and Relative Altitude Readouts	3.3	3.4

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

HSF

How easy or difficult is it to interpret the following information on HSF?

	Monochrome	Color
Flight Route	2.0	1.7
Display Range	2.3	2.2
Fuel Range Rings	3.5	3.4
Ownship's Proximity to Mountains	5.1	4.6
Surface-to-Air Threat Type (SAM,AAA)	2.6	1.6
Surface-to-Air Threat Mode (prebriefed, search, track launch)	2.4	1.6
Airborne Threat Type (enemy, unknown	2.9	1.9
Airborne Threat Mode (prebriefed, search, track, launch)	2.8	2.3
Ownship's Position Relative to Enemy Radar Coverage	1.8	1.5
Airborne Target Position Relative to Ownship Radar Coverage	1.9	1.6
Ownship MLE Boundary Arcs	3.6	2.8
Enemy MLE Boundary Arcs	3.8	2.9

Close Look Formats (CLF's)

How easy or difficult is it to interpret the following information on Close Look Formats (Detail and Formation versions)?

	Monochrome	Color
Aircraft Classification (enemy, unknown, friendly)	2.8	1.7
Classification Status (probable or known)	2.8	1.8
Aircraft Flight Vector	3.0	2.9
System Recommended Target Coding	4.0	2.3
Weapon Assignment/Readiness Coding	3.6	2.1
Formation CLF only:		
Aircraft Position and Movement	2.3	2.1
Location of Ownship Relative to Formation	3.3	3.3

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

Close Look Formats (Cont'd)	Monochrome	Color
Detail CLF only:		
Aircraft Type (fighter, bomber, specific type)	1.6	1.7
Aircraft Relative Altitude	2.5	2.5
Aircraft Speed	2.1	2.2

Engine Status Format

How easy or difficult is it to interpret the following information on the Engine Status Format?

	Monochrome	Color
Commanded Thrust, Throttle Position and Actual Thrust	2.7	2.3
Fuel Flow	3.2	2.8
Oil Pressure	2.4	2.1
Oil Quantity	2.3	1.9
EGT	2.4	2.0
Damage/Failure Coding	3.8	2.6

Fuel Status Format

How easy or difficult is it to interpret the following information on the Fuel Status Format?

	Monochrome	Color
Fuel Quantity	1.8	1.7
Pump Status (normal/failed)	3.5	2.9
Damage/Failure Coding	3.8	2.9

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

Electrical Status Format	Monochrome	Color
How easy or difficult is it to interpret the following information on Electrical Status Format?		
Element Symbology	2.0	1.6
Damage/Failure Coding	2.7	1.5

Hydraulic Status Format	Monochrome	Color
How easy or difficult is it to interpret the following information on the Hydraulic Status Format?		
Aircraft Element Supported	3.1	2.4
Level of Element Support (full support, single threat support, full failure)	4.4	3.2
Damage/Failure Coding	4.1	2.6

Stores Status Format	Monochrome	Color
How easy or difficult is it to interpret the following information on the Stores Status format?		
Weapon Complement	1.3	1.4
Type and Number of Weapons Selected	1.5	1.4
Master Arm Status	1.8	1.4
Selected Weapon Status (assigned/ ready)	2.1	1.7

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

Passive Sensor System Status Format	Monochrome	Color
How easy or difficult is it to interpret the following information on the Passive Sensor System Status format?		
Status of Passive Sensor System	3.6	2.6
Area of Degraded Coverage	5.6	3.3

Countermeasures Status

How easy or difficult is it to interpret the following information on the Countermeasures Status format?

	Monochrome	Color
Status of Jammer (off,standby,on)	1.4	1.5
Quantity of Expendable Countermeasures Selected	2.0	1.5
Permission Required Indicator	1.6	1.5
Chaff Symbology vs Flare Symbology	2.0	1.8

PILOTS' RESPONSES TO
INFORMATION CROSSCHECK QUESTIONS

This part of the questionnaire is designed to elicit your opinions on the relative ease or difficulty of crosschecking information across displays in the two modes - monochrome and color. Place a number in each column to indicate, for the monochrome and color versions, the degree to which it is easy or difficult to understand the information across displays.

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

HUD, PSF, and HSF	Monochrome	Color
How easy or difficult is it to interpret the following information on HUD, PSF and HSF?		
Flight Path Information	3.3	2.6
Ownship's Position Relative to Terrain	5.5	4.2
Threat or Missile Position Relative to ownship	2.9	2.4

HUD and HSF	Monochrome	Color
How easy or difficult is it to crosscheck the following information on the HUD and HSF?		
Ownship ATT MLE Arrow and MLE Boundary Arcs	3.5	2.6
Enemy DEF MLE Arrow and MLE Boundary Arcs	3.7	2.7

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

PSF and HSF	Monochrome	Color
How easy or difficult is it to crosscheck the following information on the PSF and HSF?		
Surface-to-Air Threat Location	3.1	1.8
Surface-to-Air Threat Type (SAM,AAA)	3.1	1.6
Surface-to-Air Threat Mode (search, track, launch)	2.5	1.6
Airborne Threat Location	2.8	2.2
Airborne Threat Type (enemy, unknown)	3.4	2.2
Airborne Threat Mode (search, track, launch)	3.1	2.0

CLF and HSF

How easy or difficult is it to crosscheck the following information on the CLF and HSF?

	Monochrome	Color
Aircraft Type (enemy, unknown, friendly)	2.6	1.8
Aircraft Heading	2.5	2.3
Target/Weapon Status	2.6	1.8

CLF and Stores Status

How easy or difficult is it to crosscheck the following information on the CLF and Stores Status format?

	Monochrome	Color
Target/Weapon Status	2.6	2.3

WSO RESPONSES TO

LOW LEVEL PENETRATION SEGMENT QUESTIONS

The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Defined below are the attributes or characteristics that you will rate for each type of display symbology.

Usability in Color. How easy was it to make use of this display element in the color display mode?

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

Usability in Monochrome. How easy was it to make use of 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?

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?

The 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

Display: PSF GROUND MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	2.3	2.7	3.1	3.8	2.4	2.1	2.5	2.0	2.4	2.6
Planned Flight Route	2.8	3.0	3.6	4.3	3.0	2.3	3.1	2.8	2.3	2.8
Ground Grid	2.9	2.6	3.1	3.0	2.7	2.9	2.6	2.6	2.6	3.1
Terrain Altitude Coding	2.5	2.7	4.4	5.4	2.3	3.0	3.6	2.3	2.3	3.1
Airspeed Readout	2.2	1.9	2.4	2.2	2.4	1.9	1.7	1.6	1.9	2.3
Heading Readout	2.6	1.9	2.8	2.1	2.1	2.2	1.7	1.8	2.3	2.8
Altitude Readout	2.5	2.5	2.8	2.8	2.9	2.1	1.7	1.8	2.7	3.1
Ground Threats:										
Threat Lethality Volume	1.9	1.5	4.1	4.6	2.3	2.3	2.8	2.1	1.9	2.3
Track Mode Tractor Beam	1.9	2.1	3.1	3.3	2.6	1.8	1.9	1.8	1.8	1.9
Launch Mode Tractor Beam	2.5	2.6	3.1	3.5	2.7	2.3	2.0	1.9	2.0	2.2
Missile Symbol	2.3	2.4	2.9	3.1	2.3	2.1	2.3	2.2	2.1	2.8
Lock On Circle (around ownship)	2.7	2.6	3.3	3.8	2.8	2.6	2.9	2.6	2.6	3.2
Airborne Threat Symbol	2.8	2.8	3.3	3.5	2.8	3.0	3.0	2.8	2.8	3.0
New View Readouts	2.9	2.6	3.3	3.1	2.4	2.8	2.5	2.5	2.6	2.8
Ownship Preview Symbol	3.5	3.7	4.0	4.6	3.0	3.1	2.7	3.2	3.1	3.7

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The 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

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

Display: HSF GROUND MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship symbol	1.5	1.6	2.4	2.9	2.1	1.5	2.3	1.9	1.7	1.8
Planned Flight Route	1.6	1.4	2.1	2.5	1.9	1.5	1.6	1.6	1.7	1.8
Flight Route Alternates	2.2	1.9	2.7	3.2	2.3	2.3	2.0	3.8	2 9	3.3
Display Range Rings	3.2	2.5	3.5	2.9	2 9	3.5	3.7	2.6	3.0	3.7
Fuel Range Rings	4.1	3.3	4.1	3.6	3 1	4 3	3 6	3.5	3.5	3.9
Terrain Above Altitude	2.6	2.3	3.8	3.8	2.3	1.9	2.0	1 9	2 7	2 6
Ground Threats:										
AAA Lethality Area	1.5	1.3	2.4	3.0	1.5	1.5	1.7	1.5	1.5	1.6
SAM Lethality Area	1.5	1.3	2.4	3.4	1.5	1.6	1.7	1.5	1.5	1 6
Track Mode Tractor Beam	1.5	1.9	2.1	2.9	1.8	1.7	1.5	1.4	1 6	1.7
Launch Mode Tractor Beam	2.2	2.5	2.7	3.2	2.2	2.4	2.1	2.1	2.1	2.2
Missile Location and Type	2.3	2.8	2.9	3.7	2.6	1 9	2.4	2.0	2 1	2.4
Lock On Circle	3.0	2 4	3.4	3.4	2 6	2.5	2 7	2.1	2.3	2.6
Airborne Threat Symbols	2.8	2.8	3.3	3.3	3.0	2.7	2.3	2.3	2.3	2.3
Ownship Missile Symbol	2.6	2.7	3.2	3.8	2 8	2.5	2 8	2 6	2 8	2 8
FLOT	2.6	2 2	2 8	2 7	2 3	2 1	2.1	2 4	2 4	3 1
General Cursor Symbol	2.1	2.3	2 4	3 0	2 0	1 6	2.3	2 1	2 1	2.3
Waypoints Target Symbol	1.7	1 9	1.9	2 5	1 9	1 9	2 2	1.8	2 1	1.8
Display Range Readout	2 2	2 4	2 4	2 7	2 7	2 1	1 9	2.1	2 4	2.5

The 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

Display: Countermeasures Status	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Jammer Status	1.6	1.4	1.7	2.1	1.7	1.4	1.3	1.3	1.5	1.6
Expendables Symbology	2.0	1.8	2.4	2.6	1.8	1.9	1.6	1.6	1.9	1.9
Expendables Status	2.1	1.7	2.4	2.7	1.9	2.1	1.9	1.5	1.9	2.1

Display: Countermeasures Programming	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Quantity Selection Options	1.8	1.5	1.9	1.6	1.8	1.6	2.1	1.8	1.6	1.8
Release Method Options (single, burst, salvo)	1.9	1.7	2.0	1.8	1.8	1.7	2.1	1.7	1.9	1.9
Permission Required Selection	2.2	1.8	2.3	1.9	2.3	1.5	1.5	1.5	2.1	2.3

WSO RESPONSES TO AIR-TO-AIR BVR SEGMENT QUESTIONS

The purpose of this questionnaire is to elicit your opinions of the symbology used in this study. Defined below are the attributes or characteristics that you will rate for each type of display symbology.

Usability in Color. How easy was it to make use of this display element in the color display mode?

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

Usability in Monochrome. How easy was it to make use of 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?

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?

The 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

Display: PSF AIR MODE

Display Element:	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	2.6	2.3	3.1	3.3	2.0	1.8	2.1	1.6	1 6	2.1
Planned Flight Route	3.0	2.5	3.7	4.0	2.3	2.2	2.7	2.7	2.1	2.4
Terrain Altitude Coding	2.8	2.1	4.3	4.2	2.1	2.5	3.3	2.5	2.6	3.1
Ground Grid	3.4	2.3	3.9	3.2	2.1	2.3	2.2	2.0	2.1	2.8
Groundpoint Symbol	4.2	3.8	4.7	5.0	3.3	3.6	3.5	3.3	3.8	4.1
Mach Readout	2.7	2.4	2.7	2.5	2.5	2.1	2 1	2.1	2.4	2.7
Heading Readout	3.1	2.1	3.2	2.3	1 8	2.4	1.8	1.8	2.3	3.1
Altitude Readout	2.2	1.9	2.2	2.0	2.3	2.0	1.5	2 5	1.9	2.5
Airborne Threats:										
Threat Symbols	2.0	1.6	2.6	2.9	1.9	2.0	2.1	1.9	2.0	2.5
Radar Coverage Sectors	2.0	1.3	2.5	3.1	1.5	1.9	1.6	1.7	1.6	2.1
Track Mode Tractor Beam	1.9	2.2	2.2	2.9	1 8	2.1	1.9	2 1	1.7	2 6
Launch Mode Tractor Beam	2.3	2.3	2.6	3.1	2.2	2 1	2.0	2 1	1 9	2 6
Missile Symbol	2.4	2.4	2.9	3.4	1.6	1.7	2.0	2.0	1.6	2.4
Lock On Circle	2.2	2.0	2 9	3 1	2 8	2.1	2.3	2 4	1.9	2.4
SAM Missile Symbol	2.4	2.2	3 0	3 2	2 3	1 8	2 5	1 9	1 7	2 6
AAA Gun Symbol	2.3	2 4	3.0	3 4	2.4	1 9	2 5	2 0	1.8	2.6
Tracked A/C Readouts range	1 9	2.5	2.2	2 8	3 0	2.3	1 9	2 3	2.4	2 9
closing rate	2 5	2 8	2 6	2 9	3 3	2 5	2 0	2 4	2 7	3 4
relative altitude	2.2	2 4	2.2	2 5	2 9	2 4	1 9	2 2	2 4	3.1
Ownship Preview Symbol	3 1	3 6	3 6	4 1	2 2	2 4	2 9	3 0	3 1	4 0

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The 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

Display: HSF AIR MODE

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Ownship Symbol	1.3	1.6	1.9	2.9	1.7	1.5	1.5	1.5	1.3	1.4
Planned Flight Route	1.8	2.0	2.2	2.9	1.6	1.6	1.9	1.8	1.6	2.0
Display Range Rings	3.3	2.7	3.4	3.1	2.6	2.8	2.7	2.1	3.1	3.6
Fuel Range Rings	4.4	3.8	4.8	4.7	3.9	5.0	4.0	3.9	4.2	4.7
AirborneThreats:										
Aircraft Symbols	1.5	1.6	2.9	3.5	1.8	1.9	2.0	1.8	2.3	2.3
Threat Radar Coverage Sector	1.8	1.5	2.5	3.1	1.7	1.7	2.0	1.9	2.0	2.2
Track Mode Tractor Beam	1.5	1.7	2.2	2.9	1.7	1.7	1.6	1.6	1.7	1.6
Launch Mode Tractor Beam	1.9	2.1	2.6	3.5	1.9	1.8	2.1	1.9	1.9	2.2
MLE Boundary Arcs	2.5	2.6	3.3	4.2	2.4	2.6	2.6	2.1	2.4	2.9
Missile Location and Type	1.7	2.4	2.6	3.7	1.8	1.9	2.1	1.9	1.9	2.4
Ownship Radar Coverage Area	1.5	1.3	2.3	2.6	1.9	1.8	1.7	1.7	1.8	1.9
Ownship Tractor Beam	2.4	2.5	3.3	3.6	1.8	1.9	1.9	1.8	2.1	2.0
MLE Boundary Arcs	3.2	3.4	4.2	4.7	3.1	3.5	3.8	3.0	3.0	3.6
Ownship Missile Symbol	2.6	2.4	3.1	3.3	2.3	2.2	2.5	2.5	1.9	2.7
SAM Missile Symbol	2.6	2.6	3.3	3.6	1.7	1.8	2.0	1.9	1.9	2.4
AAA Gun Symbol	2.8	2.9	3.5	3.9	1.7	1.9	2.0	1.9	2.1	2.6
Waypoint Target Symbols	2.0	2.1	2.4	2.7	1.5	1.7	1.6	1.7	1.7	1.6
Display Range Readout	2.3	2.1	2.7	2.3	2.1	2.1	2.3	1.9	2.0	2.7

The 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

Display: CLF DETAIL Version

Display Element:	In Color: Usability	In Color: Conspicuousness	In Monochrome: Usability	In Monochrome: Conspicuousness	Mode-independent Attributes: Location	Meaning	Precision	Timeliness	Training	Workload
Aircraft Classification Symbols	1.5	1.4	2.5	3.1	1.9	2.1	1.6	1.9	2.3	2.3
Aircraft Type Alphanumerics	1.4	1.4	1.7	1.6	1.7	1.5	1.4	1.8	2.0	1.9
Aircraft Flight Vectors	2.4	1.8	2.6	2.1	2 0	2 3	2.2	2 3	2.4	2.1
Aircraft Relative Altitude Readouts	2.8	2.3	2.9	2.4	2.9	2 6	2.2	2.3	2 7	2.9
Aircraft Mach Readouts	2.3	2.3	2.6	2.6	2.7	1 9	1 5	2.3	2 6	2.8
Target Recommendation Coding	2.1	2.1	3.8	4.7	1.9	2.4	2 0	2.4	2.7	2.4
Weapon Status Coding	1.8	1.7	3.4	4.3	1.9	2.1	2.1	1.7	2.2	2 2
Aircraft ID Numbers	2.0	2.1	2.3	2.5	2.3	2.2	1.6	1.6	3.1	2.7

The 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

Display: CLF FORMATION Version

Display Element:	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Aircraft Classification Symbols	1.3	1.3	1.9	2.7	1.7	1.5	1.5	1.7	1.7	1.8
Aircraft Flight Vectors	1.9	1.8	2.1	2.1	2.0	2.1	2.7	2.0	2.3	2.3
Target Recommendation Coding	1.8	2.1	3.3	4.9	1.8	2.9	1.9	1.9	2.7	3.1
Weapon Status Coding	1.8	2.3	2.9	4.4	1.9	2.6	1.8	1.7	2.4	2.5
Aircraft ID Numbers	2.1	1.8	2.4	2.2	2.1	2.2	1.8	1.6	2.6	2.4
Aircraft Geometric Arrangement	1.4	1.5	1.6	1.6	1.7	1.9	2.1	1.7	2.3	2.1
Ownship Bearing Vector	2.5	2.4	2.8	2.8	2.3	2.6	2.7	2.2	2.6	2.6
CLF Range Change Feature	4.0	3.7	4.1	3.9	2.9	3.8	3.1	2.4	3.1	3.6

The 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

Display: Stores Status

	In Color		In Monochrome		Mode-independent Attributes					
	Usability	Conspicuousness	Usability	Conspicuousness	Location	Meaning	Precision	Timeliness	Training	Workload
Weapon Selected Coding	1.4	1.4	2.1	2.9	1.6	1.8	1.5	1.5	1.5	1.5
Weapon Outline Symbols	1.4	1.5	1.9	2.6	1.6	1.8	1.5	1 5	1.6	1.5
Master Arm Status Indicator	1.4	1.6	1.9	2.6	1.8	1.5	1.3	1.3	1.4	1.5
Weapon Status Coding	1.8	2.3	2.9	4.1	2.1	2.4	2.0	1.9	2.2	2.1
Weapon Type/Number Readouts	1.8	1.8	2.0	2.2	2.2	1.9	1.6	1.7	1.9	1.9

Display: Stores Programming

Options Available	1.5	1.4	1.6	1.7	1.7	1.5	1.5	1.6	1.5	1.6
Indicator Box	1.4	1.4	1.5	1.6	1.6	1.5	1.4	1.6	1.5	1.6

WSO RESPONSES TO
INFORMATION INTERPRETATION QUESTIONS

This part of the questionnaire is designed to elicit your opinions on the relative usability of the two display modes - monochrome and color. Place a number in each column to indicate, for the monochrome and color versions, the degree to which it is easy or difficult to understand the particular display information.

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

HUD	Monochrome	Color
How easy or difficult is it to interpret the following information on PSF?		
Planned Flight Route	3.5	3.0
Surface-to-Air Threat Type (SAM,AAA)	3.6	1.4
Surface-to-Air Threat Mode (search, track, launch)	3.5	2.0
Airborne Threat Type (enemy, unknown)	4.6	2.5
Airborne Threat Mode (search, track, launch)	4.1	3.1
Area of Airborne Threat Radar Coverage Area	3.1	2.0
Terrain	4.7	2.2
Location of Waypoints	2.7	1.9
Range, Closing Rate, and Relative Altitude Readouts	2.6	2.4

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

HSF

How easy or difficult is it to interpret the following information on HSF?

HSF	Monochrome	Color
Flight Route	1.8	1.3
Display Range	1.9	1.8
Fuel Range Rings	4.1	2.7
Ownship's proximity to mountains	4.1	2.7
Surface-to-Air Threat Type (SAM,AAA)	2.9	1.6
Surface-to-Air Threat Mode (prebriefed, search, track, launch)	2.9	1.7
Airborne Threat Type (enemy,unknown)	4.1	1.3
Airborne Threat Mode (prebriefed, search, track, launch)	3.5	2.0
Ownship's Position Relative to Enemy Radar Coverage	2.5	1.7
Airborne Target Position Relative to Ownship Radar Coverage	2.1	1.5
Ownship MLE Boundary Arcs	4.3	2.8
Enemy MLE Boundary Arcs	4.6	3.1

Close Look Formats (CLF's)

How easy or difficult is it to interpret the following information on Close Look Formats (Detail and Formation versions)?

Close Look Formats (CLF's)	Monochrome	Color
Aircraft Classification (enemy, unknown, friendly	3.3	1.4
Classification Status (probable or known)	3.3	1.6
Aircraft Flight Vector	2.1	2.0
System Recommended Target Coding	3.6	1.7
Weapon Assignment/Readiness Coding	4.1	1.8
Formation CLF only:		
Aircraft Position and Movement	2.3	1.7
Location of Ownship Relative to Formation	2.6	2.1

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

Close Look Formats (Cont'd)	Monochrome	Color
Detail CLF only:		
Aircraft Type (fighter, bomber, specific type)	1.8	1.4
Aircraft Relative Altitude	2.9	2.8
Aircraft Speed	1.9	1.8

Fuel Status Format

How easy or difficult is it to interpret the following information on the Fuel Status Format?

	Monochrome	Color
Fuel Quantity	2.0	1.4
Pump Status (normal/failed)	3.1	1.6
Damage/Failure Coding	3.2	1.6

Stores Status Format

How easy or difficult is it to interpret the following information on the Stores Status Format?

	Monochrome	Color
Weapon Complement	1.6	1.3
Type and Number of Weapons Selected	1.9	1.3
Master Arm Status	2.3	1.3
Selected Weapon Status (assigned/ ready)	3.6	1.5

Countermeasures Status

How easy or difficult is it to interpret the following information on the Countermeasure Status format?

	Monochrome	Color
Status of Jammer (off, standby, on)	1.8	1.4
Quantity of Expendable Countermeasures Selected	2.1	1.8
Permission Required Indicator	2.4	1.8
Chaff Symbology vs Flare Symbology	1.9	1.6

WSO RESPONSES TO INFORMATION CROSSCHECK QUESTIONS

This part of the questionnaire is designed to elicit your opinions on the relative easy or difficulty of crosschecking information across displays in the two modes - monochrome and color. Place a number in each column to indicate, for the monochrome and color versions, the degree to which it is easy or difficult to understand the information across displays.

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

PSF and HSF	Monochrome	Color
How easy or difficult is it to crosscheck the following information on PSF and HSF?		
Surface-to-Air Threat Location	3.4	1.9
Surface-to-Air Threat Type (SAM, AAA)	3.3	1.5
Surface-to-Air Threat Mode (search, track, launch)	3.4	1.8
Airborne Threat Location	3.2	2.5
Airborne Threat Type (enemy, unknown)	4.1	2.4
Airborne Threat Mode (search, track, launch)	3.5	2.6

CLF and HSF

How easy or difficult is it to crosscheck the following information on the CLF and HSF?

	Monochrome	Color
Aircraft Type (enemy, unknown, friendly)	3.6	2.3
Aircraft heading	2.9	2.1
Target/Weapon Status	3.9	2.4

CLF and Stores Status

How easy or difficult is it to crosscheck the following information on the CLF and Stores Status format?

	Monochrome	Color
Target/Weapon Status	4.0	2.1

APPENDIX D

AIRCREW QUESTIONNAIRE
OPEN ENDED ANSWERS

As the last exercise in opinion data collection, the aircrew members were given a list of open ended questions and a tape recorder. Previous studies have shown this to be an effective way to elicit ideas not otherwise available. Transcripts of the tapes from the individual pilots and WSOs are summarized in this Appendix. The richness of the raw data made summarizing difficult but an attempt was made to represent all of the format ideas presented. As might be expected, both agreements and disagreements appear. There were a few comments which dealt more with the simulation than the formats; these were excluded from the summaries.

Question 1. What is your opinion of the Pathway-in-the-Sky (PITS) on the HUD? Does it provide sufficient information for flight path control during low level flight? During which flight and mission phases is it most useful? Are there any flight or mission phases when it is not useful?

5 Pilots	Difficult to follow if off path.
4 Pilots	Generally effective. Needs improvement.
4 Pilots	Less useful, not useful, don't need in air-to-air.
4 Pilots	The pits. Eliminate pathway. Inadequate. Should not be primary aid.
3 Pilots	Good cue.
3 Pilots	Better in low level than at altitude.
3 Pilots	Adequate for low level.
3 Pilots	Too sensitive.
3 Pilots	Completely inadequate as a steering device.
2 Pilots	Useful straight and level, not in maneuver.
2 Pilots	Adequate with autopilot on.
2 Pilots	Good as preview of coming commanded changes.
2 Pilots	Pitch bad during level flight.
2 Pilots	Transitional flight director too slow and difficult to understand.
1 Pilot	Adequate in azimuth.
1 Pilot	Adequate for BVR air-to-air.
1 Pilot	Confusing in color and monochrome.
1 Pilot	Path easier in monochrome.
1 Pilot	Hard to tell range to terrain on HUD.

<u>How Change</u>

3 Pilots	Need steering back to selected point, rather than strict return path to some arbitrary point.
3 Pilots	Use proportional, ILS type steering.
2 Pilots, 1 WSO	Pathway should provide SAM avoidance guidance.
2 Pilots, 1 WSO	Shoot cue should be more noticable, not an "X".
2 Pilots	Tend to lose gate. Need more solid steering target.
1 Pilot	Need filled path in air mode.
1 Pilot	Make pathway selectable.
1 Pilot	Add low altitude warning.
1 Pilot	Bank index should continue all around and not flash at some arbitrary limit.
1 Pilot	In air mode, don't show Mach for ownship and knots for closing velocity.
1 Pilot	Back seater needs complete HUD information.
1 Pilot	VSI indicator should peg at 1500 or 2000 ft/min, with digital extending beyond. That would provide more sensitivity at lower vertical speeds.

Question 2. What is your opinion of the Missile Launch Envelope (MLE) information presented on the HUD (MLE arrows and carets)? Any suggestions for changes?

13 Pilots	Very useful and intuitive.
4 Pilots	Better in color.
2 Pilots	Good in color or monochrome.
1 Pilot	Do not need color coded arrows.
1 Pilot	Make shoot cue more attention-getting.
1 Pilot	Incorporate raw range.
1 Pilot	Add ranges next to carets.
1 Pilot	Improve target and threat IDs on arrows.
1 Pilot	Have carets flash when within no-escape zone.

Question 3. What is your opinion of the Perspective Situation Format (PSF)? How well does it provide information about the tactical situation? Any suggestions for changes?

11 Pilots,5 WSOs	Provides good information well.
9 Pilots, 5 WSOs	Better in color.
3 Pilots, 6 WSOs	Good threat depiction.
3 Pilots, 2 WSOs	Particularly useful in ground mode.
3 Pilots	Difficult to use for terrain clearance.
2 Pilots, 2 WSOs	Good for situation awareness, vertical situation, tuning HSD info.
2 Pilots	Heading. airspeed and altitude redundant with HUD.
1 Pilot, 1 WSO	Useful in air mode.
1 Pilot, 1 WSO	Weak in air mode.
1 Pilot	Good idea. Needs work.
1 Pilot	Not too useful.
2 WSOs	Ground grid was helpful.
1 WSO	Confused threats and terrain in monochrome.
1 WSO	Better than we have now.

How Change

8 Pilots, 6 WSOs	Need declutter or transparency to see past near threats to mountains beyond.
1 Pilot, 1 WSO	Ground grid not helpful.
1 Pilot, 1 WSO	Ownship and pathway should be brighter or larger or different color.
1 Pilot, 1 WSO	Make PSF into a flight instrument.
1 Pilot, 1 WSO	As flight instrument, put viewpoint at ownship
1 Pilot	Add shading to show terrain height or impact point.

Question 3. (Continued) What is your opinion of the Perspective Situation Format (PSF)? How well does it provide information about the tactical situation? Any suggestions for changes?

1 Pilot	Add option for ground or airplane stabilized choice.
1 Pilot	Change PSF range with HSF.
1 Pilot	Add cockpit outline to provide visual reference.
1 Pilot	Add vertical grid lines for attitude and altitude corrections.
1 Pilot	In air mode, add contrails for track history.
2 WSOs	Add selectable ground clearance plane and altitude above terrain.
1 WSO	Code terrain ahead.
1 WSO	Need stronger indication of terrain shape below current altitude.
1 WSO	Add aircraft attitude for back seat.
1 WSO	Add abbreviated heading tape to PSF.
1 WSO	Make lock-on circle transparent.
1 WSO	Add selectable in-cockpit viewpoint.
1 WSO	Show true rather than relative altitude for air threats.
1 WSO	Show only volumes of active threats.
1 WSO	As flight instrument, add artificial horizon and velocity vector.
1 WSO	Display throughout air engagement without switching.
1 WSO	For air targets, show aspect angle, heading, velocity, range, altitude and targetting.
1 WSO	For air targets, add readouts of heading and true mach.

Question 4. Did you use the "new view" feature on the PSF to change the viewpoint of the format? How useful is the feature?

7 Pilots, 9 WSOs	Used it, liked it.
2 Pilots, 3 WSOs	Used it, didn't like it.
4 Pilots	Used it seldom or not at all.
2 Pilots, 2 WSOs	Used it in ground mode.
1 Pilot, 1 WSO	Useful in air mode.
2 Pilots, 3 WSOs	Best looking straight forward.
1 Pilot, 1 WSO	Best rotated 15 degrees down.
1 Pilot	Best in default position.
1 Pilot	Didn't like extreme adjustments.
1 Pilot	Good for flight path management, bank angle adjustment.
1 Pilot	Good for own location and threat avoidance.

Question 4.(Continued) Did you use the "new view" feature on the PSF to change the viewpoint of the format? How useful is the feature?

1 Pilot	If you select "new view," change viewpoint, deselect "new view," then select it again, viewpoint should go to changed value.
1 Pilot	Viewpoint too far back.
2 WSOs	Useful for setting personal preference.
1 WSO	Good for terrain clearance.
1 WSO	Useful for air-to-ground transition.
1 WSO	Hard to see ownship symbol with level viewpoint.

Question 5. What is your opinion of the Horizontal Situation Format (HSF)? How well does it provide information about the tactical situation? Any suggestions for changes?

9 Pilots, 13 WSOs	Excellent. Good situational awareness picture.
4 Pilots, 2 WSOs	Provides tactical information very well.
3 Pilots, 2 WSOs	Color better than monochrome.
1 Pilot, 1 WSO	Liked ability to de-center ownship.
1 Pilot	It's a pretty radar scope.
1 Pilot	Not good for close-in work.
1 Pilot	Too far from HUD for cross-check.
1 WSO	Difficult to judge altitude in HSF.
1 WSO	Almost indispensible for threat and terrain avoidance.
1 WSO	Not great for tactical information.
1 WSO	Important format. Make it larger.

How Change

4 Pilots, 3 WSOs	Add range up and range down buttons vs. range change cycle.
2 Pilots, 2 WSOs	Label range rings or make them constant radius in NM.
1 Pilot, 1 WSO	Terrain should be available from high altitude to plan descent.
1 Pilot, 1 WSO	Show preplanned alternate route earlier.
2 WSOs	Flash new threats 5 seconds or until acknowledged by WSO.
1 Pilot	Put ownship halfway between center and bottom.
1 Pilot	Move time and distance readouts to HUD or PSF. Too far away on HSF.
1 Pilot	Add time-to-go to next waypoint in air mode.
1 Pilot	Too cluttered with All Threats selected.

Question 5. (Continued). What is your opinion of the Horizontal Situation Format (HSF)? How well does it provide information about the tactical situation? Any suggestions for changes?

How Change

1 Pilot	Add declutter switch to eliminate non-immediate threats.
1 Pilot	Remove lock-on circle around ownship. It covers other information.
1 Pilot	Add aid for reaching specific time-over-target.
1 Pilot	Add predictive vector to nose of ownship.
1 WSO	Need better indication of terrain below current altitude.
1 WSO	Show WSO aircraft attitude on HSF.
1 WSO	Show full 3-D ownship launch envelope.
1 WSO	Need North-up option.
1 WSO	Add compass indication around periphery of format.
1 WSO	Add offset to left and right as well as bottom.
1 WSO	Add weapon and countermeasures select status.
1 WSO	Have range readout show total range and range of rings, e.g., 160/40.
1 WSO	Change range scales to multiples of 5 NM.
1 WSO	Increase range options.
1 WSO	Make range rings dimmer.
1 WSO	Indicate selected weapons on selected targets.
1 WSO	Indicate which are pop-up threats.
1 WSO	Add airspeed indicator.
1 WSO	Add low altitude warning.
1 Pilot, 1 WSO	Add ability to set up route deviations with waypoints to provide path guidance to pilot for flying around threats.
1 Pilot, 1 WSO	In air mode, show individual target bearing, closing velocity, aspect angle, altitude differential, missile assigned, and single or multiple.
1 WSO	Eliminate Close Look formats and window in the information on the HSF.
1 WSO	In transition, may need two HSF's, one on small scale and one on large to monitor both ground and air situations.

Question 6. Should the HSF background change color as a function of Master Mode? For example, green background in GND Mode and black background in AIR Mode. How would this information be useful?

12 Pilots, 11 WSOs	No. Leave it as it is.
3 Pilots, 3 WSOs	Yes. Might help.
1 Pilot, 2 WSOs	Didn't notice. Don't know.

Question 7. How easy is it to correlate threat type, position and mode information across the PSF and HSF? How useful is it to have threat information presented on two displays with different viewpoints?

9 Pilots, 8 WSOs	Good. No change.
2 Pilots, 3 WSOs	Better in color.
2 WSOs	Need range to threats on PSF.
1 Pilot	Not that useful.
1 Pilot	Good in ground mode, weak in air mode.
1 Pilot	Need to be more specific to support tactical decisions.
1 Pilot	Flash threat envelope for launching threats.
1 WSO	Good in air mode, not as important in ground mode.
1 WSO	Identify missile type on lethality envelopes.
1 WSO	Make threats transparent on PSF.
1 WSO	Indifferent to different viewpoints.
1 WSO	Good for identifying pop-up threats.

Question 8. How useful was the preview feature on the HSF and PSF? During which mission phases is it most useful? Any suggestions for changes?

10 Pilots, 5 WSOs	Worthless. No time to use it.
1 Pilot, 5 WSOs	Good for briefing, ingress and egress.
4 WSOs	Distracting or disorienting.
2 Pilots, 1 WSO	Good in both air and ground phases.
3 WSOs	Limited use.
2 Pilots	Good but didn't use it much.
1 Pilot	Good for back seater.
1 Pilot	Must run quicker.
1 Pilot	Replace with capability to center HSF on cursor-selected location.
1 WSO	Bad to displace real time display.
1 WSO	Revert to real time if threat launches.
1 WSO	Computer should show primary recommendations and alternates.

Question 9. Which display (HUD, PSF, HSF) did you find most useful for threat information? Lease useful? Was the distribution of threat information across the HUD, PSF, and HSF appropriate? If not, what would you change about the distribution?

Most Useful

1 Pilot, 9 WSOs	HSF most useful.
6 Pilots	HUD most useful.
2 Pilots, 3 WSOs	PSF and HSF both good.
3 Pilots, 1 WSO	All good.
4 WSOs	Used HSF for planning and advance work, then PSF for execution and close-up work.
2 Pilots, 1 WSO	PSF most useful.
2 Pilots	PSF good for threat avoidance.
1 Pilot	HUD and HSF tied for most useful.
1 Pilot	HUD, then PSF, then HSF.
1 Pilot	HUD well arranged. Missile time-of-flight was useful for timing expendables. Missile and tractor beams on HSF good.
1 Pilot	Threat warning and mode change in HUD good.

Least Useful

3 Pilots	PSF least useful.
2 Pilots	HUD least useful for threats.

Distribution of Threat Information

4 Pilots, 5 WSOs	Distribution of threat information good.

How Change Distribution

2 Pilots	Switch positions of PSF and HSF.
2 Pilots	Add more threat information to HUD.
1 Pilot	For pilot, combine information and eliminate HSF.
1 Pilot	Time-to-go for missile impact useless to pilot. WSO may use it.
1 WSO	Reduce threat depiction range on PSF, so distant threats don't cover closer ones.

Question 10. What is your opinion of the Detail Close Look format? Does it provide adequate and useful raid assessment information? Any suggestions for changes?

9 Pilots, 13 WSOs	Good. No change
4 Pilots	Unusable and confusing.
2 Pilots, 2 WSOs	Better in color. Worse in monochrome.
2 Pilots	WSO used this. Pilot didn't.
2 WSOs	Difficult to learn.
1 Pilot	Pilot may not have time to use it.

How Change.

3 Pilots, 3 WSOs	Integrate formation and detail CLFs.
2 Pilots, 4 WSOs	Hard to correlate groups between HSF and CLF.
1 Pilot, 1 WSO	Make CLF a separate display. Don't displace PSF air mode.
1 Pilot, 1 WSO	Display actual rather than relative altitude.
2 WSOs	Have digital readouts default to airspeed rather than relative altitude.
1 Pilot	Prefer Formation Close Look Format.
1 Pilot	Rather have PSF.
1 Pilot	Not sure flight vectors are useful.
1 Pilot	Speed readouts are good.
1 Pilot	Close Look Format should default to formation when first selected.
1 Pilot	Use letters rather than symbolic coding.
1 Pilot	Symbolic coding of fighters and bombers would be better.
1 WSO	Make symbols smaller to make room for more of them.
1 WSO	Assign missiles to air targets as in F14A.
1 WSO	Add arrows to flight vectors.
1 WSO	Have digital readouts default to previous selection (airspeed or relative altitude) when Close Look is reselected.
1 WSO	Use textures rather than gray shades in monochrome.

Question 11. What is your opinion of the Formation Close Look Format? Does it provide adequate and useful information about the target formation? How useful is TRACK selection feature? Any suggestions for changes?

13 Pilots, 6 WSOs	Good.
1 Pilot, 1 WSO	Confusing.
1 Pilot	Barely adequate.
1 Pilot	WSO used this. Pilot didn't.
1 Pilot	Correlated well with HSF for BVR information.

Question 11. (Continued) What is your opinion of the Formation Close Look Format? Does it provide adequate and useful information about the target formation? How useful is TRACK selection feature? Any suggestions for changes?

1 Pilot	Easier to find who's targeted than on Detail Close Look Format.
1 Pilot	Altitude and airspeed readouts good for targeting.
1 WSO	Didn't use it too much.
1 WSO	Difficult to correlate with HSF.
1 WSO	Hard to follow if groups split up.
1 WSO	Used Detail Close Look Format more because I could only see the ones I was tracking on the Formation format.

TRACK Selection

4 Pilots, 4 WSOs	TRACK select was useful.
1 Pilot, 2 WSOs	Did not use TRACK select often or at all.
1 Pilot	TRACK select was not helpful.

How Change

5 Pilots, 2 WSOs	Add ID, range, bearing, aspect angle, closing velocity, target speed, etc., to Formation CLF and eliminate Detail CLF.
2 Pilots	Make it 3-D so you can view it from different angles.
1 Pilot	Use ID letter for group and number for aircraft within group.
1 Pilot	Move to MPD.
1 Pilot	Make ownship vector more conspicuous.
1 Pilot	Formation should be relative to ownship - an eyeball picture of what crew is looking at.
1 WSO	Make symbols smaller to accommodate more of them.
1 WSO	Add auto scale change to keep targets in field of view.
1 WSO	Need more range available when formation dispurses.
1 WSO	Display target aspect very clearly.
1 WSO	When reselected, keep previously selected range.
1 WSO	Keep all the aircraft in the formation on the scope even if they were separated by a few miles.

Question 12. What is your opinion of the Engine Status Format? Does the composite thrust bar provide adequate and useful information to set and monitor thrust? Any suggestions for changes?

12 Pilots, 1 WSO	Liked it.
7 Pilots	Like the composite thrust idea.
1 Pilot, 3 WSOs	WSO needs this, too.
2 Pilots	Better in color.
1 Pilot	Nice to have.
1 Pilot	Did not like it.

How Change

3 Pilots, 1 WSO	Show oil and EGT by exception.
3 Pilots	Make fuel flow digital, take out arrows.
2 Pilots	Show digital fuel flow in hundreds of pounds per hour.
2 Pilots	Put thrust levels together.
1 Pilot	Too much critical information in one place.
1 Pilot	Seemed confusing. Simplify.
1 Pilot	Make actual thrust wider.
1 Pilot	Use conventional thrust percent or analog display.
1 Pilot	Delete throttle setting thrust bar, keep thrust command carets.
1 Pilot	Make thrust limits more obvious.
1 Pilot	Move power required.
1 Pilot	Need digital oil.
1 Pilot	Put oil and EGT closer to horizontal center of format.
1 Pilot	Show oil pressure as a bar graph, like oil quantity and EGT.
1 Pilot	Add EGT readout next to EGT gauge.
1 Pilot	Make composite format showing thrust, fuel quantity, CM and missile status, then call up other informaiton when needed.
1 Pilot	Use vertical tape for fuel flow.
1 Pilot	Add fuel totalizer.

Question 13. What is your opinion of the Stores Status format? Does it provide adequate and useful information to monitor the type, number and status of stores on board? Any suggestions for changes?

12 Pilots, 15 WSOs	Good. Useful.
3 Pilots, 8 WSOs	Color better.
1 Pilot	Nice to have. Didn't add much.
1 Pilot	Concept good. Needs a little improvement.
1 Pilot	Good in both color and monochrome.
1 Pilot	Liked halos and what's selected.
1 WSO	Difficult to represent variety of ordinance we have today.

Question 13 (Continued) What is your opinion of the Stores Status format? Does it provide adequate and useful information to monitor the type, number and status of stores on board? Any suggestions for changes?

How Change

1 Pilot	Add readout of weapon being launched.
1 Pilot	Coloring sometimes confusing. Use letters instead.
1 Pilot	Too big. Digital better.
1 WSO	Add shoot cue for WSO.
1 WSO	Add target assignments.
1 WSO	Put weapon assignment with target on HSF, then Stores Status would be less important.

Question 14. What is your opinion of the Stores Programming Format? How useful is it during preflight set up? Would the programming options be useful in flight? Any suggestions for changes?

12 Pilots, 12 WSOs	Good.
6 Pilots, 8 WSOs	Would be useful in flight.
5 Pilots, 5 WSOs	Good for preflight.
2 Pilots, 1 WSO	OK but too large.
1 Pilot, 1 WSO	Too many button presses.
1 Pilot	WSO should use in flight.
1 Pilot	Set and forget. Not useful in flight.
1 WSO	Awkward. Ripple and salvo not universal, quantities need to be more precise.

How Change

1 Pilot	Have default (leftmost) weapon selections already made, crew use only inflight.
1 Pilot	Use disk or tape to preload information.
1 Pilot	Reduce number of steps. Perhaps make it HOTAS.
1 Pilot	Use keyboard rather than stepping through selections.
1 WSO	Continuous menu around periphery would reduce button presses.
1 WSO	Allow for multiple designation of ordinance.
1 WSO	Allow pretargeting of weapons to reduce workload during critical periods.

Question 15. What is your opinion of the Countermeasures Status Format? Does it provide adequate and useful information to monitor the level and status of electronic expendable countermeasures? Any suggestions for changes?

12 Pilots, 15 WSOs	Good.
2 Pilots, 1 WSO	Color better.
1 Pilot	Important information.
1 Pilot	No difference between color and monochrome.
1 Pilot	Didn't use it. "C" and "F" were OK.
1 WSO	Better in monochrome. Maybe darker green would help the color version.

How Change

3 Pilots	Use digital for expendables remaining.
1 Pilot	Use advisory light for jammer and countdown for expendables.
1 Pilot	For ECM, indicate loss of capability.
1 Pilot	ECM standby and chaff or flares low all amber. It's confusing.
1 WSO	Could be smaller.
1 WSO	"Permission required" should be shown where crew is looking.
1 WSO	Add ability to stop automatic deployment.
1 WSO	Move cue for "Permission Required" closer to primary field of view.

Question 16. What is your opinion of the Countermeasures Programming Format? How useful is it during preflight setup? Would the programming options be useful in flight? Any suggestions for changes?

15 Pilots, 12 WSOs	Good.
2 Pilots, 6 WSOs	Useful in flight.
1 WSO	Awkward to access due to menu cycling.

How Change

1 Pilot, 1 WSO	Need more variations.
1 Pilot	Use keyboard rather than stepping through.
1 Pilot	Preprogram on tape. Plug in to airplane.
1 Pilot	"Permission required" option should be available when airplane is maneuvering.
1 WSO	Too long head down in flight. Have single switch for another option.
1 WSO	Get away from menus.
1 WSO	"Permission required" option should be available full time.

Question 17. What is your opinion of the Electrical, Hydraulic, Fuel System Status, and Passive Sensor formats? Do they provide an appropriate level of information about system health and system problems? Any suggestions for changes?

6 Pilots, 9 WSOs	Color better.
5 Pilots, 4 WSOs	Good.
4 Pilots, 1 WSO	Status formats should come up automatically with Master Caution.
1 Pilot, 1 WSO	Make them all simpler. Display only required actions.
1 Pilot	System displays for engineers, not pilots.
1 WSO	Should be able to know what systems are lost without having to refer to specific system format.
1 WSO	Nice to have schematics for electrical, hydraulic and fuel.

Checklists

1 Pilot	Checklist good.
1 Pilot	Integrate checklists on status formats.

Electrical

5 Pilots, 2 WSOs'	Electrical good.
1 Pilot, 1 WSO	Better in color.
1 Pilot	OK, but unneeded.
1 Pilot	Add alphanumerics to clarify.

Hydraulic

3 Pilots	Hydraulic somewhat difficult.
2 Pilots	Hydraulic good.
1 Pilot	Good in color. More difficult in monochrome.
1 Pilot	Cluttered and unneeded. An indicator light is sufficient.
1 Pilot	Add alphanumeric list of lost systems.
1 Pilot	Add alphanumeric labels.
1 Pilot	Substitute alphanumeric advisory for color coding of single thread systems.
1 WSO	Good in both color and monochrome.
1 WSO	Simple and clear.
1 WSO	Cryptic, needs training.

Question 17. (Continued) What is your opinion of the Electrical, Hydraulic, Fuel System Status, and Passive Sensor formats? Do they provide an appropriate level of information about system health and system problems? Any suggestions for changes?

Fuel

4 Pilots, 2 WSOs	Fuel good.
2 Pilots	Add alphanumerics to identify system components.
1 Pilot	OK but too much. Totalizer would suffice.
1 Pilot	Showing pumps and rerouting fuel lines a little confusing.
1 WSO	Difficult to read. Should be more clearly designated.
1 WSO	Fuel status should show both total and useable fuel.

Passive Sensor

8 Pilots, 7 WSOs	Even worse in monochrome.
6 Pilots, 7 WSOs	Passive Sensor very difficult.
1 Pilot	Neat picture.
1 WSO	OK.

Question 18. What is your general opinion of pictorial displays? What do you like best about the display formats used in this simulation? What do you like least? Would you like to have pictorial formats in a fighter of the future? For which displays?

12 Pilots, 16 WSOs	Good.
3 Pilots, 4 WSOs	Like these formats. All useful tactically.
4 Pilots	I like them. They are very close to what should be there.
1 Pilot, 1 WSO	Reduced workload with these formats.
1 Pilot	Increased situational awareness.

Color

2 Pilots, 3 WSOs	Color much better.
1 Pilot, 1 WSO	Color easier initially, monochrome could be effective.
1 Pilot	Love color but sometimes overused here.

Question 18. (Continued) What is your general opinion of pictorial displays? What do you like best about the display formats used in this simulation? What do you like least? Would you like to have pictorial formats in a fighter of the future? For which displays?

Liked Best

1 Pilot, 1 WSO	Liked the HSF and 3-D aspects of the PSF.
1 Pilot	HUD, pathway-in-the-sky, and Engine Status were especially easy to learn.
1 Pilot	Liked the MLE arrows, especially in color' invaluable in air-to-air combat.
1 Pilot	Liked the PSF best; it was well done.
1 Pilot	PSF and HSF are really good in correlating overall mission.
1 Pilot	Threat information excellent.
1 Pilot	Engine and system health formats were very good.
1 Pilot	Aircraft classifications on Close Look Detail format are great - easy to interpret.
1 WSO	HSF and PSF helped a lot in navigation, and in threat and terrain avoidance.
1 WSO	HSF and PSF together are excellent aids.
1 WSO	Liked the volumetric indications of SAMs and AAAs
1 WSO	All the ground mapping displays were nice.
1 WSO	Liked the countermeasures setup and weapons programming.

Liked Least

1 Pilot	Liked the HUD least.
1 Pilot	Liked the pathway (on the HUD) least; it was too loose, sloppy, and hard to follow. Not enough information on the HUD and PSF to keep out of the ground.
1 Pilot	Pathway-in-the-sky is not the greatest answer; should only be an aid.
1 Pilot	Liked monochrome PSF least, especially in long range air-to-air.
1 Pilot	Liked Detail Close Look format least; too complex.
1 Pilot	Terrain clearance was questionable.
1 WSO	Target information on HSF and Stores Status display was very difficult to interpret in monochrome.
1 WSO	Liked Passive Sensor Health format least.
1 WSO	Liked redundant displays least. It is possible to have identical displays up on either side, especially in heat of battle; irritating.

Question 18. (Continued) What is your general opinion of pictorial displays? What do you like best about the display formats used in this simulation? What do you like least? Would you like to have pictorial formats in a fighter of the future? For which displays?

Pictorial Formats in Fighters of the Future

3 Pilots, 3 WSOs	Would like to have pictorial formats in fighter of the future; absolutely.
1 Pilot	Would like to have HUD, pathway-in-the-sky, PSF, HSF and Engine Status; all are excellent.
1 WSO	The only problem I foresee is lack of 3-D awareness in some cases, working with 2-D continuously.
1 WSO	Would cut down on workload in both seats.
1 WSO	Would be very good if crews were well trained to use them. Would be great for visual or marginal VMC conditions as a crosscheck. Would have a hard time accepting them in total IFR.
1 Pilot	Would like HSF, it is invaluable. Also HUD.
1 Pilot	HSF should be on our planes right now; no reason not to. Same for electrical system formats, hydraulics, and things like that.
1 Pilot	Would like at least the PSF and HSF; the overall view that they provide is definitely needed.
1 Pilot	Would like HSF with fast update and scrolling feature, ownship-stabilized.
1 WSO	Would like to have the PSF as a radar warning display, and the HSF as a projective map display.
1 WSO	Would definitely like to have in future aircraft. Would like PSF for low level; HSF for route choice and low level; all MPD's for system analysis.

General Comments and Suggestions

2 Pilots	Use alphanumerics where necessary to clarify what the pictures are.
2 Pilots	Add trend information to heading readout.
1 Pilot	Would like "growing bar" symbology for altitude to give trend information.
1 Pilot	Make digital readouts on all displays larger.
1 Pilot	Too much symbology on all the displays.
1 Pilot	Use symbology that carries over from format to format.

Question 18.(Continued) What is your general opinion of pictorial displays? What do you like best about the display formats used in this simulation? What do you like least? Would you like to have pictorial formats in a fighter of the future? For which displays?

1 Pilot	Tone down color; too bright for dim visibility situations or night use.
1 Pilot	Increase resolution of displays, especially primary control display.
1 Pilot	Don't overuse pictures when analog displays adequate.
1 WSO	Try to declutter as much as possible.
1 WSO	Navigation and threat depiction especially good.
1 WSO	Need pictorial formats for air engagements, but not like this.
1 WSO	Need maneuvering information for air encounter.

HUD Comments and Suggestions

4 Pilots	Make all digital readouts on HUD larger.
2 Pilots	HUD should have pitch indicator to indicate where to bring airplane to get above terrain.
2 Pilots	Eliminate transitional flight director on HUD; use pathway to bring you back to preplanned route.
1 Pilot	When I'm off the pathway, I'd like a gross steering cue on HUD that tells me which direction the pathway is.
1 Pilot	Add angle of attack to the HUD.
1 Pilot	Must have "low altitude" visual warning on HUD.
1 Pilot	Show airspeed in knots on HUD, even in air mode.
1 Pilot	Zero pitch line needs to be more conspicuous on HUD.
1 Pilot	Change caution and warning alerts on HUD; one suggestion is to make only ownship symbol flash.
1 Pilot	Preferred monochrome for the HUD; weapon release cue was difficult to see in color.
1 Pilot	Heading, altitude and airspeed should be analog on HUD.
1 Pilot	Use heading tape on HUD.
1 Pilot	Put heading tape on horizon or bottom of HUD.
1 Pilot	Show acceleration and angle of attack on HUD.

Question 18.(Continued) What is your general opinion of pictorial displays? What do you like best about the display formats used in this simulation? What do you like least? Would you like to have pictorial formats in a fighter of the future? For which displays?

Other Comments and Suggestions

2 WSOs	Stores formats best.
1 Pilot	Add flight vector to PSF and HSF to aid in flight path control.
1 Pilot	Engine Status format was too busy for critical items.
1 Pilot	Eliminate (caution and warning) borders on displays; they are distracting and unneeded.
1 Pilot	Too much time spent cycling through Hydraulic, Electrical and Fuel Status formats; indicator lights and fuel totalizer would suffice.
1 Pilot	System health formats too big and too detailed.
1 WSO	Add gun symbol or alphanumerics to AAA envelopes on HSF.

Question 19. In this simulation, we demonstrated the use of a few cursor designation functions. What did you think of these functions? What do you think are appropriate cursor designation functions in fighter aircraft?

6 Pilots	Didn't use it.
2 Pilots, 3 WSOs	Functions appropriate.
1 Pilot, 2 WSOs	Easy to use.
2 Pilots	Nice to have for pilot. Better for WSO.
2 WSOs	Functions were standard, easy to learn.

Appropriate Cursor Functions

2 WSOs	Use cursor to insert waypoints for return to planned route.
1 Pilot	Important for targeting, designating aircraft, taking a closer look; for ground targets, and ground information from sensors. Very important, especially in dual mission aircraft.

Question 19. (Continued) In this simulation, we demonstrated the use of a few cursor designation functions. What did you think of these functions? What do you think are appropriate cursor designation functions in fighter aircraft?

Appropriate Cursor Functions

1 Pilot	Cursor should be available to identify waypoints, targets; to offset waypoints; to update present position; to re-center display around cursor; to display time-and-distance to cursor-display on HUD or PSF.
1 Pilot	Use to designate a threat for more information.
1 Pilot	Could be used on MPDs to select modes, or used for switching to keep hands on stick and throttle.
1 WSO	In the A6, it would be very useful to use a cursor to designate a target quickly.
1 WSO	Useful to designate new flight path, for example to avoid threats.
1 WSO	Use cursor for more thorough update of navigation system.
1 WSO	Use cursor to point out features to other crew members.
1 WSO	Need range and bearing to any cursor-selected point.
1 WSO	In air mode, use cursor to invoke expand function, do missile assignment and control data callup.

Other Comments or Suggestions

2 Pilots	Cursor difficult to use.
1 Pilot, 1 WSO	Make cursor bigger.
1 Pilot, 1 WSO	Need better cursor control method.
4 WSOs	Move cursor control keys to the left.
1 Pilot	Cursor position and use are good.
1 Pilot	Cursor needs to move faster.
1 Pilot	Cursor difficult to see.
1 Pilot	Cursor button should be controlled by left finger.
1 Pilot	Move cursor control to throttle.
1 Pilot	Make cursor a multiple position switch so that the entire process can be done with one finger in a few movements.
1 Pilot	Works fine as long as you can hook (desired item). I don't think that there's enough precision from what you can see on the HSF.

Question 19. (Continued) In this simulation, we demonstrated the use of a few cursor designation functions. What did you think of these functions? What do you think are appropriate cursor designation functions in fighter aircraft?

Other Comments or Suggestions

1 Pilot	Would have to be mechanized to be hands-on-stick-and-throttle for the pilot to be able to use.
1 Pilot	Have larger zone of acceptance for cursor. Get close then it jumps to nearest thing.
1 WSO	Too many button switches necessary.
1 WSO	Awkward, because the cursor was controlled with the right hand, and the left hand had to cross body to reach switches.
1 WSO	Put all cursor controls on the control stick, or in one place.
1 WSO	Works well. Originates on ownship, which is where it should.
1 WSO	Cursor designation took too long.
1 WSO	Very sensitive takes some practice to control.
1 WSO	If you miss a designation, you have to start all the way over; that takes too much time.
1 WSO	Have several alternate routes preprogrammed and selected with a control-display unit or switch instead of cursor.
1 WSO	Preview function was slow and didn't offer much information.
1 WSO	"New View" function was a little difficult.