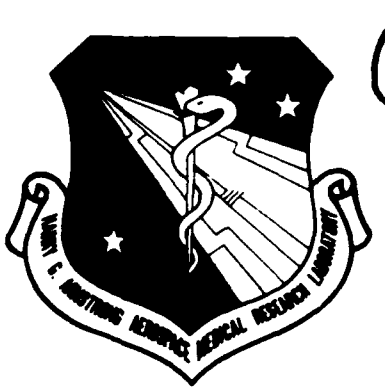
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HUMAN FACTORS REPORT ON INFORMATION MANAGEMENT REQUIREMENTS FOR NEXT-GENERATION MANNED BOMBERS (U)

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DECEMBER 1987

FINAL REPORT FOR PERIOD JUNE 1986 - OCTOBER 1987

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS N/A
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-87-042
6a. NAME OF PERFORMING ORGANIZATION Virginia Polytechnic Institute and State University 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AAMRL/HE
6c. ADDRESS (City, State, and ZIP Code) Human Factors Engineering Center Blacksburg VA 24061	7b. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6573
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-D-0514
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
62202F	7184	10	33

11. TITLE (Include Security Classification)
Human Factors Report on Information Management Requirements for Next-Generation Manned Bombers (U)

12. PERSONAL AUTHOR(S)
Beaudet, Douglas B., Price, Dennis L., Kuperman, Gilbert G.*, and Wilson, Denise L.*

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jun 86 TO Oct 87	1987 December	532

16. SUPPLEMENTARY NOTATION
*Crew Station Integration Branch
Human Engineering Division

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
05	05		Crew Systems — Artificial Intelligence
05	10		Technology Assessment
			Cockpit Automation Technology

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

A technology-free mission scenario was analyzed to determine crew information and system information management requirements. Criteria for technology insertion were developed and applied. Information sets were identified and display formats were prototyped.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Gilbert G. Kuperman	(513) 255-3727	AAMRL/HED

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

SUMMARY

The Human Factors Engineering Center (HFEC) at Virginia Polytechnic Institute and State University (VPI&SU) contracted with the Crew Station Integration Branch, Human Engineering Division of the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL/HED) to develop a methodology for identifying aircraft crewmember informational demands and information management requirements in a next-generation, manned, penetrating bomber. That methodology was to be demonstrated by applying it to an existing Crewmember Mission Scenario (CMS).

Concurrent with developing the methodology, VPI&SU developed criteria for identifying candidate technologies which satisfy crewmember and mission requirements, and reduce crewmember workload and situation awareness. The criteria are based on matching mission and crewmember requirements identified during the CMS analysis, with candidate technologies. The crewmember requirements used were informational demands, information management requirements, human factors design and behavioral issues.

This report describes HFEC's research efforts of defining information management issues for the manned, penetrating bomber described in the mission scenario by Frick, et al. (1986). A methodology is presented for analyzing the crewmember oriented mission scenario. The methodology has four objectives which are to identify: (1) mission requirements, (2) the crew's informational demands, (3) information management requirements, and (4) human factors design and behavioral issues. Criteria for technology insertion are presented and applied to identify specific information-based functions that would benefit from advanced technology application. For the identified

opportunities for technology insertion, relevant information sets are determined and conceptual display interface formats are described. The rationale for all the research work performed is also described. The report is accompanied by three appendices:

Appendix A: Bibliography/Annotated Bibliography: Human Factors Literature Review Cockpit Automation Technology

Appendix B: Guidelines for Crewmember-Machine Interface Design

Appendix C: Mission Scenario Analysis Template Data

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PREFACE

The Human Factors Engineering Center at Virginia Polytechnic Institute and State University performed this research for the Crew Station Integration Branch, Human Engineering Division, of the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL/HED). This effort supported Work Unit 7184-10-33, "Radar Information Transfer: Simulation and Analysis." That work unit is under the technical management of Mr. Gilbert G. Kuperman (AAMRL/HED) who, with the assistance of Ms. Denise L. Wilson (AAMRL/HED), served as the technical monitors for the subject research.

The effort was funded through Contract F33615-85-D-0514, Task 10, with the Southeastern Center for Electrical Engineering Education (SCEEE), St. Cloud, Florida. Mr. Jeff Craig (AAMRL/HED) served as contract monitor.

The manned, penetrating bomber simulation facility alluded to in the report is being developed for research application in support of several Air Force Systems Command and Strategic Air Command requirements. Funding for the facility development and operation was provided by the Directorate for Requirements Planning, Headquarters, Aerospace Medical Division, Brooks AFB, Texas, as a precursor activity to the Advanced Strategic Aerospace Crew Systems (ADSACS) advanced development project (P.E. 63231F/Project 3256) and by the Directorate of B-52 Programs, Deputy for Strategic Systems, and the Directorate of Projects, Deputy for the B-1B, Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio. ADSACS is directed to missionizing the bomber crew station to support the mission taking imposed by holding

strategic relocatable targets at risk. Support from the ASD system program offices is provided under the High Resolution Radar Demonstration Project of P.E. 64326 for the Strategic Convention Standoff Capability/Strategic Relocatable Target Program. Additionally, this research is directed to support the Strategic Relocatable Target (SRT) Capability Program being conducted by ASD under P.E. 63367. In both programs, advanced conceptual bomber missions and capabilities are to be explored through man-in-the-loop simulation.

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LIST OF ACRONYMS

AAM	Air-to Air Missile
AAMRL	Armstrong Aerospace Medical Research Laboratory
ACCT	Accounting/Costs Studies
ADSACS	Advanced Strategic Aerospace Crew Systems
AFP	Aircraft Flight Performance
AFPI	Aircraft Flight Performance Information
AGL	Above Ground Level
AI	Aircraft Intercept or Artificial Intelligence
AWACS	Airborne Warning and Control System
BIT	Built-In-Test
C^2	Command and Control
C^3	Command, Control, and Communications
C^3I	Command, Control, Communications, and Intelligence
CAT	Cockpit Automation Technology
CDS	Concept Definition Studies
CGD	Computer-Generated Display
CMF	Combat Mission Folder
CMI	Crewmember-Machine Interface
CMS	Crewmember Mission Scenario
CRT	Cathode Ray Tube
DS	Development Studies
EAM	Emergency Action Message
ECM	Electronic Countermeasures
EDA	Estimated Distance to Arrival
EL	Electroluminescence

ENG	Engineering Studies
ETA	Estimated Time to Arrival
HCI	Human-Computer Interaction
HFE	Human Factors Engineering
HFEC	Human Factors Engineering Center
HHCL	H Hour Control Line
HUD	Head-up Display
ICMF	Inflight Crewmember Mission Folder
IFD	Integrated Flight Display
KNOBS	Knowledge Based System
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MIMES	Mission Manager Expert System
MOE	Measures of Effectiveness
MSAT	Mission Scenario Analysis Template
OAS	Offensive Avionics System
PC	Personal Computer
PFD	Primary Flight Display
Pro-SWAT	Projective - Subjective Workload Analysis Technique
RAM/ACE	Radar Aided Mission/Aircrew Capability Exploration
RT	Relocatable Target
SAC	Strategic Air Command
SAM	Surface-to-Air Missile
SAMES	Situation Awareness Manager Expert System
SCEEE	Southeastern Center for Electrical Engineering Education
SME	Subject Matter Experts
SRT	Strategic Relocatable Target

SUAWACS	Soviet Union Airborne Warning and Control System
SWAT	Subjective Workload Analysis Technique
SYMES	System Manager Expert System
SYS	System Engineering Studies
T&E	Test and Evaluation
TAL	Transfer Alignment
TF	Terrain Following
TF/TA	Terrain Following/Terrain Avoidance
TN	Unpredictable Relocatable Target
TP	Predictable Relocatable Target
TR	Technical Report
TRS	Technical Risk Studies
VISTA	Voice Interactive System Technology Assessment
VPI&SU	Virginia Polytechnic Institute and State University
WARM	Wartime Reserve Mode

1.0 INTRODUCTION

1.1 Purpose of the Research

The purpose of this research was to (1) develop and demonstrate a methodology for identifying crewmember informational demands and information management requirements when analyzing a mission scenario that describes crewmember activities in a "technology free" context, and (2) develop and demonstrate criteria for choosing appropriate technologies to reduce crewmember workload and to improve crewmember situation awareness. Specifically, the Human Factors Engineering Center (HFEC) at Virginia Polytechnic Institute and State University (VPI&SU) developed a methodology for identifying aircraft crewmember informational demands and information management requirements in a next-generation bomber, and demonstrated that methodology by applying it to a mission scenario that describes crewmember activities without identifying on-board technologies (i.e., it is "technology free"). Concurrent with developing the methodology, HFEC developed criteria for identifying appropriate technologies for alleviating crewmember workload and improving crewmember situation awareness.

In the report, a methodology is presented for analyzing a "technology free" mission scenario. A "technology free" mission scenario describes crew activities during a realistic mission without defining or limiting itself to specific technologies--a crewmember mission scenario (CMS). By first considering the crewmembers' decision-making activities and responsibilities, the human factors engineer can define crewmember requirements, informational demands and information management requirements for the crew. This can be done

without the constraints of pre-selected technologies. These demands and requirements can then be evaluated against criteria for technology insertion.

Criteria for technology insertion are a set of interrelated rules for determining whether or not a technology is appropriate for a specific application in a defined system. Criteria are structured in a logic-tree which is applicable to different candidate technologies. By appropriately matching crewmember and mission requirements with an available technology, it is believed that an enhanced crewstation can be achieved with reduced crewmember workload, improved situation awareness, and enhanced mission effectiveness.

A CMS describes crewmember activities during each leg of a mission without describing on-board technologies ("technology free"). Technology free means that while the technological capability exists (e.g., real-time sensors), no attempt is made to describe a specific piece of equipment or the tasks associated with its proper operation.

1.2 Project Background

As part of its longstanding involvement with the Human Engineering Division of the Armstrong Aerospace Medical Research Laboratory (AAMRL), the HFEC of VPI&SU contracted to conduct formal human factors engineering research on crewmember informational demands and information management requirements in a next-generation, manned, penetrating bomber. This Technical Report is the final output of the project -- Human Factors Report on Information Management Requirements for Next-Generation Manned Bombers, under contract F33615-85-D-0514, Task 10.

VPI&SU is committed to supporting Air Force research and development. The HFEC is pleased to be a part of the important on-going research work on improving crewmember situation awareness and reducing workload. HFEC's expertise in workload evaluation, aircraft simulation, display design, human-computer interaction, ergonomics, and safety makes it exceptionally qualified to perform advanced crewstation design research.

1.3 Research Objectives

One of the primary objectives of this research was to develop a human factors technique suitable for analyzing a next-generation, manned, penetrating bomber using only a scenario that describes crewmember activities and not specific technologies. At this time, no such analysis technique is known to be widely published or used. While this research only considered the issues of informational demands and information management in a next-generation bomber, it is believed that the methodology is applicable as a general design tool for other aircraft and complex control systems, and should be used during early concept definition efforts.

The HFEC conducted a structured human factors research project. The research activities are presented below and as a flow diagram in Figure 1-1. As illustrated, each research activity contributed to the next activity. By using a building block approach, the research had a defined structure as well as traceability. The culmination of the research was the delivery of this technical report and a presentation given at AAMRL's Crew Station Integration Branch.

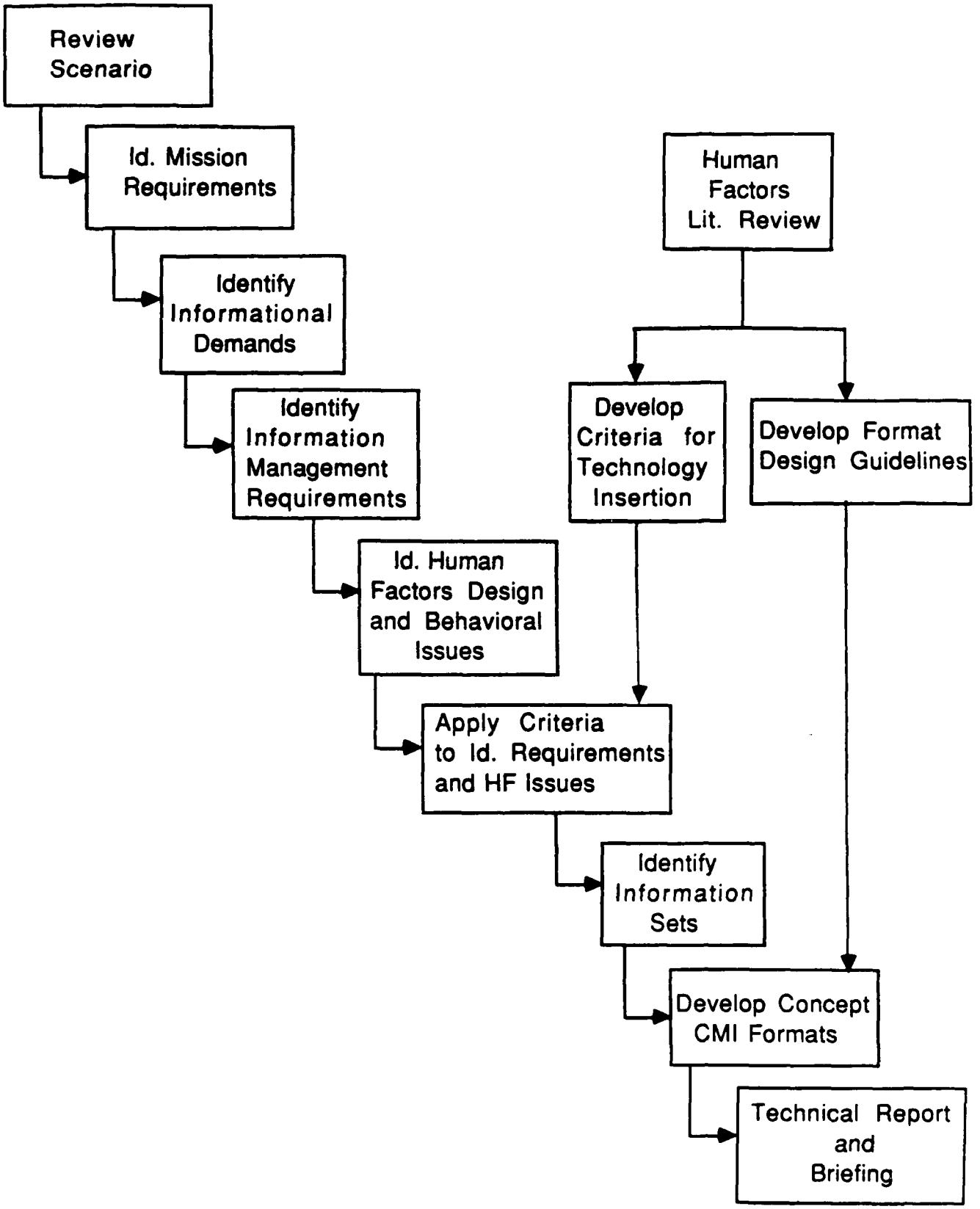


Figure 1-1. Activity Flow Diagram of Research Activity

Research Activities

(1) Perform a literature search/review on the following topics:

a) cockpit/crewstation automation technology,

b) cockpit/crewstation controls and display technology,

c) cockpit/crewstation design philosophy,

d) expert systems/artificial intelligence technology,

e) crewmember performance measurement techniques, and

f) aircraft-to-ground target acquisition technology.

(2) Develop a methodology for reviewing and analyzing the CMS and other sponsor furnished data to identify:

a) mission requirements,

b) informational demands,

c) information management requirements, and

d) human factors design and behavioral issues.

(3) Develop criteria for technology insertion.

(4) Apply criteria for technology insertion to the informational demands and information management requirements and identify opportunities for technology insertion.

(5) Develop conceptual information sets for a variety of mission scenario events.

(6) Develop "strawman" crewmember-machine interface design concepts based on technology insertion opportunities.

(7) Document and report the results to AAMRL/HED in the form of a technical briefing and technical report.

1.4 Definition of Technical Terminology

A glossary is included as part of this Technical Report. However, it is important to have a clear understanding of the following technical terminology prior to proceeding. Many of the terms listed below have multiple connotations and denotations. For the purposes of this report, the use of the terminology in the report is limited to the definitions provided here and in the glossary.

Aircraft Requirements. The specific capabilities of the aircraft needed to successfully complete a stated mission.

Automation. The accomplishment of a task by a machine instead of a human. (Wiener and Curry, 1980).

Cockpit Automation. Autopilots, flight directors, and other equipment associated with the control of the aircraft flight path and other aircraft systems. (Wiener and Curry, 1980).

Computer-Generated Displays. Using computer technology for the purposes of creating advanced visual isplay imagery which could not be achieved using conventional visual display technology.

Crewmember-Machine Interface (CMI). The proposed human-computer interaction design for the CMS aircraft and crew.

Crewmember Mission Scenario (CMS). A human-center approach to system development that makes the crewmember the primary object in the mission scenario by describing mission events and crewmember activities during each leg of the mission without specifying onboard technologies.

Criteria for Technology Insertion. Performance requirements for assessing the suitability of a candidate technology for a stated application in a defined system. The fulfillment of a set of performance requirements indicates that the technology is an acceptable solution for meeting stated technical requirements and crewmember demands.

Human-Computer Interaction. The means of communications between the human and the computer.

Information Management Requirements. Requirements which define the means of satisfying the informational demands of the crew. Information management requirements include the coordinating, monitoring, presenting, and updating of specific information or sets of information.

Information Sets. A collection of the information required by the crew to make a proper decision or to perform a task correctly.

Information Sources. Resources where data are obtained to satisfy the informational demands of the crew.

Informational Demands. Data the crew requires to be able to correctly respond to a scenario event.

Knowledge-Based Behavior. Human behavior characterized by conscious reasoning and problem-solving to make a decision when confronted with an unfamiliar situation.

Mission Requirements. Requirements which specify performances, capabilities, and constraints that must be met in order to satisfy mission goals.

Mission Scenario. A scenario that verbally describes mission events and summarizes typical operations, assumptions, and environments.

Mission Scenario Analysis Template (MSAT). A worksheet developed for recording data during the mission scenario analysis. The template is designed to be used for the analysis of each mission leg and provides data on ten parameters of interest.

Rule-Based Behavior. Human behavior characterized by invoking previously learned rules about a situation to make a decision when that recognized situation occurs.

Scenario Event. Any unplanned or planned event which occurs during the mission that requires the crew to respond.

Situation Awareness. Having information about the internal and external environment surrounding the aircraft.

Skill-Based Behavior. Sensory-motor performance that takes place without conscious control as smooth, automated, and highly integrated actions.

Systems Requirements. Those characteristics which the system (both personnel and machines) must manifest to satisfy the goal (mission) of the system. (Meister, 1985).

Technology. The application of an organized set of scientific knowledge and principles to the solution of a previously defined engineering problem.

Technology Free. Stating that a technological capability exists, but not describing how the technology is implemented. Stating a capability without specifying a piece of equipment or the tasks associated with performing the capability.

1.5 Description of Technical Report

This report proposes a methodology for analyzing a CMS and a methodology for selecting technology, demonstrates these methodologies, recommends conceptual designs, and identifies areas requiring additional human factors engineering research.

The Technical Report is the final output of this research project, as well as being a comprehensive review of the project. The Technical Report follows the logical procession of research activities in the approximate order it was performed (see Figure 1-1). To better assist the reader in finding the information he or she desires, a short description of each section is provided below.

SECTION ONE: INTRODUCTION

The reader is provided with an introduction to the research topic and the Technical Report. The section briefly describes the project including its purpose, background, and objectives. There is also a description of each section of the Technical Report.

SECTION TWO: SCENARIO REVIEW METHODOLOGY

The scenario review methodology developed for the CMS provided by Frick, et al., (1986) is discussed. The scenario review constitutes the majority of the analysis work performed on this project, and a thorough discussion of the philosophy and methodology for the scenario is provided.

SECTION THREE: MISSION REQUIREMENTS

The mission requirements for the CMS are discussed. Mission requirements are performances, capabilities, and constraints that must be met in order to satisfy mission goals. The determination of mission requirements is the basis for the assessment of the crew's informational demands and information management requirements.

SECTION FOUR: INFORMATION MANAGEMENT REQUIREMENTS

The important, integral role of information management in the CMS is presented Information management requirements are stated based on the scenario review analysis. Underlying the requirements for information management is the identification of informational demands the crew has throughout the mission. How well the crew accomplishes its mission is dependent on the timely availability, efficient communication, coordination, and management of information. As demands arise due to planned and unplanned scenario events, the crew must have the resources to respond quickly and correctly.

SECTION FIVE: HUMAN FACTORS DESIGN AND BEHAVIORAL ISSUES

The human factors design and behavioral issues peculiar to the CMS are addressed. Issues discussed are workload, stress, and training. The discussion takes into account philosophical and methodological considerations associated with the respective issues. In addition, how behavioral issues affect situation awareness, cognitive rehearsal, decision-making under uncertainty, and mental workload are addressed.

SECTION SIX: CRITERIA FOR TECHNOLOGY INSERTION

Criteria for technology insertion are proposed and structured as a logic-tree. Criteria are for assessing and recommending technologies based on operator and engineering requirements. Technology insertion recommendations are determined by which criteria are met. However, crewstation automation technology has bounded capabilities and applications and, where no automation capability exists or where none is applicable, a recommendation not to automate is made.

SECTION SEVEN: OPPORTUNITIES FOR TECHNOLOGY INSERTION

Opportunities for inserting state-of-the-art technology into the CMS aircraft information management requirements (from Sections 4.0 and 5.0) are identified. Criteria stated in Section 6.0 are applied to the requirements stated in Sections 4.0 and 5.0. Expert systems, computer-generated displays (CGD), and voice-interactive systems are considered as opportunities for technology insertion. These technologies were reviewed as part of the literature review, and a brief review of each technology is included.

SECTION EIGHT: CONCEPTUAL INFORMATION SETS

Conceptual or "strawman" designs for presenting and managing information for six scenario events are described. Conceptual information sets utilize the technologies recommended in Section 7.0. Each scenario event represents a particular condition during the mission when sets of information are demanded and must be managed effectively. Scenario events are described by what information is

demanded by the crew, the subject area of the information, and how expert systems could support the presentation and management of this information.

SECTION NINE: CREWMEMBER-MACHINE INTERFACE FORMATS

Conceptual or "strawman" visual displays are described for information sets described in Section 8.0. Display formats are based on a set of crewmember-machine interface (CMI) design guidelines (Appendix B: Guidelines for Crewmember-Machine Interface Design) adopted from formal guidelines reviewed as part of the literature review. The display formats represent sample displays for mission related, situation awareness, and system related scenario events. The emphasis of the CMI format designs is to show, by example, the potential information transfer available through the recommended CRT display technology. Display formats include the use of appropriate interface design and format techniques (e.g., functional grouping, coding, color, icons, symbology, etc.). Because of the multifunctional roles of crewmembers in the mission scenario, the conceptual displays are adaptive to changing scenario conditions or crewmember information needs (multifunction).

SECTION TEN: CONCLUSIONS

The Technical Report is concluded by reporting final recommendations for information management requirements for next-generation manned bombers. Human factors engineering issues that should be addressed in future research are also identified.

APPENDIX A: BIBLIOGRAPHY/ANNOTATED BIBLIOGRAPHY: HUMAN FACTORS LITERATURE REVIEW OF COCKPIT AUTOMATION TECHNOLOGY

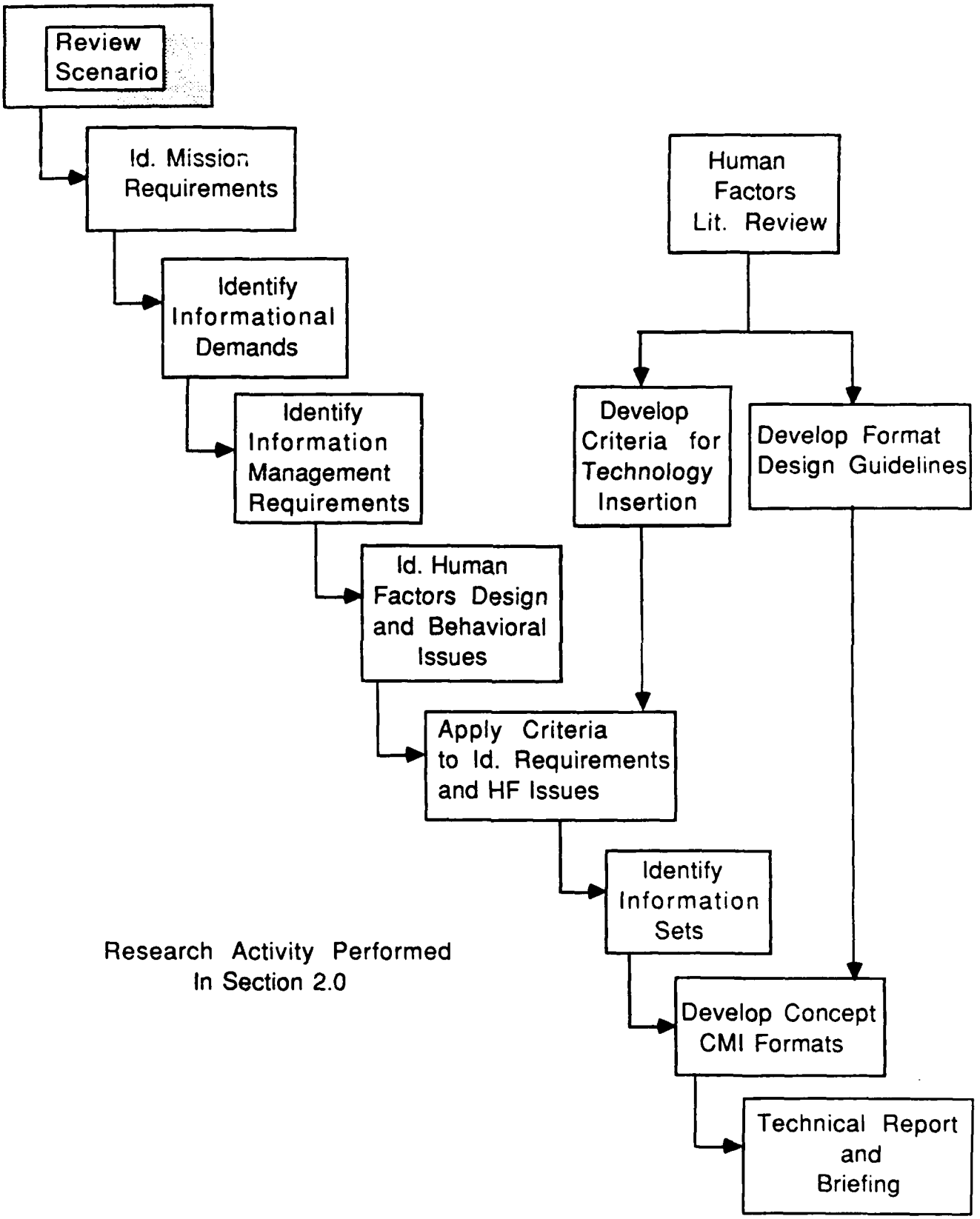
This appendix is the literature review of available and emerging state-of-the-art cockpit/crewstation technology, including, crewstation design philosophies, expert systems, visual displays, automatic target recognition systems, computer-generated displays, voice-interactive systems, and human performance measurement techniques.

APPENDIX B: GUIDELINES FOR CREWMEMBER-MACHINE INTERFACE DESIGN

This appendix contains the crewmember-machine interface (CMI) design guidelines that were used for creating conceptual CMI formats. The guidelines are extracted directly from Air Force Technical Report, ESD-TR-86-278, Guidelines for Designing User Interface Software, by Sidney L. Smith and Jane N. Mosier (1986). The Smith and Mosier (1986) report was used here because it is the most comprehensive set of user interface software guidelines currently available. The report proposes 944 guidelines for designing software to support the user interface to computer-based information systems. These design guidelines cover six functional areas; data entry, data display, sequence control, user guidance, data transmission, and data protection. For the purposes of this research, only data display guidelines were considered. Included in this appendix are display guidelines copied from pages 131-137, 141, 156-158, 163-164, and 198-204 of Smith and Mosier (1986).

APPENDIX C: MISSION SCENARIO ANALYSIS TEMPLATE DATA

This appendix contains the mission scenario analysis templates used to record data during the mission scenario analysis.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 2.0

2.0 SCENARIO REVIEW

2.1 Objectives

The major portion of this research was the review of a crewmember mission scenario (CMS) provided by Frick, et al. (1986). This scenario is described in Part 2.2 below. The philosophy behind the scenario is explained in Part 2.3. The HFEC was tasked to identify or determine the mission requirements, crew information demands, information management requirements and human factors issues in this scenario. However, no accepted methodology existed to do this. Therefore, a means to accomplish this by a disciplined scenario review technique was developed. The philosophy behind this technique is explained in Part 2.4. The traditional systems analysis approach is described in Part 2.4.1, followed by an almost comparative, general explanation of the systems analysis methodology based upon the CMS used in this research. This later explanation is in Part 2.4.2.

In 2.5, the four tasks of the scenario review are described. In Part 2.6 the template which HFEC developed to facilitate the scenario analysis is presented. Finally, Part 2.7 directs the reader to the various sections of the report which contain the results of the scenario review.

2.2 A Crewmember Mission Scenario (CMS)

HFEC reviewed an Air Force approved, technology free, mission scenario (Frick, et al., 1986) to determine information management requirements for crewmembers of a next-generation bomber. In the scenario, the aircraft used represents predicted capabilities of a

future, manned, penetrating bomber. However, the scenario is oriented to crew activities, describing human behavior and crewmember actions more than aircraft or equipment performance. This emphasis on the crew includes describing decision-making activities of the crew during each leg of the mission. For the purposes of the CMS, the aircraft's man-machine interface capability is considered "technology free." That is, crewmembers perform tasks and functions without a requirement to describe how they carry out their actions. In addition, the scenario makes no assumption of crew size or positions (i.e., "crew specialty usage" is not given).

The objective of the scenario review was to identify mission requirements and determine informational demands and information management requirements of the crew. As part of this review, human factors design issues pertaining to human performance and behavior were also identified. The results of the scenario review were the basis for defining the crew's technological support requirements. The mission scenario philosophy is described below.

2.3 CMS Philosophy

The CMS, as described by Frick, et al. (1986) is an enlightened approach to system development and represents a departure from the traditional method of developing mission profiles and scenarios. Mission profiles typically describe the logistics and major activities of a mission, and can be plotted versus time or graphed pictorially on a geographical map. Mission scenarios are usually divorced of any meaningful information pertaining to crew responsibilities, tasks, or decision-making and are limited to describing major mission events and

summarizing operations, assumptions, and environments (Meister, 1985). As a result, mission profiles and scenarios fail to provide sufficient information about the crew to permit a valid assessment of informational needs and to permit the identification of behavioral and design issues. The CMS provides this information and allows the human factors engineer to focus directly on crew requirements instead of merely extrapolating crew requirements from defined system requirements.

The CMS approach serves two purposes: (1) it makes the human element the primary design consideration, and (2) it allows technological capabilities to be applied to the crew requirements instead of technology requirements driving the human performance requirements. To the extent that crew requirements are indeed an important component of mission requirements, the explicit and declarative approach of the CMS clearly identifies crew-oriented, mission requirements. The subsequent system requirements detailed in the CMS represent the other components of mission requirements.

These two purposes represent a new view of early system development. The traditional "technology driven" approach to system development emphasizes the attainment of technological capabilities. Subsequently, established human factors techniques and methodologies for systems analysis are based on technology assessment. The CMS approach requires a new methodology for a scenario review, an evolved system analysis technique that is not technology driven.

2.4 Scenario Review Methodology

A methodology was needed that would determine crew requirements,

capabilities, and limitations prior to considering specific technologies or equipment. Given this opportunity to consider the crew in a "technology free" context, the first task was to create criteria for developing a usable methodology.

A methodology for reviewing the CMS would accomplish the following tasks:

1. Identify mission requirements.
2. Determine crew informational demands.
3. Determine information management requirements.
4. Identify human factors design and behavioral issues.

Additionally, these tasks would be accomplished without considering specific technologies. Established methods for systems analysis were not appropriate since they begin by considering technology. Therefore, an evolved methodology was needed; one based in proven application but applied in consonance with the CMS philosophy.

Developing a new methodology does not need to be a radical departure from traditional methodologies. Evolving established methodologies which consider the operator (crew) as a primary component in the system's design is a sound approach. Therefore, a new methodology is developed based on proven techniques. The basis for developing this new methodology was to amend the traditional techniques to consider the operator before the equipment.

2.4.1 Traditional Methodology. Traditionally, systems analysis has proceeded down a well traveled and proven path. A new system is desired and is defined by a mission statement and supported by system requirements. System requirements form the foundation of the conceptualization and development of the system. In aircraft

development, it is very useful to incorporate these requirements into mission profiles and scenarios. A review of the profile and scenario follows and results in the decomposition of the mission into mission requirements and performance functions. A design team of engineers then studies the mission requirements and performance functions to design a conceptual system (aircraft) which performs all identified functions and satisfies all mission requirements (Meister, 1985).

One of the major roles of human factors engineering during the conceptual stage of system development is to allocate performance functions as follows: (1) functions the crew alone performs, (2) functions the system equipment alone performs, and (3) functions the crew performs by interacting with the system. Commonly known as function allocation, it is accomplished through the application of a set of rules that define what functions are best performed by humans, machines, or both (Fitts, 1951, Price, 1985, Van Cott and Kinkade, 1972). These rules are applied to the previously identified performance functions, resulting in an initial division of labor. The final allocation is accomplished through an iterative process of trade-off studies and design alternatives. Trade-off studies assess such variables as design cost, system reliability and maintainability, and mission effectiveness (Meister, 1985).

The above methodology is often limited by its inability to optimize the human element in the system design. The design consideration of the system operator is limited to how well he/she operates equipment which satisfies the system requirements. Simply stated, the system operator is a secondary design issue during traditional system concept definition, with the primary design emphasis placed on the

incorporation of available or desired technologies. This approach cannot be applied to the CMS provided by Frick, et al. (1986) due to the nature of the scenario.

2.4.2 An Evolved Methodology. An evolved methodology was developed which considered the human element as a primary design issue at the concept definition stage. The methodology was bounded by the restriction that the CMS provided by Frick, et al. (1986) would be the only data source for analysis. In addition, this CMS does not completely describe all of the crew's activities during each mission leg (e.g., crew positions are not defined). Therefore, the goal was to analyze the available information for each mission leg of the CMS, with the focus being on the crew's actions during each leg. If a crew function was not described on a given mission leg (e.g., no mention of navigation), it was assumed that the function was occurring as would be expected without incident. The following steps were used in the evolved methodology (Figure 2-1).

Step One. The approach was to first identify the mission requirements by reviewing the CMS, because mission requirements form the foundation for defining the roles and goals of the crew during the mission. Mission requirements also put the system into a quantitative and qualitative context. Step One is performed in Section 3.0.

Step Two. A detailed mission scenario review followed the identification of mission requirements. Mission legs were categorized by mission phases. Crewmembers' informational demands and information management requirements were identified for each mission leg. These data were recorded on a Mission Scenario Analysis Template (MSAT). Human factors design and behavioral issues associated with information

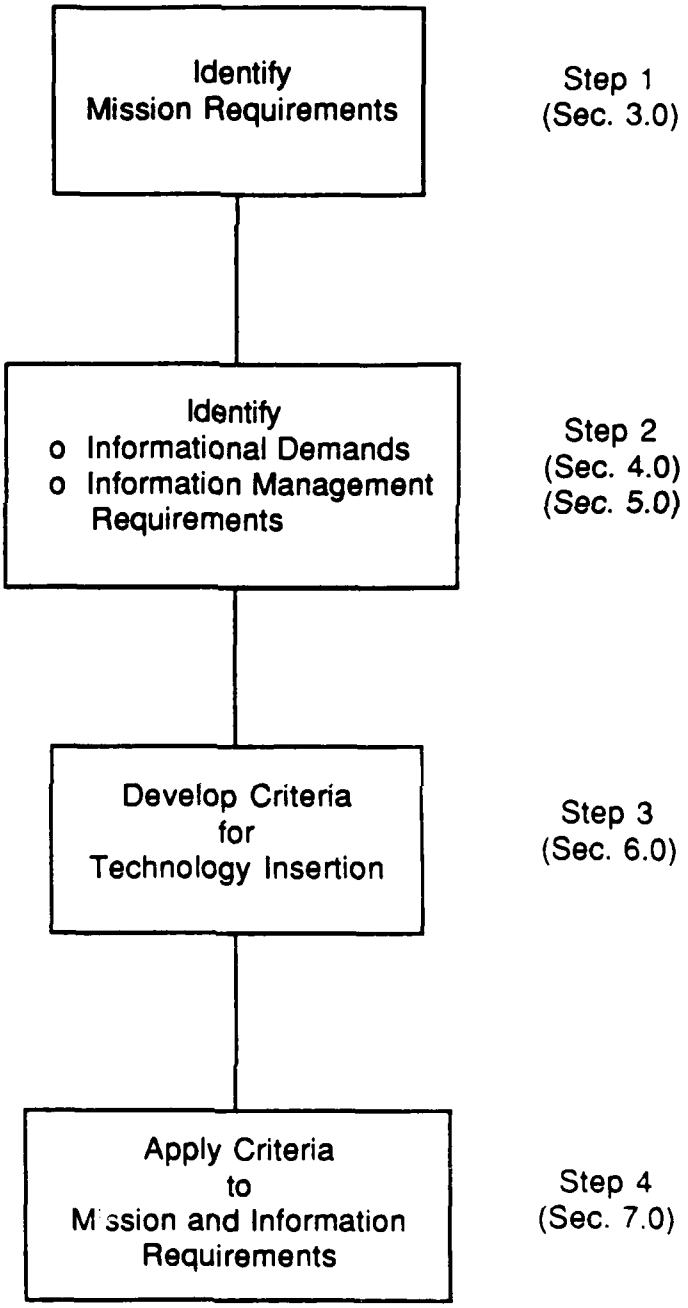


Figure 2-1. Evolved Methodology

management and mission execution were also identified. Step Two is performed in Sections 4.0 and 5.0.

Step Three. Available and developing state-of-the-art technologies were investigated. Criteria for selecting candidate technologies which satisfy crewmember and mission requirements were developed. Criteria are a logic-tree structure defining relationships between technology capabilities, operator and engineering requirements. Step Three is performed in Section 6.0.

Step Four. A quasi-function allocation was then performed via the criteria for technology insertion. Criteria were used to match crew and mission requirements with candidate technologies. Criteria were structured to consider informational demands and information management requirements previously identified and match them with candidate technologies which would support or satisfy these requirements. Step Four is performed in Section 7.0.

2.5 Scenario Review

The scenario review consisted of performing Steps One and Two as described in the previous paragraphs. The tasks performed during the scenario review served to form the basis for the next step of analysis. This methodology provides a certain degree of continuity, rather than attempting to extract information in a molecular or prioritized manner. The following tasks were performed:

(1) CMS familiarization, i.e., to read and study the scenario;

(2) to identify mission requirements as stated or inferred in the mission scenario;

(3) to identify crew informational needs and information management requirements during the mission; and

(4) to identify human factors design issues including workload, psychological stress, training and behavioral issues.

2.5.1 Task One: CMS Familiarization. Reading and studying the mission scenario was necessary for the investigators to have a working knowledge of the mission. Familiarization is a necessary part of any research work, and this research included reviewing the scenario and supplemental contract information, as well as reading relevant articles found during the literature review.

2.5.2 Task Two: Identify Mission Requirements. Mission requirements are performance requirements, capabilities, and constraints stated or inferred in the scenario. Mission requirements were defined as mission goals and underlying requirements. First, higher-order mission requirements (goals) were identified. As the scenario was reviewed, lower order requirements, capabilities and constraints were noted and categorized by: (1) aircraft requirements, (2) CMS requirements, and (3) human performance requirements.

The identification of mission requirements forms the framework for establishing and allocating functions. Functions are defined as "the means by which the system fulfills its mission requirements and accomplishes its mission" (Meister, 1985).

2.5.3 Task Three: Identify Crew Informational Demands and Information Management Requirements. The identification of crew informational demands and information management requirements was in

part already included in the scenario and only required transcription. The remaining demands and requirements were derived from a mission scenario analysis for each mission leg.

Informational demands are defined as the demands for specified sets of information required by the crew, in order to make operational decisions or perform mission related tasks. Informational demands exist for all decision-based functions.

Management requirements are defined as requirements for the obtainment, processing, transmission, and coordination of information or sets of information during each leg of the mission, as well as the overall management of information throughout the mission.

2.5.4 Task Four: Identify Human Factors Design and Behavioral Issues. Because the CMS describes crew responsibilities during each mission leg, human factors design and behavioral issues could be identified. In general, human factors design issues are characteristics of the system (aircraft) and its operating environment (mission scenario) which will affect human performance. In this study, human factors design issues are restricted to crewmember-machine interface (CMI) (man-machine interface issues). Behavioral issues are discussed in the context of mental workload, psychological stress, training, and other issues which affect crewmember behavior. Behavioral issues are discussed in Section 5.0, and crewmember-machine interfaces are discussed in Section 9.0.

2.6 Mission Scenario Analysis Template

A mission scenario analysis template (MSAT) was developed for facilitating the analysis of the CMS. The MSAT is designed to be used

for the analysis of each mission leg and provides data on ten parameters of interest:

(1) mission leg

(2) mission phase

(3) scenario event

(4) crew's response to event

(5) informational demands

(6) information sources

(7) crew's decision

(8) decision class

(9) action taken

(10) information management requirements

Figure 2-1 is an example of a completed template. The investigators completed MSATs for each crew function on each leg of the mission. Any one mission leg may have several crew functions, and each crew function has a separate template for that mission leg. A final rating was determined for each parameter on each mission analysis template.

The data obtained are critical for determining the crew's information management requirements and informational demands. The primary feature of the MSAT format is the diversity of data obtained on a one-page record. By recording only information pertinent to crew decision-making and subsequent actions, the mission scenario analysis is strictly focused on analyzing the role of the crew as decision-makers. Physical parameters such as altitude AGL, or degree changes in course are salient information for mission success, but are not necessary for analyzing the crew's decision-making role during the mission.

Mission Scenario Analysis

Record No. 105

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN5: Unpredictable RT located in search area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for locating unpredictable RT
Implication of options
CMF information (pre-planned response)
Tactical doctrine

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon
Schedule weapon delivery

(8) Decision Class:

Rule-based
Knowledge-based

(9) Action Taken:

Select launch point
Launch missile manually
Run post-release checklist

(10) Information Management Requirements:

Present CMF information
Present applicable tactical doctrine
Present flight plan for mission leg CC to DD
Coordinate information for selected launch point
Coordinate information for weapon delivery
Present post-release checklist

Figure 2-2. Sample Mission Scenario Analysis Template

The diverse content of the template permits the CMS to be analyzed in several different ways. Parameters can be analyzed within a specific mission phase, between different mission phases, or across the entire mission. Similarly, crew decision-making can be analyzed with respect to different mission phases or legs. Simply stated, the template provides the human factors engineer with a scratch sheet for recording the crew's role during the mission.

Referring to Figure 2-1, parameters 1 through 3 define the mission leg, phase and the scenario event. A scenario event is a planned or unplanned event which requires the crew to respond by making a decision and subsequent action. For any mission leg, there may be multiple scenario events. Classifying the mission by these parameters allows the role of the crew to be analyzed by mission leg, phase, planned or unplanned scenario events.

Parameter 4 describes the crew's response to the scenario event. Often this response is choosing from available options. An example of an unplanned event would be an aircraft interceptor (AI) threat encounter. The crew's response would be either to engage, avoid, or monitor the threat. The choice dictates the direction the event will take and possibly influences the final resolution of the event. Recording the crew's response defines the types of encounters the crew can be expected to face during such a mission.

Parameters 5 and 6 describe the information and information source the crew will need to make a decision after the initial response to the event. Following the previous example, if the crew decides to monitor the threat, information on the AI such as identification, course, and radar activities are required. This information would be

obtained from on-board radar, sensors, and enemy threat description data bases. These identified informational demands should be available to the crew whenever a similar event arises.

Parameter 7 is the crew's decision based on inspection of the information demanded. The information demanded by the crew must be assessed and a subsequent decision made. The decision can be classified, Parameter 8, as either knowledge-, rule-, or skill-based (Ramussen, 1983). Decision classes will be discussed in Section 5.0. The crew's decision is justified by some rationale and decision base. Recording decisions and their rationale provides a construct of what types of decisions the crew must make and what they base their rationale on.

Continuing with the example, upon examination of on-board radars and sensors, the AI threat is identified by its radar signature and plotted on a course traveling away from the aircraft. The crew makes the decision to continue monitoring the AI threat and maintain the planned course and schedule. The decision classification is a knowledge-based decision involving situation assessment and mission management. The decision is supported by tactical doctrine rationale.

Parameter 9 is the action taken as a result of the decision in Parameter 7. The action is simply carrying out the decision previously made. In the example, the action would be to continue monitoring the AI threat with on-board radar and sensors, as well as continuing with on-going scheduled activities.

Parameter 10 is the information management required while reacting to the event. An event requires information management for the sequence of activities described in the preceding paragraphs, and may

continue during following events and mission activities. Information management requirements ensure the coordination of necessary information and the successful management of information sets for a mission event. An event may continue for some time after initiation, with other events (planned or not) beginning or ending in this time frame. Here again, information management plays a key role of coordinating different information concurrently.

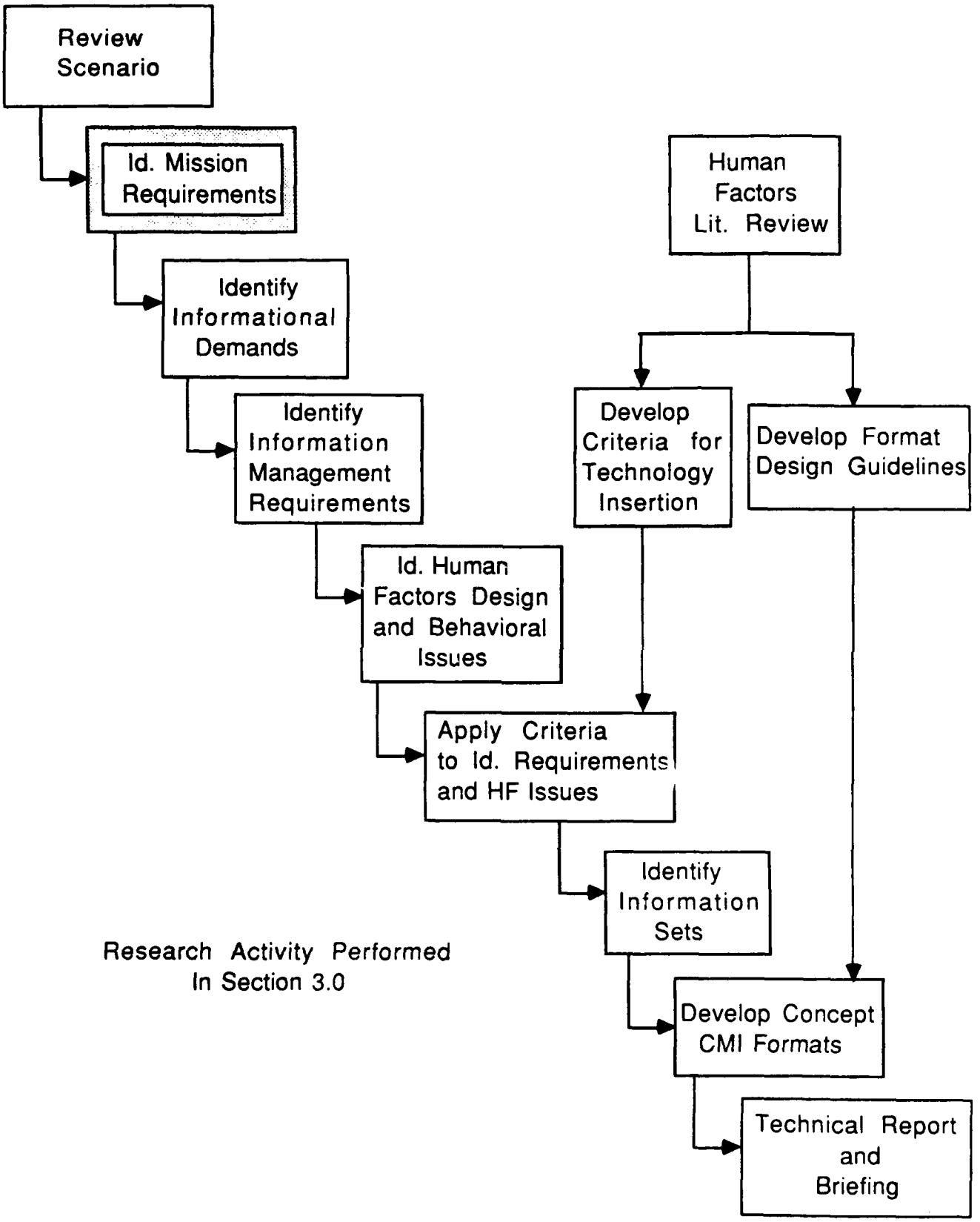
To conclude the example, information management requirements are to (1) choose a response to the event [monitor], (2) define and obtain the necessary information to evaluate the situation based on the decided response [identify, plot, reference, and assess], (3) decide on an action based on the information demanded [knowledge-based decision, supported by tactical doctrine], (4) support the accomplishment of the decision [continue monitoring and maintain on-going scheduled activities].

From the information recorded in each of the ten parameters, the crew's informational demands and information management requirements can be determined. There are two limitations in the MSAT approach. First, it does not address the issue of crew workload, which is approached separately in Section 5.0. Second, it only considers the events which occur in the CMS. This is especially important for unplanned events. While all unplanned events and contingencies cannot possibly be accounted for, it is important to be aware of this limitation. Therefore, the CMS must be written to adequately represent a complete mission, not necessarily a "worst case," but rather, one in which extensive demands are made on the CMI.

2.7 Summary

The scenario review represented the majority of the human factors analysis work for this project. The results of the scenario review are discussed in Sections 3.0, 4.0, and 5.0. After determining mission requirements, information management requirements, and human factors design and behavioral issues, opportunities for selecting technologies to meet these crew-oriented requirements can be investigated. Determining opportunities for technology insertion is discussed in Section 7.0. Copies of the MSAT sheets can be found in Appendix C.

An evolved methodology was presented which considers the human element as a primary design issue at the concept definition stage. The methodology is applicable to human factors research when performing a scenario review of a crewmember mission scenario. This methodology has four steps which are listed in Part 2.4.2.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 3.0

3.0 MISSION REQUIREMENTS

3.1 Objective

Mission requirements are higher-order objectives for the mission. Missions may have different objectives, but each mission has within it a set of requirements which bounds the intent and expectations of that mission. Establishing mission requirements defines the boundary of analysis for defining system and design requirements. In this section, Step One of the evolved methodology proposed in Part 2.4.2 is performed.

Mission requirements have an accompanying set of lower-order requirements. Lower-order requirements define the system more specifically, and collectively satisfy the higher-order requirements. How these lower-order requirements are satisfied can be interpreted as the system design. How the crew obtains information to satisfy their informational demands and managerial responsibilities can be defined as information management requirements. Informational demands and information management requirements are lower-order requirements. Therefore, the identification of mission requirements establishes heirarchical framework for defining information management requirements and informational demands (see Figure 3-1).

3.2 CMS Mission Requirements

Mission requirements are defined here as the primary capabilities of the system (aircraft) needed to successfully complete its mission. The mission requirements identified here are not intended to be a complete listing of all requirements, but they do represent those

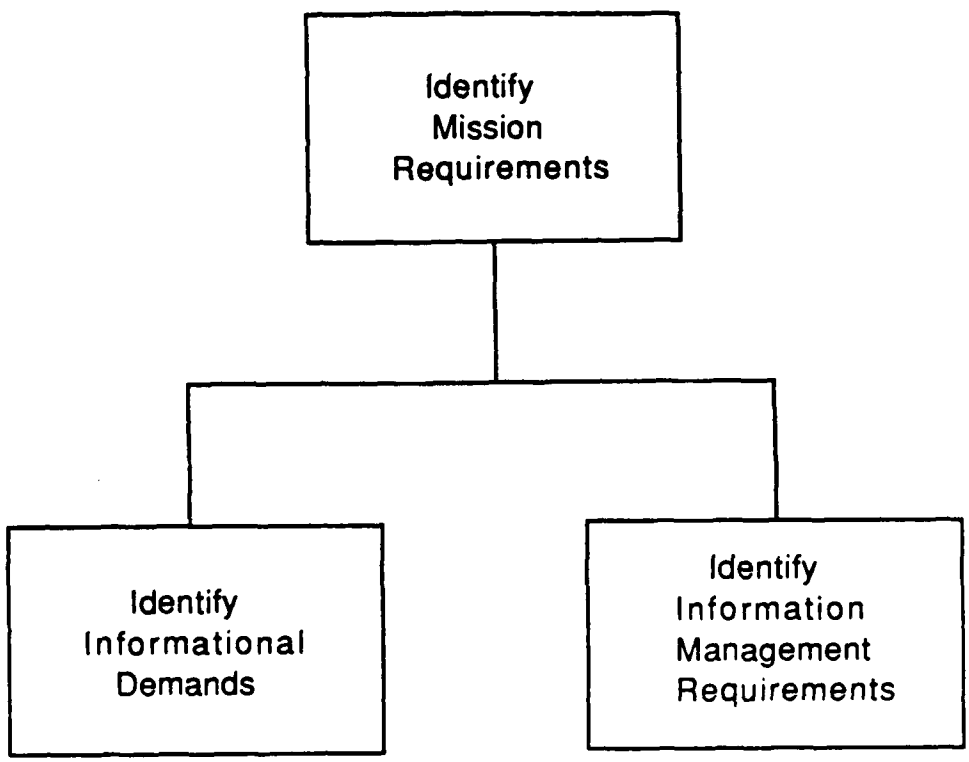


Figure 3-1. Mission Requirements Heirarchy

requirements stated or inferred in the CMS, which are important to the success of the mission.

The CMS has four general mission requirements to be met for mission success. These are:

1. penetrating enemy territory to within lethal range of fixed targets and SRTs,
2. finding and assessing the occupancy of SRTs,
3. delivering weapons effectively to fixed targets and appropriate SRTs, and
4. surviving the mission.

As was stated earlier, the above requirements are the driving force behind the design of the aircraft itself. When designing the aircraft, it is necessary to consider the effects of each mission requirement on aircraft and crew requirements. Below each of these four general mission requirements are listed aircraft, CMS, and human performance requirements.

3.2.1 Penetration Capability. The aircraft is expected to have the capability to successfully penetrate enemy territory, defeat enemy defenses and follow a prescribed course. In the design of an actual aircraft, technological capabilities that would permit such penetration are identified. Such capabilities would be specified as lower-order requirements. For the CMS, lower-order requirements which insure penetration capability are as follows:

Aircraft Requirements

1. All-weather capability.
2. Minimal radar detection.
3. XXXXXXX feet maximum and XXXXX feet minimum altitude AGL.

4. XXX to XXX knot speed range.
5. XXX radian maneuverability.
6. Automatic terrain following/terrain avoidance capability.
7. Air-to-Air radar.
8. Air-to-Ground radar.
9. Radar emission sensoring capability.
10. Auto pilot capability.
11. Navigation radar.

CMS Requirements

1. Ability to fly safely at XXX to YYY ft AGL by knowing terrain and threats.
2. Ability to identify and safely avoid obstacles.
3. Ability to evaluate current situation using historic and dynamic information, and make the optimum decision based on the information available.
4. Ability to detect lethal and non-lethal threats to the aircraft as they arise and successfully defeat or avoid such threats.
5. Ability to replan or revise when the intended flight cannot be executed as planned. Replanning should consider the best possible alternatives for maximizing mission effectiveness and success.
6. Knowledge of surrounding terrain, threats, obstacles, and passages.

Human Performance Requirements

Human capabilities also need to be specified. Given the above technology requirements, the crew can be expected to operate in an environment under heavy buffetting and rapidly changing gravitational and rotational forces. Apart from physiological fortitude, the penetrating capabilities requires human capabilities of:

(a) cognitive rehearsal

(b) situation awareness

(c) monitoring vigilance

(d) contingency planning, and

(e) rapid-decision making.

Cognitive rehearsal defines the crew's ability to mentally rehearse what they believe is going to happen in the near future. This of course is based on the assumption that the mission is progressing as planned. Cognitive rehearsal better prepares the crew to perform impending events.

Situation awareness defines the crew's ability to know the external and internal situation of the aircraft. Situation awareness is critical for successfully penetrating enemy territory, and is determined by the combined efforts of electronic sensors, single and integrated displays, crewmember vigilance, and tactical doctrine.

Monitoring vigilance defines the crew's ability to monitor the aircraft's and crew's performance and status and to react accordingly. The crew is a vital part of the "control loop" and is a critical backup if automated controls fail. The crew acts as an overall monitor when automated equipment (e.g., TF/TA) is activated. If the equipment

fails or degrades in performance, it is the responsibility of the crew to respond appropriately.

Contingency planning is the crew's ability to maintain back-up plans throughout the mission given any deviation from the original mission plan. Under autonomous operation of the mission, the responsibility of replanning the mission rests on the crew. The crew is burdened with the task of deciding what to do when an unplanned event occurs.

Rapid decision-making is the follow-up to the previous requirements. For each of the above requirements, the crew must maintain the ability to quickly receive, process, and decide on a response, given the knowledge at hand. At times the information at hand may be incomplete or wrong. In addition, the allowable time to make the decision may be extremely short. Thus, it is imperative that each crewmember display all of the above capabilities.

3.2.2 Finding and Assessing the Occupancy of SRTs. The mission requirement to find and assess the occupancy of strategic relocatable targets (SRTs) is a specific requirement of CMS mission. The requirement is fundamental for accomplishing the objectives of this mission and inherently calls upon the capabilities of advanced technologies. For the CMS, lower-order technical requirements for SRT evaluation include:

Aircraft Requirements

1. Air-to-Ground sensors.
2. Automatic target acquisition sensing capability.
3. Automatic target recognition sensing capability.
4. C3 and C2 capability.

5. Latitude/longitude navigation radar.

CMS Requirements

1. Ability to fly safely at XXX to YYY ft AGL.
2. Ability to identify and safely avoid obstacles.
3. Ability to update current navigational position using historic and dynamic information.
4. Ability to replan or revise the mission when the intended target strike cannot be executed as planned. Replanning should consider the best possible alternatives for maximizing mission effectiveness and success.
5. Knowledge of geography (terrain, threats, obstacles, and passages) surrounding targets.
6. Ability to locate, acquire, recognize, and evaluate for occupancy or activity both fixed and relocatable targets, in accordance with target acquisition descriptions in the mission scenario.

Human Performance Requirements

SRT acquisition involves the crew as the key link. The final decision of SRT recognition and occupancy rests with the crew. Therefore, the crews must have the ability to:

(a) plan and execute an effective search pattern,

(b) make decisions under varying degrees of uncertainty,

(c) make decisions under missing information, and

(d) make decisions under a limited amount of time.

The crew must plan and execute an effective search pattern. Effective search patterns are vital for SRT acquisition and often are unrecoverable decisions. There is enormous pressure on the crew to

find each SRT. "Where to look?" "How long to look?" "What is the aircraft's true location?" All these questions must be answered correctly if the target is going to be located.

Even with the assistance of automatic target recognition sensors there is expected to be a significant amount of uncertainty and/or missing information to prevent absolute identification and determination of occupancy of targets. The crew will make the final decision to commit to or abort a weapon delivery. Relative confidence in target recognition and occupancy becomes an important factor in the final decision. If a decision must be made, that decision is supported by how confident the crew is in identifying the target.

The time window for making a decision is very small, and will require the operator to quickly process and analyze a large amount of information. Therefore, the presentation and content of target acquisition information is critical for finding and assessing occupancy of SRTs.

3.2.3 Weapon Delivery. Weapon delivery is the primary objective for almost every bomber mission. The bomber travels to designated target(s), releases/launches its bombs/missiles and returns to a friendly base. Key factors in evaluating the success of the mission are known as measures of effectiveness (MOE). Weapon delivery involves factors such as determining target position, lethal weapon range, target defenses, aircraft approach requirements (altitude, speed, angle of approach, etc.), type of weapon, type of delivery, and weapon delivery point. Each factor greatly influences the MOEs for that target. Aircraft requirements which would support successful weapon delivery are listed below.

Aircraft Requirements

1. Ability to carry XXX tons of weapons.
2. Ability to carry missiles and gravity weapons.
3. Ability to support weapon arming/unarming.

CMS Requirements

1. Ability to calculate weapon delivery points and courses to maximize target destruction and minimize detonation hazards.
2. Ability to replan or revise the target strike when an unplanned event (e.g., threat or obstacle) prevents the aircraft from delivering the weapon as planned.
3. Knowledge of target area geography (terrain, threats, obstacles, and passages) surrounding targets.
4. Ability to deliver weapons at target.

Human Performance Requirements

During weapon delivery the crew is responsible for maximizing MOEs for each target. Prior to and following any weapon delivery there are a series of checklists which must be run. The crew is the final decision point to commit to or abort a weapon delivery. For the crew to take the correct action, they require specific information on the target. The presentation of information is of critical importance to delivering weapons successfully. Therefore, there are requirements for the crew during weapon delivery.

(a) ability to position aircraft so that the target is within lethal range.

(b) ability to determine best course for weapon delivery.

(c) ability to determine weapon delivery point.

(d) ability to commit to or abort a weapon delivery.

Electronic sensors can be expected to support the crew by indicating when a target is within lethal range, however, it is the responsibility of the crew to get the aircraft to that point. The crew faces the challenge of successfully defeating or avoiding enemy defenses surrounding the target. Some defenses will be known while others will be pop-up threats.

The crew will determine the best course for weapon delivery. As the crew acquires the next target, a determination will be made as to the best course for approaching, delivering against, and exiting the target area.

The crew must also determine the best time to deliver the weapon. There are different types of delivery patterns depending upon the weapon type, target position, and duration between delivery and detonation. Besides delivering the weapon, the crew must also be conscious of safely departing the target area before weapon detonation. Detonation pressure waves have the potential for disabling the aircraft, therefore, the crew must plan for wave blasts arriving after target strikes.

The crew makes the final decision between committing to or aborting a weapon delivery. It is the responsibility of the crew to assess all factors including target appropriateness for strike and ability to successfully deliver a weapon, and determine whether a weapon should be delivered or the strike should be aborted.

3.2.4 Mission Survival. Surviving the mission is as important a requirement as the other three mission requirements. The accomplishment of the mission cannot be termed a complete success unless the aircraft and crew return from the mission. This requirement places a

paradoxical requirement on the crew to avoid "life-threatening" encounters with the enemy as they attempt to achieve the other three requirements.

The most critical factor in surviving the mission is situation awareness. The crew must be aware of both internal aircraft status and the external environment around them, including both ground and air threats. While the crew is faced with the responsibility of avoiding all threats, it is the electronic sensors which bear the brunt of identifying threats in the immediate external environment. Technological requirements which will support the mission survival requirement are listed below.

Aircraft Requirements

1. All-weather capability.
2. XXX mile range.
3. XX hours continuous flight time.
4. Minimal radar detection.
5. XXX pounds capacity.
6. XXX feet maximum and XXX feet minimum altitude AGL.
7. XXX to XXX knot speed range.
8. XXX radian maneuverability.
9. Automatic terrain following/terrain avoidance capability.
10. Air-to-Air radar.
11. Air-to-Ground radar.
12. C3 and C2 capability.
13. Radar emission sensoring capability.
14. Navigation radar.

CMS Requirements

1. Ability to identify and safely avoid obstacles.
2. Ability to evaluate current situation using historic, dynamic, and doctrinal information, and make the optimum decision based on the information available.
3. Ability to be alert to lethal and non-lethal threats to the aircraft as they arise and to be able to successfully defeat or avoid such threats.
4. Ability to replan or revise the mission when the intended mission cannot be executed as planned. Replanning should consider the best possible alternatives for maximizing mission effectiveness and success.
5. Complete knowledge of geography (terrain, threats, obstacles, and passages) surrounding planned mission course.

Human Performance Requirements

Uncertainty and lack of information are the two principal factors which degrade the chances of mission survival. It is also postulated that "all the automation in the world" will not provide all the information and certainty that insures mission survival. Automation can reduce uncertainty and enhance relevant information, but it is the crew that will bear responsibility for making knowledge-based decisions which affect mission survival. Mission survival places specific requirements on the crew and these are listed below.

a. Ability to make knowledge-based decisions with missing, incomplete or incorrect information.
b. Ability to assimilate relevant information concerned with mission survival.

c. Ability to process, interpret, and manage rapidly changing information.

d. Ability to manage logistics of mission under autonomous conditions.

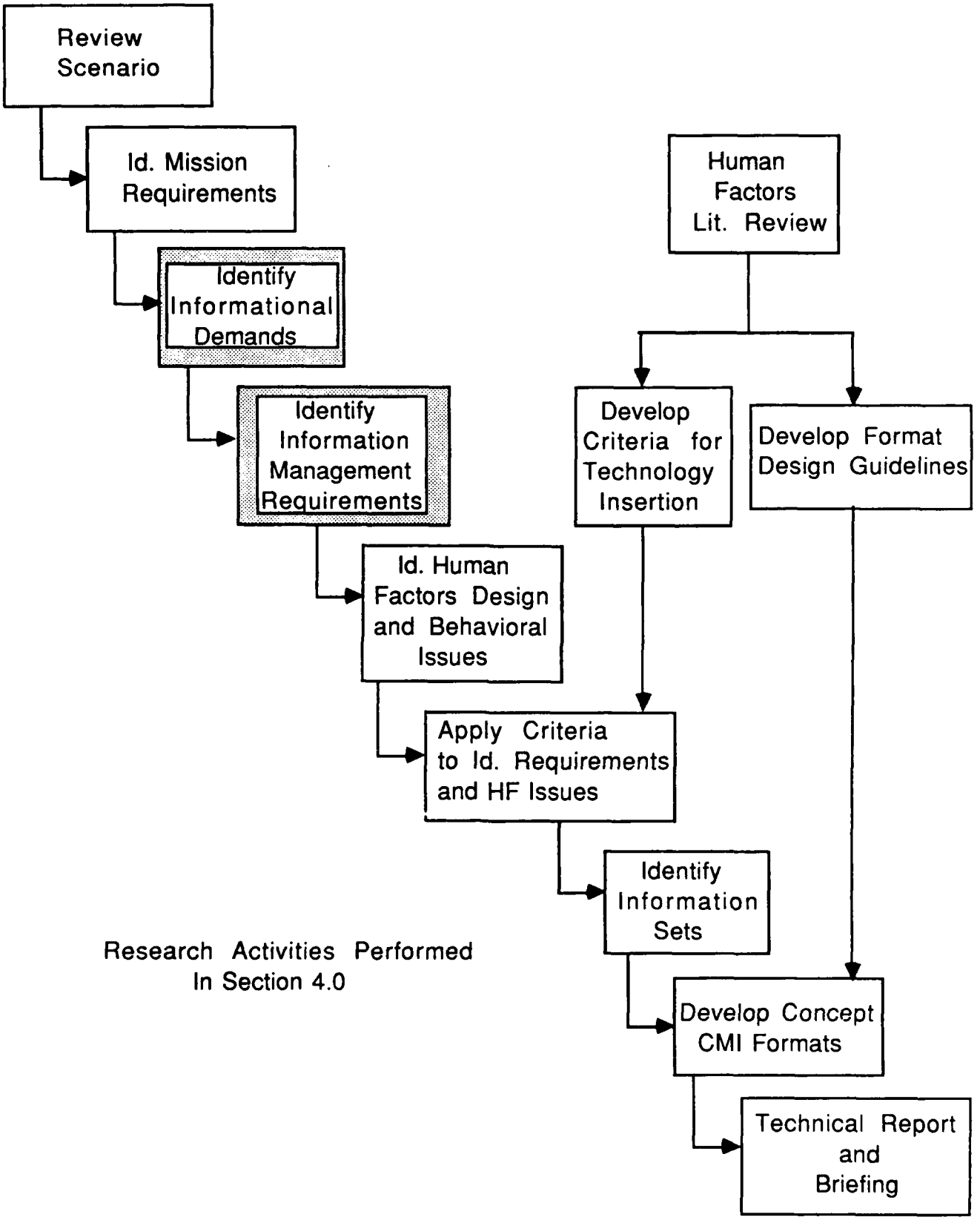
3.3 Summary

CMS mission requirements were defined. This section completes Step One of the evolved methodology proposed in Part 2.4.2. These mission requirements define the primary capabilities of the system (aircraft) needed to successfully complete its mission. Four general mission requirements to be met for mission success were identified:

1. penetrating enemy territory to within lethal range of SRTs,
2. finding and assessing occupancy of SRTs,
3. delivering weapons effectively to appropriate SRTs, and
4. surviving the mission.

The mission requirements stated above are higher-order design goals which are met by lower-order system design and crew requirements. Two lower-order requirements are information management requirements and crew requirements. In Section 4.0, information management requirements and their respective informational demands are identified. Crew requirements are addressed in Section 5.0. It is worth repeating that as the lower-order requirements are satisfied, consideration must also be given to assuring that the mission requirements are satisfied.

Mission requirements have an accompanying set of lower-order requirements. Lower-order requirements more specifically define the aircraft, CMS, and human behavioral requirements. Collectively these lower-order requirements satisfy the higher-order requirements.



Research Activities Performed
In Section 4.0

4.0 INFORMATION MANAGEMENT REQUIREMENTS

4.1 Objectives

Information management requirements and informational demands for the crew in the CMS are identified and discussed. In this section, the first part of Step Two of the evolved methodology proposed in Part 2.4.2 is performed; the second part of Step Two is performed in Section 5.0. The objectives of this section are to list the information the crew needs during the mission scenario, describe the organization of this information, and identify information management requirements for coordinating the effective presentation and management of this information. This section defines a structured relationship between the crew's informational demands, information sources, and the information management requirements of the crew as they respond to different scenario events.

4.2 Identifying the Crew's Informational Demands and Information Management Requirements

For any event which occurs during the mission, the crew has to respond in some manner to the event. The crew's response is based on assimilating specific information and making an appropriate decision or action. Informational demands are data the crew needs to respond to the scenario event. Information sources are resources where the data are obtained. Information management requirements describe how the demanded information needs to be presented and managed. Information management requirements are the means of supplying the information to the crew and include coordinating, monitoring, presenting, and updating

specific information or sets of information. Informational demands, associated information sources, and related information management requirements were identified for each scenario event as part of the mission scenario analysis.

Scenario events are both planned and unplanned events. Planned scenario events are occurrences which are intended to happen and for which the crew has a preplanned response or a set of alternative responses. By definition, unplanned events are occurrences which do not happen as part of the preplanned scenario. An unplanned event may be either a planned event which does not occur as planned (e.g., a premature descent) or it may be a totally unplanned event (e.g., a chance encounter with an enemy airborne interceptor). An unplanned event occurs concurrently with a planned event, because a mission is planned from take-off to landing. How much unplanned events contribute to additional informational demands and information management requirements of the crew greatly affects how well the crew can respond to the planned and unplanned events. How unplanned events contribute to the crew's workload is discussed in Section 5.0.

Any scenario event requires the crew to assimilate different types of information before making an appropriate decision or response. As an example, when responding to an obstacle, the crew would consider such things as the effect of the response on the mission plan, the location of area threats and other obstacles, navigation and aircraft flight performance (AFP) information. In this example, the crew requires (or demands) information regarding the preplanned mission, the external world, navigational data and aircraft flight performance to be able to appropriately respond to the event.

The mission scenario analysis provided a listing of what information was needed for each scenario event in the CMS. The analysis also provided data for determining the organization of the information. To describe the organization of the information, informational demands were classified by subject areas. As an example, does the crew require information pertaining to the planned mission, the status of the aircraft, or the immediate external world of the aircraft. Depending on the scenario event, the crew requires information from individual or multiple subject areas. Therefore, determining informational demands and information management requirements also involves determining the organization of information.

Informational demands, information sources and information management requirements were classified by subject areas. Subject areas are defined here as qualitatively independent realms of information. The data from the mission scenario analysis templates were analyzed to determine the number and realms of subject areas. Three independent subject areas were identified: (a) mission related information, (b) external situation awareness related information, and (c) system internal situation awareness information (Figure 4-1). Below, each information type is defined and the respective informational demands, information sources, and information management requirements listed.

4.2.1 Mission Related Information. Mission related information pertains to information regarding the planned mission. Types of information include mission flight plans, course changes, and scheduled activities such as planned target launch points, navigation updates,

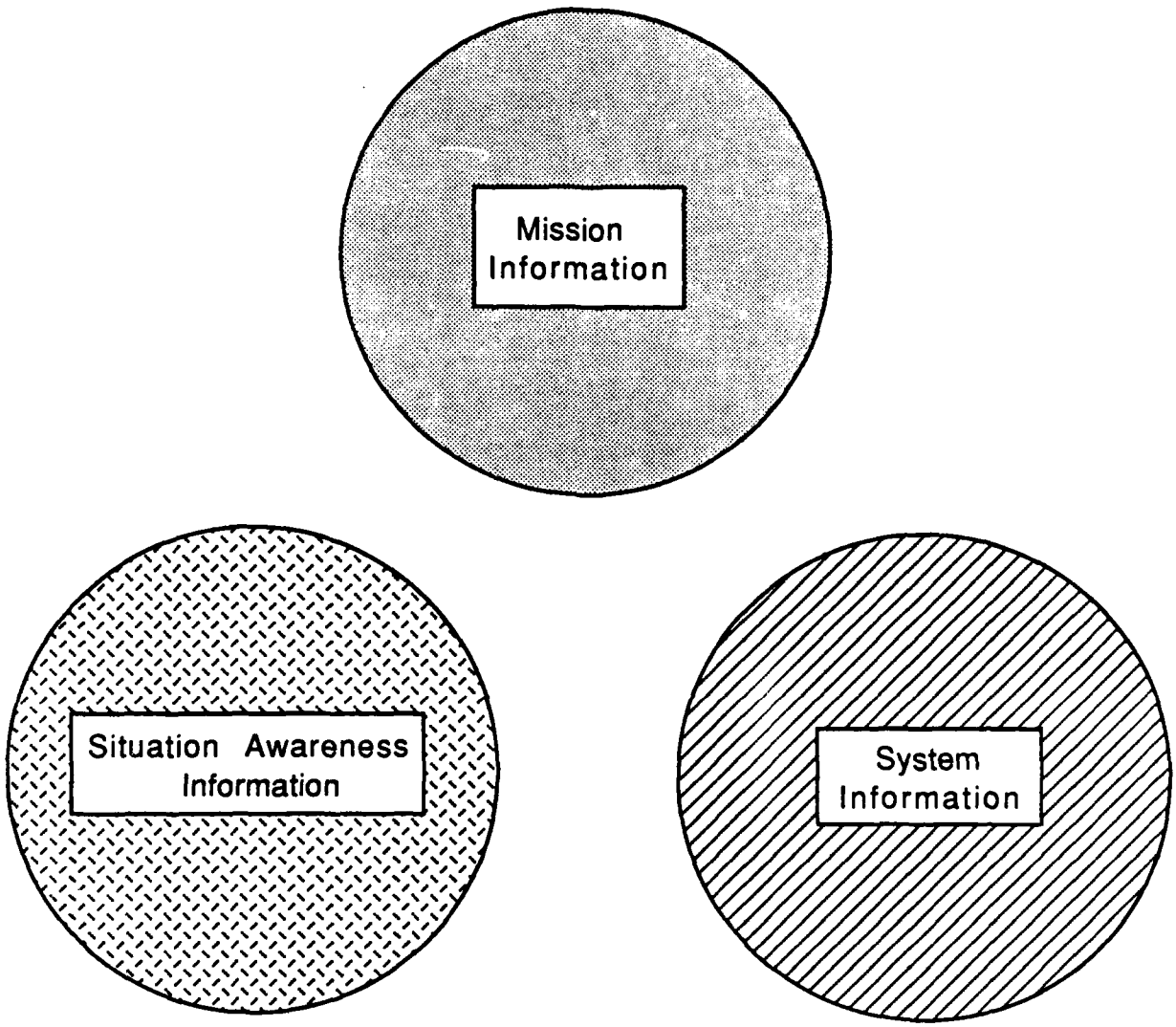


Figure 4-1. Information Subject Areas

and submitting of strike reports. Mission related information is information that only applies to that specific mission.

Mission Related Information Demands. Mission related informational demands are considered as the crew's requests for information regarding planned events throughout the mission. These informational demands are queries regarding preplanned events, target area geography or preplanned, known threats. This type of information is obtained from the crew's combat mission folder (CMF). As the crew carries out the mission they continually require information for each planned event of the mission. The CMF contains all of the applicable operational data for the crew to fly the mission.

Mission related informational demands are also the crew's requests for information regarding implications of unplanned events on the planned events and goals of the mission. The crew requires information about the planned mission as they replan or consider alternative contingency plans, because of unplanned events disrupting the planned mission. In addition, the crew may also request information on applicable tactical doctrine for responding to the unplanned event. These informational demands include response options for unplanned mission related events, such as battle damage, unplanned threats causing course deviation, or updated orders. As unplanned events occur, the crew must consider the implication of the event on the possibility for mission success.

The informational demands listed below are the crew's demands for mission related information in the CMS. These demands represent informational demands for both planned and unplanned events.

Table 4-1. Mission Related Information Demands

CMF Information (alternate PSBs)
CMF Information (area geography)
CMF Information (area threats)
CMF Information (distance to HHCL)
CMF Information (deconfliction information)
CMF Information (location and height of known obstacle)
CMF Information (mission flight plan)
CMF Information (mission planning)
CMF Information (preplanned response)
CMF Information (preplanned, known SAM radar sites)
CMF Information (fixed target information)
CMF Information (launch point)
CMF Information (unpredictable RT information)
CMF Information (predictable RT information)
CMF Schedule

Implication of EAM on mission plan
Implication of WARM on mission plan
Implications of options

Launch point for fixed target
Launch point for predictable RT
Launch point for unpredictable RT

OAS reprogramming results

Response options for aircraft off of route
Response options for mission behind schedule
Response options for level of battle damage
Response options for locating a predictable RT
Response options for locating an unpredictable RT
Response options for locating unoccupied, predictable RT
Response options for not locating unpredictable RT

Tactical Doctrine
Target book file
Target strike results
Time to detonation wave
Time to reach HHCL

Mission Related Information Sources. Information sources supply the information to meet the demands. Information sources are data bases, applicable tactical doctrine, the CMF, sensors, equipment, and checklists.

The combat mission folder (CMF) is the most vital resource for mission related information. The CMF provides the crew with the required operational data for the crew to fly the mission. The CMF contains information regarding the flight plan, known threat locations/types, target descriptions, offensive and defensive tactics, and terrain.

Tactical doctrine is also a significant resource for the crew's informational demands. Generally, when the crew contemplates options at a decision point during the mission, the crew will consider or base their decision on applicable tactical doctrine. Below are listed the corresponding information sources for the mission related informational demands.

Mission Related Information Management Requirements. Information management requirements for mission related information include the presentation and coordination of information for the informational demands listed above. For each informational demand, there is the requirement to present the information effectively and correctly. An example would be the presentation of CMF information, such as known area threats or area geography. Careful consideration must be given to choosing the most effective manner for presenting such information. Presenting information also includes presenting options for mission related events. Examples would be presenting options such as whether

Table 4-2. Mission Related Information Sources

CMF

- Area threat location/types data base
- C^2 and C^3I information
- Defensive tactics
- HHCL preparation procedures data base
- Mission flight plan
- Offensive tactics
- Target book file data base
- Target strike data base
- Weapon delivery data base

Tactical Doctrine

to strike a relocatable target (RT), mission replanning, or selecting an alternative post-strike base (PSB).

In addition, information management requirements support any coordination of mission related information to real-time activities. As an example, there is an information management requirement for coordinating information from the image/search of RTs to known imagery of the RT search area.

Listed in Table 4-3 are the information management requirements for mission related informational demands.

Mission related information should be available to the crew throughout the mission. The demand for mission related information may be spontaneous for unplanned events or scheduled for planned events. Regardless, the crew should have immediate access to the information demanded.

One way of providing this capability is to construct information sets for possible scenario events. The mission scenario analysis provides a listing of 145 different scenario events. However, this number of events can be reduced into a smaller number of general categories of events. Categorization of scenario events also provides information sets. Information sets are a structured relationship between information subject areas, informational demands, information sources, and information management requirements. Categorizing scenario events as information sets is discussed in Section 8.0.

4.2.2 Situation Awareness Information. Situation awareness information pertains to information about the external world of the aircraft. The majority of situation awareness information has to do

Table 4-3. Mission Related Information Management Requirements

Coordinate information for image/search of TN area
Coordinate information for second search/image of TN area
Coordinate information for correct to track
Coordinate information for missile reprogramming
Coordinate information for selected launch point
Coordinate information for TAL maneuver
Coordinate weapon delivery schedule
Coordinate information for mission replanning
Coordinate navigation/AFPI information to rejoin preplanned route

Estimate aircraft range, given fuel loss rate
Estimate remaining fuel upon arrival at alternate PSB

Format strike report

Present applicable tactical doctrine
Present CMF information (area threats)
Present CMF information (alternate PSBs)
Present CMF information (area geography)
Present CMF information (deconfliction considerations)
Present CMF information (mission flight plan)
Present CMF information (mission planning)
Present CMF information (fixed target information)
Present CMF information (predictable RT information)
Present CMF information (unpredictable RT information)
Present CMF schedule
Present ETA/EDA to HHCL
Present HHCL preparation procedures
Present pre-arm checklist
Present mission flight plan
Present replanned route to alternate PSB
Present OAS reprogramming report
Present target book file
Present options

Update data bases associated with mission route
Update mission flight plan data base
Update target book file data base

with the immediate external environment of the aircraft. The crew needs to know what is occurring in the air and on the ground within the vicinity of the aircraft. Situation awareness can therefore be defined as the level of relevant information the crew has versus the possible relevant information the crew could have regarding the immediate external environment of the aircraft. (Internal situation awareness is addressed as system information in Part 4.2.3.)

Situation Awareness Informational Demands. Situation awareness informational demands can be general or specific. Throughout the mission, the crew must be vigilant of external changes and events along each mission leg. This is general situation awareness information and can be assumed to be a continuous activity. An example of a continuous activity for general situation awareness is monitoring for pop-up threats, detecting weather fronts, receiving C^2 and C^3I transmissions, or monitoring for other aircraft.

There is also the case of specific situation awareness informational demands which are peculiar to a given scenario event. The event may be planned or unplanned, but the crew has the same demands for information on the current situation of an external object or activity. Examples of specific situation awareness are the monitoring of known, planned SAM acquisition radars, the tracking (course/location) of a SAM or an AI, or the imaging of an RT.

Informational demands are listed below for situation awareness information. During the mission scenario analysis, only specific, situation awareness informational demands were identified for scenario events.

Table 4-4. Situation Awareness Informational Demands

AI activity
AI missile course/position
AI missile type strike potential
AI strike potential
AI type

C^2 checklist results
Coastline activities
Confirm identification of known, preplanned SAM radar threats
Content of EAM
Content of WARM

Detection of pop-ups
Detection of target in TN search area
Direct target imaging

Image offset aimpoints
Imagery of TN search area

Location and height of tower
Location and height of obstacles
Location and height of power line

Response options for AI in search mode
Response options for AI in track mode
Response options for AI signal goes down
Response options for SUAWACS detection
Response options for SUAWACS to AI data link detection
Response options for known, preplanned SAM radar threats
Response options for SAM acquisition radar
Response options for SAM radar going down
Response options for SAM type fire control radar detected
Response options for SAM type missile firing
Response options for SAM type up-link signal detection
Response options for unknown, ground-based radar

SAM course/location
SAM radar activity
SAM radar identification
SAM strike potential
SAM type
Ship location/identification
SUAWACS activity

Time to detonation wave
Target occupancy data

Situation Awareness Information Sources. Situation awareness information sources include on-board sensors, data bases, checklists and applicable tactical doctrine. It is assumed that the greater majority of the situation awareness information will be obtained by current and future electronic sensor capabilities. This assumption does not specify any specific technology, but rather states a known fact of modern-day bombers and the acceptance of predicted capabilities in the near future.

Data bases provide the necessary information for identifying and describing enemy threats such as radar, SAMs, and aircraft and ships. These data bases match external emission signatures to known, enemy threat signatures to provide an accurate identification of the threat.

Tactical doctrine is a reference source for responding to external events such as enemy threats. Applicable tactical doctrine is also an information input for the crew deciding on response options for defensive measures.

Listed in Table 4-5 are information sources for the situation awareness informational demands listed previously.

Situation Awareness Information Management Requirements. Information management requirements for situation awareness information is probably the most challenging management requirement. Given the nature of the mission, specific situation awareness occurrences require expedient presentation of information to the crew. Therefore, a great emphasis must be placed on the sensing system to acquire and process information quickly so that the information can be presented to the crew. The crew, in turn, is burdened with the task of initiating a response within an acceptable timeframe.

Table 4-5. Situation Awareness Information Sources

AAM tracking sensors
AI data base
AI missile data base
AI radar data base
Aircraft tracking sensors

C^2 link checklist

External communications sensors

Forward-looking radar sensors

Radar data base

SAM radar tracking sensors
SAM tracking sensors
SAM data base
SAM radar data base

Tactical Doctrine
Target imagers/sensors
Target occupancy sensors

Coordination and presentation of situation awareness information is very important to enhance the crew's situation awareness. Information obtained by offensive and defensive electronic sensing must be coordinated to provide the crew with the best defensive electronic countermeasures (ECM), evasive maneuvers, and navigational tracking information, as well as offensive imaging of RTs and fixed targets.

Detection, identification, presentation, monitoring and tracking of enemy threats are a major function of situation awareness information management. Information must be handled for monitoring activities of ground based radars such as SAM radars; aircraft, such as AIs and SUAWACS; naval ships; and in addition, track surface-to-air missile launches. Situation awareness information management requires keeping close tabs on every external object with the capability of affecting the planned mission.

Presented in Table 4-6 are the identified information management requirements for situation awareness in the CMS.

Situation awareness information should be available to the crew throughout the mission. The demands for situation awareness information are mostly spontaneous due to unplanned events, such as non-prelocated SAM acquisition radars and encounters with enemy AIs. Scheduled (planned) events, like target imaging, also require expedient processing and presentation of information. General situation awareness such as on-going defensive radar monitoring, weather front detecting, receiving C^2 and C^3I transmissions, and terrain mapping requires the same attention to providing current and correct information as is required for specific situation awareness.

Table 4-6. Situation Awareness Information Management Requirements

Coordinate countermeasures information
Coordinate evasive maneuvers information
Coordinate information for correct to track
Coordinate information for radar jamming
Coordinate information for image/search of TN area
Coordinate information for second search/image of TN area
Coordinate information for mission replanning

Monitor AI activity
Monitor and track AI
Monitor and track SUAWACS
Monitor for AI activity
Monitor for possible, additional SAM launches
Monitor SAM acquisition radar activity
Monitor SAM radar activity
Monitor SUAWACS activity

Present AI missile course/position
Present AI search radar detection/identification
Present AI type and strike potential
Present C^2 link checklist
Present detection of unknown, ground-based radar
Present ground-based radar identification/locatoin
Present direct target imaging
Present image offset aimpoints
Present imagery of target in TN area
Present target occupancy information
Present location and height of obstacles
Present location and height pop-ups
Present location and height of powerline
Present options
Present SAM acquisition radar detection/identification
Present SAM radar(s) detection/identification
Present SAM radar activity
Present SAM radar signal detection/identification
Present SAM target engagement radar detection
Present SAM course/position
Present SAM course/position
Present SAM firing and up-link signal detection

Table 4-6. (Continued)

Present SAM launch detection/identification
Present SAM type and strike potential
Present SAM up-link signal detection
Present ship detection/identification
Present time to detonation wave
Present EAM
Present WARM
Present WARM

Record EAM

Submit strike report

Information sets including situation awareness information are discussed in Section 8.0.

4.2.3 System Information. System information plays a primary role in any mission sortie. System information is defined here as any information pertaining to the aircraft performance, capability, equipment status (including malfunction or failure), or operational procedures and checklists. The crew has a continuous need for information regarding the status of the aircraft. Naturally, the specific information needed depends on the crewmember's position and functions and on the aircraft status itself. However, throughout the mission and for every scenario event, some level of system information is required.

System Informational Demands. System informational demands cover the information required to operate the aircraft, regardless of the actual mission. System information includes aircraft flight performance information (AFPI) and navigation information which are continually referenced and updated during the mission. Another major type of information is the results of operational checklists, such as takeoff, flight, weapon delivery, and terrain following (TF). Operational checklists are a necessary but time consuming part of the mission for the crew. Many checklist items refer to verifying the settings of control switches. What is important about checklists are the results of the checklist, rather than the actual performance of the checklist. Therefore, the crew's informational demands for checklists are for the results of the checklist.

An important capability of most modern-day systems and equipment is the built-in-test (BIT) for identifying failures or malfunctions in

demands for results of failure analysis are an important component towards resolving the equipment failure in the aircraft. In addition, system information can provide procedures for trouble-shooting faults and failures in the failed equipment when the BIT is not sufficient.

Response options for system related decisions are part of the crew's system informational demands. As an example, given the current fuel level status of the aircraft, what are the response options for the given scenario event? Such information requires a significant assimilation and processing of information to present viable options.

Listed in Table 4-7 are the system informational demands for the CMS which were identified during the mission scenario analysis.

System Information Sources. Information sources for system information are sensors, equipment, data bases and checklists. On-board sensors are the myriad of sensors for monitoring the aircraft system's health and status. Equipment makes up the aircraft system and is the individual resource for obtaining equipment information. Checklists and data bases are the documentation and resources for the successful operation of the aircraft while in-flight.

Listed in Table 4-8 are information sources for the systems informational demands listed above.

System Information Management Requirements. Information management requirements for system information require the presentation of continuously monitored system status information and also the coordination of specific system and equipment information. Information management requirements exist for two separate functions; monitoring the health and status of the aircraft, and coordinating

Table 4-7. System Informational Demands

AFPI data
Analysis of battle damage to aircraft
Analysis of damage to Doppler radar
Analysis of damage to fuel system
Analysis of operational status of jammer
Analysis of operational status of primary radar
Analysis of jammer BIT
Analysis of missile BIT
Analysis of primary radar BIT

Bomb abort checklist results
Bomb run checklist results

Climb checklist results

Fuel loss rate
Fuel level status

Missile abort checklist
Missile BIT report
Missile launch checklist results
Missile post-release checklist results
Missile pre-launch checklist results

Navigation data

Pre-Bomb run checklist results
Procedures for fault tree analysis of jammer malfunction
Procedures HHCL preparation
Procedures for primary radar failure analysis

Response options for jammer malfunction
Response options for missile radar altimeter malfunction
Response options for primary radar failure
Response options for level of battle damage
Response options for selecting climb point, given fuel loss
Response options for TF fly-up

Strike phase equipment status
Strike phase preparation procedures

TF descent checklist results
TF interrupt/climb checklist results
TF resumption checklist results
TF system status

Weapon launcher capability, given battle damage
Weapon release data

Table 4-8. System Information Sources

AFPI equipment

Bomb abort checklist
Bomb run checklist

Communication receiver equipment

Doppler radar BIT equipment
Doppler radar system equipment

Equipment fault analysis data base
Equipment check-out checklists

Fuel status sensors

Jammer BIT equipment
Jammer equipment

Missile BIT equipment
Missile launch checklist
Missile post-release checklist
Missile pre-launch checklist

Navigation equipment

OAS equipment
On board sensors

Pre-bomb run checklist
Primary radar BIT equipment
Primary radar equipment

TF descent checklist
TF interrupt/climb checklist
TF resumption checklist
TF system equipment

Weapon launcher equipment

information regarding flight performance of the aircraft itself.

As the crew performs operations or functions with the aircraft, such as a weapon delivery, an enormous amount of information is processed and coordinated without presenting this information to the crew. Information management requires continually updating data bases associated with on-going operations. These data bases are related to aircraft flight performance, navigation, and flight dynamics.

Conversely, there is a multitude of system status information which could be presented to the crew continuously. Determining who should receive what information and with what frequency is dependent upon the crewmember, frequency that the information is used, and the importance of the information. Presentation of system information must be effective but requires a careful blending of information from multiple subject areas.

Information management requirements are listed in Table 4-9 for system informational demands identified in the mission analysis.

The diversity of the system information presented requires that special consideration be given to how best to present the information to the crew (e.g., AFPI vs. fault analysis procedures). Therefore, not only are there information management requirements, but there are also information presentation issues.

4.3 Summary

Information management requirements and informational demands for the CMS crew were identified and discussed. This section completes the first part of Step Two of the evolved methodology proposed in Part 2.4.2; the second part of Step Two is presented in Section 5.0. In

Table 4-9. System Information Management Requirements

Coordinate information for radar jamming
Coordinate information for aborting missile launch
Coordinate information for failure analysis of primary radar
Coordinate information for malfunction analysis of jammer
Coordinate information for resuming TF
Coordinate information for termination of external emissions

Estimate aircraft range, given fuel loss rate
Estimate remaining fuel upon arrival at alternate PSB

Present AFPI
Present battle damage assessment for weapon launcher
Present battle damage report
Present before-descent checklist
Present bomb abort checklist
Present bomb run checklist
Present bomb run checklist
Present C^2 link checklist
Present climb checklist
Present damage report on Doppler radar system
Present damage report on fuel system
Present descent checklist
Present fault diagnostics for jammer malfunction
Present fault diagnostics for primary radar
Present fault-tree analysis procedures for primary radar
Present HHCL preparation procedures
Present jammer malfunction information
Present jammer operational status
Present missile radar altimeter failure
Present navigation information
Present pre-arm checklist
Present pre-bomb run checklist
Present primary radar failure information
Present primary radar operational status

Table 4-9. (Continued)

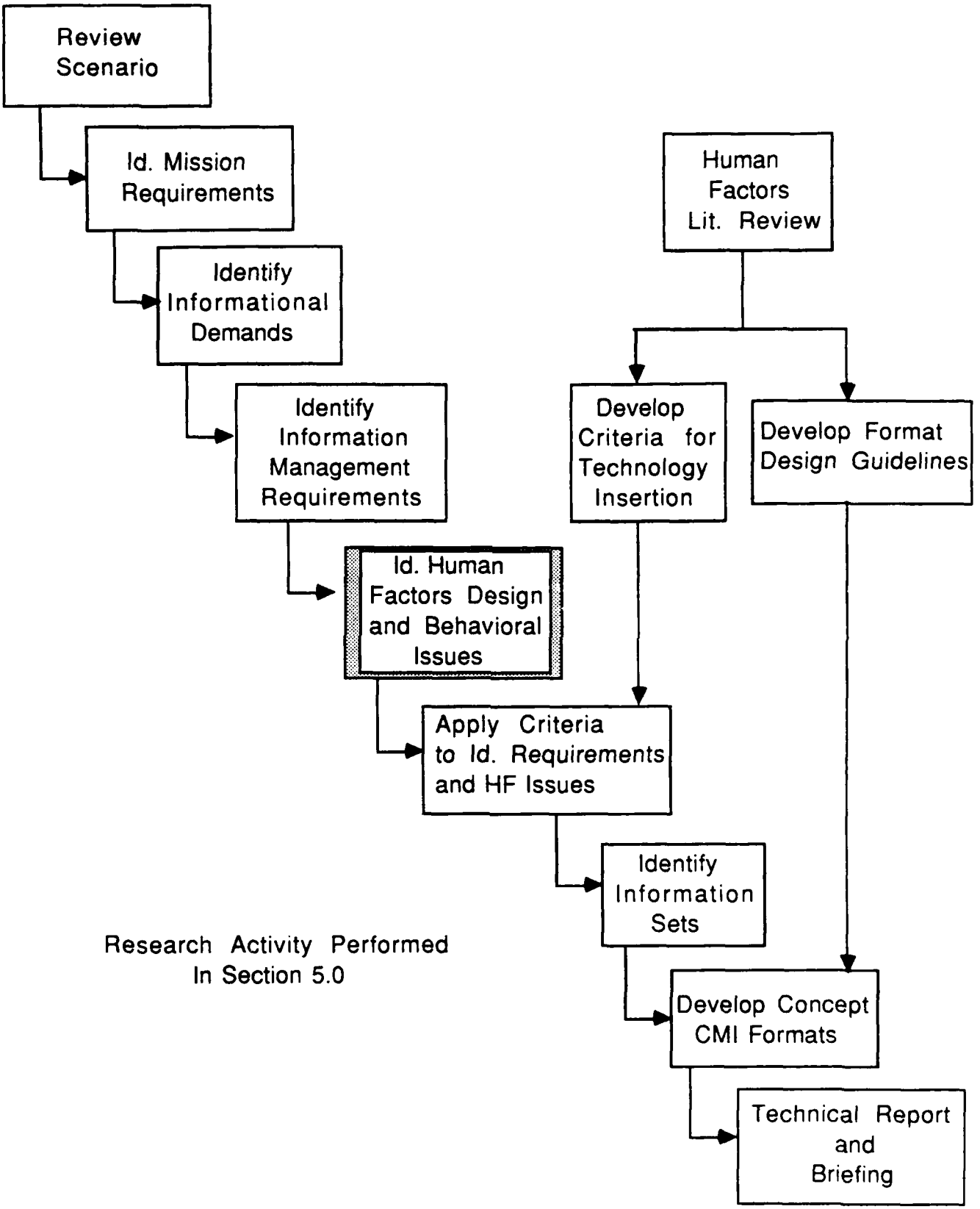
Present missile abort checklist
Present missile launch checklist
Present missile malfunction report
Present missile post-release checklist
Present missile pre-launch checklist
Present switch-over information for back-up to primary radar
Present switch-over information for primary to back-up radar
Present TF descent checklist
Present TF interrupt/climb checklist
Present TF resumption checklist

Update navigation data base
Update systems associated with primary radar

this section, a structured relationship was defined between the crew's informational demands, information sources, and information management requirements of the crew as they respond to scenario events. Informational demands are data the crew needs to respond to a scenario event. Information sources are the resources where the data are obtained. Information management requirements are the means of supplying the information to the crew and include coordinating, monitoring, presenting, and updating specific groups or sets of information.

Informational demands, information sources and information management requirements were categorized by subject areas. Subject areas are defined as qualitatively independent realms of information. Three independent subject areas were identified: (a) mission related information, (b) external situation awareness related information, and (c) system (internal situation awareness) related information.

The information management requirements and informational demands identified in this section will be considered again in Section 7.0 when opportunities for technology insertion are discussed. The information subject areas delineated in this section will be considered again in Sections 7.0, 8.0, and 9.0 when opportunities for technology insertion are discussed and their implementation conceptualized.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 5.0

5.0 HUMAN FACTORS DESIGN AND BEHAVIORAL ISSUES

5.1 Objectives

Human factors design and behavioral issues are the factors which affect the crew's ability to perform crewmember requirements optimally. Crewmember requirements are the capabilities the crew needs to possess in order to accomplish the mission. How well the crew functions in the CMS operational environment is addressed by considering the human factors design and behavioral issues imbedded in the CMS. In this section, the second part of Step Two of the evolved methodology proposed in Part 2.4.2 is performed; the first part was completed in Section 4.0.

Reviewing the CMS included identifying of human factors design issues with the potential to disrupt or degrade mission effectiveness. These issues are workload, psychological stress, and training (Figure 5-1).

Each issue has a significant effect on crewmember performance. Workload issues and psychological stress affect function allocation for the crew and the design of the flight-deck. Training is directly affected by system design, function allocation and technology insertion. In the case of this research, flight-deck design is not a factor under consideration. However, technology insertion, a component of flight-deck design, is a research consideration. In this section, the effects of workload, psychological stress, and training issues are discussed as human factors design and behavioral issues in the CMS.

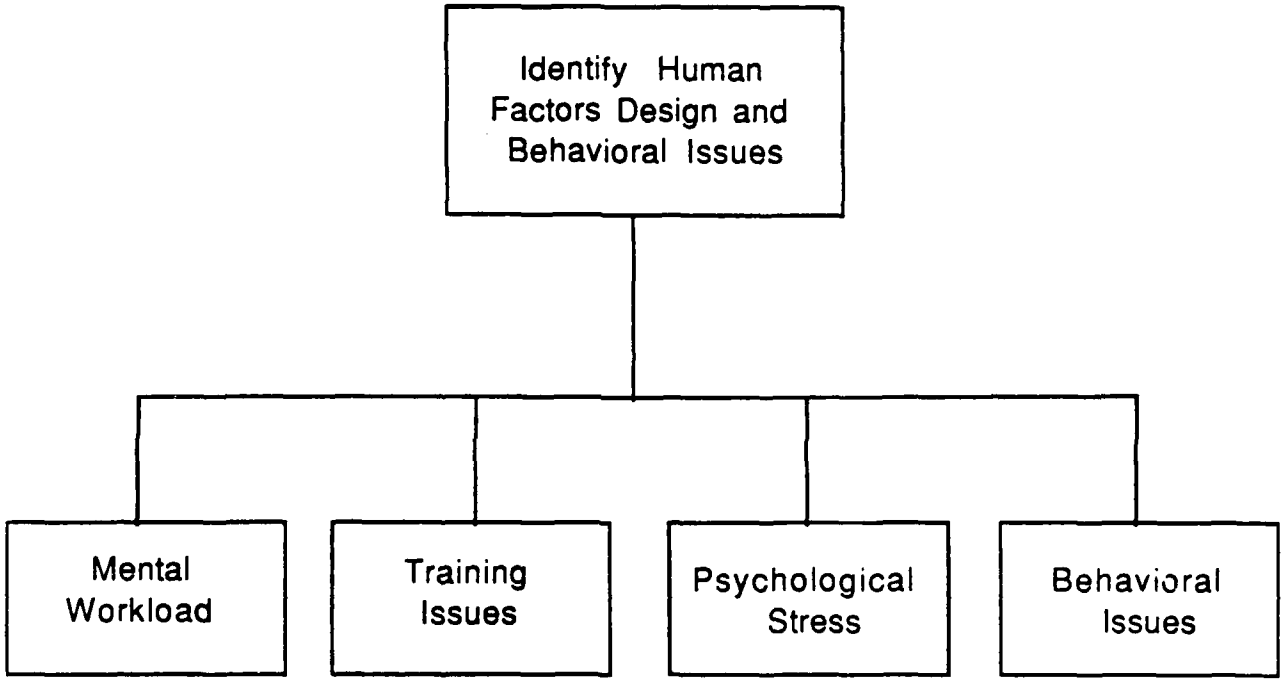


Figure 5-1. Human Factors Design and Behavioral Issues

5.2 Measuring Workload

Workload is a complex issue in the field of human factors. The word workload is itself a nebulus title for an elusive measure of human activity. Gopher and Donchin (1986) found it more productive to define workload by the multiple applications of the word than to define the word per se. Unfortunately for matters of quantification, the measurement of task demands on humans is not a simple task. Unlike machinery, humans adapt themselves to tasks at hand and are able to perform an infinite combination of cognitive and/or motor tasks with relatively little adjustment.

The ability of humans to adapt has made the measurement of the loading of humans for a given job difficult. If people can perform a multitude of jobs, and each of these jobs having a certain amount of cognitive and motor skills associated with it, then workload measurement techniques must be flexible or numerous to accommodate the enormous variance in human activities. Reviews of workload measurement techniques have shown that it is easier to develop a new workload measurement technique for a new application, than to try to "flex" an existing technique when applying it to a new application (O'Donnell and Eggemeier, 1986; Wickens, 1984; Wierwille and Williges, 1978.)

Physiological parameters, mental loading, average of time occupied, instantaneous loading, subjective impressions, objective measures, and reserve capacity can (and have) all be used to measure workload. The technique that is usually chosen by a researcher is the technique that measures the characteristic of human loading and performance for which the researcher is most interested in obtaining an estimated value. Excellent guidelines for selecting a workload

analysis technique can be found in Wierwille and Williges (1978). However, while more than one measurement technique may be available for a given paradigm, the researcher should be aware of which techniques provide significant measures of workload and avoid nonsignificant techniques (Casali and Wierwille, 1982; Casali and Wierwille, 1983; Rahimi and Wierwille, 1982; and Wierwille and Connor, 1983).

Berliner, Angell, and Shearer (1964) developed a taxonomy for the four processes of universal behavior: perceptual, mediational, communication, and psychomotor (Table 5-1). Perceptual, mediational, and communication processes can be identified for the crew in the CMS. Each process defines mutually exclusive activities and specific behaviors. By inspection, the activities and behaviors described in the CMS are primarily cognitive processes rather than motor actions. Therefore, mental workload for the crew in the CMS is of particular interest in this report.

5.2.1 Measuring Mental Workload. Mental workload is no better defined than workload itself. The shift in technology towards mostly automated, complex control systems has reduced the operator's physical exertion and increased the operator's mental exertion (Moray, 1982). This shift has also complicated the issue of measuring mental workload. Williges and Wierwille (1979) in their white paper on mental workload begin with two conclusions on the subject.

> Namely, there is no single, agreed upon definition of mental workload, and there is no single, universal metric of it. Mental workload is a theoretical construct, and as such, might best be defined operationally. Clearly, it relates to

Table 5-1. Taxonomy of Universal Behaviors

Process	Activities	Specific Behaviors
Perceptual	Searching for and receiving information	Detects Inspects Observes Reads Receives Scans Surveys
	Identifying objects, actions, events	Discriminates Identifies Locates
Mediational	Information processing	Categorizes Calculates Codes Computers Interpolates Itemizes Tabulates Translates
	Problemsolving and decision-making	Analyzes Calculates Chooses Compares Computes Estimates Plans
Communication		Advises Answers Communicates Directs Indicates Informs Instructs Requests Transmits

Table 5-1. (Continued)

Process	Activities	Specific Behaviors
Psychomotor	Simple/Discrete	Activates Closes Connects Disconnects Joins Moves Presses Sets
	Complex/Continuous	Adjusts Aligns Regulates Synchronizes Tracks

From: Berliner, C., Angell, D., and Shearer, J. W. (1964). Behaviors, measures, and instruments for performance evaluation in simulated environments. In Proceedings of the Symposium and Workshop on the Quantification of Human Performance. Albuquerque, NM.

factors such as operator stress and effort, but these concepts also require operational definitions (p. 549)

Mental workload is measured in a variety of ways. There are three basic categories for measuring mental workload: (1) physiological measures, (2) performance-based measures, and (3) subjective measures (O'Donnel and Eggemeier, 1986). Table 5-2 is not comprehensive, but gives the reader a feeling of the numerous and diverse available techniques. The mental workload measurement measures listed below are referenced from Eisen and Hendy (1987), O'Donnell and Eggemeier (1986), Wierwille (1979), and Williges and Wierwille (1979). These references should be consulted for a thorough treatment of methodologies and appropriate applications for a specific analysis technique.

Physiological Measures. The sheer number of physiological measuring techniques make it prohibitive to discuss each in this report. However, Meister (1985) provides a review of many of the measures listed above including numerous citations on researcher's successes and failures with each technique.

Past reviews and evaluations of different workload techniques (Wierwille, 1979, Williges and Wierwille, 1979) have reported that many of the physiological measurement techniques are intrusive, complicated, and for some measures require qualified medical technicians. Researchers have been less than successful in establishing physiological measures as a standard for mental workload analysis. The validity or applicability for some techniques have been questioned, and it would be best to consult research and reviews for a given technique

Table 5-2. Mental Workload Analysis Technique

Physiological Measures

- Flicker Fusion Frequency, Critical Fusion Frequency
- Galvanic Skin Response, Skin Impedence
- Electrocardiogram, Phonocardiogram, Plethysmogram
- Electromyogram
- Muscle Tension
- Electroencephalogram
- Evoked Cortical Potentials
- Eye and Eyelid Movement
- Pupillary Dialation
- Respiration Analysis
- Body Fluids Analysis
- Speech Pattern Analysis

Performance-Base Meaures

- Single Primary Task Measures
  - Human Error Rate
  - Speed of Performance
  - Percent of Time Occupied
- Multiple Primary Task Measures
- Secondary Task Measures
  - Loading Task Paradigm
  - Subsidiary Task Paradigm

Subjective Measures

- Rating Scales
  - Cooper-Harper
  - Modified Cooper-Harper
  - University of Stockholm Scales
  - NASA Bipolar Scales
- Psychometric Techniques
  - Magnitude Estimation
  - Mission Operability Assessment Technique
  - Subjective Workload Analysis Technique
- Interviews

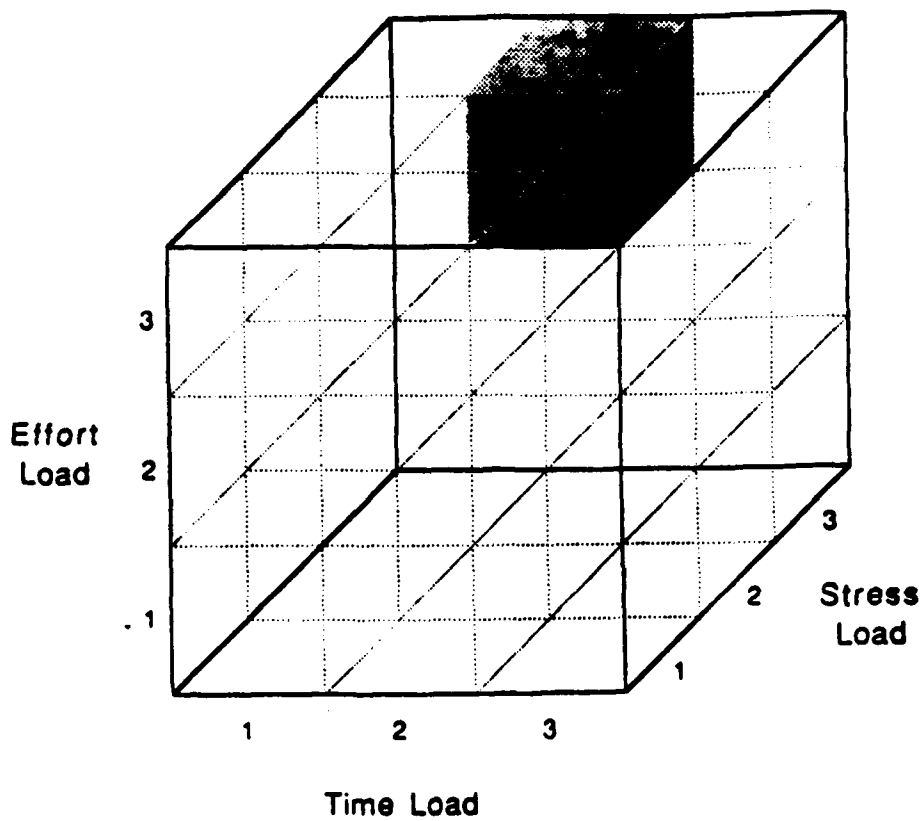


Figure 5-2. SWAT Three-Dimensional Conjoint Measurement Technique

before selecting one (Meister, 1985; O'Donnell and Eggemeier, 1986; and Wierwille, 1979).

Obviously, physiological techniques would be inappropriate for evaluating mental workload for the CMS. The simple reason is that there are no warm bodies to analyze. In addition to and regardless of the disagreement between researchers, physiological techniques are known to be intrusive, technically complex, sometimes hazardous and subject to question. Physiological techniques also do not consider subjective workload data obtained from the subjects. The other two categories for mental workload analysis might well be worth investigating in lieu of physiological measures.

Performance-Based Measures. Performance-based analysis techniques typically provide a valid measure of subjects' ability to perform a task, but fail to consider subjective loading (e.g., fatigue, motivation, stress) experienced by the subject. For a detailed discussion of performance-based measures, the reader should see the Chiles and Alluisi (1979) review of the major methods for performance measurement. Primary and secondary task methods are two of the more popular methods and are briefly reviewed here.

Primary task measures are used to measure whether or not a subject is overloaded when performing a task. Theoretically, if the subject can consistently perform the task adequately, the subject is not overloaded. Two of the major criticisms of primary task performance measurement are that:

(1) primary task measures are best suited to detecting the existence of an overload situation (Eggemeier, 1984; Wierwille and Williges, 1978); their merit is minimal

when considering differences in workload below ...[100%] (Eisen and Hendy, 1987, p. 16).

and,

(2) workload can only be measured on a comparative basis because there is no absolute measure of it. Hence, primary task performance as a measure of workload is inadequate when no other task condition exists with which it can be compared (Meister, 1985, p. 89).

Secondary task measures introduce a secondary loading (or task) to the subject to determine the subject's available mental capacity. The secondary task is subordinate to the performance of the primary task, and it is assumed that the performance of the primary task meets an acceptable criterion. Reserve capacity is then an inverse measurement of actual workload. Secondary loading techniques vary and a survey of techniques can be found in Ogden, Levine, and Eisner (1979).

Secondary measures are an established method for estimating mental workload. This does not mean that they are not without criticism. The overall methodology of secondary measures has been criticized for: (1) assuming primary task stability when it may not exist, (2) introducing a secondary task which may be intrusive to the primary task, (3) assuming averaging (or trade-offs) between primary and secondary tasks does not exist, and (4) making critical assumptions about human processing capacities (Fisk, et al., 1983; Meister, 1985; Pew, 1979).

Primary and secondary task analysis is based on actual measurement of human success versus failure in performance of different tasks. This form of analysis requires data not available in or appropriate for

a mission scenario. For these reasons, performance-based measures are not appropriate for analyzing the CMS.

Subjective Measures. Subjective assessments from participants provide critical information of how the participant perceives his/her task loading. However, these measures are susceptible to variance between participants and individual participant motivation (Meister, 1985). Subjective measures have been used independently to determine mental workload or to corroborate objective measures. Methods for obtaining subjective measures range from opinion surveys and interviews (Hart and Bortolussi, 1984) to rating scale techniques. The Subjective Workload Analysis Technique (SWAT) and the Cooper-Harper (CH) technique are discussed here, because they are two of the better known and more widely used subjective rating techniques for measuring mental workload.

SWAT was developed by AAMRL (Reid, Shingledecker, and Eggemeier, 1981) for measuring crewmember mental workload on three dimensions. The dimensions measured are time load, mental effort load, and stress load, with each dimension rated by the subject on a 3-point ordinal scale (Figure 5-3). SWAT employs a conjoint measurement technique in which the rating for each of the three dimensions is combined into one interval scale rating. Ratings are recorded, by task, immediately following the performance of the task. A criticism of the SWAT technique is that the three dimensions are not orthogonal, therefore, biasing the interval scale ratings (Boyd, 1983).

Cooper-Harper (CH) rating scale (Cooper and Harper, 1969) is commonly accepted as a standard subjective measurement technique in the aviation industry (Eisen and Hendy, 1987, Wickens, 1984). CH is a

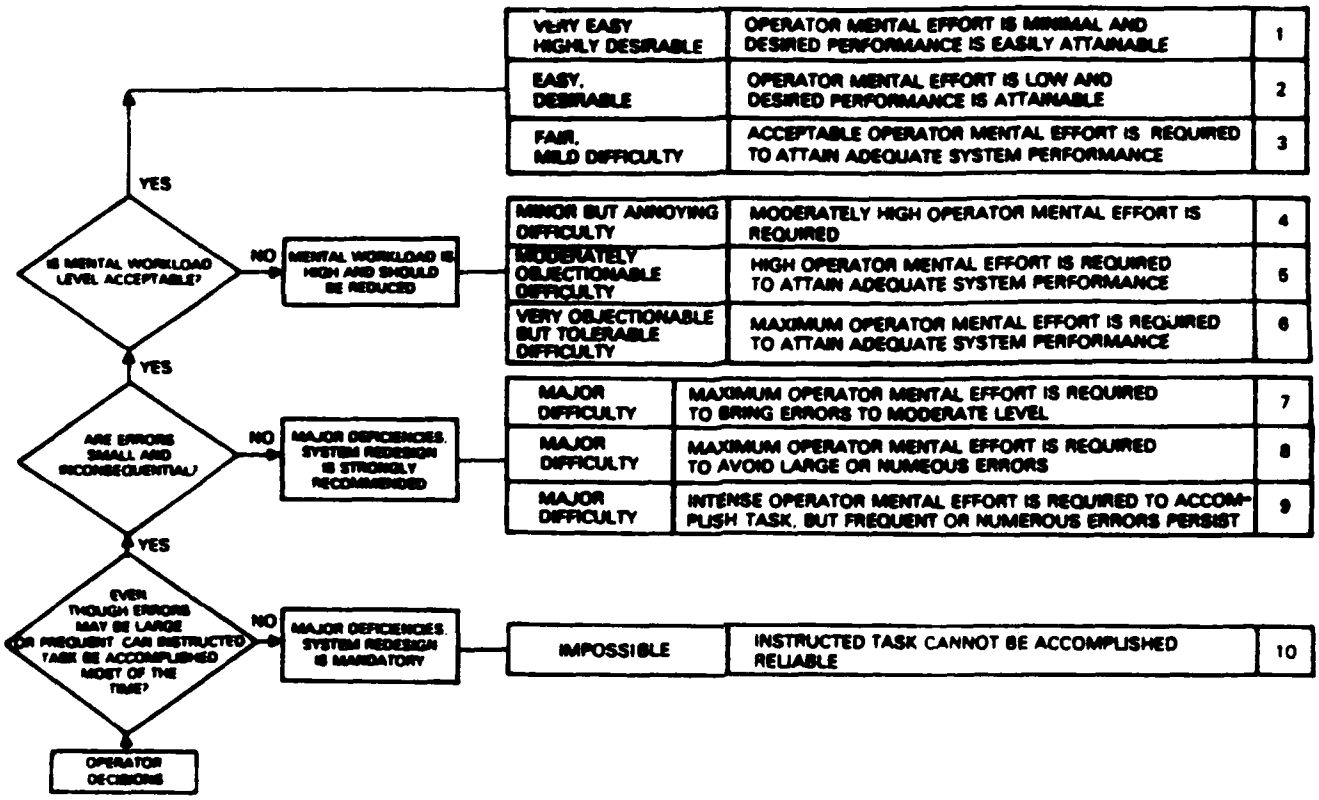


Figure 5-3. Modified Cooper-Harper Rating Scale Technique
From: Wierwille and Casali (1983).

decision-tree method used in evaluating aircraft handling qualities. This method requires subjects to make a series of up to 10 yes/no decisions on aircraft handling qualities. The more "yes" responses from the subject, the higher the subject rating score. Scores are based on a 10-point ordinal scale. The technique has been proven to be useful as well as reliable, but has also been criticized for its limited applicability. Obviously, CH would be inappropriate for the CMS because handling qualities are not an issue of interest. However, the methodology could be modified to suit a CMS analysis of mental workload. One such modification is the Modified Cooper-Harper (MCH) rating scale.

The (MCH) technique was developed to expand the applicability of CH to other areas for measuring mental workload. MCH also uses the decision-tree method with a 10-point rating scale. However, MCH uses more generalized statements of mental workload in the decision nodes. The decision-tree is more generic, and, therefore, more applicable to other activities. Wierwille has validated MCH as part of a series of studies evaluating multiple mental workload measures using a flight simulator (Casali and Wierwille, 1982, 1983a, 1983b, 1984; Skipper Rieger, and Wierwille, 1986; Wierwille and Connor, 1983; Wierwille and Casali, 1983; Wierwille, Rahimi, and Casali, 1985).

The MCH decision-tree technique was designed for use in a dynamic simulator environment. MCH requires subjects to make decisions based on actual physical sensations. Therefore, MCH is not applicable as a projective method for evaluating mental workload. However, MCH could possibly be modified as a Projective-MCH, much like what was done with Pro-SWAT (discussed below). Further investigation would be needed to

determine if such a technique was useful and valid.

Given the unique format of the CMS (technology free, undefined crew and function allocation) neither SWAT nor Cooper-Harper could be applied, due to the limited amount of crewmember data and lack of crewmembers. However, Eggleston and Quinn (1984) have modified SWAT to provide a projective estimate of the crew's mental loading during preliminary system designs.

Projective SWAT (Pro-SWAT) is used during the trade-off design stage of system design. A combination of written and verbal descriptions of the system and tasks is developed which represents alternative designs and potential task scenarios. The methodology for Pro-SWAT is best described by Eggleston and Quinn (1984):

> Pro-SWAT requires task-knowledgeable raters to mentally project themselves into the operation of the defined system, imagine performing the task and then report the magnitude of the workload "experienced" at selected times (Eggleston and Quinn, 1984, p. 695).

There are three areas of concern when using Pro-SWAT. First, "its primary limitation is in the ability of the subjects to accurately assess workload based solely on task and equipment descriptions" (Eisen and Hendy, 1986). Second, the system design must be described in sufficient detail so that there is no question or confusion from subjects as to the capabilities and limitations of the system. Third, the selection and instruction of task-knowledgeable raters are critical. Pro-SWAT is even more prone to variance than post hoc subjective analysis measures, due to subjects' interpretation of system

requirements in relation to the subjects' own image or self-confidence.

Pro-SWAT is an attractive technique for estimating workload during preliminary design, because it does not require mockups, equipment or simulation. Eggleston and Quinn (1984) address the concerns discussed above by suggesting ways of reducing subject variance and increasing the validity of the estimates. Pro-SWAT is also attractive because it provides a smooth transition to using SWAT during critical design and simulation of the system.

Pro-SWAT would not be appropriate for analyzing the CMS because the CMS aircraft is technology free and has an undefined crew size. The absence of a system description prevents any valid analysis of crew workload, since function allocation, equipment descriptions and interfaces (actual or projective) are required.

5.2.2 Assessing Mental Workload from the CMS. Mental workload cannot be validly analyzed from the CMS alone. However, mental workload can be assessed based on inspecting the CMS for factors which affect mental workload. The investigators assessed the mission as described in the CMS and recorded factors which will affect mental workload. A final listing of factors which affect mental workload was compiled.

5.3 Mental Workload Factors

1. Crewmember workload will often be high and exceed human capability if decision-making and mission management requirements are not supported by technology insertion.

2. Response and decision times are very short and must be performed repeatedly and without error. Crewmembers will not be able to meet this criterion if unassisted by information management systems.
3. Crewmember responsibilities will be numerous and will include the following functions:
   (a) mission management (e.g., decision-making, replanning)
   (b) pilotage
   (c) navigation
   (d) communication
   (e) offensive warfare
   (f) defensive warfare
4. Crewmember interaction among functions identified in item 3 will be high and continuous during mission.
5. Unplanned mission events have the potential to greatly increase crewmember workload.

5.4 Psychological Stress Issues

The analysis and quantification of stress is another complex problem. A virtual labyrinth exists for the study of stress and it would go beyond the scope of this research to even attempt to discuss the subject. Stress cannot be sufficiently addressed with only the information provided in the CMS. However, factors which are known to induce or increase stress levels can be discussed with respect to the CMS. For the purposes of this study, stress is psychological stress as defined by Berkhout (1972):

> The psychological factors discussed [below] are those most often encountered in the operation of complex modern technology. These include monotony, which is understood to include sensory deprivation and boredom, job or task anomalies, the disruption of daily rhythms, and genuine danger (Berkhout, 1972, p. 435).

Psychological factors affect human performance in different ways. It is a fairly safe assumption that monotony will not be a stress factor for the CMS crew during the mission. However, monotony may be a significant psychological factor during the hours of pensive waiting and boredom before orders for the mission are issued. This report does not attempt to address the issue of pre-mission monotony, but only identifies it as a psychological factor with latent effects on crewmember performance.

Task anomalies are defined by Berkhout (1972) as tasks or jobs which exhibit "arbitrary infliction of pain, distorted feedback, demonstrations of disapproval and anger, and misleading or contradictory instruction for performing tasks" (p. 436). Berkhout suggests that these types of tasks or jobs bring out "the qualities of axiety, frustration, and fear." Anomalous tasks should be designed out of the system where possible and respected as a potential source for degradation in crew performance.

to ineffective subsystems or defective equipment could cause the crew to lose confidence in their aircraft, subsystem equipment, or themselves. If the crew loses confidence in the aircraft system, this could quite possibly lead to the failure of the mission and potentially the loss of the aircraft and crew.

As mission complexity increases and the opportunities for deviations between the planned mission and the actual mission occur (due to unbriefed threats) threat capabilities, sustained battle damage, unplanned for enemy tactics, etc.), task anomolies will be more frequently encountered.

Circadian rhythm disruption causes degradation in human performance. Circadian rhythm is the body's time clock. The effects of disruption to the circadian rhythm have been studied for years, and it is common knowledge that disruption causes a degradation in human performance and increases psychological stress.

The time duration of the mission, especially when added to the time spent in the aircraft awaiting orders, is more than long enough to cause a disruption in periodicity. How much the crew will be affected is undefinable at this level of analysis, but is a factor which must be evaluated and researched. The fact that disruption will occur is in itself a requirement to investigate and measure its effect.

Genuine danger elicits basic survival instincts and physiological responses in humans. The Air Force and others have spent a great deal of time addressing the issue of how genuine danger affects crew performance. Even with advanced training and high levels of system experience, crewmembers are affected by genuine danger and will respond physiologically and psychologically to dangerous situations. How well

they respond to danger is often dependent upon their own capabilities and the aircraft's capabilities. A breakdown of the crew's confidence in the aircraft can seriously affect the crew's ability to defeat the perceived danger.

Psychological stress, as defined here, is inherent in the type of environment described in the CMS, and is an important design issue which must be addressed. The intended operating environment for the aircraft is obviously very hostile, and its effect on the crew will be significant.

As was true with mental workload, so also psychological stress cannot be validly analyzed from the CMS alone. However, the investigators assessed the mission as described in the CMS (Frick, et al., 1986) and recorded factors with the potential for increasing psychological stress. A final listing of factors which contribute to increased psychological stress was compiled.

1. Mission duration will be over XX hours long with XX hours in very hostile territory. Crewmember performance will be affected by high levels of psychological stress. Crewmembers can be expected to be under enormous mental pressure, suffering from prolonged exposure to high levels of stress.
2. Crewmember performance will be affected due to disruption of circadian rhythm and sustained physiological stress. Mission duration including pre-flight duration will disrupt normal body functions and patterns.
3. Crewmember performance will suffer because of the following task anomalies:

   (a) Pain, due to mission duration, G-forces, cold, vibration

and buffeting.

(b) Tension and anguish, due to the life-threatening environment during the mission.

(c) Anxiety due to contradictory, incorrect or missing information from sensors, data bases, and the environment.

5.5 Training Issues

The expected introduction of more state-of-the-art technology onto the flight-deck raises issues concerning training the crew to operate an abundance of technology successfully, and confidently. The crew must be able to successfully operate the equipment, if the equipment is to serve its purpose. The crew must also have confidence in the technology, otherwise the crew will neither trust it nor depend on it in time of need. New technology also brings about changes on the flight-deck. For example:

1. New tasks and responsibilities accompany any new piece of equipment. Even if new equipment eliminates tasks for the crew, new tasks and functions must be learned for operating the new equipment.
2. A reallocation of tasks either due to task sharing or changes accompanies new equipment. Most of the technology introduced is often designed to automate crew functions and reduce crew workload. This will cause a reallocation of functions and tasks between crew and machine, and subsequently require retraining the crew to perform new supervisory tasks and functions.

3. As the level of automation rises, the role of the crew shifts from system operator/monitor to system manager/controller. The crew must be retrained in their new "hands off" role as managers of a highly automated system. This raises a strong human factors issue of keeping the crew "in the loop" of flying (meaning overall operation) the aircraft. The crew must be trained to stay in close tune to what automated functions are currently being performed as if they were controlling it all themselves (situation awareness).
4. Automation often relegates the crew to a back-up mode. This requires training the crew as stand-by operators, where tasks are performed very infrequently. This is also a critical concern in keeping the crew "in the loop" of flying the aircraft.
5. The introduction of new technology also invites the opportunity for new tactics. As on-board equipment becomes more advanced, more options and tactics are available to the crew. The crew must be trained in tactics, as well as getting the maximum amount of information out of the system.

5.6 Behavioral Issues

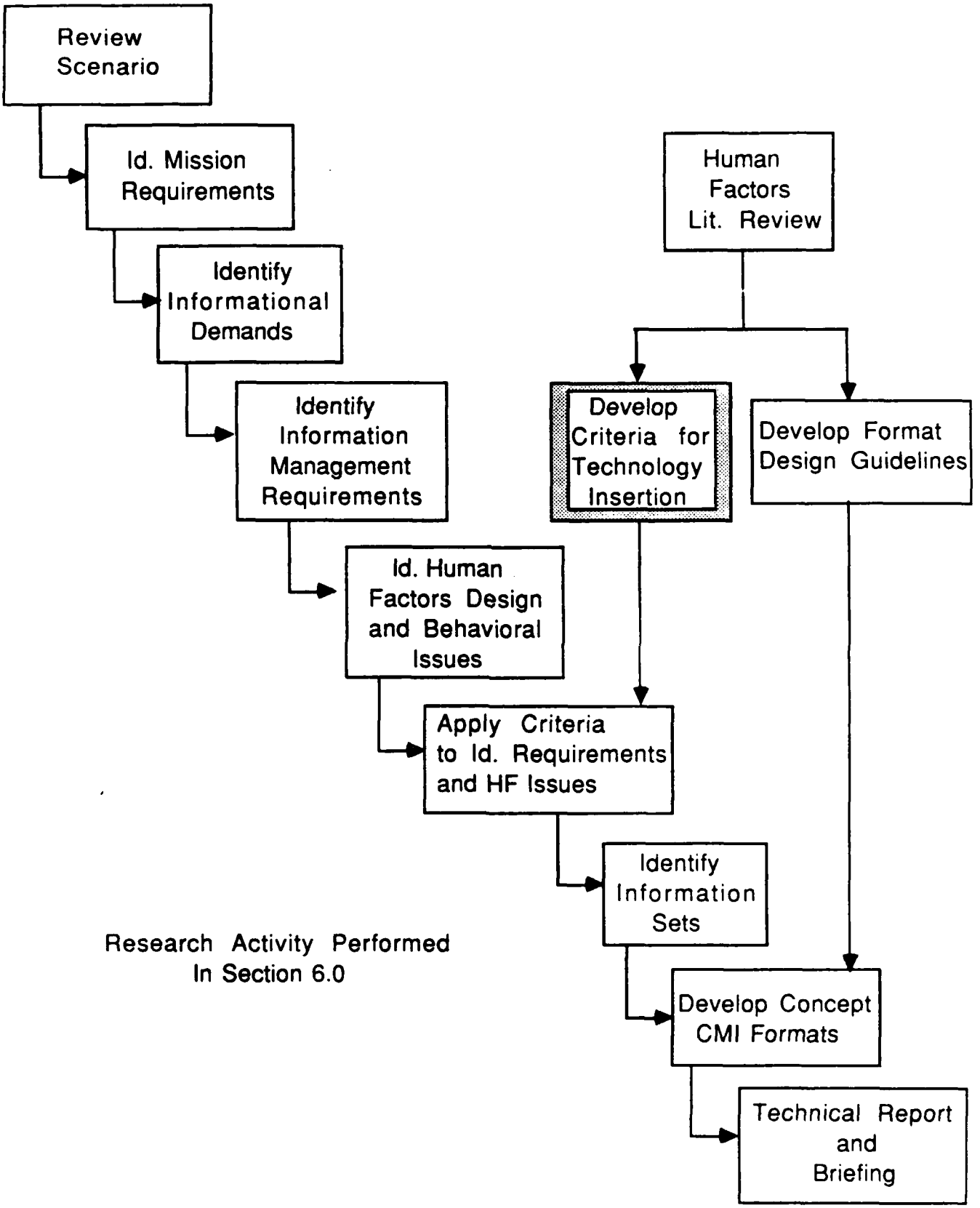
Behavioral issues affect the crew's cognitive processing capabilities. Commonly referred to as performance shaping factors (Swain and Guttman, 1980), behavioral issues have the potential to cause a degradation in operator performance. By identifying behavioral issues prior to system design, the potential effects of these issues on crewmember performance can be minimized by attenuating the effects through proper design of the system.

Identifying behavioral issues in the CMS consisted of reviewing each leg of the mission for behavioral issues which had the potential for degrading the crews performance. Another way of considering behavioral issues is to determine factors of behavior (such as decision-making, reasoning, information processing capability, and situation awareness) which exist in the environment being analyzed. Five behavioral issues were identified in the scenario review of the CMS.

1. Decision-making will exist at three distinct levels:
   a. knowledge-based decisions.
   b. rule-based decisions.
   c. skill-based decisions.
2. The crew utilizes four processes of human behavior
   a. perceptual processes
   b. mediational processes
   c. communication processes
   d. psychomotor processes
3. Situation awareness will vary greatly during the mission.
4. Information demands and information management requirements will often exceed human perceptual capabilities.
5. Human perceptual/mediational, communication, and psychomotor requirements will often exceed human capability.
6. Decision-making will be affected by item 3 and will contribute to decision-making with uncertainty or based on incomplete information.
7. Crewmember health and status must be monitored to insure that the crewmember is an active part of the operational loop.

5.7 Summary

Human factors design and behavioral issues which affect the CMS crew's ability to perform crewmember activities were identified and discussed. This section completes the second part of Step Two of the evolved methodology proposed in Part 2.4.2; the first part of Step Two is presented in Section 4.0. Mental workload, psychological stress, training issues and general behavioral issues were identified as human factors issues. The principles and methods of measurement for each issue were reviewed briefly. How each issue affects crewmember performance was discussed as well as considering the overall effects of each issue on mission success. The human factors design and behavioral issues identified in this section will be considered again in Section 7.0 when opportunities for technology insertion are discussed.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 6.0

6.0 CRITERIA FOR TECHNOLOGY INSERTION

6.1 Objective

Criteria for technology insertion are proposed to guide the assessment and recommendation of technologies to support crewmember information requirements identified in Section 4.0 and 5.0. This section represents Step Three of the evolved methodology presented in Part 2.4.2. Technology insertion matches crewmember information management requirements and associated informational demands with technologies which have the capability of fulfilling technical requirements and supporting crewmember demands. Only technologies which support information-based requirements were considered. In this section, two existing methodologies for technology insertion are reviewed. Criteria for technology insertion are proposed which consider both engineering requirements and crewmember demands when assessing a technology.

6.2 Introduction to Technology Insertion

Traditionally, technology evolves because (a) a new technology is developed which supersedes an existing technology, or (b) people demand the development of a new technology for a new application. Technology is defined here as the application of scientific principles to accomplish a solution for a stated problem in commerce or industry. Criteria for selecting technology (existing or desired) is defined here as performance requirements for assessing a stated technology. The fulfillment of a set of performance requirements indicates that the technology is an acceptable solution for meeting stated technical requirements and crewmember demands.

6.3 Flight-Deck Technology Insertion

The aircraft flight-deck has gone through a metamorphosis. It has gone from control yoke, analog gauges and dials to fly-by-wire control with digital displays, color CRTs, and automatic pilots. The development of sophisticated aircraft and sensors has percipitated the flooding of pilots and crewmembers with information and responsibilities to the point of saturation. The unavoidable result has been the overloading of the crew's perceptual, mediational, and communication processes. Flight-deck automation technology was introduced to offset the advances to aircraft equipment technology. Advances in flight-deck automation allowed further advances in aircraft design. The issue has come to be viewed as a dilemma of how much automation is enough? How do designers select appropriate types and quantities of technology?

The question of how much automation is enough (or too much) has been a point of interest for human factors in recent years. Weiner and Curry (1980) wrote one of the first and most cited articles on the controversy of cockpit automation. In the article, they discuss both the advantages and disadvantages of cockpit automation. The primary objective of the article was to present both sides of the issue and provide broad design guidelines for some of the more "critical problem areas." Five years later Weiner (1985) exposed the negative side of flight-deck automation and the dangers of over-automating--warning that the crew must maintain an active role in the control loop to remain effective in critical incidents (i.e., the need for keeping the crew "in-the-loop").

Boehm-Davis, et al. (1983) reported on a NASA-industry workshop on flight-deck automation which addressed the advantages and disadvantages of flight-deck automation as well as defined areas of further research. Their findings were similar to those of Wiener and Curry (1980) and went on to rate the importance of current research topics in flight-deck automation.

6.4 Methodologies for Technology Insertion

Guidelines, criteria, or standards for choosing technologies for any system do not exist exclusively, but are tied into an overall methodology for system design. Two existing methodologies exist for aircraft crewstation design which incorporate the assessment of technology and the role of human factors as a direct input during early design efforts.

The Air Force developed two methodologies for the development of new systems based on the assessment of developing or existing technologies and how human factors issues (e.g., function allocation, projective workload, performance measures) are affected by candidate technologies. These two methodologies are: the Radar Aided Mission/Aircrew Capability Exploration (RAM/ACE) exploratory development research program, and the Cockpit Automation Technology (CAT) advanced development project.

Each methodology is unique and approaches early efforts in systems development with a different philosophy. They are both large scale efforts in systems design and not directly applicable to the effort in this research. However, both methodologies are applicable in an actual system development situation. Each methodology is presented below and

includes a discussion of the goals and philosophy of each.

6.4.1 Radar Aided Mission/Aircrew Capability Exploration (RAM/ACE) Technology Forecasting and Assessment Methodology. The Air Force developed a methodology for technology forecasting and assessment for the RAM/ACE program. The methodology is intended for general use during early system design. The methodology assesses the technical performance, effects on operator workload, and costs of competing technololgies. Eggleston and Kulwicki (1984a) state three major goals of the RAM/ACE methodology.

1. Development of a structured, preferrably quantitative, value analysis methodology that assesses emerging technologies by system/mission utility, operator workload, and cost,
2. Demonstration of the methodology with selected technologies that would affect the design of a fighter aircraft crew station, particularly the sensor suite, and
3. Evaluation of the methodology and selected technologies through the use of man-in-the-loop simulations.

Eggleston and Kulwicki (1984b) describe how system design and technology assessment is often conducted in a "bottom-up fashion." Individual candidate technologies are assessed, selected for, and integrated into a system before human factors design issues are sufficiently addressed. In essence, the system is designed from the available technology. A top-down approach is proposed where candidate technologies are evaluated quantitatively on the value of "system utility, as well as technical performance, and [addressing] human factors [issues] early in conceptual design" (p. 31). The philosophy of a top-down approach is to have system requirements and human factors

drive the design by serving as a rating system for evaluating candidate technologies.

The RAM/ACE methodology is depicted graphically in Figure 6-1. As illustrated, there are two levels of analysis that occur sequentially. In the first level, value analysis, a technology data base is used to generate technology concepts for a system under design. A baseline system is introduced as a benchmark for analysis and evaluation. The baseline system can be combined with a variety of candidate technologies to represent alternative designs.

A two tier analysis is performed as part of the value analysis. Tier 1 is a traditional technology assessment, where technology performances and constraints, risks, reliability, and costs are evaluated. Tier 2, is the top-down analysis. System performance models are used to evaluate "system utility." Subjective workload techniques are used to estimate "projective workload assessment" for the baseline system and varying combinations of candidate technologies. Tier 2 analysis also includes using cost models to better estimate costs of alternative technologies.

The outcome of value analysis is a quantitative assessment of candidate technologies and alternative designs. From this analysis, potential technologies for implementation are selected from the original set. The selected technologies are evaluated again in the second level of analysis.

The second level, empirical evaluation, is a series of various levels of mock-ups, prototypes and simulations to determine the best combination of technologies for the system. Empirical evaluation is accomplished through simulation at three distinct levels; (1) micro

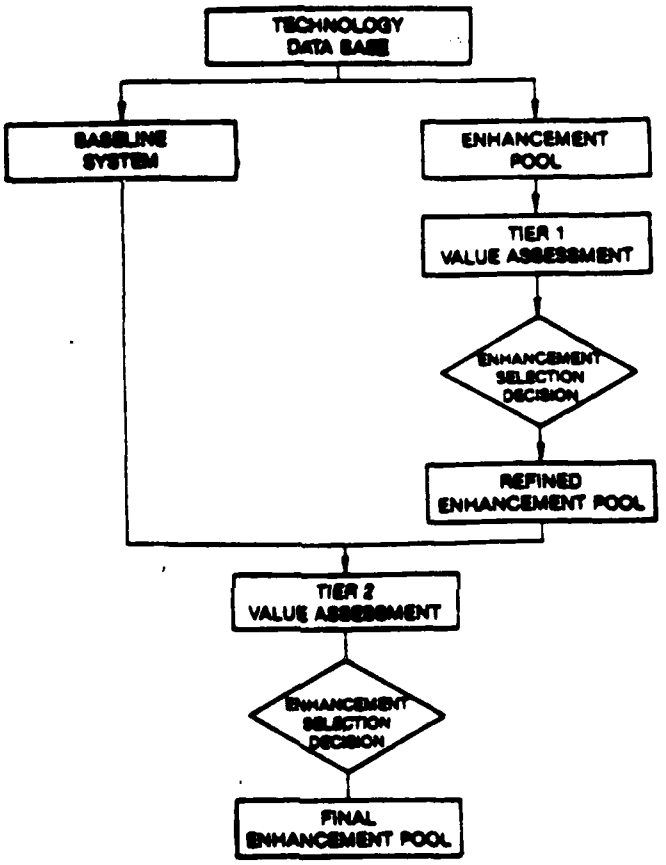


Figure 6-1. RAM/ACE Methodology
From: Eggleston and Kulwicki (1984a)

or part task simulation, (2) full task simulation, and (3) mission simulation. All three levels of simulation use the baseline system from value analysis as a benchmark and are run with different combinations of technology. The three levels represent increasing levels of realism in simulation, thus providing a better assessment of human factors design issues. The output of each simulation level eliminates less desirable technologies from further consideration.

The final results of the RAM/ACE methodology are recommendations for what appears to be the best qualified technologies for the system. While RAM/ACE is fairly straightforward in levels of analysis, each level is an involved and complex process. This is especially true of level 2, empirical evaluation, where simulation costs and time requirements are certain to be major factors.

The RAM/ACE methodology addresses the critical issue of including human factors in the design loop early in system development and technology assessment. It also proposes a valid approach in top-down analysis where the system defines the technology rather than the technology defining the system.

The RAM/ACE methodology is not appropriate for this research since many of the major components of analysis do not exist (e.g., a technology data base, system performance models, simulation packages). This methodology demands an existing, validated laboratory that goes far beyond the scope of this research.

6.4.2 Cockpit Automation Technology (CAT) Methodology. The Air Force developed the CAT methodology to provide guidance to contractors on how to design systems and select technologies with human factors as a primary input. Faced with the challenge of enhancing crew

performance in response to increasing lethality of enemy threats and advanced aircraft technology, the Air Force undertook an effort to develop a methodology for addressing these issues in the early stages of crewstation design. Aretz (1984) defines the goal of the CAT project.

> The goal of the project was to develop a structured human factors design methodology that can be used by designers to assess emerging technologies and relate them to system requirements and human performance characteristics so that the feature of the resulting designs satisfy specific operation mission objectives (p. 487).

The CAT project is aimed at establishing a baseline or "prototype" methodology for contractor human factors engineers to use as crewstation design efforts. The baseline methodology is a structured approach which focuses design efforts on the importance of human factors. There are four major stages to the CAT methodology: mission characterization, function allocation, integration and design, and validation (see Figure 6-2). A thorough discussion of these four stages can be found in Aretz (1984).

Aretz (1984, p. 487) presents six features the CAT methodology must meet to achieve the goals of the project. These six features are also criteria for evaluating other methodologies for technology insertion:

1. The ability to predict and measure cockpit effectiveness by mission phases and tasks.

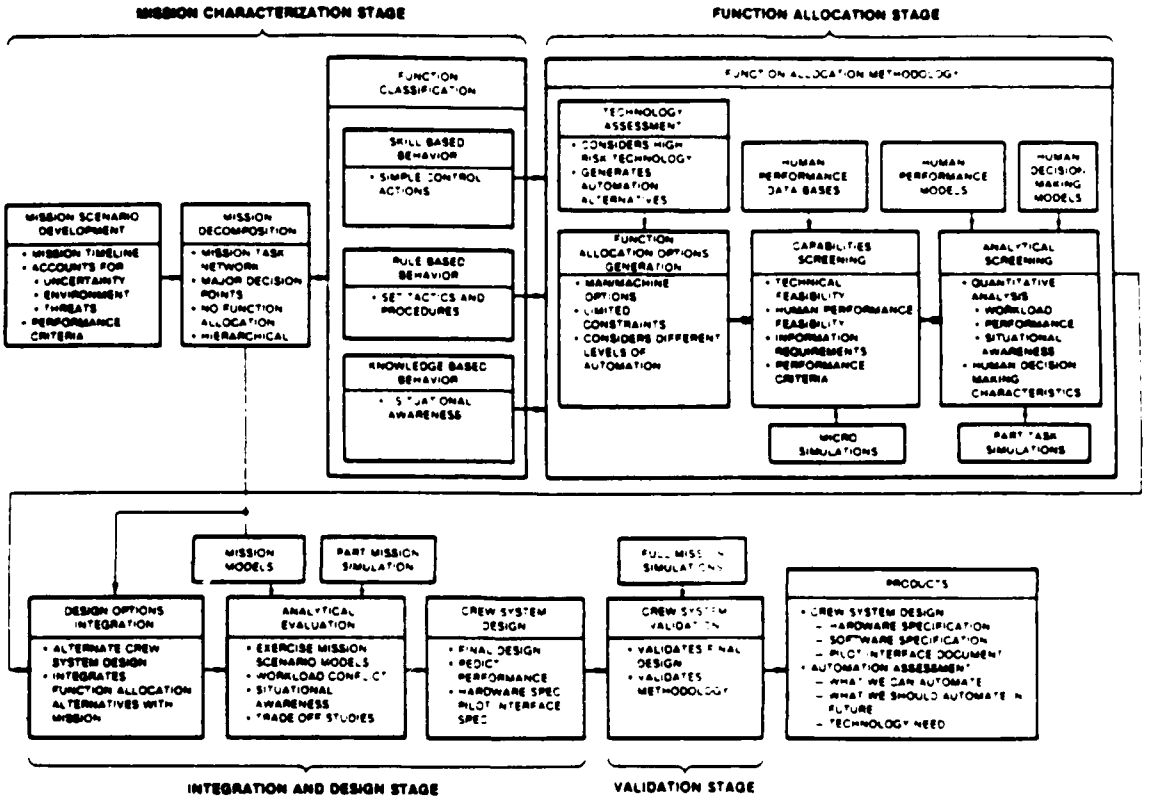


Figure 6-2. CAT Methodology
From: Aretz (1984)

2. The ability to correlate workload to mission outcome (survivability, lethality, etc.) as a function of automation technologies.
3. The ability to recommend the most cost-effective automation approaches and to translate those recommendations into crew interface documentation and cockpit design.
4. The ability to draw from the extensive human factors data base.
5. The ability to consider early continuous design inputs from operational aircrews.
6. The ability to use progressive levels of simulation.

The research performed in this report is not under the constricts of the CAT project, but does reflect much of the CAT philosophy. A "technology free" mission scenario is in keeping with the CAT methodology, and has been utilized in past CAT projects (Kuperman and Kulwicki, 1984). Other research activities such as developing criteria for technology insertion, determining information management requirements, and assessing human factors design and behavioral issues are also part of the CAT methodology.

CAT does not describe the particulars of performing a technology assessment, but states that it should be performed and specifies when it should be performed. This is in accordance with the goal that CAT should only provide a baseline direction for the research and not provide a cookbook of research methods. This goal has encouraged the CAT methodology to change as it has matured. McNeese, et al. (1985) reported upon further investigation of the CAT methodology that important lessons and new questions had arisen, "indicating that a

human factors methodology is no simple matter, yet remains important to develop" (p. 884).

The CAT methodology involves much more than the activities performed on this research. The CAT methodology was not applied to this research because the research is based singulary on the analysis of the CMS and is focused on identifying information management requirements for the crew, rather than the entire system.

6.5 CMS Criteria for Technology Insertion

The methodologies discussed above are intended for use at a higher level of system design than the level of this research. Evaluating and selecting technologies for a system is a complex, iterative process involving almost every engineering discipline in a continuum of trade-off studies. It would be presumptuous to propose a methodology that supersedes or makes obsolete the standard process of trade-off design. However, it is worthwhile to propose a methodology for considering technologies when working with a CMS. The methodology includes crewmember requirements as criteria for technology insertion. Candidate technologies can then be selected human factors engineering studies and traditional engineering trade-off studies.

For the purposes of this research, it is assumed that (1) there is an ability to successfully apply a technology, and (2) there exists a genuine demand for a technology, before a technology can be inserted into a system. Both conditions must exist for a technology to be considered. Traditionally, the former requirement has been the dominant criterion for choosing a technology for a system. The latter requirement was often assumed to be fulfilled when the former

requirement was fulfilled. As was discussed earlier in this section, if there is no true demand for the technology, the real possibility exists for introducing a detrimental technology rather than a beneficial technology. Therefore, it is necessary that both requirements be satisfied before a technology should be introduced to any system under consideration.

One way of considering whether or not a technology is appropriate for insertion is as a logic-tree criteria chart. This chart is inserted at the back of the report. Boolean logic provides a traceable and valid methodology for deciding on whether or not a technology is appropriate for a system under consideration. The logic-tree includes the requirements a technology must possess to be considered appropriate for technology insertion. The structure of the tree makes it suitable for application to a wide variety of technologies. In order to present a complete logic-tree, all aspects of engineering design were included. However, for this research only human factors related branches of the tree are discussed in detail.

Logic-trees are an established and proven methodology for determining cause-effect relationships. Logic-trees have been applied extensively as fault-trees in safety engineering. The analysis technique uses either deductive logic (reasoning from a general fact to a specific conclusion) or inductive logic (reasoning from a specific fact to a general conclusion) to establish the course of conditions or events which must occur (criteria) to produce a stated outcome (technology insertion).

Boolean logic states the conditions necessary for any event to occur. It enumerates the possible conditions which must exist, and

states whether the conditions must exist concurrently (AND gate ⌓), or if one condition need only exist for the event to occur (OR gate ⌒). If the logic-tree enumerates all possible conditions then the logic-tree should represent a valid representation of what events must occur for the desired outcome to occur.

Logic-trees have the attribute of being depicted graphically, therefore providing a visual representation of the logic structure. This adds to understanding the relationships between the numerous conditions associated with one desired event. Referring to the logic-tree criteria chart at the back of the report, the desired event is to choose an appropriate technology for a stated application. There are a total of 50 possible prerequisites or conditions which may apply when considering a specific technology for a stated application in the system.

Table 6-1 is a descriptive legend of the entire logic-tree criteria chart to provide the reader with an introductory understanding of the chart. Below, a more detailed discussion of the human factors section of the logic-tree is presented. This discussion includes how the logic-tree can be applied to the CMS.

The technical requirement branch of the logic-tree criteria chart (conditions 2-33) addresses the prerequisits the technology must possess to be considered appropriate and applicable. Technologies can be either proven (condition 3) or unproven (condition 25).

Acceptable, proven technology. A proven technology is a technology which is well proven and established (condition 4) in its field or is a new, state-of-the-art technology which has recently been proven in its field (condition 18). Both types of proven technology

Table 6-1. Descriptive Legend of the Logic-Tree Criteria Chart for Technology Insertion

Block Number	Description
	(see Figure 6-3)
1	Technology insertion is appropriate when there is: · an ability to apply a technology, and · a demand for technology insertion
	When there exists an ability to apply a technology
2	An ability to apply a technology exists if: · the technology is acceptable and proven, or · the technology is acceptable but unproven
	- For cases where the technology is proven
	(See Figure 6-4)
3	A technology can be acceptable and proven if: · Acceptable, proven technology is an established technology, or · Acceptable, proven technology is a new and state-of-the-art technology
4	Acceptable, proven technology is established if: · Established technology is an effective solution, and · Established technology is a feasible solution
	(See Figure 6-5)
5	Established technology is an effective solution if: · Effective solution offers beneficial performance, and · Effective solution offers operator acceptance
6	Effective solution offers beneficial performance if: · Beneficial performance in a previous, identical application, or: · Beneficial performance in a previous, similar application
7	Beneficial performance in a previous, identical application if: · Previous identical application meets measures of effectiveness for new application

(continued)

Block Number	Description
8	Beneficial performance in a previous, similar application if: · Previous identical application meets measures of effectiveness for new application
9	Effective solution offers operator acceptance if: · Operators accept the technology as reliable, · Operators are confident in the capability of the technology, and · Operators accept technology as a useful tool
10	Operators accept the technology as reliable if: · Subject matter experts and human factors engineering studies conclude that the operator accepts the technology as reliable
11	Operators are confident in the capability of the technology if: · Subject matter experts and human factors engineering studies conclude that the operator is confident in the capability of the technology
12	Operators accept technology as a useful tool if: · Subject matter experts and human factors engineering studies conclude that the operator accepts the technology as a useful tool
	(See Figure 6-6)
13	Established technology is a feasible solution if: · Feasible solution meets system application requirements, · Feasible solution meets engineering requirements, · Feasible solution meets cost/benefit requirements, and · Feasible solution meets operator performance requirements
14	Feasible solution meets system application requirements if: · System engineering studies determine if technology meets system application requirements
15	Feasible solution meets engineering requirements if: · Engineering studies determine if technology meets engineering requirements
16	Feasible solution meets cost/benefit requirements if: · Accounting studies determine if technology meets cost/benefit requirements

(continued)

Block Number	Description
17	Feasible solution meets operator performance requirements if: • Human factors engineering studies determine if technology meets operator performance requirements
18	Acceptable, proven technology is a state-of-the-art technology if: • State-of-the-art technology is an effective solution, • State-of-the-art technology is a feasible solution, and • State-of-the-art technology is a mature technology **(See Figure 6-7)**
19	State-of-the-art technology is an effective solution if: • see blocks 6, 7, 8, 9, 10, 11, 12 **(See Figure 6-8)**
20	State-of-the-art technology is a feasible solution if: • see blocks 13, 14, 15, 16, 17 **(See Figure 6-9)**
21	State-of-the-art technology is a mature technology: • Mature technology was proven during the concept stage, • Mature technology was proven during the development stage, and • Mature technology was proven during the test and evaluation stage
22	Mature technology was proven during the concept stage if: • Technology validated at concept definition stage
23	Mature technology was proven during the development stage if: • Technology validated at development stage
24	Mature technology was proven during the test and evaluation stage if: • Technology validated at test and evaluation stage **- For cases where the technology is unproven** **(See Figure 6-10)**
25	Unproven technology is acceptable if: • unproven technology is acceptable in conceptual stage, or • unproven technology is acceptable in developmental stage

(continued)

Block Number	Description
26	Acceptable, unproven technology in conceptual stage if: • Concept technology is technically feasible, • Concept technology is an effective solution, and • Concept technology is economically feasible
27	Concept technology is technically feasible if: • Concept definition studies determine the technical feasibility of the concept and associated knowledge gaps for the technology, and • Technical risk studies determine if the developmental risks are technically acceptable
28	Concept technology is an effective solution if: • Concept definition studies determine if the implementation potential of the concept is an appropriate, effective solution, and • Technical risk studies determine if the concept can be developed in the stated time period
29	Concept technology is economically feasible if: • Technical risk studies determine if the cost to develop the concept into a state-of-the-art technology is feasible
30	Acceptable, unproven technology in developmental state if: • Developmental technology validated in conceptual stage • Developmental technology is an effective solution, and • Developmental technology is economically feasible
31	Developmental technology validated in conceptual stage if: • see block 26
32	Developmental technology is an effective solution if: • see block 28
33	Development technology is economically feasible: • see block 29
	When there exists a demand for technology insertion
	(See Figure 6-11)
34	Demand for technology insertion if: • Operator perceptual limits are exceeded, • Operator mediational limits are exceeded, • Operator communication limits are exceeded, or • Operator psychomotor limits are exceeded

(continued)

Block Number	Description
	- For cases where operator perceptual limits are exceeded
35	Operator perceptual limits are exceeded if: · Perceptual limits exceeded due to excessively large quantity of information to identify or organize, · Perceptual limits exceeded due to excessively small quantity of time to identify or organize information, or · Perceptual limits exceeded due to excessively high requirements for correctness in identifying or organizing information
36	Perceptual limits exceeded due to excessively large quantity of information to identify or organize if: · Human factors engineering studies determine if operator perceptual limits are exceeded due to excessively large quantity of information to identify or organize
37	Perceptual limits exceeded due to excessively small quantity of time to identify or scan information if: · Human factors engineering studies determine if operator perceptual limits are exceeded due to excessively small quantity of time to identify or scan information
38	Perceptual limits exceeded due to excessively high requirements for correctness in identifying or organizing information if: · Human factors engineering studies determine if operator perceptual limits are exceeded due to excessively high requirements for correctness in identifying or organizing information
	- For cases where operator mediational limits are exceeded
39	Operator mediational limits are exceeded if: · Mediational limits exceeded due to excessively large quantity of information to process and problem solve · Mediational limits exceeded due to excessively small quantity of time to process and problem solve information, or · Mediational limits exceeded due to excessively high requirements for correctness in processing and problem solving information
40	Mediational limits exceeded due to excessively large quantity of information to process and problem solve: · Human factors engineering studies determine if operator mediational limits are exceeded due to excessively large quantities of information to process and problem solve

(continued)

Block Number	Description
41	Mediational limits exceeded due to excessively small quantity of time to process and problem solve information if: • Human factors engineering studies determine if operator mediational limits are exceeded due to excessively small quantity of time to process and problem solve information
42	Mediational limits exceeded due to excessively high requirements for correctness in processing and problem solving information if: • Human factors engineering studies determine if operator mediational limits are exceeded due to excessively high requirements for correctness in processing and problem solving information
	- For cases where operator communication limits are exceeded
43	Operator communication limits are exceeded if: • Communication limits exceeded due to excessively large quantity of information to receive or transmit, • Communication limits exceeded due to excessive small quantity of time to receive or transmit information, or • Communication limits exceeded due to excessively high requirements for correctness in receiving or transmitting of information
44	Communication limits exceeded due to excessively large quantity of information to receive or transmit if: • Human factors engineering studies determine if operator communication limits are exceeded due to excessively large quantity of information to receive or transmit
45	Communication limits exceeded due to excessively small quantity of time to receive or transmit information if: • Human factors engineering studies determine if operator communication limits are exceeded due to excessively small quantity of time to receive or transmit information
46	Communication limits exceeded due to excessively high requirements for correctness in receiving or transmitting of information if: • Human factors engineering studies determine if operator communication limits are exceeded due to excessively high requirements for correctness in receiving and transmitting of information

(continued)

Block Number	Description
	- For cases where operator psychomotor limits are exceeded
47	Operator psychomotor limits are exceeded if: · Psychomotor limits exceeded due to excessively large quantity of activities to be performed, · Psychomotor limits exceeded due to excessively small quantity of time to perform activities, or · Psychomotor limits exceeded due to excessively high requirements for correctness when performing activities
48	Psychomotor limits exceeded due to excessively large quantity of actions to be performed if: · Human factors engineering studies determine if operator psychomotor limits are exceeded due to excessively large quantity of actions to be performed
49	Psychomotor limits exceeded due to excessively small quantity of time to perform activities if: · Human factors engineering studies determine if operator psychomotor limits are exceeded due to excessively small quantity of time to perform activities
50	Psychomotor limits exceeded due to excessively high requirements for correctness when performing activities if: · Human factors engineering studies determine if operator psychomotor limits are exceeded due to excessively high requirements for correctness when performing activities

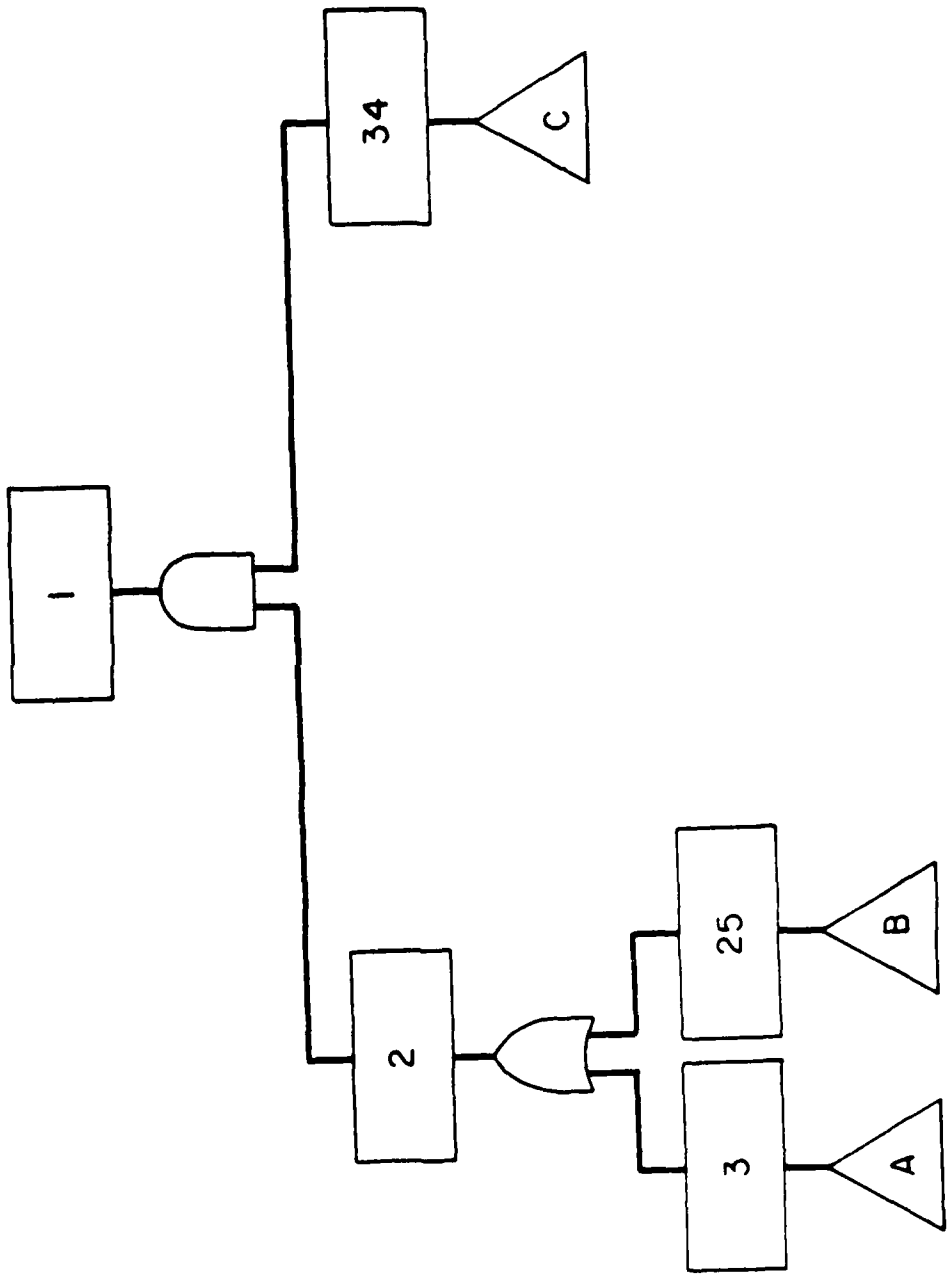


Figure 6-3. Criteria for an Appropriate Technology

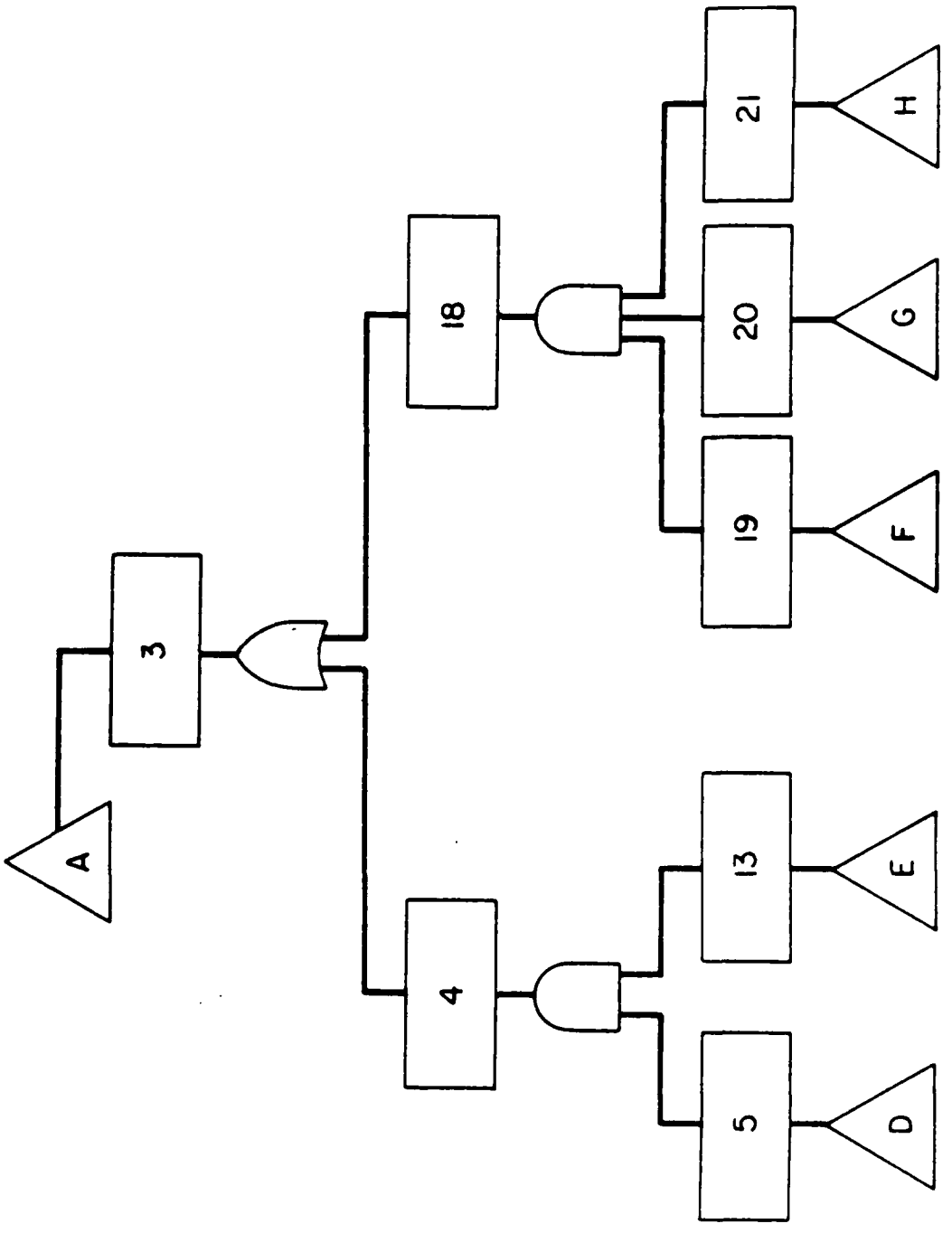


Figure 6-4. Criteria for an Acceptable, Proven Technology

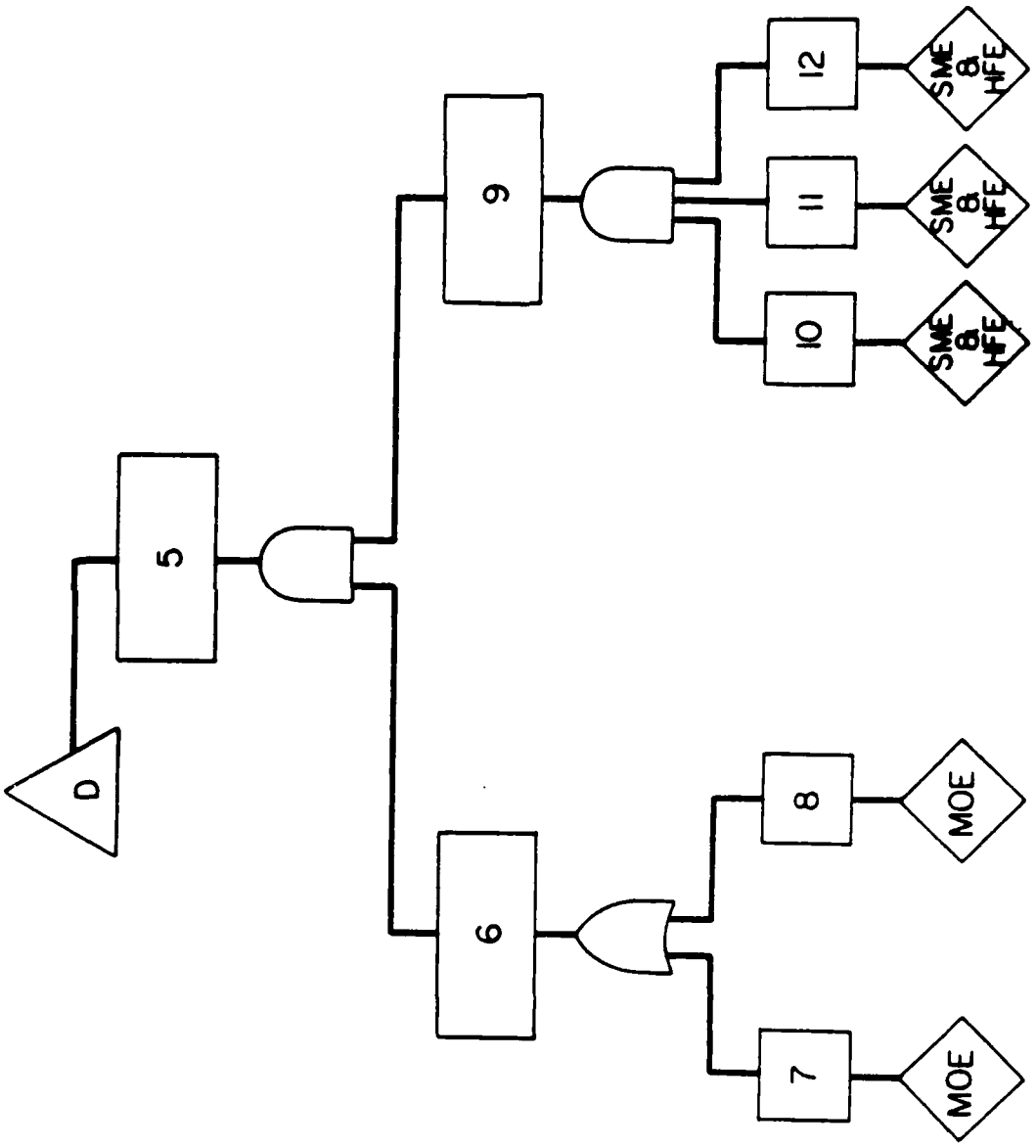


Figure 6-5. Criteria for an Acceptable, Proven, Established Technology Being an Effective Solution

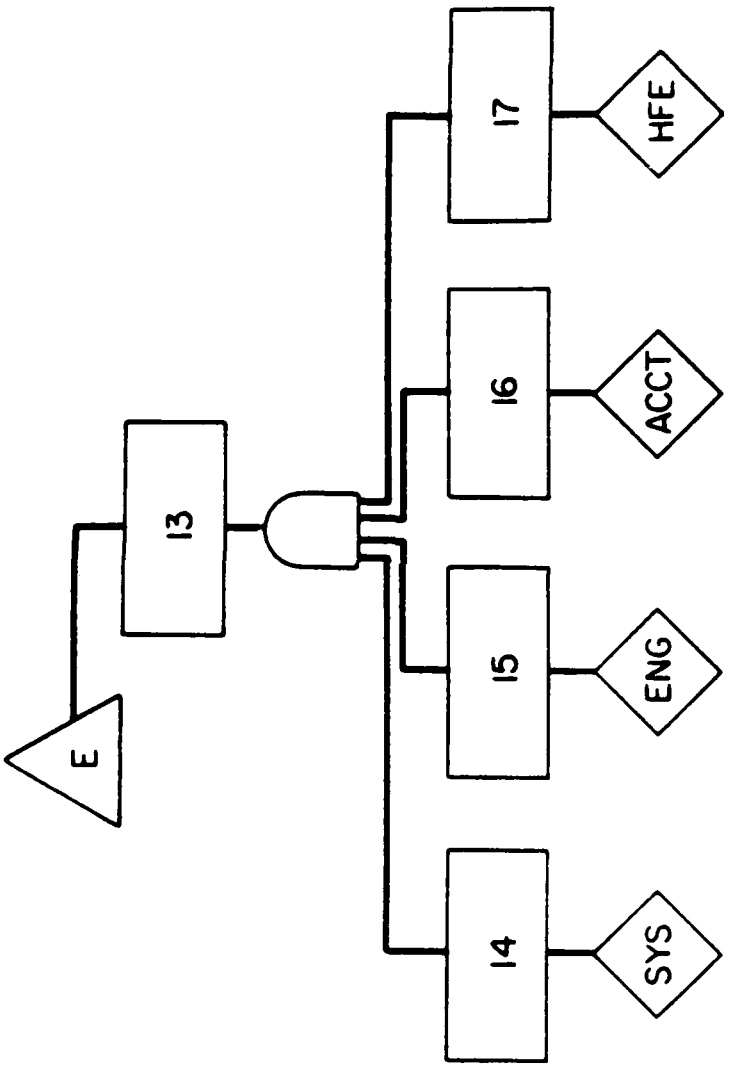


Figure 6-6. Criteria for an Acceptable, Proven, Established Technology Being a Feasible Solution

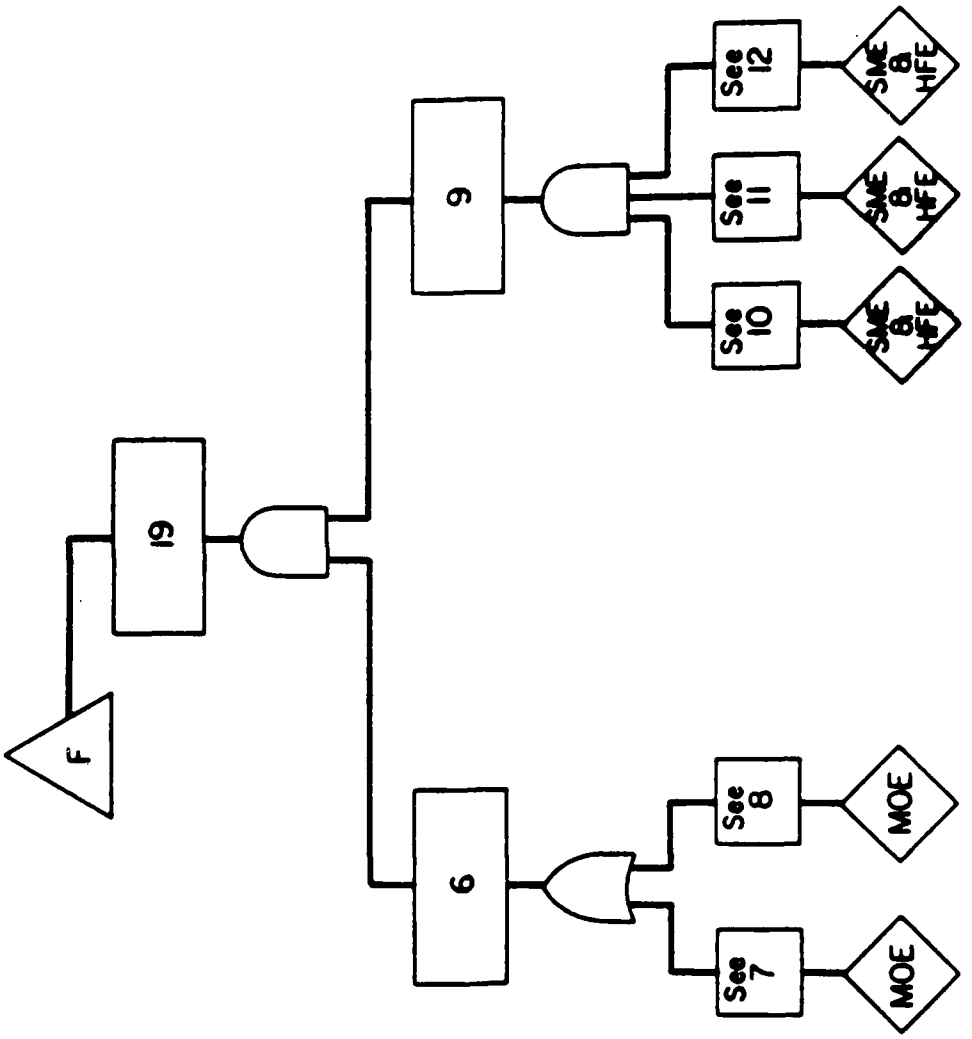


Figure 6-7. Criteria for Acceptable, Proven, State-of-the-art Technology Being an Effective Solution

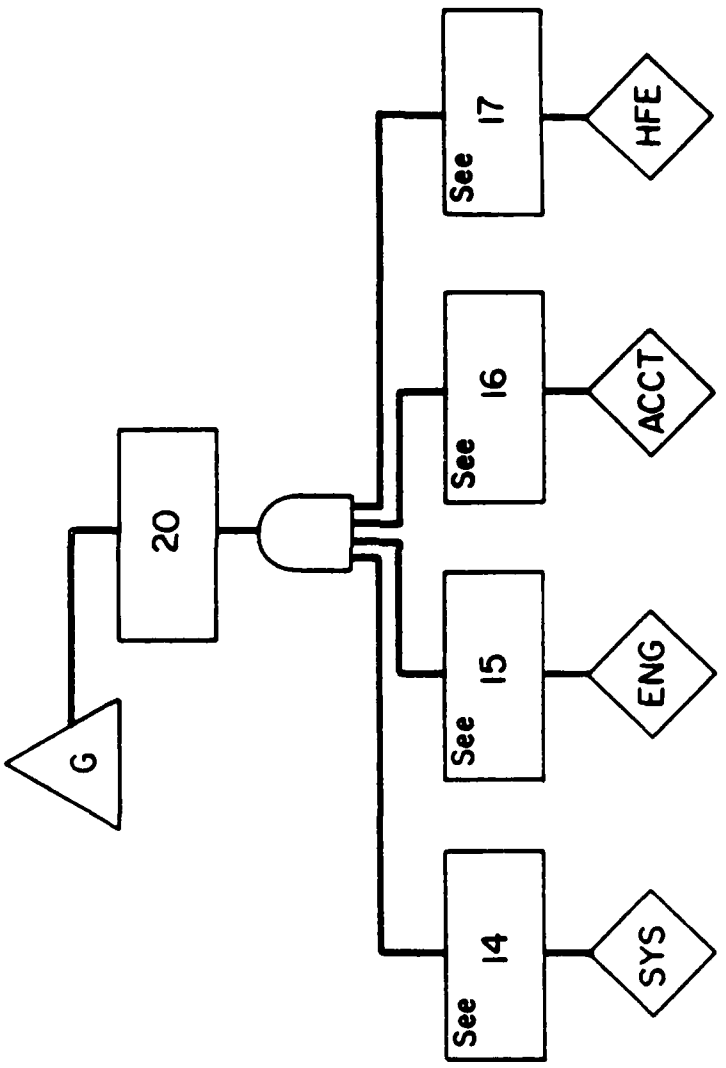


Figure 6-8. Criteria for Acceptable, Proven, State-of-the-art Technology Being a Feasible Solution

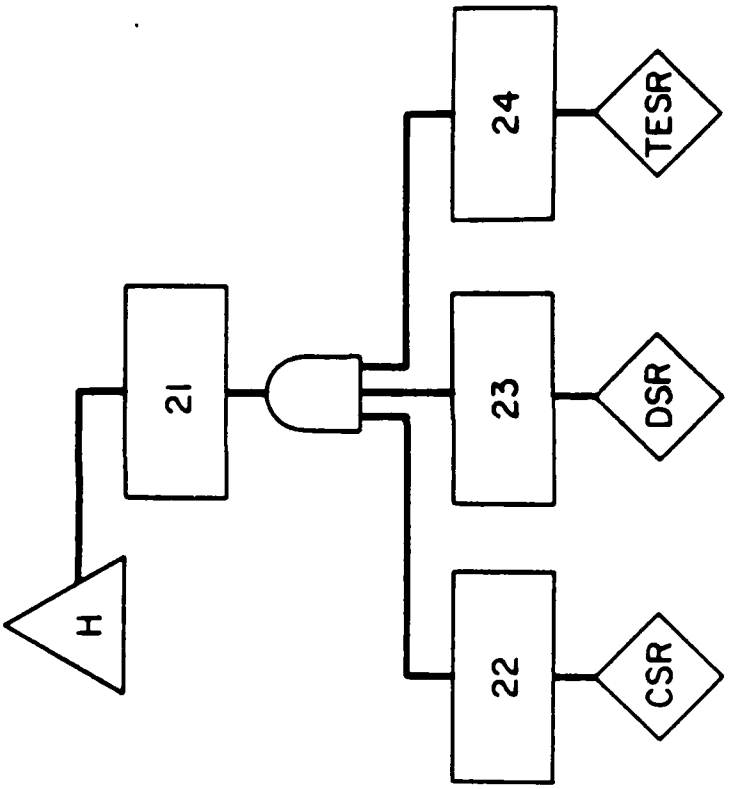


Figure 6-9. Criteria for Acceptable, Proven, State-of-the-art Technology Being a Mature Technology

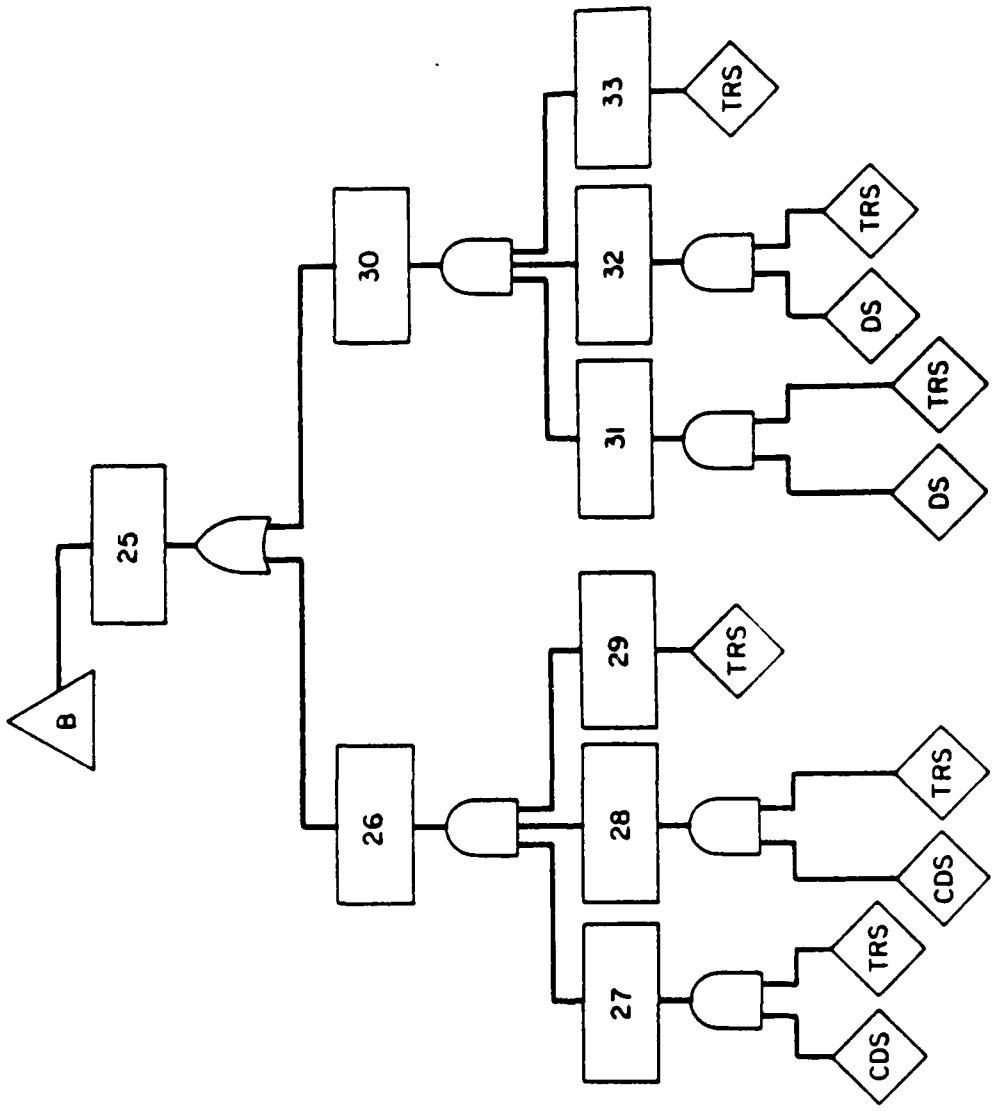


Figure 6-10. Criteria for Acceptable, Unproven, Technology

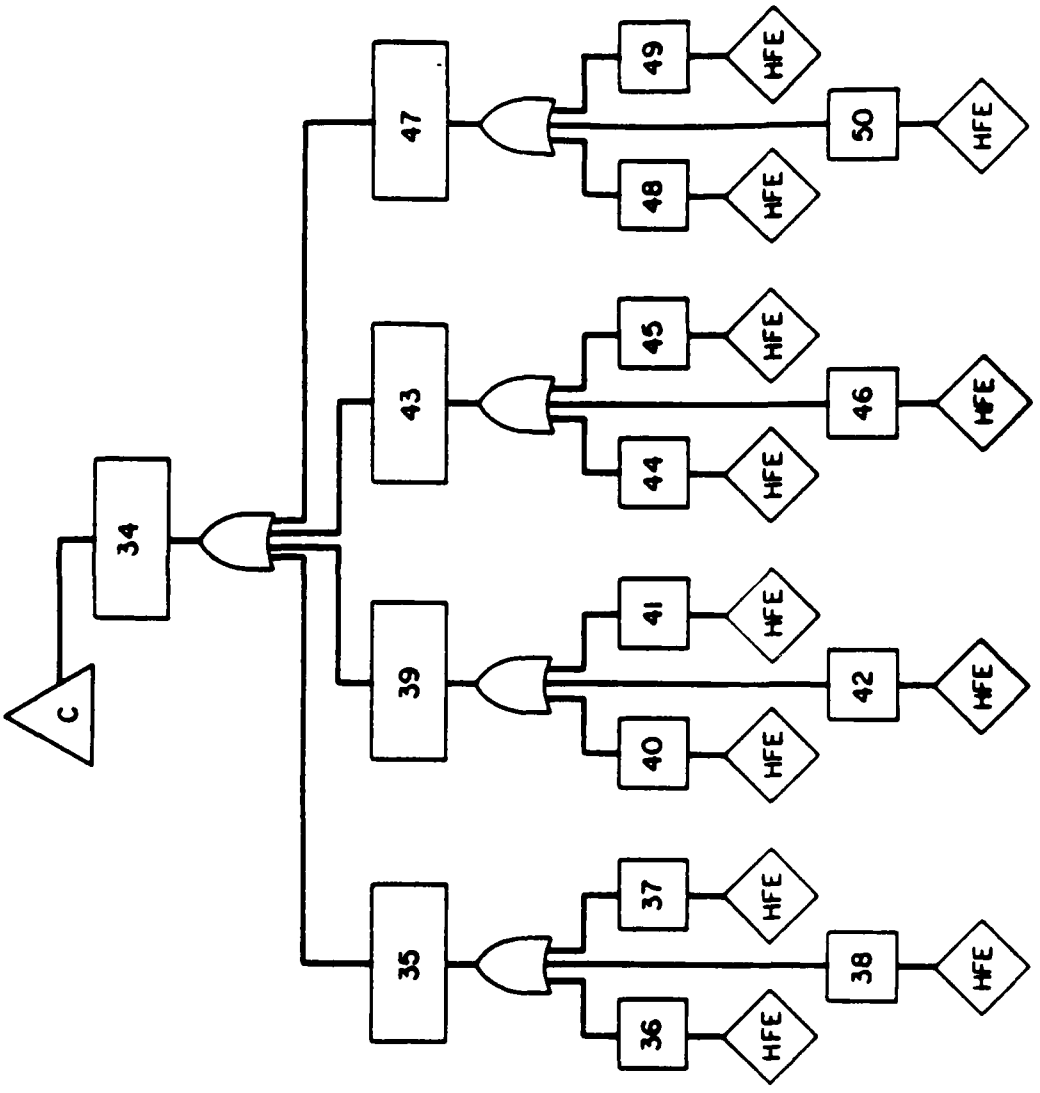


Figure 6-11. Criteria for a Demand for Technology Insertion

must be effective solutions (conditions 5 and 19). An effective solution being a technology which has been used in identical (condition 7) or similar (condition 8) applications and yielded beneficial results (condition 6). These beneficial results can be stated as measures of effectiveness (MOEs) for judging the technology.

An effective solution must also meet operator acceptance requirements (condition 9). Operators must respect the technology as being reliable (condition 10), have confidence in its capabilities (condition 11), and believe that the technology is a useful piece of equipment (condition 12).

These conditions are best answered by soliciting subjective ratings from subject-matter-experts (SMEs), and conducting human factors engineering analysis studies on operator acceptance (HFE studies). For the case of the CMS, HFE studies would be performed when candidate technologies had been identified for a specific application. Studies would research operator acceptance for past applications, involving techniques such as interviewing operators and analyzing performance data from existing systems.

A proven technology (established or new, state-of-the-art) must also be a feasible solution (conditions 13 and 20). Feasibility is measured in several different ways, however, all measures must be acceptable for the technology to be considered feasible. Systems engineering must determine if the technology meets stated requirements for the system under consideration (condition 14) by conducting system engineering studies (SYS studies). All other engineering disciplines (e.g., electrical, mechanical, software) excluding system and human factors engineering, must determine if the technology meets their

respective requirements (condition 15) through the accomplishment of engineering studies (ENG studies). In addition to being technically feasible, a technology must also be economically feasible (condition 16) which is determined by cost or accounting studies (ACCT studies). Feasibility also includes operator performance requirements (condition 17). Human factors engineering studies determine whether the technology is a feasible solution from an operator performance standpoint (HFE studies).

Determining technology feasibility from an operator performance standpoint involves performing preliminary function and task analysis studies to determine how much time and effort the technology demands of the operator. HFE studies would evaluate characteristics of the technology such as the user-interface for acceptability, operator workload, and human reliability. HFE studies would also evaluate how well the technology meshes with other previously selected technologies and investigate possible clashes between competing operator performance requirements.

The condition which distinguishes an established, proven technology from a new, state-of-the-art, proven technology is determining whether or not the latter is technically mature (condition 21). An established, proven technology is assumed to be technically mature. Technical maturity can be measured for a specific technology as the maturation of the concept (condition 22), its development (condition 23), and its testing and evaluation (condition 24). Stated another way, some technologies are so new and have such a limited application record that there are knowledge gaps (unanswered questions) and implementation potential (adaptability) questions for the

technology. These technologies should be evaluated by reviewing the reports on the technology's progression from the concept stage (CSR), through the development stage (DSR), to the test and evaluation stage (ESR).

Acceptable, unproven technology. A technology does not have to be proven in the field to be acceptable. A technology may be an acceptable, unproven technology (condition 25). Unproven technologies are either a concept for a technology (condition 26) or a technology currently under development (condition 30). A contemporary example is technology involved with the Space Defense Initiative. Much of the research was initiated to investigate concepts for new technology. As concepts are validated, they are then developed into a new technology. Therefore, methods exist for investigating unproven technologies for possible insertion into a system under consideration.

Unproven technologies, conceptual or developmental, have three major conditions to meet. First, the technical feasibility of the technology must be acceptable (conditions 27 and 31). Concept definition studies (CDS) and technical risk studies (TRS) should be consulted to determine if knowledge gaps and technical risks are acceptable. Naturally, one would expect knowledge gaps and technical risks to decrease as a technology progresses from the concept to the development stage.

Second, the potential effectiveness of the technology must be acceptable (conditions 28 and 32). Again, concept definition studies and technical risk studies should be consulted to determine the implementation potential of the technology and the projected time frame until completion. As the technology progresses from concept through

development stages, better estimates should be available as to the implementation potential and time until completion for the technology. However, there are always potential risks that the development stage of the technology may reveal. New problems may arise which affect implementation of the technology and extend the development time frame for the technology.

Third, an unproven technology must be economically feasible (conditions 29 and 33). The cost to research a concept for a specific application may be too great. Similarly, the cost to develop the technology may be too great to justify developing the technology. Such concerns are addressed in technical risk studies (TRS).

Demand for Technology Insertion. The demand for technology insertion (conditions 34-50) is the initiative for considering a technology for insertion into a system. A demand for technology exists because a person's behavioral processes have been exceeded (condition 34). As mentioned earlier in this report, Berliner et al. (1964) defined four universal behavior processes: perceptual, mediational, communication, and psychomotor. The perceptual process is a person's ability to sense stimuli (e.g., organize information). The mediational process is a person's ability to reason through and process information. The communication process is a person's ability to transmit and receive information. The psychomotor process is a person's ability to coordinate and perform motor tasks. It is an oversimplification, but it can be said that the human race creates things to alleviate these processes or extend our manipulation of these processes beyond our own physiological and mental capabilities. Simply stated, technology allows us to do things we could not possibly do by our own accord.

Identifying why a demand for technology exists greatly facilitates determining the optimal technological solution. In general, there are four reasons why a demand for technology exists in a system. First, the operator's perceptual limits are exceeded by the requirements of the system (condition 35). Perceptual limits are exceeded when the rate of sensory stimuli is greater than the operator could possibly sense (condition 36). The sheer quantity of sensations is too great, either due to quantity or complexity of the stimuli. Perceptual limits are also exceeded when the available time to receive and organize sensory stimuli is shorter than the time required by the operator to sense the information (condition 37). In addition, perceptual limits are exceeded when a high degree of reliability is required for receiving and organizing the information correctly (condition 38). Reliability for sensing and organizing information correctly may exceed human reliability, precipitating an excessive back-log of information and exceeding time limits.

Second, the operator's mediational limits are exceeded by the requirements of the system (condition 39). Mediational limits are exceeded when the rate of information to be processed or problem-solved is greater than the operator could possibly process or resolve (condition 40). This may occur when the quantity of information is too great to be processed or resolved by the operator. Mediational limits are also exceeded when the available time to process or problem-solve information is shorter than the time required by the operator to process or resolve information (condition 41). Time limits are caused due to numerous tasks, or simply due to a very brief amount of time to process or resolve information. Mediational limits can also be

exceeded when a high degree of reliability is required for processing information or solving the problem correctly (condition 42). Reliability for problem-solving information correctly may exceed human reliability, precipitating an excessive back-log of information and exceeding time limits.

Third, the operator's communication limits are exceeded by the requirements of the system (condition 43). Communication limits are exceeded when the rate of information to be received or transmitted is greater than the operator could possibly accept or send (condition 44). The quantity of information could be too great or too complex for the operator to handle. Communication limits are also exceeded when the available time to receive or transmit information is shorter than the time required by the operator to receive or transmit information (condition 45). Information transfer rates can cause overloading due to time-sharing by the operator because of numerous tasks, or simply due to high information transfer rates. In addition, communication limits are exceeded when a high degree of reliability is required for receiving or transmitting information correctly (condition 46). Reliability for correctly transmitting or receiving information may exceed human reliability, precipitate an excessive back-log of information and cause unacceptable time delays.

Fourth, the operator's psychomotor limits are exceeded by the requirements of the system (condition 47). Psychomotor limits are exceeded when the number of actions to be performed are greater than the operator is capable of performing (condition 48). There may be too many actions to be performed, actions could be too complex, or actions could physically exceed human motor capabilities. Psychomotor limits

are also exceeded when the available time to perform an action is shorter than the time required by the operator to perform the action (condition 49). Actions may have to be performed too rapidly, concurrently, or repetitively, thus causing the operator's psychomotor capabilities to be exceeded. Additionally, time-sharing by the operator because of numerous tasks may cause the psychomotor limits to be exceeded. Psychomotor limits are also exceeded when a high degree of reliability is required for performing actions correctly (condition 50). Actions may have to be performed with a degree of precision or accuracy that exceeds human psychomotor capabilities.

Operator perceptual, mediational, communications, and psychomotor limits would all be addressed in the analysis of the CMS (HFE studies). One method of analyzing the CMS, would be to identify crewmember requirements where behavioral processes could be exceeded. Relative limits would be defined for an analysis of this type. Obviously, the analysis cannot determine absolutely where the crew are overburdened, and where they are within their limits. However, an analysis of the CMS should provide very early indications of crewmember requirements which would benefit from technology that alleviates certain behavioral processes.

Consider the requirement to search and image an unpredictable RT search area or determining occupancy of a predictable RT. A time line analysis for these types of events, or a task analysis of events would clearly indicate that the crew's task would benefit greatly by some type of technology for interpreting imaging by electronic sensors or imaging equipment. Establishing this demand, a fairly brief technology search determines if the idea is within the realm of modern-day

technology. If candidate technologies or concepts are found, then the technical half of the logic-tree criteria chart can be applied. If no candidates are identified, then alternative concepts or solutions must be investigated.

6.6 Summary

Criteria for technology insertion were developed. This section completes Step Three of the evolved methodology proposed in Part 2.4.2. Two methodologies emphasizing human factors engineering during the development of a system and the associated selection of technologies for the system were reviewed (RAM/ACE and CAT). Each represents a concerted effort to introduce human factors into the design loop at the very early stages of system concept definition. These methodologies provided guidance for developing criteria for technology insertion.

Criteria for technology insertion were presented as a logic-tree criteria chart. The chart is based on Boolean logic and patterned after the accepted fault-tree analysis methodology. For technology insertion to be considered appropriate, there must be a demand for the technology and a capability to apply the technology successfully. The hierarchy of the logic-tree is designed to be applicable to a variety of technologies and incoporates the necessary requirements from the different disciplines of engineering design.

The logic-tree criteria chart was described, and how it can be applied to the CMS discussed. Listed below are overall procedures for the human factors engineering aspect of technology insertion.

Table 6-2. Procedures for Technology Insertion

1. Identify crewmember requirements for the system under consideration and determine functions which may benefit from technology insertion.

   · For this research, crewmember performance requirements, information management requirements and informational demands were identified and determined to be appropriate for technology insertion.

2. Perform a literature review on technologies associated with the functions under consideration.

   · For this research, flight-deck automation technologies associated with information presentation and management were reviewed.

3. Perform a human factors study for each candidate technology.

   · Determine the purpose, intended use, inherent advantages and disadvantages of each technology. Investigate past applications of the technology and operator acceptance. In addition, evaluate candidate technologies for design issues and applicability to operator performance requirements.

4. Specify in the logic-tree criteria chart the requirements the technology must possess to satisfy crewmember requirements.

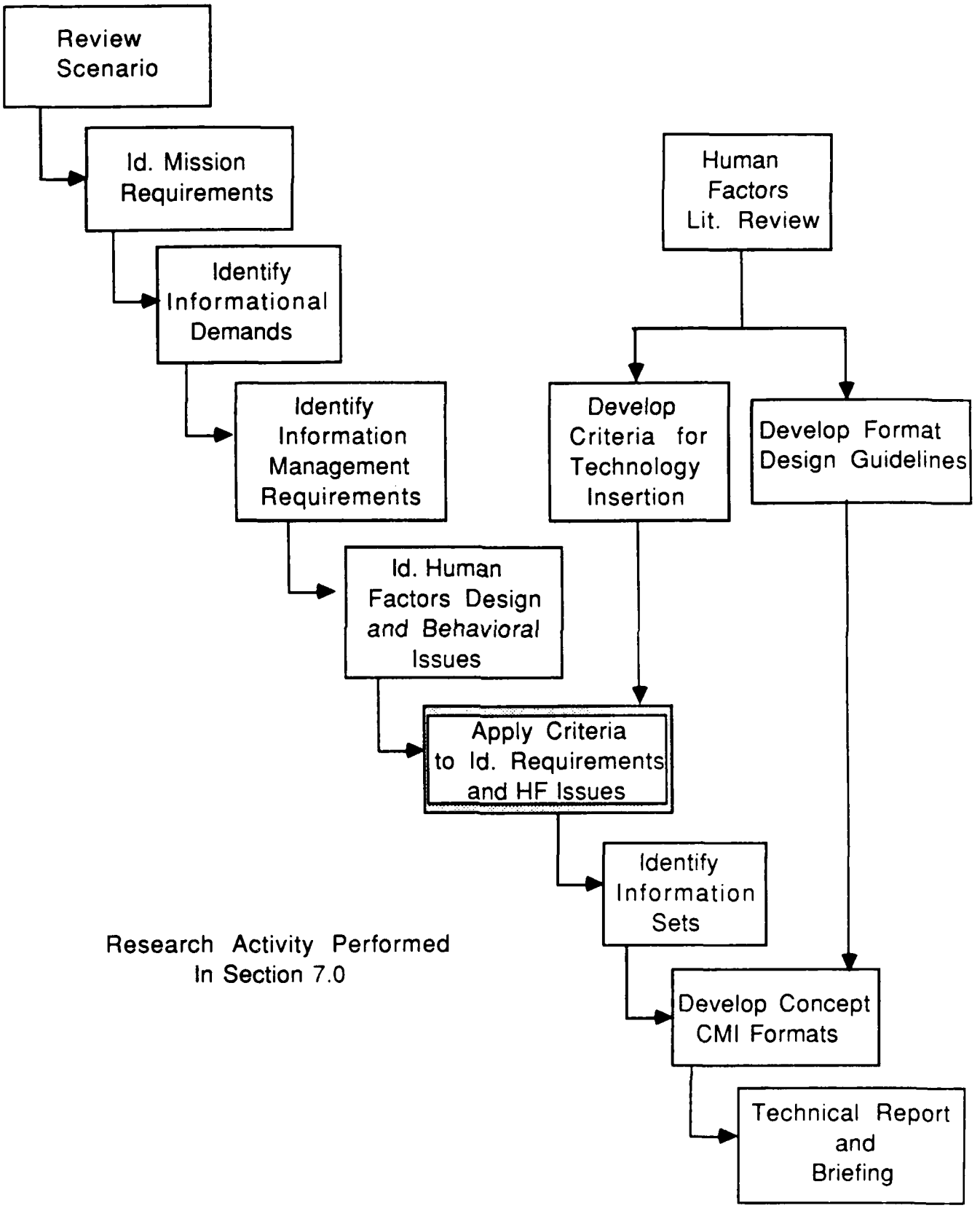
   · For each identified crewmember requirements, specify the characteristics the desired technology must possess. Example, a crewmember requirement to make numerous rule-based decisions, rapidly, with high reliability could be supported by an expert system, which is capable of supporting rule-based decisions.

5. Apply candidate technologies to the human factors branches of the logic-tree criteria chart.

   · Technologies are applied to the logic-tree criteria chart for possible selection. For each technology, the appropriate branch of the tree must be examined. Technologies which satisfy human factors requirements can be applied to the other branches of the logic-tree where the other disciplines of engineering design are considered.

6. Identify technologies which fail the logic-tree criteria chart.

   · If no technology exists which supports the characteristics desired by a given crewmember requirement, a decision should be made as to whether or not to automate. Technology is bounded and where no suitable technology exists for a given function, that function should not be automated.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 7.0

7.0 OPPORTUNITIES FOR TECHNOLOGY INSERTION

7.1 Objectives

The objectives of identifying opportunities for technology insertion are to bring together the predefined requirements for the CMS (Sections 4.0 and 5.0) with the criteria for selecting technology (Section 6.0) and to identify those requirements that would benefit from technology insertion. This section represents Step Four of the evolved methodology in Part 2.4.2. The goal is to introduce technology where it would enhance crewmember situation awareness and reduce workload. An overall requirement is that the technology should promote mission success.

7.2 Technologies Reviewed for Possible Insertion.

The literature review generated an abundance of articles on cockpit automation: artificial intelligence, flight management systems, interactive controls, speech recognition and color displays to name the more popular technologies. However, the greater majority of the articles are devoted to either the investigation of a specific technology's capabilities and limitations, or to the promotion of a specific technology. There appears to be a definite absence in the literature on evaluating similar human-machine interface technologies based on their comparative advantages and disadvantages for performing different functions. This is not surprising since an experimental design for such a study would be complex and costly.

The scope of the research did not permit an in-depth evaluation and comparison of human-machine interface technologies. Three

categories of cockpit automation technologies were selected and reviewed:

- expert systems,
- computer-generated displays, and
- voice-interactive systems.

The review was limited to articles addressing human factors issues of the technologies. Periodicals reviewed included, but were not limited to Applied Ergonomics, Ergonomics, Human Factors, and the International Journal of Man-Machine Studies. Numerous annual conferences were reviewed including Proceedings of the Human Factors Annual Meeting, Proceedings of IEEE Transactions on Systems, Man, and Cybernetics, and Behavioral Engineering Technology Conference Proceedings. The review is a collection of recent articles on flight-deck automation technology, expert systems, flight-deck design philosophy, and human performance measures. The majority of articles are post-1980, and therefore, the review is not a comprehensive review on any of the topics.

7.3 Opportunities for Technology Insertion

Opportunities for technology insertion were identified by applying criteria for technology insertion identified in Section 6.0 to technologies reviewed during the literature review. Demands for technology support were identified during the scenario review and were stated in Section 4.0. The logic-tree criteria chart also includes consideration for engineering disciplines other than human factors. While these aspects of systems design are critically important, they could not be evaluated as part of this research. Instead, only human

factors engineering criteria were considered.

Five opportunities for applying technology to the CMS aircraft system were identified. Three of the opportunities involve expert systems, and the other two opportunities are for computer-generated displays and speech recognition/generation systems. In the paragraphs which follow, each opportunity is fully discussed and includes the rationale for proposing that technology. Additionally, a brief overview of the fundamentals of each technology is also presented at the beginning of each sub-section.

7.4 Expert Systems

Expert systems are computer programs with expertise in a specific area of knowledge. Expert systems are an outgrowth of the field of artificial intelligence (AI), which can be defined as "the science that tries to create intelligent behavior on computers" (Dym, 1985). Whether or not a computer can exhibit intelligent behavior has generated controversy, and debate among scientists and pscyhologists for years (Grabiner, 1986) and will not be resolved here. This report advances the Brachman et al. (1983) summary definition of expert systems:

> An expert system is one that has expert rules and avoids blind search, reasons by manipulating symbols, grasps fundamental domain principles, and has complete weaker reasoning methods to fall back on when expert rules fail and to use in producing explanations. It deals with difficult problems in a complex domain, can take a problem description in lay terms and convert it to an internal representation appropriate for processing with its expert rules, and it can reason about its own knowledge (or lack thereof), especially to reconstruct paths rationally for explanation and self-justification (p. 50).

In clearer language, expert systems are computer programs that are experts on a specific subject. If you communicate the facts or lack of facts on the subject to the computer program and query it as to what these facts mean or do not mean, the program will respond with an answer and its confidence in the answer. The answer should be reasonable and acceptable to an expert on the subject.

There are several reasons why expert systems exist: (1) they have the capacity to retain vast quantities of knowledge on a subject (Hillman, 1985), (2) overall they reason through this information at a much greater speed and accuracy than a human expert on the subject (Ott, 1985), (3) an expert system can be replicated readily, while human experts cannot (Hayes-Roth et al., 1983), (4) expert systems are inanimate equipment not subject to the requirements and mortality of people (Waterman, 1986), and (5) expert systems can be constructed where no human experts exist (Waterman, 1986).

7.4.1 Expert Systems Architecture. The field of expert systems is based in computer science. To attempt a short-course in expert systems would be incomplete and shallow. Several references provide an excellent in-depth discussion on expert systems; Dym (1985), Hayes-Roth et al. (1983), Simons (1984), Waterman (1986), and Williamson (1986).

For the purposes of this report, expert systems are defined on a general level. Williamson's architecture of a knowledge-based expert system (Williamson, 1986), depicted in Figure 7-1, will be used as a model for explanation. There are three major components of an expert system (1) a knowledge base, (2) an inference engine, (3) an input/output system.

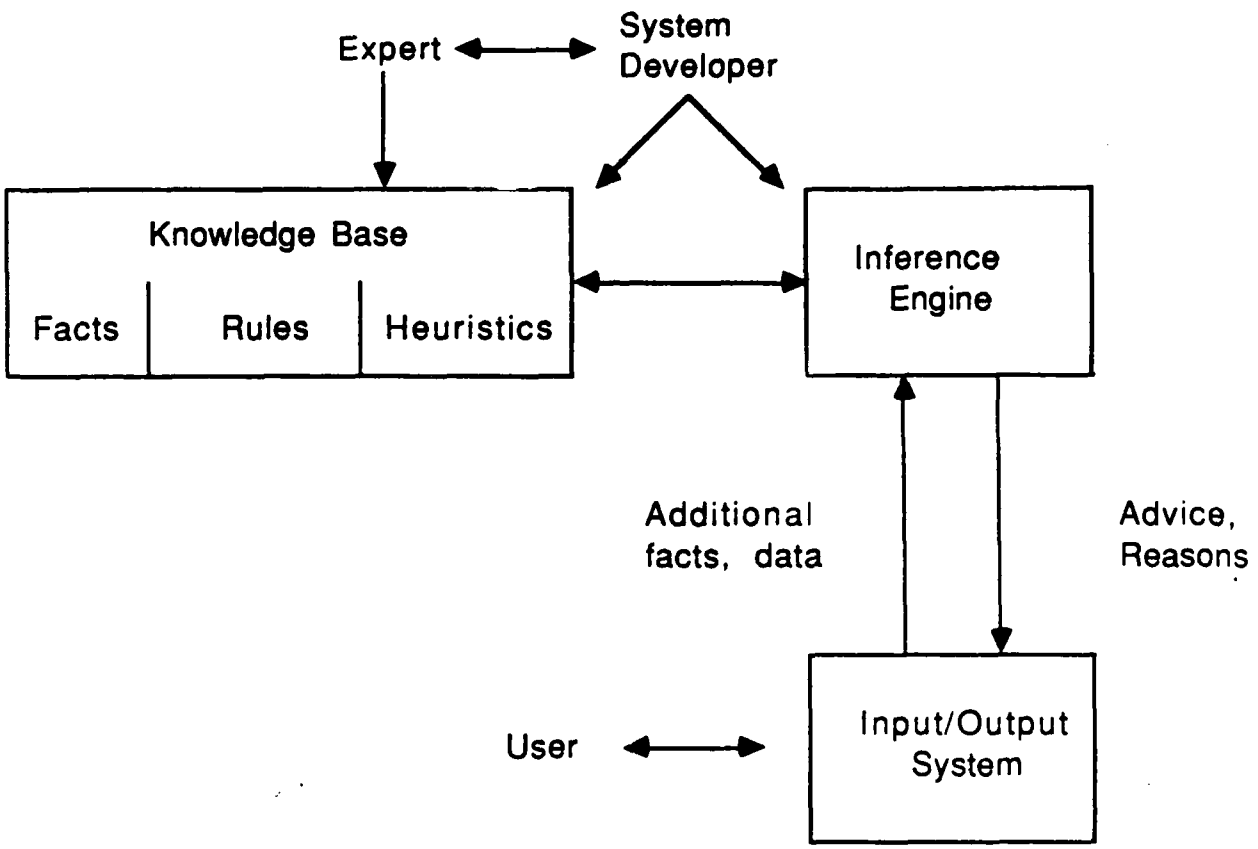


Figure 7-1. Knowledge-Based Expert System Architecture (From Williamson, 1986)

The Knowledge Base. The knowledge base is an assemblage of a body of knowledge on a specific subject. A knowledge base contains facts, rules, and heuristics. Facts, or descriptive knowledge, are known, available information on the subject and could readily be found in any comprehensive text on the subject. Rules, or prescriptive knowledge, are prescribed courses of action to be taken in the presence of certain conditions. Heuristics, or expert knowledge, is the knowledge of underlying principles or accumulated experience on the subject. Fact, rules, and heuristics are gathered from subject references and human experts on the subject.

The Inference Engine. The inference engine is the procedures, or control mechanisms, the system will use to solve problems. There are two types of control mechanisms--data driven, or goal driven. The system developer is responsible for developing the logic and reasoning that the inference engine will use, and for determining how the inference engine interfaces with the knowledge base and the input/output system.

A data driven, or forward-chaining, inference engine uses available facts to obtain the desired answer. The inference engine begins by assembling all available facts regarding a stated problem. A hierarchy of rules is applied to answer the problem. The inference engine uses the knowledge base to determine which rules to apply and what logical conclusions can be drawn from each rule. The inference engine continues to apply rules until the goal is met or all rules are exhausted.

A goal driven, or backward-chaining, inference engine begins with a known or desired goal (answer) and reasons backwards to the set of

facts that would yield the initial goal. Again, the knowledge base supports a hierarchy of rules which are applied and reasoned through. In this case, the rules are directed toward seeking the facts and not the goal. As the inference engine reasons, the user is continuously prompted for facts until the inference engine has enough information to state the basic facts necessary to reach the stated goal.

The Input/Output System. The input/output system is the interface between the user and the expert system. The user controls the expert system through a medium which is usually a visual (CRT) display and an input control (QWERTY keyboard). Facts and data are entered into the system, as well as requests for answers, advice, and supporting reasons or logic. Many expert systems also provide programming capability to update the knowledge base or modify the inference engine.

7.4.2 Expert Systems in Flight-Deck Automation. Currently, there are numerous efforts to introduce expert system and other forms of artificial intelligence onto the flight-deck. Expert systems are being developed to automate or support crewmember functions. These efforts are funded largely by Air Force research in advanced crewstation design. The basic concept is to utilize the benefits of artificial intelligence (usually knowledge-based expert systems) to reduce pilot (or crew) workload and increase overall situation awareness. Below are some of the on-going research programs and their objectives:

- Aircrew Combat Mission Enhancement (Alluisi, 1986). Technology developments consisting of the hardware, software, and interfaces enabling crews to optimize tactical air combat performance.

- Decision Augmentation Systems (Hopson, Zachary, 1982). Research efforts aimed at facilitating the crew's decisionmaking, problem solving, and planning functions through the implementation support algorithms.

- Electronic Crewmember (Moss and Reising, 1985). The development of knowledge based decision support/making computers. Intended to support pilot's role as system manager.

- Flight Management System (Hudson and Young, 1983). Concerned with developing computer-crew interfaces and the implementation of algorithms to support mission (re)planning and management during a mission.

- Knowledge Based System - KNOBS (Engelman, et al., 1979). An expert system for tactical mission planning and consultation.

- Pilots' Associate (Eisenhardt, 1985). An expert system technology for supporting tactics, mission planning, situation assessment and system status in an advanced fighter.

- Pilot Vehicle Interfaces (Pohlmann, et al., 1985). Designing the primary role of the pilot as systems manager rather than systems operator through the introduction of "smart avionics" which provide high level decision support for the pilot.

- Super Cockpit (Furness, 1986). A revolutionary crew station concept of virtual information portrayal and interactive mediums (sight, sound, touch) are being developed for advanced military aircraft cockpit application.

In the literature, expert systems/artificial intelligence are envisioned as a potential answer to the problems of the increasing threat of more sophisticated weapon systems and complex flight decks:

Alluisi, 1986; Aretz, et al., 1986; Bird and Scneble, 1983; Broadwell, 1985; Engelman et al., 1979; Eisenhardt, 1985; Furness, 1986; Hammer, 1983; Ott, 1985; Harris et al., 1984; Hopson, 1983; Hudson, 1983; Kuperman and Wilson, 1986; Madni, 1983; Moss and Reising, 1985; Moss et al., 1984; Perfett, 1982; Pholmann et al., 1985; Rockmore and Riemenschiner, 1983; and Retelle et al., 1986.

The maturation of expert systems over the past twenty years has made it possible to introduce expert systems onto the flight-deck in the near future. The authors cited above advocate a variety of applications for expert systems on the flight deck:

- "electronic crewmembers"
- fault diagnostic systems
- flight/aircraft management systems
- flight navigation systems
- flight (re)planning systems
- military - mission management systems
- military - tactical mission (re)planning systems
- military - target acquisition/recognizer systems
- military - threat situation assessment systems

7.4.3 Opportunities for Expert Systems. The concept of using expert systems for mission support or management is not a new concept. In the previous paragraph, it is evident that expert systems have become increasingly popular in military systems. Clearly, expert systems have the capability to support information management requirements for a variety of systems. Section 4.0 identified three primary areas where information management has a primary role in mission success. These areas are:

1. Mission management
2. Situation awareness management
3. System management

Each area requires a capability to process large quantities of information in relatively short periods of time, and to organize and mediate information with a high level of reliability. These characteristics would be identified in Section 6.0 as system requirements exceeding operator behavior process limits, resulting in a demand for technology (conditions 34-50).

The above subject areas also require subject-matter expertise, data-base management, information transfer and communication, and knowledge- and rule-based decision making. These characteristics would be identified in Section 6.0 as performance capabilities for a proven, new and state-of-the-art technology (conditions 13-23). Essentially, the five characteristics define the major reasons for using an expert system.

In Section 4.0 it was stated that mission, situation awareness and system information management functions have severe time constraints associated with them, making human processing capabilities alone an unsatisfactory solution. Conversely, expert systems have much shorter processing times than a human or a team of humans.

Mission, situation awareness, and system management areas do not have mutually exclusive information management requirements. As discussed in Section 4.0, each area provides input to and requests information from the other areas. This requires an ability to share and communicate information between areas. Expert systems have the capability to share and communicate information between different expert systems.

Different functions have information management requirements across the three identified areas. While the number of crew positions

identified in the CMS are not fixed, it is reasonable to assume that crewmembers will have information management requirements in these three areas. Therefore, specific informational demands will be determined by crew position. Conceptually, the relationship between a B-1B crew (4 crewmembers) and the three areas of information management is shown in Figure 7-2.

As discussed in Section 4.0, mission, situation awareness, and system subject areas have various types of informational demands. It is easy to foresee different crewmembers, performing different functions, requiring similar informational demands from the same data resources. How the information is presented to the crew must be tailored to each crew function or position.

Expert systems have the inherent capability of generating output information in whatever format the user prefers (i.e., human-computer interaction design, or user-system interface design). Information content can be tailored to individual crew positions or formatted differently for various crew functions.

It is proposed that an expert system be developed for each of the three areas of information management. Current research and development programs are advocating expert systems for each of these areas (Eisenhardt, 1985, Furness, 1986, Kuperman and Wilson, 1986). How each expert system should be used as information managers for the three areas identified above is discussed in the following subsections.

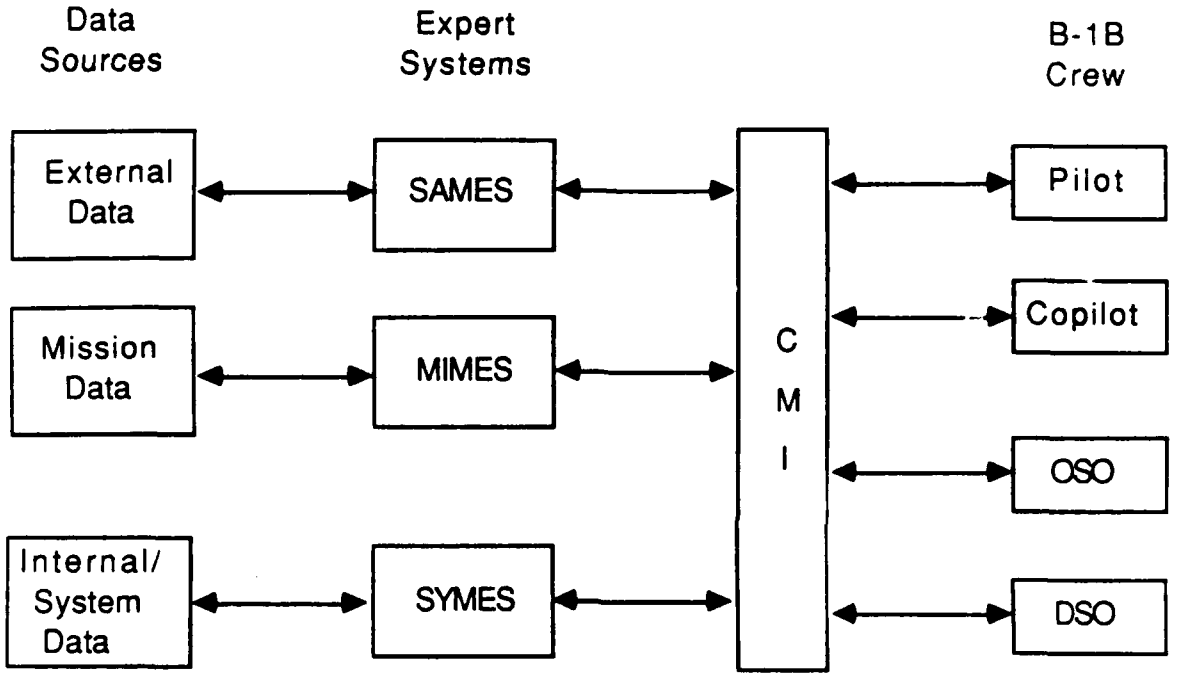


Figure 7-2. Relationship Between Information Management Experts Systems and B-IB Crew Positions

7.4.3.1 Mission Manager (MIMES). The mission manager expert system (MIMES) supports the informational demands and information management requirements identified in Sections 4.0. MIMES is illustrated in Figure 7-3. MIMES is predicted to be the largest and most sophisticated expert system of the three systems. MIMES supports information management for the following mission management requirements:

- (Re)Planning Mission
- Offensive Tactics
- Defensive Tactics
- Combat Mission Folder

Mission (re)planning is performed by MIMES throughout the mission as planned and unplanned events occur. If the mission proceeds as planned without interruption, MIMES performs the same mission scheduling activities the crew typically performs. By having MIMES perform planned scheduling activities, the crew can concentrate on the current events of the mission. MIMES tracks mission events, performs scheduled activities for planned mission events, and prompts the crew to perform crew functions such as course changes, TAL maneuvers, navigation updates, and weapon launches.

The scenario analysis indicated that unplanned events were the primary motive for mission replanning. MIMES' data bases are updated as unplanned events occur. MIMES' inference engine then re-evaluates the original mission plan for the probability of mission success. MIMES' inference engine performs an overall evaluation of possible offensive and defensive tactics, alternatives for maximizing mission success, and applicable SAC tactical doctrine. Based on this analysis,

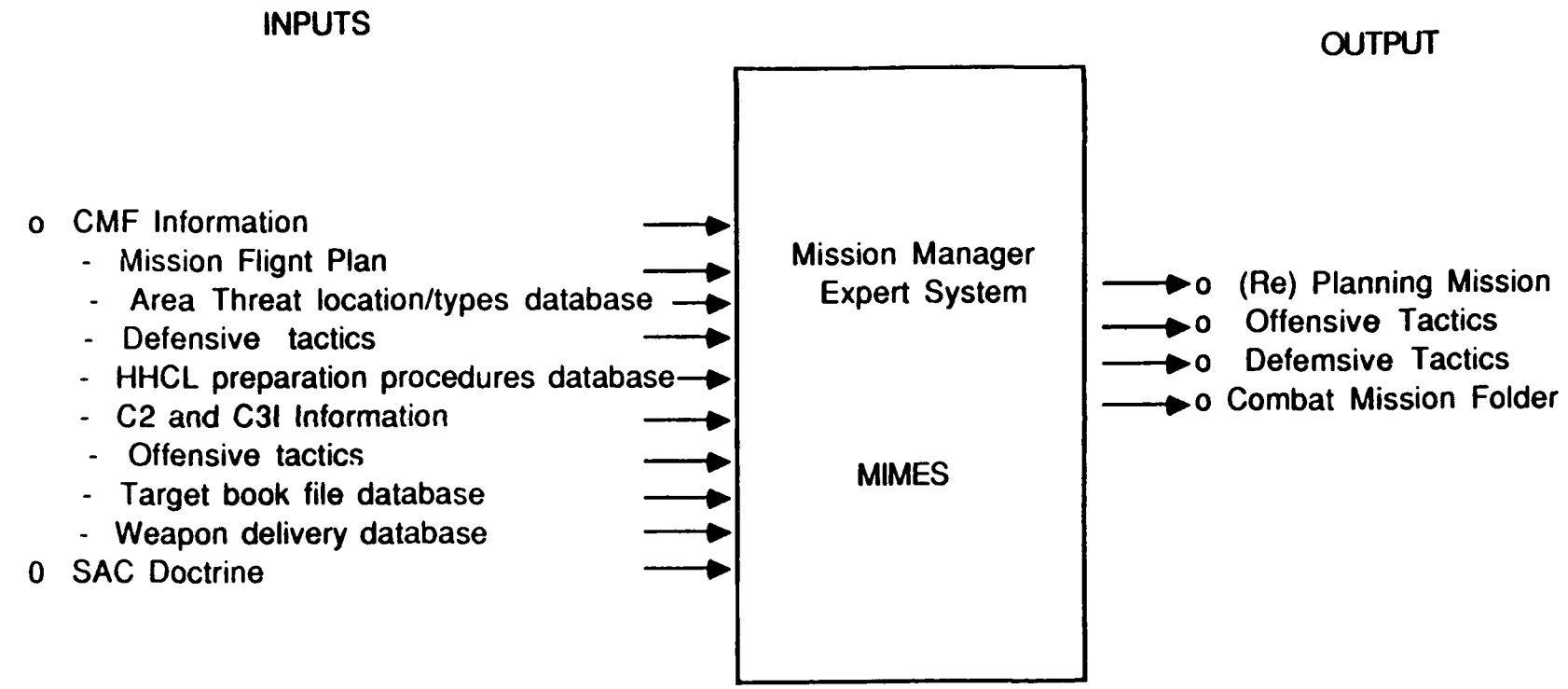


Figure 7-3. Mission Manager Expert System

MIMES provides a recommendation to the crew on the probability for mission success for the current plan. MIMES also provides probabilities for success for any alternative plans based on its replanning program. The crew then has the option to continue or replan the mission.

MIMES provides expert advice on offensive tactics. Its data bases are dynamically updated via an interface with the SAMES and SYMES (see below) data bases. Based on the current status of the aircraft and the environment surrounding the aircraft, MIMES recommends offensive tactics (e.g., target strike) which are supported by offensive tactical doctrine rules. MIMES also assigns probabilities of tactical success and mission success for implementing each tactic.

MIMES also serves as an expert consultant for defensive tactics. Similar to offensive tactics, MIMES' data bases are continuously updated as to enemy threats. MIMES' monitors air and ground threats, includuing both planned and pop-up threats. Its fast-time processing speed permits it to analyze a threatening situation and present the threat and possible defensive tactics to the crew quickly. Defensive tactics are presented with associated probabilities for tactical and mission success, if implemented.

MIMES is driven by the combat mission folder (CMF). The CMF is basically the game book for the mission sortie. MIMES is programmed with mission related information much like an automated CMF, as described in Frick et al. (1986) and the Inflight CMF (ICMF), as described by Kuperman and Wilson (1986). CMF information is loaded into MIMES during pre-flight. Programs loaded into MIMES inference engine and data bases contain specific information and instructions for

the mission. Throughout the mission, MIMES references the CMF as a knowledge core for reasoning mission alternatives.

7.4.3.2 Situation Awareness Manager (SAMES). The situation awareness manager expert system (SAMES) is designed to support informational demands and information management requirements on the external environment of the aircraft. SAMES is illustrated in Figure 7-4 and is designed to service the following situation awareness management requirements:

- Automatic Target Recognition/Occupancy
- On-board Electronic Sensor Management
- External Electronic Emission Signal Analysis
- External Communications Reception (C^2, C^3, C^3I)

By continuously updating the SAMES' data base on external events, SAMES serves as an expert consultant on the aircraft's external world. Electronic sensors used for monitoring the external world update the SAMES' data bases. Sensor readings are continuously scanned for changes in the external environment. These changes are automatically entered into SAMES' data base, making it a dynamic data resource.

SAMES' inference engine continuously re-evaluates the environment for potential threats and dangers. If a developing or potentially dangerous situation arises, SAMES advises appropriate crewmembers of the situation. The obvious advantage is that SAMES performs this activity continuously and without operator prompting. In addition, crewmembers can query SAMES for specific environment activity or updates of specific threats or objects.

SAMES' data bases contain a library of electronic emission signals that the mission sortie might encounter. This library can be changed

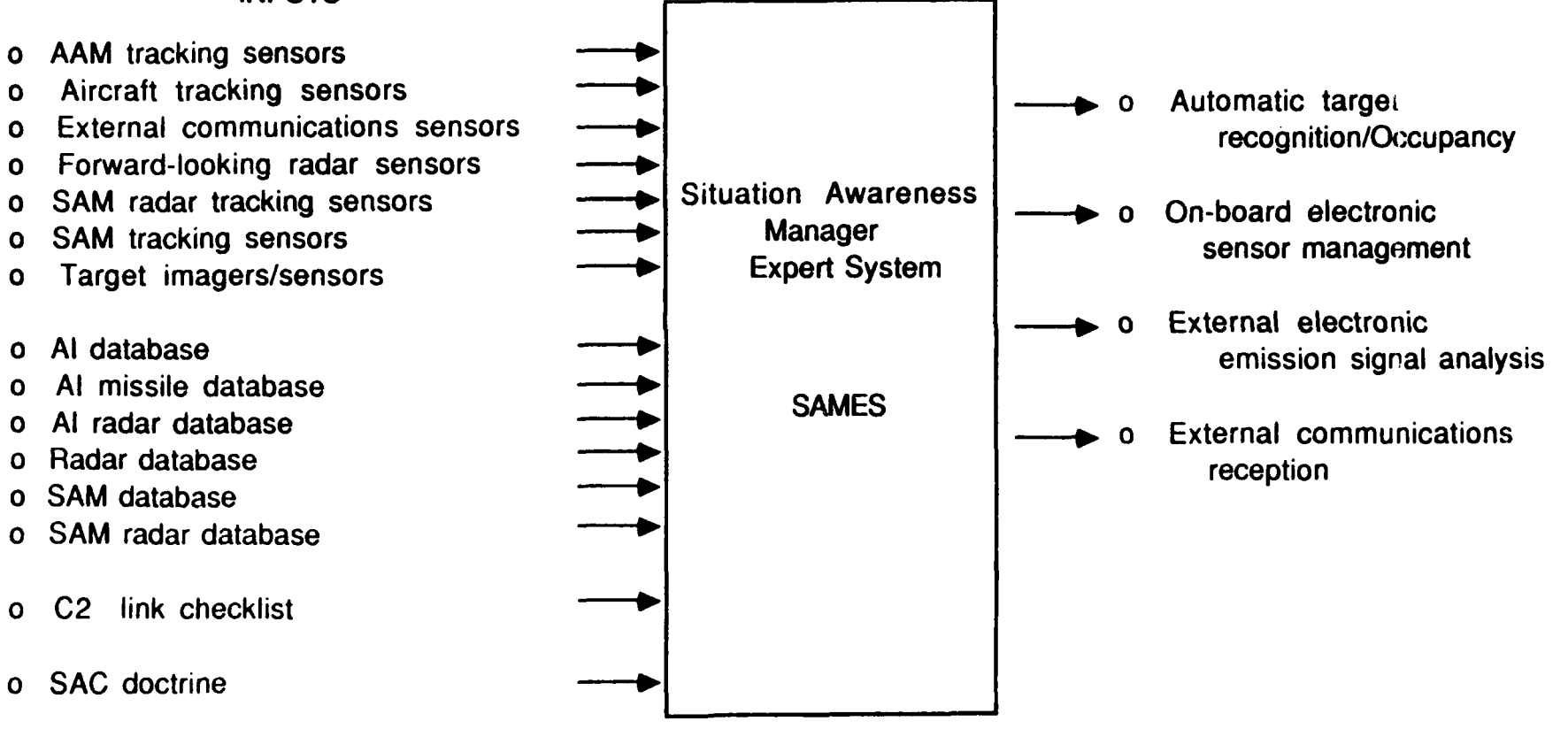


Figure 7-4. Situation Awareness Expert System

or modified depending upon the specific sortie. By searching the library, SAMES identifies external electronic emissions detected by the aircraft's external sensors. SAMES is programmed to identify electronic emissions unless otherwise directed by the crew. This, of course, relieves the crew of the burden of prompting SAMES for identification of emission signals, and expedites identification time for SAMES. SAMES reports the identification of the signal with an associated confidence level of its identification.

SAMES also serves as a quasi-answering machine for communications. Under an assumption of operation in the "SILENT" mode for the CMS sortie, SAMES receives, documents, and reports all radio communications. These communications include friendly C^2, C^3, C^3I, and if possible enemy communications. The purpose here is to alleviate the crew of all responsibilities of monitoring communication transmissions. SAMES only records transmissions, the crew still is responsible for reviewing the communications.

7.4.3.3 System Manager (SYMES). The system manager expert system (SYMES) is primarily concerned with the condition of the aircraft (internal situation awareness). System management requirements which are accomplished by SYMES include:

- Aviation Status
- Aircraft Integrity
- Automatic Fault Diagnostics
- Mission Logistics
- Crewmember Status

SYMES is the on-board engineering, logistics and maintenance department. Illustrated in Figure 7-5, SYMES is designed to relieve the crew of on-going flight maintenance tasks and operations checklists. SYMES provides the crew with management-by-exception of the aircraft itself. Unless the crew instructs SYMES otherwise, SYMES performs skill-based tasks such as systems monitoring and rule-based tasks such as fuel reserves management without crewmember consent. This action greatly reduces the crew's responsibilities and loading for on-going system activities.

SYMES is intended to keep the aircraft in the air without considering external factors. As an on-board system "guru," SYMES' data bases are loaded with the aircraft flight and maintenance manuals necessary to address in-flight system events. The inference engine applies a combination of rule-based process control and fault diagnostic techniques to manage the aircraft.

SYMES monitors the current and elapsed aviation status of the aircraft during the mission. By tracking aviation status during the mission, burn rates, fuel consumption predictions and electronic demands can be calculated. The crew can prompt SYMES to refigure parameters such as fuel consumption, or expected flight-time, given course changes or mission replanning. Also, by monitoring aviation status, SYMES can run checklists in fast-time and report failed items to the crew in a fraction of the time the crew would need to run the same checklist.

SYMES also monitors the current and elapsed condition of the crew. Crewmember status (health and well-being) is a critical factor in the mission. If a crewmember were to become incapacitated (e.g.,

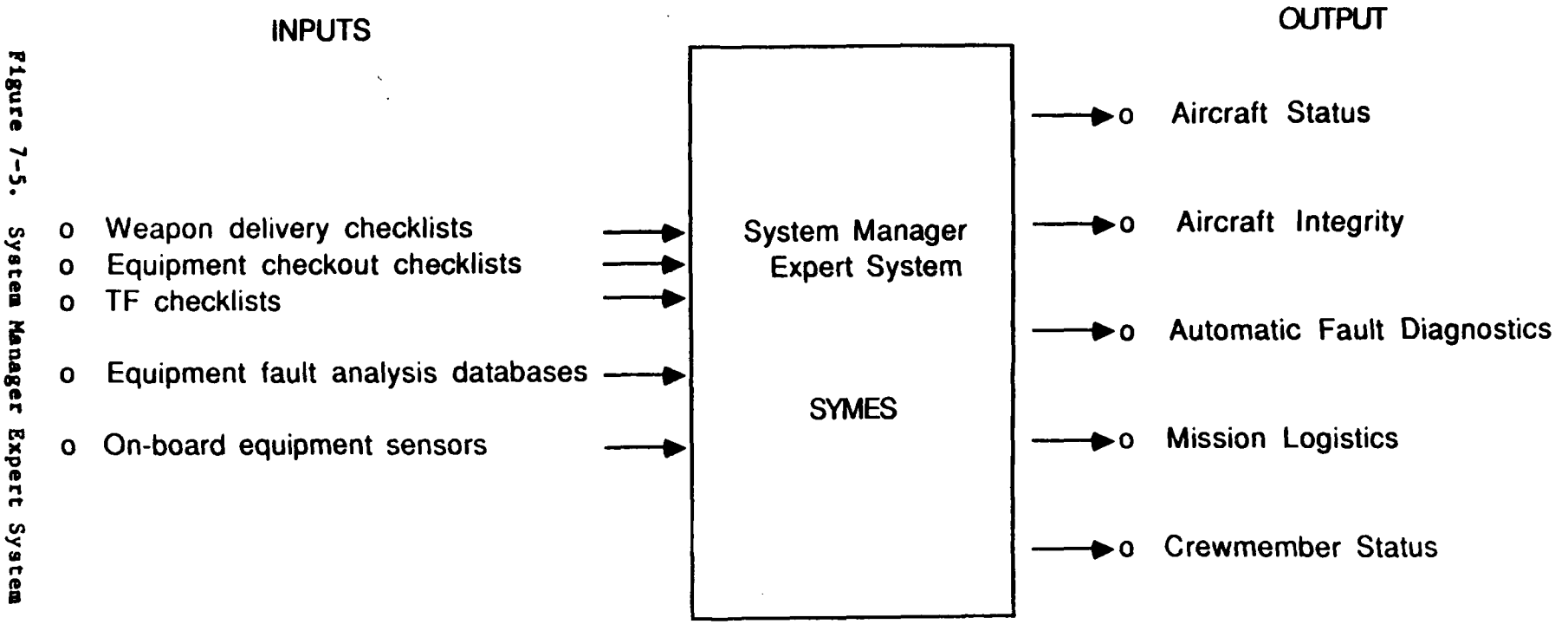


Figure 7-5. System Manager Expert System

unconscious), reallocation of that crewmembers' functions would be necessary. SYMES monitors crewmember vital functions to guard against a system failure due to an uncapacitated crewmember. SYMES is capable of immediately describing a function reallocation plan to the crew as well as advising the crew of the crewmember's condition. Monitoring crewmember status is an important part of monitoring other internal factors of the aircraft.

SYMES, being a rule-based expert system, runs checklists completely and at the appropriate times. Checklists are a critical part of any aircraft flight management system. However, running checklists are time consuming and vulnerable to human errors. The crew is only interested in the results of the checklist -- "Did the item check-out OK?" Reallocating the responsibility of running checklists to SYMES instead of the crew, significantly reduces the crew's overall workload and increases the reliability of running the checklist completely and correctly.

SYMES has automatic fault diagnostic capabilities. Using expert systems as expert fault detectives is becoming common practice (see Section 6.0). SYMES inference engine could be programmed to use either forward or backward chaining to diagnose in-flight faults. Such a capability would free the crew from the distraction of diagnosing the failure of a piece of equipment or sub-system. SYMES would diagnose the fault, and decide how to repair the fault or reconfigure around the fault to provide the optimum recovery from the fault. SYMES would report the fault and the repair options available to the crew. The crew would decide on the most appropriate repair option, and either SYMES and/or the crew would make the repairs. Because, SYMES is a

rule-based expert system, the crew could query SYMES for reasons, logic, and rules applied to reach its diagnosis. This information might be useful in determining the repair option. The diagnostic/"workaround" capability of SYMES is most dramatically evident in the presence of multiple degraded subsystems. Individual degraded mode checklists may well include mutually exclusive or contradictory items while SYMES would be expected to provide a self-consistent optimization strategy for degraded mode operation.

Mission logistics is a vital part of mission success. Mission logistics includes monitoring such factors as weapon stores and supplies, fuel supplies, fluid levels, and life support equipment. The role of mission logistics is quite specific--keep track of expendables and report excessive uses and low levels. Expendable items are indeed a precious commodity, once they have been expended, there is no chance for recovering more items. The role of mission logistics is well suited for an expert system. Monitoring what might be analogized as the rationing of mission supplies, SYMES performs a mundane, but critical, task. Relieving the crew of this task insures that the task will not be omitted or partially completed. It also frees the crew from managing the task throughout the mission--thus, reducing workload and improving task reliability.

7.5 Computer-Generated Displays

Visual displays are a popular topic in human factors engineering and especially so for aerospace applications. Over the past fifty years, human factors engineering has advanced its knowledge of visual displays based largely on aerospace research. In fact, much of

academia's lecture material on visual displays draws from aerospace research (Grether and Baker, 1972; Helander, 1987; Huchingson, 1981; Sanders and McCormick, 1987; Woodson, 1981). The topic is vast with numerous applications and a multitude of display technologies.

Certainly, one of the more challenging tasks for a human factors engineer is selecting the optimum visual display technology for a given application. Choosing a display technology involves much more than picking a display dial off of a shelf. In this part of the Technical Report, computer-generated displays (CGDs) are discussed as a possible technology for presenting information required by the crew of the CMS. The technology is reviewed and applied to the logic-tree criteria chart developed in Section 6.0.

CGDs are defined here as using computer technology for the purposes of creating advanced visual display imagery which could not be achieved using conventional display technology (electro-mechanical displays). CGDs use any display technology with the inherent capability to receive and display multi-dimensional imagery an to dynamically display information (alphanumeric or graphic) as generated and formatted by a computer.

A natural attraction of CGDs is their versatility to effectively use color-coding and display shapes in any orientation. CGDs also have the capability to integrate different types of information on a single display using almost any kind of formatting. A single CGD can also be used for multiple applications with in the same system.

CGD technology is typically a microcomputer used in conjunction with a programmable display technology. Common examples of programmable display technologies are cathode ray tubes (CRTs),

gas-plasma displays, electroluminescence (EL) displays, multiplexed liquid crystal displays (LCD) and light emitting diode (LED) displays, and collimated displays. Computer terminal CRTs are the most common example of a CGD visual display. Gas-plasma, EL, LCD, and LED technologies are flat panel displays, meaning the display device is relatively flat as compared to the bulky CRT display. Flat panel displays are used when minimizing weight, size and power usage are important factors. Collimating displays use small CRTs to project images onto a clear display surface (e.g., windscreen or visor). Head-up and helmet mounted displays are popular examples of collimated displays.

CGD technology was developed to utilize the computer's information generation capabilities to produce advanced visual displays. These displays present graphical and/or textual information which cannot be created using traditional electromechanical display technology. Because CGDs are a programmable display they are useful for a wide variety of applications. CGDs are nothing new to the flight-deck. Their incorporation into the flight-deck exists today in the form of multifunction displays, integrated flight displays (IFPs), primary flight displays (PFDs), head-up displays (HUDs), and flight management systems.

7.5.1 Computer-Generated Display Architecture. An overview of CGD architecture is presented. Consider a personal computer with a CRT display as an example of a CGD (Figure 7-6). The personal computer (PC) system consists of hardware, software, input control (keyboard), and output display (CRT). The hardware, software and keyboard all affect what is displayed on the CRT. In addition, the CRT has

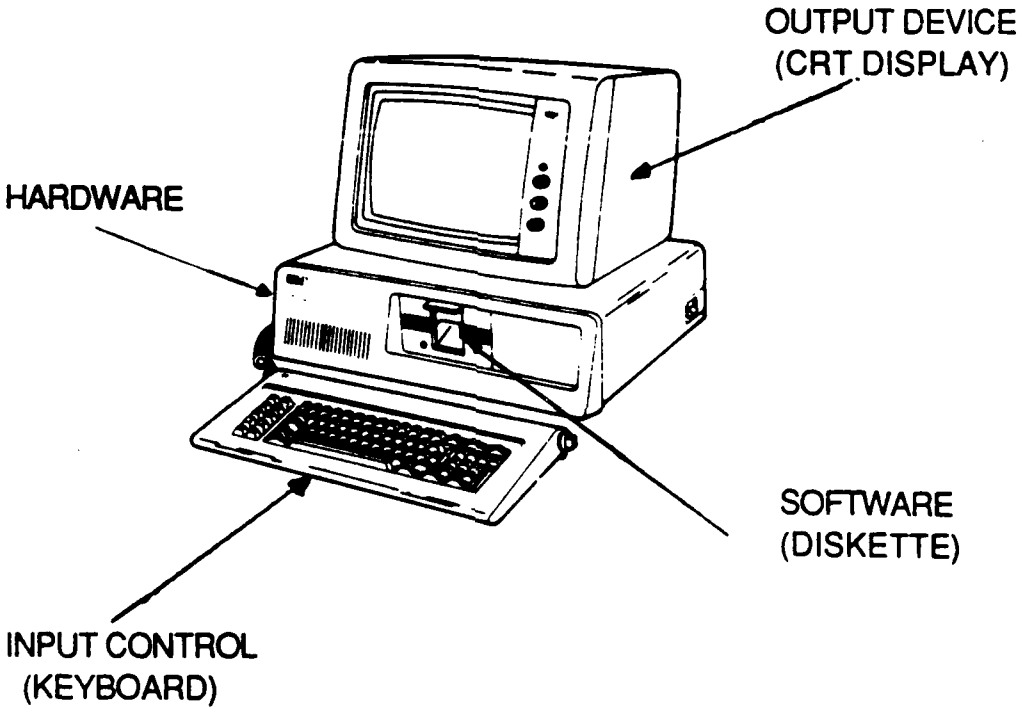


Figure 7-6. Personal Computer System

limitations as to what it can and cannot display (e.g., monochromatic versus color display).

Hardware refers to the physical components in the PC and include the central processing unit, available memory (read only, random access), and input/output ports. Simply stated, the hardware are the subcomponents inside the PC. Naturally, the subcomponents inside the PC are assumed to collectively offer the capability to receive, process, and generate (output) information. It is this generated information which is presented on the CRT; hence the term computer-generated visual display.

Software is a medium for describing how information should be received, processed, and generated by the PC hardware. Software is tailored to the type of computer being used, but is physically independent from the computer. A software language is a formal mode of communication understood by both the user and the computer (e.g., Fortran). A computer program is a structured set of commands, written in a software language, which provides instruction for how the hardware should handle information for a specific application. A computer program can also be changed to modify how information is handled by the hardware.

The input control is an object a user manipulates to communicate information to the PC. Popular input control devices include keyboards, mice, light pens, and touch tablets and screens. Input controls are physical devices for actuating an input message to the computer; however, it is the software which defines how the actuation should be interpreted by the computer. What a user wishes to communicate to the computer often depends on what is displayed on the CRT.

The CRT is the output display for the PC. The CRT screen displays information generated by the PC. Although the CRT displays information, it is the computer program which defines what information should be displayed and how this information should be displayed. Thus, the CRT is only a means of communicating information from the computer to the user. A CRT display was chosen for this example, however, an LCD, LED, HUD, etc., display technology could have been selected.

A specific CGD technology is selected based on visual display requirements and specifications for a specific application. There are many specifications such as weight, size, power consumption, resolution, chromaticity, and graphics capabilities which determine which display technology should be implemented. There are also user-specific requirements for legibility, readability, and viewing angles and distances which affect technology selection. These are the types of requirements and specifications which are entered into the logic-tree criteria chart when selecting a CGD technology.

The computer program is the key to computer-generated displays (CGDs). Because a computer program is flexible, in that the program can be modified, so too is the information displayed on CGDs. Computer programs define how information is received by the computer via the input control and displayed by the computer on the CRT. This aspect of the computer program is often called the human-computer interaction (HCI). A quality HCI should present information clearly and understandably to the user, as well as permit the user to input information in a simple and logical manner. The HCI for the CMS aircraft will be discussed in greater detail in Section 9.0. Appendix B contains guidelines for developing quality human-computer interfaces.

In summary, the hardware and software define the computer's capabilities and limitations. The computer program defines the function the computer is programmed to perform. Understandably, for a computer program to be effective, the user should feel comfortable and confident interacting with the program. The input control is the tool the user manipulates to communicate to the computer. The output display is the means of communication which the computer uses to present information to the user. Finally, the human-computer interaction (HCI) defines how the user inputs information to the computer and how output information is visually displayed to the user.

7.5.2 Computer-Generated Displays in Flight-Deck Automation. Advances in display and microcomputer technologies have invited flight-deck designers and aircraft manufacturers to introduce CGD technology onto the flight-deck. This introduction has resulted in new, advanced flight displays. CGD flight displays have specific design principles (Jensen, 1980; Roscoe, et al., 1981). Some of these are pictorial realism, magnification, integration, pursuit presentation, quickening, and prediction. In the following paragraphs, these six display principles are reviewed. This review also provides a general description of current research on and implementation efforts for CGDs in flight-deck automation.

Pictorial Realism. Pictorial realism or contact analog displays present a computer-generated rendition of the real world. These displays depict objects in the real world as animated objects set in animated three-dimensional space. Pictorial realistic displays use a person's natural understanding of apparent distances to highlight an object's location; up-down, left-right, close-far. This principle uses

a combination of digitized scenery (e.g., topography) blended with electronically-sensed or known information on objects in the immediate area (air and surface) to illustrate the world around the aircraft.

Pictorially realistic displays are used to provide situational information to the crew. Such displays permit the crew to use their natural understanding of physical space to process situational information. Therefore, the crew gains situational awareness of the external world through their perception of what is displayed on the CGD display. Pictorial realistic displays are currently being researched for use as digital moving map displays (DeMyer, 1982), tactical situation awareness (Hawkins et al., 1983), and flight management systems (Leffler, 1982).

Magnification. Magnification (scaling) is used to indicate apparent distances between objects in pictorial displays. Magnification helps to better indicate the aircraft's position relative to another object (e.g., map coordinate, weather front, second aircraft, obstacle). Pictorial displays use a defined scale of magnification to equate relative distances on the display to actual distances in the outside world. The magnification factor required to obtain apparent distances depends on the size of the display screen and the type of pictorial displayed.

Roscoe et al. (1981) reported that magnification factors in the range of 1.20 to 1.29 yield sufficient apparent distances on pictorial displays. However, as the pictorial subject size increases, the screen size would also have to increase to maintain the proper magnification level. Screen sizes are limited on flight-decks, therefore, magnification by itself cannot be applied. Magnification is used in

any pictorial display which indicates apparent distances and is usually associated with the other display principles discussed in this section.

The effects of magnification on apparent distances need to be investigated for computer-generated displays. The majority of the research on magnification effects was performed by imaging objects on a flat screen by a projective periscope. It is unclear whether or not the magnification factors reported by Roscoe et al. (1981) are appropriate for CGDs. This question could be answered with current CGD technology, since magnification factors can be modified in computer programs for CGDs.

Integration. Conventional flight-deck displays require pilots or other crewmembers to integrate information from several separate parametric displays. This requires a significant amount of eye-scanning and information processing by a crewmember. Parametric displays indicate accurate, quantitative information, but they are not well suited for rapid, qualitative interpretation of the state of the system required in aircraft control (Sanders and McCormick, 1987).

Integrated displays attempt to correct for qualitative display deficiencies by combining related information onto a single display. CGDs are used as integrated displays to combine different kinds of information on one display. The integrated CGD is formatted to enhance the qualitative as well as the quantitative presentation of multiple kinds of information. Integrated CGDs are not simply a single display screen which displays multiple, single parametric displays.

Currently, integrated CGDs are very popular in flight-deck automation. Integrated information is used on vertical situation

displays which indicate altitude, radar altitude, flight path angle, and desired flight path information (Houck et al., 1986); primary flight displays which indicate attitude, flight direction, flight path vector, airspeed, altitude, and heading information (Hutchinson, 1986); navigation displays which provide geographic guidance and flight planning in conjunction with flight management systems (Summers and Miller, 1983); militarized horizontal situation displays which show the flight path of the aircraft superimposed on a map of terrain and threats being overflown (Merrifield, 1986); militarized situation displays which indicate on-board weapon stores as well as showing a three-dimensional view of the terrain and threats over which the aircraft is flying (Furness, 1986); and system status displays which indicate aircraft and equipment operational status and malfunctions (Gershzohn, 1986).

Pursuit versus compensatory presentation. There are two types of displays which present error information for a tracking task: pursuit and compensatory. Pursuit displays have at least two indices, one representing the pilot's own airplane and the other representing the target or desired position or course. Both symbols move against a common scale or reference system. Compensatory displays usually have only one moving index with the direction and distance between it and a fixed-reference index representing the error to be nulled (Roscoe et al., 1981). Research consistently indicates that pursuit tracking is superior to compensatory tracking (Jensen, 1980; Roscoe et al., 1981). Computer-generated displays can be programmed to operate as either pursuit or compensatory displays. Such CGDs would most likely be used with the integrated display concepts noted in the previous paragraph.

Quickening. Display quickening uses feedback signals to provide an immediate presentation of the imminent results of the controller's actions. Because of the lags due to system dynamics in complex systems (e.g., aircraft), controllers must anticipate the system's response to a given action. Such systems become unstable as the frequency of control inputs increase. System control is greatly enhanced by displays which use derivative terms to indicate the relationship between controller input and anticipated system response. Algorithms quickly analyze the rate of change in the system to immediately indicate the degree of error between the actual and desired value.

Display quickening has had favorable experimental results, but is noted as having severe drawbacks. Namely, the quickened display may give the controller a false sense of security because it only displays error differences, rather than the actual situation. Quickened displays also do not present a complete set of control information, leaving the controller with an incomplete picture of what is occurring with the system. Therefore, while display quickening would greatly enhance a pilot's ability to fly at very low altitudes, it would not provide information about a future obstacle in the flight path.

Prediction. Predictor displays present estimates of future conditions relative to future desired conditions. Algorithms calculate in fast-time what changes will occur in the system given the current condition and control inputs. Algorithms can be formulated for predicting extreme conditions (i.e., maximum or minimum change) or a weighted-average condition. CGDs have the capability to calculate algorithms and graphically present predictions as either charts, graphs, or pictorial displays. A predictor display would provide the

pilot flying at very low altitude with information regarding the aircraft's capability to ascend and clear a future obstacle.

On the flight-deck, predictor displays are being developed for relating present aircraft position to desired future aircraft position and predicted aircraft position. "Pathway in the sky" is a popular illustrative example which combines virtual imaging predicting the aircraft's future position and desired course (Furness, 1986; Hawkins et al., 1983).

7.5.3 Opportunities for Computer-Generated Displays. Many opportunities exist to incorporate CGDs into the flight-deck of the CMS aircraft. As was discussed in the previous paragraphs, CGDs are already being introduced or considered for a myriad of flight-deck applications. Therefore, the question is not whether or not to consider CGDs as an opportunity for technology insertion, but how to effectively apply CGD technology to the flight-deck.

The scenario review determined that the crew requires, processes and generates a large amount of information throughout the mission. It was also determined that the information could be classified into three separate subject areas. Further, it was determined that the crew could not possibly obtain, process, and react to this vast quantity of information, and therefore, technological support was required. Based on stated criteria for technology, three expert systems were recommended for the CMS aircraft.

By default, the expert systems recommended also include CGD systems since they are a computer system which generates output to visual displays. An unresolved technological question is what specific display technology to use (e.g., CRT, LCD, LED, EL). While CRT

technology is by far the most popular technology, the other technologies are making significant improvements in display resolution and data transfer capabilities. To correctly select a display technology, a series of engineering trade-off studies would be conducted by the different engineering disciplines to evaluate candidate displays (conditions 14-17 of the criteria chart). These studies would determine the most appropriate display technology for a specific application. In this research, trade-off studies were not conducted and, therefore, no specific display technology is recommended.

The expert systems recommended have the potential for generating pictorial, graphical, textual, and numerical information. Conceptual displays are developed in Section 9.0 for each expert system application. These concepts attempt to optimize the human-computer interaction. In the paragraphs below, the display principles reviewed in the Section 7.4.2 are applied to each of the three expert systems.

For the mission manager expert system (MIMES), pictorial displays could be used to communicate mission related data. Two- or three-dimensional pictorial displays could be used which integrate the mission flight plan and scheduled events with a digitized moving map display.

Vertical situation displays could be used to illustrate altitude flight plans, known obstacle heights, or target imaging and launch points. Target data or scheduled events could be presented as formatted text. In addition, options and recommendations for decision-making events (e.g., mission replanning) could be listed along with a display option to request more information on any option

or recommendation.

For the situation awareness manager expert system (SAMES), area threats and obstacles could be displayed using pictorial displays. Known threat descriptions could be presented as displayed text or positioned on a digitized map of the area. Threat lethality envelopes could also be depicted graphically. Predictor and quickening displays principles could be integrated to provide the pilot with enhanced handling capabilities coupled with greater situational awareness of predicted flight path envelopes.

Weather fronts, detonation waves, and other aircraft activity could be represented on a horizontal situation display. Such a display would provide a "bird's eye" view looking down on the aircraft and terrain below. Predictor displays could be used to illustrate predicted flight path envelopes for airborne threats.

For the system manager expert system (SYMES), aircraft equipment status could be displayed on a pictorial of the aircraft. Such a display would provide the crew with qualitative information of what component failed by its position on the aircraft (e.g., aileron hydraulic pump failure). Component failures could also be displayed in a schematic of the related subsystem. Such a schematic would illustrate the subsystem configuration and highlight the failed component. Quantitative information on a component failure could be displayed as a brief description after SYMES has determined the fault or malfunction. The crew would also have the option of requesting more detailed fault descriptions.

System status information could be presented using a combination of textual and graphical displays. Automated checklists which are run

by SYMES could be displayed as a single affirmative response if all checklist items passed. If a checklist item failed, the explanation of why the item failed could be displayed. Also, mission logistics information (e.g., fuel and fluids status, expendable and weapon stores) could be displayed using graphics or as listed information. Predictor displays could be used for graphically presenting estimates of remaining flight time and distance given the current aircraft status.

There are other opportunities for using CGDs besides expert systems. Aircraft flight performance information (AFPI) could be presented to the crew as integrated flight displays (IFDs) as discussed in Part 7.5.2.

Generally referred to as primary flight displays (PFDs), the literature reviewed concludes that the integration of AFPI reduces crewmember eye-scanning time and information-processing time, and greatly increases crewmember performance. In addition, AFPI is continuously displayed information on the flight-deck, therefore, integrating the information reduces the amount of physical area needed for separate parameter displays to the physical area needed for one PFD.

PFDs were applied to the logic-tree criteria chart in Section 6.0. Based on the information in the literature reviewed (Hutchinson, 1986; Leffler, 1982; Summers and Miller, 1983; Weihrauch, 1978), PFDs are a new, state-of-the-art technology, which have been proven in previous aircraft applications (conditions 18, 20, 21). PFDs have also been demonstrated experimentally to result in improved pilotage versus pilotage with conventional parametric displays and have been accepted

by pilots (Summers and Miller, 1983) (condition 19). As discussed earlier, PFDs were developed to enhance the pilot's perceptual ability to integrate different types of information (conditions 34 and 35). Therefore, PFDs satisfy both the physical technological requirements (condition 2) and the human behavioral demands for technology (condition 34) in the logic-tree criteria chart in Section 6.0. The incorporation of PFDs into the flight-deck of the CMS aircraft would enhance the quantitative and qualitative presentation of aircraft flight performance information.

7.6 Voice-Interactive Systems

A voice-interactive system is comprised of a computer system with speech recognition and speech generation capabilities for the explicit purpose of interacting with people (Simpson et al., 1986). Speech recognition and generation technologies are relatively new and fast developing technologies (Damos, 1986; Pisoni, 1986; Simpson, et al., 1985; Waterworth, 1982). Voice-interactive systems are predicted to offer potential solutions for reducing crew workload and decluttering over-crowded visual displays (Simpson et al., 1985). Its possible application to flight-deck automation is well documented in recent years (Aretz, 1983; Furness, 1986; Glenn, et al., 1986; Hawkins, et al., 1983; Mountford, et al., 1983; Wetherbee, 1983; Zenyuh and Reising, 1986). However, some researchers question the value or applicability of the two technologies in aircraft systems (Damos, 1986; Robinson and Eberts, 1985, 1987; Steiner, Burkhart, and Berson, 1983).

In this section, speech recognition and generation technologies are reviewed briefly. Voice-interactive systems are recommended for

technology insertion into the CMS aircraft based on satisfying criteria for insertion described in Section 6.0.

7.6.1 Voice-Interactive System Architecture. Speech recognition and generation technologies may be used independently or jointly. However, these technologies are separate and have different architectures. Speech recognition interprets human speech and translates it into a machine language so that the computer can understand the transmitted information. Speech generation is just the opposite. Speech generation translates computer outputs into a human language (e.g., English) so that the operator can understand the transmitted information. When the two technologies are used jointly, a voice-interactive system, an effective input/output system is created which utilizes an alternative channel other than the often overloaded visual-manual channel (Simpson, et al., 1985).

Speech Recongition Technology. Recognizing and interpreting human speech electronically is not a small challenge for science. Human speech with all of its languages, pronunciations, dialects, and multiple-meanings does not conform with how we program computers to communicate. Translating human speech into something the computer recognizes and understands can be done several different ways. Simpson, et al. (1985) define that:

> from a human factors perspective, a speech recognition system is a human speaker, a recognition algorithm, and a device that responds appropriately to the recognized speech. The algorithm recognizes different human speech utterances and translates them into symbol strings....The device assigns meanings to the symbol strings in the context of the human's task (Simpson, et al., 1985, p. 116).

A speech recognition system can be speaker dependent or independent (Schmandt, 1985). If it is speaker dependent, this means

it will only recognize certain words from a single person. The voice of one person speaking certain words is recorded along with the meaning of each word on what is known as a trained template (Schmandt, 1985). The trained template is the speech recognition system's vocabulary and language. These systems typically only recognize and interrupt the recorded-person's voice. It is easy to see how this technique can be a tedious process if a large vocabulary is involved. Also, a separate template must be recorded for each potential speaker.

An independent voice recognition system recognizes the voice of any person who speaks clearly and properly and enunciates his spoken words. The template is programmed with standard pronunciations, acoustic features of speech, and phonemic descriptions and utterances (Schmandt, 1985). The speech recognition system then analyzes what any speaker said versus what sounds like what the speaker said, and determines what the speaker said and meant.

An independent speaker recognition system is limited in its vocabulary to those utterances it can identify. These systems are also plagued by the inherent problem of non-standardized human speech. Because speech is subject to enormous variability, independent speaker recognition systems have a higher error rate than speaker dependent systems (Pisoni, 1986).

Speech recognition systems can be discrete or connected speech systems (Schmandt, 1985). Discrete speech means that the speaker must pause between each word, so that words are spoken separately (e.g., "display ... map ... of ... Dayton"). A word in this case may actually be a phrase (e.g., "call AWACS"). Pauses in speech make it easier for the system to recognize and identify what is being said. It also is a

slow, cumbersome, and inefficient way of interacting with the equipment.

Connected speech systems recognize word strings, phrases or short sentences when they are spoken naturally. Connected speech is closer to what people consider normal communication, but it is still limited to brief communications. However, the individual words are spoken with the same intonation pattern as if they were read from a list (Simpson, et al., 1985). In addition, enunciation, coarticulation, dialects, and pronunciation of multiple syllable words may result in words being misidentified or phrases misunderstood (Schmandt, 1985).

The most advanced form of speech recognition is continuous speech understanding. This form combines connected speech recognition with the ability to accomplish tasks using continuous speech input (Simpson, et al., 1985). Continuous speech understanding is the optimum form of speech recognition, since it most closely approximates natural language communication. Understandably, it is also the most difficult form of speech recognition technology to develop.

Besides the problems noted above, word recognition is still a significant problem. Schmandt (1985) identified three types of word recognition errors that are still unresolved: incorrect recognition of words, misidentified words, and vocal sounds (e.g., sneezing) mistaken as words. Another problem source is poor acoustics in the operational environment. Noisy environments degrade speech recognition performance far below optimum levels reached in the sterile laboratory (Moore and McKinley, 1986).

Speech recognition technology is still a developing technology. As a result, the reputation of the technology suffers from its own

immaturity. Simpson, et al. (1985) discuss ten limitations in applying speech recognition technology from a review of case studies. However, Simpson, et al. (1985) go beyond critiquing the current state-of-the-art technology and present a system design methodology for speech recognition and generation. In this methodology, the authors address when and how to appropriately incorporate speech recognition and generation into a new or existing system. The authors also make recommendations for reducing the effects of the limitations in the technology.

Speech Generation Systems. Speech generation systems are the inverse of speech recognition systems. Speech generation systems convert strings of computer output code into audio signals which communicate information by immitating human speech. Speech generation systems are developed for operation in a defined subject area and cannot communicate information outside of this defined subject area.

There are two methods for generating speech: synthesized speech and digitized speech. Synthesized speech generation uses algorithms containing rules of pronunciation for a given language to produce speech directly from strings of computer code. Digitized speech utilizes a digital recording of a human speaker to generate speech.

Synthesized speech is also known as synthesis by rule because of its rule-based methodology. Rules of phonemes (sounds of speech) provide the necessary characteristics of speech duration, energy, accent, and resonance to immitate a human voice. Additional rules provide direction for eliminating ambiguity between similar words. A complex combination of filters and resonators model the vocal tract to produce the quasi-human speech sounds. Synthesized speech can be

either male or female, with manufacturers typically offering between one to six voice types.

Digitized speech uses a recording of an actual person's voice to generate speech. The recording usually is a recording of a human speaker saying all the possible words which may be spoken by the machine. This technique provides high quality speech generation and is technically simple to record, but is very costly to manipulate (Schmandt, 1985).

Digitization is another method where the computer digitally records a series of human speech as sample speech waveforms. Digital recordings are often compressed in format using techniques such as Fourier Transform, Linear Predictive Coding, or Waveform Parameter Encoding (Schmandt, 1985; Simpson, et al., 1985). To generate speech, computer output text is matched with corresponding waveforms to generate words and phrases. Speech is generated via digital to analog conversion and transmitted through a speaker. The quality of the digitized speech is largely dependent upon the fidelity of the digital recording.

An important consideration for speech generation is vocabulary size. Synthesized speech can have an unlimited vocabulary because an algorithm-based synthesizer can be programmed to pronounce new words. Digitized speech is limited to a fixed vocabulary of either the spoken words recorded or the sample waveforms digitally recorded. Fixed vocabulary systems are programmable by either the vendor or the user, depending on the manufacturer.

Speech generation systems are judged for user acceptability along three parameters: data rate, intelligibility, naturalness. Data rate

refers to the speech rate of the generator. Data rate can usually be varied by the programmer and has a significant effect on intelligibility and naturalness. Intelligibility refers to the listener's ability to correctly recognize words stated by the speech generator. Naturalness is the listener's subjective rating of how much the generated speech sounds like human speech. Naturalness and intelligibility are not as strongly correlated with each other as they are with data rate (Simpson, et al., 1985). This is because a pronounced word may be intelligible even if it is not a natural pronunciation of the word.

7.6.2 Voice-Interactive Systems in Flight-Deck Automation. A voice interactive system is a candidate technology for insertion into the CMS aircraft. Technical problems in applying speech recognition and generation systems do exist, however, the technology as a whole is making substantial progress as an effective, new, state-of-the-art technology. It will be years before voice-interactive systems can be successfully introduced onto the flight-deck, but researchers are already investigating the best ways of introducing the technology to the flight-deck. This includes research to identify the advantages and disadvantages of speech recognition and generation technology in the flight-deck environment.

Aretz (1983) evaluated manual response for data entry versus vocal response in a fighter cockpit simulator. Aretz found that while manual control response had significantly smaller response times, vocal response was more effective with respect to flying performance measures.

Furness (1986) advocates the role of voice interactive systems in the Super Cockpit concept. Furness not only predicts voice interactive systems as an alternative control method, but proposes the use of 3-dimensional auditory displays.

Glenn, et al. (1986) reported on early investigations into the potential gains from combining eye movements and voice commands as a new form of interface control. However, to the best of the authors' knowledge, no experimental results have been published.

Hawkins, et al. (1983) reported no significant differences between the effectiveness of using pictorial, textual, or voice displays for representing emergency procedures to crewmembers. It is interesting to note that subjects had preferences to voice or textual presentation over pictorial presentation.

Moore and McKinley (1986) reported on various AAMRL studies on speech related areas. Areas of interest mentioned were intelligibility of speech in the presence of various noises as a function of oxygen mask and microphone masking, and as affected by sustained acceleration.

Mountford, et al. (1983) investigated the integration of a speech-interactive system with a prototype automatic target recognizer. A speech-interactive system was determined to offer greater performance benefits for a target recognition task scenario than did a speech recognition with visual prompting or a conventional visual-manual system.

Robinson and Eberts (1985) evaluated tracking and response performance when information was presented pictorially or by computer generated speech. The results indicated that pictorial presentation

yielded quicker responses and improved learning over speech presentation.

Robinson and Eberts (1987) performed additional studies to investigate crew performance using speech displays versus visual displays in the cockpit environment. The authors reported that pictorial subjects responded more quickly than speech subjects in single and dual tasks experiments. Also, pictorial subjects performed better at maintaining the context of the event than speech subjects.

Simpson and Marchionda-Frost (1984) reported on synthesized speech rate and pitch effects on the intelligibility of warning messages for pilots. The authors reported that speech rates and pitch frequencies had a significant effect on pilot intelligibility. The authors also reported that intelligibility is also dependent upon pilots having prior training with the accent and "phraseology" of the synthesizer voice (Simpson and Marchionda-Frost, 1984).

Steiner, Burkhart, and Berson (1983) investigated the possibilities of using voice generation as a means of operator feedback. Their results indicated a combination of visual and voice feedback led to enhanced performance, and recommended that both auditory and visual feedback should be used for critical tasks.

Wetherbee (1983) reported on the development of the Voice Interactive System Technology Assessment (VISTA) program. The intent of the program advocates the development of a speech recognition and generation system in future Navy fighter cockpits. (The goal being to use the auditory system to minimize pilot workload.)

Wickens, et al. (1984) report that there are limits as to what information can be presented aurally and what information should be

presented visually. Verbal information such as short responses, list reading or textual descriptions are suitable for voice-interactive systems. However, spatial information such as graphical presentations or tracking data should be presented visually. The authors also concluded that verbal and spatial information can be presented conjointly, but further research is needed in the role of verbal and spatial processes in flight-deck automation.

Zenyuh and Reising (1986) found positive results by combining the head-up display (HUD) with speech recognition over combining HUDs with a remote touch panel. The experimentation was conducted using a static mockup. In addition, they found no significant difference between combined HUD and speech recognition and the standard multifunction control system.

7.6.3 Opportunities for Voice-Interactive Systems. Identifying opportunities for voice-interactive systems in the CMS is less precise than for expert systems and computer-generated displays. Voice-interactive systems are usually recommended when selecting between specific crewmember-machine interfaces. In this case, the technology is being recommended as a candidate crewmember-machine interface. Determining what interfaces are best for each mission event is a task which would occur during the detailed design of the system.

Crewmember requirements identified in Sections 4.0 and 5.0 are matched against voice-interactive system technology and applied to the logic-criteria chart in Section 6.0. The mission analysis identified that the crew has a very high rate of information transfer with on-board information data bases. This represents excessive loading of

communication processes (condition 43). Also, the analysis determined that for any scenario event, numerous items must be presented to the crew in a short time frame. These items range from requested information such as descriptions to spontaneous information such as warnings. Here, perceptual and communication processes are subject to excessive loading (conditions 35 and 43). Finally, the crew must assimilate a large quantity simultaneously, therefore, information should be presented using multiple information channels if possible.

The advances and achievements in voice-interaction systems were discussed earlier. Clearly, the research supports the opportunity for considering voice-interaction systems (conditions 19, 20, 21). In addition, researchers recommend utilizing voice-interaction systems as an alternative input-output channel between operator and machine (Damos, 1986; Mountford, et al., 1983; Schmandt, 1985; Simpson, et al., 1985; Wickens, et al., 1984). These authors recommend applying voice-interaction systems prudently with visual-manual systems as the traditional input-output channel.

Before committing to a voice-interaction system for any application a critical review of the technology and its appropriate application to the system is necessary. This, of course, is represented by the many branches of the logic-tree criteria chart related to engineering requirements. As discussed earlier, on-going research has shown that speech voice-interaction systems are not a panacea for off-loading the overloaded visual channels of the operator (Robinson and Eberts, 1987, 1985). Thus, as reported by Simpson, et al. (1985):

> a substantial effort in human factors research is needed to develop procedures for selecting appropriate tasks for the voice mode and for integrating voice interaction into the total system design (p. 137).

For the CMS, human factors research would focus on introducing a voice-interaction system as an alternative or supplementary channel for information transfer. A voice-interactive system could be used in parallel with the traditional "visual-manual channel." This would allow the crewmember the option of utilizing either channel for accessing information.

There exists in the CMS system many non-critical, informational demands which could be fulfilled using voice-interaction systems. As an example, requests for descriptive information on approaching targets could be made orally by a crewmember. The crew could then listen to this information rather than reading it off of a CRT screen or printed paper.

Speech generation has been used extensively as an aural warning indicator. Its use has ranged from nuclear power plants, to automobiles, to military aircraft. Its applicability has often depended upon the type of warning presented and the warning's significance relative to other warnings. The application has met with success (military aircraft), failure (automobiles), and ambivalence (nuclear power plants). The effective application of any warning indicator (alarm) is a complex and involved process. Simply inserting a speech generator does not provide an effective warning indicator. However, in the case of military aircraft, it appears that spoken warnings have been inserted effectively (Simpson and Williams, 1980; Simpson, et al., 1985).

Voice-interactive systems could be coupled with the expert systems and multifunction displays already recommended. Speech systems would provide an alternative medium to the visual for presenting information. Conceptually, different expert systems could be addressed individually by a crewmember. An expert system output could be presented aurally, using unique voices to distinguish each expert system.

For CGDs, speech systems could be used for blending or fusing information (Wetherbee, 1983; Zenyuh and Reising, 1986). This ability would help declutter displays by off-loading the appropriate type of information to speech generators. Crewmembers could select what information they prefer presented visually or aurally.

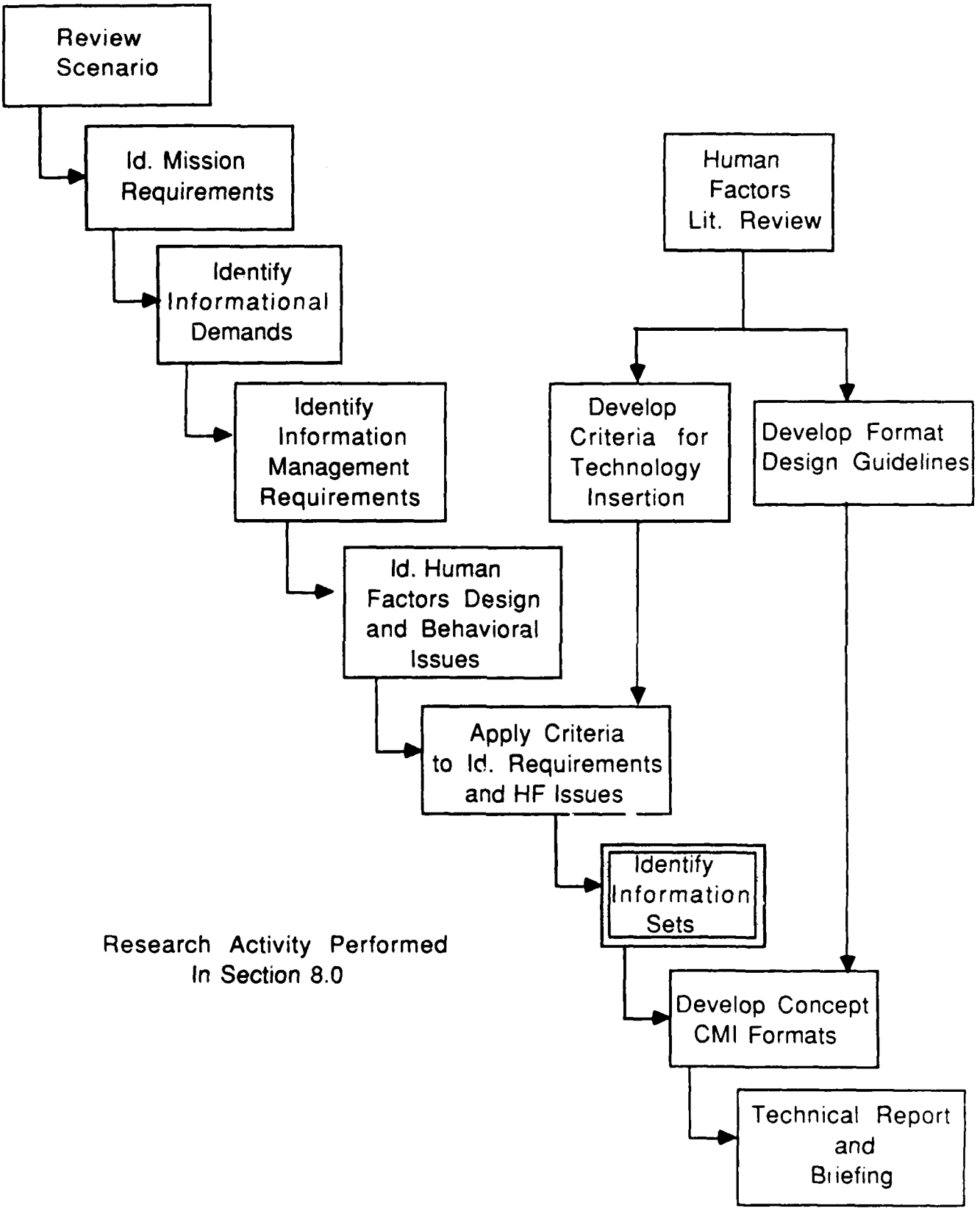
It is recommended here that voice-interactive systems be retained as an alternative input-output channel throughout the detailed design of the crew-machine interface. The decision of precisely how and when to use voice-interactive systems must be made based on human factors studies on the design for the crew-machine interface. These studies typically involve assessing operator performance for different interface technologies and designs (condition 17). Empirical results are obtained from workload measurement experiments (Aretz, 1983; Damos, 1986; Robinson and Eberts, 1987, 1985). The most accurate test conditions for evaluating speech systems would be under simulation or prototype conditions (Simpson, et al., 1985).

7.7 Summary

Five opportunities for technology insertion were identified. Three of them were for using expert systems to support information management requirements. Computer-generated displays were recommended

for presenting information from expert systems, multiple sensors, or gauges to the crew. Voice-interactive systems were recommended for supporting non-critical, secondary level control options. This section completes Step Four of the evolved methodology proposed in Part 2.4.2.

The next analysis step would be to evaluate these technologies at a more detailed level of system design. A manageable number of technolgoies can be evaluated under the constricts of traditional trade-off studies by the different engineering disciplines.


Review Scenario
Id. Mission Requirements
Identify Informational Demands
Identify Information Management Requirements
Id. Human Factors Design and Behavioral Issues
Apply Criteria to Id. Requirements and HF Issues
Identify Information Sets
Develop Concept CMI Formats
Technical Report and Briefing
Human Factors Lit. Review
Develop Criteria for Technology Insertion
Develop Format Design Guidelines
Research Activity Performed In Section 8.0

8.0 CONCEPTUAL INFORMATION SETS

8.1 Objective

An information set is a collection of the information required by the crew to make a proper decision or perform a task correctly. Each mission event requires specific combinations of information from the three information subject areas (mission related, situation awareness, system) identified in Section 4.0.

In this section, information sets for six scenario events in the CMS are described. Crew informational demands for each scenario event are discussed and listed by information subject area. In addition, expert systems proposed in Section 7.0 are applied to each scenario event to demonstrate the potential use of the technology.

8.1.1 Information Sets. An information set is an enumeration of what information is needed to correctly perform a given mission event (Figure 8-1). Different information sets may share information, but each event will typically require specific combinations of information. An important human factors consideration in an information set is when to present certain information and what information needs to be presented together. Certain information should be presented at the same time or blended together, while other information should be presented separately or possibly only upon request.

The mission scenario analysis templates (MSAT) completed during the mission scenario analysis provides a ready listing of information sets by scenario event. Similar or redundant events can be compared and contrasted to determine what information is shared or unique.

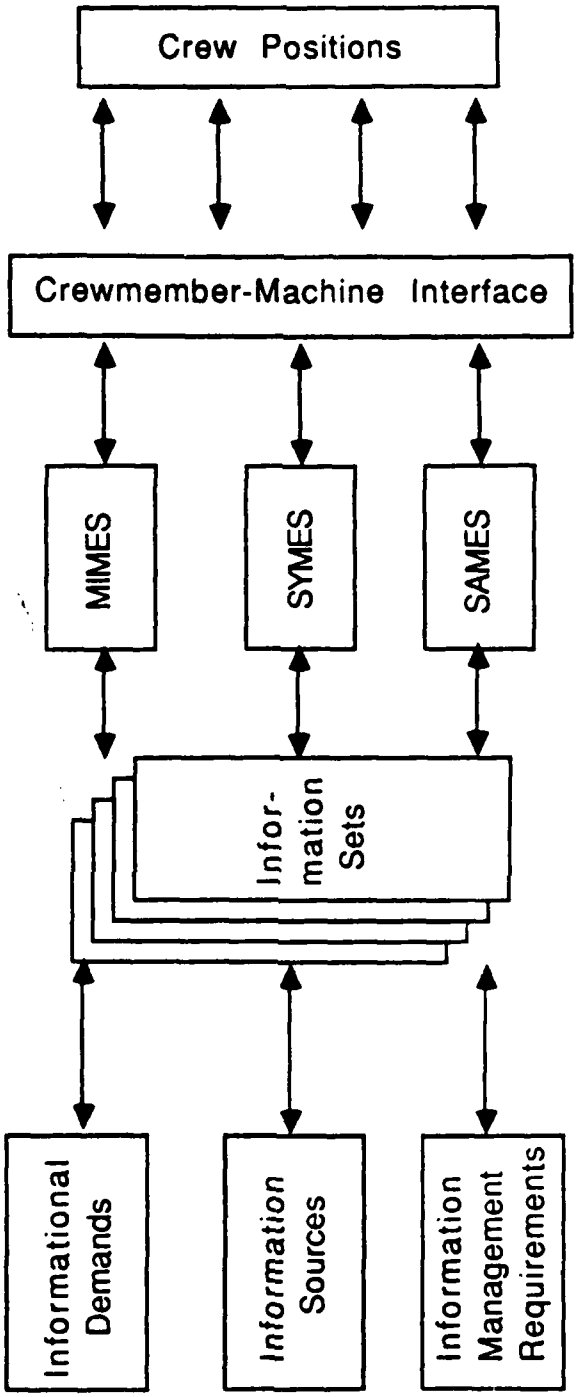


Figure 8-1. Role of Information Sets in Mission Events

Information sets can then be constructed for general scenario events such as delivering a missile against a fixed target or responding to an active SAM radar. Information sets for six general scenario events are presented. These six events occur frequently and represent the more critical mission events in the CMS.

8.2 CMS Information Sets

Six information sets were selected from the mission scenario analysis of the CMS. Each information set is divided into mission related, situation awareness, and system information as discussed in Section 4.0. Within each set is a list of information required to appropriately respond to the mission event. In the simplest sense, the information sets can be viewed as the minimum information the crew needs to make a decision or perform a task correctly. The six information sets are for:

(1) A Fixed Target Strike

(2) A Predictable RT Strike

(3) An Unpredictable RT Strike

(4) SAM Radar Activity

(5) A Missile Attack

(6) An Enemy Aircraft Encounter

8.2.1 Information Set for a Fixed Target Strike. Weapon delivery on a fixed target is a planned mission event in the CMS. While weapon delivery is considered an offensive action, the event also involves pilotage, navigation and defensive actions. Information is sorted as mission related, situation awareness, and system information. The type

of target to be struck and the type of weapon to be delivered determine what offensive information is included in the information set. In addition, there is a subset of pilotage, navigation and defensive information. This subset of information is the continuous exchange of information necessary to fly the mission (e.g., AFPI, navigation, threat detection), regardless of the current event.

The type of weapon to be delivered (missile or gravity) determines what offensive information is needed. A fixed target strike requires the crew to perform specific tasks in a defined order. These tasks include running weapon delivery checklists, locating the target, possibly performing a TAL maneuver (missile delivery only), and delivering the weapon at planned launch coordinates.

Independent of the type of weapon to be delivered, the crew coordinates activities such as maintaining the planned flight path, performing navigation updates, monitoring for area threats (known or pop-up), and terrain following (TF). This type of information also requires timing coordination and logical blending of combinations of information.

Applicable tactical doctrine is an important part of weapon delivery. It is a knowledge base for the crew to reference. In this instance, applicable tactical doctrine applies to SAC tactical doctrine regarding weapon delivery against a fixed target as well as responding to encounters with (possible) enemy threats.

Listed below is the information set for a missile strike against a fixed target. A missile weapon was chosen to illustrate informational demands for a missile delivery.

Table 8-1. Information Set for a Fixed Target Strike (missile delivery)

I. Mission Related Information

- mission flight plan
- applicable tactical doctrine
- target coordinates
- weapon delivery program
- known, area threats
- navigation update window
- TAL maneuver window
- launch point/altitude

II. Situation Awareness Information

- enemy threat detection/identification
- pop-up obstacle detection/identification
- applicable tactical doctrine
- TF

III. System Information

- AFPI data
- navigation data
- TF resumption checklist results
- missile pre-launch checklist results
- missile launch checklist results
- missile post-release checklist results
- missile weapon delivery information

Expert systems could serve a vital role in weapon delivery. Target strikes and associated weapon delivery require a great deal of information processing and interpretation during a very small time frame. This requirement specifies perceptual, mediational, and communication processes with the capability to handle large amounts of information quickly and correctly. In addition, there are the continuous functions and tasks which must be performed regardless of the specific event (e.g., aircraft flight performance, obstacle and threat detection). Collectively, all of these functions would overwhelm the crew if some level of automation was not provided.

The expert systems discussed in Section 7.0 satisfy the above requirements and alleviate the crew of many of the tasks. Thus, allowing the crew to focus their attention on the target strike. Expert systems could support the retrieval and processing of raw data, and presentation of information throughout the target strike. Also, the expert systems could perform these tasks at a much faster rate than the crew. Although timeline analysis was not a part of this mission scenario analysis, it is obvious by inspection that time windows are very small for performing activities such as weapon delivery.

The mission manager expert system (MIMES) would contain within its knowledge base the mission flight plan, applicable doctrine, weapon delivery program, target coordinates, and knowledge of area threats. In addition, the inference engine could recommend time windows for navigation updates, TAL maneuvers, and launch points and altitudes to optimize the measures of effectiveness for the target strike. An important consideration is that MIMES could perform all of the above functions autonomously without crewmember query. Information would be

presented automatically at the appropriate time or could be requested ahead of time by the crew.

The situation awareness manager expert system (SAMES) could support the external situation awareness requirements for a fixed target strike. For this scenario event, situation awareness is primarily locating the target. Even though the target is in a known, fixed location, the crew must first locate the target and then approach the target along a defined course. SAMES could support the retrieval of raw data from the target recognition and navigation systems, process this information and present the information to the crew.

The other area of situation awareness for a target strike event is detection and identification of uncharted obstacles and pop-up enemy threats. Such encounters are unplanned events and require continuous monitoring throughout the mission. When such an encounter occurs, the crew must respond quickly and correctly to avoid or defeat the encounter. SAMES could support the crew's informational demands for these encounters by continuously monitoring, and quickly processing the identification of the obstacle or threat. Based on applicable tactical doctrine for responding to the object identified, SAMES could recommend alternative actions for avoiding or defeating the obstacle or threat.

The system manager expert system (SYMES) could support the weapon delivery activities which need to be performed throughout the target strike. Primarily, these activities are the running of checklists for the type of weapon to be delivered. While checklists are a critically important part of systems management, it is the results of the checklists which are of interest to the crew. SYMES could run these checklists, reporting the results to the crew, thus, alleviating the crew of

this time consuming task. In addition, a programmed checklist would be performed completely and correctly; a level of performance the crew may not be able to always meet, given the numerous ongoing activities during a target strike.

As discussed in Section 7.0, SYMES is also the default superintendent of the aircraft. SYMES is intended to keep the aircraft in the air without considering external factors. Therefore, during a scenario event such as a target strike, SYMES would continuously monitor aircraft flight performance information (AFPI) status and automatically report and analyze out-of-tolerance parameters. This capability of reporting by exception alleviates the crew from monitoring the myriad of parameters measured on-board the aircraft. Again, such a capability permits the crew to focus their attention on the event.

8.2.2 Information Set for a Predictable RT Strike. Delivering a weapon against a predictable RT is a planned scenario event. The information set includes all of the information needed for a fixed target strike and, in addition, the information unique for a predictable RT. Predictable RTs require target imaging and occupancy assessment. Occupancy assessment involves complex, problem solving on the part of the crew. The crew makes a knowledge-based decision as to whether or not the target is occupied based on the target imagery. Therefore, an important piece of information is the target imagery.

Delivering a weapon against a predictable RT involves coordinating planned flight paths and imaging points to obtain an optimal imagery of the target. Activities must be performed within specific time and distance windows. This involves synchronizing the planned mission and the actual mission events (i.e., presenting the mission flight schedule

in unison with the on-going mission).

Activities involved with a predictable RT target strike include additional piloting and navigating efforts. Locating and imaging the target involves certain piloting and navigating actions. These actions must be coordinated with the mission flight plan.

Listed in Table 8-2 is the information set for a gravity weapon delivery against a predictable RT. A gravity weapon was chosen as an example of informational demands for a gravity weapon delivery.

Here again, expert systems could support important functions. The majority of the informational demands for a predictable RT strike were also existent for fixed targets. To avoid redundancy in the discussion, only those informational demands specific to predictable RT events are discussed here. Namely, these demands are concerned with the imaging of the target and determining whether or not the target is occupied.

MIMES could support informational demands for target imagery and occupancy assessment. MIMES' knowledge base could have within it graphic imagery of what the target imagery should resemble and what the imagery should resemble when occupied. The inference engine could then evaluate expected imagery versus obtained imagery to determine an assessment of whether or not the target is occupied. Such an assessment would include a confidence rating of the assessment. MIMES could perform this activity continually as the aircraft passes through the imaging aimpoints for the target. The crew would base their decision of target occupancy on their own interpretation of the situation and the interpretation of MIMES' assessment.

Table 8-2. Information Set for a Predictable RT Strike (gravity weapon delivery)

I. Mission Information
- mission flight plan
- applicable tactical doctrine
- target coordinates
- weapon delivery program
- known, area threats
- navigation update window
- imaging points/altitude
- occupancy criterion
- roll-in window
- launch point/altitude

II. Situation Awareness Information
- locate target
- enemy threat detection/identification
- pop-up detection/identification
- applicable tactical doctrine
- TF

III. System Information
- AFPI data
- navigation data
- TF resumption checklist results
- bomb pre-run checklist results
- bomb run checklist results
- bomb post-run checklist results
- bomb run abort checklist results
- weapon delivery information

In addition, the potential of encountering an enemy threat may be increased for a predictable RT strike because of possible terminal area defenses. Basically, striking a predictable RT is more dangerous than a fixed target, demands more information and subsequently requires more information management. Therefore, the proposition of supporting crew functions with expert systems, as discussed in Section 7.0, is even more attractive.

8.2.3 Information Set for an Unpredictable RT Strike. Unpredictable RT strikes are the most challenging of the three types of target strikes. Information sets for unpredictable RT strikes include the informational demands listed for predictable RTs and fixed targets and in addition, include target searching information. The crew is burdened with searching an area for a possible target and deciding whether or not to strike the target. This involves a great amount of knowledge-based assessment of search area imaging and possible target imagery. Therefore, crewmember demands are very great for high quality imagery.

The fact that the crew is searching-out its target sharply increases the potential for encountering an enemy threat or obstacle. The possibility of either unplanned event heightens the crews vigilance for possible encounters.

As with predictable RTs, weapon deliveries against unpredictable RTs include additional piloting and navigational efforts on the part of the crew. The crew must now search out an area for a target applying techniques for locating RTs.

Listed in Table 8-3 is the information set for a gravity weapon delivery against an unpredictable RT. A missile delivery was chosen for purposes of an example.

Table 8-3. Information Set for an Unpredictable RT (missile delivery)

I. Mission Information

- mission flight plan
- applicable tactical doctrine
- target coordinates
- weapon delivery program
- known, area threats
- search area
- navigation update window
- TAL maneuver window
- imaging points/altitude
- occupancy criterion
- launch point/altitude

II. Situation Awareness Information

- enemy threat detection/identification
- pop-up detection/identification
- applicable tactical doctrine
- TF

III. System Information

- AFPI data
- navigation data
- TF resumption checklist results
- missile pre-launch checklist results
- missile launch checklist results
- missile post-release checklist results
- missile weapon delivery information

Target strikes against unpredictable RTs include the difficult task of searching an area for the target. This creates a substantial amount of additional work for the crew. As with target strikes against predictable RTs, MIMES could support the target searching requirement and alleviate the crew from part of the additional work. MIMES could be programmed to conduct a structured search of area attempting to detect and identify the designated target. This would involve coordinating search patterns of electronic sensors for detecting and identifying targets to maximize the amount of area searched in the available time. MIMES would automatically attempt to detect, recognize and identify a possible target. MIMES would present possible target detections and confidence levels of actual target identification.

Target strikes against unpredictable RTs are probably the most susceptible to enemy threats or obstacles. This is because of the location of the targets and the requirement to search an area. Here again, the use of SAMES is invaluable as a support measure for providing early warning and recommendations for reacting to either an unplanned enemy threat or obstacle.

8.2.4 Information Set for SAM radar activity. Encountering SAM radar activity is an unplanned event. This assumption is made because an optimum flight plan and mission would not encounter such a threat. If a radar threat is known to exist along the flight path, there is still no assurance that the threat will be active. Regardless, the crew's immediate reaction is the same -- identify the SAM radar, monitor the SAM radar activity, and determine potential strike lethality of the SAM. How the crew responds depends on the type of SAM and the radar activity exhibited by the SAM radar site (e.g., radar

activity switches from tracking to firing mode).

The primary concerns of the crew are to identify the SAM radar, determine its location and radar mode, and assess the lethality of the SAM. These concerns all address external situation awareness. There is a heightened awareness to the outside environment, because a threat has been detected. The crew demands information about the threat as well as any additional threats.

The crew is also concerned with how the encounter might affect the immediate and overall mission plan. Depending on the mission leg, the crew may be actively involved with a planned mission event. In this situation, the crew must deal with both events concurrently. Applicable tactical doctrine is important in determining which event has higher priority. However, the crew often has several options regarding how they could respond. Mission related information includes demands for priority of multiple events, mission flight plan, threat location, locations of known threats, and the schedule of planned events in the near future.

Associated with situation awareness information and mission related information is system information on the immediate capabilities of the aircraft to respond to the threat. Equipment failure, system malfunction or battle damage may restrict or limit the response options available to the crew. Therefore, the crew also is interested in the current capabilities of the aircraft at the time of the encounter.

Listed in Table 8-4 is the information set for responding to SAM radar activity. The radar activity is assumed to be generic, but could be defined as acquisition, tracking or firing mode radar.

Table 8-4. Information Set for SAM radar activity

I. Mission Information

- mission flight plan
- known, area threats
- applicable tactical doctrine

II. Situation Awareness Information

- SAM radar detection/identification
- SAM type and strike potential
- SAM radar activity
- other threat detection/identification
- applicable tactical doctrine

III. System Information

- AFPI data
- navigation data
- aircraft status

Reacting to SAM radar activity requires an expedient and accurate assessment of the situation followed by a rapid response. In assessing the situation, raw data from electronic sensors must be processed concurrently to obtain the necessary information. Large quantities of information need to be processed almost instantaneously. Additionally, the reliability of the information must be very high to insure that the correct response option is chosen. Here again are requirements for perceptual, mediational, and communication processes. These processes should have large working capacities to handle information in a small time frame and with a high degree of reliability.

In the area of situation awareness, emitted signals must be referenced to radar signature data bases to identify the radar type and mode. Signal emissions must also be accurately located. The type of signal present must be identified by the radar signature, as well as the SAM's location and strike potential. Clearly, SAMES could be utilized to coordinate and process this information automatically. Upon detection of the radar signal, SAMES would perform the above activities reporting information regarding the radar and SAM as it is determined.

There is also a need to consider the impact of the response option on the immediate mission plan, as well as the overall mission plan. Response options need to be evaluated to determine the best option or alternative options. The crew is burdened with considering multiple options while also reacting to the initial detections of the SAM radar activity and quite possibly performing a planned event.

MIMES could perform the function of determining possible response options. MIMES would determine the possible options and present the

options to the crew. The advantage here is that an expert system consideration of possible alternatives would be comprehensive and based on tactical doctrine. Options could be presented along with a confidence rating in each option, the rating indicating relative confidence in selecting that option. The crew could choose from the response options presented by SAMES or the crew could respond on their own.

System related information such as capabilities and constraints could be managed and presented by SYMES. Information transfer between SYMES and MIMES is crucial for considering response options. Clearly, if the aircraft is partially degraded, then certain responses are no longer viable. The two expert systems could exchange information without any interface with the crew. SYMES would also present any system information to the crew as requested.

8.2.5 Information Set for a Missile Attack. The information set for a missile attack is small but focused. The event is unplanned and requires immediate response with few options. The crew's informational demands are centered on identifying the missile type, determining the missile's course and location, and determining whether or not any additional threats exist at that time. Following the assimilation of this information, the crew chooses a response with the best chances of defeating the attack (e.g., evasive maneuvers and/or defensive countermeasures). There is little opportunity to contemplate the implication of the response on the overall mission.

If a planned event such as a target strike is occurring when the missile attack occurs, the crew must determine how to react to both events. This may involve reacting to the event with the higher

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priority. For enemy missile attacks during an ongoing planned event, the crew's response will most likely involve some degree of spontaneous replanning.

The crew's response may be so extreme that a significant effort of mission replanning is necessary after the attack has been defeated. In this case, the crew must decide upon the best option for performing as much of the original mission as possible. Mission replanning is supported by applicable tactical doctrine and CMF information of mission replanning. There is also the possibility of battle damage as a result of the attack. If this occurs, the extent and nature of the battle damage will also be a factor in replanning the mission.

Listed in Table 8-5 is the information set for responding to a missile attack. The missile attack is assumed to be a SAM attack for purposes of an example information set.

Responding to a surface-to-air missile (SAM) (or an air-to-air missile (AAM) attack) requires a fast assimilation of information pertaining to the missile type, course and location. This information must be gathered quickly from electronic sensors and processed so that the crew can decide on a course of action. A delay in presenting information, not presenting all of the above information, or presenting information incorrectly could seriously hinder the crew's attempt to defeat the attack. This is an event which requires a high amount of perceptual, mediational, and communication processes. These processes must be able to handle the above information in an extremely short timeframe and be able to present the information completely and correctly.

Table 8-5. Information Set for Missile Attack (SAM)

I. Mission Information

- mission flight plan
- known area threats
- applicable tactical doctrine

II. Situation Awareness Information

- SAM detection/identification
- SAM type and strike potential
- SAM radar activity
- other threat detection/identification
- applicable tactical doctrine

III. System Information

- AFPI data
- navigation data
- aircraft status
- evasive maneuvers
- defensive countermeasures

The expert system discussed in this section and Section 7.0 could support the requirements for responding to a missile attack. As was discussed for the information set for a SAM radar encounter, SAMES could respond to a missile launch detection autonomously by identifying, tracking and plotting the missile. SAMES would present this information to the crew automatically and recommend the best response combinations for defeating the attack. Again, SAMES' recommendations would be based on applicable tactical doctrine for defeating the type of missile in the current situation. Of course, the situation could also involve an on-going planned event, where event priorities will determine the recommended response.

Under the conditions of an attack, mission replanning will probably not be addressed until the missile has been successfully defeated and the threat ceases to exist. MIMES could continually replan the mission as the crew responds to the missile and threat. After enemy threats have been defeated, MIMES would present mission replanning options based on applicable doctrine and replanning information from the CMF. Additionally, MIMES would receive inputs from SYMES on the nature and extent of any battle damage incurred. System status information would permit MIMES to make a better estimate of how much of the remaining mission could be accomplished.

System information could be obtained, managed and shared via SYMES. SYMES would monitor vital aircraft flight performance information (AFPI) as the crew attempts to defeat the missile attack. SYMES would also report system status and provide battle damage reports for any damage incurred as a result of the missile attack. Finally, SYMES would be capable of reporting predicted flight capabilities and

remaining in-the-air time given the current status of the aircraft.

8.2.6 Information Set for Enemy Aircraft Encounter. Encounters with enemy aircraft are an expected but unplanned scenario event. An enemy aircraft may be encountered anywhere during the mission, but will most likely be encountered during the penetration, strike, and egress parts of the mission. (Enemy aircraft encountered in the CMS were aircraft interceptors (AI), and a SUAWACS.)

The informational set for encountering an enemy aircraft is primarily concerned with the identification, course, location, and activity of the enemy aircraft. The crew's informational demands are similar to that of other unplanned, enemy threats (e.g., radar detection and missile attacks). However, response options for countering an enemy aircraft are different because the enemy now has the ability to pursue the crew.

Encountering an enemy aircraft requires the crew to make a response based on their situational awareness of the aircraft. The crew needs to know what type of a threat the enemy aircraft poses to the mission. The crew also needs to know what additional threats are known to be in the area (e.g., SAM sites). Therefore, the crew needs to know very specific information about the aircraft as well as general information about the environment, in order to maximize their situational awareness for that event. This information should be obtained as rapidly as possible, so that the crew can make an informed decision.

If an enemy aircraft is encountered during an on-going planned event, such as a target strike, the crew's response will be influenced by the current situation and schedule of the planned event. The

priority of the events will determine how the crew will respond. The crew will act according to applicable tactical doctrine and mission planning for a conflict between performing a planned event and responding to an enemy aircraft.

Another factor which will affect how the crew will respond is the status of the aircraft. Depending on the remaining resources of the aircraft, different defensive tactics can be employed (e.g., evasive maneuvers and defensive countermeasures). System status information is again an important input the crew must consider while contemplating alternative responses.

As with the other enemy threats discussed earlier, the crew's response will most likely impact the planned mission. Mission replanning may or may not be possible at the time of the encounter, but will be an important factor after the encounter is over. Replanning may in fact be used to avoid or bypass the enemy aircraft. Regardless of the response, the crew will consider mission impact as a result of the enemy aircraft encounter.

Listed in Table 8-6 is the information set for responding to an enemy aircraft encounter. An AI encounter is assumed to be for purposes of an example information set.

Informational demands for responding to an encounter with an enemy aircraft require rapid identification, location, course and activity of the enemy aircraft. In addition, informational demands exist for knowledge of any additional threats known to be in the immediate area. If the encounter occurs during a scheduled mission event, then the crew must determine the priority of the two events and decide on their response according to applicable tactical doctrine and mission planning.

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Table 8-6. Information Set for Enemy Aircraft Encounter (AI)

I. Mission Information

- mission flight plan
- known area threats
- applicable tactical doctrine

II. Situation Awareness Information

- AI detection/identification
- AI type and strike potential
- AI activity
- other threat detection/identification
- applicable tactical doctrine

III. System Information

- AFPI data
- navigation data
- aircraft status
- evasive countermeasures
- defensive countermeasures

The volume of information in this information set must be obtained, processed and presented to the crew in the most timely manner. This will permit the crew to make the best response with the necessary information. These requirements specify perceptual, mediational, and communication processes. Processes which must have the capability to handle large amounts of information in an expeditious manner and with a high level of reliability.

SAMES could be applied here to support the crew's situation awareness informational demands. As discussed throughout this section, SAMES could assimilate the necessary information on the enemy aircraft and present this information concisely to the crew. This information would include the identification, location, course, lethality, and activity of the aircraft, as well as the known threats which also exist in the immediate area. In addition, SAMES would present applicable tactical doctrine and CMF mission planning for responding to the aircraft type.

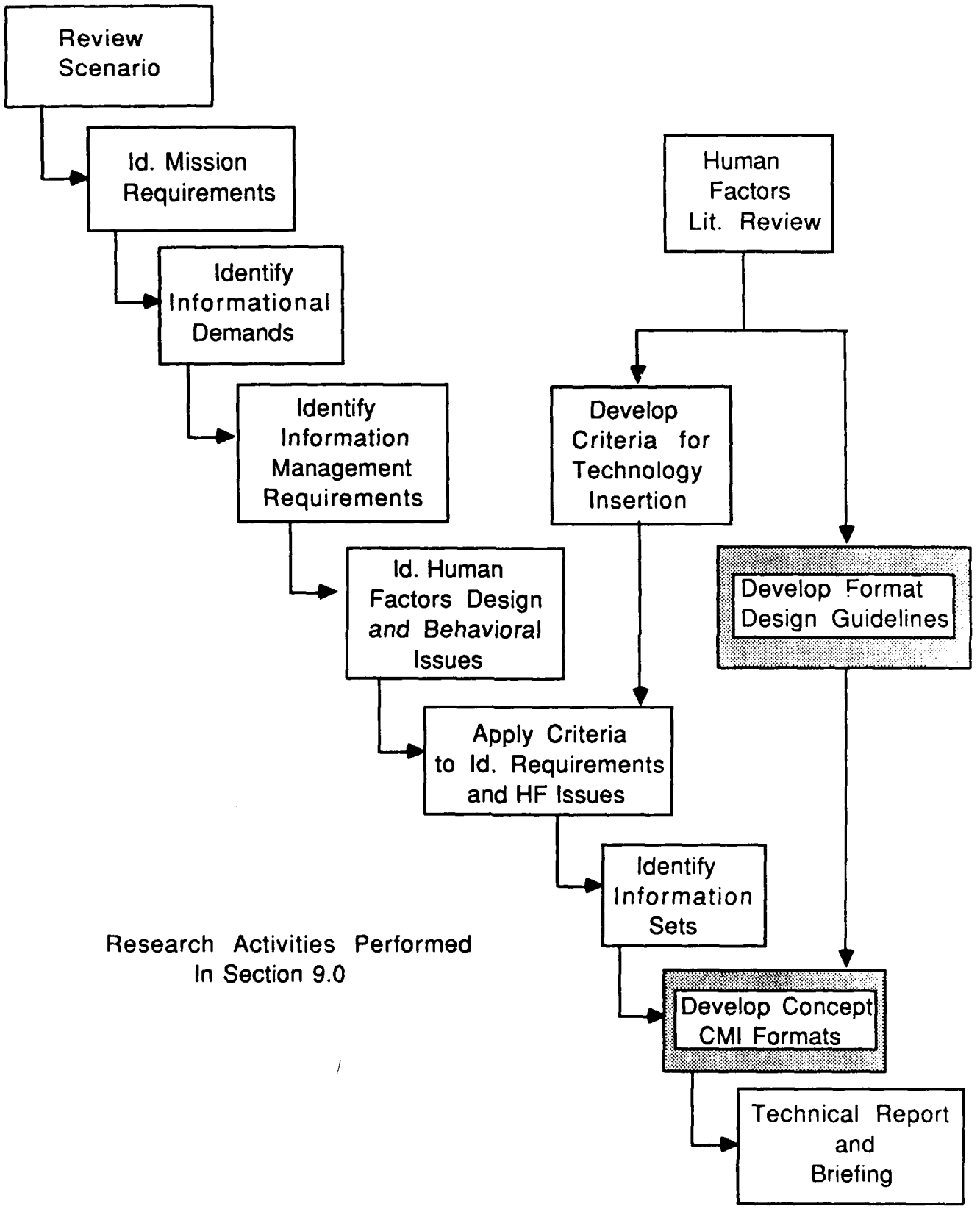
MIMES could supply important information regarding mission impact due to the encounter, and mission replanning options for rejoining the mission. MIMES would also support prioritizing events when an enemy aircraft is encountered during a planned mission event. Prioritizing would be supported by appropriate tactical doctrine and mission planning for the conflicting events.

System information regarding aircraft status and remaining resources could be provided by SYMES. SYMES would transfer this information to SAMES for response options and MIMES for mission impact recommendations. SYMES would also monitor vital AFPI during evasive

maneuvers, informing the crew when AFP parameters exceed preset toierances.

8.3 Summary

Six information sets from the mission scenario analysis were described. Each information set is composed of the informational demands required by the crew to respond to a scenario event. For each information set, informational demands were classified by information subject areas. These areas are mission related, situation awareness, and system information. Crew requirements were described by the information needed to respond to a given scenario event. Expert systems proposed in Section 7.0 were applied to each scenario event. This provided a demonstration of the potential use of expert system technology.



Research Activities Performed
In Section 9.0

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9.0 CREWMEMBER-MACHINE INTERFACE FORMATS

9.1 Objective

Crewmember-machine interface (CMI) formats are conceptual or "strawman" display formats for the computer-generated displays recommended in Section 7.0. The information displays are taken from the information sets described in Section 8.0. Display formats are based on guidelines for designing user interface software developed by Smith and Mosier (1986). The displays illustrate various methods of presenting information for specific mission scenario events. The emphasis of this section is to show by example the potential for information transfer available with the computer-generated display technology recommended in Section 7.0. These displays are conceptual and should not be interpreted as formal recommendations for developing programmable displays.

This section begins with an introduction to human-computer interaction (HCI). HCI is the means of communications between the human and the computer. Developing an HCI for a specific application is a highly, iterative design process that requires the designer to conduct a series of empirical and experimental studies to develop an acceptable user interface software. Guidelines exist and should be applied for designing user interface software. These guidelines are general rules and recommendations for creating user-computer software interfaces. Implementing a design process and applying design guidelines are a necessary part of any HCI development effort.

Following the introduction, conceptual displays are presented for the three information subject areas identified in Section 4.0: mission

related information, situation awareness related information, and system related information. For each subject area, several different displays are presented and discussed. Each display represents a method for presenting information on a different mission scenario event. Display formats and associated guidelines are discussed for each display concept presented.

9.2 Human-Computer Interaction

HCI is the means of communications between the human and the computer. Developing an HCI can be considered a human factors design process for creating a quality interface between the human and the computer for the explicit purpose of facilitating communication processes between the two. In designing computer-based information systems, like the CMS aircraft, special attention must be given to the software supporting the user interface (Smith and Mosier, 1986). This interface between the human and the computer may be even more important than equipment and workplace layout (Williges, Williges, and Elkerton, 1987).

The design of a quality HCI involves the elements of engineering, science, and art (Rubinstein and Hersh, 1984). The process incorporates the disciplines of psychology, human factors, and computer science. The reader is directed to Card, Moran, and Newell (1983), for an indepth review of the role of the three elements in HCI design. There are no "cookbook recipes" for developing an optimum HCI for every application. Every designer, to some extent, uses a design process, applies theory and lessons learned, and adds his/her own personal preferences when developing an HCI for a specific application.

Only recently has the HCI design process been formally documented (Rubinstein and Hersh, 1984; Williges, Williges, and Elkerton, 1987) and comprehensive design guidelines have been developed (Engel and Granda, 1975; Smith and Mosier, 1986; Williges and Williges, 1984). Below, the value of a design process and guidelines to developing a quality HCI are discussed.

Williges, Williges, and Elkerton (1987) proposed a design process which has four stages of iterative design activities (Figure 9-1). Stage 1 is the initial design stage in which the preliminary software interface is specified from a series of user-focused studies. Stage 2 is an evaluation stage during which the software interface evolves through iterative design studies as shown by the dashed feedback loop. The resulting operational software interface developed through this iterative design process is evaluated in Stage 3. Stage 3 is the final proving ground for evaluating the software interface under formal experimental conditions. Experimentation validates the design and provides new insights that form the basis for additional human factors software design guidelines as shown in the feedforward loop.

Guidelines for designing user interface software were developed out of the need for establishing consistent and appropriate design practices. Guidelines serve several different purposes (Smith and Mosier, 1986). First, they are a compilation of established and proper programming practices (i.e., rules of thumb for the design of the user-computer interface) that serve as a knowledge base for the designer. Second, they provide the designer with general guidance upon which to derive specific rules appropriate for a particular application. Third, they are criteria for developing a human-computer

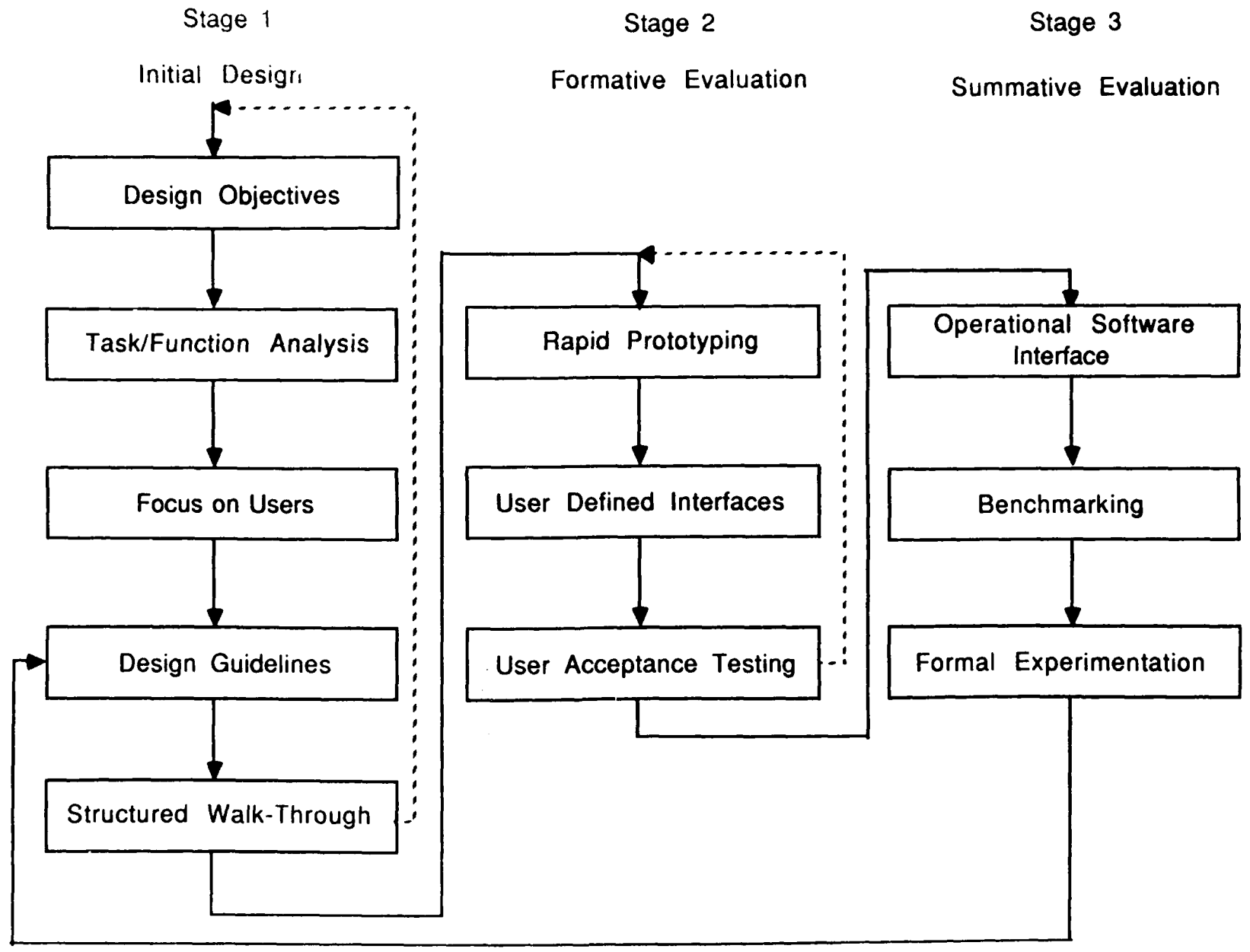


Figure 9-1. Three Stages of Human-Computer Interaction Design Process

interface or evaluating an existing interface.

Smith and Mosier (1986) present 944 guidelines for designing user interface software. By far, this technical report is the most comprehensive collection of design guidelines for user interface software development. There are design guidelines for six different design areas: data display, data entry, sequence control, user guidance, data transmission, data protection. For the purposes of this research, only guidelines for data display were considered.

Data display guidelines provide general concepts and "rules of thumb" for presenting and formatting data on a visual display (e.g., CRT). These guidelines provide recommendations and suggestions for designing, formatting and highlighting data on displays. Guidelines are provided for data displayed as text, forms, tables, or graphics. It should be noted that guidelines cannot tell a designer what the specific contents of a display should be, but only how those contents should be presented. What information should be displayed is determined by a detailed task analysis of the user's information requirements (Dumas, 1987).

The Smith and Mosier guidelines (1986) were used during the development of conceptual displays because they are the most comprehensive guidelines currently available. These guidelines represent seven years of Air Force sponsored research. The authors know of no other guidelines that provide the breadth of information or level of detail as found in Smith and Mosier (1986).

9.3 Conceptual CMI Displays

The displays presented below illustrate the potential for information transfer available with the computer-generated display (CGD) technology recommended in Section 7.0. Several displays are presented for each of the three information subject areas identified in Section 4.0.

Display content and context are discussed by information subject area as well as mission event. Displays are described by informational content as they relate to a specific mission event. The context of the information displays, including formatting and highlighting techniques for both pictorial (graphic) and textual displays are also discussed. Through the use of appropriate interface design and format techniques (e.g., functional grouping, color coding, icons, symbology, etc.), large amounts of information can be presented in a clear and uncluttered manner. Formatting techniques, such as color coding, are used to distinguish geography, as well as highlight important landmarks and mission events.

9.3.1 Mission Information Displays. In earlier discussions, mission related information was defined as information pertaining to the particular mission the aircraft was flying. Mission related information includes mission flight plans, course changes, and scheduled activities such as planned target launch points, navigation update points and strike reports. Below, three mission information displays are presented and explained. These displays are: a horizontal pictorial mission flight plan display, a horizontal pictorial replanned mission flight plan display, and a vertical pictorial target

strike plan display.

Mission flight plan display. Figure 9-2 is a horizontal pictorial of a mission flight plan display. Using computer-generated graphics, the mission manager expert system (MIMES) dynamically presents the continuous course of the aircraft over the current leg of the mission. This display provides qualitative and quantitative information on the aircraft's actual position and heading relative to the mission plan and surrounding terrain.

The aircraft is represented by an aircraft icon on the display to highlight the aircraft's position. The icon is stationary with the digitized map moving underneath. This accomplishes the effect of the aircraft icon moving across the area terrain without having the icon move off the display area. The planned mission flight path is superimposed on a moving map. If the aircraft is on its proper flight path, the icon would also follow the flight path. The flight path is highlighted as a heavy solid line, the circle represents a planned turn point with an associated new course heading.

The orientation of the display is heading-up rather than north-up. All horizontal displays would be heading-up displays to maintain consistency and prevent orientation confusion. A compass heading is presented at the top-center of the display to indicate the actual heading of the aircraft.

The display also contains quantitative information. Actual versus desired altitude AGL and ground speed are presented in the top-right corner. The mission leg is presented at the bottom-center of the display and in the bottom-right is a window for zooming in or out to view the flight plan along a greater or smaller distance. A scale of

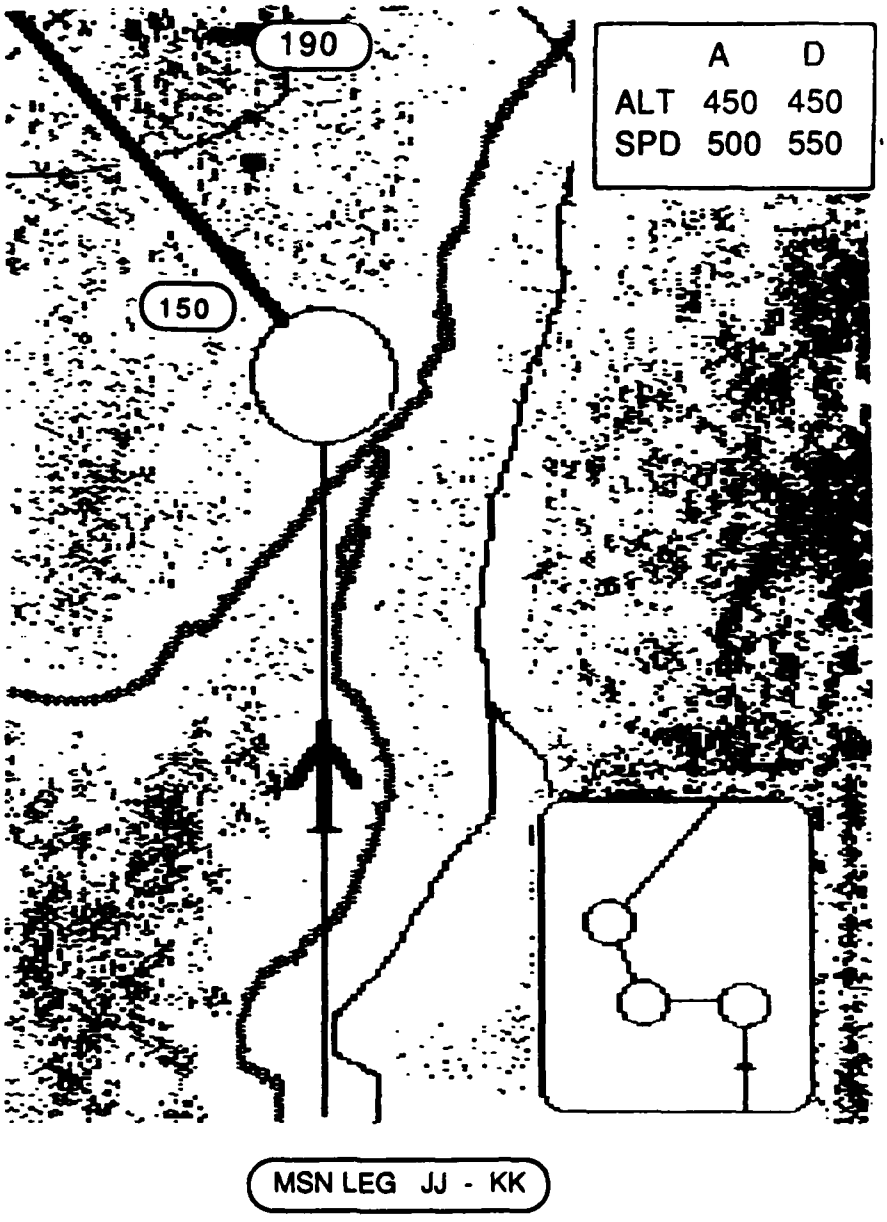


Figure 9-2. Mission Flight Plan Display

the display map is presented at the bottom-left of the display to indicate apparent distances.

Replanned mission flight plan display. Figure 9-3 is a horizontal pictorial display of a replanned mission flight plan display. The purpose of this display is to provide qualitative and quantitative information to the crew on a replanned mission flight plan.

The new flight path requires the pilot to alter course to the left from the original mission flight plan. This course change is represented by a heavy solid line angled accurately to the left just ahead of the current aircraft position. A new course heading is displayed for the replanned flight path. The abandoned, preplanned flight path is temporarily shown as a dashed line.

MIMES continuously updates the display orientation and content. As the pilot changes heading onto the new flight path, the original flight path disappears and the heavy line indicating the new flight path and background terrain dynamically rotate to the center to maintain a heading-up display orientation. Again, the aircraft icon is stationary and the area map moves. The compass heading, altitude and ground speed indicators also change appropriately. The mission leg is presented at the bottom-center and the zooming-window is again presented in the lower-right of the display to permit the user to zoom-in/zoom-out for a different perspective of the mission flight plan.

Target strike plan display. Figure 9-4 is a vertical pictorial display of a planned target strike. A vertical display was chosen to illustrate the potential to emphasize apparent altitude in a mission

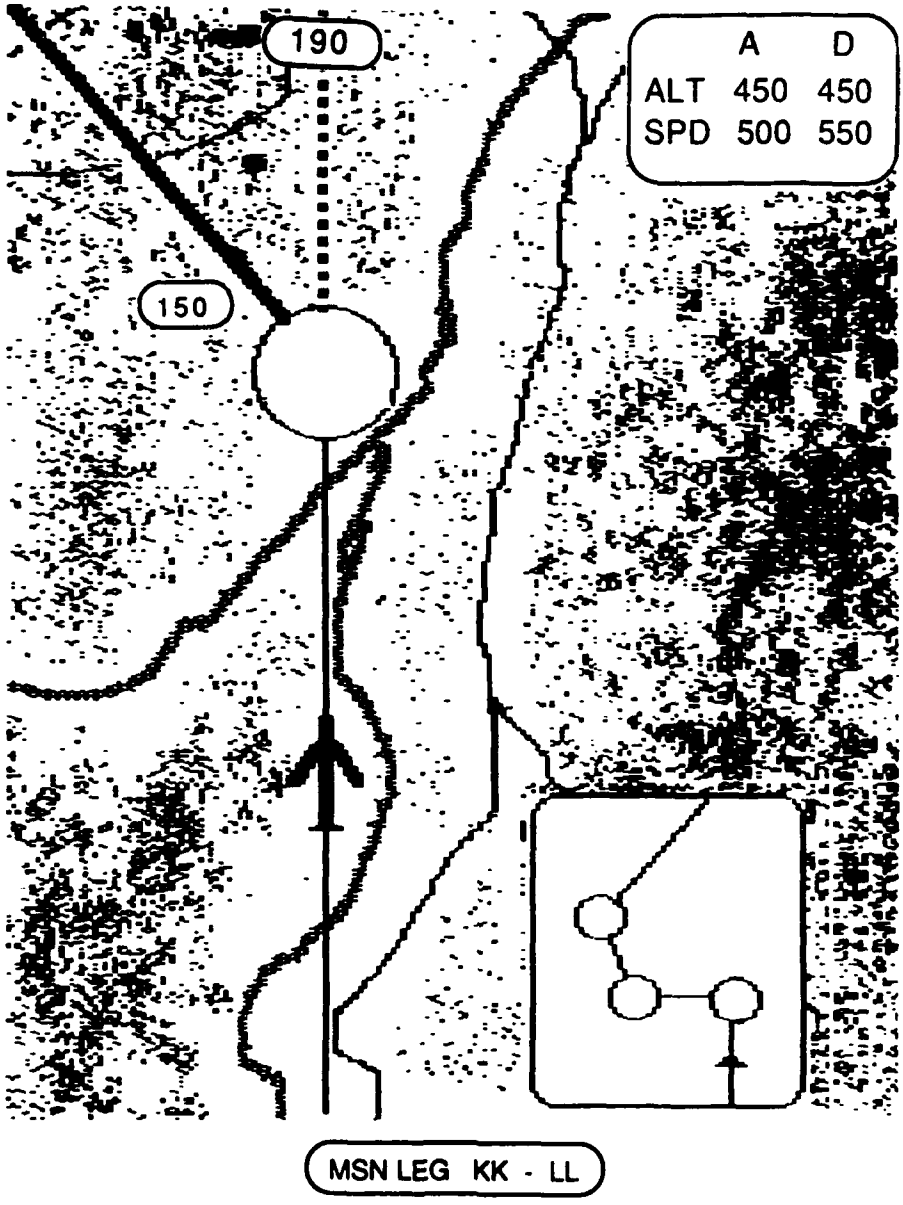


Figure 9-3. Re-Planned Mission Flight Plan Dispay

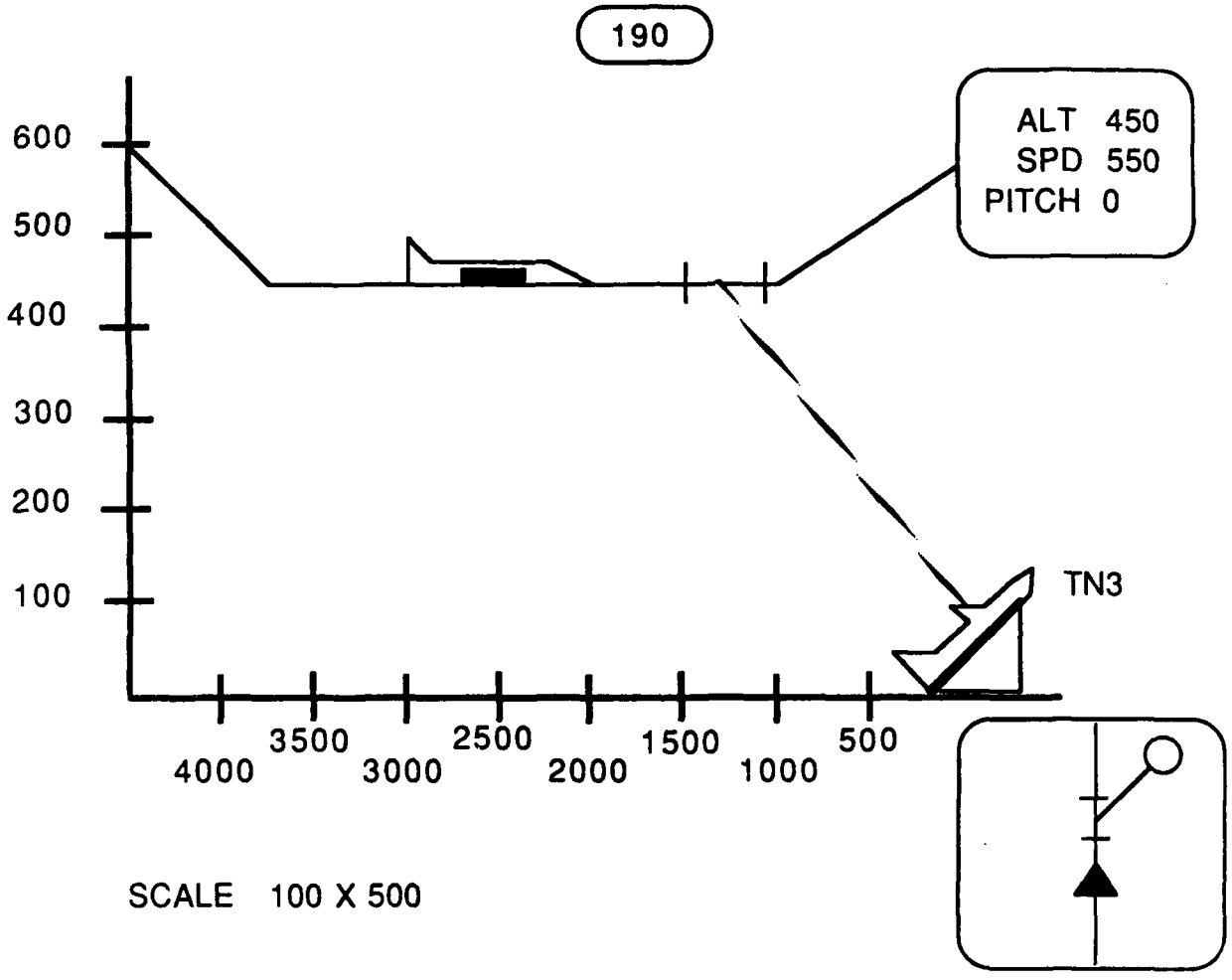


Figure 9-4. Target Strike Plan Display

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related display. This display provides qualitative information on the apparent position of the aircraft with respect to the target, as well as quantitative information on the flight path, launch points and times, and target location.

A planned flight path is plotted versus distance to the target. The aircraft icon is stationary on the horizontal axis, but is dynamic on the vertical axis to provide a qualitative indication of apparent altitude and pitch. Ground speed is implicit in the movement of ground-based objects and the flight path across the display area. Actual, quantitative values for altitude, pitch, and ground speed are displayed in the top-right corner of the display.

If the aircraft is flying its planned flight path, then the aircraft icon should follow the plotted flight path. The ordinate scale on the left-side of the display is an altitude scale. The abscissa scale on the bottom of the display is a distance scale.

A variety of information coding is used in this display to provide qualitative information. The target launching window is highlighted by the dash marks and by highlighting on the planned flight path. The target launch is planned as a frontal launch as illustrated by the dashed line from the launch window to the target. The target is a ground-based SAM launch site as illustrated by the SAM icon and associated target number. In the bottom-right corner is a windowed horizontal pictorial display which provides a qualitative indication of target distance and angle from the aircraft.

9.3.2 Situation Awareness Information Displays. Situation awareness information was defined in Section 4.0 to be information

about the external world of the aircraft. This information includes general situation awareness for continuous activities such as monitoring for pop-ups and other aircraft, detecting weather fronts, and receiving radio transmissions, or specific situation awareness for a particular mission event such as monitoring of known, planned SAM radar sites, tracking of enemy threats and aircraft, and imaging of relocatable targets.

In situation awareness information displays, strategic information about enemy offenses and defenses is presented using annotated pictorial displays. Below four situation awareness information displays are presented and explained. These four displays are: a horizontal pictorial ground threat display, a horizontal pictorial dentonation wave threat display, a contact analog airborne threat display, and a vertical pictorial obstacle display.

Ground threat display. Figure 9-5 is a horizontal pictorial display illustrating ground-based threats surrounding the mission flight path. This display provides qualitative information on the aircraft's apparent position versus the location of ground-based threats in the immediate area. The display also provides quantitative information of exactly what known threats are present, the mission flight path, and the actual heading, altitude and speed of the aircraft.

Ground-based threats and obstacles are placed in their relative position on a digitized moving map. The mission flight path and aircraft position are superimposed onto the map to form a horizontal situation display. A scale of the display map is presented at the bottom-left of the display to indicate apparent distances. The

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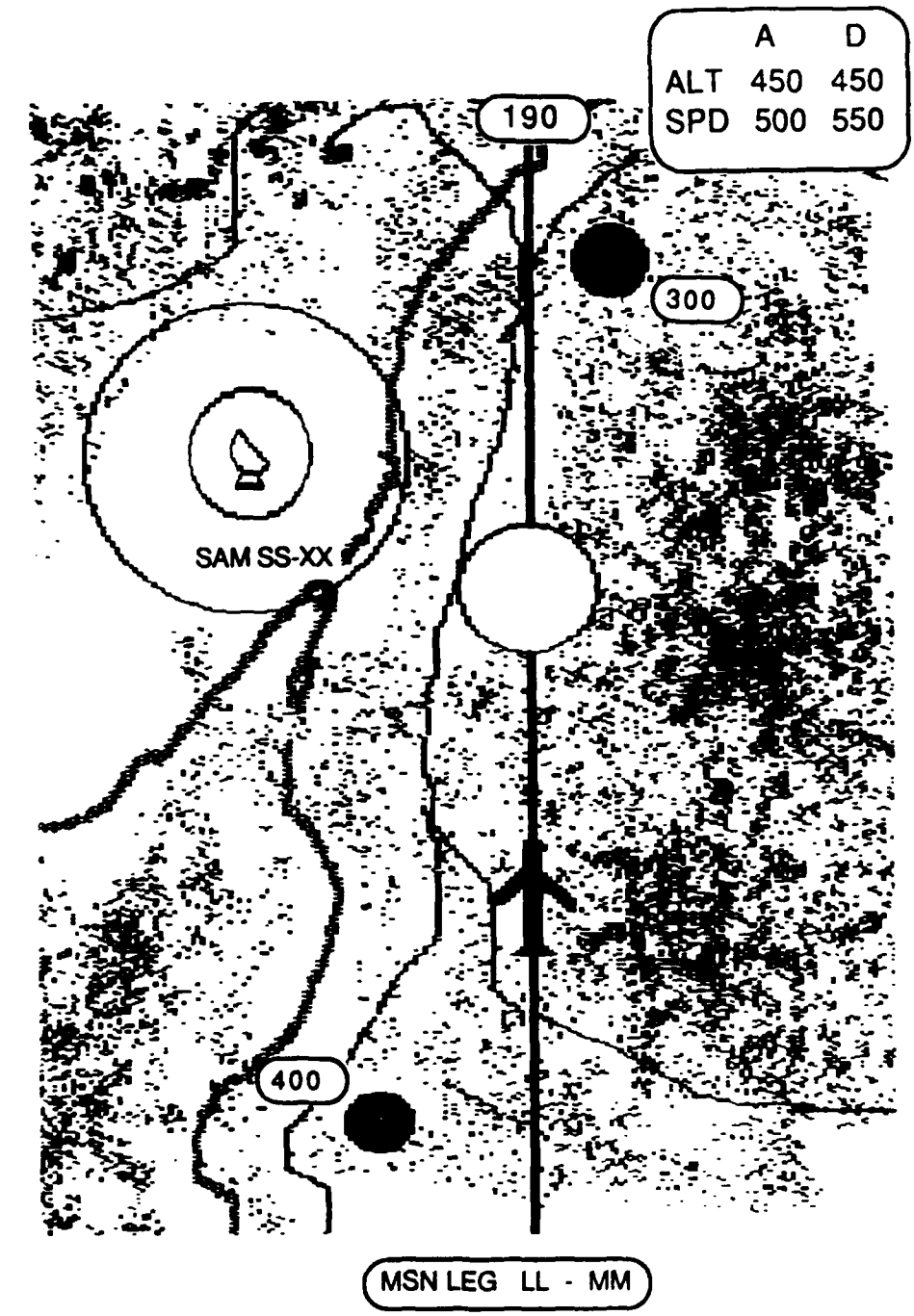


Figure 9-5. Ground Threat Display

zoom-in/zoom-out window is not presented on this display, but could be requested by control input if the crewmember required such information.

SAM radar/launch missile sites are indicated by the double concentrics. The outer circle represents the acquisition radar range and the inner circle represents the missile lethality range for the SAM site. If the SAM firing radar is active, then the inner concentric is filled with a red color. If neither radars are active the concentrics are clear. Ranges are also indicated by the amount of the circle displayed. Obstacles are indicated as the blackened circles.

Quantitative information is presented for each ground-based threat and obstacle. Each ground-based threat is identified by type. Each obstacle is identified by height AGL. Aircraft heading, altitude, and ground speed are listed in the same format as for the mission related displays.

Detonation threat display. Figure 9-6 is a horizontal pictorial display of an approaching detonation wave. The purpose of this display is to provide qualitative information on the distance and time to the arrival of a detonation wave, so that the crew is properly prepared for the impact. Quantitative information on distance and time could be presented as text, aurally using voice synthesis technology, or both.

The detonation wave is indicated by the ripples of waves moving toward the aircraft from the bottom-right corner of the display. Estimated time to arrival and predicted impact are presented in front of the first wave. The aircraft icon is stationary with the terrain moving underneath and the detonation waves moving across the display area.

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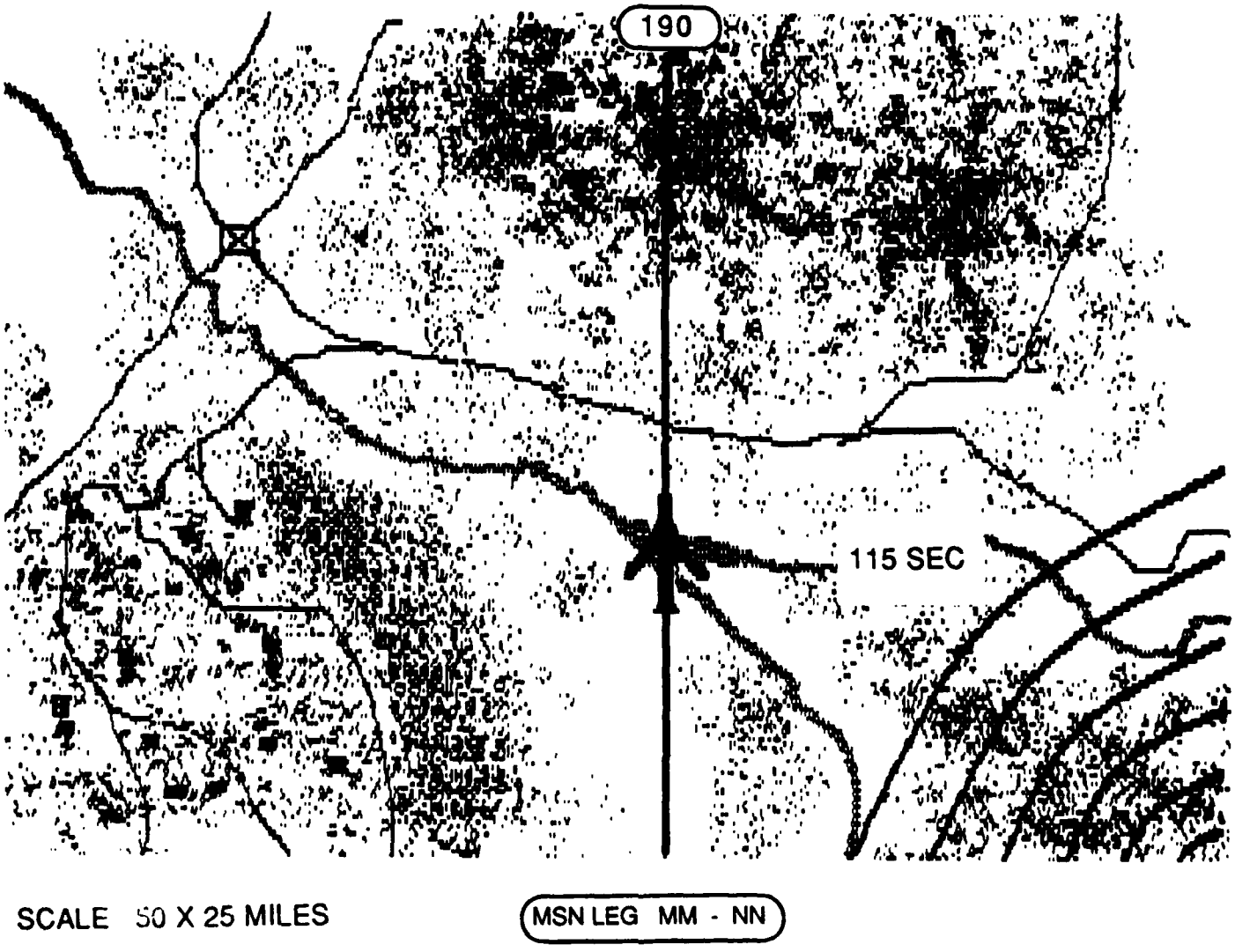


Figure 9-6. Detonation Wave Threat Display

Color coding could be used in this display to indicate the threat of the detonation wave. As an example, red waves could indicate a dangerous threat, amber waves a moderate threat, and black waves a minimum threat.

Airborne threat display. Figure 9-7 is a contact analog display illustrating an airborne threat from three enemy aircraft interceptors (AI). The purpose of this display is to utilize the concepts of three-dimensional displays discussed in Section 7.0 to create apparent headings and distances of airborne threats. This information is presented in a qualitative pictorial of the outside environment.

The pictorial display is forward-looking with sky above, ground below, and AIs to the left. A color-coding scheme might be blue for sky, green for ground, red for airborne threats, white for friendly aircraft. The planned flight path is illustrated as the vertical posts converging on the horizon which is the heavy horizontal line.

An evasive action course is presented on the display as the parallel curvilinear lines curving to the right and up. This qualitative information on a recommended course of action comes from SAMES. Such information would also have to be presented quantitatively, which could be accomplished visually, aurally, or both. A 360° air traffic radar display is windowed at the bottom-center of the display. Approaching AIs are indicated on the radar display area.

Obstacle display. Figure 9-8 is a vertical pictorial display illustrating aircraft position relative to the terrain. A vertical situation display is used to show apparent distances between the aircraft and the ground.

The aircraft icon is stationary and the digitized terrain moves

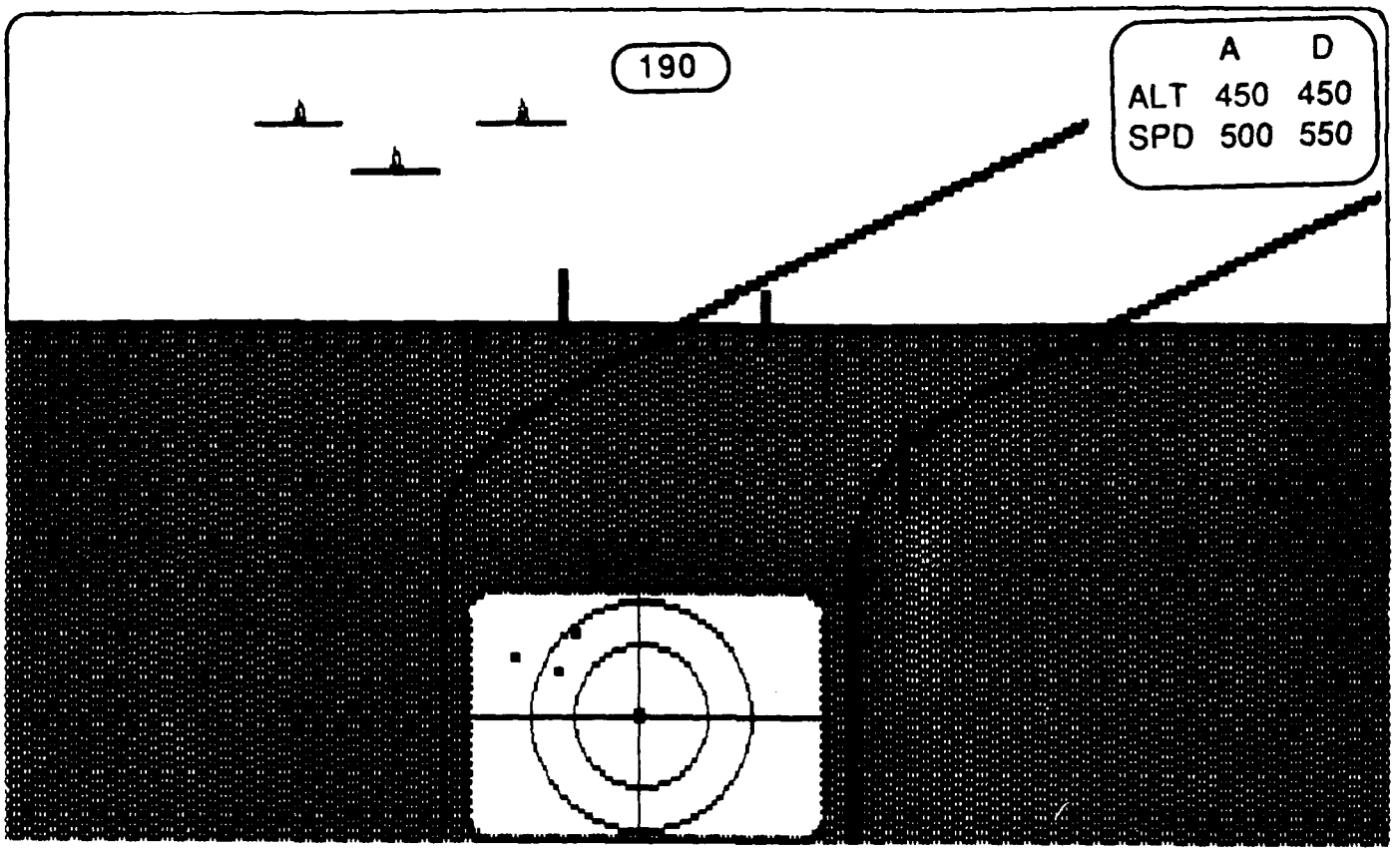


Figure 9-7. Airborne Threat Display

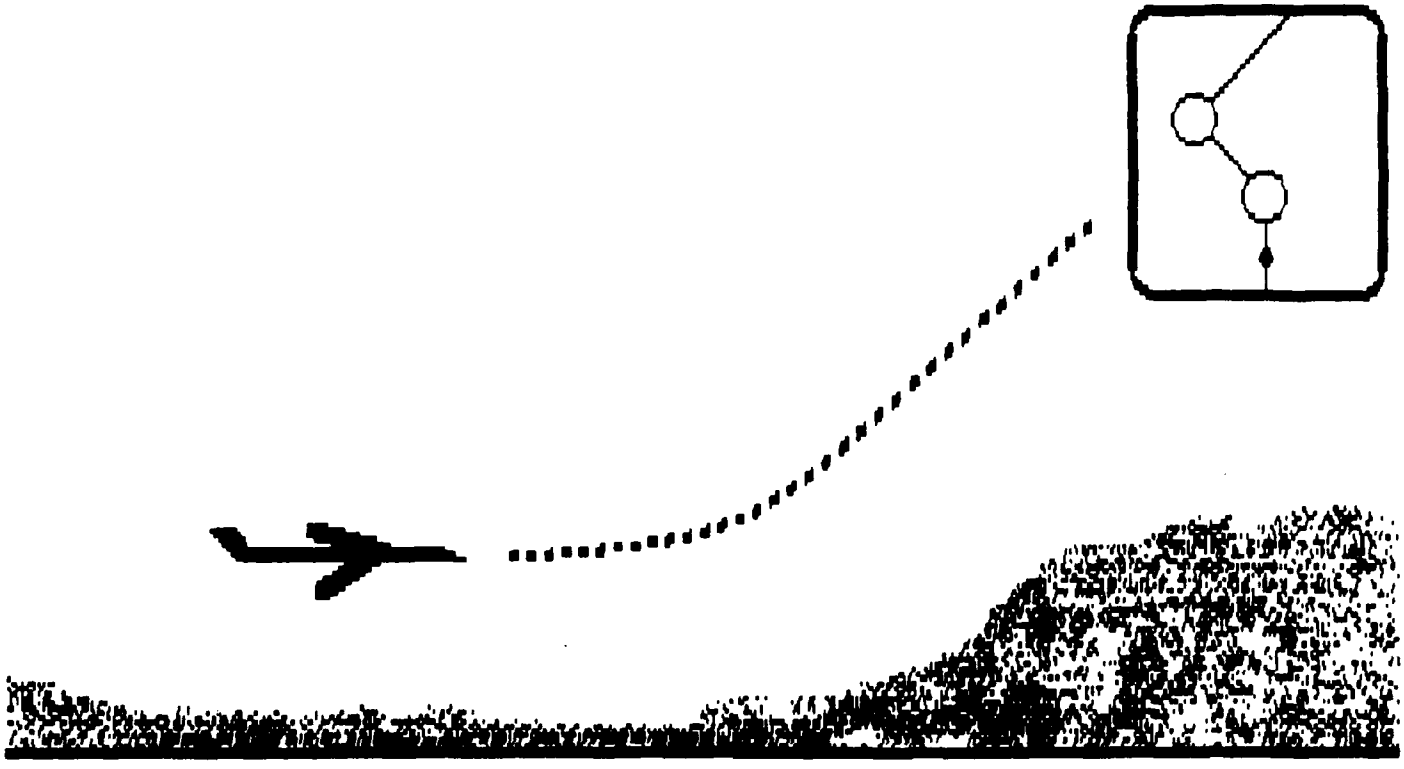


Figure 9-8. Obstacle Display

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across the screen. The dashed curvilinear lines represent predicted maximum ascent for the aircraft. This vertical situation display provides qualitative information regarding the aircraft's path relative to area terrain. From this display a pilot gains an immediate understanding of present and future altitude AGL. Apparent distances are indicated by the display scale located in the bottom-left corner. A pictorial horizontal situation display is windowed in the top-right corner of the display to highlight aircraft position along the mission flight path.

9.3.3. System Information Displays. System information is any information pertaining to aircraft performance, capability, equipment malfunction or failure, and operational procedures and checklists. System information displays provide information about aircraft flight performance, aircraft status, mission stores, checklist results, and fault diagnostics and repair. Below three system information displays are presented and explained. These three displays are: a radar switchover display, a radar fault diagnostics display, and a mission stores display.

Radar Switchover Display. Figure 9-9 is a graphic pictorial of a logic diagram for two similar radar devices in a parallel configuration. The purpose of this display is to show radar equipment status and configurations through the effective use of schematics, icons, and color-coding.

For this example, the primary radar is faulty and has been switched off-line, and the secondary radar is operational and has been switched on-line. The display provides qualitative information of the status and configuration of a primary radar and its secondary radar.

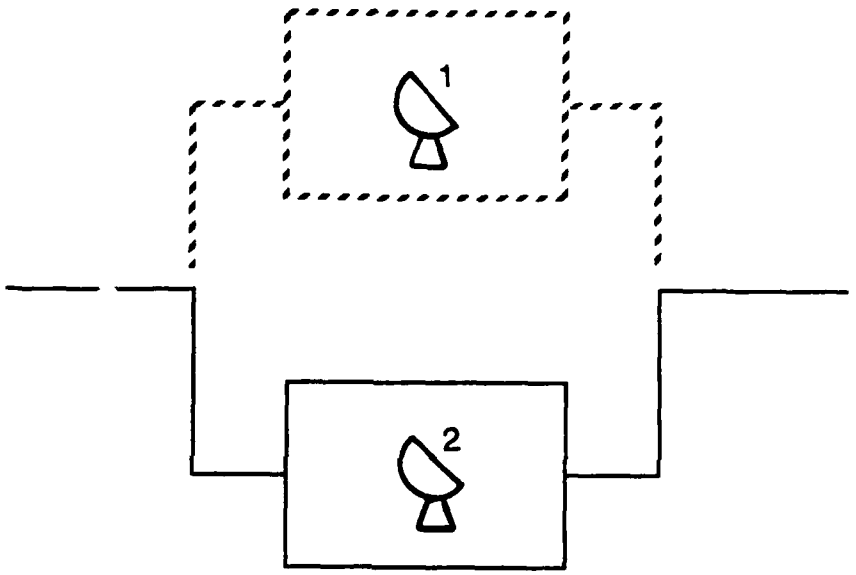


Figure 9-9. Radar Switchover Display

Numbered, radar icons are used to define the two pieces of equipment. The primary radar is highlighted to indicate that it is faulty. The logic path to the primary radar is detatched from the circuit logic path to indicate that the primary radar is off-line.

Color-coded highlighting techniques could be used here to indicate faulty, degraded, operational, and secondary equipment. Equipment outlined in red would signify faulty equipment, amber would signify degraded equipment, green would signify operational equipment, and white would signify operational secondary equipment.

Radar Fault Diagnostics Display. Figure 9-10 is a textual display of radar fault diagnostics by the system manager expert system (SYMES). This display reports the results of SYMES' fault diagnostics of a faulty radar. The purpose of this display is to provide the crewmember with a concise report on the status of a faulty radar.

On this display, the specific radar is identified and a short description of the fault is stated. Alternative options for responding to the faulty radar are presented as well as a recommendation for the best alternative, given the situation. For each line item, the crew has the option of requesting additional information. The crew could request more information on the inferences used to arrive at the fault diagnosis, the implications of each alternative, or the inferences used to arrive at the recommended best alternative.

Mission Stores Display. Figure 9-11 is a pictorial display of the aircraft's horizontal outline. The purpose of this display is to illustrate the position and status of mission stores. Mission stores are significantly heavy supplies that are expended during the mission (e.g., fuel, weapons, chaff, flares). As supplies are used during the

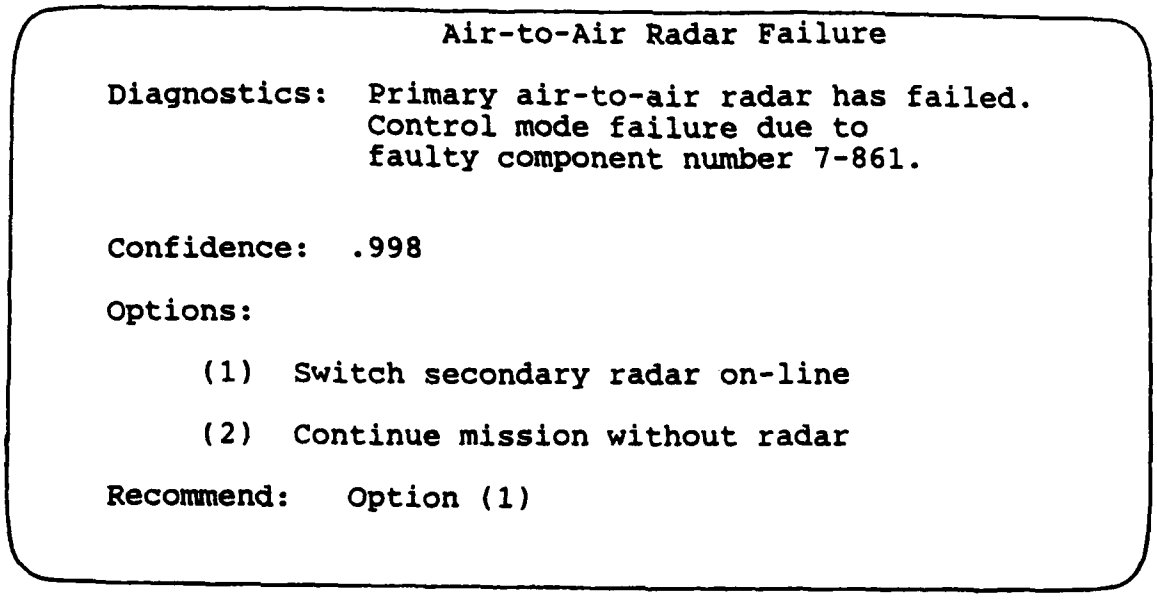


Figure 9-10. Radar Fault Diagnostics Display

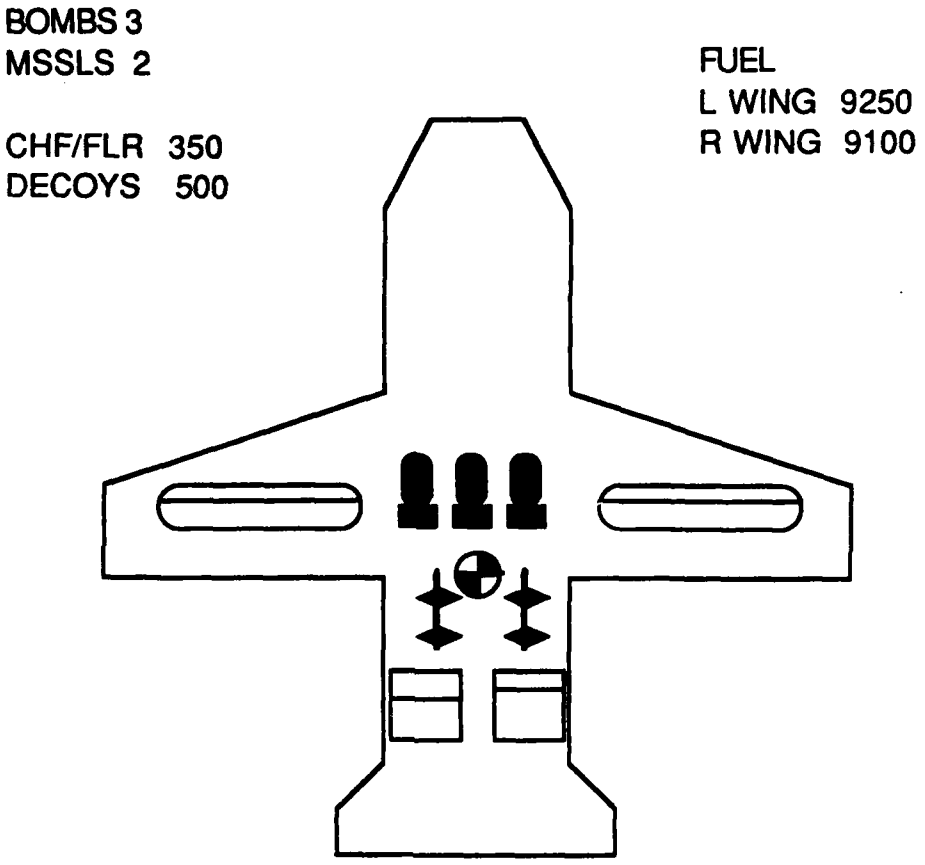


Figure 9-11. Mission Stores Display

mission, the aircraft lightens and the center of gravity shifts with respect to which supplies have been expended. Information on status levels and positions of these stores is critical to enable the proper balancing of the aircraft. This display qualitatively and quantitatively presents information on mission stores.

Information detailing the position and status of mission stores is indicated on the aircraft schematic and listed along the left and right sides of the display. Status levels and positions are provided for onboard bombs, missiles, chaff/flares, EW decoys, and fuel tanks. On the schematic, mission store balances and the center of gravity are shown. If the aircraft becomes unbalanced, red color-coding is used to indicate where the aircraft is unbalanced.

9.4 Summary

The displays presented in this section illustrate the potential for information transfer available with the computer-generated display (CGD) technology recommended in Section 7.0. The CMI displays developed here are conceptual simplifications and should not be considered formal recommendations for display formats. It was illustrated that both pictorial and textual, alone and in combination, displays can be developed for conveying mission, situation awareness, and system related information for mission events. Further, because of the multifunctional roles of crewmembers in missions, these conceptual displays are adaptive to changing scenario conditions or crewmember information needs.

The necessity for a formal design process and comprehensive design guidelines for developing a quality human-computer interface was also discussed. The development of an HCI for a specific application is a

highly iterative process involving developing an initial HCI design and then refining it through a series of experimental and empirical studies. Design guidelines provide general and specific recommendations for developing interface software and can serve as criteria for evaluating the software. Empirical and experimental studies are focused on continually measuring user performance over iterative designs of interface software to improve and refine the software and, hence, the resulting display. Therefore, developing CMI display formats should be accomplished as a structured research effort.

Any HCI research effort should implement a design process which includes measuring user performance and acceptance. Many research methods are available, however, the use of rapid prototyping man-in-the-loop simulators is regarded as a highly efficient means of evaluating user interface software during the developmental stages (Gould and Lewis, 1983; Kuperman and Wilson, 1986; Williges, Williges, and Elkerton, 1987). Rapid prototyping is a quick and relatively inexpensive technique to use, given the availability of a simulator.

Rapid prototyping is a straightforward technique. The adequacy of interface designs is evaluated by measuring user performance and acceptability. As an example, information sets could be presented to subjects using alternative CMI format designs. Subjects' performance would be measured as well as obtaining subjective ratings for different HCI designs. Rapid-prototyping could be implemented as part of an overall design process (Williges, Williges, and Elkerton, 1987) to refine the interface and obtain an optimal HCI design.

10.0 Summary and Recommendations

10.1 Summary

A methodology was developed to review a technology-free Crewmember Mission Scenario (CMS) to identify aircraft/crewmember informational demands and information management requirements in a next-generation, manned, penetrating bomber. The methodology used a mission scenario analysis template (MSAT) to obtain data on ten parameters of interest. These parameters were: mision leg, mission phase, scenario event, crew's response to event, informational demands, information sources, crew's decision, decision class, action taken and information management requirements.

The methodology was a four step process:

Step One: identify mission requirements by review of the CMS.

Step Two: provide a detailed CMS review, using MSAT.

Step Three: develop criteria for technology insertion for evaluating available and developing state-of-the-art technologies for possible application to the CMS aircraft.

Step Four: apply criteria for technology insertion to match crew and mission requirements with candidate technologies.

Step One results. Four basic mission requirements were identified from the CMS. These requirements are to: 1) penetrate enemy territory to within lethal range of fixed targets and SRTs, 2) find and assess the occupancy of SRTs, 3) deliver weapons effectively on fixed targets

and SRTs, and 4) survive the mission. Each of these four basic mission requirements was further investigated to determine aircraft, more detailed CMS, and human performance requirements. These results are found in Section 3.0 of this report.

Step Two results. In order for mission events to be met, certain information is demanded by the crew. A detailed analysis of the scenario was performed to identify crewmember informational demands, the sources of such information and the requirements to manage such information. The analysis included the review of the CMS for mission related information, situation awareness information, and system information. These results are in Section 4.0.

A detailed review of the scenario was also performed to identify human factors design and behavioral issues. Mental workload, psychological stress, training and behavioral issues emerged. These are discussed in Parts 5.3, 5.4, 5.5, and 5.6 of this report.

Step Three results. Procedures and criteria for technology insertion were developed. These procedures were centered on a logic tree criteria chart. Section 6.0 contains this information.

Step Four results. The application of the procedures developed in Step 3 to the CMS resulted in identifying opportunities for technology insertion using expert systems, computer-generated displays and voice-interactive systems. The expert systems included a mission manager, a situation awareness manager, and a system manager. These are discussed in Section 7.0.

Section 8.0 described CMS information sets. This section discusses the offensive and defensive information which should be presented at the same time or blended together, and which should be

presented separately. The CMS analysis identified six sets of information, sets for: a fixed target strike, a predictable RT strike, an unpredictable RT strike, SAM radar activity, a missile attack, and an enemy aircraft encounter. Each of these sets was described under the information subject areas of mission related, situation awareness, and system information.

Section 9.0 presented conceptual display formats for the computer-generated displays recommended in Section 7.0. Guidelines for developing user interface software (Smith and Mosier, 1986) are applied to mission, situation awareness, and system related sets. The emphasis of this section was to show by example the potential for information transfer available with computer-generated display technology.

10.2 Recommendations

The new generation advanced manned bomber will require extensive simulation studies to determine the crew station design. Information management is at the center of any configuration. The allocation of functions, given the complexity of informational demands, is itself complex. Simulations of worst case scenarios in various segments of a mission should be conducted. Issues to be resolved include:

- the crew size;
- crewmember decisionmaking responsibilities and rules;
- crew group decisionmaking;
- individual workstation controls and displays;
- formatting of displays;
- the effects of prolonged stress, cues, cognitive rehearsal, short term memory, situation awareness, and operator workload on performance.

These many variables create a large combinatorial problem that needs to be addressed systematically through simulation. A simulator that can be easily reconfigured to various function allocations to the machines and to the humans is needed to assist in the optimization of interfaces. This simulator should be capable of accepting the data bases identified in this study. These data bases should be sufficient to meet the information requirements identified herein. It should be capable of simulating the dynamic content these bases will have during a mission.

The simulator should be designed to easily accept changes in controls and displays and in crew station configuration. It should be capable of evaluating the effects on human performance of a fully encapsulated cockpit of limited windscreen visibility, and of buffetting and maneuvering. It should also be capable of evaluating contingency and emergency responses, which may be part of a worst case scenario series of events.

The simulator should be capable of accepting new technologies for evaluation and study. Those recommended for such consideration are expert systems, computer-generated displays and voice-interactive systems.

The expert systems recommended from this review are: the mission manager expert system (MIMES), the situation awareness manager expert system (SAMES) and the system manager expert system (SYMES). MIMES supports information management for:

- (Re)Planning Mission
- Offensive Tactics
- Defensive Tactics

- Combat Mission Folder

SAMES services the following situation awareness information management topics:

- Automatic Target Recognition/Occupation
- On-board Electronic Sensor Management
- External Electronic Emission Signal Analysis
- External Communicatcns Reception (C^2, C^3, C^3I)

SYMES manages:

- Aviation Status
- Aircraft Integrity
- Automatic Fault Diagnosis
- Mission Logistics
- Crewmember Status

Computer-generated displays and voice-interactive systems are recommended as possible crewmember-machine interface technologies. Both technologies have attributes which make them well suited for insertion into the CMS aircraft.

A formal design process is recommended for any research and/or development effort in human-computer interaction. Williges, Williges, and Elkerton (1987) is recommended as an example design process. Guidelines are recommended for designing user interface software. Smith and Mosier (1986) is recommended as the most comprehensive compilation of design guidelines available.

Finally, an important point for human factors engineers to remember is that technological resolution of a design issue is not merely accomplished through automation. Recent trends in aircraft

automation have demonstrated the vulnerability of over-automation or inappropriate automation (Wiener, 1985). The correct insertion of technology, whether automated equipment, computers or other technologies, is accomplished through detailed analysis of operator needs for given functions. Only then can the human factors engineer determine the proper balance of human ability and technological capability in successfully performing that function. This point again stresses the need to consider the human before choosing a given technology to satisfy a system requirement.

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GLOSSARY

Aircraft Requirements. The specific capabilities of the aircraft needed to successfully complete a stated mission.

Artificial Intelligence. The use of computers in tasks that are normally considered to require knowledge, perception, reasoning, learning, understanding, and similar problem-solving abilities.

Automation. The accomplishment of a task by a machine instead of a human.

Behavioral Issues. Issues which affect a person's cognitive processing and performance capabilities. Also known as performance shaping factors.

Flight-deck Automation. The implementation of technological capability for the purposes of automating certain crew functions.

Computer-Generated Displays. Using computer technology for the purposes of creating advanced visual display imagery which could not be achieved using conventional visual display technology.

Crewmember-Machine Interface (CMI). The proposed human-computer interaction design for the CMS aircraft and crew.

Crewmember Mission Scenario (CMS). A human-centered approach to system development that makes the crewmember the primary object in the mission scenario by describing mission events and crewmember activities during each leg of the mission without specifying on-board technologies.

Criteria for Technology Insertion. Performance requirements for assessing the suitability of a candidate technology for a stated application in a defined system. The fulfillment of a set of performance requirements indicates that the technology is an acceptable solution for meeting stated technical requirements and crewmember demands.

Expert Systems. Computer programs which use a collection of facts, rules of thumb, and other knowledge about a given field, coupled with methods of applying those rules, to make inferences in a specific area of knowledge.

Human-Computer Interaction. The means of communications between the human and the computer.

Human Factors Design Issues. Issues with the potential to disrupt or degrade human performance of a task or function.

Information Management Requirements. Requirements which define the means of satisfying the informational demands of the crew. Information management requirements include the coordinating, monitoring, presenting, and updating of specific information or sets of information.

Information Sets. A collection of the information required by the crew to make a proper decision or to perform a task correctly.

Information Sources. Resources where data are obtained to satisfy the informational demands of the crew.

Informational Demands. Data the crew requires to be able to correctly respond to a scenario event.

Knowledge-Based Behavior. Human behavior characterized by conscious reasoning and problem-solving to make a decision when confronted with an unfamiliar situation.

Mental Workload. A relative measure of the amount of mental exertion an operator expends when performing a task or function and which is based on a stated measurement technique and scale.

Mission Requirements. Requirements which specify performances, capabilities, and constraints that must be met in order to safisfy mission goals.

Mission Scenario. A scenario that verbally describes mission events and summarizes typical operations, assumptions, and environments.

Mission Scenario Analysis Template (MSAT). A worksheet developed for recording data during the mission scenario analysis. The template is designed to be used for the analysis of each mission leg and provides data on ten parameters of interest.

Psychological Stress. The psychological factors most often encountered in the operation of complex modern technology (eg. boredom, monotony, danger, task anomalies, and disruption of daily rhythms).

Rule-Based Behavior. Human behavior characterized by invoking previously learned rules about a situation to make a decision when that recognized situation occurs.

Scenario Event. Any unplanned or planned event which occurs during the misssion that requires the crew to respond.

Situation Awareness. Having information about the internal and external environment surrounding the aircraft.

Skill-Based Behavior. Sensory-motor performance that take place without conscious control as smooth, automated, and highly integrated actions.

Speech Generation. Computer systems which convert strings of computer output code into audio signals which communicate information by imitating human speech.

Speech Recognition. Computer systems which recognize and convert human speech into strings of computer input code and respond appropriately to the recognized speech.

System Requirements. Those characteristics which the system (both personnel and machines) must manifest to safisty the goal (mission) of the system.

Technology. The application of an organized set of scientific knowledge and principles to the solution of a previously defined engineering problem.

Technology Free. Stating that a technological capability exists, but not describing how the technology is implemented. Stating a capability without specifying a piece of equipment or the tasks associated with performing the capability.

Training Issues. Issues pertaining to the education of the crew to successfully operate equipment and perform a task or function correctly.

Voice-Interactive Systems. A computer system with speech recognition and generation capabilities for the explicit purpose of interacting with people.

Workload. A relative measurement of human activity or performance which is based on a stated measurement technique and scale.

Appendix A

Bibliography/Annotated Bibliography: Human Factors Literature Review of Cockpit Automation Technology

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Part I: The Bibliography

This technical report's bibliography is a broad sampling of applicable articles chosen from various sources. Among the sources sampled were the Human Factors Society Conferences, Human Factors, Ergonomics, Engineering Index, and The International Journal of Man-Machine Studies. The articles are a foundation upon which the technical report is based, but do not represent an exhaustive search.

The bibliography is divided into five categories: control/display, cockpit automation, expert systems, design philosophies, and human performance measures. Articles were assigned a category; however, there is some overlap between categories. Some articles may have easily fit into either of two sections. An arbitrary decision had to be made.

Part II: The Annotated Bibliography

Each of the articles in the bibliography is described generally in a few sentences. Reading the annotated bibliography allows one to understand the essence or purpose of the article. The document is not a substitute for the article itself; the annotated bibliography simply provides the reader with enough information to decide whether that article satisfies a need or whether there is potentially another more applicable article.

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Roscoe, A. H. and Grieve, B. S. (1986). The impact of new technology on pilot workload. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 91-104). Warrendale, PA: Society of Automotive Engineers.

Roscoe, S. N. (1979). When the day is done and shadows fall, we miss the airport most of all. Human Factors, 21, 369-383.

Schendel, J. D., and Johnston, S. D. (1983). A study of methods for engaging moving targets. Human Factors, 25, 693-700.

Sharit, J., and Salvendy, G. (1982). Occupational stress: Review and reappraisal. Human Factors, 24, 129-162.

Shifrin, C. A. (1986). USAF investigates ways to improve performance of future fighter pilots. Aviation Week and Space Technology, June 23, 161-163, 165.

Shingledecker, C. A., Crabtree, M. S., and Eggemeier, F. T. (1985). Methods and systems for measuring human performance capabilities. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 210-214). Santa Monica, CA: Human Factors Society.

Skipper, J. H., Rieger, C. A., and Wierwille, W. W. (1986). Evaluation of decision-tree rating scales for mental workload estimation. Ergonomics, 29, 585-599.

Teichner, W. H., and Mocharnuk, J. B. (1979). Visual search for complex targets. Human Factors, 21, 259-275.

Wickens, C. D., and Yeh, Y. Y. (1983). The dissociation between subjective workload and performance: A multiple resource approach. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 244-248). Santa Monica, CA: Human Factors Society.

Wickens, C. D., Yeh, Y. Y., Fuld, R. B., and Hodel, S. (1985). A comparison of operator performance in manual and automated versions of a dynamic decision-making task. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1089-1091). Santa Monica, CA: Human Factors Society.

Wiener, E. L., Curry, R. E., and Faustina, M. L. (1984). Vigilance and task load: In search of the inverted U. Human Factors, 26, 215-222.

Wierwille, W. W. (1979). Physiological measures of aircrew mental workload. Human Factors, 21, 575-593.

Wierwille, W. W., and Casali, J. G. (1983). A validated rating scale for global mental workload measurement applications. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 129-133). Santa Monica, CA: Human Factors Society.

Wierwille, W. W. and Connor, S. A. (1983). Evaluation of 20 workload measures using a psychomotor task in a moving-base aircraft simulator. Human Factors, 25, 1-16.

Wierwille, W. W., Rahimi, M., and Casali, J. G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. Human Factors, 27, 489-502.

Williams, L. J. (1982). Cognitive load and the functional field of view. Human Factors, 24, 683-692.

Williges, R. W., and Wierwille, W. W. (1979). Behavioral measures of aircrew mental workload. Human Factors, 21, 549-574.

Guidelines

Abbot, T. S., Moen, G. C., Person, L. H., Keyser, G. L., Jr., Yenni, K. R., and Garren, J. L., Jr. (1980). Flight investigation of cockpit-displayed traffic information utilizing coded symbology in an advanced operational environment. Washington, D.C.: NASA.

Adams, J. J. (1982). Simulator study of a pictorial display for general aviation instrument flight. Washington, D.C.: NASA.

Corrick, G. E. (1979). Detection of different target types in realistic terrain, China Lake, CA: Hughes Aircraft Company.

Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (1986). Warrendale, PA: Society of Automotive Engineers.

A general analysis tool for addressing the development and evaluation of an aerospace mission information structure. (1984). Huntsville, AL: System Development Corporation.

Rogers, J. G. (1973). Development of design criteria for sensor displays. Springfield, VA: National Technical Information Service.

Simons, J. C., Kirtland, W. H., and Perez, W. A. (1986). Strategic mission decomposition: Volume I measures of effectiveness and study planning materials. Dayton, OH: Systems Research Laboratories, Inc.

Smith, S. L. and Mosier, J. N. (1986). Guidelines for designing user interface software. Bedford, MA: Mitre Corporation.

Tijerina, L., Chevalaz, G., and Myers, L. B. (1985). Human factors aspects of computer menus and displays in military equipment. Columbus, OH: Battelle.

Target Acquisition

Aaranson, J., Sharits, T., Sharp, E., and Ancona, D. (1985). Target detection as a function of color-coding and field density. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1066-1069). Santa Monica, CA: Human Factors Society.

Middlekauf, D. C. (Ed.), (1974). Air-to-ground target acquisition source book: A review of the literature. Orlando: Martin Marietta.

Parkes, K. R. (1972). Human factors in air-to-ground target acquisition. Unpublished doctoral dissertation, Loughborough University of Technology, Loughborough, England.

Cockpit Automation

Aaranson, J., Sharits, T., Sharp, E., and Arcona, D. (1985). Target detection as a function of color-coding and field density. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1066-1069). Santa Monica, CA: Human Factors Society. Paper reports the results of a study to determine baseline target detection performance as a function of chromatic color coding and field symbol density.

Aretz, A. J. (1984). Cockpit automation technology. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 487-491). Santa Monica, CA: Human Factors Society. Presented in this paper is a prototype methodology to establish a baseline approach in the development of a new human factors crew station design methodology for emerging weapon systems.

Barnes, M. J. (1985). An information-processing approach to decision aiding. In IEEE 1985 Proceedings of the International Conference on Cybernetics and Society (pp. 636-640). Tucson, Arizona: IEEE. A threat evaluation task was broken into three information processing tasks and was then studied. It was found that the limiting factor for the threat evaluation task was not the number of threats but the response loading factors.

Berson, B. L., Boucek, G. P., and Hanson, D. C. (1984). Evaluating new concepts for aircrew alerting. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 921-925). Santa Monica, CA: Human Factors Society. Guidelines for improving and standardizing future aircraft alerting systems are presented.

Bird, M. W., and Schneble, R. (1983). Predictive controller issues for trajectory control. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 249-254). Warrendale, PA: Society of Automotive Engineers. The development of a trajectory control system for the 1990's will be realizable as indicated by trends in hardware, computer science technology, and analytical techniques. Discussed are various issues that may prove to be vital to control systems development.

Boehm-Davis, D. A., Curry, R. E., Wiener, E. L., and Harrison, R. L. (1983)). Human Factors of flight-deck automation: Report on a NASA-industry workshop. Ergonomics, 26, 953-961. The NASA-industry workshop is summarized discussing automation of the flight deck. In taking human factors issues into consideration, it is questionable whether flight deck functions should be automated.

Broadwell, M., Smith, J., Barnette, J., and Staros, C. (1985). Decision aiding for tactical aircraft. SPIE Applications of Artificial Intelligence II, 548, 153. An airborne mission/route planner system, currently under development is described and discussed. The tasks performed vary from requiring subjective reasoning to requiring precise, synchronized processing.

Eisenhardt, R. G. (1985). Pilot's associate definition study. Ann Arbor, MI: Perceptionics. Final report prepared for Defense Advanced Research Projects Agency (DARPA). Air combat operational and technological problems in the 1995 technology time frame are analyzed for application of artificial intelligence technology.

Glickstein, I. (1985). The metamorphosis of the military aircraft cockpit. Aerospace America, 23, 48-52. The new military cockpit is described as being self-reliant and rational, able to reduce pilot workload and improve mission performance.

Hakkinen, M. T., and Williges, B. H. (1984). Synthesized warning messages: Effects of an alerting cue in single- and multiple-function voice synthesis systems. Human Factors, 26, 185-195. The effectiveness of preceding synthesized voice warning messages with an alerting cue was examined. The study compared the cue as a function of the amount of information presented by the voice synthesis and the workload level in the primary task.

Hopson, J., and Zachary, W. (1982). Experiences in aiding airborne decision-making. In Behavioral Objectives in Aviation Automated Systems Proceedings, 1982 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 211-224). Warrendale, PA: Society of Automotive Engineers. This paper describes research aimed at structuring decision augmentation system design by defining, developing, and applying appropriate design techniques for a variety of airborne platforms.

James, W. G. (1984). AI applications to military pilot decision aiding -- A perspective on transition. In Third Aerospace Behavioral Engineering Technology Conference Proceedings, 1984 Society of Automotive Engineers Aerospace Congress and Exposition (pp.). Warrendale, PA: Society of Automotive Engineers. This paper reviews the transition experience with previous "new" technologies into fleetwide military use and speculates on the specific attitudes and programs required to increase the likelihood of successful transition of pilot decision aiding.

Johannsen, G. and Rouse, W. B. (1983). Studies of planning behavior of aircraft pilots in normal, abnormal, and emergency situations. IEEE Transactions on Systems, Man, and Cybernetics, 13, 267-278. As automation takes over the manual tasks associated with man-machine systems, planning will become the central function for the human operator. An experimental methodology for the study of human planning behavior is needed.

Lizza, G. D., Howard, B., and Islam, C. (1983). Magic -- Riding the crest of technology or Do you believe in magic. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 526-530). Santa Monica, CA: Human Factors Society. With the advent of integrated electronics displays in advanced cockpit design, the role of dynamic mockups is becoming increasingly important. Described is one such mock-up incorporating state-of-the-art microprocessors, graphic systems, and voice capability.

Madni, A. (1983). Integrated modelling approaches in advanced cockpit automation. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 427-432). Warrendale, PA: Society of Automotive Engineers. A multi-model integrated approach to designing cockpit automation is described. This approach relies on the selective use of one or more of these models depending on the specific tactical function and the mission requirement being addressed.

McNeese, M. D., Warren, R., and Woodson, B. K. (1985). Cockpit automation technology: A further look. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 884-888). Santa Monica, CA: Human Factors Society. As the development of a structured human factors crew station continues, new questions have arisen. Here is a discussion of several of these questions and issues.

Merrifield, J. T. (1986). NASA/Douglas team studies fly-by-wire control concepts. Aviation Week and Space Technology, October 27, 38-41. An investigation of fly-by-wire control concepts is one of many aimed at early incorporation of human factors in the design of transport aircraft for the 1990's. The NASA/Douglas findings are described.

Moss, R. W., and Reising, J. M. (1985). Cockpit automation: Design and implementation issues. In Fourth Aerospace Behavioral Engineering Technology Conference Proceedings, 1985 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 41-45). Warrendale, PA: Society of Automotive Engineers. The electronic crewmember (EC) and the pilot can work together as a team, as described by this paper. A scheme for characterizing different levels of cockpit automation is reviewed, followed by a discussion of operational situations in which the pilot is most likely to trust EC decisions.

Moss, R. W., Reising, J. M., and Hudson, N. R. (1984). Automation in the cockpit: Who's in charge? In Third Aerospace Behavioral Engineering Technology Conference Proceedings, 1984 Society of Automotive Engineers Aerospace Congress and Exposition (pp.). Warrendale, PA: Society of Automotive Engineers. Levels of automation and decision making are discussed, arriving at an overall design philosophy for allocating tasks to the pilot and the computer.

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Mountford, S. J., Schwartz, J., and Graffunder, K. (1983). Evaluation of speech technology for automatic target recognition. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 965-969). Santa Monica, CA: Human Factors Society. An experiment integrating a speech-interactive system with a prototype automatic target recognizer is described. The results indicate significantly better flight control performance during simultaneous speech-interaction for the targeting tasks.

Perfitt, T. E., Fileccia, G. L., and Young, W. L. (1982). Trajectory generation -- An automation concept of the future. In Behavioral Objectives in Aviation Automated Systems Proceedings, 1982 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 203-209). Warrendale, PA: Society of Automotive Engineers. Military and commercial developments over the past decade relating to trajectory generation are reviewed. Airborne mission replanning and pilot assistance that uses trajectory generation are described.

Pulat, B. M. and Pulat, P. S. (1985). A workstation assessor for crew operations - WOSTAS. International Journal of Man-Machine Studies, 22, 103-126. A computer aided interactive model for workstation assessment in crew station design for communication, command, and control activities is described.

Rockmore, A. J., and Riemenschneider, R. A. (1983). Pilot support for mission planning using expert systems. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerosapce Congress and Exposition (pp. 233-241). Warrendale, PA: Society of Automotive Engineers. A Route Planning Aid that finds a high quality route to and from a heavily defended target is described.

Roske-Hofstrand, R. J., and Paap, K. R. (1986). Cognitive networks as a guide to menu organizations: An application in the automated cockpit. Ergonomics, 29 1301-1311. It is suggested that a menu-driven interface controls information in the domain of expertise of the end users. The difficulty that inexperienced users typically have in assessing the panels can be reduced by making the menu organization consistent with the user's cognitive organization.

Simpson, C. A., and Marchionda-Frost, K. (1984). Synthesized speech rate and pitch effects on intelligibility of warning messages for pilots. Human Factors, 26, 509-517. This study discovers whether speech rate and voice pitch of "phoneme" synthesized speech affects pilots' accuracy and response time to typical threat warning messages.

Sorkin, R. D. and Woods, D. D. (1985). Systems with human monitors: A signal detection analysis. Human-Computer Interation, 1, 49-75. New automation has put the human in the role of monitor. Problems can then be analyzed in a signal detection format in which the human operator and the automated component monitor partially correlated noisy channels.

Stein, K. J. (1986). Multisensor process expected to replace discrete subsystems. Aviation Week and Space Technology, June 23, 119-121. The trends and improvements of integrated avionics concepts are discussed. These concepts are focused on multisensor processors that will address the total weapons system.

Weener, E. F. (1984). Flight deck automation decisions. In Third Aerospace Behavioral Engineering Technology Conference Proceedings, 1984 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 3-8). Warrendale, PA: Society of Automotive Engineers. This paper describes the various automation factors which are considered in the process of developing a design for a flight deck.

Wiener, E. L., and Curry, R. E. (1980). Flight-deck automation: Promises and problems. Ergonomics, 23, 995-1011. The state-of-the-art of human factors in flight-deck automation is presented, identifying a number of critical problem areas. Also, broad design guidelines are offered.

Controls and Displays

Ackerman, P. L., Schneider, W., and Wickens, C. D. (1984). Deciding the existence of a time-sharing ability: A combined methodological and theoretical approach. Human Factors, 26, 71-82. Experimental and statistical methods for examining individual differences in dual-task performance and time-sharing ability are reviewed and criticized.

Aretz, A. J. (1983). A comparison of manual and vocal response modes for the control of aircraft systems. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 97-101). Santa Monica, CA: Human Factors Society. Vocal and manual response modes were compared in single and dual task conditions on the basis of flight performance, response time, and errors made while attempting various tasks. The results indicate that manual response is more effective with response time data but the vocal mode is effective with flying performance data.

Arnaut, L., and Greenstein, J. S. (1985). Two experiments investigating the effects of control-display gain and method of cursor control on touch tablet performance. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 122-126). Santa Monica, CA: Human Factors Society. The effects of control-display gain, method of cursor movement, and target resolution on target selection performance with a touch tablet are investigated by means of two experiments.

Barfield, W., West, B., Robertson, M., Taylor, F. L., and Tamplin, N. Stress as a function of the rate at which information is presented on a video display terminal. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 516-520). Santa Monica, CA: Human Factors Society. Because of the need to develop human factors principles that improve human-computer interaction, this experiment examines the relationship between stress and performance by varying rates of information and density levels on a video display terminal.

Bilferno, M. A., Stanley, D. L. (1983). The touch-sensitive control/display unit: A promising computer interface. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 409-413). Warrendale, PA: Society of Automotive Engineers. Installation of a touch-sensitive control/display unit could improve the operational reliability of future aircraft cockpits, providing that basic human factors issues are addressed early in the development phase of this device. The implementation and benefits are discussed.

Calhoun, G. L., Janson, W. P., and Arbak, C. J. (1986). Use of eye control to select switches. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 154-158). Santa Monica, CA: Human Factors Society. Eye-controlled switching as a biocybernetic control approach is examined. The switching has been thought to increase system effectiveness while reducing pilot workload.

Calhoun, G. and Arbak, C. J. (1984). Eye-controlled switching for crew station design. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 258-262). Santa Monica, CA: Human Factors Society. The components of an eye-control system developed to examine the use of eye line of sight as an alternate control interface for crew station design is described.

Carter, R. C. (1982). Search time with a color display: Analysis of distribution functions. Human Factors, 24, 203-212. The primary purpose of this article is to provide a contribution to the understanding and prediction of human search times for targets on color displays.

Christensen, C., Baggen, E. A., and Snyder, H. L. (1985). Performance measures and subjective evaluations for two color displays. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1075-1078). Santa Monica, CA: Human Factors Society. Two color displays with differing image generation technologies were studied to evaluate task performance and subjective preference. The two displays were the standard cathode ray tube shadow mask display and the newer liquid crystal/cathode ray tube display.

Chu, Y. Y., and Madni, A. M. (1983). Intelligent display interface for situation monitoring, management and maintenance (M3). In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 865-869). Santa Monica, CA: Human Factors Society. A generic intelligent display interface (IDI) concept and elements of IDI features are described. It is suggested that the IDI design concept can provide a coherent human/automation team in the monitoring, management, and maintenance of power/propulsion plants.

Craig, A. (1981). Monitoring for one kind of signal in the presence of another: The effects of signal mix on detectability. Human Factors, 23, 191-197. An experiment is described which tests monitoring and signal detection in the presence of other signals. The results indicate that signal detectability is impaired by the presence of another kind of signal, especially if the monitored signal has low detectability on its own.

Damos, D. (1986). The effects of using voice generation and recognition systems on the performance of dual tasks. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1359-1370). Santa Monica, CA: Human Factors Society. The effects of voice generation and recognition systems on dual-task performance are presented and their implications discussed.

Davies, S. E., Bury, K. F., and Darnell, M. J. (1985). An experimental comparison of a windowed versus a non-windowed operating system environment. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 250-254). Santa Monica, CA: Human Factors Society. The effects of a windowed versus a non-windowed working environment on user performance are compared.

DeMyer, D. (1982). Digital moving map display. In Behavioral Objectives in Aviation Automated Systems, Proceedings, 1982 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 143-150). Warrendale, PA: Society of Automotive Engineers. The basic feasibility of the Digital Moving Map Display for the modern cockpit is demonstrated. Effect of color, declutter, scaling (zoom), map orientation, and the quantification of digital storage and processing requirements have been evaluated.

Doll, T. J. (1986). Development of three-dimensional audio signals. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 21-31). Warrendale, PA: Society of Automotive Engineers. The described research is directed toward developing technology for generating, and presenting via headphones, audio signals which appear to come from a highly localized point in space.

Doll, T. J. (1986). Synthesis of auditory localization cues for cockpit applications. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1172-1176). Santa Monica, CA: Human Factors Society. Techniques are developed accurate spatial information via audio signals delivered to the listener through headphones.

Dornheim, M. A. (1986). Crew situational awareness drives avionics developments. Aviation Week and Space Technology, June 23, 114-116. The complexities and importance of increasing tactical situation awareness for fighter crews are discussed.

Eggleston, R. G., Chechile, R. A., Fleischman, R. N., and Sasseville, A. M. (1986). Modeling the cognitive complexity of visual displays. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 675-678). Santa Monica, CA: Human Factors Society. An approach for measuring the cognitive complexity of visual display formats is presented. The approach involves modeling both the knowledge that can be extracted from a format and the knowledge an operator brings to the task.

Francas, M., Brown, S., and Goodman, D. (1983). Alphabetic entry procedure with small keypads: Key layout does matter. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 187-190). Santa Monica, CA: Human Factors Society. The entry of alphabetic characters on an enhanced telephone system was examined. The results extend the superiority of QWERTY to small keypads and a restricted typing space.

Geiselman, R. E., Landee, B. M., and Christen, F. G. (1982). Perceptual discriminability as a basis for selecting graphic symbols. Human Factors, 24, 329-337. A performance based criterion for selecting among alternative symbols to be used in graphic displays was developed. The specific criterion developed was an index of perceptual discriminability.

Gershzohn, G. (1986). Presentation of information on multifunction displays: Abnormal and emergency spacecraft operations. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 51-58). Warrendale, PA: Society of Automotive Engineers. The capability of a multifunction display system to present data regarding malfunctioning manned spacecraft systems is illustrated.

Glenn, III, F. A., Iavecchia, H. P., Ross, L. V., Stokes, J. M., Weiland, W. J., Weiss, D., and Zaklad, A. L. (1986). Eye-voice-controlled interface. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 322-326). Santa Monica, CA: Human Factors Society. The Occular Attentional-Sensing Interface System is an innovative human-computer interface which utilizes eye movement and voice commands to communicate messages between the operator and system. Some technical issues and applications are discussed.

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Gopher, D., Hilsernath, H., and Raij, D. (1985). Steps in the development of a new data entry device based upon two hand chord keyboard. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 132-136). Santa Monica, CA: Human Factors Society. An efficient alternative to the QWERTY keyboard is described.

Harding, A. N. (1980). The use of helmet mounted displays in helicopters. In Oborne, D. J., and Levis, J. A. (Eds.), Human Factors in Transport Research, Volume I (pp. 97-105). London: Academic Press. The benefits of Helmet Mounted Displays are discussed. They enhance the likelihood of obstacle and threat detection.

Hardwood, K., Wickens, C., and Kramer, A. (1986). The perceived relations between color, direction, and speed of motion. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 440-444). Santa Monica, CA: Human Factors Society. The perceived relations between color, direction of motion, and speed of motion are investigated. There are important implications for the use of color in dynamic flight displays.

Hawkins, J. S., Reising, J. M., Woodson, B. K., and Bertling, S. J. (1984). A study of programmable switch symbology. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 118-122). Santa Monica, CA: Human Factors Society. A multifunction switch is one way to solve the problem of diminishing real estate in the modern cockpit. The described study looked at pictorial coding of such a switch.

Hawkins, J. S., Reising, J. M., and Gilmour, J. D. (1983). Information interpretation through pictorial format. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 243-248). Warrendale, PA: Society of Automotive Engineers. A series of studies are discussed in which the objective is to develop advanced methods of information transfer for the pilots of high performance fighter aircraft.

Hawkins, J. S. Reising, J. M., Lizza, G. D., and Beachy, K. A. (1983). Is a picture worth 1000 words -- written or spoken? In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 970-972). Santa Monica, CA: Human Factors Society. The effectiveness of pictorial format representation of emergency procedures to aircrew members are compared to text or voice representation.

Helmet-mounted cockpit displays expected to replace HUDs, (1986). Aviation Week and Space Technology, June 23, 111. The article discusses the expected replacement of old HUDs with newer helmet-mounted cockpit displays.

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Herron, S. (1980). A case for early objective evaluation of candidate display formats. In Proceedings of the Human Factors Society 24th Annual Meeting (pp. 13-16). Santa Monica, CA: Human Factors Society. The importance of objectively evaluating candidate symbology for aircraft cockpits early in the developmental process is illustrated.

Hill, S. G., and Kroemer, K. H. E. (1985). Preferred declination of the line of sight. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 625-629). Santa Monica, CA: Human Factors Society. Preferred head position was studied and it was found that head position and target distance had significant effects on preferred angle while the task had no influence.

Houck, R., Kelly, B. D., and Wiedemann, J. (1986). An integrated display for vertical situation awareness in commercial transport aircraft. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 61-64). Warrendale, PA: Society of Automotive Engineers. The rationale and developmental issues for a sideview presentation vertical situation display for use in commercial transport airplanes is discussed.

Jagacinoski, R. J., Miller, D. P., and Gilson, R. D. (1979). A comparison of kinesthetic-tactual and visual displays via a critical tracking task. Human Factors, 21, 79-86. The feasibility of using the critical tracking task to evaluate kinesthetic-tactual displays was investigated. It seems that this methodology holds considerable promise and under certain conditions may yield results comparable to those of visual tracking.

Jensen, R. S. (1980). Ergonomics in modern cockpit displays. In Oborne, D. J., and Levis, J. A. (Eds.), Human Factors in Transport Research, Volume I (pp. 61-69). London: Academic Press. CRTs and their role in the presentation of flight information are discussed.

Knapp, B. B. (1984). Scaling military symbols: A comparison of techniques to derive associative meaning. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 309-313). Santa Monica, CA: Human Factors Society. The use of symbolic representations of concepts is explored in the context of their inherent, associative meaning.

Knapp, B. G., Moses, F. L., and Gellman, L. H. (1982). Information highlighting on complex displays. In A. Badre and B. Shneiderman (Eds.), Directions in Human Computer Interaction, Norwood, NJ: Ablez. This article discusses categories of formatting techniques aimed at enhancing information assimilation.

Leffler, M. F. (1982). Advanced technology in the flight station. In Behavioral Objectives in Aviation Automated Systems Proceedings, 1982 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 97-101). Warrendale, PA: Society of Automotive Engineers. The evolutionary process that has led to the development of airborne digital systems and the integration of emerging technologies (such as color electronics displays into the cockpit) is presented and discussed.

Luder, C. B., and Barber, P. J. (1984). Redundant color coding on airborne CRT displays. Human Factors, 26, 19-32. An experiment is described that compares the use of redundant color coding for search and identification tasks under dual-task conditions.

Martin, K. W. (1980). The influence of extremes of ambient illumination on cockpit display design. In Oborne, D. J., and Levis, J.A . (Eds.), Human Factors in Transport Research, Volume I (pp. 79-87). London: Academic Press. This paper gives a brief account of one program examining the effects of high ambient illumination on cockpit delays, which represents a small but important part of the visual interference of man and aircraft.

McKannon, T. M., and Bohn, C. A. (1983). Improving the operator interface through the use of a touch interactive display. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 203-207). Warrendale, PA: Society of Automotive Engineers. The benefits of a touch interactive display are elaborated upon within the context of existing systems in actual flight test.

Merrifield, J. T. (1986). Boeing developing new cockpit displays to ease pilot workload. Aviation Week and Space Technology, June 23, 109-110, 113. The reasoning and the skeptical views behind the push for new automated cockpit displays are described.

Mitchell, N. B. (1985). The impact of scene digitization on distance judgements. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 297-299). Santa Monica, CA: Human Factors Society. A study is described in which it was found that distance judgements were more influenced by the order in which the stimuli, digitized or degraded, were presented than by the visual clutter, or texture, in the presentation itself.

Monk, T. H. (1981). The interaction between the edge effect and target conspicuity in visual search. Human Factors, 23, 615-625. The term edge effect in visual search is used to describe the finding that targets appearing in the outer half of a display have longer search times than those in the inner half. The interaction between the edge effect and target conspicuity was explored.

Monty, R. W., Snyder, H. L., and Birdwell, G. G. (1983). Keyboard design: An investigation of user preference and performance. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 201-205). Santa Monica, CA: Human Factors Society. The effects of several alphanumeric keyboards were studied with characteristics including: audible feedback, location, size, and shape of the carriage return key.

Murch, G. M. and Taylor, J. M. (1986). Effective use of color on avionics displays. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 219-225). Warrendale, PA: Society of Automotive Engineers. General guidelines that should be followed and basic principles that should be understood in order to create effective color displays for avionics applications are reviewed.

Moore, T. J., and McKinley, R. L. (1986). Research on speech processing for military avionics. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1331-1335). Santa Monica, CA: Human Factors Society. This paper describes the approach used to conduct research in the development and evaluation of military speech communication systems, mentions the types of studies done using this approach and gives examples of the types of data generated by these studies.

Munson, R. C., and Horst, R. L. (1986). Evidence for global processing of complex visual displays. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 776-780). Santa Monica, CA: Human Factors Society. Results are reported from two experiments that bear on the issue of what strategies and cognitive processes are evoked by humans in the evaluation complex visual displays.

Pisoni, D. B. (1986). A brief overview of speech synthesis and recognition technologies. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1326-1330). Santa Monica, CA: Human Factors Society. An overview of several aspects of speech synthesis and recognition technologies is provided. Specifically, speech synthesis by rule using automatic text-to-speech conversion and speaker-dependent isolated word recognition are discussed.

Post, D. L. (1986). U.S. Air Force color display issues. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 227-247). Warrendale, PA: Society of Automotive Engineers. The U.S. Air Force has special problems and requirements regarding electronic color displays. An overview of the ways in which the Air Force uses color displays is provided and associated display design issues are discussed.

Post, D. L., Lippert, T. M., and Snyder, H. L. (1983). Color contract for head-up displays. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 933-937). Santa Monica, CA: Human Factors Society. Recent evidence suggests that a useful metric of color contrast can be formulated in terms of distance between colors in a perceptually uniform color space. The present research relates distance in several spaces to response speeds for reading colored numerals superimposed on colored backgrounds.

Reising, J. M., Zenyuh, J. P., and Martin, R. L. (1986). Color formatting issues in pictorial displays. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 249-253). Warrendale, PA: Society of Automotive Engineers. As aircraft cockpits become more complex, pilot-vehicle interface engineers will continue to search for new ways to intergate and simplify the vast amounts of information available to the pilot. This paper reviews selected current methods of conveying this information and applications that go beyond them.

Robinson, C. P. and Eberts, R. E. (1987). Comparison of speech and pictorial displays in a cockpit environment. Human Factors, 29, 31-44. Current trends in cockpit design use speech to present secondary information. This article discusses findings contrary to these trends suggesting that for spacial information, pictorial displays are advantageous.

Robinson, C. P., and Eberts, R. E. (1985). There's a voice in the sky: But can a picture tell you more? In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 343-352). Santa Monica, CA: Human Factors Society. Through this experiment it was found that with pictorial input, subjects responded quicker and improved more with learning than did subjects with speech input.

Robinson, G. H. (1979). Dynamics of the eye and head during movement between displays. A qualitative and quantitative guide for designers. Human Factors, 21, 343-352. This paper provides a designer or systems analyst with a guide to human performance limitations in vision when fixation must be redirected from one display to another.

Roe, G. (1980). Ergonomics in the design of a future advanced fighter cockpit. In Oborne, D. J., and Levis, J. A. (Eds.), Human Factors in Transport Research, Volume I (pp. 70-78). London: Academic Press. The basic ergonomic aspects of cockpit design are reviewed, with special consideration given to: anthropometry, visual requirements, and data display.

Roscoe, S. N., Corl, L., and Jensen, R. S. (1981). Flight display dynamics revisited. Human Factors, 23, 341-353. Good old ideas for pictorial flight displays that were once impractical are reconsidered in the light of current microcomputing and display technology.

Schmandt, C. (1985). Voice Communications with computers. In H. R. Hartson (Ed.), Advances in Human-Computer Interaction Volume I (pp. 133-159). Norwood, NJ: Ablex. Design implications and performance criteria for a conversational speech interface are considered.

Schultz, E. E. (1985). Decluttering methods for high density computer-generated graphic displays. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 300-303). Santa Monica, CA: Human Factors Society. Several decluttering methods were compared to the speed and accuracy of user performance which results. The effectiveness of the methods were dependent on the degree to which each method makes essential graphic information distinctive from the nonessential.

Sidorak, W. (1983). Information processing using helmet mounted displays and voice interactive systems. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 155-166). Warrendale, PA: Society of Automotive Engineers. Assessment of helmet mounted virtual image display technologies for application to surveillance-type aircraft indicates that suitably augmented designs can replace large screen displays and improve operator performance.

Simpson, C. A., McCauley, M. F., Rolond, E. F., Ruth, J. C., and Williges, B. H. (1985). System design for speech recognition and generation. Human Factors, 27, 115-142. This article reviews human factors research on the design of systems that use speech recognition for human control of the system or that use speech generation for the display of information. This article includes a definition of terms, review of current research, and a discussion of future research needs in both fields.

Simpson, C. A. and Williams, D. H. (1980). Response time effects of alerting tone and semantic context for synthesized voice cockpit warnings. Human Factors, 22, 319-330. This paper points out that the recommendation for a voice warning should be preceded by a tone to attract attention to the warning has no experimental evidence as support. The effect of a tone before the voice warning was to lengthen response time.

Skira, C. A. (1984). Integrating the future fighter's controls. Aerospace America, 22, 60-64. This article discusses integrated controls that will let the pilot concentrate on the job at hand without being overwhelmed by new control devices.

Spiker, A. Rogers, S. P., and Cicinelli, J. (1986). Selecting colour codes for a computer-generated topographic map based on perception experiments and functional requirements. Ergonomics, 29, 1313-1328. Here is a description of a series of human factors analyses that guided the selection of chromatics and luminances for a computer-generated topographic map. This CRT-displayed digital map will greatly facilitate the navigational accuracy and situational awareness of army helicopter aviators during low level and nap-of-the earth flight.

Steiner, B. A., Burkhart, B. J., and Berson, B. L. (1983). Voice feedback protocols. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 108-111). Santa Monica, CA: Human Factors Society. The design of this study was to evaluate the relative effectiveness of three different types of feedback (visual, auditory or both) provided to an operator during a simulated voice control launch scenario.

Summers, L. G., and Miller, J. I. (1983). Primary flight display: A step beyond EADI's. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 415-424). Warrendale, PA: Society of Automotive Engineers. Various aspects of primary flight displays (PFD) are discussed including: advantages and disadvantages of the concept, the development of PFDs, and requirements such as compatability with head-up display.

Tufano, D., and Gwynne, J. T. (1986). Cockpit cursor control: Effects of task loading and controller location. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 642-646). Santa Monica, CA: Human Factors Society. Current trends in tactical aircraft missions and avionics require two-dimensional control of a display cursor by the pilot. This study looked at varied cursor controller location in respect to task loading.

USAF to test self-repairing control concepts (1986). Aviation Week and Space Technology, June 23, 122, 124. This article describes the Air Force test to study how the flight control system reconfigures to employ remaining control surfaces to cope with an emergency.

Vidulich, M. A. (1986). Response modalities and time-sharing performance. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 337-341). Santa Monica, CA: Human Factors Society. The value of speech responses as a control device in a dual-task experiment is examined. The results suggest that in operational environments the judicious use of speech technology can enhance performance.

Waterworth, A. (1982). Man-machine speech dialogue acts. Applied Ergonomics, September, 203-207. The paper outlines a preliminary classification of man-machine dialogues in terms of dialog acts and subdialogues.

Weihrauch, M. (1978). Display technology. In Session IIc of overview aircraft design and development (pp. 1-32). Culver City: Hughes Aircraft Company. Discussed is the evolution of airborne display technology from the pre-World War I "flying machines" through the "work horses" of World War II to the sophisticated weapon systems presently on the drawing board.

Weintraub, D. J., Haines, R. F., and Randle, R. J. (1985). Head-up Display (HUD) utility II: Runway to HUD transitions monitoring eye focus and decision times. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 615-619). Santa Monica, CA: Human Factors Society. This paper discusses the idea that the advantage of the Head-Up Display is the virtual image it presents as opposed to the Head-Up distinction itself.

Weitzman, D. O. (1985). Color coding revisited. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1079-1083). Santa Monica, CA: Human Factors Society. The advantages and disadvantages of color coding in information displays are summarized, based on the available experimental data. Recommendations are made for the effective use of color in complex information displays.

Wenzel, E. M. (1986). Effects of stimulus characteristics and task demands on pilot's perception of dichotic messages. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1177-1181). Santa Monica, CA: Human Factors Society. The investigation here is of pilot performance when auditory advisory messages are presented dichotically, either with or without a concurrent pursuit task requiring visual/motor dexterity.

Wetherbee, J. D. (1983). Voice interactive systems technology assessment. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 195-198). Warrendale, PA: Society of Automotive Engineers. The feasibility and functional utility of voice interactive system in the Navy F/A-18 aircraft is evaluated.

Wickens, C. D., Vidulich, M., and Sandry-Garza, D. (1984). Principles of S-C-R compatibility with spatial and verbal tasks: The role of display-control location and voice-interactive display-control interfacing. Human Factors, 26, 533-543. A pilot's tasks may be categorized into those that demand predominantly verbal operations and those that are spatial. Described are two experiments that define two principles of compatibility of interfacing such tasks with controls and displays.

Wilson, D. L., Burns, R. K., and Kuperman, G. G. (1985). Feature positive coding effects on object localization. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 292-296). Santa Monica, CA: Human Factors Society. An investigation of feature positive information coding is conducted and discussed Included topics were clutter level and display polarity as independent variables.

Zenyuh, J. P., and Reising, J. M. (1986). A comparison of three methods for controlling aircraft systems. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 638-641). Santa Monica, CA: Human Factors Society. The objective of this study was to compare the relative effectiveness of three modes of subsystem control: a voice recognition system with visual feedback presented on the head-up display, a standard multi-function control device with a tailored switching logic, and a remotely operated multi-function control with feedback presented on a head-up display.

Aircraft Design Philosophies

Adelman, L. (1983). A psychological approach to evaluating decision support systems. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 492-495). Santa Monica, CA: Human Factors Society. This paper provides an overview of a standardized questionnaire built around the foundation of a multi-attribute utility assessment hierarchy, and utilizing psychometric guidelines for test construction.

Alluisi, E. A. (1986). Aircrew combat mission enhancement (ACME) technology. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 45-47). Santa Monica, CA: Human Factors Society. The aircrew combat mission enhancement technology consists of the hardware, software, and associated interfaces and integration that will enable aircrews to reach the acme of tactical air combat performance. Uses for the technology in times of war and peace are described.

Eggleston, R. G., and Kulwicki, P. V. (1984a). Estimating the value of emerging fighter/attack system technologies. Paper presented at the NATO Defense Research Group (DRG) Panel VIII Workshop, Shivenham, England. A method for system development and acquisition cycle for the procurement of a modern weapon system is described. It is found to be a complex and often lengthy affair.

Eggleston, R. G., and Kulwicki, P. V. (1984b). A technology forecasting and assessment method for evaluating system utility and operator workload. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 31-35). Santa Monica, CA: Human Factors Society. This paper proposes the use of a top down approach to technology assessment. The top down approach has the advantage of evaluating technologies along dimensions of system utility, as well as technical performance.

Furness III, T. A. (1986). The super cockpit and its human factors challenges. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 48-52). Santa Monica, CA: Human Factors Society. A revolutionary virtual crew station concept titled the "Super Cockpit" is introduced with its applications and operational advantages.

Greitzer, F. L., Hershman, R. L., and Kaiwi, J. (1985). Intelligent interfaces for C2 operability. In IEEE 1985 Proceedings of the International Conference on Cybernetics and Society (pp. 782-786). Tucson, Arizona: IEEE. There has been disappointing progress in improving combat system operability. This article suggests that isolated user-computer transactions rather than more contextual goal directed support might be the cause.

Harwood, K., and Sanderson, P. (1986). Skills, rules and knowledge: A discussion of Ramussen's classification. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1002-1006). Santa Monica, CA: Human Factors Society. In this paper a discussion is presented of the antecedents, the emergence, and the impact of Rasussen's skill, rule, and knowledge based behavior classification.

Hess, R. A. and Backman, A. A. (1984). An engineering approach to determining visual information requirements for flight control tasks. In IEEE 1984 Proceedings of the International Conference on Cybernetics and Society (pp. 286-298). Tucson, Arizona: IEEE. An experimental and analytical investigation of visual information requirements for a simplified, multiloop flight control task was undertaken.

Kieras, D. and Polson, P. G. (1985). An approach to the formal analysis of user complexity. International Journal of Man-Machine Studies, 22, 365-394. A formal approach to analyzing the user complexity of interactive systems or devices is described, based on theoretical results from cognitive psychology. Making a system more usable can be accomplished by altering its design until the knowledge is adequately simplified.

Kuperman, G., and Kulwicki, P. V. (1984). Mission scenarios for cockpit automation technology. In Proceedings of the Institute of Electronic and Electrical Engineers Sixth Digital Avionics Systems Conference (pp. 102-107). Institute of Electronic and Electrical Engineers. This paper describes the development and applications of a detailed tactical fighter attack mission scenario package for exploitation in an Air Force advanced development program directed to developing and validating an advanced crew system design methodology.

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Kuperman, G. G., Moss, R. W., and Bondurant III, R. A. (1983). Crew assessment methods applied to derivative fighter cockpits. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 473-477). Santa Monica, CA: Human Factors Society. A set of crew system assessment tools (which may be employed early in the cockpit design process, at the concept evaluation and refinement stage) are applied to current weapon system acquisiton.

Lintern, G., Thomley-Yates, K. E., Nelson, B. E., and Roscoe, S. N. (1987). Content, variety, and augmentation of simulated visual scenes for teaching air-to-ground attack. Human Factors, 29, 45-59. Presented in this article are various methods for teaching air-to-ground attack by using simulation.

Michaelis, P. R., and Wiggins, R. H. (1982). A human factors engineer's introduction to speech synthesis. In A. Badre and B. Shneiderman (Eds.), Directions in Human Computer Interaction. Norwood, NJ: Ablex. The first half of the article describes how speech synthesizers work. The second half is devoted to human factors concerns: how synthesizers should be used and when snythesizers should be used, for example.

Mitchell, C. M., and Miller, R. A. (1983). Design strategies for computer-based information displays in real-time control systems. Human Factors, 25, 353-369. Two strategies are defined for the design of integrated, computer-based information displays for real-time control systems. The effects of display type on operator performance were considered.

Morris, N. M., Rouse, W. B., and Ward, S. L. (1985). Information requirements for effective human decision making in dynamic task allocation. In IEEE 1985 Proceedings of the International Conference on Cybernetics and Society (pp. 720-724). Tucson, Arizona: IEEE. Effective implementation of human-computer interaction is hampered by gaps in our understanding of what the nature of this interaction should be. The research program described is an effort to fill those gaps.

Moss, R. W., and Hudson, N. (1983). The scientific approach and cockpit design -- They are compatible. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 227-231). Warrendale, PA: Society of Automotive Engineers. The authors present a framework for applying techniques and processes currently used in advanced crew system design.

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Parsons, H. M., Williges, R. C., Topmiller, R. C., Jones, E. R., Hendrick, H. W., Snyder, H. L., Eggleston, R. G., and Birt, J. A. (1979). Human factors engineering for the Air Force; A complete examination. In Proceedings of the Human Factors Society 23rd Annual Meeting (pp. 574-575). Santa Monica, CA: Human Factors Society. The technical findings of an Air Force-contractor study are reviewed. The study comprehensively examined the needs of human factors engineering in the research, development, test-and-evaluation, and operations process for Air Force Systems.

Pohlmann, L. D., Shelnutt, J. B., and Gilmour, J. D. (1985). Pilot vehicle interfaces with smart avionics systems. In Fourth Aerospace Behavioral Engineering Technology Conference Proceedings, 1985 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 47-53). Warrendale, PA: Society of Automotive Engineers. A set of five high level design goals for smart pilot vehicle interfaces are presented. These goals are intended to provide a unifying conceptual architecture from which guidance can be derived.

Price, H. E. (1985). The allocation of functions in systems. Human Factors, 27, 33-45. Described is the systems approach to design and how the allocation of functions is a part of it, as a five-step procedure with four principal rules for arriving at a hypothetical allocation.

Reising, J. M., and Butterbaugh, L. C. (1986). Rapidly reconfigurable crewstation. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 53-56). Santa Monica, CA: Human Factors Society. The rapidly reconfigurable crewstation is described as an aid in the implementation process of development.

Retelle, J. P., and Kaul, M. (1985). DARPA pilot's associate program. Transportation Research Circular. 310, 6-14. The pilot's associate program, one of three applications in the Defense Advanced Research Projects Agency's strategic computing program, is discussed.

Simpson, C. A., McCauley, M. E., Roland, E. F., Ruth, J. C., and Williges, B. H. (1985). System design for speech recognition and generation. Human Factors, 27, 115-141. Reviewed in this article is human factors research on the design of systems that use speech recognition for human control of the system or that use speech generation for the display information.

Wiener, E. L. (1985). Beyond the sterile cockpit. Human Factors, 27, 75-90. The advance of cockpit automation has raised questions of how much the operator should be involved. It is suggested that the recommendation of humans serving as monitors must be reconsidered, and that humans must be brought back into a more active role in the control loop.

Expert Systems/Artificial Intelligence

Aretz, A., Guardino, A., Portfield, T., and McClain, J. (1986). Expert system advice: How should it be given? In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 652-656). Santa Monica, CA: Human Factors Society. Three methods of advice presentation (pilot-computer interface) were investigated, automatic, subject requested, and a combination of the two. It was found that the automatic condition was the best.

Basden, A. (1983). On the application of expert systems. International Journal of Man-Machine Studies, 19, 461-477. This article seeks to bring together a number of issues relevant to the application of expert systems by discussing their advantages and limitations, their roles and benefits, and the influence that real-life applications might have on the design of expert systems software.

Ben-Bassat, M. and Freedy, A. (1982). Knowledge requirements and management in expert decision support systems for (military) situation assessment. IEEE Transactions on Systems, Man, and Cybernetics, 12 (pp. 479-490). Situation assessment constitutes a fundamental problem in many decision making processes. This paper describes, categorizes, and analyzes the problems.

Buffalano, A. C., Jr. (1985). DARPA research focuses on the technology to probe beyond current expert systems and test the technology for three specific military purposes. Aerospace America, 23 (pp. 41-43). The advancing research carried on by DARPA in the area of expert systems is described.

Coombs, M., and Alty, J. (1984). Expert systems: An alternative paradigm. International Journal of Man-Machine Studies, 20, 21-43. There is an interest in the potential of expert systems yet few projects on their applications. This article argues that this is because the human experts are rarely required to perform the role that computer-based experts are programmed to adopt.

Dyn, C. L. (1985). Expert systems: New approaches to computer-aided engineering. Engineering with Computers, 1, 9-25. An overview is presented of the new field of expert (knowledge-based) systems.

Ehrenreich, S. L. (1981). Query languages: Design recommendations derived from the human factors literature. Human Factors, 23, 709-725. This paper reviews the human factors literature dealing with query systems. Included are issues to consider when determining a query language's suitability.

Engleman, C., Berg, C. H., and Bischoff, M. (1979). KNOBS: In Proceedings of the Sixth International Joint Conference on Artificial Intelligence. Tokyo, Japan: Information Processing Society of Japan. An experimental knowledge based tactical air mission planning system and rule based aircraft identification simulation facility. (pp. 247-249). The KNOBS (from knowledge based system) is discussed. It refers to an experimental system under development to explore the applicability of artificial intelligence techniques to the implementation of a mission planning consultant.

Giffin, W. C., and Rockwell, T. H. (1984). Computer-aided testing of pilot response to critical in-flight events. Human Factors, 26, 573-581. Pilot response to critical in-flight events is described employing a unique methodology including an interactive computer aided scenario testing system.

Grabiner, J. V. (1986). Computers and the nature of man: A historian's perspective on controversies about artificial intelligence. Bulletin of the American Mathematical Society, 15, (2), 113-126. The purpose of this paper is to provide a historical perspective on recent controversies about artificial intelligence, and to make clear that these are in fact controversies about the nature of man.

Hammer, J. M. (1983). A computerized, procedural aid for flight crews. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 870-873). Santa Monica, CA: Human Factors Society. A computer program for detecting pilot error is described. This program observes pilot actions through the aircraft controls and state.

Hammer, J. M. (1984). An intelligent flight-management aid for procedure execution. IEEE Transactions on Systems, Man, and Cybernetics, 14, 885-888. A computer program is described that contains a model of the procedures used in the operation of a twin engine aircraft.

Harris, S. D., and Helander, M. G. (1984). Machine intelligence in real systems: Some ergonomic issues. In G. Salvendy (Ed.), Human-Computer Interaction (pp. 267-27 . Amsterdam: Elsevier. An overview is given of some ergonomic issues in human-machine symbiosis. Problems of defining performance objectives and quantifying performance are first reviewed and some implications for product liability are discussed.

Hayes-Roth, F., Waterman, D. A., Lenat, D. B. (Eds.), (1983). Building expert systems. Reading, MA: Addison-Wesley.

Hillman, D. J. (1985). Artificial intelligence. Human Factors, 27, 21-31. Artificial intelligence areas relevant to human factors and automation including expert systems, natural-language understanding, and intelligent robotics are reviewed and illustrated.

Jackson, P., and Lefrere, P. (1984). Advice giving systems. International Journal of Man-Machine Studies, 20, 63-86.

Kidd, A. L. and Cooper, M. B. (1985). Man-machine interface issues in the construction and use of an expert system. International Journal of Man-Machine Studies, 22, 91-102. The effectiveness and acceptability of an expert system is critically dependent on its man-machine interface. This paper uses a framework of three central man-machine interface issues as a basis for evaluating a prospector-type expert system shell.

Kuperman, G., and Wilson, D. L. (1986). An expert system approach to workload reduction. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 702-706). Santa Monica, CA: Human Factors Society. Described is one artificial intelligence application area: an expert system for assisting in aircraft navigation.

Lambird, A. B., Lavine, D., and Kanai, L. N. (1984). Distributed architecture and parallel nondirectional search for knowledge-based cartographic feature extraction systems. International Journal of Man-Machine Studies, 20, 107-120. An overview is presented of the many types of knowledge that must be modeled in remote sensing and cartography, and architectural and control aspects deemed important for cartographic expert systems are discussed.

Madni, A. M. and Moses, F. (1985). An intelligent soldier-vehicle interface for future close combat vehicles. In IEEE 1985 Proceedings of the International Conference on Cybernetics and Society (pp. 754-756). Tucson, Arizona: IEEE. An overview is presented of an intelligent soldier-vehicle interface for close combat vehicles.

Michaelis, P. R., Miller, M. L., and Hendler, J. A. (1982). Artificial intelligence and human factors engineering: A necessary synergism in the interface of the future. In A. Badre and B. Schneiderman (Eds.), Directions in Human/Computer Interaction (pp. 79-94). Norwood, NJ: Ablex. A new generation of computer based systems offers the potential to be an amplifier and catalyst for human thought. A synergistic relationship has been developed and is illustrated using two ongoing research projects.

Ott, L. M. (1985). Artificial intelligence -- What does it offer combat aircraft? In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 889-892). Santa Monica, CA: Human Factors Society. The role of artificial intelligence in meeting the need to aid the pilot in the assessment of information is discussed.

Phelps, R. H. (1983). Application of psychological principles to decision support system design: An overview. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 479-481). Santa Monica, CA: Human Factors Society. In this overview of the Behavioral Decision Making session, the definition of a decision support system and a psychological perspective are described.

Phillips, E. R., Eike, D. R., and Fleger, S. A. (1986). Human factors issues in designing explanation facilities for expert troubleshooting systems. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 502-506). Santa Monica, CA: Human Factors Society. Presented are results of an extensive literature review designed to identify and define specific human factors issues which must be addressed to determine guidelines or standards for explanation facility design.

Raphael, B. (1976). The thinking computer. San Francisco: Freeman.

Rouse, S. H., Rouse, W. B., and Hammer, J. M. (1982). Design and evaluation of an onboard computer-based information system for aircraft. IEEE Transactions on Systems, Man, and Cybernetics, 12, 451-463. The information seeking by human operators through technical systems is discussed, as well as types of information and forms of presentation.

Rouse, W. B. (1981). Human-computer interaction in the control of dynamic systems. Computing Surveys, 13, 71-99. Modes of human-computer interaction in the control of dynamic systems are discussed, considering the problem of allocating tasks between human and computer.

Simons, G. L. (1984). Introducing artificial intelligence. Manchester, England: National Computing Centre.

Thacker, Patapray (1984). Artificial intelligence. Unpublished literature review of artificial intelligence, Virginia Polytechnic Institute and State University, Blacksburg, VA. Results of a limited literature survey on artificial intelligence are summarized.

Van Cott, H. P. (1984). From control systems to knowledge systems. Human Factors, 26, 115-122. This paper examines the human activities of controlling, knowing, and understanding as stages in human evolution. It considers these activities in relation to technology and shows how they have been shaped by it.

Williamson, M. (1986). Artificial intelligence for microcomputers. New York: Bradley Communications.

Zachary, W. (1985). Beyond user-friendly: Building decision-aid interfaces for expert end users. In IEEE 1985 Proceedings of the International Conference on Cybernetics and Society (pp. 641-647). Tucson, Arizona: IEEE. This article discusses the problem in the concept of user-friendly decision aids; they presume the user is a novice. The expert user is restricted and cannot operate to his or her fullest potential.

Human Performance Measurement Techniques

Boucek, G. P., Pfaff, T. A., Smith, W. D. (1983). Methods and instrumentation for evaluation of advanced displays and pilot performance. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerospace Contress and Exposition (pp. 211-218). Warrendale, PA: Society of Automotive Engineers. Data handling and integration of automated tasks are requiring more pilot attention. Here is a discussion of various methods for evaluating the man-machine interface at different levels of system design.

Boyd, S. P. (1983). Assessing the validity of SWAT as a workload measurement instrument. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 124-128). Santa Monica, CA: Human Factors Society. The subjective interactions between the dimensions used in SWAT are studied to determine if the ranking process is accurate enough to derive the workload scale.

Burke, M. W., Gilson, R. D., and Jagacinski, R. J. (1980). Multimodal information processing for visual workload relief. Ergonomics, 23, 961-975. Primary and secondary tracking tasks are used to determine the superiority of using a quickened kinesthetic-tactual to relieve workload with a visual display.

Casali, J. G. and Wierwille, W. W. (1982). A sensitivity/instrusion comparison of mental workload estimation techniques using a flight task emphasizing perceptual piloting activities. In IEEE 1982 Proceedings of the International Conference on Cybernetics and Society (pp. 598-602). New York: IEEE. Workload estimation techniques were compared to determine their relative sensitivity and intrusion in applications to a piloting situation which emphasized the use of perceptual processes.

Casali, J. G., and Wierwille, W. W. (1983). A comparison of rating scale, secondary-task, physiological, and primary-task workload estimation techniques in a simulated flight task emphasizing communications load. Human Factors, 25, 623-641. Sixteen potential metrics of pilot workload were investigated regarding their sensitivity to communication load and their intrusion on primary-task performance.

Casali, J. G., and Wierwille, W. W. (1984). On the measurement of pilot perceptual workload: a comparison of assessment techniques addressing sensitivity and intrusion issues. Ergonomics, 27, 1033-1050. A flight simulator-based study was conducted to examine fourteen distinct mental workload measures. Both the relative sensitivity of the measures to changes in mental workload and the differential intrusion of the changes on the primary task performance were assessed

Chiles, W. D., and Alluisi, E. A. (1979). On the specification of operator or occupational workload with performance-measurement methods. Human Factors, 21, 515-528. Five performance-measurement methods have been described in literature for use in operator or occupational workload specifications. A review and analysis of these methods yielded an indication of which method is preferable for various situations.

Cole, B. L., Hughes, P. K. (1984). A field trial of attention and search conspicuity. Human Factors, 26, 299-313. Two types of conspicuity are defined and studied to provide measures. The two kinds of conspicuity were found to be related in a systematic way.

Craig, A. (1980). Effect of prior knowledge of signal probabilities on vigilance performance at a two-signal task. Human Factors, 22, 361-371. Vigilance performances were studied to determine the effect of known signal probabilities. Results indicate that prior knowledge tends to stabilize performance over a session.

De Maio, J., Bell, H. H., and Brunderman, J. (1983). Pilot oriented performance measurement. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 463-467). Santa Monica, CA: Human Factors Society. In the past, flight simulator results have been evaluated by aircraft state oriented automated performance measurement systems (APMS). Discussed is an alternative pilot oriented APMS which can better interpret pilot performance.

Eisen, P. S., and Hendy, K. C. (1987). A preliminary examination of mental workload, its measurement and prediction. Downsview, Ontario: Defence and Civil Institute of Environmental Medicine. This document reports the results of a literature review, reviews the objectives of mental workload research, and defines terms which are related to the study of mental workload.

Eubanks, J. L., and Killeen, P. R. (1983). An application of signal detection theory to air combat training. Human Factors, 25, 449-456. After reviewing pilot performance in the simulator for Air-to-Air Combat, it was found that the theory of signal detection represents a promising approach to studying changes in pilot decision making behavior as a result of training.

Fisk, A. D., Derrick, W. L., and Schneider, W. (1983). The assessment of workload: Dual task methodology. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 229-233). Santa Monica, CA: Human Factors Society. Outlined are three major assumptions often associated with dual task experiments conducted to assess operator workload. These assumptions are shown to be incorrect and three criteria which should be met are discussed.

Fisk, A. D. and Schneider, W. (1981). Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. Human Factors, 23, 737-750. It is concluded from experiments that vigilance tasks should be structured to minimize continuous and repetitive control processing. A consistent relationship between signals and noise will reduce vigilance problems.

Grossman, J. D., and Whitehurst, H. O. (1979). The relative effects of multiple factors on target acquisition. Human Factors, 21, 423-432. Two laboratory experiments were conducted to assess the usefulness of visual acuity as a personnel selection criterion. Factors including acuity were ranked by their effect on the variance of the data.

Hart, S. G., and Bortolussi, M. R. (1984). Pilot errors as a source of workload. Human Factors, 26, 545-556. A pilot opinion survey was conducted to develop a data base for creating simulation scenarios that impose predetermined levels of pilot workload. It was found that errors could be conceptualized as a cause of workload rather than a symptom.

Hutchins, S. G., Greitzer, F. L., and Kelly, R. T. (1984). Operator loading effects in a simulated tactical decision-making problem. In Proceedings of the Human Factors Society 28th Annual Meeting (pp. 879-883). Santa Monica, CA: Human Factors Society. The objective of this effort was to explore the nature of the degradation in performance, in a military command and control environment, when human capacity limits are exceeded.

King, M. G., Stanley, G. V., and Burrows, G. D. (1984). Visual search processes in camouflage detection. Human Factors, 26, 223-234. In a search/detection task, the systematic increase in reaction time with task load implies that feature-integration processing was required to achieve target detection.

Kramer, A. G., Sirevaag, E. J., and Braune, R. (1986). Assessment of pilot workload: Converging measures from performance based, subjective and psychophysiological techniques. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 139-146). Warrendale, PA: Society of Automotive Engineers. The relationship between the P300 component of the event-related brain potential and the processing demands of a complex real-world task is explored.

Ogden, G. D., Levine, J. M., and Eisner, E. J. (1979). Measurement of workload by secondary tasks. Human Factors, 21, 529-548. Limitations in using secondary tasks for workload measurement are discussed, and directions for future research are presented.

Perfitt, T. E., Fileccia, G. L., and Young, W. L. (1982). Trajectory generation -- An automation concept of the future. In Behavioral Objectives in Aviation Automated Systems Proceedings, 1982 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 203-209). Warrendale, PA: Society of Automotive Engineers. Military and commercial developments over the past decade relating to trajectory generation are reviewed. Airborne mission replanning and pilot assistance that use trajectory generation are described.

Pulat, B. M. and Pulat, P. S. (1985). A workstation assessor for crew operations - WOSTAS. International Journal of Man-Machine Studies, 22, 103-126. A computer aided interactive model for workstation assessment in crew station design for communication, command, and control activities is described.

Ramusen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. IEEE Transactions of Systems, Man, and Cybernetics, SMC-13,(3), 257-266. A taxonomy for human performance is presented. The author classifies human performance as either skill, rule, or knowledge-based. The author also discusses requirements for different types of models for representing human performance.

Rockmore, A. J., and Riemenschneider, R. A. (1983). Pilot support for mission planning using expert systems. In Second Aerospace Behavioral Engineering Technology Conference Proceedings, 1983 Society of Automotive Engineers Aerosapce Congress and Exposition (pp. 233-241). Warrendale, PA: Society of Automotive Engineers. A route planning aid that finds a high quality route to and from a heavily defended target is described.

Rogers, W. H., and Moeller, G. (1984). Comparison of abbreviation methods: Measures of preference and decoding performance. Human Factors, 26, 49-59. Two experiments were conducted to determine the optimal method for abbreviating any specific set of words. The findings were discussed in terms of word abbreviation similarity and the ability of subjects to apply rule knowledge to aid in practiced decoding.

Roske-Hofstrand, R. J., and Paap, K. R. (1986). Cognitive networks as a guide to menu organizations: An application in the automated cockpit. Ergonomics, 29 1301-1311. It is suggested that when a menu-driven interface controls information in the domain of expertise of the end users, the difficulty that inexperienced users typically have in assessing the panels can be reduced by making the menu organization consistent with the user's cognitive organization.

Roscoe, S. N. (1979). When the day is done and shadows fall, we miss the airport most of all. Human Factors, 21, 369-383. A visual free time task was utilized to determine the amount of visual time the navigator had available, during flight over the prescribed course, for a nonflight-related task. The data indicate that the navigator's normal workload was demanding. Also, the duty of navigating required 92.2% of the copilot's total visual time whereas the engine and flight instruments were utilized only 4% of the time.

Roscoe, A. H. and Grieve, B. S. (1986). The impact of new technology on pilot workload. In Fifth Aerospace Behavioral Engineering Technology Conference Proceedings (pp. 91-104). Warrendale, PA: Society of Automotive Engineers. This paper describes a limited scientific study to compare the levels of workload experienced by pilots flying the Boeing 767 and 737 aircraft.

Schendel, J. D., and Johnston, S. D. (1983). A study of methods for engaging moving targets. Human Factors, 25, 693-700. Research focused on two methods for engaging moving targets: tracking and trapping. Interest was in determining the conditions under which either method would prove superior.

Sharit, J., and Salvendy, G. (1982). Occupational stress: Review and reappraisal. Human Factors, 24, 129-162. Presented is an overview of the topic of occupational stress. The article is intended to alert researchers to the practical considerations relevant to this topic.

Shifrin, C. A. (1986). USAF investigates ways to improve performance of future fighter pilots. Aviation Week and Space Technology, June 23, 161-163, 165. Discussed is the U.S. Air Force's program evaluating the use of drugs as a means of increasing performance in fighter pilots. Included are: tolerance to the modern and future fighter aircraft and pilot's ability to perform to their limits in that environment.

Shingledecker, C. A., Crabtree, M. S., and Eggemeier, F. T. (1985). Methods and systems for measuring human performance capabilities. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 210-214). Santa Monica, CA: Human Factors Society. Considered are several factors which contribute to the interpretability, sensitivity, and practical utility of standardized task batteries. The batteries were designed to assess the effects on human performance of work environments, stressors, biochemically active agents and performance enhancement interventions.

Simpson, C. A., and Marchionda-Frost, K. (1984). Synthesized speech rate and pitch effects on intelligibility of warning messages for pilots. Human Factors, 26, 509-517. This study discovers whether speech rate and voice pitch of "phoneme" synthesized speech affects pilots' accuracy and response time to typical threat warning messages.

Skipper, J. H., Rieger, C. A., and Wierwille, W. W. (1986). Evaluation of decision-tree rating scales for mental workload estimation. Ergonomics, 29, 585-599. The present study was directed at developing refinements in the decision-tree rating scale and at obtaining additional background information.

Sorkin, R. D. and Woods, D. D. (1985). Systems with human monitors: A signal detection analysis. Human-Computer Interation, 1, 49-75. New automation has put the human in the role of monitor. Problems can then be analyzed in a signal detection format in which the human operator and the automated component monitor partially correlated noisy channels.

Stein, K. J. (1986). Multisensor process expected to replace discrete subsystems. Aviation Week and Space Technology, June 23, 119-121. The trends and improvements of integrated avionics concepts are discussed. These concepts are focused on multisensor processors that will address the total weapons system.

Teichner, W. H., and Mocharnuk, J. B. (1979). Visual search for complex targets. Human Factors, 21, 259-275. Using various data, it was found that search time decreases and stimulus processing rate increases as the number of dimensions in a multidimensional target increases, and that the rate of processing increases as a function of total stimulus information.

Weener, E. F. (1984). Flight deck automation decisions. In Third Aerosapce Behavioral Engineering Technology Conference Proceedings, 1984 Society of Automotive Engineers Aerospace Congress and Exposition (pp. 3-8). Warrendale, PA: Society of Automotive Engineers. This paper describes the various automation factors which are considered in the process of developing a design for a flight deck.

Wiener, E. L., and Curry, R. E. (1980). Flight-deck automation: Promises and problems. Ergonomics, 23, 995-1011. The state-of-the-art of human factors in flight-deck automation is presented, identifying a number of critical problem areas. Also offered are broad design guidelines.

Wickens, C. D., and Yeh, Y. Y. (1983). The dissociation between subjective workload and performance: A multiple resource approach. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 244-248). Santa Monica, CA: Human Factors Society. A theory of the dissociation between subjective measures of mental workload and performance is described and discussed.

Wickens, C. D., Yeh, Y. Y., Fuld, R. B., and Hodel, S. (1985). A comparison of operator performance in manual and automated versions of a dynamic decision-making task. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1089-1091). Santa Monica, CA: Human Factors Society. Two dynamic decision tasks have been designed to investigate operator behavior in manual and automated systems. Rationale for the study and the nature of the tasks are detailed.

Wiener, E. L., Curry, R. E., and Faustina, M. L. (1984). Vigilance and task load: In search of the inverted U. Human Factors, 26, 215-222. Most studies have failed to demonstrate the left hand branch of the curve representing task demand and performance. The purpose of this study was to explore whether low-level additional demand on the monitor would result in improved performance.

Wierwille, W. W. and Connor, S. A. (1983). Evaluation of 20 workload measures using a psychomotor task in a moving-base aircraft simulator. Human Factors, 25, 1-16. The sensitivity and intrusion of 20 pilot workload assessment techniques were compared using a psychomotor loading task in a three-degree-of-freedom moving-base aircraft simulator.

Wierwille, W. W., Rahimi, M., and Casali, J. G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. Human Factors, 27, 489-502. A shift is occurring in human operator participation in more automated systems. Sixteen workload estimation techniques were evaluated as to their sensitivity and intrusion in a flight task emphasizing mediational behavior.

Wierwille, W. W. (1979). Physiological measures of aircrew mental workload. Human Factors, 21, 575-593. After studying physiological workload measures it was concluded that several measures appear promising, but that more research is needed to provide convincing evidence of viability. However, physiological techniques can be combined with others to provide a more complete understanding of the workload associated with a given task.

Wierwille, W. W., and Casali, J. G. (1983). A validated rating scale for global mental workload measurement applications. In Proceedings of the Human Factors Society 27th Annual Meeting (pp. 129-133). Santa Monica, CA: Human Factors Society. A new rating scale for mental workload (MCH scale) is presented. The scale is recommended for applications in which overall mental workload is to be assessed.

Williams, L. J. (1982). Cognitive load and the functional field of view. Human Factors, 24, 683-692. Discussed is an experiment in which visual display factors were kept constant but cognitive load was varied. It was found that cognitive load modulated the functional field of view.

Williges, R. W., and Wierwille, W. W. (1979). Behavioral measures of aircrew mental workload. Human Factors, 21, 549-574. Measurements of aircrew workload were divided into general categories. These categories were then subdivided into classes and were reviewed specifically in regard to flight test and evaluation. It was found that no single measure can be recommended as a definitive behavioral measure of mental workload.

Guidelines

Abbot, T. S., Moen, G. C., Person, L. H., Keyser, G. L., Jr., Yenni, K. R., and Garren, J. L., Jr. (1980). Flight investigation of cockpit-displayed traffic information utilizing coded symbology in an advanced operational environment. Washington, D.C.: NASA. The purpose of this study was to assess the benefit of coded traffic symbology in a flight environment and to obtain an initial assessment of pilot ability to monitor the traffic display.

Adams, J. J. (1982). Simulator study of a pictorial display for general aviation instrument flight. Washington, D.C.: NASA. The purpose of this described study is to see whether a pictorial display can improve situation awareness, pilot-aircraft system dynamic characteristics, and system performance.

Anderson, N. S. and Olson, J. R. (1985). Methods for designing software to fit human needs and capabilities. Washington, D.C.: National Academy Press. Computer software is usually developed with little or no user input into the design process frequently resulting in sophisticated computer systems that are difficult to use or require extensive training programs. The described workshop on software human factors was convened to identify and describe methods that software designers can employ that incorporate the user into the design team.

Atwood, M. E. (1983). Human factors in computer systems current trends and recommended directions: Proceedings of the vail workshop. Lawrence, Kansas: The Human Factors Society. This objective of this workshop was to develop a central theme and structure for pursuing future research in the area of human factors in computer systems.

Bolt, R. A. (1984). The human interface: where people and computers meet. Belmont, CA: Lifetime Learning Publications. Different examples of human-computer interface are described showing the various interface styles that one could employ.

Card, S. K., Moran, T. P., and Newell, A. (1983). The psychology of human-computer interaction. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. The purpose of this book is to help lay the scientific foundation for an applied psychology concerned with human users of interactive computer systems.

Corrick, G. E. (1979). Detection of different target types in realistic terrain. China Lake, CA: Hughes Aircraft Company. This report documents a study carried out under a target acquisition program. An algorithm has been developed which relates target acquisition performance to weapon delivery.

Engel, S. E. and Granda, R. E. (1975). Guidelines for man/display interfaces. Poughkeepsie Laboratory: IBM. This report documents a set of human factors guidelines relating to the interface between a user of an interactive computing system and a display terminal connected to the system. Areas covered include display frame layout, frame content, command languages, error prevention and recovery, response times, and behavioral principles.

Foley, J. D., Wallace, V. L., and Chan, P. (1981). The human factors of graphic interaction tasks and techniques. U.S. Army Research Institute. The promises of interactive graphics is to provide a user with a medium for communication with a computer which is at once benign, responsive, and graphic. One of the first places to start in the development of methodology and structures to make interaction interfaces easier is in the process by which the designer selects the devices the user uses to achieve elementary tasks. The purpose of this report is to provide some systematic structure for this process.

A general analysis tool for addressing the development and evaluation of an aerospace mission information structure. (1984). Huntsville, AL: System Development Corporation. This report describes the methodology used for the development and analysis of a man-machine system information structure for a typical tactical air-to-ground combat mission. In addition an indepth discussion on data base application is presented.

Inform: User interface guidelines. (1984). These guidelines are to provide consistency in INFORM user interfaces. A small subset of the entire user interface is addressed: menu design, help screen design, work screen design, and report design.

Murch, G. (19XX). The effective use of color: Physiological Principles. Tekniques, 7, 13-31. The basic functions of human color vision are described from a physiological perspective, deriving some general principles for the effective use of color.

Rogers, J. G. (1973). Development of design criteria for sensor displays. Springfield, VA: National Technical Information Service. The objective of this work is to conduct applied research using analytical and experimental investigations for identifying, defining and validating advanced concepts which may be applied to future aircraft instrumentation systems.

Rubenstein, R. and Hersh, H. (1984). The human factor: Designing Computer systems for people. U.S.A.: Digital Press. Enough is now known about human factors to build computer systems that are easy to use that meet people's needs. This book offers guidelines for good human-oriented design.

Simons, J. C., Kirtland, W. H., and Perez, W. A. (1986). Strategic mission decomposition: Volume I measures of effectiveness and study planning materials. Dayton, OH: Systems Research Laboratories, Inc. This report proposes measures of effectiveness for assessing crew performance and workload for an advanced concept bomber flying low altitude penetrations against relocatable targets.

Smith, S. L. and Mosier, J. N. (1986). Guidelines for designing user interface software. Bedford, Massachusetts: Mitre Corporation. This report offers guidelines for design of user interface software in six functional areas: data display, sequence control, user guidance, data transmission, and data protection.

Tijerina, L., Chevalaz, G., and Myers, L. B. (1985). Human factors aspects of computer menus and displays in military equipment. Columbus, OH: Battelle. Battelle has completed a comparative analysis of the contents of military interface design documents and described some examples of current military automated systems which reflect the presence or absence of good ergonomic design in their interfaces. The objective of this effort is to detail existing trends and practices in military computer systems interface design and to provide recommendations for enhancing the ergonomics of future systems.

Target Acquisition

Aaranson, J., Sharits, T., Sharp, E., and Ancona, D. (1985). Target detection as a function of color-coding and field density. In Proceedings of the Human Factors Society 29th Annual Meeting (pp. 1066-1069). Santa Monica, CA: Human Factors Society.

Middlekauf, D. C. (Ed.), (1974). Air-to-ground target acquisition source book: A review of the literature. Orlando: Martin Marietta.

Parkes, K. R. (1972). Human factors in air-to-ground target acquisition. Unpublished doctoral dissertation, Loughborough University of Technology, Loughborough, England.

Appendix B

Guidelines for Crewmember-Machine Interface Design

This appendix contains the crewmember-machine interface (CMI) design guidelines that were used for creating conceptual CMI formats. The guidelines are referenced directly from Air Force Technical Report, ESD-TR-86-278, Guidelines for Designing User Interface Software, by Sidney L. Smith and Jane N. Mosier (1986). The Smith and Mosier (1986) report was used here because it is the most comprehensive set of user interface software guidelines currently available. The report proposes 944 guidelines for designing software to support the user interface to computer-based information systems. These design guidelines cover six functional areas; data entry, data display, sequence control, user guidance, data transmission, and data protection. For the purposes of this research, only data display guidelines were considered. Included in this appendix are display guidelines copies from pages 131-137, 141, 156-158, 163-204 of Smith and Mosier (1986).

Consistency •4

Use consistent logic in the design of graphic displays, and maintain standard format, labeling, etc., for each method of graphic presentation.

COMMENT: Consistency in graphic design will allow users to focus on changes in displayed data without being distracted by changes in display format.

COMMENT: The standardization advocated here has to do with the logic of user interface design, not with internal processing by graphics software. Recent efforts to establish international standards for graphics software have been focused on the internal encoding, processing, storage and transmission of graphics displays in digital form. Such data processing standards do not in themselves specify or significantly constrain user interface design.

REFERENCE: Tufte, 1983.

SEE ALSO: 2.0•6.

Only Necessary Information Displayed •5

Tailor graphic displays to user needs and provide only those data necessary for user tasks.

COMMENT: Current advances in the technology (and theory) of graphic display permit realistic depiction of complex natural scenes. Such technology has been successfully applied to generate displays for arts and entertainment, and may also find increasing application to information displays. For many information displays, however, less may be more: an abstracted schematic diagram, omitting much detail, may convey more effective information than a photographic image. For any particular application, the amount of detail needed should be determined based on a task analysis.

REFERENCE: Tucker, 1984; Tufte, 1983.

SEE ALSO: 2.0•2.

Highlighting Critical Data •6

When a user's attention must be directed to a portion of a graphic display showing critical or abnormal data, highlight that feature with some distinctive means of data coding.

EXAMPLE: On a bar chart, one bar representing an out-of-tolerance condition might be textured or shaded differently to call attention to it and to contrast it with other bars.

COMMENT: More specific recommendations for highlighting different kinds of graphic displays are provided elsewhere in this section.

SEE ALSO: 2.6•1.

2.4 Graphics

•7 Reference Index or Baseline

When a user must compare graphic data to some significant level or critical value, include a reference index or baseline in the display.

EXAMPLE: A horizontal line might be displayed on a profit-and-loss graph to indicate where displayed curves exceed the break-even point.

COMMENT: Most data plots include a displayed baseline of some sort. An additional reference index may be displayed as well. The baseline should be chosen with care to provide an appropriate reference for displayed data. A graph without a baseline, or with a poorly chosen baseline, may distort the interpretation of displayed data.

COMMENT: More specific recommendations for indexing different kinds of graphic displays are provided elsewhere in this section.

REFERENCE: Tufte, 1983.

•8 Text Annotation

When a graph contains some outstanding or discrepant feature that merits attention by a user, consider displaying supplementary text to emphasize that feature.

EXAMPLE: A flow diagram for process control might include a current advisory message, POSSIBLE PRESSURE VALVE FAILURE, as well as appropriate graphic indications of the problem.

COMMENT: This recommendation derives from the lore of audiovisual aids, where speakers are exhorted to "get the message across" with words as well as pictures. In some information system applications, a graphic display may convey many messages at once. It might then prove difficult to determine which message(s) should be stated in words. As in other aspects of display design, some priorities must be established in relation to the user's information requirements.

REFERENCE: Tufte, 1983.

•9 ▸ Data Annotation

When precise reading of a graphic display is required, annotate the display with actual data values to supplement their graphic representation.

EXAMPLE: Adjacent numeric annotation might be added to the ends of displayed bars on a bar graph; numeric data might be displayed to mark the points of a plotted curve.

COMMENT: Some displays may require complete data annotation, but many displays will require annotation only for selected data elements.

▸ Consistent Annotation Format •10

Format any displayed annotation consistently in relation to the graphic elements.

EXAMPLE: Labels might always be placed over the displayed points with which they are associated.

COMMENT: Sometimes it might be necessary to displace a label from its "standard" position to avoid overlap or crowding on the display; such exceptions should themselves be handled consistently.

SEE ALSO: 2.4•4.

▸ Normal Orientation for Labels •11

Display the annotation of graphic displays, including labels for the axes of graphs, in a normal orientation for reading text.

EXAMPLE: For users reading English, labels should be displayed horizontally, even for the vertical axis of a graph.

COMMENT: A conventional text orientation of labels will permit faster, more accurate reading. With a printed graph, it may be possible to tilt the page to read a disoriented label. With an electronic display, a user usually cannot tilt the display screen but instead must tilt his/her head.

COMMENT: More specific recommendations for labeling different kinds of graphic displays are provided elsewhere in this section.

REFERENCE: Noyes, 1980; Tufte, 1983.

Standard Symbols •12

Establish standard meanings for graphic symbols and use them consistently within a system and among systems with the same users.

EXAMPLE: As a negative example, if an aircraft symbol is used to denote an aircraft on one display, that symbol should **not** be used to mark airfields on another display.

COMMENT: If users may be unfamiliar with the graphic symbology used, consider incorporating a legend to define displayed symbols. Alternatively, users might be allowed to request a supplementary display of symbol definitions or to request the definition of a particular displayed symbol by pointing at it.

REFERENCE: Foley and Van Dam, 1982; Hopkin and Taylor, 1979.

4

2.4 Graphics

•13 ▶ **Pictorial Symbols**

Design pictorial symbols (e.g., icons, pictograms) to look like the objects or processes they represent, and test the resulting symbol set with a representative group of users to ensure that the intended meanings will be understood.

COMMENT: Some pictorial symbols have conventional meanings within a user population, which must be followed to ensure their correct interpretation. Novel symbol design must always be tested. It can happen that a symbol whose meaning seems perfectly clear to its designer may **not** be understood by system users.

REFERENCE: Barnard and Marcel, 1984; Smith, Irby, Kimball and Verplank, 1982.

SEE ALSO: 3.1.8•3.

•14 **Simple Texture Codes**

In selecting textures to code displayed areas, choose simple hatching rather than elaborate patterns.

COMMENT: Compared with manual drafting methods, it is temptingly easy to have a computer generate texture codes of considerable complexity. A designer should resist that temptation. When in doubt, create some sample displays and check them to ensure that texture codes do not produce distracting visual effects such as moire patterns.

COMMENT: Texture coding is a technique specifically related to graphics. Other kinds of display coding — size, shape, brightness, color, etc. — can be applied more generally in display design. Display coding is considered in Section 2.6 of these guidelines.

REFERENCE: Tufte, 1983.

Zooming for Display Expansion •15

When a user may need to perceive graphic relations more accurately, or to view pictures, diagrams, maps, etc. in greater detail, provide a zooming capability that allows the user to expand the display of any selected area.

COMMENT: Zooming can increase display spacing among crowded data items so that they can be perceived better. Thus an air traffic controller might expand a portion of a situation display to see more clearly the spacing of converging tracks that threaten a collision.

COMMENT: Zooming can increase the degree of detail, i.e., can add data to a display. Thus a user might expand a city map to see detailed road structures that are not shown in a small-scale map. When used this way, a zooming capability implies that graphic data be "layered" hierarchically at different levels of aggregation, which may require complex data files and data management techniques.

COMMENT: Zooming might be implemented as a continuous function, by which a display can be expanded to any degree, analogous to a continuous panning capability. Or zooming might be implemented in discrete increments, as in increasing the magnification of an optical instrument to x2, x4, etc. Incremental zooming, with abrupt changes in display scale, may tend to disorient a user, but might prove acceptable in some applications.

SEE ALSO: 2.7.2•13.

▶ Show Changing Scale •16

When a map or other graphic display has been expanded from its normal coverage, provide some scale indicator of the expansion factor.

EXAMPLE: A linear indicator of current map scale might be shown in the margin, or perhaps simply a numeric indication of the display expansion factor (e.g., x4).

COMMENT: In many applications it may be helpful to show the scale even for a display with normal, unexpanded coverage.

SEE ALSO: 2.7.2•14.

2.4 Graphics

•17 ▶ Show Overview Position of Visible Section

When a display has been expanded from its normal coverage, provide some graphic indicator of the position in the overall display of the visible section.

EXAMPLE: In a corner of any frame of an expanded display, the computer might show a rectangle representing the overall display, in which a smaller rectangle is placed to indicate the position and extent of the currently visible portion of that display.

COMMENT: A graphic indication of the current coverage of an expanded display will provide some visual context to help a user maintain a conceptual orientation between the visible part and the whole display from which that part has been expanded.

REFERENCE: Foley and Van Dam, 1982.

SEE ALSO: 2.4.8•11, 2.7.2•15.

•18 Animation for Dynamic Display

Consider animation, the movement of data elements under computer control, for displaying a temporal sequence of changing events, or for the pictorial display of complex objects.

EXAMPLE: For air traffic control, sequential frames of radar data might be displayed (with time compression) to aid perception of the tracks from moving aircraft.

EXAMPLE: A complex molecular structure might be perceived more effectively if a viewer is shown sequential displays depicting a computer-stored model from different angles.

EXAMPLE: An architect might demonstrate a proposed building design with a sequential "walk through" displayed from a computer-stored model.

COMMENT: Animation can be used to enhance a variety of graphic displays, including scatterplots, curves, bar graphs, flow charts, etc. Computer tools to support display animation are growing more powerful, and should find increased use in information displays. Prototype testing may be required to determine optimal timing for sequential display, which will vary with different applications.

REFERENCE: MS 5.15.3.6.3; Dunn, 1973; Tucker, 1984.

SEE ALSO: 2.7.3•4.

-7

▶ Highlighting by Animation •19

When sequential relations or other connectivity between display elements requires highlighting, consider animation for that purpose.

EXAMPLE: Connectivity might be emphasized by an arrow moving repeatedly between two displayed elements.

EXAMPLE: Sequential relations might be emphasized by an animated "sprite", i.e., a moving pointer under computer control.

COMMENT: There was a time when viewers of "sing-along" motion pictures were exhorted to "follow the bouncing ball" which marked their place. A moving marker of that kind is now often called a "sprite", or sometimes a "movable object block" (MOB). Sprites can simplify the process of animating computer-generated displays. Once a graphic element has been defined to a computer as a sprite, that element can be moved about a display independently of a fixed background or of other sprites.

COMMENT: If only one element is shown moving on an otherwise stable display, that moving element will be seen as distinctive. Such animated highlighting is probably subject to diminishing returns. If one sprite is good for directing a user's attention, two may **not** be. The simultaneous display of multiple sprites may confuse a user.

Printing Graphic Displays •20

When on-line graphic displays must be printed, allow users to display the material exactly as it will appear in the printed output.

COMMENT: On-line displays can offer some advantages over printed graphics, in terms of animation and highlighting. When a user is preparing a display for printed output, however, it is important that limitations of the print medium can be taken realistically into account. If the printed version does not appear satisfactory, it may be necessary to reformat the display in some way. Alternatively, it may be possible to find a printer with greater capabilities.

▶ Scaling Against a Reference Index •10

If different variables on a single graph seem to require different scales, consider scaling them against a common baseline index, rather than showing multiple scales.

EXAMPLE: Rather than showing sales in units and profits in dollars, both might be graphed in terms of percent change from a baseline period.

COMMENT: An indexed chart can permit comparisons among different variables when multiple scales would otherwise be needed. However, care should be taken in selecting an appropriate base period against which to index, in order to ensure that comparisons will not be biased.

COMMENT: Index scaling may also be appropriate for showing the effect of a single variable (such as money) whose units of measurement change in real value with time.

SEE ALSO: 2.4•7.

Aids for Scale Interpolation •11

Where accuracy of reading graphic data is required, provide computer aids for exact interpolation.

EXAMPLE: It might suffice to allow users to request a fine grid as an optional display feature; or it might be better to display vertical and horizontal rules that a user could move to intersect the axes of a chart; or it might prove best simply to let a user point at any data item and have the computer label that item with a readout of its exact value(s).

▶ Unobtrusive Grids •12

When grid lines are displayed, ensure that they do not look like data and do not obscure data elements — curves, bars, plotted points, etc.

COMMENT: Grid lines should be thinner than data curves, and should be invisible behind depicted objects and areas such as the bars on a bar chart. Note in particular that heavy vertical grid lines may conceal the height of plotted peaks.

COMMENT: In this respect, electronic displays offer more flexibility than printed graphs. Grids can be displayed or suppressed by user selection. For reading the value of a particular data point, perhaps no grid is needed at all. A user might simply ask the computer to display the value of any selected point.

REFERENCE: Cleveland, 1985; Tufte, 1983.

2.4.6 Graphics - Pictures and Diagrams

Pictures and diagrams show relations among the various elements of objects or processes.

•1 Pictures

Use pictorial displays in applications where it is necessary to show accurately detailed representations of real or imaginary objects or processes.

EXAMPLE: Pictorial displays aid in the analysis of objects and events, as in the case of photo interpretation.

EXAMPLE: Pictorial displays support a variety of computer-aided design applications, including the design of aircraft, artificial hearts, automobiles, etc.

COMMENT: In some applications it may be possible for a computer to synthesize pictorial displays from stored data. This is true in computer-aided design, where the computer must display a designed object that does not yet exist. For a map-reading task, a computer might synthesize perspective views of terrain from topographic data, where real images are not available.

COMMENT: For some information-handling tasks the display of detailed images (photographs) will help users. In other instances, simplified line drawings may be more readily comprehended.

COMMENT: Dynamic display of "moving pictures" can exploit various animation techniques to improve the pictorial representation of complex objects and processes.

REFERENCE: Foley and Van Dam, 1982.

•2 Diagrams

Use diagrams to show spatial relations, with selective focus on the data specifically required by a user's task, in applications where a full pictorial rendering might be unnecessarily complicated.

EXAMPLE: Diagrams are used to support many applications, ranging from mechanical assembly/maintenance instruction to the representation of electronic circuitry, or floor plans, or organizational hierarchies.

COMMENT: Diagrams are here considered a special form of picture. Diagrams should be kept as simple as possible, omitting unnecessary data. A system diagram for a subway engineer would have to be quite complex, showing accurate distances and directions, and perhaps the relation between subway sections and surface streets, utility lines, etc. But a subway diagram intended for a tourist might display simply the connecting links between one station and another.

SEE ALSO: 2.0•2, 2.4•5.

Linking Sectional Diagrams •3

When diagrammed data exceed the capacity of a single display frame and must be shown in separate sections, provide an overview for the diagram, a consistent notation to indicate the logical linking of its various sections, and an easy means for users to move from one section to another.

EXAMPLE: The sections of a diagram might be assigned letter codes, which could be shown in the overview and at any internal branch points, and which could be entered by a user to request the display of various sections.

COMMENT: General guidelines for linking sectional displays by paging/scrolling are considered elsewhere under the topic of display framing. The concern here is to establish a coherent structure to show logical relations among the separately displayed parts of a diagram. The solution may require internal notation and perhaps replication of some portions of the diagram from one section to another.

COMMENT: An alternative approach might be to construct a hierarchic diagram with a zooming capability to show greater detail. That capability represents a potential advantage of computer-generated electronic displays over printed diagrams.

SEE ALSO: 2.4•15, and Section 2.7.2.

Highlighting •4

If a picture or diagram contains data of particular significance, implying a special need for user attention, highlight those data.

EXAMPLE: Selected portions of pictures might be highlighted by adding a box outline to the display, or perhaps a blinking arrow; diagram elements might be highlighted by bolding or video reversal, or perhaps by color coding.

EXAMPLE: Highlighting might be used to indicate a computer analysis of design deficiencies in a depicted object, or an assessment of damage when monitoring a system that has been degraded in some way.

SEE ALSO: 2.4•6, 2.6•1.

2.4.6 Graphics - Pictures and Diagrams

•5 Rotation

In an application where a user must examine a depicted object from different viewpoints, allow the user to rotate its displayed image.

COMMENT: The axis of rotation will generally be the center of the depicted object. Where that is not the case, some indication of the rotation axis should be displayed. In some applications it might also help the user to display some explicit separate indication ("gnomon") of the degree of rotation and the current orientation of the depicted object.

COMMENT: In applications where a user must make a detailed comparison of two (or more) displayed objects, it may be necessary to allow independent rotation, translation and superposition of their images.

REFERENCE: Foley and Van Dam, 1982; Foley, Wallace and Chan, 1984.

•6 Aids for Pictorial Analysis

When users must analyze pictorial images in detail, provide appropriate computer aids for that purpose.

EXAMPLE: For examining displayed surfaces, it might be helpful to allow a user to specify/control the light source adopted for computer-generated images.

EXAMPLE: For photo interpretation, computer processing can sometimes improve the visual quality of stored images, as by edge enhancement.

EXAMPLE: For examining the component structure of a complex object, as for an assembly or maintenance task, it might be helpful to allow a user to "explode" an aggregate display into its several elements.

EXAMPLE: For examining the internal structure of a depicted object, it might be helpful to allow a user to request auxiliary displays of specified cross-sections or transect diagrams.

EXAMPLE: For more detailed structural analysis of depicted objects, it might be necessary to provide computer aids for calculating area, volume, center of gravity, modes of vibration, stresses, heat transfer, etc.

Maps and situation displays are a form of diagram showing geographic relations among objects or events.

Maps •1

Provide maps to display geographic data, i.e., direction and distance relations among physical locations.

COMMENT. Here the term "map" refers to the display of relatively stable geographic data, or the display of slowly changing data such as weather. When mapped data change more quickly, as in the display of aircraft tracks for air traffic control, those diagrams are called "situation displays". Design recommendations for maps will generally pertain also to situation displays.

SEE ALSO. 2.4.8•15.

Consistent Orientation •2

When several different maps will be displayed, adopt a consistent orientation so that the top of each map will always represent the same direction.

EXAMPLE. In common use, most maps are oriented so that North is upward.

Consistent Projection •3

When maps represent large geographic areas, adopt a consistent method of projecting the earth's curvature on the flat display surface.

COMMENT. For large areas, any method of projection will introduce some distortion of apparent distances in the display. The projection used should be one which minimizes the practical effects of that distortion for the application at hand. If a selected method of map projection is used consistently, viewers can learn to compensate in some degree for the distortion it introduces.

REFERENCE. Hopkin and Taylor, 1979.

2.4.8 Graphics - Maps and Situation Displays

•4 Labeling Maps

Label significant features of a map directly in the display, when that can be done without cluttering the display.

COMMENT: When labeling and other desired annotation are too extensive to incorporate in the map itself, that material might be shown in some separate, peripheral area of the display. In that case, auxiliary coding might be used to link annotation with associated map features, e.g., by matching symbol codes.

COMMENT: An alternative to fixed labeling would be to permit user interaction with computer-generated graphic displays. If a user selected a mapped point, a label might be temporarily displayed. If a user selected a marginal label, its associated map location might be highlighted.

COMMENT: With interactive graphics, it may be possible to design maps with hierarchic levels of portrayed detail and labeling, so that a user can "zoom in" to examine an area in greater detail or "zoom out" for an aggregated overview.

SEE ALSO: 2.4•10, 2.4•11.

•5 ▶ Consistent Positioning of Labels

Position labels on a map consistently in relation to the displayed features they designate.

EXAMPLE: The names of cities and towns might always be placed immediately above the corresponding symbols showing their locations.

COMMENT: As a practical matter, map displays can get very crowded. It may not always prove feasible to maintain a consistent placement for labels, with the result that designers will be tempted to put labels wherever they will fit. In such a crowded display, labels may obscure map features, and vice versa. Locating and reading labels will be slowed, particularly when map features are displayed closely adjacent to the beginning of labels. Under these circumstances, some other approach to map labeling should be considered to avoid crowding.

REFERENCE: Noyes, 1980.

Area Coding •6

When different areas of a map must be defined, or when the geographic distribution of a particular variable must be indicated, consider the use of texture patterns or color or tonal codes for that purpose.

EXAMPLE Coding might help define different areas of interest, such as the Eastern, Central, Mountain and Pacific time zones on a map of the United States, or perhaps areas of current rainfall on a weather map.

EXAMPLE Area coding might be used to indicate a geographic variable such as elevation or a demographic variable such as population.

COMMENT In many applications it may be desirable to limit area coding to one variable in order to assure effective information assimilation, in which case a designer should select that variable which is most significant. Another approach might be to allow a user to specify which variable will be coded on a map and to change that selection at will depending upon current task requirements. In some special applications, however, it may be feasible to superimpose several kinds of area coding to permit multivariate data analysis by skilled users.

SEE ALSO Section 2.6.

▶ Tonal Codes •7

Where users must make relative judgments for different colored areas of a display, consider employing tonal codes (different shades of one color) rather than spectral codes (different colors).

EXAMPLE For reading topographic maps, tonal variation might be used to show the relative height of displayed areas, perhaps with darker hues used to code greater heights.

COMMENT This recommendation represents an exception to other guidelines advocating distinctive code values. Coding by tonal variation should be considered only for applications where perception of relative differences along a single dimension is more important than perception of absolute values.

COMMENT People can order categories along a continuous dimension to match tonal variations in one color, whereas people do not have a natural means of ordering **different** colors.

COMMENT This recommendation is based on research with layer tints on printed displays. Some testing may be required to determine whether a particular electronic display permits effective variation in color tones.

REFERENCE Phillips, 1982.

SEE ALSO 2.6•24

2.4.8 Graphics - Maps and Situation Displays

•8 ▸ **Ordered Coding**

Where different areas of a map are coded by texture patterns or tonal variation, order the assigned code values so that the darkest and lightest shades correspond to the extreme values of the coded variable.

EXAMPLE. For indicating the height of mapped terrain, dark shades might be used for high elevations and light shades for low.

COMMENT. Orderly assignment of code values will help users perceive and remember the categories represented by the code.

•9 **Highlighting**

If one area in a map represents data of particular significance, implying a special need for user attention, highlight that area.

EXAMPLE: On a weather map, special area coding might be used to indicate severe storm conditions.

SEE ALSO: 2.4•6.

•10 **Panning for Flexible Display Framing**

When a map exceeds the capacity of a single display frame, in terms of the required extent and detail of coverage, consider providing users a capability to pan the display frame over the mapped data in order to examine different areas of current interest.

COMMENT. General guidelines for viewing different parts of an extended display by paging or panning/scrolling are considered elsewhere under the topic of display framing. Panning will permit users to move continuously over a map in any desired direction, without encountering any internal boundaries imposed by predefined display framing.

COMMENT. An alternative approach might be to define various sections of a large map and link those sections by the same techniques used for linking sections of a large diagram. One risk in that approach is that an area of interest might be at a boundary where none of the sectional maps provide adequate coverage. Thus some degree of overlapped coverage is probably needed at the boundaries of displayed map sections.

SEE ALSO: 2.4.6•3, 2.7.2•12.

4

▶ Show Overview Position of Visible Section •11

When a user pans over an extended display in order to view different sections, provide some graphic indicator of the position in the overall display of the visible section.

EXAMPLE: In a corner of a panned display, the computer might show a rectangle representing the overall display, in which a smaller rectangle is placed to indicate the position and extent of the currently visible portion of that display.

COMMENT: While panning across a map, moving from one section to another, a user may lose track of what is being displayed, and be uncertain how to move in order to see some other area of interest. An indicator of current position will help maintain user orientation.

SEE ALSO: 2.4•17, 2.7.2•15.

Aiding Distance Judgments •12

When a user must judge distances accurately on a map or other graphic display, provide computer aids for that judgment.

COMMENT: Some designers display for this purpose a movable grid whose scale is controlled automatically by the computer depending upon current map expansion. Some designers have suggested that the grid might consist of a vertical and a horizontal line displayed across a series of concentric range rings. It might be more helpful to display a scaled line (ruler) that a user could move to intercept any two displayed points directly.

COMMENT: For exact measurement, it might be better to allow a user to select (point at) any two points and have the computer "read-out" their separation distance directly. The same technique might be used to determine the direction (bearing) between two points.

Aids for Analyzing Maps •13

When the use of mapped data may be complex, provide computer aids for data analysis.

EXAMPLE: In topographic analysis, computers might analyze contour data at different sites to calculate slopes and sun exposure for land use planning, or might calculate sight angles to determine radar coverage from different locations, etc.

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2.4.8 Graphics - Maps and Situation Displays

•14 Mapping Nongeographic Data

In applications where the geographic distribution of nongeographic data must be displayed, consider adding other graphic elements to a map for that purpose.

EXAMPLE: A symbol might be displayed in different sizes to indicate a particular measure in different localities, such as average population age, or average annual rainfall, or incidence of a particular disease.

EXAMPLE: Small stacked bars might be superimposed on the different areas of a map to indicate the local distribution of some data measure, such as population distribution by age, education, or income.

COMMENT: Alphanumeric characters might be added to a map to show data, but those will not aid a direct visual comparison across areas in the same way that graphic symbols can do. Moreover alphanumeric data may be confused with labels and other kinds of annotation.

•15 Situation Displays

When it is necessary to show the geographic location of changing events, which is often the case for monitoring real situations, combine event data with a map background.

EXAMPLE: A display for air traffic control might superimpose aircraft tracks on a background of geographic coordinates, with supplementary annotation and/or coding to indicate track identification, speed, heading, altitude, etc.

•16 Indicating Data Change

When changes in mapped data are significant for a user's task, include auxiliary graphic elements to indicate those changes.

EXAMPLE: Auxiliary coding might be needed to indicate the movement of storm fronts on a weather map.

COMMENT: In dynamic maps, i.e., situation displays, data changes involving movement can be shown directly. On static displays, arrows can be added to indicate the direction of movement of mapped elements. Where movement over an extended area must be represented, as in showing weather fronts, directional "pips" can be added to displayed contour lines. Some designers recommend that such pips should be displayed one to two times as large as alphanumeric characters, and that pip spacing should be five to ten times the pip width.

SEE ALSO: 2.6•20, 2.7.3•4.

Selectable Data Categories •17

If the particular data categories required at different stages in a user's job cannot be exactly predicted, allow the user to select the categories needed for any information handling task.

EXAMPLE: In monitoring aircraft separation for collision avoidance, a user might choose to display selectively the aircraft tracks within a particular altitude zone.

EXAMPLE: To help identify an unrecognized aircraft track, a user might choose to add flight plan data temporarily to an air traffic display.

COMMENT: This recommendation does not lessen the designer's responsibility for determining user needs. Where user information requirements can be defined, displays should be designed to provide necessary data. User selection from available data categories may represent desirable flexibility to meet changing task requirements. However, there is a risk of "data indigestion" if a user selects the wrong categories or too many categories.

COMMENT: Categories of selectable data might include relatively stable elements (e.g., defined flight paths, zones of radar coverage, etc.) as well as the variable elements that represent changing data (e.g., aircraft tracks).

COMMENT: If auxiliary coding is adopted for different data categories, such as shape coding of symbols, code values should be chosen to be distinctive for any likely **combination** of displayed categories.

COMMENT: Users should be provided a ready reminder of what data categories are available, and an easy means of selecting (or suppressing) displayed categories. This implies category selection by menu or function keys.

SEE ALSO: 2.7.1•5.

Stable Reference for Changing Data •18

When graphic data are changing and displays are automatically updated, provide some stable display elements, e.g., coordinates, geographic boundaries, etc.

EXAMPLE: For vehicular control, a common display convention is to depict a moving element (aircraft) against a fixed background (horizon).

COMMENT: Stable display elements provide a frame of reference to help users assimilate and interpret data changes.

COMMENT: Moving data may overlay and temporarily obscure other display elements, such as fixed background data. When that happens, the display update logic must determine which data categories have priority on the display and which may be obscured by others, and should restore the obscured elements when the overlaid data moves away, and should further ensure that no data are erased from the display in the process of obscuring and restoring data.

SEE ALSO: 2.7.3•1.

2.5 Format

Format refers to the organization of different types of data in a display to aid assimilation of information.

•1 Consistent Format

Adopt a consistent organization for the location of various display features from one display to another.

EXAMPLE: One location might be used consistently for a display title, another area might be reserved for data output by the computer, and other areas dedicated to display of control options, instructions, error messages, and user command entry.

EXCEPTION: It might be desirable to change display formats in some distinctive way to help a user distinguish one task or activity from another, but the displays of any particular type should still be formatted consistently among themselves.

COMMENT: The objective is to develop display formats that are consistent with accepted usage and existing user habits. Consistent display formats will help establish and preserve user orientation. There is no fixed display format that is optimum for all data handling applications, since applications will vary in their requirements. However, once a suitable format has been devised, it should be maintained as a pattern to ensure consistent design of other displays.

REFERENCE: BB 1.1, 1.8.5; EG 2.2.5, 2.3, 2.3.3; MS 5.15.3.2.1, 5.15.3.3.4; Foley and Van Dam, 1982; Stewart, 1980.

SEE ALSO: 4.0•6.

•2 Distinctive Display Elements

Make the different elements of a display format distinctive from one another.

EXAMPLE: Different display areas ("windows") can be separated by spacing (where space permits); outlining can also be used to separate different areas, so that displayed data, control options, instructions, etc., are distinct from each other.

REFERENCE: EG 2.3; MS 5.15.3.1.5; Stewart, 1980.

SEE ALSO: 3.0•8, 4.0•8.

▶ Spacing to Structure Displays •3

Use blank space to structure a display.

COMMENT: Closely packed data are difficult to locate and difficult to read. Thus blank space can be used to advantage to separate different groups of data. Related data items within a group, however, should be displayed close enough to minimize eye movement time in scanning those data.

REFERENCE: Tullis, 1983.

Paging Crowded Displays •4

When a display contains too much data for presentation in a single frame, partition the data into separately displayable pages.

COMMENT: And provide convenient control procedures to allow users to move easily from one page to another.

REFERENCE: BB 4.4.1, 4.4.2; Stewart, 1980.

SEE ALSO: 2.7.2•6.

▶ Related Data on Same Page •5

When partitioning displays into multiple pages, take into account the type of data, and display functionally related data items together on one page.

COMMENT: This recommendation is easily followed for text displays, involving primarily the elimination of "widows", considerate placement of illustrations, etc. For displayed data forms and tables, data grouping and continuation of headers must be considered. The partitioning of graphics displays may require radical redesign.

▶ Page Labeling •6

In a multipage display label each page to show its relation to the others.

SEE ALSO: 2.7.2•5, 2.7.2•6, 4.2•7.

Integrated Display •7

When coherent display is required to aid user perception of relations among data sets, provide those data in an integrated display rather than partitioning them into separate windows.

REFERENCE: EG 2.3.2.

SEE ALSO: 2.7.2•1

•8 **User-Defined Data Windows**

When the need to view several different kinds of data jointly cannot be determined in advance, allow a user to define and select separate data windows that will share a single display frame.

COMMENT: Depending upon user needs (and system capability), data windows might appear simultaneously as segments of a joint display, might be overlaid in varying degrees so as to obscure one another, or might be displayed sequentially at the user's option. In the latter condition, multiple display windows will differ little from multiple display pages, except perhaps in speed of sequential access.

SEE ALSO: 2.7.5•3.

•9 ▶ **Adequate Window Size**

When a display window must be used for data scanning, ensure that the window can display more than one line of data.

REFERENCE: Elkerton, Williges, Pittman and Roach, 1982.

•10 **Display Title at Top**

Begin every display at the top with a title or header, describing briefly the contents or purpose of the display; leave at least one blank line between the title and the body of the display.

REFERENCE: BB 1.1.1, Table 1; PR 4.5.2.

SEE ALSO: 4.2•6.

•11 **Command Entry, Prompts, Messages at Bottom**

Reserve the last several lines at the bottom of every display for status and error messages, prompts, and command entry.

COMMENT: Assuming that the display is mounted physically above the keyboard, which is the customary placement, a user can look back and forth from keyboard to display more easily when prompts and command entry area are at the bottom of the display.

COMMENT: As a corollary to this recommendation, when separate command sets are associated with different display windows, such as options for display control (size of the window, positioning, etc.), those should be shown at the bottom of each window.

REFERENCE: PR 4.5.3; Granda, Teitelbaum and Dunlap, 1982.

SEE ALSO: 3.1.5•2, 4.0•7.

Logical Data Organization •12

Ensure that displays are formatted to group data items on the basis of some logical principle, considering trade-offs derived from task analysis.

REFERENCE: BB 1.8.1.

▶ Grouping for Data Comparison •13

If users must analyze sets of data to discern similarities, differences, trends, and relationships, structure the display format so that the data are consistently grouped.

EXAMPLE:

(Good)

Cost		Output	
Actual	Predicted	Actual	Predicted
947	901	83	82
721	777	57	54
475	471	91	95

(Bad)

Cost		Output	
Actual	Predicted	Predicted	Actual
947	901	82	83
721	777	54	57
475	471	95	91

REFERENCE: BB 1.8.6; Tullis, 1981.

▶ Data Grouped by Sequence of Use •14

Where displayed data are used in some spatial or temporal order, consider grouping those data by sequence of use to preserve that order.

EXAMPLE: Data in an electronic display should match the order of items in an associated paper data form.

REFERENCE: BB 1.8.2; PR 4.10.7.

SEE ALSO: 1.[illegible]•25, 1.4•27, 2.4.7•5.

▶ Data Grouped by Function •15

Where sets of data are associated with particular questions or related to particular functions, consider grouping each set together to help illustrate those functional relationships.

REFERENCE: BB 1.8.2; Tullis, 1981.

3

2.5 Format

•16 ▶ **Data Grouped by Importance**

Where some displayed data items are particularly important, i.e., provide significant information and/or require immediate user response, consider grouping those items at the top of the display.

REFERENCE: BB 1.8.2; Tullis, 1981.

•17 ▶ **Data Grouped by Frequency**

Where some data items are used more frequently than others, consider grouping those items at the top of the display.

COMMENT: Principles of data grouping also apply to the display/listing of control options.

COMMENT: These recommendations for data grouping in display formatting follow familiar human engineering principles for display/control layout in equipment design.

REFERENCE: BB 1.8.2.

SEE ALSO: 3.1.3•21.

•18 ▶ **Data Grouped Alphabetically or Chronologically**

When there is no appropriate logic for grouping data by sequence, function, frequency or importance, adopt some other principle such as alphabetical or chronological grouping.

REFERENCE: BB 1.8.1.

SEE ALSO: 2.1•23

=4

Coding refers to distinctive means for highlighting different categories of displayed data for user attention.

Highlighting Critical Data •1

Provide distinctive coding to highlight important display items requiring user attention, particularly when those items are displayed infrequently.

EXAMPLE: Such items might include recently changed data, or discrepant data exceeding acceptable limits, or data failing to meet some other defined criteria.

COMMENT: "Highlight" is used here in its general sense, meaning to emphasize or make prominent, and is **not** restricted to any particular method of display coding such as brightening or inverse video.

COMMENT: Highlighting is most effective when used sparingly, adding emphasis to a display which is relatively uniform in appearance except for just a few highlighted items.

COMMENT: For some purposes position coding, i.e., displaying important items consistently in a particular location, might be a sufficient means of highlighting, as when an error message appears in a space otherwise left blank. But auxiliary codes may still be needed to highlight important items, even if they are positioned consistently.

REFERENCE: EG 2.1.3, 2.3.12; MS 5.15.3.3.1.

▶ Removing Highlighting •2

If highlighting is used to emphasize important display items, remove such highlighting when it no longer has meaning.

EXAMPLE: If highlighting identifies an error, remove that highlighting when the error is corrected.

Coding by Data Category •3

Provide display coding in applications where a user must distinguish rapidly among different categories of displayed data, particularly when those data are distributed in an irregular way on the display.

2.6 Coding

•4 Meaningful Codes

Adopt meaningful or familiar codes, rather than arbitrary codes.

EXAMPLE: A three-letter mnemonic code (DIR = directory) is easier to remember than a three-digit numeric code.

COMMENT: An arbitrary code, such as a Social Security Number, may eventually become familiar through frequent use.

REFERENCE: BB 3.6.2; MS 5.15.3.3.1.

•5 ▶ Familiar Coding Conventions

Adopt codes for display (and entry) that conform with accepted abbreviations and general user expectations.

EXAMPLE: Use M for "male", F for "female", rather than arbitrary digits 1 and 2. In color coding, use red for danger.

COMMENT: If in doubt, an interface designer can survey prospective users to determine just what their expectations may be.

SEE ALSO: 2.6•32, 4.0•14.

•6 Definition of Display Codes

When codes are assigned special meaning in a display, provide a definition at the bottom of the display that replicates the code being defined.

EXAMPLE: The legend on a map is a common example.

EXAMPLE: For a color code each definition should be displayed in its appropriate color, as RED = hostile displayed in red.

REFERENCE: BB 7.6.1.

SEE ALSO: 4.4•21.

•7 Consistent Coding Across Displays

Assign consistent meanings to symbols and other codes, from one display to another.

COMMENT: When coding is **not** consistent, the user's task of display interpretation may be made more difficult than if no auxiliary coding were used at all.

REFERENCE: BB 3.6.1, 7.6.2; MS 5.15.3.3.1.

SEE ALSO: 2.0•14, 4.0•13.

6

Alphanumeric Coding •8

Consider alphanumeric characters for auxiliary coding in display applications such as graphics where the basic data presentation is not already alphanumeric.

COMMENT: Select alphanumeric codes that are visually distinct for visual displays, and phonetically distinct for auditory displays (or in any application where displayed codes must be spoken).

REFERENCE: EG Table 1.

SEE ALSO: 1.0•18.

▶ Consistent Case in Alphabetic Coding •9

For alphabetic codes display all letters consistently either in upper case or in lower case.

COMMENT: For data display, upper case labels may be somewhat more legible. For data entry, computer logic should **not** distinguish between upper and lower case codes, because users find it hard to remember any such distinction.

REFERENCE: BB 1.3.3.

SEE ALSO: 1.0•27.

▶ Combining Letters and Numbers •10

When codes combine both letters and numbers, group letters together and numbers together rather than interspersing letters with numbers.

EXAMPLE: Letter-letter-number ("HW5") will be read and remembered somewhat more accurately than letter-number-letter ("H5W").

COMMENT: Unfortunately, there are common instances in which this practice has not been followed, such as the coding of British and Canadian postal zones.

REFERENCE: BB 1.5.1; MS 5.15.3.5.8.

▶ Short Codes •11

When arbitrary codes must be remembered by the user, ensure that they are no longer than four or five characters.

EXCEPTION: When a code is meaningful, such as a mnemonic abbreviation or a word, it can be longer.

REFERENCE: BB 1.5.2; MS 5.15.3.5.8.

SEE ALSO: 1.0•15.

7

2.6 Coding

•12 **Special Symbols**

Consider using special symbols, such as asterisks, arrows, etc., to draw attention to selected items in alphanumeric displays.

SEE ALSO: 4.3•19.

•13 ▶ **Consistent Use of Special Symbols**

When using special symbols to signal critical conditions, use them **only** for that purpose.

SEE ALSO: 2.6•7.

•14 ▶ **Markers Close to Words Marked**

When a special symbol is used to mark a word, separate the symbol from the beginning of the word by a space.

COMMENT: A symbol immediately adjacent to the beginning of a word will impair legibility.

REFERENCE: Noyes, 1980.

•15 **Shape Coding**

Consider coding with geometric shapes to help users discriminate different categories of data on graphic displays.

COMMENT: Approximately 15 different shapes can be distinguished readily. If that "alphabet" is too small, it may be possible to use component shapes in combination, as in some military symbol codes.

REFERENCE: EG Table 1.

•16 ▶ **Establishing Standards for Shape Coding**

When shape coding is used, assign codes based on established standards or conventional meanings.

EXAMPLE: A number of international, national, and organizational standards for shape coding exist, and those should be followed where they apply.

COMMENT: Although shape codes can often be mnemonic in form, their interpretation will generally rely on learned association as well as immediate perception. Existing user standards must be taken into account by the display designer.

REFERENCE: MS 5.15.3.3.6.

SEE ALSO: 2.6•7, 4.0•13.

8

Line Coding •17

For graphic displays, consider using auxiliary methods of line coding, including variation in line type (e.g., solid, dashed, dotted) and line width ("boldness").

COMMENT Perhaps three or four line types might be readily distinguished, and two or three line widths.

REFERENCE EG 2.3.

SEE ALSO 2.4.3•6.

▶ Underlining for Emphasis •18

When a line is added simply to mark or emphasize a displayed item, place it **under** the designated item.

COMMENT A consistent convention is needed to prevent ambiguity in the coding of vertically arrayed items.

COMMENT For words composed from the Roman alphabet, underlining probably detracts from legibility less than would "overlining".

REFERENCE MS 5.15.3.3.5.

▶ Coding by Line Length •19

Consider using codes with lines of varying length for applications involving spatial categorization in a single dimension.

EXAMPLE The length of a displayed vector might be used to indicate speed.

COMMENT Perhaps four lengths can be reliably distinguished in practical use. Long lines will add clutter to a display, but may be useful in special applications.

REFERENCE EG Table 1.

▶ Coding by Line Direction •20

Consider using codes with lines of varying direction for applications involving spatial categorization in two dimensions.

EXAMPLE The angle of a displayed vector might be used to indicate direction, i.e., heading or bearing.

COMMENT Users can make fairly accurate estimates of angles for lines displayed at ten-degree intervals.

REFERENCE Smith, 1962a.

SEE ALSO Section 1.2.

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2.6 Coding

•21 Limited Use of Size Coding

Consider size coding, i.e., varying the size of displayed alphanumerics and other symbols, only for applications where displays are not crowded.

COMMENT Perhaps as many as five sizes might be used for data categorization, but two or three will probably prove the practical limit.

REFERENCE EG Table 1; MS 5.15.3.3.6.

•22 ▶ Adequate Differences in Size

For size coding, a larger symbol should be at least 1.5 times the height of the next smaller symbol.

COMMENT An increase in symbol height must usually be accompanied by a proportional increase in width to preserve a constant aspect ratio and so facilitate symbol recognition.

REFERENCE MS 5.15.3.3.6.

•23 Limited Use of Brightness Coding

Consider coding by differences in brightness for applications that only require discrimination between two categories of displayed items; i.e., treat brightness as a two-valued code, bright and dim.

EXAMPLE A data form might display dim labels and bright data items, in order to facilitate data scanning.

COMMENT Perhaps as many as four brightness levels might be used, but at some risk of reduced legibility for the dimmer items. It will be safer to reserve brightness as a two-valued code, particularly for displays whose overall intensity can be adjusted at the terminal by a user.

REFERENCE EG 2.1.4, Table 1.

SEE ALSO 1.4•16.

▶ Brightness Inversion •24

When a capability for brightness inversion is available (so-called "reverse video"), where dark characters on a bright background can be changed under computer control to bright on dark, or vice versa, consider brightness inversion for highlighting critical items that require user attention.

COMMENT: Brightness inversion is obviously limited to use as a two-valued code, i.e., a displayed item is either shown with standard or inverted brightness. If brightness inversion is used for alerting purposes, as recommended here, it should be reserved consistently for that purpose, and **not** be used for general highlighting.

REFERENCE: PR 3.3.4.

SEE ALSO: 2.6•7.

Color Coding for Relative Values •25

When the relative rather than the absolute values of a variable are important, consider displaying gradual color changes as a tonal code to show the relative values of a single variable.

EXAMPLE: In displaying ocean depth, a saturated blue might be used to show the deepest point, with gradually desaturated blues to show decreasing depth.

COMMENT: A gradual change in color might be achieved by varying saturation, starting with a saturated hue and gradually adding white. Or the change might be in intensity, starting with an intense hue and gradually adding black. Or the change might be in hue, moving gradually from red through orange, yellow, green, etc.

COMMENT: People can easily make relative color comparisons when colors are displayed simultaneously. However, people find it more difficult to make absolute color judgments. Part of the problem is color **naming**. A particular blue-green hue might be named "green" by one person but "blue" by another. In the example above, a user could not be expected to associate any particular shade of blue with a specific ocean depth.

COMMENT: Gradual color changes should not be used when absolute values are important, or to code data into discrete categories. As an example, in displaying revenues to determine the point at which a company becomes profitable, it would be more appropriate to use two distinctly different colors, such as black and red, with the color changing at the point of profitability.

SEE ALSO: 2.4.8•7.

2.6 Coding

•26 Color Coding for Data Categories

When a user must distinguish rapidly among several discrete categories of data, particularly when data items are dispersed on a display, consider using a unique color to display the data in each category.

EXAMPLE: Different colors might be used effectively in a situation display to distinguish friendly, unknown, and hostile aircraft tracks, or alternatively to distinguish among aircraft in different altitude zones.

COMMENT: Color is a good auxiliary code, where a multicolor display capability is available. A color code can be overlaid directly on alphanumerics and other symbols without significantly obscuring them. Color coding permits rapid scanning and perception of patterns and relationships among dispersed data items.

COMMENT: Perhaps as many as 11 different colors might be reliably distinguished, or even more for trained observers. As a practical matter, however, it will prove safer to use no more than five different colors for category coding.

COMMENT: With some display equipment now providing millions of different colors, designers may be tempted to exploit that capability by using many different colors for coding. The capability to display many colors may be useful for depicting complex objects, and for providing tonal codes to show the relative values of a single variable. However, such a capability is not useful for coding discrete categories, except that it may allow a designer to select more carefully the particular colors to be used as codes.

REFERENCE: BB 7.2; EG Table 1; MS 5.15.3.3.7; Smith, 1962b; Smith, 1963a; Smith and Thomas, 1964; Smith, Farquhar and Thomas, 1965.

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▶ Easily Discriminable Colors •27

When selecting colors for coding discrete categories of data, ensure that those colors are easily discriminable.

EXAMPLE: On a light background, a good choice of colors might be red, dark yellow, green, blue and black; on a dark background, good colors might be a somewhat desaturated red, green and blue, plus yellow and white.

COMMENT: The harder it is for a user to identify a displayed color, the less useful will be the color code. If many colors are used, colors will be closer in hue and harder to discriminate. If color coding is applied to symbols that subtend small visual angles, which makes color perception difficult, there will be a special need to limit the number of colors used.

COMMENT: Varying saturation and intensity in addition to hue may increase the discriminability of colors. For instance, on a dark background a designer might select a saturated yellow but a desaturated red.

COMMENT: Colors selected for coding should be tested with users to ensure that they are easily discriminable. Testing should be conducted under realistic conditions, since such factors as display type and ambient room lighting will affect color perception. If colors will be used for displaying text, care should be taken to ensure that colored letters are legible as well as discriminable.

▶ Conservative Use of Color •28

Employ color coding conservatively, using relatively few colors and only to designate critical categories of displayed data.

COMMENT: Casual, arbitrary use of colors on every display may cause displays to appear "busy" or cluttered. Casual use of color will also reduce the likelihood that significant color coding on particular displays will be interpreted appropriately and quickly by a user.

REFERENCE: BB 7.1.

▶ Adding Color to Formatted Displays •29

Add color coding after displays have already been designed as effectively as possible in a monochrome format.

COMMENT: Do **not** use color coding in an attempt to compensate for poor display format. Redesign the display instead.

REFERENCE: BB 7.3.

.3

2.6 Coding

•30 ▶ **Redundant Color Coding**

Make color coding redundant with some other display feature such as symbology; do **not** code only by color.

COMMENT: Displayed data should provide necessary information even when viewed on a monochromatic display terminal or hard-copy printout, or when viewed by a user with defective color vision.

REFERENCE: BB 7.4, 7.6.3; MS 5.15.3.3.7.

•31 ▶ **Unique Assignment of Color Codes**

When color coding is used, ensure that each color represents only **one** category of displayed data.

COMMENT: Color will prove the dominant coding dimension on a display. If several **different** categories of data are displayed in red, say, they will have an unwanted visual coherence which may hinder proper assimilation of information by a user.

REFERENCE: BB 7.6.1; Smith and Thomas, 1964.

•32 ▶ **Conventional Assignment of Color Codes**

Choose colors for coding based on conventional associations with particular colors.

EXAMPLE: In a display of accounting data, negative numbers might be shown as red, corresponding to past use of red ink for that purpose.

EXAMPLE: Red is associated with danger in our society, and is an appropriate color for alarm conditions. Yellow is associated with caution, and might be used for alerting messages or to denote changed data. Green is associated with normal "go ahead" conditions, and might be used for routine data display. White is a color with neutral association, which might be used for general data display purposes.

COMMENT: Other associations can be learned by a user if color coding is applied consistently.

REFERENCE: BB 7.7.1, 7.7.2, 7.7.3; MS 5.15.4.6.1.f.

SEE ALSO: 2.6•5, 4.0•13, 4.0•14, 4.3•19.

▶ Brightness and Saturation to Draw Attention •33

Use brighter and/or more saturated colors when it is necessary to draw a user's attention to critical data.

COMMENT. On some display equipment, designers can vary the intensity as well as the saturation for individual hues. On those displays, both intensity and saturation can be used to draw a user's attention to critical data.

COMMENT. Although saturated and/or intense hues are useful for drawing a user's attention, their overuse will result in a display which is garish and difficult to view for long periods.

COMMENT. When deciding the desired saturation of any given display color, consider the ambient lighting under which the display will be viewed. Colors that appear highly saturated in a darkened room will appear less saturated when viewed under high ambient illumination.

▶ Saturated Blue for Background Color •34

Use saturated blue only for background features in a display, and **not** for critical data.

EXAMPLE. Saturated blue might be used for shading background areas in graphic displays, where its lower apparent brightness could possibly be of benefit. Or saturated blue might be used to display a background grid or familiar scale on a graphic display.

COMMENT. The human eye is not equally sensitive to all colors, nor are its optics color-corrected. Blue symbols appear dimmer than others, and are more difficult to focus.

COMMENT. If blue must be used for displayed data, use a desaturated blue or cyan in order to make the data more legible.

REFERENCE. BB 7.6, 7.7.5; Weitzman, 1985.

Blink Coding •35

Consider blink coding when a displayed item implies an urgent need for user attention.

COMMENT. If used sparingly, blinking symbols are effective in calling a user's attention to displayed items of unusual significance. Blinking characters may have somewhat reduced legibility, and may cause visual fatigue if used too much.

COMMENT. Perhaps three or four blink rates might be reliably distinguished, but it will probably prove safer to use blinking as a two-level code, blinking versus nonblinking.

REFERENCE. BB 1.10.2, 1.10.3; EG Table 1; MS 5.15.3.3.2; Smith and Goodwin, 1971b; Smith and Goodwin, 1972.

SEE ALSO. 4.3•19.

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2.6 Coding

•36 ▶ **Blinking Marker Symbols**

When a user must read a displayed item that is blink coded, consider adding an extra symbol such as an asterisk to mark the item, and then blinking that marker symbol rather than blinking the item itself.

COMMENT: This practice will draw attention to an item without detracting from its legibility.

REFERENCE: BB 1.10.3; Smith and Goodwin, 1971b.

•37 ▶ **Optimal Blink Rate**

When blink coding is used, select a blink rate in the range from 2 to 5 Hz, with a minimum duty cycle (ON interval) of 50 percent.

COMMENT: Although equal ON and OFF intervals are often specified, an effective code can probably be provided even when the OFF interval is considerably shorter than the ON (a "wink" rather than a blink), as in occulting lights used for Navy signaling.

REFERENCE: BB 1.10.4; MS 5.15.3.3.2.

•38 **Coding with Texture, Focus, Motion**

Consider other visual coding dimensions for special display applications, including variation in texture, focus, and motion.

COMMENT: Texture can be useful for area coding in graphic displays. Only two levels of focus are feasible, clear and blurred, with the risk that blurred items will be illegible. Perhaps 2 to 10 degrees of motion might be distinguished, in applications where motion is an appropriate and feasible means of display coding.

REFERENCE: EG 2.3.

SEE ALSO: Section 2.4.

4

Auditory Coding •39

Consider auditory displays as a means of supplementing visual display, or as an alternative means of data output in applications where visual displays are not feasible.

EXAMPLE: Auditory signals may be helpful in alerting users to critical changes in a visual display.

EXAMPLE: Auditory output might be used to permit telephone access to computer-stored data.

EXCEPTION: Auditory display may be impractical in situations where high ambient noise prevents accurate listening.

COMMENT: As compared with visual displays, an auditory display offers a potential advantage in attracting a user's attention; a user does not have to "listen at" an auditory display in order to hear it. On the other hand, auditory displays suffer from a number of comparative disadvantages. Auditory displays generally do not offer as great a range of coding options. Auditory displays do not permit easy scanning to discern critical data items, or items that may have been missed at first listening. For human listeners with normal vision, auditory displays do not provide a natural representation of spatial relations.

REFERENCE: MS 5.15.3.9.1.

SEE ALSO: 1.3•30, 4.0•26 thru •29.

▶ Distinctive Auditory Coding •40

For auditory displays, employ distinctive sounds to code items requiring special user attention.

EXAMPLE: A variety of signals may be available, including sirens, bells, chimes, buzzers, and tones of different frequency.

COMMENT: Tones may be presented in sequence to enlarge the signal repertoire.

REFERENCE: Smith and Goodwin, 1970.

SEE ALSO: 4.3•19.

▶ Voice Coding •41

For auditory displays with voice output, consider using different voices to distinguish different categories of data.

COMMENT: At least two voices, male and female, could be readily distinguished, and perhaps more depending upon fidelity of auditory output, and listening conditions.

REFERENCE: Simpson, McCauley, Roland, Ruth and Williges, 1985; Smith and Goodwin, 1970.

2.6 Coding

•42 ▶ **Coding Synthesized Voice Alarms**

If computer-generated speech output is used for auditory display, add a special alerting signal to introduce voice alarms and warning messages in order to distinguish them from routine advisory messages.

REFERENCE. Hakkinen and Williges, 1984; Simpson and Williams, 1980.

SEE ALSO 4.0•26 thru •29.

-8

Display control refers to procedures by which a user can specify what data are shown, and how.

Flexible Display Control by User •1

When user information requirements cannot be exactly defined by the designer, allow users to tailor displays flexibly on line by controlling data selection, data coverage within a display frame, data updating and suppression.

COMMENT: Here user control of data display is distinguished from the broader control of transaction sequences covered in Section 3 of these guidelines.

COMMENT: Display control by users is certainly a necessary capability in general-purpose data processing systems. In a designed information system, i.e., a system created to perform specific tasks, the need for display control by users will depend on the degree to which users' information requirements can be anticipated by designers. In effect, if you know what data the system users will need, then design the displays to provide those data. If you are uncertain about user requirements, then provide users with some flexibility to control display configuration themselves.

COMMENT: Some more specialized methods of display control (e.g., rotation) are discussed elsewhere in guidelines pertaining to graphic data entry.

SEE ALSO: 2.0•1, 2.0•8, 2.8•1, and Section 1.6.

2.7.1 Display Control - Selection

Selection refers to the means for specification of data outputs, either by a user or automatically.

•1 **User Selection of Data for Display**

For general data processing systems, allow users to specify the data for displayed output; for specific information handling applications, allow users to select data for display as needed to meet task requirements.

COMMENT: Flexibility of data selection by users can be exercised, of course, only within the limits of what data are available within a computer system, and what means for data selection have been provided by the designer.

SEE ALSO: 2.0•2, 2.0•8, 2.8•1.

•2 **Display Identification Labels**

When a user will select data displays, assign to each display an identifying label, i.e., an alphanumeric code or abbreviation that can facilitate display requests by the user.

COMMENT: An identifying label will help users remember different displays and provide a convenient means for requesting them. Even in systems where users exercise little initiative in data selection, where displays are largely configured in advance by designers, some kind of display identification will help users understand the displayed consequences of sequence control actions.

COMMENT: It may also the helpful to include an identifying label in any separately selected "window" that might be overlaid on another display, as noted in Section 2.7.5.

REFERENCE: BB 1.2.3, MS 5.15.3.1.13.

SEE ALSO: 4.2•6.

•3 ▶ **Meaningful Display Labels**

The display identification label should be unique, short, but meaningful enough to be remembered easily.

COMMENT: As conceived here, the display label serves as a shorthand identification. The label does not take the place of a full, descriptive title. The full title would be displayed separately.

COMMENT: Where flexibility is desired, it may be good practice to let a user assign names to the particular sets of data that constitute commonly used displays, either as formal names or else as nicknames associated by the computer with the formal names.

SEE ALSO: 2.5•10, 4.2•6.

▶ Consistent Format for Display Labels •4

Place the identifying label used for display selection in a prominent and consistent location on each display.

EXAMPLE: The top left corner of the display might be used for this purpose.

REFERENCE: BB 1.2.4.

SEE ALSO: 2.5•1, 4.0•6, 4.2•6.

Selectable Data Categories •5

If the particular data categories required at different stages in a user's job cannot be exactly predicted, allow the user to select the categories needed for any information handling task.

EXAMPLE: In monitoring aircraft separation for collision avoidance, a user might choose to display selectively the aircraft tracks within a particular altitude zone.

EXAMPLE: To help identify an unrecognized aircraft track, a user might choose to add flight plan data temporarily to an air traffic display.

COMMENT: This recommendation does not lessen the designer's responsibility for determining user needs. Where user information requirements can be defined, displays should be designed to provide necessary data. User selection from available data categories may represent desirable flexibility to meet changing task requirements. However, there is a risk of "data indigestion" if a user selects the wrong categories or too many categories.

COMMENT: Categories of selectable data might include relatively stable elements (e.g., defined flight paths, zones of radar coverage, etc.) as well as the variable elements that represent changing data (e.g., aircraft tracks).

COMMENT: If auxiliary coding is adopted for different data categories, such as shape coding of symbols, code values should be chosen to be distinctive for any likely **combination** of displayed categories.

COMMENT: Users should be provided a ready reminder of what data categories are available, and an easy means of selecting (or suppressing) displayed categories. This implies category selection by menu or function keys.

SEE ALSO: 2.4.8•17.

2.7.1 Display Control - Selection

•6 **Fast Response to Display Request**

Ensure that system response to simple requests for data display take no more than 0.5 to 1.0 second.

COMMENT: When display output is paced in segments (blocks, paragraphs, etc.), response time refers to output of the first segment. The recommended response time of 0.5 to 1.0 second should apply when a user makes a request (usually perceived as "simple") for the next page of a multipage display, or when a display begins to move in response to a scrolling command. The response to a request for a new display may take somewhat longer, perhaps 2 to 10 seconds, particularly if the user perceives such a request to involve more complicated operations, such as accessing different files, transforming data, etc.

COMMENT: The desirability of rapid display generation is often discounted in practice, particularly for general purpose, time-shared systems where other practical design considerations may dictate slower computer response. For dedicated systems, however, those designed to help perform defined information handling tasks, rapid response should be an explicit design goal, with computer output capabilities designed accordingly.

REFERENCE: EG Table 2.

SEE ALSO: 3.0•14, 4.2•2, 4.2•3.

•7 ▶ **Signaling Completion of Display Output**

If display generation is slow, notify the user when display output is complete.

EXAMPLE: A nonobtrusive auditory signal such as a chime should suffice for this purpose.

•8 **Regenerating Changed Data**

Where the computer must regenerate a display to update changed data items, consider regenerating only those changed items if that will speed display output.

COMMENT: The critical design issue here is speed of display. It may be easier for the computer to regenerate an entire display than to change just one item. But if that results in slower computer response to the user, then the added work of selective display regeneration may be worth-while.

COMMENT: Partial display regeneration to show data changes should only be used, of course, when that can be accomplished without erasing unchanged data.

2

▶ Initial Erasure to Replace Changed Data •9

When the computer must regenerate a display to update changed data, erase old data items before adding new data items to the display.

COMMENT: The aim here is to avoid any momentary user confusion that might result from watching portions of old data being overwritten and partially overlapped by portions of new data.

▶ Nondestructive Overlay •10

If changing data elements temporarily overlay and obscure other display data, ensure that the obscured data are **not** permanently erased but will reappear if the overlaid data are later removed.

EXAMPLE: In a situation display moving track data may temporarily obscure stable background data.

COMMENT: To govern the appearance of data overlay, it may be necessary to establish a hierarchy of data categories to determine which will be shown when displayed in combination. Actively changing data will generally take priority over more stable background/reference data.

SEE ALSO: 2.4.8•15, 2.7.5•10.

Printing Displays Locally •11

When displayed data are of potential long-term interest, give users some easy means to print paper copies locally, within security restraints.

COMMENT: Users should not have to remember displayed data. Optional printout allows a user to record data from one display to compare with another, and so deal with situations where a designer has not anticipated the need for such comparison.

COMMENT: A user should **not** have to take notes or transcribe displayed data manually. That practice underutilizes the data handling potential of the computer, and risks transcription errors by the user.

REFERENCE: BB 4.4.6; EG 4.2.14; MS 5.15.9.2; PR 4.10.1.

SEE ALSO: 6.2•7, 6.4•7.

2.7.2 Display Control - Framing

Framing refers to user control of data coverage by display movement, including paging, scrolling, offset, etc.

•1 Integrated Display

In designing displays, include all data relevant to a user's current transaction in one display frame or page.

COMMENT: This recommendation is particularly important when critical data items must be compared by a user. Do **not** rely on a user to remember data accurately from one display frame to another.

COMMENT: If a user requests a display output that exceeds the capacity of a single frame, than it is obviously not possible for any designer to ensure an integrated display. However a designer can mitigate the problems associated with use of extended displays, by providing effective means for identifying and controlling sequential access to different portions of the display.

REFERENCE: EG 3.4.4.

SEE ALSO: 2.0•1, 2.5•5, 2.5•7, 4.0•5, 4.4•1.

•2 Easy Paging

When requested data exceed the capacity of a single display frame, give users some easy means to move back and forth over displayed material by paging or panning/scrolling.

EXAMPLE: Dedicated function keys might be provided for paging forward and back.

COMMENT: Note that critical data requiring integrated display for effective assimilation should be included in a single frame, and **not** dispersed over several pages. Paging is acceptable when the user is looking for a specific data item, but **not** when the user must discern some relationship in a set of data.

REFERENCE: BB 4.4.1, 4.4.2, 4.4.9; EG 6.3.8; MS 5.15.3.1.11.

•3 ▶ Continuous Numbering in Multipage Lists

When a list of numbered items exceeds one display page, number the items continuously in relation to the first item on the first page.

REFERENCE: EG 2.3.10.

4

2.7.2 Display Control - Framing

•11 ▶ **Labeling Scrolling Functions**

When a scrolling orientation is maintained consistently, choose names for display framing functions that refer to movement of the data being displayed, and not to movement of the display frame (or window).

EXAMPLE: In this case, the command "Up 10" should mean that displayed data will move up ten lines behind the (conceptually fixed) display frame, with the effect that ten lines of previous data will disappear from the top of the display, and ten lines of subsequent data will appear at the bottom.

REFERENCE: EG 2.3.16.

•12 **Panning for Flexible Display Framing**

When a display exceeds the capacity of a single frame, in terms of the required extent and detail of coverage, consider providing users a capability to pan the display frame over the data in order to examine different areas of current interest.

COMMENT: A panning capability, sometimes called display "offset", can allow a user to move continuously over an extended display in any desired direction, without encountering any internal boundaries imposed by predefined display framing. Panning control might be accomplished by some continuous-action device such as a joystick, perhaps "dragging" a displayed framing element and then requesting display regeneration. There is some risk that a user might become disoriented in this process.

COMMENT: An alternative approach is to define discrete pages or sections of a large display, assign those sections identifying labels, and allow a user to specify directly which section should be displayed. This approach requires the user to pay specific attention to the labeling of different sections, which extra effort may help maintain orientation to the display as a whole. One risk in this approach, for a continuous display such as a map, is that an area of interest might be at a boundary where none of the sections provide adequate coverage. Thus some degree of overlapped coverage might be needed at the boundaries of displayed sections.

COMMENT: For some applications, it might prove helpful to allow a user to specify a particular location (such as a point on a map) and then automatically offset the display frame to be centered around that location.

SEE ALSO: 2.4.6•3, 2.4.8•10.

5

Zooming for Display Expansion •13

When a user may need to perceive displayed data relations more accurately, or to view data in pictures, diagrams, maps, etc. in greater detail, provide a zooming capability that allows the user to expand the display of any selected area.

COMMENT Zooming can increase display spacing among crowded data items so that they can be perceived better. Thus an air traffic controller might expand a portion of a situation display to see more clearly the spacing of converging tracks that threaten a collision.

COMMENT Zooming can increase the degree of detail, i.e., can add data to a display. Thus a user might expand a city map to see detailed road structures that are not shown in a small-scale map. When used this way, a zooming capability implies that data can be "layered" hierarchically at different levels of aggregation, which may require complex data files and data management techniques.

COMMENT Zooming might be implemented as a continuous function, by which a display can be expanded to any degree, analogous to a continuous panning capability. Or zooming might be implemented in discrete increments, as in increasing the magnification of an optical instrument to x2, x4, etc. Incremental zooming, with abrupt changes in display scale, may tend to disorient a user, but might prove acceptable in some applications.

REFERENCE Foley and Van Dam, 1982.

SEE ALSO 2.4•15.

▶ Show Changing Scale •14

When a display has been expanded from its normal coverage, provide some scale indicator of the expansion factor.

EXAMPLE A linear indicator of current map scale might be shown in the margin, or perhaps simply a numeric indication of the display expansion factor (e.g., x4).

COMMENT In many applications it may be helpful to show the scale even for a display with normal, unexpanded coverage.

SEE ALSO 2.4•16.

2.7.2 Display Control - Framing

•15 Show Overview Position of Visible Section

When a display has been panned and/or expanded from its normal coverage, provide some graphic indicator of the position in the overall display of the currently visible section.

EXAMPLE: In a corner of the display frame the computer might show a rectangle representing the overall display, in which a smaller rectangle is placed to indicate the position and extent of the currently visible portion of that display.

COMMENT: A graphic indication of the current coverage of a panned or expanded display will provide some visual context to help a user maintain a conceptual orientation between the visible part and the whole display from which that part has been excerpted.

COMMENT: In some special applications it may be possible to provide a user with two separate display screens, one to show an overview for general reference, and the other to show an expanded portion of that overview display.

REFERENCE: Foley and Van Dam, 1982.

SEE ALSO: 2.4•17, 2.4.8•11.

•16 Framing Integrally for All Data

Ensure that framing functions perform integrally so that panning and/or zooming will affect all displayed data in the same way.

EXAMPLE: On a situation display, zooming should expand background data such as geographic boundaries to the same scale as the expansion of overlaid "active" data.

•17 Return to Normal Display Coverage

If a user is allowed to pan over an extended display, or zoom for display expansion, provide some easy means for the user to return to normal display coverage.

EXAMPLE: Return to normal display coverage might be accomplished by a function key labeled RETURN, or perhaps RESET.

COMMENT: A user who has panned to some special area in an extended display, or who has expanded a display to examine some particular section in detail, may suddenly need to return quickly to normal display coverage. Perhaps the user has received an alerting message requiring attention to another portion of the display. Quick return to normal coverage will allow the user to re-establish a familiar orientation to the display as a whole.

COMMENT: Here normal coverage might always be defined as that data coverage shown when a display was initially generated. Or it might be desirable in some instances to allow a user to specify what is to be considered normal coverage for any particular display.

Update refers to the regeneration of displayed data, by user request or automatically, to show current changes.

Automatic Display Update •1

When displayed data are changing as a result of external events, a user should be able to request automatic update (computer regeneration) of changed data, and be able to control the update rate.

EXCEPTION: In an operations monitoring task, requirements may dictate the circumstances and rate of display updating.

REFERENCE: MS 5.15.3.4.2.

Highlighting Changed Data •2

When data have changed following automatic display update, consider highlighting those data changes temporarily.

EXAMPLE: A change in a critical data item might be highlighted with reverse video, or might be marked with a blinking symbol.

COMMENT: The desirable interval for highlighting changed data will depend on the importance of those data. If data changes imply a need for special user attention, then highlighting might continue until the user takes some specific acknowledgement action. Otherwise, highlighting might be removed after several seconds, or might continue until a user takes some other control action.

SEE ALSO: 2.6•1

Readability of Changing Data •3

If users must accurately read changing data values, ensure that those data are displayed long enough to be read.

COMMENT: A current design standard specifies that for accurate reading, data should be displayed in a fixed position and updated no more than once per second. In some applications, however, a slower update rate may be required. When in doubt, test user performance with prototype displays to determine appropriate update rates.

COMMENT: If users need only to monitor general trends in changing data values, and do not need to take exact readings, somewhat faster update rates may be acceptable. Again, prototype testing will sometimes be needed to determine appropriate update rates.

REFERENCE: MS 5.15.3.4.1.

2.7.3 Display Control - Update

•4 **Visual Integration of Changing Graphics**

If a user must visually integrate changing patterns on a graphic display, update the data at a rate appropriate to human perceptual abilities for that kind of data change.

EXAMPLE: Effective display of changing radar data for track detection and monitoring requires repeated, sequential output of stored data frames, and the timing of successive frames is critical for optimizing pattern perception.

COMMENT: Slowly developing patterns may be seen more easily with time compression, i.e., with rapid display of sequentially stored data frames. Fast changing data may require time expansion, i.e., slowed output, to aid pattern perception. For critical applications, experiment with prototype displays to determine proper timing.

COMMENT: In some applications it may help to allow a user to control the speed for update of displayed data.

COMMENT: In applications where the timing of display update is variable, it may help to indicate the currently selected time scale on the display.

COMMENT: Similar considerations apply to auditory displays, where speeding or slowing sound signals may aid pattern recognition.

REFERENCE: MS 5.15.3.6.3; Chao, 1985; Foley and Van Dam, 1982.

•5 **Display Freeze**

When displayed data are automatically updated, allow users to stop the process (by "freeze" or "stop action") at any point, in order to examine changed data more deliberately.

EXCEPTION: For an operations monitoring task, requirements may dictate that current data changes be continuously viewed; in such a case, display freeze might be useful during some subsequent playback of recorded data for purposes of operational analysis.

COMMENT: For some applications, it might also prove helpful if a user could step incrementally forward or back in a time sequence, in order to examine data changes frame by frame.

REFERENCE: MS 5.15.3.4.3.

•6 ▸ **Labeling Display Freeze**

When a display has been frozen, annotate that display with some appropriate label to remind users of its frozen status.

REFERENCE: MS 5.15.3.4.4.

SEE ALSO: 4.4•13.

▸ Signaling Changes to Frozen Data •7

When a display being updated in real time has been frozen, warn users if some significant (but not displayed) change is detected in the computer processing of new data.

SEE ALSO: 4.4•13.

▸ Resuming Update After Display Freeze •8

When a display being updated in real time has been frozen, and then a user elects to resume update, resume display update at the current real-time point unless otherwise specified by the user.

COMMENT In some applications, a user might wish to resume display update at the point of stoppage, and so display change would thenceforth lag real-time data change. Or perhaps a user might choose to see a speeded "replay" of interim changes to regain current display status. In practice, however, such options might risk confusion.

REFERENCE: MS 5.15.3.4.3.

Prediction Display •9

To help a user understand and respond effectively to complex data changes, consider displaying a prediction of future data states based on computer analysis of an appropriate model of the data dynamics.

EXAMPLE: Prediction display might be used to aid the control of any rapidly changing process involving complex dynamics, such as depth control for a high-performance submarine.

COMMENT: The concept of prediction display extends the practice of dynamic display update, from simply showing recent and current data states, to anticipate future changes in data. In effect, a computer can iterate in "fast time" changes in a dynamic data model, and then display its current prediction of future real-time changes. The usefulness of such prediction will depend upon the accuracy of the underlying data model. As it happens, where prediction display can help users, as in complex vehicular control or process control applications, the dynamics of process change are often defined sufficiently well to permit valid computer modeling.

COMMENT: A consistent logic should be adopted for computer modeling and prediction in relation to possible user action. For dynamic control appplications, one feasible logic is for a computer to predict and display the future consequences if the user persists in the current control action. As an alternative, a computer might predict and display the consequences if the user were to cease any control action. Either logic could prove helpful. But whichever is adopted should be used consistently.

COMMENT: Prediction displays should be formatted to distinguish clearly between actual current data and extrapolated future data.

2.7.4 Display Control - Suppression

Suppression refers to user control of display coverage by temporary deletion of specified data categories.

•1 **Temporary Suppression of Displayed Data**

When standard data displays are used for special purposes, allow users to temporarily suppress the display of data not needed for the current task.

COMMENT: Data selections made originally for one purpose may not be appropriate for another. When task requirements shift rapidly, it may be more efficient to suppress temporarily the display of unneeded data categories, rather than to regenerate a display with different selection criteria.

SEE ALSO: 2.0•1.

•2 ▶ **Labeling Display Suppression**

When data have been suppressed from a display, annotate the display with some appropriate label to remind users that data have been suppressed.

•3 ▶ **Signaling Changes to Suppressed Data**

When data have been suppressed from a display, warn users if some significant (but not displayed) change is detected in the computer processing of new data.

•4 ▶ **Resuming Display of Suppressed Data**

When data have been suppressed from a display, provide users with some means to quickly restore the display to its complete, originally generated form.

COMMENT: If a function key is used to restore suppressed data, that key action should have no other consequences. For instance, if a user must press RETURN to restore suppressed data, that key should only restore data and should not also move a displayed cursor to some other position.

COMMENT: In some applications, it may be desirable to restore suppressed data automatically, after expiration of a predetermined *time-out*, rather than relying on a user to remember to do it.

Window overlays can be temporarily added to a display to show requested data, menus, user guidance, etc.

Temporary Window Overlays •1

When it is necessary to add requested data or other features temporarily to a current display, consider providing window overlays for that purpose.

EXAMPLE: On a map display, if a user requests detailed data about a particular location, the computer might display an overlaid window with tabular or textual description, which could later be removed by user action.

COMMENT: Here temporary window overlays should be distinguished from the more stable "windows" consistently provided in display formatting, such as the various defined display areas that might be dedicated to showing the display title, a date-time group, user prompting, a composed control entry, an error message, etc.

COMMENT: Window overlays can be used to show data of temporary or extraneous interest. By contrast, if a set of data must be viewed continuously or in an integrated display with other data, then that data set should be available as a selectable data category.

SEE ALSO: 2.7.1•5, and Section 2.5.

Predefined Windows •2

When the value of particular window overlays can be determined during interface design, those overlays should be predefined and offered to users under computer control.

EXAMPLE: A menu of currently appropriate control options might be superimposed on a current display by user selection of the displayed menu title.

COMMENT: The aim here is to allow a user to select window overlays that have already been designed, rather than having to specify a desired window from scratch. User display control should be kept as simple as possible, so that a user can spend time assimilating data instead of manipulating the display of data.

2.7.5 Display Control - Window Overlays

•3 User-Specified Windows

When the need to view several different kinds of data jointly cannot be determined in advance, allow a user to specify and select separate data windows that will share a single display frame.

COMMENT: Users may abuse such a capability for arbitrary window definition, adding so many windows to a display that the resulting hodgepodge defies interpretation. A designer can do little to prevent that. However, the designer can try to ensure that the means for window creation and control are made as efficient as possible.

COMMENT: Depending upon user needs (and system capability), data windows might appear simultaneously as segments of a joint display, might be overlaid in varying degrees so as to obscure one another, or might be displayed sequentially at the user's option. In the latter condition, multiple display windows will differ little from multiple display pages, except perhaps in speed of sequential access.

COMMENT: This recommendation assumes that it is mostly data overlays which a user will want to create. Other kinds of window overlays would usually be offered under computer control, such as those providing error messages and other forms of user guidance. It is possible, however, that a user might wish to define certain kinds of non-data windows, such as an overlay of "favorite" menu options, or an overlaid guidance "memo" composed for the user's own purposes. Perhaps a user should be allowed to create those kinds of window overlays as well.

SEE ALSO: 2.5•8.

•4 Consistent Window Control

Ensure that the means provided users to control window overlays operate consistently from one display to another for each type of overlay.

COMMENT: Control of predefined windows may simply involve "opening" and "closing" them, by selection of displayed option labels or function keys. Control of user-defined windows may require user specification of window contents, window size and positioning on the display. Such window control must be learned by a user, and consistent design of control logic will aid that learning.

COMMENT: Some advocates of window overlays predict that standard methods of window control will become part of the basic support software for user interface design.

REFERENCE: Foley and Van Dam, 1982.

3

Easy Suppression of Window Overlays •5

Provide an easy means for a user to suppress the display of window overlays.

EXAMPLE: A requested guidance overlay might be removed by user selection of a RETURN function key; a menu overlay displayed under computer control might disappear automatically following user selection of an option from that menu.

SEE ALSO: Section 2.7.4.

Labeling Windows •6

When a user can select predefined window overlays, assign to each overlay an identifying label.

COMMENT: Labeling window overlays may help users request and recognize them, in the same way that display labeling can aid display selection.

SEE ALSO: 2.7.1•2.

Indicate Active Window •7

If several window overlays are displayed at once, indicate to the user in which window (if any) an action can currently be taken.

EXAMPLE: A prominent cursor might be displayed in the currently active window, or perhaps the displayed border of an active window might be highlighted in some way.

COMMENT: Addding window overlays to a display can increase the conceptual complexity of control actions as well as the difficulty of data assimilation. Consider a case in which several windows are shown, including some menu overlays and some data windows. There it is important to indicate to a user which window is currently "active", i.e., whether the next action will result in a menu selection or a data change.

SEE ALSO: 2.6•1.

▶ Easy Shifting Among Windows •8

If several window overlays are displayed at once, provide some easy means for a user to shift among them to select which window shall be currently active.

COMMENT: The most direct method might be to allow a user to select a window by pointing anywhere within its displayed borders, but that action might be confused with the selection of a particular item within the window. Some designers provide a special symbol for window selection in the border itself.

2.7.5 Display Control - Window Overlays

•9 Consistent Control Within Windows

When control actions such as command entry may be taken by a user working within a window overlay, ensure that those control actions will be consistent from one window to another.

EXAMPLE: Cursor positioning controls and data editing capabilities should operate consistently within all windows.

COMMENT: If controls in one window operate differently than in another, user confusion will be unavoidable.

•10 Nondestructive Overlay

When a window overlay temporarily obscures other displayed data, ensure that the obscured data are **not** permanently erased but will reappear if the overlay is later removed.

SEE ALSO: 2.7.1•10.

Design change of software supporting data display functions may be needed to meet changing operational requirements.

Flexible Design for Data Display •1

When data display requirements may change, which is often the case, provide some means for users (or a system administrator) to make necessary changes to display functions.

COMMENT: Display characteristics that may need to be changed include those represented in these guidelines, namely, the types of data that can be displayed, formatting and coding logic, and the capabilities offered for display control.

COMMENT: Many of the preceding guidelines in this section imply a need for design flexibility. Much of that needed flexibility can be provided in initial interface design. Some guidelines, however, suggest a possible need for subsequent design change, and those guidlines are cited below.

SEE ALSO: 2.0•2, 2.0•8, 2.0•11, 2.5•8, 2.7.1•1, 2.7.1•3.

APPENDIX C

Mission Scenario Analysis Template Data

This appendix contains the mission scenario analysis templates (MSAT) completed during the scenario review of the CMS document. The MSAT form was developed for facilitating the analysis process. Each of the 145 completed MSATs represent a separate mission scenario event, either planned or unplanned, that required the crew to respond in some manner. These MSATs are working copies completed during the actual research. As a result, some of the terminology used does not directly correlate with the terminology used in the Technical Report. As an example, during the research "external sensors" meant aircraft sensors that electronically sensed the external environment. In the Technical Report, individual types of external sensors are identified.

Mission Scenario Analysis

Record No. 1

(1) Mission Leg: E to F

(2) Mission Phase: Penetration

(3) Scenario Event (Planned Y):

Rx execute orders

(4) Crews' Response to Event:

Commit to mission - Carry out HHCL procedures

(5) Informational Demands:

Time to HHCL
Distance to HHCL
HHCL procedures
CMF schedule

(6) Information Sources:

CMF
HHCL procedures
Tactical doctrine
ETA/EDA to HHCL

(7) Crews' Decision:

Carryout HHCL procedures

(8) Decision Class:

Rule-based

(9) Action Taken:

Put on goggles
Run Pre-arm checklist
Curtail ext. emissions
Configure personal equipment

(10) Information Management Requirements:

Present CMF schedule
Present HHCL procedures
Present ETA/EDA to HHCL
Present pre-arm checklist
Coordinate external emission termination

Mission Scenario Analysis

Record No. 2

(1) Mission Leg: E to F

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

WARM message received

(4) Crews' Response to Event:

Read WARM message

(5) Informational Demands:

Content of WARM message
Implication of WARM message on mission

(6) Information Sources:

Communications receiver
Tactical doctrine

(7) Crews' Decision:

Take note of WARM message for future reference

(8) Decision Class:

Rule-based

(9) Action Taken:

Read WARM message

(10) Information Management Requirements:

Present WARM message
Record WARM message for possible future reference

3 x 4

Mission Scenario Analysis

Record No. 3

(1) Mission Leg: E to F

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

Unknown radar detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for unknown radar
Implication of options
Radar identification
Tactical doctrine

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Assess/Monitor unknown radar

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Monitor radar
Attempt to identify and locate radar

(10) Information Management Requirements:

Present detection of unknown radar
Present options
Present applicable tactical doctrine
Monitor radar activity

Mission Scenario Analysis

Record No. 4

(1) Mission Leg: F to G

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

Identification of unknown, ground-based radar

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Radar threat description
Response options to radar
Implications of operations
Tactical doctrine

(6) Information Sources:

External sensors
Radar classification database
Tactical doctrine

(7) Crews' Decision:

Continue to monitor
Search for related signals

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Continue to monitor radar sensors
Search for related signals

(10) Information Management Requirements:

Present identification of unknown radar
Present threat potential of radar
Monitor threat radar activity
Present any new signals
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 5

(1) Mission Leg: G to SD

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

SUAWACS detected/Id.

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SUAWACS detection
Radar classification
Tactical doctrine
Aircraft fuel status
CMF schedule

(6) Information Sources:

Radar sensors
Radar class. database
Tactical doctrine
System status data
CMF

(7) Crews' Decision:

Descend aircraft
Descend to low attitude flight

(8) Decision Class:

Rule-based to descend
Knowledge-based to low altitude flight

(9) Action Taken:

Start descent
Run before descent checklist
Run descent checklist

(10) Information Management Requirements:

Descent of aircraft (checklists, system status)
Vigilance of SUAWACS activity
Present options
Present aircraft fuel status
Present CMF schedule

2

Mission Scenario Analysis

Record No. 6

(1) Mission Leg: SD to LO

(2) Mission Phase: Penetration

(3) Scenario Event (Planned Y):

Continue vigilance of SUAWACS

(4) Crews' Response to Event:

Continue vigilance

(5) Informational Demands:

SUAWACS activity
Alert to possible new threats

(6) Information Sources:

Radar sensors
Ext. sensors

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Continue vigilance of SUAWACS
Search for new threats

(10) Information Management Requirements:

Vigilance of SUAWACS activity
Search for new threats

3

Mission Scenario Analysis

Record No. 7

(1) Mission Leg: SD to LO

(2) Mission Phase: Penetration

(3) Scenario Event (Planned Y):

Preparation for penetration/strike phase

(4) Crews' Response to Event:

Carry out preparation procedures

(5) Informational Demands:

Equipment status
Strike phase preparation procedures
CMF schedule

(6) Information Sources:

Equipment checkout checklists
CMF Strike phase preparation procedures

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Check all equipment

(10) Information Management Requirements:

Present CMF schedule
Present equipment checkout checklists
Present strike phase preparation procedures

4

Mission Scenario Analysis

Record No. 8

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

SUAWACS-AI data link detected, located, and identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options to SUAWACS-AI data link
Implications of options
Tactical doctrines
Ext. sensor activity

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Empty countermeasures and monitor AI

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures
Monitor AI and SUAWACS

(10) Information Management Requirements:

Present options
Report SUAWACS-AI data link activity
Coordinate countermeasures information
Monitor SUAWACS and AI activity
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 9

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

AI radar detected in search mode - SUAWACS still present

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options to enemy AI searching radar
AI identification
AI strike potential
AI location
SUAWACS activity

(6) Information Sources:

Tactical doctrine
External sensors
AI database

(7) Crews' Decision:

Employ countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures
Monitor and track AI
Monitor and track SUAWACS

(10) Information Management Requirements:

Present detection of AI radar in search mode
Present AI identification and strike potential
Present options
Present applicable tactical doctrine
Monitor and track AI
Monitor and track SUAWACS

Mission Scenario Analysis

Record No. 10

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

AI is detected in track mode

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI type in track mode
Implications of options
AI activity
Tactical doctrine
SUAWACS activity

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Employ additional countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ additional countermeasures
Monitor and track AI
Monitor and track SUAWACS

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Coordinate countermeasures information
Monitor and track AI
Monitor and track SUAWACS

Mission Scenario Analysis

Record No. 11

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

AI missile launch detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options to AI missile launch
Implications of options
Missile threat potential
External situations
AI missile course
AI activity

(6) Information Sources:

Tactical doctrine
AI missile database
External sensors

(7) Crews' Decision:

Perform evasive maneuvers

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive maneuvers
Monitor AI activity
Track AI missile

(10) Information Management Requirements:

Present options
Present missile threat potential
Coordinate evasive maneuvers information
Monitor AI and SUAWACS activity
Track AI missile
Present navigation/AFPI information

Mission Scenario Analysis

Record No. 12

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

2nd AI missile launched/detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI missile launch
Implications of options
Missile threat potential
AI activity
AI missile course

(6) Information Sources:

Tactical doctrine
AI missile database
External sensors

(7) Crews' Decision:

Perform additional countermeasures and maneuvers

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform additional countermeasures and maneuvers
Monitor AI activity
Track AI missile

(10) Information Management Requirements:

Present options
Present missile threat potential
Present applicable tactical doctrine
Coordinate countermeasures and maneuvers
Monitor AI and SUAWACS activity
Track AI missile

Mission Scenario Analysis

Record No. 13

(1) Mission Leg: LO to H

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

AI signal goes down
SUAWACS signals continue

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options when AI activity goes down
Implications of options
AI activity
SUAWACS activity

(6) Information Sources:

External sensors
Tactical doctrine

(7) Crews' Decision:

Stop previous measures and resume flight plan

(8) Decision Class:

Knowledge-base

(9) Action Taken:

Defensive measures terminated
Resume flight plan

(10) Information Management Requirements:

Present options
Monitor SUAWACS activity
Monitor for AI activity
Present mission flight plan
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 14

(1) Mission Leg: H to J

(2) Mission Phase: Penetration-coast-in

(3) Scenario Event (Planned Y):

CMF scheduled activities
- -Enemy territory coast-in
- -Perform navigation update
- -Activate TF

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

Coastline activities	TF descent checklist results
AFPI data	CMF schedule
Navigation data	

(6) Information Sources:

External sensors	TF descent checklist
AFPI equipment	CMF
Navigation equipment	

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Monitor coast-in	Run TF descent checklist
Perform navigation update	Activate TF

(10) Information Management Requirements:

Present coast-in activities
Present AFPI
Present navigation information
Update navigation database
Present IF descent checklist
Present CMF schedule

Mission Scenario Analysis

Record No. 15

(1) Mission Leg: H to J through TP3 to N

(2) Mission Phase: Penetration into target strike

(3) Scenario Event (Planned N):

Jammer malfunction

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for jammer malfunctions
Implications of options
Identify jammer malfunction

(6) Information Sources:

Tactical doctrine
Jammer equipment BIT

(7) Crews' Decision:

Analyze jammer malfunction

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Analyze and assess jammer malfunction

(10) Information Management Requirements:

Present jammer malfunction BIT
Present options
Coordinate information for jammer malfunction analysis
Present applicable tactical doctrine

4-2

Mission Scenario Analysis

Record No. 16

(1) Mission Leg: H to J through TP3 to N

(2) Mission Phase: Penetration into target strike

(3) Scenario Event (Planned N):

Jammer malfunction analysis

(4) Crews' Response to Event:

Perform fault tree analysis

(5) Informational Demands:

Fault tree for jammer
Fault analysis procedures
Analysis results

(6) Information Sources:

Jammer fault analysis procedures (fault tree)
Jammer fault analysis test equipment

(7) Crews' Decision:

Use fault tree procedures to isolate fault

(8) Decision Class:

Rule-based

(9) Action Taken:

Perform sequence of prescribed tasks to isolate fault

(10) Information Management Requirements:

Present fault tree analysis procedures
Coordinate information for on-going fault tree analysis

Mission Scenario Analysis

Record No. 17

(1) Mission Leg: H to J

(2) Mission Phase: Penetration, coast-in

(3) Scenario Event (Planned Y):

Known, pre-planned, SAM radar threats (2) encountered

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for radar threat
Implication of options
Confirm Id of planned threat radars
SAM location
CMF planned response

(6) Information Sources:

Tactical doctrine
External sensors
CMF

(7) Crews' Decision:

Monitor SAM radar/activity

(8) Decision Class:

Rule-based

(9) Action Taken:

Monitor SAM radar

(10) Information Management Requirements:

Present SAM radar threat identification and location
Present options
Present radars activity
Present CMF information
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 18

(1) Mission Leg: J to K

(2) Mission Phase: Penetration

(3) Scenario Event (Planned Y):

Known, pre-planned, SAM radar threat

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM radar threat
Implication of options
Affirm Id of pre-planned threat
SAM location
CMF planned response

(6) Information Sources:

Tactical doctrine
External sensors
CMF

(7) Crews' Decision:

Avoid threat and monitor radar

(8) Decision Class:

Rule-based

(9) Action Taken:

Fly course to avoid threat
Monitor radar

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present SAM radar threat identification and location

Mission Scenario Analysis

Record No. 19

(1) Mission Leg: J to K

(2) Mission Phase: Penetration

(3) Scenario Event (Planned N):

Pop-up (power line)

(4) Crews' Response to Event:

Climb aircraft to additional altitude
Descend aircraft and resume TF

(5) Informational Demands:

Height of power line
Location of power line
AFPI data
Navigation data
TF resumption checklist results

(6) Information Sources:

External sensors
AFPI equipment
Navigation equipment
TF resumption checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Climb aircraft
Run TF checklist
Descend aircraft
Resume TF

(10) Information Management Requirements:

Present pop-up location and height
Present AFPI
Present navigation information
Present TF resumption checklist

Mission Scenario Analysis

Record No. 20

(1) Mission Leg: K to L

(2) Mission Phase: Target strike

(3) Scenario Event (Planned Y):

PT1: predictable RT - missile target

(4) Crews' Response to Event:

Perform target strike activities

(5) Informational Demands:

Missile pre-launch checklist results
Navigation update information
Image offset aimpoints data (x2)
Direct image aimpoint data
Target occupancy information
CMF information (PT1 info)

(6) Information Sources:

Missile pre-launch checklists
Navigation equipment
Target imagers/sensors
Target recognizers/occupancy sensors
CMF

(7) Crews' Decision:

Target located and occupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist
Perform navigation update
Perform (2) image offsets
Perform (1) image direct
Ascertain target occupancy

(10) Information Management Requirements:

Present pre-launch checklist
Present navigation information
Present image offset information
Present direct imagery information
Present target occupancy information
Coordinate predictable RT information assimilation
Update navigation database
Present CMF information

Mission Scenario Analysis

Record No. 21

(1) Mission Leg: K to L

(2) Mission Phase: Target strike

(3) Scenario Event (Planned Y):

PT1: Occupied, predictable RT - missile target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for occupied RT
Implications of options
Tactical doctrine
CMF planned response

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon as planned

(8) Decision Class:

Rule-based

(9) Action Taken:

Schedule weapon delivery
Correct to track
Continue with mission flight plan

(10) Information Management Requirements:

Present options
Present CMF information
Coordinate weapon delivery schedule

Mission Scenario Analysis

Record No. 22

(1) Mission Leg: L to M

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Course change and transfer alignment (TAL) maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

AFFI data
Navigation data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL manuever

(10) Information Management Requirements:

Present navigation information
Present AFPI
Coordinate TAL maneuver information
Present CMF schedule

Mission Scenario Analysis

Record No. 23

(1) Mission Leg: L to M

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

PT2: Predictable RT - missile target

(4) Crews' Response to Event:

Perform target strike activities for a missile strike

(5) Informational Demands:

Missile pre-launch checklist results
Navigation update information
Image offset aimpoint data
Target occupancy data
CMF information (PT2 info)

(6) Information Sources:

Missile pre-launch checklist
Navigation equipment
Target imagers/sensors
Target recognizers/occupancy sensors
CMF

(7) Crews' Decision:

Target located and occupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run pre-launch missile checklist
Perform nav. update
Perform (1) image offset
Perform (1) image direct
Ascertain target occupancy

(10) Information Management Requirements:

Present pre-launch checklist
Present navigation information
Present image offset information
Coordinate predictable, RT information
Update navigation database
Present CMF information

Mission Scenario Analysis

Record No. 24

(1) Mission Leg: L to M

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

PT2: Occupied, predictable RT - missile target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for occupied RT
Implications of options
Tactical doctrine
Pre-planned mission response
CMF information

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon as planned

(8) Decision Class:

Rule-based

(9) Action Taken:

Schedule weapon delivery
Continue with mission as planned

(10) Information Management Requirements:

Present options
Present CMF information
Coordinate weapon delivery schedule
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 25

(1) Mission Leg: L to M

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Perform navigation update and resume TF

(4) Crews' Response to Event:

Perform navigation update and resume TF

(5) Informational Demands:

CMF schedule
AFPI data
Navigation data
TF resumption checklist results

(6) Information Sources:

CMF
AFPI equipment
Navigation equipment
TF resumption checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform navigation update
Run TF resumption checklist
Descend aircraft
Resume TF

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database
Present TF resumption checklist

Mission Scenario Analysis

Record No. 26

(1) Mission Leg: M to IPTP3

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Weapon delivery-manual
Two consecutive missile launches

(4) Crews' Response to Event:

Perform weapon delivery

(5) Informational Demands:

Results of missile pre-launch checklists
Results of missile launch checklists
Results of missile launches
Results of missile post-release checklists
Launch points
Launch altitude
CMF information

(6) Information Sources:

Tactical doctrine
CMF
Missile pre-launch checklist
Missile launch checklist
Missile post-release checklist
AFPI equipment
Navigation equipment

(7) Crews' Decision:

Launch missiles

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist (x2)
Run missile launch checklist (x2)
Launch missile (x2)
Run missile post-release checklist (x2)
Ascend aircraft to launch altitude

(10) Information Management Requirements:

Present missile launching checklists
Coordinate aviation/navigation data
Present CMF information
Present applicable tactical doctrine

Mission Scenario Analysis

Record No. 27

(1) Mission Leg: M to IPTP3 to TP3 to N

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP3: Predictable RT-gravity weapon target

(4) Crews' Response to Event:

Perform predictable RT strike activities for a gravity weapon target

(5) Informational Demands:

Pre-bomb run checklist results
Image offset aimpoint data
Image target directly data
Bomb run checklist results
Target occupancy data
CMF schedule

(6) Information Sources:

Pre-bomb run checklist
Bomb run checklist
Target imagers/sensors
Target recognizers/occupancy sensors
CMF

(7) Crews' Decision:

Target located and unoccupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run pre-bomb run checklist
Run bomb run checklist
Perform image offset aimpoint
Perform direct target imaging
Ascertain target occupancy

(10) Information Management Requirements:

Present Pre-bomb checklist
Present image offset aimpoint information
Present direct target imaging information
Present target occupancy information
Coordinate predictable RT information assimilation
Present CMF schedule

Mission Scenario Analysis

Record No. 28

(1) Mission Leg: L to M

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP3: Unoccupied, predictable RT-gravity weapon target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for unoccupied, predictable RT
Implications of options
Tactical doctrine
CMF planned response

(6) Information Sources:

Mission pre-planning
CMF
Tactical doctrine

(7) Crews' Decision:

Do not release weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

Abort weapon delivery
Run bomb abort checklist
Change course to bypass target

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present bomb abort checklist
Coordinate bomb abort information
Coordinate change in course information

Mission Scenario Analysis

Record No. 29

(1) Mission Leg: TP3 to N

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Jammer returned to normal operation

(4) Crews' Response to Event:

Jammer restored to operating condition

(5) Informational Demands:

Jammer operational status

(6) Information Sources:

Jammer equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Restore jammer to normal operation

(10) Information Management Requirements:

Continued fault diagnostics which resulted in restoring jammer
Presentation of jammer operational status

Mission Scenario Analysis

Record No. 30

(1) Mission Leg: TP3 to N

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Primary radar control made fails

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options to primary radar failure
Implications of options
Tactical doctrine
CMF
Identification of failure

(6) Information Sources:

Tactical doctrine
CMF
Radar BIT

(7) Crews' Decision:

Start assessment of radar control mode

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Switch-over to back-up radar
Start analysis of primary radar failure

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Coordinate switch-over to back-up radar information
Coordinate failure analysis of primary radar failure

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Mission Scenario Analysis

Record No. 31

(1) Mission Leg: TP3 to N

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Perform navigation update
-Descend aircraft

(4) Crews' Response to Event:

Perform navigation update
Descend aircraft

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform navigation update
Descend aircraft at point N

(10) Information Management Requirements:

Present navigation update information
Present AFPI
Present CMF schedule
Update navigation database

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Mission Scenario Analysis

Record No. 32

(1) Mission Leg: N to P

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Primary radar control mode returns to normal operation

(4) Crews' Response to Event:

Primary radar control mode returned to normal operation

(5) Informational Demands:

Primary radar operational status

(6) Information Sources:

Primary radar equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Restore primary radar control mode
Switch-out back-up radar
Update all systems

(10) Information Management Requirements:

Continued fault diagnostics which resulted in restoring the primary radar control mode
Present switch-over information for primary and back-up radars
Coordinate updating systems associated with radar control mode

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Mission Scenario Analysis

Record No. 33

(1) Mission Leg: P to Q

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Climb aircraft at point Q

(4) Crews' Response to Event:

Climb aircraft at point Q

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Climb aircraft at point Q

(10) Information Management Requirements:

Present navigation information
Present AFPI
Present CMF schedule

Mission Scenario Analysis

Record No. 34

(1) Mission Leg: P to Q

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Format and submit strike report

(4) Crews' Response to Event:

Format and submit strike report

(5) Informational Demands:

Target strike results to that time
Target strike report format
CMF schedule

(6) Information Sources:

Target strike results database
Target strike report formats
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Format and submit strike report

(10) Information Management Requirements:

Present CMF schedule
Format strike report
Submit strike report

Mission Scenario Analysis

Record No. 35

(1) Mission Leg: Q to IPTP4

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Heading change
-Run pre-bomb checklist

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule
Pre-bomb run checklist results

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF
Pre-bomb run checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change headings
Climb aircraft
Run pre-bomb checklist

(10) Information Management Requirements:

Present navigation information
Present AFPI
Present CMF schedule
Present pre-bomb run checklist

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Mission Scenario Analysis

Record No. 36

(1) Mission Leg: Q to IPTP4 to TP4

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP4: Predictable RT - gravity weapon target

(4) Crews' Response to Event:

Perform predictable RT strike activities for a gravity weapon delivery

(5) Informational Demands:

CMF schedule
Image offset aimpoint data
Direct target imagery data
Bomb run checklist results
Target occupancy data

(6) Information Sources:

CMF
Bomb run checklist
Target imagers/sensors
Target recognizers/occupancy sensors

(7) Crews' Decision:

Target located and occupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run bomb run checklist
Perform image offset aimpoint
Perform direct target imaging
Ascertain target occupancy

(10) Information Management Requirements:

Present CMF schedule
Present image offset aimpoint information
Present direct targeting image information
Present target occupancy information
Coordinate predicatble RT information requirements

Mission Scenario Analysis

Record No. 37

(1) Mission Leg: IPTP4 to TP4

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP4: Occupied, predictable RT - gravity weapon target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for occupied, predictable RT
Implications of options
Tactical doctrine
CMF planned response

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon as scheduled

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Schedule weapon delivery
Roll-in to target
Release weapon
Run TF resumption checklist
Resume TF
Run post-release checklist

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present navigation/AFPI information for roll-in
Coordinate weapon delivery schedule
Present TF resumption checklist
Present post-release checklist

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Mission Scenario Analysis

Record No. 38

(1) Mission Leg: IPTP4 to TP4

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM tracking radar detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM tracking radar
Implications of options
Tactical doctrine
CMF data on SAM threats
SAM location

(6) Information Sources:

Tactical doctrine
CMF
External sensors

(7) Crews' Decision:

Employ radar countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present SAM radar threat identification and location
Coordinate countermeasures initiated against SAM tracking radar

Mission Scenario Analysis

Record No. 39

(1) Mission Leg: IPTP4 to TP4

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

High tower detected in flight path

(4) Crews' Response to Event:

Perform sharp turns to avoid tower

(5) Informational Demands:

Tower position
Navigation data
AFPI data

(6) Information Sources:

External sensors
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Take evasive action to avoid hitting tower
Perform navigation update, once past tower

(10) Information Management Requirements:

Present tower location
Present AFPI
Present navigation information

Mission Scenario Analysis

Record No. 40

(1) Mission Leg: TP4 to T1

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Planned course change for next target, T1
-Possible pop-up hazards

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

Navigation data
AFPI data
Detection of Pop-ups
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
External sensors
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Change altitude
Watchful for pop-ups

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI

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Mission Scenario Analysis

Record No. 41

(1) Mission Leg: TP4 to T1

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Fixed target strike - gravity weapon, automatic

(4) Crews' Response to Event:

Perform fixed target strike activities for a gravity weapon strike, automatic delivery

(5) Informational Demands:

Pre-bomb run checklist data
Image offset aimpoint data
Bomb run checklist results
Correct to track data
Weapon release data
Post-release bomb run checklist results
CMF schedule

(6) Information Sources:

Pre-bomb run checklist
Bomb run checklist
Post-bomb run checklist
Weapon delivery equipment
Target imagers/sensors
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run pre-bomb run checklist
Run bomb run checklist
Perform image offset aimpoint
Correct to track
Release weapon, automatic mode
Run post-release bomb run checklist

(10) Information Management Requirements:

Present pre-bomb run checklist
Present bomb run checklist
Present image offset aimpoint information
Coordinate weapon release information
Present post-release bomb run checklist
Present CMF information

Mission Scenario Analysis

Record No. 42

(1) Mission Leg: T1 to IPT2

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Detection and identification of known, pre-planned SAM radar threat

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for pre-known SAM radar threat
Implications of options
Confirm identification of planned threat
SAM radar activity
CMF planned response

(6) Information Sources:

Tactical doctrine
External sensors
CMF

(7) Crews' Decision:

Monitor SAM radar/activity

(8) Decision Class:

Rule-based

(9) Action Taken:

Monitor SAM radar/activity

(10) Information Management Requirements:

Present SAM radar threat identification and location
Present options
Present radar activity
Present CMF information
Present applicable tactical doctrine

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Mission Scenario Analysis

Record No. 43

(1) Mission Leg: T1 to IPT2

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Prepare for next target, T2
-Prepare for detonation waves from TP4 and T1

(4) Crews' Response to Event:

Perform activities as planned

(5) Informational Demands:

TF resumption checklist results
Navigation data
AFPI data
Pre-bomb run checklist results
CMF schedule
Time of arrival for detonation waves TP4 and T1

(6) Information Sources:

TF resumption checklist
Navigation equipment
AFPI equipment
Pre-bomb run checklist
CMF
Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist
Descend aircraft
Resume TF
Run pre-bomb run checklist
Prepare for detonation waves

(10) Information Management Requirements:

Present TF resumption checklist
Present navigation information
Present AFPI
Present pre-bomb run checklist
Present CMF schedule
Present time to detonation waves

Mission Scenario Analysis

Record No. 44

(1) Mission Leg: IPT2 to T2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target (T2)

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Change altitude
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Update navigation database
Present AFPI

Mission Scenario Analysis

Record No. 45

(1) Mission Leg: IPT2 to T2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T2: fixed target strike - gravity weapon

(4) Crews' Response to Event:

Perform fixed target strike activities when a gravity weapon is to be delivered (automatic release)

(5) Informational Demands:

Image offset aimpoints data (x2)
Bomb run checklist
CMF schedule
Weapon release data

(6) Information Sources:

Target imagers/sensors
Bomb run checklist
Navigation equipment
Weapon launcher equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run bomb run checklist
Perform (2) image offset aimpoints
Correct to track
Release weapon, automatic mode

(10) Information Management Requirements:

Present CMF schedule
Present bomb-run checklist
Present image offset aimpoint information (x2)
Coordinate information for weapon release
Coordinate information for correct to track

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Mission Scenario Analysis

Record No. 46

(1) Mission Leg: IPT2 to T2

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM tracking radar detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM tracking radar
Implications of options
Tactical doctrine
CMF data on SAM threats
SAM location

(6) Information Sources:

Tactical doctrine
CMF
External sensors

(7) Crews' Decision:

Employ radar countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures against SAM radar

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present SAM radar threat identification and location
Coordinate countermeasures initiated against SAM tracking radar

Mission Scenario Analysis

Record No. 47

(1) Mission Leg: T2 to R

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
- -Resume TF
- -Run post-release checklists for T2
- -Format and submit strike reports
- -Prepare for detonation wave from T2

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

TF resumption checklist results	Target strike results
Navigation data	Target strike report format
AFPI data	CMF schedule
Post-release checklist results	Time to detonation wave T2

(6) Information Sources:

TF resumption checklist	Target strike database
Navigation equipment	Target strike report format
AFPI equipment	CMF
Post-release checklist	Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist	Format and submit target strike report
Descend aircraft	
Resume TF	Prepare for detonation wave T2
Run post-release checklist	

(10) Information Management Requirements:

Present TF resumption checklist	Format strike report
Present navigation information	Submit strike report
Present AFPI	Present CMF schedule
Present post-release checklist	Present time to deton. wave T2

Mission Scenario Analysis

Record No. 48

(1) Mission Leg: R to LT3

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Change course

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate TAL maneuver information

Mission Scenario Analysis

Record No. 49

(1) Mission Leg: R to LT3

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Missile radar altimeter malfunction occurs

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for missile radar altimeter malfunction	CMF
	Missile BIT report
Implication of options	OAS reprogramming report
Tactical doctrine	Target book (file)

(6) Information Sources:

Tactical doctrine	OAS
CMF	Target book (file)
Missile BIT	

(7) Crews' Decision:

Select a later target for semiballistic launch

(8) Decision Class:

Rule-based

(9) Action Taken:

Select later target for use of malfunctioning missile
Select T4 as future target for malfunctioning missile
Enter T4 as future target for missile in target book (file)

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present malfunctioning missile BIT report
Present OAS reprogramming report
Present target book (file)
Coordinate missile reprogramming
Coordinate target book updating

Mission Scenario Analysis

Record No. 50

(1) Mission Leg: R to LT3

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target, T3

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 51

(1) Mission Leg: R to LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T3: fixed target strike - missile weapon, automatic

(4) Crews' Response to Event:

Perform fixed target strike activities for a missile weapon strike, automatic delivery

(5) Informational Demands:

Missile pre-launch checklist results	Weapon release data
Missile launch checklist results	Post-release checklist results
Correct to track data	CMF schedule

(6) Information Sources:

Missile pre-launch checklist	Weapon launcher equipment/sensors
Missile launch checklist	Post-release checklist
Navigation/AFPI equipment	CMF schedule

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run missile pre-launch checklist	Launch missile in automatic mode
Run missile launch checklist	Run post-release checklist
Correct to track	

(10) Information Management Requirements:

Present CMF information
Present missile pre-launch checklist
Present missile launch checklist
Present navigation/aviation information
Coordinate weapon delivery information
Present post-release checklist

Mission Scenario Analysis

Record No. 52

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target, TN1

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 53

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN1: Unpredictable RT - missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

Missile pre-launch checklist results
Missile launch checklist results
Detection of target in TN1 search area
Imagery of TN1 search area
CMF information

(6) Information Sources:

Missile pre-launch checklist
Missile launch checklist
Target imager/searcher sensors
CMF

(7) Crews' Decision:

Image/search of TN1 area finds no target
-Search TN1 area a second time

(8) Decision Class:

Rule-based

(9) Action Taken:

Run missile pre-launch checklist
Run missile launch checklist
Search/image TN1 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Present missile pre-launch checklist
Present missile launch checklist
Coordinate information for image/search of TN2 area

Mission Scenario Analysis

Record No. 54

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Second image/search of TN1 area for occupancy

(4) Crews' Response to Event:

Perform image/search of TN1 area

(5) Informational Demands:

CMF information
Imagery of TN1 search area
Detection of TN1 in search area

(6) Information Sources:

CMF
Target imager/searcher sensors

(7) Crews' Decision:

TN1 area is unoccupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Search/image TN1 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Present image/search information
Coordinate information for second search of TN1 area

Mission Scenario Analysis

Record No. 55

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

No target is found in TN1 area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for not locating an unpredictable RT
Implications of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not deliver weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

No missile is fired
Run missile abort checklist

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present missile abort checklist

Mission Scenario Analysis

Record No. 56

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Mission behind schedule

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for behind schedule
Implications of options
Tactical doctrine
CMF schedule
AFPI data

(6) Information Sources:

Tactical doctrine
CMF
AFPI equipment

(7) Crews' Decision:

Accelerate aircraft

(8) Decision Class:

Rule-based

(9) Action Taken:

Accelerate aircraft

(10) Information Management Requirements:

Present options
Present CMF schedule
Present applicable tactical doctrine
Present AFPI

Mission Scenario Analysis

Record No. 57

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

TF system fly-up due to jamming

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for TF fly-up
Implications of options
Tactical doctrine
TF system status
Navigation data
AFPI data

(6) Information Sources:

Tactical doctrine
TF system equipment
Navigation equipment
AFPI equipment

(7) Crews' Decision:

Override fly-up

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Fly aircraft manually

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present TF system status
Present navigation information
Present AFPI

Mission Scenario Analysis

Record No. 58

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM acquisition radar detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type acquisition radar
Implications of options
Tactical doctrine
SAM location
CMF information

(6) Information Sources:

Tactical doctrine
CMF
External sensors

(7) Crews' Decision:

Monitor and locate SAM radar

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Monitor SAM acquisition radar
Locate SAM acquisition radar

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM acquisition radar identification and location
Present SAM radar activity
Present CMF information

Mission Scenario Analysis

Record No. 59

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM radar in fire control mode

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM radar in fire control mode
Implication of options
Tactical doctrine
SAM radar activity

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Take evasive action
Employ countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive action
Employ countermeasures

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate evasive action information (navigation/AFP information)
Coordinate countermeasures information

Mission Scenario Analysis

Record No. 60

(1) Mission Leg: LT3 to S

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM radar goes down

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM radar going down
Implications of options
Tactical doctrine
SAM radar activity
CMF schedule

(6) Information Sources:

Tactical doctrine
External sensors
CMF

(7) Crews' Decision:

Rejoin pre-planned route

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Rejoin pre-planned route

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate navigation/AFPI information to rejoin pre-planned route
Present CMF information

Mission Scenario Analysis

Record No. 61

(1) Mission Leg: S to IPTP5

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF schedule activities
-navigation update for next target, TP5
-run pre-bomb checklist

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule
Pre-bomb run checklist results

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF schedule
Pre-bomb run checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Run pre-bomb run checklist
Correct to track

(10) Information Management Requirements:

Present navigation information
Present AFPI
Present CMF schedule
Present pre-bomb run checklist
Coordinate correct to track information

Mission Scenario Analysis

Record No. 62

(1) Mission Leg: IPTP5 to TP5

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP5: Predictable RT - gravity weapon target

(4) Crews' Response to Event:

Perform predictable RT strike activities for a gravity weapon delivery

(5) Informational Demands:

CMF schedule
Navigation data
Bomb run checklists results
Image offset aimpoint data
Direct target imagery data
Target occupancy data

(6) Information Sources:

CMF
Navigation equipment
Bomb run checklist
Target imagers/sensors
Target occupancy sensors

(7) Crews' Decision:

Target located and occupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform navigation update
Run bomb run checklist
Perform image offset aimpoint
Perform direct target imaging
Ascertain target occupancy

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Update navigation database
Present image offset aimpoint information
Present direct target imaging information
Present target occupancy information
Coordinate predictable RT information

Mission Scenario Analysis

Record No. 63

(1) Mission Leg: IPTP5 to TP5

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP5: Occupied, predictable RT - gravity weapon target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for occupied, predictable RT
Implications of options
Tactical doctrine
CMF information (planned response)

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon as scheduled

(8) Decision Class:

Rule-based

(9) Action Taken:

Schedule weapon delivery
Roll-in target
Release weapon

(10) Information Management Requirements:

Present options
Present CMF information (planned response)
Present applicable tactical doctrine
Coordinate weapon delivery schedule
Present navigation/aviation information for roll-in

Mission Scenario Analysis

Record No. 64

(1) Mission Leg: IPTP5 to TP5

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM firing detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type missile firing
Implications of options
Tactical doctrine
Missile identification
Missile course/position

(6) Information Sources:

Tactical doctrine
Missile signature database
External sensors for tracking SAMs

(7) Crews' Decision:

Employ countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present missile identification information
Coordinate and present SAM tracking/location
Coordinate countermeasures information requirements

Mission Scenario Analysis

Record No. 65

(1) Mission Leg: TP5 to T

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Descend aircraft to TF
-Run post-release checklist for TP4
-Run missile pre-launch checklist for TP6
-Avoid known power lines
-Prepare for detonation wave TP5

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

TF resumption checklist results	Missile pre-launch check. results
Navigation data	CMF schedule
AFPI data	Power line location and height
Post-release checklist results	Time to detonation wave

(6) Information Sources:

TF resumption checklist	Missile pre-launch checklist
Navigation equipment	CMF
AFPI equipment	External sensors
Post-release checklist	Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist	Run missile pre-launch checklist
Descend aircraft	Watch for power lines
Resume TF	Prepare for detonation wave TP5
Run post-release checklist	

(10) Information Management Requirements:

Present CMF schedule	Present post-release checklist
Present TF resumption checklist	Present missile pre-launch check.
Present nav. information	Present power line locations
Present AFPI	Present time to deton. wave TP5

Mission Scenario Analysis

Record No. 66

(1) Mission Leg: T to LTP6

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate information for TAL maneuver

Mission Scenario Analysis

Record No. 67

(1) Mission Leg: T to LTP6

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target, TP6

(4) Crews' Response to Event:

Perform navigation update activities

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 68

(1) Mission Leg: T to LTP6

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP6: Predictable RT - missile target

(4) Crews' Response to Event:

Perform target strike activities for a predictable RT with a missile weapon

(5) Informational Demands:

Missile launch checklist results
Target image offset aimpoint data
Direct target imaging data
Target occupancy data
CMF information

(6) Information Sources:

CMF
Missile launch checklist
Target imagers/sensors
Target occupancy sensors

(7) Crews' Decision:

Target located but inactive

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile launch checklist
Perform target image offset aimpoint
Perform direct target imaging
Ascertain target activity

(10) Information Management Requirements:

Present CMF information
Present missile launch checklist
Present target image offset aimpoint information
Present direct target imagery information
Present target occupancy information

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Mission Scenario Analysis

Record No. 69

(1) Mission Leg: LTP6 to U

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP6: Unoccupied, predictable RT - missile target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for unoccupied predictable RT
Implication of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not launch weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

Abort weapon delivery
Run missile abort checklist

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present missile abort checklist
Coordinate information for aborting missile launch

Mission Scenario Analysis

Record No. 70

(1) Mission Leg: LTP6 to U

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities if TP6 is unoccupied
- -Resume TF
- -Format and submit strike reports

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

TF resumption checklist results	Target strike results
Navigation data	Target strike report format
AFPI data	CMF schedule

(6) Information Sources:

TF resumption checklist	Target strike database
Navigation equipment	Target strike report format
AFPI equipment	CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist	Correct to track
Descend aircraft	Format and submit target strike report
Resume TF	

(10) Information Management Requirements:

Present TF resumption checklist
Present navigation information
Present AFPI
Format strike report
Submit strike report
Present CMF schedule

Mission Scenario Analysis

Record No. 71

(1) Mission Leg: U to V

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Prepare for next target, T4

(4) Crews' Response to Event:

Perform activities as planned
- -Perform navigation update
- -Resume TF
- -Run missile pre-launch checklist

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data
TF resumption checklist results
Missile pre-launch checklist results

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment
TF resumption checklist
Missile pre-launch checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Climb aircraft	Descend aircraft/resume TF
Perform navigation update	Correct to track
Run TF resumption checklist	Run missile pre-launch checklist

(10) Information Management Requirements:

Present CMF schedule	Present AFPI
Present navigation information	Present TF resumption checklist
Update navigation database	Present missile pre-launch check.

Mission Scenario Analysis

Record No. 72

(1) Mission Leg: V to LT4

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate information from TAL maneuver to missile guidance system

Mission Scenario Analysis

Record No. 73

(1) Mission Leg: V to LT4

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Prepare for T4 target strike

(4) Crews' Response to Event:

Perform activities as planned
- -Run C^2 link checklist
- -Run missile launch checklist
- -Change heading

(5) Informational Demands:

C^2 link checklist results	AFPI data
Missile launch checklist results	CMF schedule
Navigation data	

(6) Information Sources:

CMF	*Navigation equipment*
C^2 link checklist	AFPI equipment
Missile launch checklist	

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run C^2 link checklist	Climb aircraft
Run missile launch checklist	Correct to track
Change heading	

(10) Information Management Requirements:

Present CMF schedule
Present C^2 link checklist
Present missile launch checklist
Present navigation information
Present AFPI
Coordinate information for correct to track

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Mission Scenario Analysis

Record No. 74

(1) Mission Leg: LT4 to W

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T4: Fixed target strike - missile launch semiballistic

(4) Crews' Response to Event:

Launch missile in semiballistic mode
Descent aircraft to TF

(5) Informational Demands:

Launch point
AFPI data
Navigation data
Weapon release data
CMF schedule
TF resumption checklist results
Missile post-release checklist results

(6) Information Sources:

CMF
AFPI equipment
Navigation equipment
Weapon launcher equipment/sensors
Missile post-release checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Launch missile in semiballistic mode
Run TF resumption checklist
Descend aircraft
Resume TF
Run missile post-release checklist

(10) Information Management Requirements:

Present missile launchpoint
Present CMF schedule
Present AFPI
Present navigation information
Coordinate weapon delivery information
Present TF resumption checklist
Present missile post-release checklist

Mission Scenario Analysis

Record No. 75

(1) Mission Leg: LT4 to W

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Emergency action message (EAM) received

(4) Crews' Response to Event:

Read EAM

(5) Informational Demands:

Content of EAM
Implication of EAM on mission

(6) Information Sources:

Communication receiver
Tactical doctrine

(7) Crews' Decision:

EAM does not apply to this sortie

(8) Decision Class:

Rule-based

(9) Action Taken:

Record EAM

(10) Information Management Requirements:

Present EAM
Record EAM
Present applicable tactical doctrine

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Mission Scenario Analysis

Record No. 76

(1) Mission Leg: W to X

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

SAM radar and missile launch detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type missile launch
Implications of options
Tactical doctrine
Missile identification
Missile course/position

(6) Information Sources:

Tactical doctrine
Missile signature database
External sensors for tracking SAMs

(7) Crews' Decision:

Employ countermeasures

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ countermeasures

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present missile identification information
Coordinate and present SAM tracking/location
Coordinate countermeasures information requirements

Mission Scenario Analysis

Record No. 77

(1) Mission Leg: X to Y

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL manuever

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Change heading
Climb aircraft

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate information for TAL maneuver

Mission Scenario Analysis

Record No. 78

(1) Mission Leg: W to X to Y

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN2: Unpredictable RT - missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

CMF information
Missile pre-launch checklist results
Missile launch checklist results
Detection of target in TN2 search area
Imagery of TN2 search area

(6) Information Sources:

CMF
Missile pre-launch checklist
Missile launch checklist
Target imager/searcher sensors

(7) Crews' Decision:

Image/search of TN2 area finds no target

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist
Run missile launch checklist
Search/image TN2 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Present missile pre-launch checklist
Present missile launch checklist
Coordinate information for image/search of TN2 area

Mission Scenario Analysis

Record No. 79

(1) Mission Leg: X to Y

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

No target is found in TN2 area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for not locating an unpredictable RT
Implications of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not launch weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

No missile is launched
Correct to track

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present navigation/AFPI information
Coordinate correct to track information

Mission Scenario Analysis

Record No. 80

(1) Mission Leg: Y to Z

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Change heading

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate information for TAL maneuver

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Mission Scenario Analysis

Record No. 81

(1) Mission Leg: Y to Z

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN3: unpredictable RT - missile target
-Missile launch checklists completed previously

(4) Crews' Response to Event:

Search TN3 area for target

(5) Informational Demands:

CMF information
Imagery of TN5 search area
Detection of target in TN3 search area

(6) Information Sources:

CMF
Target imager/searcher sensors

(7) Crews' Decision:

Image/search of TN3 area finds no target
-Search TN3 area a second time

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Search/image TN3 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Coordinate information for search/image of TN3 area

8

Mission Scenario Analysis

Record No. 82

(1) Mission Leg: Y to Z

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Second image/search of TN3 area for occupancy

(4) Crews' Response to Event:

Perform image/search of TN3 area

(5) Informational Demands:

CMF information
Imagery of TN3 search area
Detection of TN3 in search area

(6) Information Sources:

CMF
Target imager/searcher sensors

(7) *Crews' Decision:*

TN3 area is unoccupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Search/image TN3 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Present image/search information
Coordinate information for second search of TN3 area

Mission Scenario Analysis

Record No. 83

(1) Mission Leg: Y to Z

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

No target is found in TN3 area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for not locating an unpredicatable RT
Implications of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not launch weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

No missile is launched
Run missile abort checklist

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present missile abort checklist

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Mission Scenario Analysis

Record No. 84

(1) Mission Leg: Y to Z

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Mission behind schedule
-Planned descent to TF

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for behind schedule
Implications of options
Tactical doctrine
CMF schedule
TF resumption checklist results
Navigation data
AFPI data

(6) Information Sources:

Tactical doctrine
CMF
TF resumption checklist
Navigation equipment
AFPI equipment

(7) Crews' Decision:

Accelerate aircraft

(8) Decision Class:

Rule-based

(9) Action Taken:

Accelerate aircraft
Run TF resumption checklist
Descend aircraft
Resume TF
Correct to track

(10) Information Management Requirements:

Present options
Present CMF schedule
Present applicable tactical doctrine
Present TF reusmption checklist
Coordinate information for resuming TF

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Mission Scenario Analysis

Record No. 85

(1) Mission Leg: Z to Z1

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Prepare for next target, TP7

(4) Crews' Response to Event:

Perform activities as planned
-Navigation update
-Resume TF
-Run missile pre-launch checklist

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data
TF resumption checklist results
Missile pre-launch checklist results

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment
TF resumption checklist
Missile pre-launch checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update
Run TF resumption checklist
Descending aircraft/resume TF
Correct to track
Run missile pre-launch checklist

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Update navigation database
Present AFPI
Present TF resumption checklist
Present missile pre-launch checklist

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Mission Scenario Analysis

Record No. 86

(1) Mission Leg: Z1 to Z2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Present AFPI
Coordinate information for TAL maneuver

8

Mission Scenario Analysis

Record No. 87

(1) Mission Leg: Z1 to Z2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target, TP7

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

Navigation data
AFPI data
CMF schedule

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 88

(1) Mission Leg: Z1 to Z2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP7: Predictable RT - missile target

(4) Crews' Response to Event:

Perform target strike activities for a predictable RT with a missile weapon

(5) Informational Demands:

Missile launch checklist results
Target image offset aimpoint data
Direct target imaging data
Target occupancy data
CMF information

(6) Information Sources:

CMF
Missile launch checklist
Target imagers/sensors
Target occupancy sensors

(7) Crews' Decision:

Target located but unoccupied

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile launch checklist
Perform target image offset aimpoint
Perform direct target imaging
Ascertain target occupancy

(10) Information Management Requirements:

Present CMF information
Present missile launch checklist
Present target image offset aimpoint information
Present direct target imagery information
Present target occupancy information

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Mission Scenario Analysis

Record No. 89

(1) Mission Leg: Z1 to Z2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TP7: Unoccupied, predictable RT - missile target

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for unoccupied, predictable RT
Implications of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not launch weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

Abort weapon delivery
Run missile abort checklist

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present CMF information
Present missile abort checklist
Coordinate information for aborting missile launch

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Mission Scenario Analysis

Record No. 90

(1) Mission Leg: Z1 to Z2

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

CMF schedule activities if TP7 is unoccupied
- -Resume TF
- -Run pre-bomb checklist

(4) Crews' Response to Event:

Performed scheduled activities

(5) Informational Demands:

TF resumption checklist results
Navigation data
AFPI
Pre-bomb run checklist results
CMF schedule

(6) Information Sources:

TF resumption checklist
Navigation equipment
AFPI equipment
Pre-bomb run checklist
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist
Descend aircraft
Resume TF
Correct to track
Run Pre-bomb run checklist

(10) Information Management Requirements:

Present TF resumption checklist
Present navigation information
Present AFPI
Present pre-bomb run checklist
Present CMF schedule
Coordinate information for correct to track

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Mission Scenario Analysis

Record No. 91

(1) Mission Leg: Z2 to T5

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target (T5)

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

CMF schedule
Navigation data
AFPI

(6) Information Sources:

Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present navigation information
Update navigation database
Present AFPI

Mission Scenario Analysis

Record No. 92

(1) Mission Leg: Z2 to T5

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T5: Fixed target strike - gravity weapon, automatic delivery

(4) Crews' Response to Event:

Perform fixed target strike activities for a gravity weapon strike with automatic delivery

(5) Informational Demands:

Bomb-run checklist results	AFPI
Image offset aimpoint data	Correct to track data
Direct target imaging data	Weapon release data
TF resumption checklist results	CMF

(6) Information Sources:

Bomb-run checklist	AFPI equipment
Target imagers/sensors	Navigation equipment
CMF	Weapon release equipment
TF resumption checklist	

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run bomb-run checklist	Descend aircraft/resume TF
Perform image offset aimpoint	Correct to track
Perform direct target imaging	Release weapon, automatic mode
Run TF resumption checklist	

(10) Information Management Requirements:

Present CMF information	Present AFPI
Present bomb-run checklist	Present navigation information
Present image offset aimpoint information	Coordinate weapon release information
Present direct target imaging information	Coordinate information for correct to track
Present TF resumption checklist	

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Mission Scenario Analysis

Record No. 93

(1) Mission Leg: T5 to AA

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activity
(Extremely short mission leg)

(4) Crews' Response to Event:

Perform scheduled activity
-Run post-release checklist

(5) Informational Demands:

CMF schedule
Post-release checklist results

(6) Information Sources:

CMF
Post-release checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run post-release checklist

(10) Information Management Requirements:

Present CMF schedule
Run post-release checklists

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Mission Scenario Analysis

Record No. 94

(1) Mission Leg: AA to BB

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activity
-Format and submit strike report
-Prepare for detonation wave from

(4) Crews' Response to Event:

Format and submit strike report

(5) Informational Demands:

Test strike results
Target strike format
CMF schedule
Time to detonation wave T5

(6) Information Sources:

Target strike results
Target strike report formats
CMF
Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Format and submit strike report
Prepare for detonation wave from T5

(10) Information Management Requirements:

Present CMF schedule
Format strike reports
Submit strike reports
Present time to detonation wave from T5

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Mission Scenario Analysis

Record No. 95

(1) Mission Leg: AA to BB

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

SAM acquisition radar detected/identified/located

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type acquisition radar
Implications of options
Tactical doctrine
SAM activity
CMF information

(6) Information Sources:

Tactical doctrine
CMF
External sensors

(7) Crews' Decision:

Monitor for fire control radar

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Monitor SAM acquisition radar
Monitor for possible SAM fire control radar

(10) Information Management Requirements:

Present SAM acquisition radar identification/location
Present options
Present applicable tactical doctrine
Present SAM radar activity
Present CMF information

Mission Scenario Analysis

Record No. 96

(1) Mission Leg: AA to BB

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

SAM radar in fire control mode

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM radar in fire control mode
Implications of options
Tactical doctrine
SAM radar activity
SAM type strike potential

(6) Information Sources:

Tactical doctrine
External sensors
SAM type database

(7) Crews' Decision:

Take evasive action and employ countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive action
Employ countermeasures
Monitor SAM radar activity

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate evasive action information (navigation/AFP information)
Coordinate countermeasures information
Present SAM type strike potential

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Mission Scenario Analysis

Record No. 97

(1) Mission Leg: AA to BB

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Aircraft diverted from route

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for aircraft off of route
Implications of options
Tactical doctrine
CMF schedule
Navigation data
AFPI data

(6) Information Sources:

Tactical doctrine
CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

Plan course to rejoin pre-planned route

(8) Decision Class:

Knowledge-based

(9) Action Taken:

New route planned to rejoin pre-planned route
Monitor SAM radar threat

(10) Information Management Requirements:

Present options
Present CMF schedule
Present applicable tactical doctrine
Present navigation information
Present AFPI
Coordinate mission route replanning
Update databases associated with mission route

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Mission Scenario Analysis

Record No. 98

(1) Mission Leg: BB to CC

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

SAM radar goes down

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM radar going down
Implications of options
Tactical doctrine
CMF schedule
SAM radar activity

(6) Information Sources:

Tactical doctrine
CMF schedule
External sensors

(7) Crews' Decision:

Rejoin pre-planned route

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Rejoin pre-planned route

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate navigation/AFPI information to rejoin pre-planned route
Present CMF information

Mission Scenario Analysis

Record No. 99

(1) Mission Leg: BB to CC

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

Detection and identification of two (2) known, pre-planned SAM radar threats

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for pre-known SAM radar threats
Implications of options
Confirm identification of pre-known SAM threats
SAM radar activity
CMF planned response

(6) Information Sources:

Tactical doctrine
CMF
External sensors

(7) Crews' Decision:

Monitor (2) SAM radar activities

(8) Decision Class:

Rule-based

(9) Action Taken:

Monitor both (2) SAM radar activity

(10) Information Management Requirements:

Present SAM radar threat identification and location
Present options
Present applicable tactical doctrine
Present CMF information
Present (2) SAM radar activity

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Mission Scenario Analysis

Record No. 100

(1) Mission Leg: BB to CC

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Perform navigation update
-Perform TAL maneuver

(4) Crews' Response to Event:

Perform navigation update
Perform TAL maneuver

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Climb aircraft
Perform navigation update
Perform TAL maneuver

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database
Coordinate information for TAL maneuver

Mission Scenario Analysis

Record No. 101

(1) Mission Leg: BB to CC

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN4: Unpredictable RT-missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

CMF information-TN4 information
Missile pre-launch checklist results (TN4 and TN5)
Missile launch checklist results (TN4 and TN5)
Detection of target in TN4 search area
Imagery of TN4 search area

(6) Information Sources:

CMF
Missile pre-launch checklists (TN4 AND TN5)
Missile launch checklists (TN4 and TN5)
Target imagers/searchers sensors

(7) Crews' Decision:

Image/search of TN4 area finds no target

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist (2)
Run missile launch checklist (2)
Search/image TN4 area (area unoccupied)

(10) Information Management Requirements:

Present CMF information
Present missile pre-launch checklist (TN4 and TN5)
Present missile launch checklist (TN4 and TN5)
Coordinate information for image/search of TN4 area

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Mission Scenario Analysis

Record No. 102

(1) Mission Leg: BB to CC

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

No target is found in TN4

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for not locating an unpredictable RT
Implications of options
Tactical doctrine
CMF information

(6) Information Sources:

Tactical doctrine
CMF

(7) Crews' Decision:

Do not launch weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

No missile is launched
Correct to track

(10) Information Management Requirements:

Present options
Present CMF information
Present applicable tactical doctrine
Present navigation/AFPI information
Coordinate information for correct to track

Mission Scenario Analysis

Record No. 103

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Perform TAL maneuver for next target, TN5

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Change heading

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Coordinate information for TAL maneuver

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Mission Scenario Analysis

Record No. 104

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN5: Unpredictable RT - missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

CMF information
Missile checklists results (ran on last leg)
Detection of Target in TN5 search area
Imagery of TN5 search area

(6) Information Sources:

CMF
Missile checklists
Target imagers/searcher sensors

(7) Crews' Decision:

Image/search of TN5 area locates TN5 target

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Check missile checklists results (pre-launch and launch)
Search/image TN5 search area
Ascertain TN5 occupancy in target search area

(10) Information Management Requirements:

Present CMF information
Present missile checklists results
Coordinate information for image/search of TN5 area
Present imagery of target in TN5 area

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Mission Scenario Analysis

Record No. 105

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN5: Unpredictable RT located in search area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for locating unpredictable RT
Implication of options
CMF information (pre-planned response)
Tactical doctrine

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Deliver weapon
Schedule weapon delivery

(8) Decision Class:

Rule-based
Knowledge-based

(9) Action Taken:

Select launch point
Launch missile manually
Run post-release checklist

(10) Information Management Requirements:

Present CMF information
Present applicable tactical doctrine
Present flight plan for mission leg CC to DD
Coordinate information for selected launch point
Coordinate information for weapon delivery
Present post-release checklist

Mission Scenario Analysis

Record No. 106

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

TF jamming occurs during target strike of TN5

(4) Crews' Response to Event:

Run TF interrupt/climb checklist
Fly aircraft manually

(5) Informational Demands:

TF interrupt/climb checklist results
Navigation data
AFPI data
CMF schedule

(6) Information Sources:

TF interrupt/climb checklist
Navigation equipment
AFPI equipment
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF interrupt/climb checklist
Fly aircraft manually
Fly aircraft within mission flight plan

(10) Information Management Requirements:

Present TF interrupt/climb checklist
Present navigation information
Present AFPI
Present CMF schedule

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Mission Scenario Analysis

Record No. 107

(1) Mission Leg: CC to DD

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

TF jamming ceases

(4) Crews' Response to Event:

Run TF resumption checklist and resume TF

(5) Informational Demands:

TF resumption checklist results
Navigation data
AFPI data

(6) Information Sources:

TF resumption checklist
Navigation equipment
Navigation equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run TF resumption checklist
Descend aircraft
Resume TF
Correct to track

(10) Information Management Requirements:

Present TF resumption checklist
Present navigation information
Present AFPI
Coordinate information for correct to track

Mission Scenario Analysis

Record No. 108

(1) Mission Leg: DD to EE

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

AI search radar is detected, identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI type in search mode
Implications of options
Tactical doctrine
CMF information (geography)
AI type
AI strike potential
AI activity

(6) Information Sources:

Tactical doctrine
CMF
AI radar signature database
AI description database
External sensors

(7) Crews' Decision:

Descend aircraft

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Descend aircraft to low altitude
Vigilant for pop-ups
Monitor AI activity

(10) Information Management Requirements:

Present AI search radar detection/identification
Present AI type, strike potential
Present options
Present applicable tactical doctrine
Present CMF information (geography)
Present AFPI/navigation information
Present AI activity

Mission Scenario Analysis

Record No. 109

(1) Mission Leg: DD to EE

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

AI in track mode

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI type in track mode
Implications of options
Tactical doctrine
AI activity

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Employ countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Automatic countermeasures employed

(10) Information Management Requirements:

Present options
Present sensor readings
Coordinate information for employed countermeasures
Monitor AI activity

Mission Scenario Analysis

Record No. 110

(1) Mission Leg: DD to EE

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

AI missile launch detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI missile launch
Implications of options
Missile threat potential
AI activity
AI missile course

(6) Information Sources:

Tactical doctrine
AI missile database
External sensors

(7) Crews' Decision:

Employ additional countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Employ evasive maneuvers
Monitor AI activity
Track AI missile

(10) Information Management Requirements:

Present options
Present missile threat potential
Coordinate information for countermeasures
Monitor AI activity
Track AI missile

Mission Scenario Analysis

Record No. 111

(1) Mission Leg: DD to EE

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

AI signal goes down

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options when AI goes down
Implications of options
Tactical doctrine
AI activity

(6) Information Sources:

External sensors
Tactical doctrine

(7) Crews' Decision:

Stop previous measures and resume flight plan

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Terminate defensive countermeasures
Climb aircraft
Resume flight plan

(10) Information Management Requirements:

Present options
Present tactical doctrine
Monitor for AI activity
Present mission flight plan for DD to EE

Mission Scenario Analysis

Record No. 112

(1) Mission Leg: DD to EE

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

CMF scheduled activity
-Perform TAL maneuver
-Perform navigation update

(4) Crews' Response to Event:

Perform TAL maneuver
Perform navigation update

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Change heading
Climb aircraft
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Coordinate TAL maneuver
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 113

(1) Mission Leg: EE to FF

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN6: Unpredictable RT - missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

CMF information-TN6 information
Missile pre-launch checklist results
Missile launch checklist results
Detection of target in TN6 search area
Imagery of TN6 search area

(6) Information Sources:

CMF
Missile pre-launch checklists
Missile launch checklist
Target imagers/searcher sensors

(7) Crews' Decision:

Image/search of TN6 area locates target TN7

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist
Run missile launch checklist
Search/image TN6 area
Ascertain TN6 occupancy in TN6 search area

(10) Information Management Requirements:

Present CMF information (TN6 information)
Present missile pre-launch checklist
Present missile launch checklist
Coordinate information for image/search of TN6 area
Present imagery of target in TN6 area

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Mission Scenario Analysis

Record No. 114

(1) Mission Leg: EE to FF

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN6: Unpredictable RT located in search area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for locating unpredictable RT
Implications of options
CMF information (pre-planned response)
Tactical doctrine

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Schedule weapon delivery
Deliver weapon

(8) Decision Class:

Rule-based
Knowledge-based

(9) Action Taken:

Select a launch point
Launch missile manually
Run post-release checklist
Correct to track

(10) Information Management Requirements:

Present CMF information (mission pre-planning)
Present applicable tactical doctrine
Present flight plan for mission leg EE to FF
Coordinate information for selected launch point
Coordinate information for weapon delivery
Present post-release checklist
Coordinate information for correct to track

Mission Scenario Analysis

Record No. 115

(1) Mission Leg: EE to FF

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

Second pass of AI
AI search radar is detected, identified during TN6 target strike

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI type in search mode
Implications of options
Tactical doctrine
CMF information (geography)
AI type
AI strike potential
AI activity

(6) Information Sources:

Tactical doctrine
CMF
AI radar signature database
AI description database
External sensors

(7) Crews' Decision:

Deliver weapon against target
Employ countermeasures and descend aircraft

(8) Decision Class:

Rule-based
Knowledge-based

(9) Action Taken:

Deliver weapon (see Record #114)
Descend aircraft
Vigilant for pop-ups
Monitor AI activity

(10) Information Management Requirements:

Present AI search radar detection/identification
Present AI type, strike potential
Present options
Present applicable tactical doctrine
Present CMF information (geography)
Present navigation/AFPI information
Coordinate information for employed countermeasures
Present AI activity

Mission Scenario Analysis

Record No. 116

(1) Mission Leg: FF to GG

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

AI missile launch detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for AI missile launch
Implications of options
Missile threat potential
AI activity
AI missile course

(6) Information Sources:

Tactical doctrine
AI missile database
External sensors

(7) Crews' Decision:

Employ additional countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Employ additional countermeasures
Monitor AI activity
Track AI missile

(10) Information Management Requirements:

Present options
Present missile threat potential
Coordinate information for countermeasures
Monitor AI activity
Track AI missile

Mission Scenario Analysis

Record No. 117

(1) Mission Leg: FF to GG

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

AI signal goes down

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options when AI goes down
Implications of options
Tactical doctrine
AI activity

(6) Information Sources:

External sensors
Tactical doctrine

(7) Crews' Decision:

Stop previous measures and resume flight plan

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Terminate defensive countermeasures
Climb aircraft
Resume flight plan

(10) Information Management Requirements:

Present options
Present tactical doctrine
Monitor for AI activity
Present mission fight plan for FF to GG

Record No. 118

(1) Mission Leg: FF to GG

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN7: Unpredictable RT - missile target

(4) Crews' Response to Event:

Perform activities for an unpredictable RT with a missile selected for delivery

(5) Informational Demands:

CMF information (TN7 information)
Missile pre-launch checklist results
Missile launch checklist results
Navigation data
AFPI data
Detection of target in TN7 search area
Imagery of TN7 search area

(6) Information Sources:

CMF
Missile pre-launch checklist
Missile launch checklist
Navigation equipment
AFPI equipment
Target imagers/searcher sensors

(7) Crews' Decision:

Image/search of TN7 area locates target TN7

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Run missile pre-launch checklist
Run missile launch checklist
Change heading
Climb aircraft
Search/image TN7 area
Ascertain TN7 occupancy in TN7 search area

(10) Information Management Requirements:

Present CMF information (TN7 information)
Present missile pre-launch checklist
Present missile launch checklist
Coordinate information for image/search of TN7 area
Present navigational AFPI information
Present imagery of target in TN7 area

Record No. 119

(1) Mission Leg: FF to GG

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

TN7: Unpredictable RT located in search area

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for locating an unpredicatable RT
Implications of options
CMF information (pre-planned response)
Tactical doctrine

(6) Information Sources:

CMF
Tactical doctrine

(7) Crews' Decision:

Schedule weapon delivery
Resume TF
Deliver weapon on leg GG to HH

(8) Decision Class:

None

(9) Action Taken:

Descend aircraft
Resume TF
Correct to track

(10) Information Management Requirements:

Present CMF information (mission pre-planning)
Present applicable tactical doctrine
Present navigation information
Present AFPI information
Coordinate information for correct to track

Mission Scenario Analysis

Record No. 120

(1) Mission Leg: GG to HH

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Deliver weapon against TN7

(4) Crews' Response to Event:

Perform activities for missile launch against an unpredictable RT

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver
Schedule launch point
Launch weapon manually
Run post-release checklist

(10) Information Management Requirements:

Present CMF schedule
Present flight plan from GG to HH
Coordinate information for selected launch position
Coordinate information for TAL maneuver
Coordinate information for weapon delivery
Present post-release checklist

Mission Scenario Analysis

Record No. 121

(1) Mission Leg: GG to HH

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF schedule activity
-Perform navigation update

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data
TF resumption checklist results

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment
TF resumption checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Perform navigation update
Run TF resumption checklist
Descend aircraft/resume TF
Correct to track

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database
Present TF resumption checklist
Coordinate information for correct to track

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Mission Scenario Analysis

Record No. 122

(1) Mission Leg: HH to LT6/IPT7

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Planned course change and TAL maneuver

(4) Crews' Response to Event:

Perform TAL maneuver

(5) Informational Demands:

CMF schedule
Navigation data
AFPI data

(6) Information Sources:

CMF
Navigation equipment
AFPI equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Perform TAL maneuver

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Coordinate information from TAL maneuver

Mission Scenario Analysis

Record No. 123

(1) Mission Leg: HH to LT6/IPT7

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
- -Prepare for T7 target strike
- -Avoid known power line

(4) Crews' Response to Event:

Perform activities as planned
- -Run checklists
- -Climb aircraft

(5) Informational Demands:

CMF schedule	AFPI data
Missile pre-launch checklist results	Power line location and height
Missile launch checklist results	

(6) Information Sources:

CMF	AFPI equipment
Missile pre-launch checklist	External sensors
Missile launch checklist	

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run missile pre-launch checklist	Climb aircraft
Run missile launch checklist	Watch for power line

(10) Information Management Requirements:

Present CMF schedule
Present missile pre-launch checklist
Present missile launch checklist
Present AFPI
Present power line location and height

Mission Scenario Analysis

Record No. 124

(1) Mission Leg: LT6/IPT7 to T7

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T6: Fixed target strike - automatic missile launch

(4) Crews' Response to Event:

Launch missile
Descend aircraft to TF

(5) Informational Demands:

CMF schedule
Weapon release data
Post-release checklist results
TF resumption checklist results
AFPI data
Navigation data

(6) Information Sources:

CMF
Weapon launcher equipment
Missile post-release checklist
TF resumption checklist
AFPI equipment
Navigation equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Automatic missile launch
Run post-release checklist
Run TF resumption checklist
Descend aircraft
Resume TF

(10) Information Management Requirements:

Present CMF schedule
Coordinate information for weapon delivery
Present post-release checklist
Present TF resumption checklist
Present AFPI
Present navigation information

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Mission Scenario Analysis

Record No. 125

(1) Mission Leg: LT6/IPT7 to T7

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T7: Fixed target strike - gravity weapon

(4) Crews' Response to Event:

Perform fixed target strike activities when a gravity weapon is to be delivered

(5) Informational Demands:

Pre-bomb run checklist results
Bomb run checklist results
Image offset aimpoints (x2)
Weapon release data
CMF schedule
TF resumption checklist results

(6) Information Sources:

CMF
Pre-bomb run checklist
Bomb run checklist
Target imagers/sensors
Weapon launcher equipment
TF resumption checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run pre-bomb run checklist
Run bomb run checklist
Perform (2) image offset aimpoints
Correct to track
Release weapon
Run TF resumption checklist
Descend aircraft

(10) Information Management Requirements:

Present CMF schedule
Present pre-bomb run checklist
Present bomb run checklist
Present image offset aimpoints (x2)
Coordinate information for correct to track
Coordinate information for weapon release
Present TF resumption checklist

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Mission Scenario Analysis

Record No. 126

(1) Mission Leg: LT6/IPT7

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

Navigation update for next target (T7)

(4) Crews' Response to Event:

Perform navigation update

(5) Informational Demands:

CMF schedule
AFPI data
Navigation data

(6) Information Sources:

CMF
AFPI equipment
Navigation equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change heading
Change altitude
Perform navigation update

(10) Information Management Requirements:

Present CMF schedule
Present AFPI
Present navigation information
Update navigation database

Mission Scenario Analysis

Record No. 127

(1) Mission Leg: T7 to IPT8

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

SAM radar signal detected, identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type radar
Implications of options
Tactical doctrine
SAM radar activity

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Employ jamming

(8) Decision Class:

Rule-based

(9) Action Taken:

Employ jamming techniques
Monitor SAM radar activity

(10) Information Management Requirements:

Present SAM radar signal detection/identification
Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate information for jamming

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Mission Scenario Analysis

Record No. 128

(1) Mission Leg: T7 to IPT8

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
-Run post-release checklist
-Run pre-bomb run checklist
-Prepare for detonation wave from T7

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

CMF shcedule
Post-release checklist results
Pre-bomb run checklist results
Time to detonation wave from T7

(6) Information Sources:

CMF
Post-release checklist
Pre-bomb run checklist
Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run post-release checklist
Run pre-bomb run checklist
prepare for detonation wave T7

(10) Information Management Requirements:

Present CMF schedule
Present post-release checklist
Present pre-bomb run checklist
Present time to detonation wave from T7

Mission Scenario Analysis

Record No. 129

(1) Mission Leg: T7 to IPT8

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Two obstacles identified

(4) Crews' Response to Event:

Negotiate aircraft around obstacles

(5) Informational Demands:

Obstacles location
CMF information (area geography)
CMF schedule

(6) Information Sources:

External sensors
CMF

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Change course to avoid first obstacle
Change course to avoid second obstacle
Resumt flight plan

(10) Information Management Requirements:

Present obstacles (2) location
Present CMF information (area geography)
Present CMF schedule
Navigation/AFPI information

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Mission Scenario Analysis

Record No. 130

(1) Mission Leg: IPT8 to T8

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM fire control radar detected, identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type radar in fire control mode
Implications of options
Tactical doctrine
SAM radar activity
SAM radar type strike potential

(6) Information Sources:

Tactical doctrine
External sensors
SAM type databases

(7) Crews' Decision:

Take evasive action and employ countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive action
Employ countermeasures
Monitor SAM radar activity

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate evasive action information (navigation/AFPI information)
Coordinate countermeasures information
Present SAM type strike potential

Mission Scenario Analysis

Record No. 131

(1) Mission Leg: IPT8 to T8

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM launched. Up-link guidance signal detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for up-link signal detected
Implications of options
Tactical doctrine
SAM course/position

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Continue with previous counteractions

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Continue evasive action
Continue with countermeasures

(10) Information Management Requirements:

Present SAM up-link signal detection
Present options
Present applicable tactical doctrine
Monitor SAM radar activity
Track SAM

Mission Scenario Analysis

Record No. 132

(1) Mission Leg: IPT8 to T8

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM detonates in close proximity causes battle damage to aircraft

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for battle damage
Implications of options
Tactical doctrine
Battle damage to aircraft
SAM radar activity

(6) Information Sources:

Tactical doctrine
On-board sensors
External sensors

(7) Crews' Decision:

Assess damage and continue with mission

(8) Decision Class:

Rule-based

(9) Action Taken:

Assess battle damage
Assess aircraft performance while damaged
Monitor SAM radar activity

(10) Information Management Requirements:

Present battle damage
Present options
Present applicable tactical doctrine
Present possible aircraft performance
Monitor SAM radar activity

Mission Scenario Analysis

Record No. 133

(1) Mission Leg: IPT8 to T8

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T8: Fixed target strike-gravity weapon
-Battle damage occurs after bomb-run checklist

(4) Crews' Response to Event:

Perform fixed target strike activities, given that aircraft has sustained battle damage

(5) Informational Demands:

Bomb run checklist results
Image offset aimpoints (x2)
Weapon release data
CMF schedule
Ability to deliver weapon given battle damage

(6) Information Sources:

CMF
Bomb run checklist
Target imagers/sensors
Weapon launcher equipment

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run bomb run checklist
Determine weapon delivery capability
Perform (2) image offset aimpoints
Release weapon

(10) Information Management Requirements:

Present CMF schedule
Present bomb run checklist
Present battle damage assessment for weapon launcher
Present image offset aimpoints (x2)
Coordinate information for weapon release

Mission Scenario Analysis

Record No. 134

(1) Mission Leg: T8 to JJ

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Detailed damage analysis

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for level of damage
Implications of options
Tactical doctrine
CMF information (mission planning)
Detailed analysis of damage to doppler radar and fuel system

(6) Information Sources:

Tactical doctrine
CMF
Doppler BIT
Fuel system

(7) Crews' Decision:

Continue with mission

(8) Decision Class:

Rule-based

(9) Action Taken:

Assess battle damage to doppler radar system
Assess battle damage to fuel system

(10) Information Management Requirements:

Present level of damage to doppler radar system
Present estimate for the rate of fuel loss
Present applicable tactical doctrine
Present CMF information (mission planning)

Mission Scenario Analysis

Record No. 135

(1) Mission Leg: T8 to JJ

(2) Mission Phase: strike

(3) Scenario Event (Planned N):

Mission re-planning due to battle damage

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for level of battle damage
Implications of options
Tactical doctrine
Fuel loss rate
CMF information (a. mission planning; b. planned and alternate PSBs; c. deconfliction considerations)

(6) Information Sources:

Tactical doctrine
Fuel system
CMF

(7) Crews' Decision:

Complete flight plan thru strike phase and then proceed to alternate PSB

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Calculate aircraft range, given fuel loss rate
Re-plan mission
Select alternate PSB
Calculate remaining fuel at alternate PSB

(10) Information Management Requirements:

Present options
Present CMF information (mission planning, PSBs, deconfliction)
Present applicable tactical doctrine
Present fuel loss rate
Calculate aircraft range, given fuel loss rate
Calculate remaining fuel at alternate PSB
Coordinate information for mission re-planning

Mission Scenario Analysis

Record No. 136

(1) Mission Leg: T8 to JJ

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF planned activity
-Prepare for detonation wave from T8
-Run post-release checklist

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

CMF schedule
Post-release checklist results
Time to detonation wave T8

(6) Information Sources:

CMF
Post-release checklist
Weapon delivery database

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run post-release checklist
Prepare for detonation wave

(10) Information Management Requirements:

Present CMF schedule
Present post-release checklist
Present time to detonation wave from T8

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Record No. 137

(1) Mission Leg: JJ to IPT9D

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
- -Format and submit strike reports
- -Navigation update
- -Run pre-bomb checklist

(4) Crews' Response to Event:

Perform scheduled activities

(5) Informational Demands:

CMF schedule	Navigation data
Target strike results	AFPI data
Target strike report format	Pre-bomb run checklist results

(6) Information S rces:

CMF	Navigation equipment
Target strike database	AFPI equipment
Target strike report format	Pre-bomb run checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Format and submit target strike report	Perform navigation update
	Run pre-bomb run checklist
Change heading	Correct to track
Climb aircraft	

(10) Information Management Requirements:

Present CMF schedule
Format strike report
Submit strike report
Present AFPI
Present navigation information
Update navigation database
Present pre-bomb run checklist
Coordinate information for correct to track

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Mission Scenario Analysis

Record No. 138

(1) Mission Leg: IPT9D to T9D

(2) Mission Phase: target strike

(3) Scenario Event (Planned N):

SAM launch detected, identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type
Implications of options
Tactical doctrine
SAM identification
SAM strike potential
SAM course/position

(6) Information Sources:

Tactical doctrine
SAM database
External sensors

(7) Crews' Decision:

Jam SAM

(8) Decision Class:

Rule-based

(9) Action Taken:

Jam SAM
Track SAM
Monitor for additional SAMs

(10) Information Management Requirements:

Present SAM launch detonation/identification
Present SAM course
Present SAM type and strike potential
Present options
Present applicable tactical doctrine
Monitor for possible, additional SAM launches

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Mission Scenario Analysis

Record No. 139

(1) Mission Leg: IPT9D to T9D

(2) Mission Phase: target strike

(3) Scenario Event (Planned Y):

T9D: DALS target-gravity weapon target

(4) Crews' Response to Event:

Perform DALS target strike activities when a gravity weapon is to be delivered

(5) Informational Demands:

Bomb run checklist results
Image offset aimpoints (x2)
Direct target imaging
CMF schedule

(6) Information Sources:

Bomb run checklist
Target imagers/sensors
CMF schedule

(7) Crews' Decision:

Do not release weapon

(8) Decision Class:

Rule-based

(9) Action Taken:

Run bomb run checklist
Perform (2) image offset aimpoints
Perform direct target imaging
No weapon is released
Correct to track

(10) Information Management Requirements:

Present CMF schedule
Present bomb run checklist
Present image offset aimpoints (x2)
Present direct target imaging
Coordinate information for correct to track

6

Mission Scenario Analysis

Record No. 140

(1) Mission Leg: T9D to KK

(2) Mission Phase: strike

(3) Scenario Event (Planned Y):

CMF scheduled activities
- -Run bomb abort checklist
- -Navigation update
- -C^2 link checklist
- -Resume TF

(4) Crews' Response to Event:

Perform activities

(5) Informational Demands:

CMF schedule	Navigation data
Bomb abort checklist results	AFPI data
Target strike results	TF resumption checklist results
Target strike report format	C^2 link checklist results

(6) Information Sources:

CMF	Navigation equipment
Bomb abort checklist	AFPI equipment
Target strike database	TF resumption checklist
Target strike report format	C^2 link checklist

(7) Crews' Decision:

None

(8) Decision Class:

None

(9) Action Taken:

Run bomb abort checklist	Run C^2 link checklist
Format & submit target strike report	Run TF resumption checklist
Change heading	Descend aircraft/resume TF
Perform navigation update	Correct to track

(10) Information Management Requirements:

Present CMF schedule	Update navigation database
Format strike report	Present C^2 link checklist
Submit strike report	Present TF resumption checklist
Present AFPI	Coordinate information for correct to track
Present navigation information	

Mission Scenario Analysis

Record No. 141

(1) Mission Leg: KK to SC

(2) Mission Phase: egress

(3) Scenario Event (Planned N):

Select climb point

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options given fuel loss situation
Implications of options
Tactical doctrine
CMF schedule
CMF information (flight plan, area threats)
Climb checklist results
AFPI data

(6) Information Sources:

CMF
Tactical doctrine
AFPI equipment
Navigation equipment

(7) Crews' Decision:

Select climb point and begin to climb

(8) Decision Class:

Rule-based

(9) Action Taken:

Select climb point
Start climb
Run climb checklist

(10) Information Management Requirements:

Present CMF schedule
Present CMF information (mission flight plan, area threats)
Present options
Present climb checklist
Present AFPI
Present navigation information

Mission Scenario Analysis

Record No. 142

(1) Mission Leg: KK to SC

(2) Mission Phase: egress

(3) Scenario Event (Planned N):

Ship is detected and SAM acquisition radar detected/identified

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type acquisition radar
Implications of options
Tactical doctrine
SAM radar identification
SAM radar activity
Ship location/identification

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Continue climb and monitor SAM acquisition radar

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Continue climb
Monitor SAM acquisition radar activity

(10) Information Management Requirements:

Present ship detection/identification
Present SAM acquisition detection/identification
Present options
Present applicable tactical doctrine
Monitor SAM acquisition radar activity

Mission Scenario Analysis

Record No. 143

(1) Mission Leg: SC to LO

(2) Mission Phase: egress

(3) Scenario Event (Planned N):

SAM target engagement radar detected and subsequent missile firing detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type missile firing

Implications of options	SAM type
Tactical doctrine	SAM strike potential
SAM radar activity	SAM location

(6) Information Sources:

Tactical doctrine
External sensors

(7) Crews' Decision:

Perform evasive maneuvers and employ countermeasures

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive maneuvers
Employ countermeasures
Track SAM

(10) Information Management Requirements:

Present SAM target engagement radar detection
Present SAM firing and up-link signal detection
Present SAM type and strike potential
Track SAM
Present options
Coordinate evasive maneuvers information (navigation/AFPI)
Present applicable tactical doctrine
Coordinate countermeasures information
Monitor SAM radar activity

Mission Scenario Analysis

Record No. 144

(1) Mission Leg: SC to LO

(2) Mission Phase: egress

(3) Scenario Event (Planned N):

First SAM firing misses and second SAM firing detected

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM type missile firing
Implications of options
Tactical doctrine
SAM radar activity
SAM type
SAM strike potential
SAM location

(6) Information Sources:

Tactical doctrine External sensors

(7) Crews' Decision:

Continue with previous counteractions

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Perform evasive maneuvers
Employ countermeasures
Track SAM

(10) Information Management Requirements:

Present SAM firing and up-link signal detection
Present SAM type and strike potential
Track SAM
Present options
Present applicable tactical doctrine
Monitor SAM radar activity
Coordinate evasive maneuvers information
Coordinate countermeasures information

Mission Scenario Analysis

Record No. 145

(1) Mission Leg: SC to LO

(2) Mission Phase: egress

(3) Scenario Event (Planned N):

Second SAM misses and SAM radar goes down

(4) Crews' Response to Event:

Consider options

(5) Informational Demands:

Response options for SAM going down
Implications of options
Tactical doctrine
Fuel status
SAM radar activity

(6) Information Sources:

Tactical doctrine
Fuel status sensors
External sensors

(7) Crews' Decision:

Resume climb and proceed to alternate PSB

(8) Decision Class:

Knowledge-based

(9) Action Taken:

Resume climb
Rejoin re-planned route
Proceed to alternate PSB

(10) Information Management Requirements:

Present options
Present applicable tactical doctrine
Present SAM radar activity
Coordinate navigation/AFPI information to rejoin re-planned route
Present re-planned route to alternate PSB

U.S.Government Printing Office: 1988 — 548-053/80110