REPORT ON USAF STUDIES BOARD WORKSHOP ON AUTOMATION IN COMBAT AIRCRAFT IN THE 1990s

DR. ROBERT HENNESSY

COMMITTEE ON HUMAN FACTORS
NATIONAL RESEARCH COUNCIL

A list of organizational structure sponsoring the "Automation in Combat Aircraft" Study.

Members of the Air Force Studies Board

AUTOMATION IN COMBAT AIRCRAFT

1982

COMMITTEE ON AUTOMATION IN COMBAT AIRCRAFT
AIR FORCE STUDIES BOARD

COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
(FORMERLY ASSEMBLY OF ENGINEERING)

NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES

A statement on the basic problem

This chart lists the objective of the study, its scope, and the approach.

HUMAN OR MACHINE TO PERFORM A FUNCTION?

". . . A LITTLE REFLECTION MAKES IT CLEAR THAT THE CENTRAL ISSUE IN CHOOSING COMPONENTS FOR A COMPLEX SYSTEM IS USUALLY NOT SO MUCH WHICH COMPONENT WILL DO A BETTER JOB, AS WHICH COMPONENT WILL DO AN ADEQUATE JOB FOR LESS MONEY, LESS WEIGHT, LESS POWER, OR WITH A SMALLER PROBABILITY OF FAILURE AND LESS NEED FOR MAINTENANCE."

(PAUL FITTS, 1962)

SUBJECT OF STUDY:

AUTOMATION OF HUMAN DECISION PROCESSES

OBJECTIVE:

MOVE THE COGNITIVE CONTENT OF FLYING AN AIRCRAFT AND MANAGING ITS WEAPONS FROM THE AIRCREW TO AN AUTOMATED SYSTEM

SCOPE:

FIGHTER/ATTACK AIRPLANE (SINGLE-SEAT) PERFORMING ANY OF THE USUAL TACTICAL MISSIONS INCLUDING THE AIRCRAFT, ITS SENSORS, COMMUNICATIONS AND OTHER SYSTEMS

APPROACH:

SUBCOMMITTEES:

1. FUNCTIONS
2. TECHNOLOGY
3. HUMAN FACTORS

The next two charts list the members of the 1981 Summer Study on - Automation in Combat Aircraft. The first charts lists the Steering Committee and Functions Subcommittee.

Membership of the Human Factors and Technology Subcommittee is shown in this chart.

1981 Summer Study on: Automation in Combat Aircraft

Organizational Outline

Steering Committee

Robert A. Duffy (Chairman), Charles Stark Draper Laboratory, Inc.
Richard G. Cross, Jr. (Vice Chairman), BDM Corporation
Charles A. Berry, National Foundation for the Prevention of Disease
Joseph C.R. Licklider, Massachusetts Institute of Technology
John J. Martin, Bendix Corporation
Brockway McMillan, Bell Telephone Laboratories, Inc. (retired)
Samuel C. Phillips, TRW Energy Products Group
Clayton S. White, Oklahoma Medical Research Foundation (retired)

Julian Davidson, System Development Corporation (exofficio as chairman of the Air Force Studies Board)

Technical Directors:
Charles A. Fowler, MITRE Corporation
Willis H. Ware, Rand Corporation

Functions Subcommittee

Barton Krawetz (Chairman), U.S. Department of Defense
Charles Abrams, U.S Naval Air Development Center*
Neal Blake, Federal Aviation Administration*
C. Eric Ellingson, MITRE Corporation
John J. Martin, Bendix Corporation
Robert O'Donohue, BDM Corporation*
William S. Ross, McDonnell Aircraft Company*
Frank Scarpino, Air Force Wright Aeronautical Laboratories*
Don B. Shuster, Sandia Laboratories*

*Part-time participant.

Human Factors Subcommittee

Stuart K. Card (Chairman), Xerox Corporation
Charles A. Berry, National Foundation for the Prevention of Disease*
Renwick E. Curry, NASA Ames Research Center
Robert Hennessy, National Research Council*
Joseph C.R. Licklider, Massachusetts Institute of Technology
H. McIlvaine Parsons, Human Resources Research Organization*
Robert W. Swezey, Science Applications, Inc.
Clayton S. White, Oklahoma Medical Research Foundation (retired)

Technology Subcommittee

F. Robert Naka (Chairman), Science Applications, Inc.
Donald L. Beckman, Bendix Corporation
Don A. Doty, Vought Corporation
Gordon England, General Dynamics Corporation
Charles E. Hathaway, BDM Corporation
Morris Ostgaard, Air Force Wright Aeronautical Laboratories*
Gerald K. Slocum, Hughes Aircraft Company

*Part-time participant.

The subcommittee goals are illustrated in this chart.

This chart illustrates the Interaction Matrix showing systems that are used simultaneously. In the matrix, "P" emphasizes pilot interactions. The chart illustrates the number of interactions involving the pilot.

SUBCOMMITTEE: GOALS

I. FUNCTION

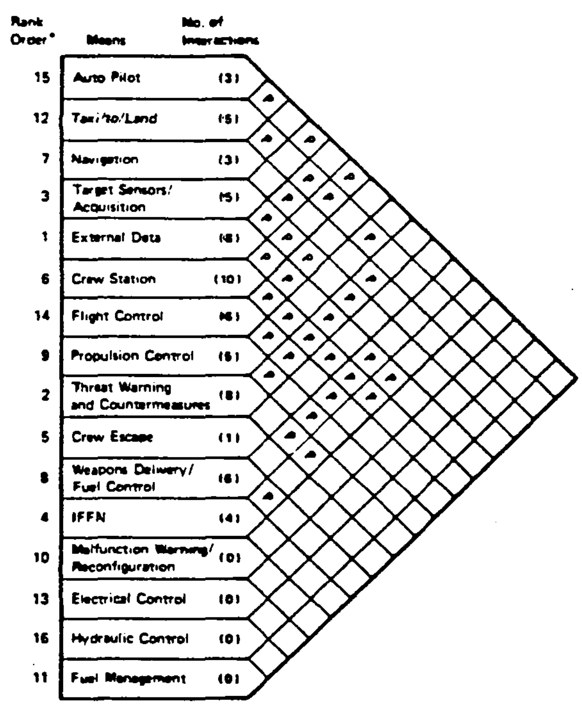
IDENTIFIED IMPORTANT MISSION FUNCTIONS AND OPPORTUNITIES FOR AUTOMATION

II. TECHNOLOGY

IDENTIFIED WHAT COULD BE ACCOMPLISHED THROUGH AUTOMATION

III. HUMAN FACTORS

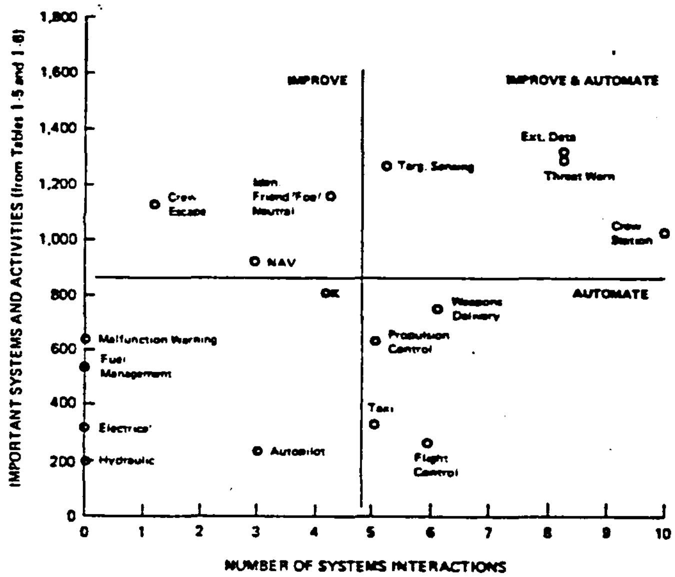
IDENTIFIED WAYS IN WHICH AUTOMATION CAN BE USED TO LESSEN PILOT WORKLOAD



*From Table 1-7.

Estimates of system importance are shown as a function of the number of interactions (i.e., the degree to which a pilot must use two or more systems concurrently). This correlation allows systems to be grouped according to whether they need to be "improved," "improved and automated," or "automated," or are "OK" as they are.

The first part of the chart illustrates combat aircraft systems and activities requiring attention to design and/or automation (in alphabetical order). The second part lists the rank order of combat aircraft systems and activities mature enough for automation.

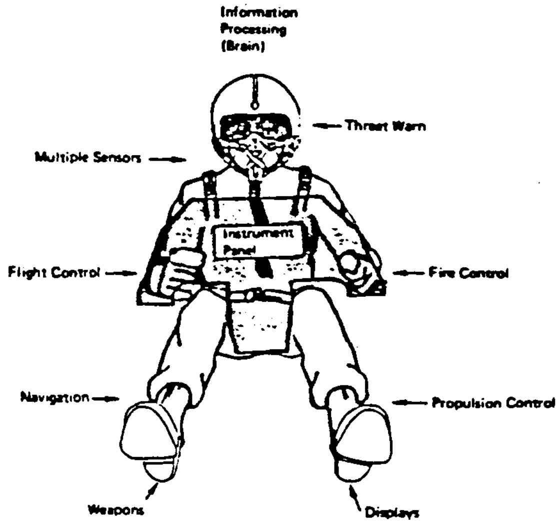


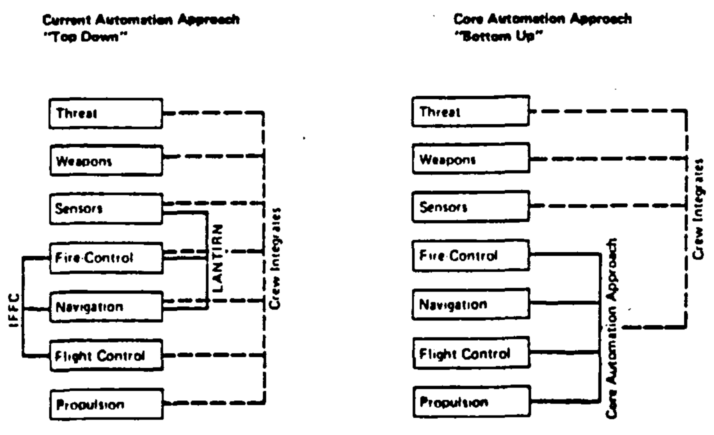
Systems and Activities
Crew Escape
Crew Station
External Data
IFFN
Navigation
Target Sensing/Acquisition
Threat Warning/Countermeasures

Rank Order	Systems and Activities
1	Flight Control
2	Propulsion
3	Weapons Delivery/Fuel Control
4	Crew Station
5	Threat Warning/Countermeasures
6	External Data
7	Target Sensing/Acquisition

The pilot is the automation "core," processing all the data from aircraft elements. The result is a high workload and a limit on performance.

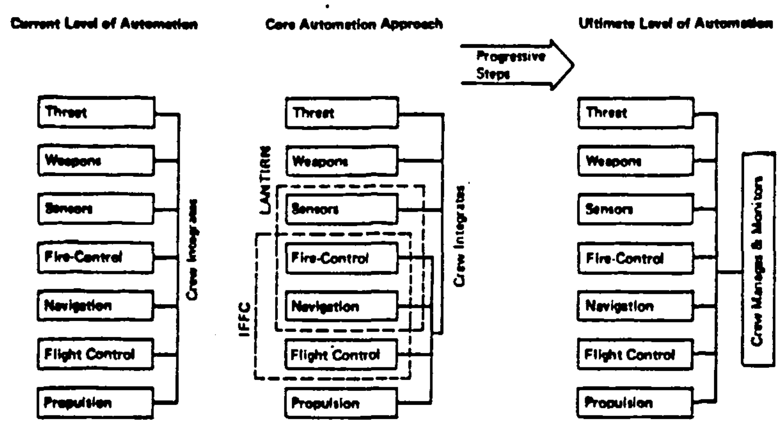
In the current automation approach (left side of figure), the LANTIRN programs links together weapons delivery, target sensing and acquisition, fire control, and navigation. The IFFC program links together fire control, navigation, and flight control. In both programs, the crew integrates all of the functions. In the recommended core automation approach (right side of figure), fire control, navigation, flight control, and propulsion are integrated to form a composite function called flight trajectory and attitude control. The crew integrates this core function with the other mission functions.


Information
Processing
(Brain)
Threat Warn
Multiple Sensors
Instrument
Panel
Flight Control
Fire Control
Navigation
Propulsion Control
Weapons
Displays


Current Automation Approach
"Top Down"
Threat
Weapons
Sensors
Fire Control
Navigation
Flight Control
Propulsion
LANTIRN
IFFC
Crew Integrates
Core Automation Approach
"Bottom Up"
Threat
Weapons
Sensors
Fire Control
Navigation
Flight Control
Propulsion
Core Automation Approach
Crew Integrates

In the current level of automation (left), the crew integrates all mission functions. In the recommended core automation approach (middle), the crew integrates the composite function of flight trajectory and attitude control with the other mission functions. In the ultimate level of automation (right), all the functions are integrated, and the crew manages and monitors the system.

The basic reasons for automating and some alternatives to automation



WHY AUTOMATE?

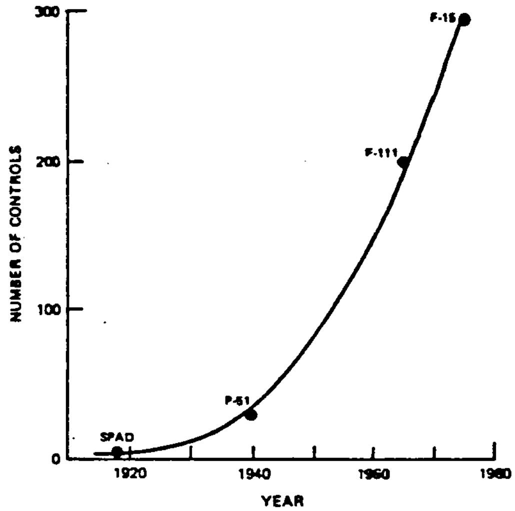
- Reduce Excessive Workload
- Reduce Errors
- Improve Performance
- Add New Capabilities

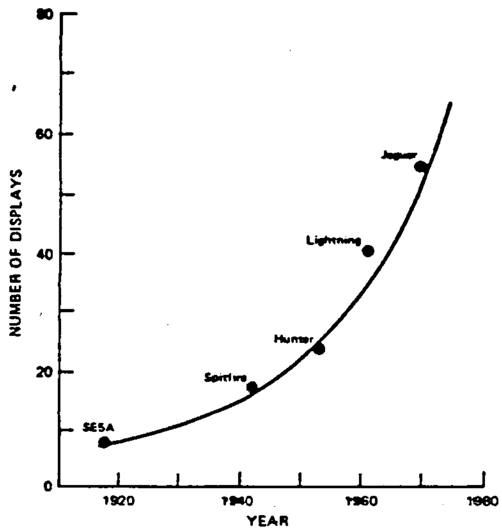
ALTERNATIVES TO AUTOMATION

- Procedures
- Training
- Human Factors Engineering

The next two charts compare cockpit controls in both US and British fighter aircraft. This chart illustrates the number of cockpit controls per crew member in US fighter aircraft, 1920 to 1980.

This chart illustrates the number of cockpit displays in British fighter aircraft, 1920 to 1980.


300
200
100
0
NUMBER OF CONTROLS
F-15
F-111
P-51
SPAD
1920
1940
1960
1980
YEAR


80
60
40
20
0
NUMBER OF DISPLAYS
Lightning
Hunter
Spitfire
SE5A
1920
1960
1980
YEAR

Automation can proceed along three dimensions: the automation of control tasks, the automation of monitoring tasks, and the automation of tactical and planning tasks.

A listing of automation guidelines for combat aircraft.

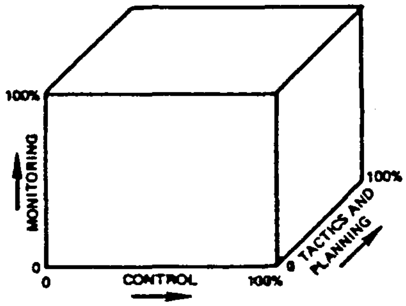


TABLE 2-4. Automation Guidelines For Combat Aircraft

When to Automate

To reduce excessive workload

1. Consider automating to avoid perceptual saturation.
2. Consider automating to reduce concurrent tasks.
3. Consider automating tasks on compressed time-lines.
4. Consider automating to avoid pilot bandwidth limitations.
5. Consider automating to eliminate or consolidate small-scale operations.

To reduce errors

6. Consider automating routine tasks.
7. Consider automating memorization tasks.
8. Consider automating sequential and timed tasks.
9. Consider automating seldom-performed tasks.
10. Consider automating monitoring tasks.
11. Consider automating tasks pilots find boring and unmotivating.

To improve performance

12. Consider automating precision tasks.
13. Consider automating emergency-prevention devices.
14. Consider automating complex mathematical or logical tasks.

To add new capability

15. Consider automating to avoid the combination of low-altitude flight and any other task.
16. Consider automating complex tasks that must be performed rapidly.

How to Automate

Control tasks

17. Design aircraft controls and displays to be compatible with pilots' mental representations of the tasks.
18. Use automation to eliminate peak task demands.
19. Provide optional capability for manual operation of the system.
20. Allow for different pilot styles.

Monitoring tasks

21. Keep false-alarm rate low.
22. Provide operationally-relevant information.
23. Allow for pilot query.
24. Design alarms to indicate the extents of emergencies.
25. Expose pilots to all alerts and to important combinations.

Planning and Tactical Maneuvers

(Research needed)

Pitfalls of Automation

26. Beware of reliability and maintenance problems in complex systems.
27. Beware of unnecessary use of automation.
28. Beware of the lack of pilot acceptance.
29. Beware of substitution of emergency backup systems for main systems.
30. Beware of the loss of pilots' manual skills.
31. Beware of increased training requirements.
32. Beware of failure modes for complex systems.
33. Beware of system inflexibility or unmodifiability.
34. Beware of unknowns.

The next two charts contain the findings and conclusions of the study group. No priority ranking is intended in the ordering of these findings and conclusions.

Findings and conclusions continued

FINDINGS AND CONCLUSIONS*

1. The complexity of today's missions and high-performance aircraft has created workloads that at times impose intolerable demands on combat pilots.

2. Air Force development and application of automated features can improve operational effectiveness and enhance the chances for survival of pilots and combat aircraft.

3. The technology for automation of all routine tasks and of some others is now available. Full automation is costly and complex, however, and is not necessary in all manned combat aircraft.

4. The Air Force does not have an established position on the requirements for automation in aircraft.

5. There is currently no systematic, widely applied technology for allocating functions between automated systems and the pilot. Similarly, there is no criterion for balancing the costs of automating particular functions against the resulting improvements in combat performance.

6. Computer technology makes it possible to develop dynamic, integrated, and comprehensive automated systems for future combat aircraft. A systems approach, emphasizing the core function of flight trajectory and attitude control, is a logical and necessary starting point.

7. The aircrews' stated immediate need is for improved ability to fly low, at night, and during severe weather, using terrain for cover from enemy defenses. The critical and essential functions that could be automated to achieve this goal have not been completely identified, although current programs should illuminate this issue.

8. In such programs as AFTI-16 and LANTIRN, and in the development of technology for TF/TA, the Air Force research and development community is addressing important problems. These programs will develop technologies and an engineering perspective that are a valuable base on which to build. The approach remains piecemeal, however, and without clearly stated or widely understood objectives. A much-needed unifying focus is missing.

---

9. There is a large gap between what is known in a laboratory setting of the basic characteristics of human psychomotor performance, and what is known about how pilots actually fly and react in modern combat aircraft. Much of the knowledge needed to design an automated aircraft that uses pilots' skills to the best advantage lies within that gap.

10. In the past, the unreliability of avionics systems has been a major contributor to the downtime or unavailability of combat aircraft. No effort to improve combat performance by further automation can succeed without adequate attention to the reliability and maintenance of the equipment.

11. Fighter aircraft under development or now entering the inventory are not automated to the extent that the pilot is wholly free to assess and monitor the combat situation and to plan his further strategy. No aircraft has provided him with effective, accessible aids for assessing alternative strategies.

12. Insufficient attention has been paid to past efforts at automation. A study of such efforts could help developers to repeat past successes and avoid past shortcomings.

13. Identification of unknown objects as friend, foe, or neutral (IFFN) is difficult today. IFFN will become much more important in the future because of improvements in weapons' ranges.

14. In tactical maneuvers in high-performance aircraft, pilots often fly at the edge of the safe ejection envelope. Current automatic ejection equipment is inadequate for such situations; the number of injuries and fatalities suffered by pilots who eject from combat aircraft is increasing.

*No priority ranking is intended in the ordering of these findings and conclusions.

This chart presents a summary of the recommendations made by the study group.

Recommendations continued

RECOMMENDATIONS

1. There is a recognized need for automation. The primary goals should be to increase combat effectiveness to enhance survival of pilots and aircraft, and to decrease pilot work load.

2. There is evidence that such automation can be available in the 1990s. A firm decision can and should be made to automate specific critical functions and/or infrequently performed but essential functions that are currently performed manually.

3. A systems-oriented program aimed at improving and developing automation for the 1990s should be initiated now. The goal should be a core design that would form the basis of automated functions, building on flight trajectory and attitude control systems. Such a systems approach could prevent piecemeal automation that could be costly and would result in only partial solutions not adaptable to growth.

4. Four functional groups are promising candidates for automation: (1) flight trajectory and attitude control, (2) engine and power systems control, (3) weapons delivery and fire control, and (4) navigation and communications functions. Combinations of these functional families can be accomodated by the evolving technology.

5. The increasing number of displays used to present information to pilots, the amounts of information and instructions displayed, the limited cockpit area available for display, and the otherwise complex environment of the aircraft have created special problems. Complicated displays are difficult to read, and controls and functional mode selection are cumbersome and time-consuming. Consequently, necessary actions may sometimes be neglected. To reduce pilot workload and increase operational effectiveness, functions that divert attention from critical actions should be automated.

---

6. A method for allocating functions between automated systems and the pilot must be developed. A multidisciplinary team should examine potential hardware and software techology, as well as human performance, to lay the basis for clear decisions in this regard. The objective should be a practical method for quantifying the improvements in performance and survival that result from automating particular functions.

7. A separate and fundamental study should be initiated to shed light on (1) the mental model pilots create to aid in performing their combat tasks, (2) the performance characteristics of the controls and displays through which the pilot and automated systems interact, and (3) human capabilities. This study should develop a multitask, experimental and analytic program to model pilot behavior. This program could be used as an aid in designing advanced automated systems, and in particular the cockpits of the future.

8. Automating or partially automating a higher class of appropriate cognitive functions, such as the ability to assess the combat situation, or to plan strategies and escape routes, should be a part of the Air Force's long-range program.

9. The rising trend in fatalities and serious injuries relating to aircraft escape systems indicates a need for improvements. Air Force activity in modifying escape systems (ACES II) may meet this need. The problem must be addressed, through either the ACES II program or a completely new approach.

10. Identification of objects for beyond visual range as friend, foe, or neutral (IFFN) cannot be automated with any confidence today. An automated system for such identification would permit important gains in combat effectiveness. A coordinated effort on this front is needed.

TACTICAL

AIRCRAFT

COCKPIT

DEVELOPMENT

AND

EVALUATION

PROGRAM

TACDEP

DR. K.R. BOFF

HE-80-8-80

For additional background on this subject the reader is referred to the NAEC paper "Integrated Perceptual Information for Designers" which is reproduced as an Addendum at the end of this paper.

EXECUTIVE SUMMARY

TACTICAL AIRCRAFT COCKPIT DEVELOPMENT & EVALUATION PROGRAM (TACDEP)

Program Manager: Kenneth R. Boff, Ph.D.
Air Force Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base OH 45433
(513) 255-4820 (AV-785)

Objective: Development of a sound theoretical and empirical basis for matching the perceptual and psychomotor characteristics of the pilot to the layout, displays, controls and portrayal of information within the crew station. This matching implies the development of a synergistic pilot/aircraft system for which the requirements for and packaging of controls and displayed information are determined on the basis of systems effectiveness criteria.

Background: Today's operational aircrews continue to be saturated with task workload, despite the infusion of advanced technology. This is true because a large measure of the variance in system effectiveness depends on the operator's ability to acquire, process and implement task critical information. Nonetheless, cockpit design has been principally driven by technology considerations. While advanced weapons and digital avionics systems have proliferated, there has been very little systematic integration and management of the pilot/aircraft interface. The resultant growth in cockpit complexity has, in turn, increased pilot workload and reduced pilot/system reliability and effectiveness. An integrated cockpit design technology which specifically takes into account the perceptual and psychomotor capabilities of the operator is needed.

Approach: Development of a credible cockpit design technology centered on the information requirements of the pilot is dependent on 1) objective identification of task critical information germane to mission requirements and aircraft/weapon system control and 2) the configuration and portrayal of this information in the cockpit based on the perceptual and psychomotor characteristics of the human operator. This requires identification of and the ability to model and measure the variables which affect sensory acquisition and perceptual processing of information (e.g. physical characteristics of the environment or the display, operator workload and experience).

TACDEP is developing the necessary technical data base, and will begin work in FY82 on performance modeling and measurement methodologies. Advanced display and control concepts (e.g. visual, aural and proprioceptive) will be modeled, demonstrated and evaluated. Empirical evaluation studies will begin in a range of areas including boresighted vs. non-boresighted target acquisition, eye control as a biocybernetic technique, stereoscopic information displays and applications of artificial intelligence in the cockpit.

Products: TACDEP will develop 1. empirically-based principles and methodology for the management and measurement of pilot/system information processes, 2. validated display concepts, and 3. applicable models and metrics that will enable accurate predictions of pilot/system performance for the design and evaluation of aircraft crew stations.

PURPOSE

AN EXPLORATORY DEVELOPMENT PROGRAM. .

- TO DEVELOP HUMAN ENGINEERING TOOLS FOR CREW SYSTEM DESIGN
- EXPLORE ADVANCED CONTROL DISPLAY INTERFACES FOR CREW SYSTEMS

TACDEP DEVELOPMENT AREAS

#1 DATA BASE DEVELOPMENT

#2 ADVANCED CONCEPT DEVELOPMENT & MODELING

#3 PERFORMANCE MEASUREMENT

#4 TESTBED ENHANCEMENT

HE-80-8-89

EXECUTIVE SUMMARY

PROGRAM: Integrated Perceptual Information for Designers (IPID) Study

PROGRAM MANAGER: Dr. Kenneth R. Boff
AFAMRL/HEA
Wright-Patterson AFB OH 45433
(513) 255-4820 (AV) 785-4820

Engineering Technical Advisor: Mr. Edward A. Martin
Air Force Deputy for Equipment Engineering
Simulator Division

PROGRAM OBJECTIVES: a) to consolidate perceptual data pertaining to the variables that may influence an operator's ability to acquire or process displayed information and b) to distill this consolidation into a specialized data compendium of the relevant models, data, illustrations, etc. bearing on perceptual inputs to operational and simulator display design.

BACKGROUND: Currently, there is enhanced concern within DoD regarding the operator's contribution to systems effectiveness. Data regarding the variables that impact the operator's ability to acquire and process task critical information is of prime importance to the design of effective controls and displays. The problem is that these data do not now exist in a form useful to design engineers. As a result, current operational and simulator display designs have not fully capitalized on human sensory and perceptual characteristics.

DISCUSSION: IPID is a multi-agency supported effort principally managed by the Air Force Aerospace Medical Research Laboratory at Wright-Patterson AFB. It is organized as a three-phase program. The three phases are interactive and overlapping.

PHASE A: This phase is concerned with the consolidation of sensory and perceptual data into a Handbook of Perception and Human Performance. It is intended that this Handbook will be published by a reputable commercial publisher. It will provide the source material upon which subsequent IPID products will be based. This phase involves bringing together over 60 recognized experts in a range of subareas of perception and human performance. The anticipated product delivery date is 15 Feb 1984.

PHASE B: This phase is concerned with a) analytic review and consolidation of applied research data in simulation and control/displays and b) distillation of the Handbook into a generic engineering data compendium. These combined data will be integrated and presented in a format developed under a previous effort that will enable their effective use by two target populations: simulator engineers and operational control/display designers. Tailored information access techniques will be packaged in a set of companion user's guides. Product delivery is anticipated for May 1984.

INTEGRATED PERCEPTUAL INFORMATION FOR DESIGNERS

FOR FURTHER INFORMATION, CALL: Dr. Kenneth Boff
AV 785-4820
(513)255-4693

IPID OBJECTIVE

- PROVIDE DESIGNERS WITH EASILY ACCESSIBLE SOURCE OF DATA ON HUMAN OPERATOR CHARACTERISTICS GERMANE TO DISPLAY DESIGN
- TARGET USERS:
  - — SIMULATION ENGINEERS
  - — INFORMATION DISPLAY DESIGNERS

PHASE C: This phase is concerned with digitizing the engineering data compendium and development of a "User Friendly" data base management system to facilitate information access. The envisioned system would aid the designer in acquiring the data relevant to his problem with a higher degree of reliability than is possible with conventional keyword access technology. Such a system would incorporate features available through the current state of the art in artificial intelligence.

APPLICATIONS: When used appropriately, the IPID data base will be a valuable design resource for:

1. Developing specifications based on sensory or perceptual characteristics, (i.e. matching simulator display characteristics to human sensor capabilities). For example, it should not be necessary to simulate a specific force of 0.01 G since this is, under most conditions, below the threshold of detectability.

2. Evaluating specifications or prioritizing design options. Many existing specification requirements and industrial standards do not have a sound basis for their existence. The sensory and perceptual data can be a resource for their evaluation.

3. Generating new design or training alternatives. Data from Regan, Beverly and Cynader (1979), Regan (1980), Ginsburg (1980), and others suggest that specific sensory capabilities may be enhanced through special training procedures. This portends a new approach to pilot training as well as a new generation of specialized training devices which are geared toward improving the pilot's "natural" ability to acquire and process information.

IPID PROGRAM

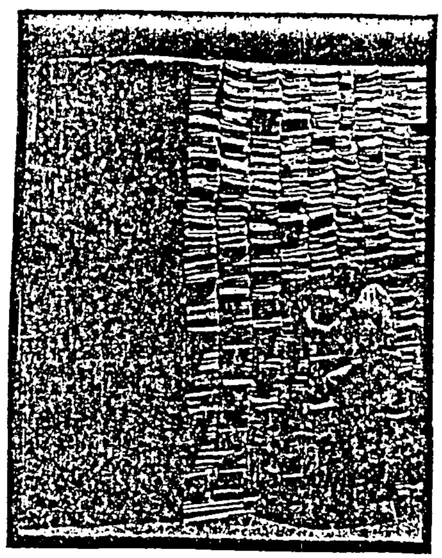
SPONSORED BY:

- AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
- AIR FORCE HUMAN RESOURCES LABORATORY
- AIR FORCE DEPUTY FOR SIMULATORS
- SIMULATOR DIVISION, AIR FORCE DEPUTY FOR ENGINEERING
- US ARMY RESEARCH INSTITUTE
- US ARMY HUMAN ENGINEERING LABORATORY
- US NAVAL TRAINING EQUIPMENT CENTER

HE 80 9 26

IPID

- VOLUME OF EXISTING DATA IS OVERWHELMING
- PERTINENT DATA NEEDS TO BE IDENTIFIED AND EVALUATED WITH RESPECT TO THE DESIGNER'S PROBLEM



IPID INFORMATION MANAGEMENT OBJECTIVES

		PRODUCTS
• CONSOLIDATION	→	HANDBOOK
• PRESENTATION	→	DATA COMPENDIUM
• ACCESSIBILITY	→	USER'S GUIDES 1. SIMULATOR DESIGNERS 2. CONTROL/DISPLAY DESIGNERS

HE-80-12-2

IPID HANDBOOK OF SENSATION AND PERCEPTION

- CREDIBLE SOURCE OF SELECTED, INTERPRETED DATA
  - MULTI-VOLUMES
  - OVER 2000 PAGES
  - OVER 1600 FIGURES
- CITABLE, COMPANION VOLUME TO DATA BASE
- PUBLISHED JOINTLY BY GOVERNMENT AND OUTSIDE PUBLISHER

HE-80-10-51

IPID

SELECTED HANDBOOK TOPICS

- VISUAL SENSITIVITY TO SPATIAL PATTERNS
- VESTIBULAR PROPRIOCEPTION AND KINESTHETIC SENSITIVITY
- EYE MOVEMENTS AND PERCEIVED VISUAL DIRECTION
- METHODS OF SIMULATING SPACE AND MOTION
- ACCELERATION AND MOTION IN DEPTH
- SPACE PERCEPTION
- BINOCULAR PERCEPTION
- SPEECH PERCEPTION AND COMMUNICATION
- INTERSENSORY INTERACTIONS
- MOTOR CONTROL

HE-81-10-73

IPID

SELECTED HANDBOOK TOPICS

- INFORMATION PROCESSING (VISUAL AND AUDITORY)
- VISUAL FORM RECOGNITION
- ANALYSIS OF OBJECT AND EVENT PERCEPTION
- EFFECTS OF CONTROL DYNAMICS ON PERFORMANCE
- MONITORING AND SUPERVISORY CONTROL
- DECISION MAKING AND HUMAN PERFORMANCE
- OPERATOR WORKLOAD
- VIGILANCE, MONITORING AND SEARCH
- OPERATOR EFFICIENCY AS A FUNCTION OF ENVIRONMENTAL STRESS, FATIGUE AND CIRCADIAN RHYTHMS

HE-81-10-74

IPID ENGINEERING DATA COMPENDIUM

- DATA FROM HANDBOOK OF PERCEPTION & HUMAN PERFORMANCE
- SUPPLEMENTAL DATA re:
  - INFORMATION CODING, PORTRAYAL AND FORMAT
  - TARGET DETECTION, RECOGNITION, DISCRIMINATION
  - VIBRATION AND LARGE AMPLITUDE MOTION
  - AUTOMATION AND ALLOCATION OF FUNCTION
  - MAN-COMPUTER DIALOGUE
  - FEEDBACK, WARNING AND ATTENTIONAL DIRECTORS
  - OPERATOR-COUPLED DYNAMIC CONTROL

HE-82-7-5

IPID DATA COMPENDIUM

- CONTENTS DERIVED FROM:
  - — SELECTIVE LITERATURE REVIEW
    - PROFESSIONAL JOURNALS
    - GOVERNMENT AND INDUSTRIAL REPORTS
  - — ONGOING GOVERNMENT AND INDUSTRIAL RESEARCH
  - — EXPERT CONSULTATION
- SYNTHESIZED INTO:
  - — PERCEPTUAL PRINCIPLES AND DETAILED MODELS
  - — PARAMETRIC MULTIVARIATE RELATIONSHIPS
  - — GRAPHS, MODELS, ILLUSTRATIONS AND FORMULAE
- WITH
  - — BACKGROUND REFERENCE DATA
  - — QUANTITATIVE EVALUATIONS
  - — QUALITATIVE EVALUATIONS
- IN
  - — EASILY USABLE AND MAINTAINABLE FORMAT

HE-80-10-43

EXAMPLE OF PROPOSED DATA BASE FORMAT

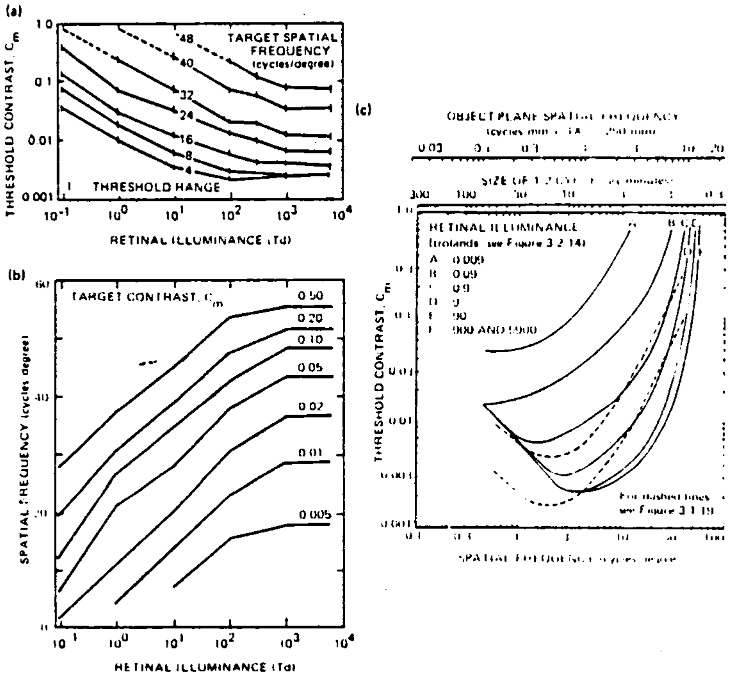


Figure 3.2.33. Effect of Luminance on Contrast Sensitivity. The test conditions for this study [illegible] were

- Sinusoidal grating
- 4.5 degree wide by 8.2 degree high field
- Monochromatic green illumination 525 nm
- Dark surround
- [illegible]
- [illegible]
- 1 subject

[illegible]

[illegible]

[illegible] Figure 3.1.24.)

HE-80-10-44

PRODUCTS

HANDBOOK

- INCLUDES REFERENCE TO SOURCE MATERIAL
- PROVIDES CONTEXTUAL PERSPECTIVE
- EACH PARAGRAPH/ ARTICLE SELF-CONTAINED, CITABLE AND FULLY ILLUSTRATED
- ORGANIZED AS A SOURCE BOOK AND PROFESSIONAL REFERENCE
- SEPARATE OVERVIEW AND INTERACTION CHAPTERS

DATA COMPENDIUM

- ORGANIZED AROUND PERCEPTUAL PRINCIPLES, FUNCTIONS, CHARACTERISTICS, AND MODELS PRESENTED IN GRAPHIC FORMAT
- ORGANIZED TO ENHANCE ITS USEFULNESS AS A DESIGN TOOL
- PROVIDES:
  - RECOMMENDATIONS
  - CAVEATS
  - CROSS REFERENCING TO DATA BASE AND HANDBOOK

USER'S GUIDES

- DATA ACCESS TECHNIQUES INCLUDING
  - INDICES
  - TREE DIAGRAMS
  - MINI-TUTORIALS
- ALLOWS USER TO RAPIDLY DETERMINE WHERE DATA ARE OR ARE NOT AVAILABLE

HE-81-10-2

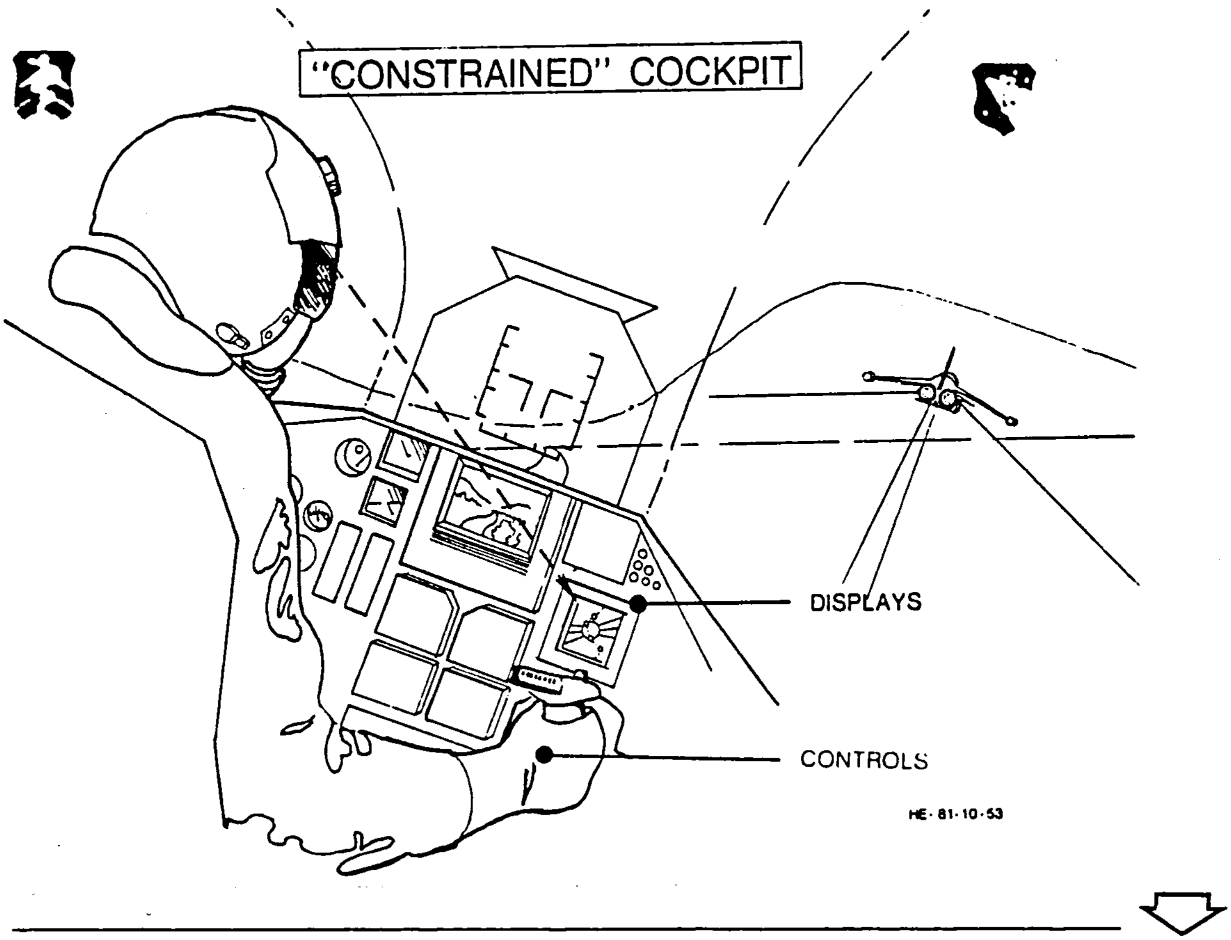
IPID PAYOFF

IPID DATA BASE WILL BE A DESIGN RESOURCE FOR:

- GENERATING DESIGN OPTIONS SPECIFICATIONS, AND STANDARDS FOR DISPLAY:
  - — QUALITY (e.g. COLOR, RESOLUTION)
  - — ORGANIZATION AND FORMAT (e.g. FOV, UPDATE RATE)
  - — CONTENT (e.g. TEXTURE, THRESHOLD CONSIDERATIONS)
- EVALUATION AND PRIORITIZATION OF DESIGN OPTIONS, SPECIFICATIONS AND STANDARDS
- GENERATING NEW DESIGN AND TRAINING CONCEPTS

IPID AREAS OF APPLICATION

- COCKPIT CONTROL/DISPLAY DESIGN
- AUTOMATION INTERFACE ISSUES
- WORKLOAD EVALUATION
- PILOT SELECTION
- C^3 SYSTEMS
- SIMULATION
- TRAINING



WAYS TO IMPROVE COCKPITS

- INFORMATION ORGANIZATION AND PORTRAYAL
  - ELIMINATE HIGHLY CODED INFORMATION
  - ORGANIZE INFORMATION "SPATIALLY"
  - USE PICTORIAL REPRESENTATION
  - SCREEN/LIMIT/SELECT INFORMATION AUTOMATICALLY
- "HIGH BANDWIDTH" CONTROL INTERFACES
  - USE NATURAL PSYCHOMOTOR CONTROL INPUTS
    HEAD/EYES/HAND/VOICE
- AUTOMATION

TACTICAL AIRCRAFT COCKPIT DEVELOPMENT AND EVALUATION PROGRAM (TACDEP) FACILITIES

DESCRIPTION OF FACILITY

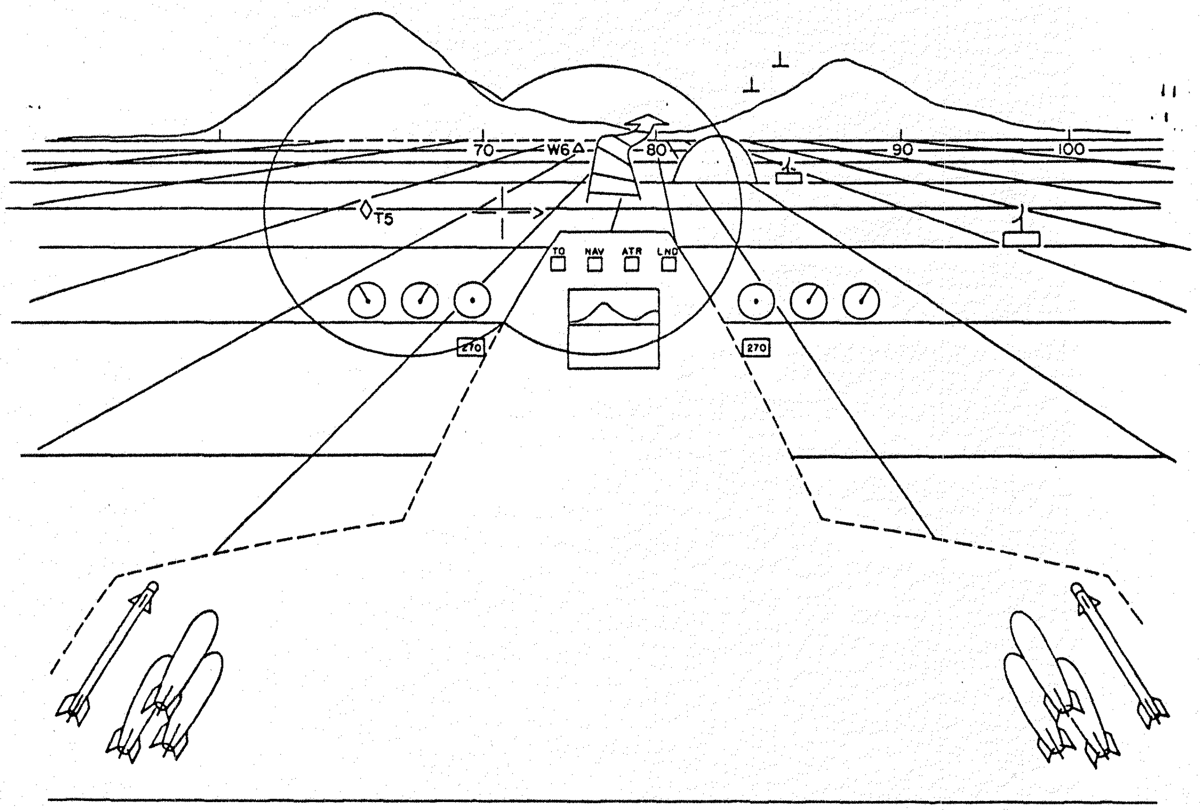
The existing TACDEP facility consists of a fixed base two seat (F-15 type) cockpit with selected instrumentation and controls. Six central processors linked through a multiport memory provide flight dynamics, weapon delivery dynamics, target dynamics and performance scoring. Visual presentations are generated via E&S PSII line graphics processors and are presented as virtual images on wide field-of-view binocular helmet-mounted displays. The orientation of the visual scene in space is adjusted instantaneously on the helmet-mounted display using signals from a 6 degree-of-freedom helmet-mounted sight. The cockpit facility can be used to simulate air-to-air or air-to-ground missions. The two crew positions can be used as a single two seat cockpit or two single seat aircaft operated interactively.

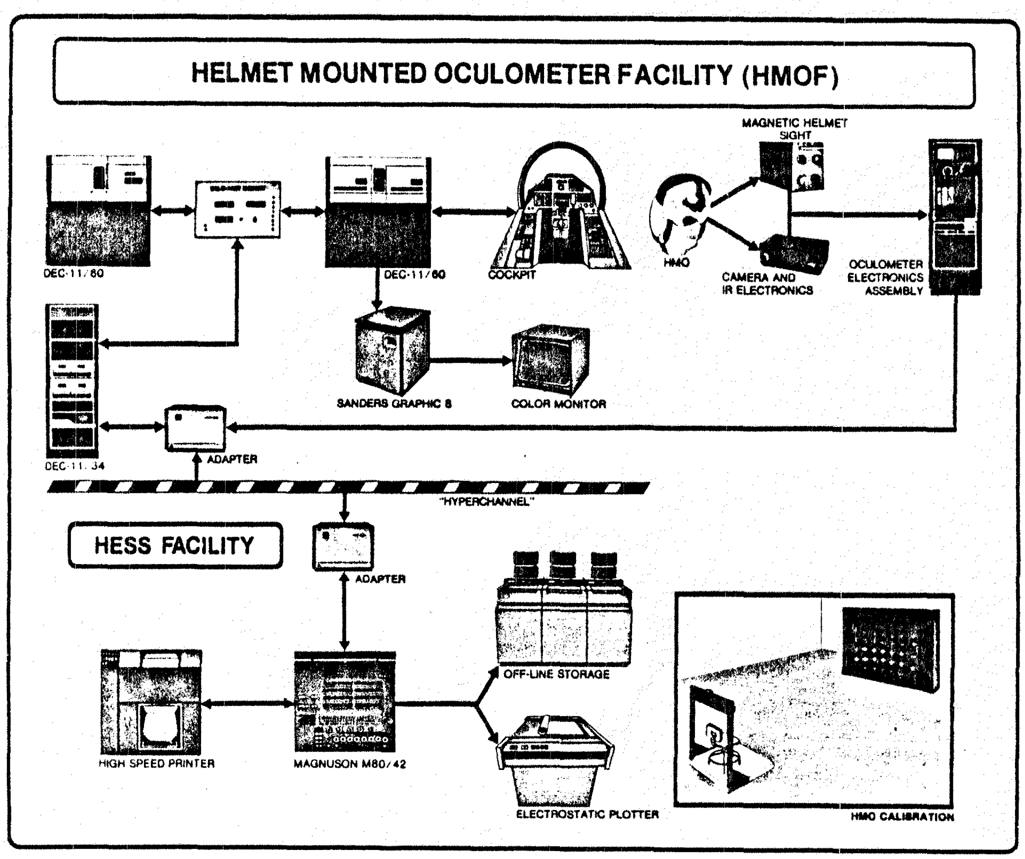
PURPOSE

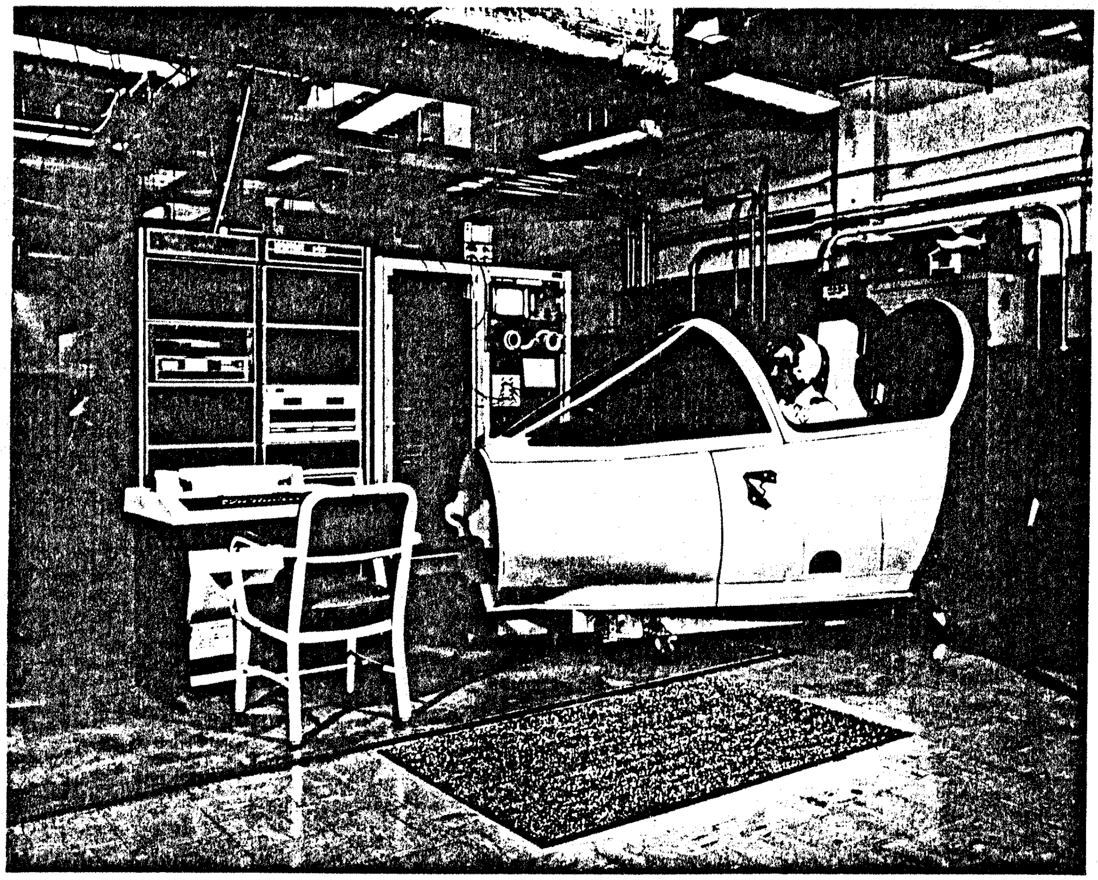
The purpose of this facility is to provide a flexible research tool for investigating crew interface factors in the design of advanced cockpits. The facility will permit the development and evaluation of advanced control/display concepts while performing measure of crew workload and performance. Additionally, this facility will be used to demonstrate cost effective alternatives for visual simulators for flight training.

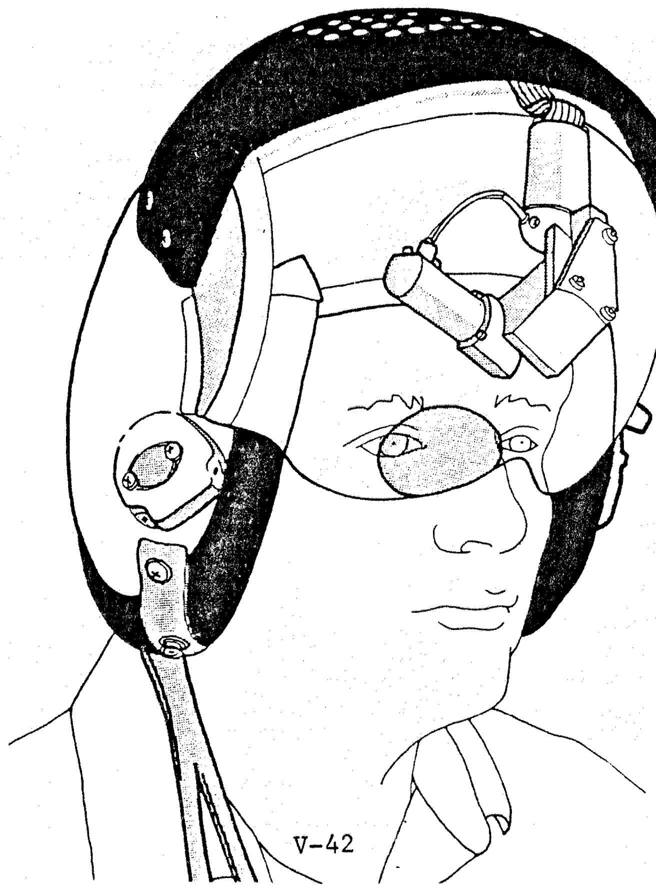
PLANS

During FY 82-83, a helmet-mounted oculometer (eye position measuring system) will be incorporated into this facility. Future plans include upgrading the visual scene generators to provide color raster/computer generated imagery. The facility will also be interfaced to the Manned Threat Quantification (MTQ) facility also described in this document. Generic cockpits for air-to-air, air-to-ground and multipurpose missions will be added to the facility in the out years.


70
W6
80
90
100
T5
TO
NAV
ATR
LND
270
270


HELMET MOUNTED OCULOMETER FACILITY (HMOF)
DEC-11/60
DEC-11/60
COCKPIT
MAGNETIC HELMET SIGHT
HMO
CAMERA AND IR ELECTRONICS
OCULOMETER ELECTRONICS ASSEMBLY
SANDERS GRAPHIC 8
COLOR MONITOR
DEC-11/34
ADAPTER
"HYPERCHANNEL"
HESS FACILITY
ADAPTER
OFF-LINE STORAGE
HIGH SPEED PRINTER
MAGNUSON M80/42
ELECTROSTATIC PLOTTER
HMO CALIBRATION





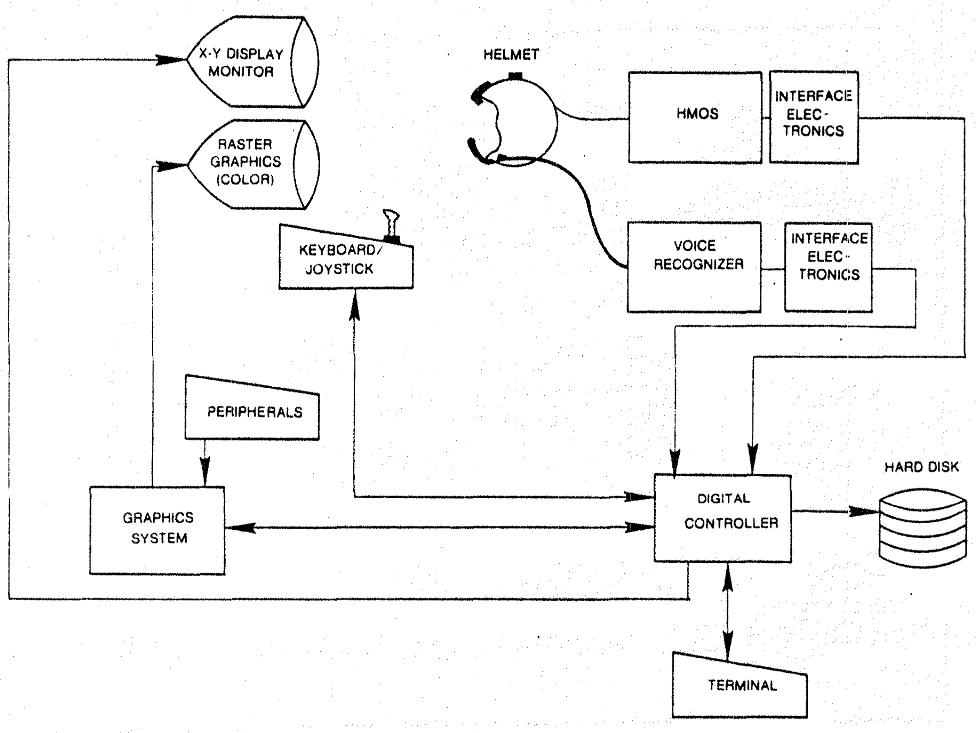
HELMET MOUNTED OCULOMETER SYSTEM

PERFORMANCE

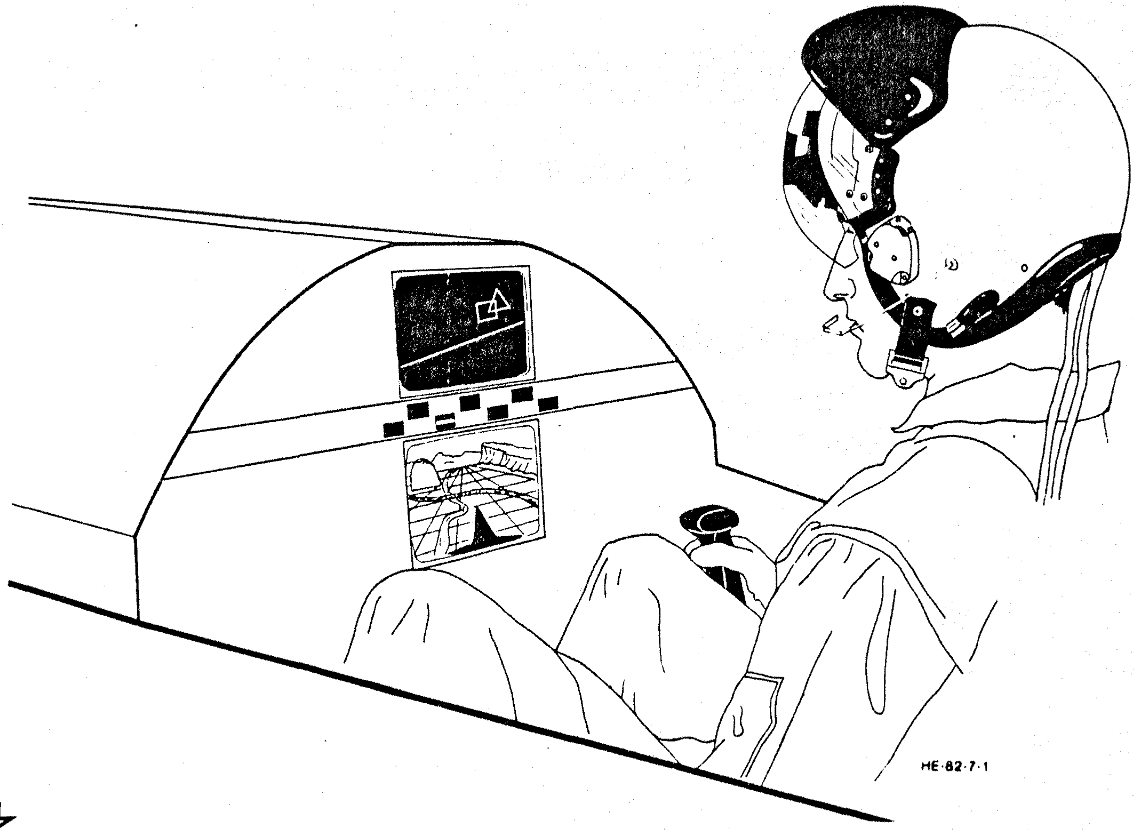
- MOTION BOX — >2 Ft^3
- TRACKED EYE ACCURACY
  - 0° TO 50° Az, 0° TO 30° EL — 0.41° RMS
  - 50° TO 78° Az, 30° TO 60° EL — 0.72° RMS
- UPDATE RATE — 60Hz
- WEIGHT ADDED TO HELMET — 15 oz

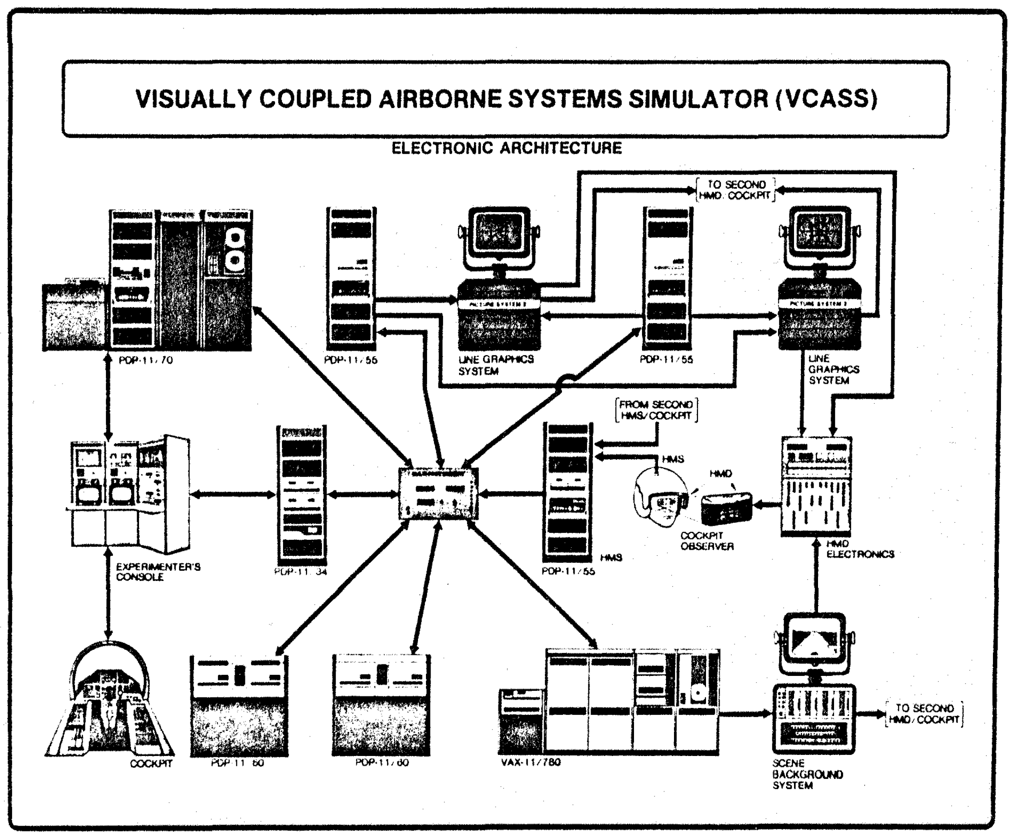
HE-82-1-60

EYE COUPLED VOICE CONTROL SYSTEM



HE-82-6-47

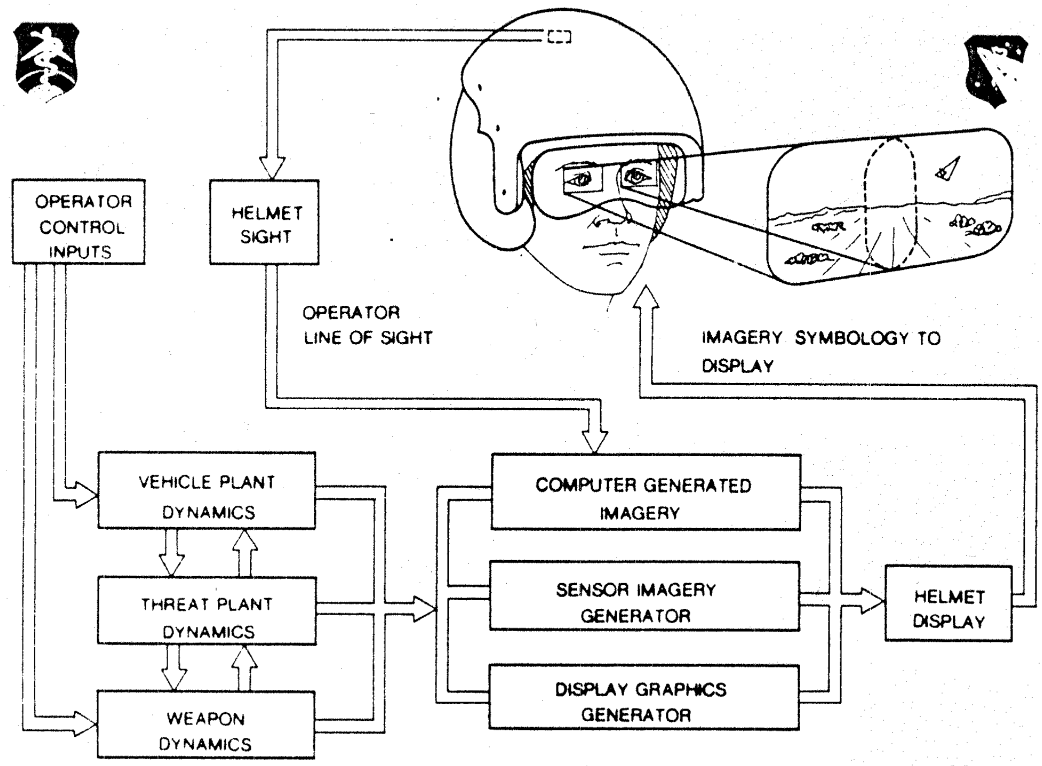

HE-82-7-1


VISUALLY COUPLED AIRBORNE SYSTEMS SIMULATOR (VCASS)
ELECTRONIC ARCHITECTURE
TO SECOND HMD/COCKPIT
PDP-11/70
PDP-11/55
LINE GRAPHICS SYSTEM
PDP-11/55
LINE GRAPHICS SYSTEM
FROM SECOND HMS/COCKPIT
HMS
HMD
EXPERIMENTER'S CONSOLE
PDP-11/34
PDP-11/55
HMS
COCKPIT OBSERVER
HMD ELECTRONICS
COCKPIT
PDP-11/60
PDP-11/60
VAX-11/780
SCENE BACKGROUND SYSTEM
TO SECOND HMD/COCKPIT

VISUALLY COUPLED AIRBORNE SYSTEMS SIMULATOR (VCASS)

- AN INTERACTIVE FULL SCENE VISUAL SIMULATION SYSTEM IMPLEMENTED UNIQUELY WITH VISUALLY COUPLED SYSTEM TECHNOLOGY

VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR



VCASS DESIGN REQUIREMENTS

- PRESENTS COCKPIT, DISPLAYS, TARGETS, SCENE, AS VIRTUAL IMAGES IN HEMISPHERICAL SPACE
- HARDWARE INDEPENDENT CREW STATION CONFIGURATIONS
- INTEGRATES PERFORMANCE/WORKLOAD METRICS
- PROVIDES ALTERNATIVE HEAD/EYE CONTROL OPTIONS IN COCKPIT
- PORTABILITY
- ADVANCED SYSTEM CONCEPT DEMONSTRATIONS

Proceedings of the National Aerospace & Electronics Conference, 18-20 May 1982, Dayton, OH

INTEGRATED PERCEPTUAL INFORMATION FOR DESIGNERS

Kenneth R. Boff, Ph.D.

Air Force Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio 45433

Currently, there is enhanced concern within the Armed Forces regarding the operator's contribution to systems effectiveness. Data regarding the variables which impact the operator's ability to acquire and process task critical information are of prime importance to the design of effective controls and displays. The problem is that these data do not now exist in a form useful to design engineers. As a result, current designs have not fully capitalized on human sensory or perceptual characteristics. One reason for this is that the amount of visual, aural and proprioceptive data in the existing literature is staggering. Psychologists and design engineers cannot review or keep abreast of all this information. Hence, an urgent need exists to compile and integrate sensory/perceptual data which can be effectively applied in the systems design process. The Integrated Perceptual Information for Designers (IPID) Program is concerned with the comprehensive consolidation and packaging of perceptual and human performance data to enable their use as an effective resource to designers of displays and controls for simulator and operational aircrew systems. IPID is a multi-agency supported effort (Table 1) principally managed by the Air Force Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base.

The Design Process

Fundamentally, the design process involves the conceptual translation of functional performance requirements into system/subsystem specifications. For example, in the design of an aircrew simulator, training requirements are identified and reduced by task and cue analyses to specification of the information which must be displayed and the necessary characteristics of the display (i.e., quality and format). These must then be translated, by the designer, into quantitative system/subsystem specifications.

In actual practice, however, there is insufficient information available to the designer to enable the design process to work in an objective fashion. It is left up to the designer to use "best judgement" in those areas where data are lacking. The decision process schematically illustrated in Figure 1 (from Boff and Martin, 1980) is recursive throughout systems design. (Though this figure addresses the aircrew simulator design process in particular, it is representative of the design decision process in general.) Typically, design decisions are made on the basis of phenomenological integration of a set of variables that are not necessarily optimal in terms of satisfying requirements for an effective operator interface. These include the state-of-the-art technology, past approaches, cost/performance trade-offs, management constraints, and limited human factors guidelines. In the absence of data, the designer must make basic assumptions about what information is necessary to satisfy training requirements, what approach should be used to portray the information (i.e., display format) and what quality is required.

IPID Information Management Objectives

Over the years, government laboratories have developed many handbooks and guidelines intended to support the use of human factors data by design engineers. A problem is that few of these have had any substantial impact on the design of aircrew simulators and operational controls and displays. Several studies concerning the use and misuse of human factors data by design engineers (Meister and Farr, 1966, and Meister and Sullivan, 1967) suggest that this may be due to the fact that relevant data are typically neither accessible nor communicated with respect to the specific needs of the designer. For the most part, these materials have been prepared with the human factors specialist in mind, rather than the designer (Rogers and Armstrong, 1977). Furthermore, emphasis is often placed on contextual supporting material embedded in academic terminology and jargon, rather than graphic and quantitative relationships. The net result is that the designer typically fails to recognize the relevancy of these data to his problem.

Based on lessons learned from a review of the relevant literature and collaboration with design engineers in government and industry, the IPID program was formulated around the following information management objectives.

1. CONSOLIDATION: First, sensory and perceptual data germane to design requirements must be identified, collected, and credibly consolidated. This will be done by the individuals who best understand the limitations of these data. To accomplish this task, a geographically distributed team of sixty recognized experts in more than forty subareas of perception was organized. Their collective effort will be documented as a Handbook of Perception and Human Performance, which will serve as a primary data resource for follow-on products. The range of subject matter includes data for each sensory modality (including visual, auditory, vestibular, tactile and chemo-senses) and for the principle variables which influence higher order perceptual processing and performance. The Handbook will be organized as a professional level reference with emphasis on self-contained, independently accessible units of information. It will be packaged in multiple volumes with over 1600 figures, tables and illustrations. All captions will be self-explanatory with complete documentation including precise descriptions of the independent and dependent variables, available information on reliability of the measures, detailed descriptions of parameters for curves or conditions, and a succinct summary of the most important points of the figure, table or illustration. The Handbook will be published through the government by a private publisher and will be available on a commercial distribution basis.

2. PRESENTATION: The second information management objective is the effective presentation of these data in a format that can be readily interpreted by the designer with respect to his needs. Graphic and functional relationships, perceptual principles, detailed models, illustrations, formulae, specific recommendations and illustrated examples of data application will be used to present selected areas of applied research (government and industry) in addition to data distilled from and fully cross-referenced to the Handbook of Perception and Human Performance. These will collectively be documented as an Engineering Data Compendium. Other features of the Compendium include indicators of data reliability, caveats to data application and

standardized units of measurement (U.S. Department of Commerce: National Bureau of Standards: International System of Units, 1977). Relevant technical areas not covered by the Compendium will be identified as areas excluded by choice or as existing gaps in the current state of knowledge for which there are no reliable data available.

The Compendium development process (Figure 2) will involve iterative review and validation of data by a) a subset of the Handbook subject matter experts to ensure continued reliability of data reformatted from the Handbook, and b) several samples of the end user population to validate the "useability" of the data format (Klein, 1979).

3. ACCESSIBILITY: The third information management objective is concerned with the efficient accessibility of data by the end user. This objective is confounded by the fact that perceptual concepts which need to be accessed typically lie outside the scope of the designer's previous training or experience. Access to these concepts requires their linkage to information or issues that are familiar to the designer.

The approach to data accessibility involves development of specialized users guides which bear a modular relationship to the IPID Compendium. These users guides will be designed to lend structural organization to the Compendium in accordance with user design requirements issues. Each guide will provide multiple methods for accessing the Compendium (Figure 3) including high resolution indices, design checklists and mission/equipment related branching logic diagrams (Figure 4). It will also incorporate supporting material including tutorials, glossary of abbreviations, acronyms, and technical terms, as well as design examples illustrating specific data applications.

Optimal satisfaction of this objective is constrained by the fact that the current state-of-the-art of information retrieval is not sufficiently refined to enable reliable cross-disciplinary access to information. One approach under consideration for potentially overcoming this problem involves automating the Engineering Data Compendium through development of a "user friendly" computerized data base management system. The envisioned system would aid the designer to acquire data relevant to his problem with a higher degree of reliability than is possible with conventional hardcopy access technology. Such a system would incorporate features available through the current research in artificial intelligence and knowledge based systems technology.

Use of IPID Data as a Design Resource

The sensory and perceptual data consolidated in the IPID study products are specifically germane to the needs of the aircrew simulator and operational control/display designer. These data provide functional relationships for the variables that influence the acquisition and processing of information as well as motor control output (Kaufman, 1974, 1979). However, there are limiting factors to the value of these data. Specifications suggested by this information may not in many instances be practical in terms of technology or cost required for implementation. In fact, in many instances current technology cannot match the limitations of human perceptions. As an example, consider the situation in Computer Generated Imagery, wherein the displayed image of a light source is decreased in area as the square of the calculated viewing distance so as to provide a change in retinal image size that conforms with normal visual experience. The displayed image cannot be reduced below one pixel which, for most displays, subtends an angle two to four times larger than the optimal resolution limit (Stenger, Thomas, Braunstein, and Zimmerman, 1981).

When used appropriately, the IPID data products will prove to be a valuable resource to the experienced engineer and designer for:

1. Generating design options, specifications and standards based on sensory or perceptual characteristics. These will be a useful resource in specifying display quality (Table 3), organization, and format of information content.

2. Evaluating specifications/standards and prioritizing design options. In many instances, the sensory and perceptual data can provide a useful basis for the objective evaluation of existing specification requirements and industrial standards which may not have an empirical basis for their existence (Genco and Task, 1981; Harris and Harding, 1981).

3. Generating new design alternatives. New conceptual insights that might otherwise not be considered may occur through serendipity. As an example, data from Regan, Beverley, and Cynader (1979), Regan (1980), Ginsburg (1980) and others suggest that specific sensory capabilities may be enhanced through special training procedures. This portends a new generation of training devices geared toward improving the pilot's "natural" ability to acquire and process information.

Specific areas where IPID data will be applicable include: evaluating the impact of fidelity incompatibility in full mission simulation (e.g. errors of omission, errors of inclusion and errors of synchronization; Boff and Martin, 1980); defining objective and subjective measures of workload, vigilance and supervisory control for command and control operations and tactical/strategic aircrew; defining operator-oriented interfaces in automated systems; and defining pilot or specialized operator selection criteria and visual standards (Ginsburg, 1981).

Where visual sensitivity data have been accessible to designers (Farrell and Booth, 1975; O'Donnell, 1979; Kraft, Anderson and Elworth, 1980), they have been successfully exploited in the specification of visual displays (Kraft and Schaffer, 1978). The optimal use of IPID as a resource, however, is dependent on improving the state of knowledge in other technical areas essential to the design of effective simulator and operational controls and displays. Principal among these is the identification of specific operator information requirements and definition of criteria for satisfactory performance of specified subtasks, tasks, and issions. Future research is planned at the Human Engineering Division of AFAMRL which directly addresses these problems.

REFERENCES

Boff, K.R. and Martin, E.A. Aircrew Information Requirements in Simulator Display Design: The Integrated Cueing Requirements Study. Proceedings of the Second Interservice/Industry Training Equipment Conference. 1980, 355-362.

Farrell, R.J. and Booth, J.M. Design Handbook for Imagery Interpretation Equipment. Boeing Aerospace Company, Seattle, WA, 1975.

Genco, L.V. and Task, H.L. Aircraft Transparency Optical Quality: New Methods of Measurement. Air Force Aerospace Medical Research Laboratory Technical Report, AFAMRL-TR-81-21, 1981.

Ginsburg, A. The Measurement, Interpretation and Improvement of Spatial Vision for Target Acquisition in Terms of a Multi-channel Model of Vision. (Abstract) Review of Air Force Sponsored Research: Flight and Technical Training. USAF Academy, March 1980.

Ginsburg, A. Proposed New Vision Standards for the 1980's and Beyond: Contrast Sensitivity. Air Force Aerospace Medical Research Laboratory Technical Report, AFAMRL-TR-80-121, 1981.

Harris, J.S. and Harding, K.G. Study and Evaluation of Existing Techniques for Measuring Aircraft Windscreen Optical Quality: Development of New Techniques for Measuring Aircraft Windscreen Optical Distortion. Air Force Aerospace Medical Research Laboratory Technical Report, AFAMRL-TR-81-25, 1981.

Kaufman, L. Sight and Mind. New York: Oxford University Press, 1974.

Kaufman, L. Perception: The World Transformed. New York: Oxford University Press, 1979.

Klein, G.A. User's Guides: Some Theoretical Guidelines for Their Use. Klein Associates, Yellow Springs, OH. TR-SCR-79-8, 1979.

Kraft, C.L., Anderson, C.D., and Elworth, C.L. Psychophysical Criteria for Visual Simulation Systems. Air Force Human Resources Laboratory Technical Report, AFHRL-TR-79-30, 1980.

Kraft, C.L. and Shaffer, L.W. Visual Criteria for Out of the Cockpit Visual Scenes. NATO Advisory Group for Aerospace Research and Development Specialist Meeting on Piloted Aircraft Environment Simulation Techniques, Brussels, Belgium, 1978.

Meister, D. and Farr, D.E. The Utilization of Human Factors Information by Designers. Office of Naval Research, NONR Contract #4974-00, 1966.

Meister, D. and Sullivan, D. A Further Study of the Use of Human Factors Information. Engineering Psychology Branch, Office of Naval Research, NONR Contract #4974-00, 1967.

O'Donnell, R.D. Contributions of Psychophysiological Techniques to Aircraft Designs and Other Operational Problems. NATO Advisory Group for Aerospace Research and Development, AGARD-AG-244, 1979.

Regan, D. Assessment and Development of Visual Flying Skills by the Application of the Channel Theory of Vision. (Abstract) Review of Air Force Sponsored Research: Flight and Technical Training. USAF Academy, March 1980.

Regan, D., Beverly, K., and Cyander, M. The Visual Perception of Motion in Depth. Scientific American, 1979, 241(1), 136-151.

Rogers, J.G. and Armstrong, R. Use of Human Engineering Standards in Design. Human Factors, 1977, 19(1), 15-23.

Stenger, A.J., Thomas, J.P., Braunstein, M., and Zimmerman, T.A. Advanced CIG Techniques Exploiting Perceptual Characteristics. Air Force Human Resources Laboratory Technical Report, AFHRL-TR-80-61, 1981.

U.S. Department of Commerce: National Bureau of Standards. The International System of Units (SI). NBS Special Publication 330, 1977.

TABLE 1

IPID PROGRAM SPONSORS

- Air Force Aerospace Medical Research Laboratory
- Air Force Deputy for Simulators
- Simulator Division, Air Force Deputy for Engineering
- U.S. Army Research Institute (Ft. Rucker Field Unit)
- U.S. Army Human Engineering Laboratory
- U.S. Naval Training Equipment Center

TABLE 2

Selected Handbook Chapters

- Sensitivity to Light
- Color Vision and Colorimetry
- The Temporal Dimension of Vision
- Visual Sensitivity to Spatial Patterns
- Vestibular Proprioception and Kinesthetic Sensitivity
- Eye Movements
- Audition I: Stimulus, Physiology, Thresholds
- Audition II: Loudness, Pitch, Localization, Aural Distortion, Pathology
- Cutaneous Sensitivity
- Methods of Simulating Space and Motion
- The Perception of Posture and Self Motion
- Acceleration and Motion in Depth
- Eye Movements and Visual Direction
- Representation of Motion and Space in CRT and Cinematic Displays
- Binocular Perception
- Visual/Auditory Information Processing
- Motor Control
- Approaches to the Description and Analysis of Complex Patterns
- The Description and Analysis of Object and Event Perception
- Visual Form Recognition
- The Effects of Control Dynamics on Performance
- Monitoring and Supervisory Control in Complex Man/Machine Systems
- Decision Making and Human Performance
- Attention Processing Resources and Operator Workload
- Changes in Operator Efficiency as a Function of Environmental
- Stress, Fatigue and Circadian Rhythms

TABLE 3

DISPLAY QUALITY ISSUES

- Reflections, glare, seams
- Luminance range
- Resolution requirement
- Magnification
- Scene overlays and inserts
- Color differences
- Temporal intensity fluctuations
- Later vergence, collimation
- Luminosity functions
- Discontinuous position, size and orientation
- Object Motion
- Raster visibility, masking
- Spread functions of point sources with smoothing
- Accommodation stimuli
- Streaking from intersections and insertions
- Interdisplay lag tolerances
- Scene misalignments
- Binocular deviations

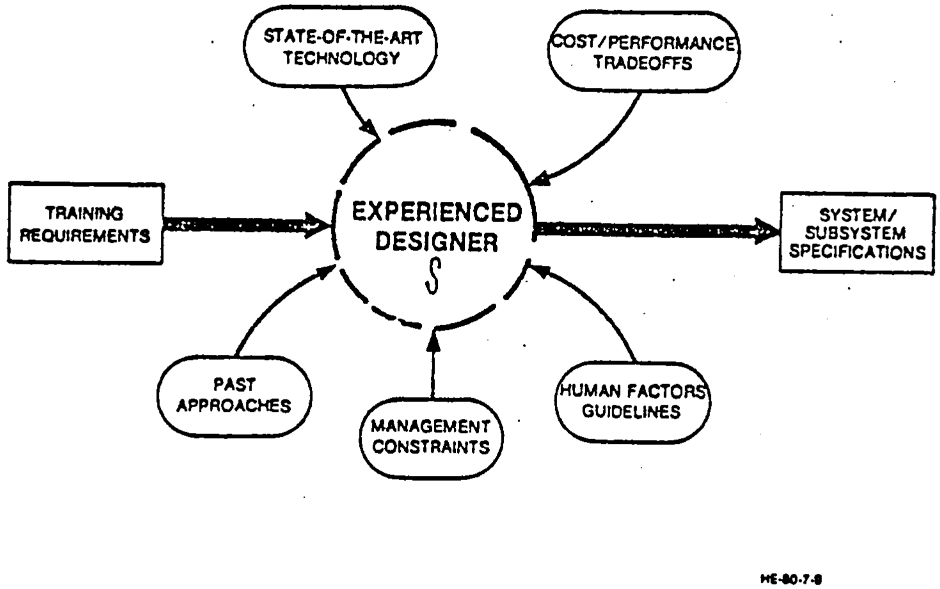


Figure 1

IPID COMPENDIUM DEVELOPMENT PROCESS

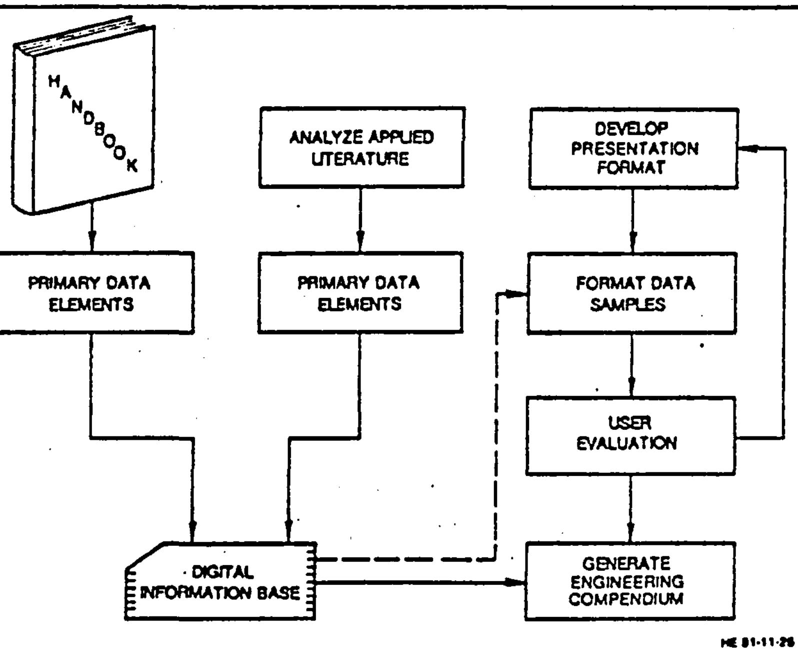


Figure 2

IPID HOW TO ACCESS THE DATA COMPENDIUM

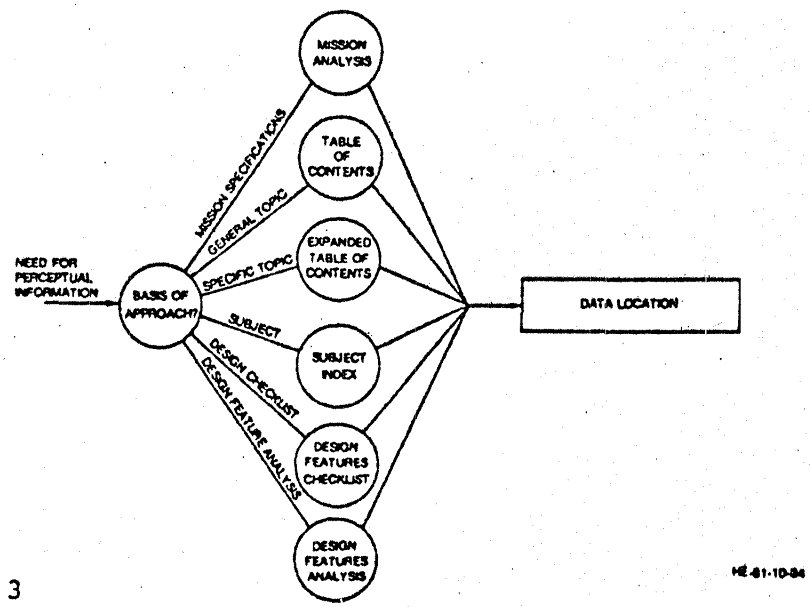


Figure 3

IPID USER'S GUIDE: MISSION RELATED FEATURE ANALYSIS

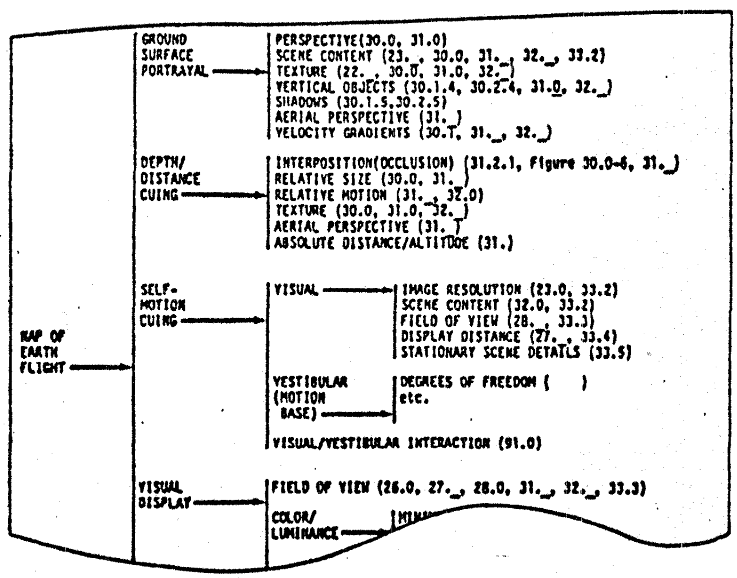


Figure 4

CURRENT TRENDS IN AIRCRAFT COCKPITS

by
Keith H. Miller
Boeing Aerospace Company
for the
Boeing Commercial Airplane Company

THE 757/767 FLIGHT DECK DESIGN REFLECTS THE EXPERIENCE GAINED IN PRODUCING MORE THAN 4,000 BOEING COMMERCIAL JET TRANSPORTS. THE NEW FLIGHT DECK INCORPORATES DIGITAL COMPUTERS AND ADVANCED DISPLAYS INTO A TOTALLY COORDINATED AND INTEGRATED SYSTEM THAT IS THE PRODUCT OF OVER A DECADE OF RESEARCH, DEVELOPMENT, AND TESTING.

BOEING'S FLIGHT DECK DESIGN INCLUDES FULLY MONITORED, SIMPLIFIED SYSTEMS; A QUIET, DARK COCKPIT; AND AUTOMATIC FLIGHT OPTIMIZATION TO ENHANCE THE CAPABILITIES OF THE CREW AND THE AIRPLANE WHILE MAINTAINING OPTIMUM WORKLOAD LEVELS FOR TWO-CREW OPERATION. THE FLIGHT DECK IS A SYNTHESES OF STATE-OF-THE-ART ADVANCES IN DIGITAL FLIGHT MANAGEMENT AND CONTROL, CATHODE RAY TUBE ELECTRONIC DISPLAYS, AND MICRO-PROCESSOR COMPUTER TECHNOLOGY. THE 757/767 FLIGHT DECK IS THE MOST ADVANCED AVAILABLE ON ANY COMMERCIAL AIRPLANE.

THESE NEW FLIGHT DECKS ARE A CASE STUDY OF HOW HUMAN FACTORS AND HUMAN ENGINEERING SPECIALISTS HAVE HAD A DRAMATIC IMPACT ON THE DESIGN OF AN AEROSPACE SYSTEM.

I AM GOING TO BRIEFLY REVIEW THE HUMAN FACTORS PHILOSOPHY THAT WAS APPLIED TO THE DESIGN OF THESE FLIGHT DECKS.

I WILL THEN BRIEFLY DESCRIBE A FEW OF THE MOST INTERESTING CONTROL AND DISPLAY CONCEPTS.

INTRODUCTION

757/767 FLIGHT DECK DESIGN IS THE MOST ADVANCED AVAILABLE ON ANY COMMERCIAL AIRPLANE

- 2-CREW OPERATION
- FULLY MONITORED, SIMPLIFIED SYSTEMS
- QUIET, DARK COCKPIT
- SYNTHESIS OF STATE-OF-THE-ART ADVANCES IN DIGITAL FLIGHT MANAGEMENT AND CONTROL
- COLOR CRT DISPLAYS
- MICROPROCESSOR COMPUTER TECHNOLOGY
- SHOW ONLY WHAT IS REQUIRED TO SAFELY OPERATE THE AIRPLANE

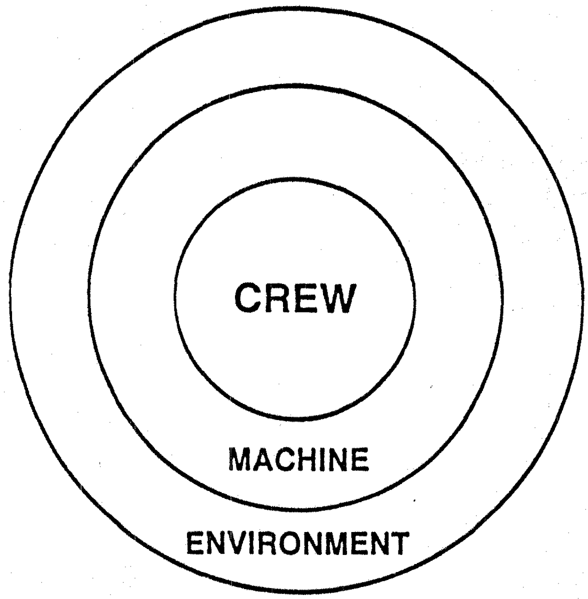
THE FLIGHT DECK DESIGN PHILOSOPHY HAS, FROM THE VERY INCEPTION, BEEN TO SYNTHESIZE A CREW CENTERED DESIGN.

THE GOAL WAS TO MINIMIZE THE POTENTIAL FOR HUMAN ERROR.

THIS APPROACH HAS PROVEN TO ACHIEVE AN EFFECTIVE TOTAL AIRPLANE SYSTEM.

FOR CREW CENTERED DESIGN, TWO CLASSES OF HUMAN ERROR NEED TO BE CONSIDERED: SYSTEMATIC ERRORS AND RANDOM ERRORS.

Crew Centered Design



- Minimize potential for human error
- Achieves an effective total airplane system

Human Error

- **Systematic error**
  - Predictable
  - Involves equipment or procedural characteristics which promote or induce error
- **Random error**
  - Unpredictable, inevitable
  - Unrelated to detailed design implementation

USE OF CURRENT OPERATING EXPERIENCE AND PROVEN SUCCESSFUL DESIGNS LOWERS THE RISK OF SYSTEMATIC HUMAN ERROR. WHEN NEW FUNCTIONS ARE REQUIRED, A STRUCTURED DESIGN PROCESS CULMINATING IN OPERATIONAL VALIDATION TESTING IS USED TO ENSURE THAT SOURCES OF SYSTEMATIC ERROR ARE IDENTIFIED AND CORRECTED.

SYSTEM SIMPLIFICATION IS THE MOST EFFECTIVE MEANS OF MINIMIZING THE OPPORTUNITIES FOR RANDOM ERRORS. CREW CENTERED DESIGN FOCUSES ON PROVIDING FOR ALTERNATE MEANS OF ERROR DETECTION BY THE CREW AND SYSTEMS DESIGNS WHICH PROVIDE ADEQUATE TIME FOR ERROR CORRECTION.

HURRIED ACTIONS, WHETHER EXTERNALLY IMPOSED OR SELF-INDUCED, INCREASE THE LIKELIHOOD OF RANDOM HUMAN ERROR. THEREFORE, HEAVY EMPHASIS IS PLACED ON DESIGNS WHICH REDUCE THE NEED FOR TIME-CRITICAL CREW ACTIONS.

Control of Systematic Human Error

- Use past design and operating experience
- Develop and test alternative solutions for new functions

Control of Random Human Error

- Simplify systems
- Provide for error detection
- Minimize consequences of error
- Reduce need for time-critical actions

FUNCTIONAL SIMPLIFICATION CAN REDUCE THE POTENTIAL FOR OPERATING ERRORS WHILE IMPROVING MACHINE RELIABILITY.

REDUNDANCY SIMPLIFIES CREW OPERATION BY MAINTAINING CONSISTENT OPERATION BY MAINTAINING CONSISTENT OPERATING PROCEDURES AND SYSTEM FUNCTIONS AFTER A FAILURE.

AUTOMATION INVOLVES ADAPTATION OF THE MACHINE TO THE CREW BY CHANGING THE NATURE OR TIMING OF THE INTERACTIONS BETWEEN THEM. EFFECTIVE SYSTEMS DESIGN INVOLVES A BLEND OF SIMPLIFICATION, REDUNDANCY, AND AUTOMATION APPROPRIATE TO EACH SUBSYSTEM.

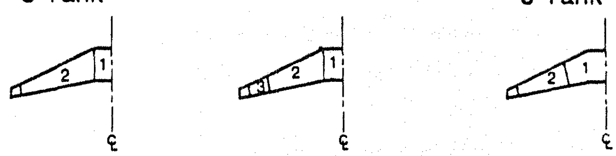
ACHIEVING DESIGN SIMPLICITY REQUIRES DETAILED ANALYSIS OF ALL RELEVANT FACTORS. CREW OPERATING PROCEDURES ARE GIVEN EQUAL CONSIDERATION WITH FACTORS SUCH AS WEIGHT AND RELIABILITY. IN THIS DESIGN REFINEMENT EXAMPLE, FUEL SYSTEM COMPONENT AND OPERATIONAL SIMPLICITY WERE MAINTAINED WHILE ACHIEVING THE DESIRED WEIGHT REDUCTION.

Effective Systems

- **DESIGN SIMPLICITY**
- **EQUIPMENT REDUNDANCY**
- **AUTOMATED FEATURES**

Simplicity Through Design Refinement

Wing Fuel Tank Development – Example



	Original 3-Tank	5-Tank	Revised 3-Tank
	Jan '78	Jun '79	Jan '80
Wing Structure Weight	Base	Large Decrease	Large Decrease
Fuel System Weight	Base	Moderate Increase	Small Increase
Total Weight	Base	Moderate Decrease	Large Decrease
Crew Operation	Simple	More Complex	Simple

757/767 SYSTEM DESIGNS USE TWO CLASSES OF REDUNDANCY: TRIPLEX - FOR CRITICAL SYSTEMS, AND DUAL - FOR IMPORTANT SYSTEMS. IDENTICAL REDUNDANCY MAINTAINS ESSENTIALLY THE SAME OPERATING PROCEDURES AND FUNCTIONS AFTER FAILURE OF ONE OF THE REDUNDANT ELEMENTS.

OPTIMUM WORKLOAD LEVELS CAN BE ACHIEVED THROUGH APPROPRIATE APPLICATION OF SYSTEM AUTOMATION.

CREW SELECTABLE AUTOMATION ENABLES THE PILOTS TO TAILOR THE LEVEL OF AUTOMATION TO THEIR NEEDS AT THE MOMENT.

CLEARLY, WHILE EXCESSIVE WORKLOAD CAN HAMPER CREW OPERATIONS, LOWERING AN ALREADY ACCEPTABLE LEVEL OF WORKLOAD THROUGH AUTOMATION DOES NOT ASSURE THAT EFFECTIVE CREW/SYSTEM INTERACTION WILL RESULT.

Redundancy

- **Triplex**
  - Inertial reference systems
  - Electronic flight instrument symbol generation
  - Automatic flight control and flight director system
  - AC electric power sources—each capable of operating all essential loads
  - ILS receivers
- **Dual**
  - Flight and engine instruments
  - Flight management computer
  - Navigation radios
  - Communication radios
  - Automatic pressurization controllers
  - Air data systems
  - Warning and caution alerts

Automation

- Optimize crew/system interaction
- Achieve appropriate level of workload

THE HERITAGE OF THE NEW FLIGHT DECK CONCEPTS IS SHOWN HERE.

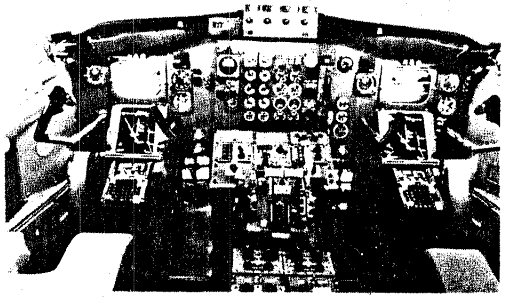
PICTURED CLOCKWISE FROM THE LOWER LEFT ARE THE COCKPITS OF THE UNITED STATES SST PROJECT (1969), THE NASA TCV BOEING 737 (1973 TO PRESENT) AND THE YC-14 (1976). THE BREAKTHROUGHS INTRODUCED IN THESE PROJECTS CULMINATED IN THE DESIGN OF THE 757/767 FLIGHT DECK SHOWN IN THE LOWER RIGHT AND ON THE RIGHT HAND SCREEN.

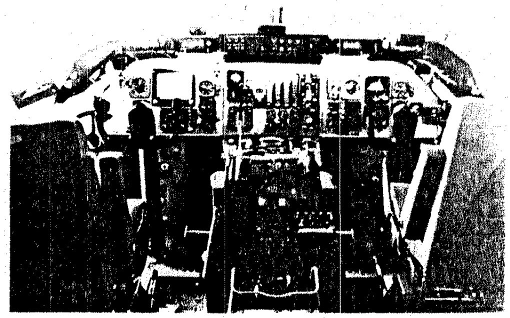
THE EFFICIENT AND COMFORTABLE DESIGN INCLUDES FLAT WINDSHIELDS FOR FORWARD VISION AND CURVED SIDE WINDOWS WITH A GEOMETRY THAT WILL PROVIDE A LOW NOISE, HEADSETS-OFF ENVIRONMENT WITH OPTIMUM INTERNAL AND EXTERNAL VISION CHARACTERISTICS. HIGH RESOLUTION COLOR CRTS, VISIBLE IN ALL LIGHTING CONDITIONS, ARE COMPLEMENTED BY A LOW PROFILE CONTROL COLUMN ALLOWING FULL VIEW OF THE PRIMARY INSTRUMENTS.

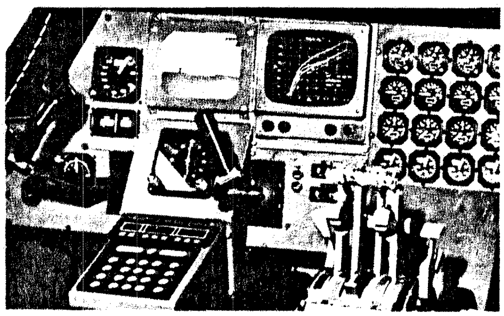
THE BOEING 757/767 FLIGHT DECK LAYOUT IS A "QUIET, DARK COCKPIT" IN WHICH INDICATIONS OF SYSTEM OPERATIONS ARE RESERVED FOR CONDITIONS THAT REQUIRE ACTION BY THE FLIGHT CREW. VERY FEW GREEN OR BLUE LIGHTS, SIGNIFYING NORMAL SYSTEM OPERATION OF SYSTEMS IN TRANSIT, ARE USED IN THIS FLIGHT DECK. IN ADDITION, THE THREE MAJOR FUNCTIONS OF OPERATION, STATUS, AND MAINTENANCE HAVE BEEN SEPARATED SO THAT THEY MAY BE BROUGHT TO THE ATTENTION OF THE FLIGHT AND GROUND CREWS SELECTIVELY AS THEY ARE NEEDED.

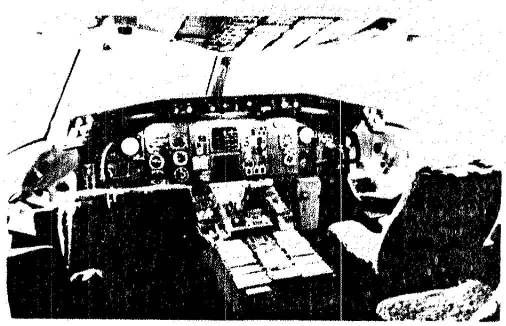
THE 757 AND 767 AIRPLANES HAVE IDENTICAL COCKPIT LAYOUTS. THIS EMPHASIS ON COMMONALITY IS DESIGNED TO ALLOW FLIGHT CREW PERSONNEL TO RECEIVE COMMON TYPE RATINGS WHICH WOULD APPLY TO BOTH THE 757 AND 767 AIRPLANES.

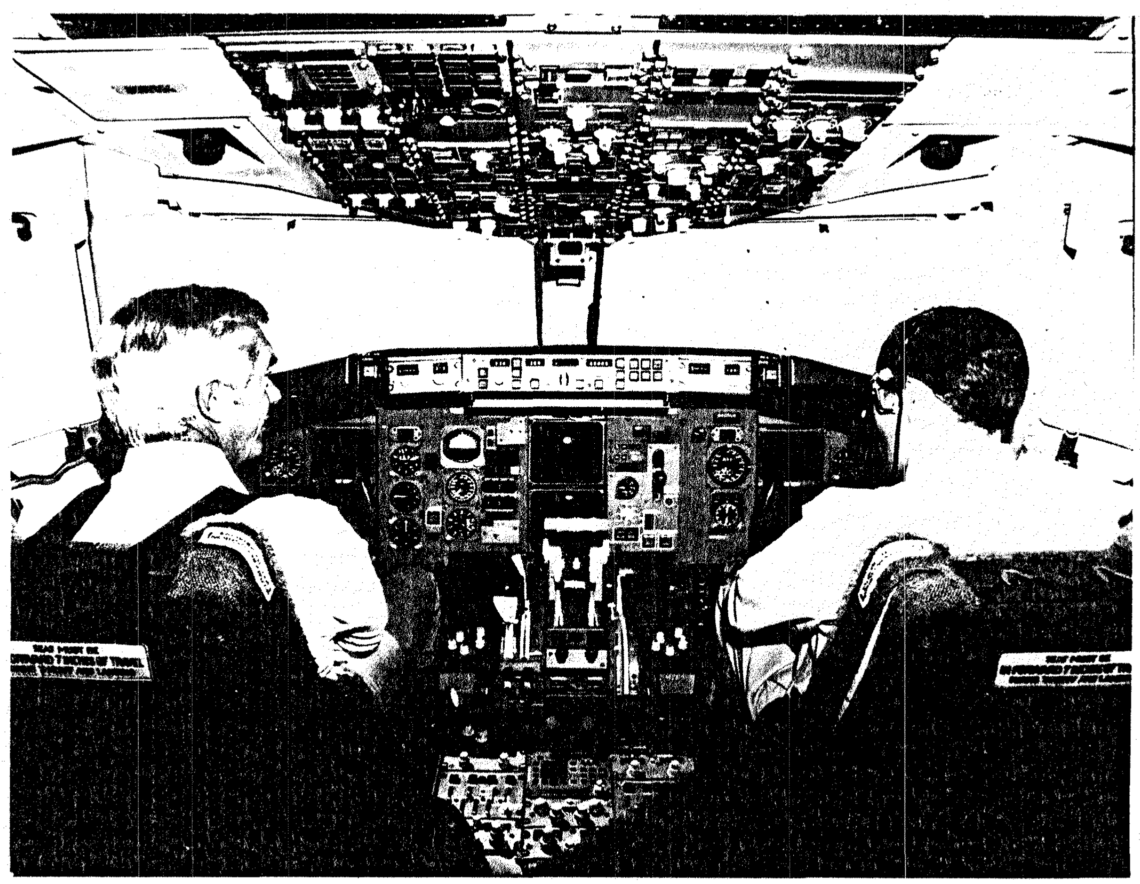
Flight Deck Development











DESIGNED AS A SPACIOUS, COMFORTABLE WORK AREA, THE FLIGHT DECK FEATURES IMPROVEMENTS IN FLIGHT INSTRUMENTATION AND AUTOMATIC FLIGHT CONTROL SYSTEMS UTILIZING RECENT ADVANCES IN DIGITAL ELECTRONICS. AN INERTIAL REFERENCE SYSTEM (IRS) WHICH UTILIZES LASER GYROSCOPES, RATHER THAN GIMBALLED GYROSCOPES, WORKS IN CONJUNCTION WITH THE FLIGHT MANAGEMENT SYSTEM (FMS) FOR ADVANCED AUTOMATIC GUIDANCE AND CONTROL. COLORED CATHODE RAY TUBE (CRT) DISPLAYS ARE UTILIZED FOR FLIGHT INSTRUMENTATION, ENGINE INSTRUMENTATION, AND THE CAUTION/WARNING SYSTEM.

NOTE HOW UNCLUTTERED THIS CONTROL PANEL LAYOUT IS.

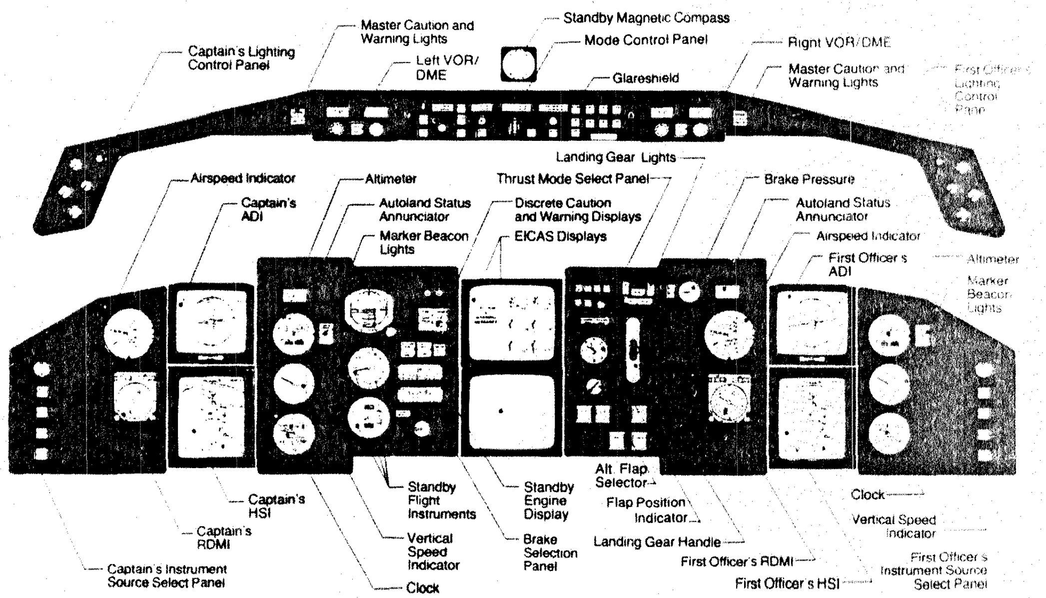
THE ADVANCED FLIGHT MANAGEMENT SYSTEM OFFERS FULLY INTEGRATED DIGITAL AVIONICS WITH SIMPLE CREW INTERFACE PROCEDURES, GREATLY IMPROVED CAPABILITIES, AUTOMATIC SYSTEMS MONITORING, AND A HIGH DEGREE OF REDUNDANCY AND RELIABILITY. THE SYSTEM HAS BEEN DESIGNED TO REDUCE CREW WORKLOAD THROUGH AUTOMATION OF MANY FLIGHT MANAGEMENT FUNCTIONS. THESE INCLUDE NAVIGATION AND GUIDANCE, AUTOMATIC FLIGHT CONTROL, ENGINE MONITORING, CAUTION AND WARNING ADVISORIES, PERFORMANCE MANAGEMENT AND FLIGHT PLANNING.

MULTICOLOR ELECTRONIC FLIGHT INSTRUMENTS IMPROVE CREW ORIENTATION WITHIN THE NAVIGATION ENVIRONMENT. EXTENSIVE USE OF DIGITAL ELECTRONICS AND A COMPUTER DATA BASE RESULTS IN A HIGHLY RELIABLE SYSTEM, WITH THE FLEXIBILITY TO INCORPORATE FUTURE ENHANCEMENTS WITHOUT EXTENSIVE HARDWARE MODIFICATIONS.

AIRPLANE SUBSYSTEMS ARE AUTOMATICALLY MONITORED AND THE CREW IS ALERTED WHEN CREW AWARENESS IS APPROPRIATE. FAULT DATA IS STORED AND PROVIDED TO GROUND MAINTENANCE CREWS. BUILT-IN TEST EQUIPMENT (BITE) ALLOWS FAULT ISOLATION TO THE LRU LEVEL WITHIN ONE MINUTE.

The Flight Deck

Pilots' Main Panel and Glareshield



FLIGHT MANAGEMENT SYSTEM

DESIGNED FOR SIMPLIFIED OPERATION

- **EASY PREFLIGHT AND SYSTEM INITIATION**
  - STORED FLIGHT PLANS
  - SIMPLE INPUT PROCEDURES
  - PRESERVED IRS "LAST POSITION"
- **AUTOMATIC FEATURES**
  - OPTIMIZED 3D NAVIGATION, AUTOMATIC CLIMB, CRUISE, DESCENT, AND HOLDING
  - AUTOMATIC CATEGORY IIIB ILS APPROACH
  - NAVAID TUNING
- **CONTINUOUSLY UPDATED FLIGHT DATA**
  - ROUTES, PROGRESS REPORT, CLIMB, DESCENT
  - ENGINE OUT INFORMATION
- **MULTICOLOR CRT DISPLAYS**
  - INCLUDES FLIGHT PARAMETERS, FLIGHT DIRECTOR, WEATHER RADAR
  - AUTOMATIC ENGINE AND SYSTEMS MONITORING (EICAS)

FM82-21E•
4-27-82

THROUGH THE FLIGHT MANAGEMENT SYTEM THE CREW OF A 757 OR 767 CAN ACCOMPLISH MORE EFFECTIVELY THE SAME TASKS REQUIRED IN OLDER GENERATION AIRPLANES, AND AT REDUCED WORKLOADS. AS A RESULT, THE CREW WILL HAVE MORE TIME FOR THE OPTIMIZED MANAGEMENT OF THE AIRPLANE AND THE FLIGHT, MORE TIME FOR IN-FLIGHT PLANNING, AND MORE TIME FOR OUTSIDE WATCH.

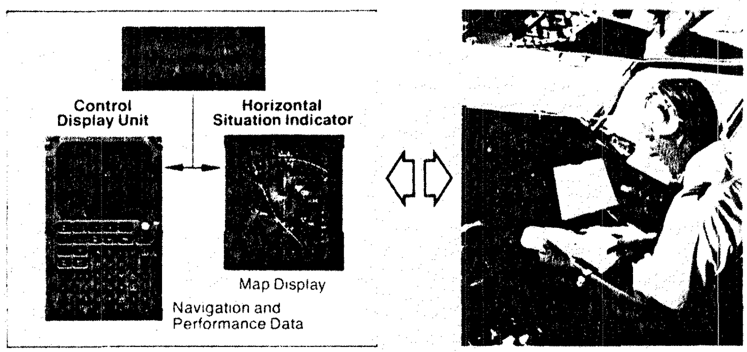
THE BOEING FMS IS DESIGNED TO ALLOW THE CREW TO ACCESS THE TOTAL RANGE OF ITS PERFORMANCE, NAVIGATION, AND ADVISORY CAPABILITY AT ANY TIME AND IN ANY FLIGHT CONTROL MODE.

SUPPORTED BY HUMAN ENGINEERING STUDIES AND INCORPORATING THE VIEWS OF AIRLINE OPERATORS AND PILOTS, ALL FLIGHT DECK INSTRUMENTATION IS DESIGNED TO PRESENT INFORMATION TO THE CREW FOR ACCURATE AND RAPID INTERPRETATION. THE UNIQUE FLIGHT MANAGEMENT SYSTEM DISPLAYS PROVIDE CONTINUOUS PATH-IN-SPACE PRESENTATIONS THAT FREE THE PILOT FROM THE TASK OF INTEGRATING DATA FROM MANY SOURCES INTO A MENTAL PICTURE OF FLIGHT PROGRESS. THE RESULT IS A FLIGHT DECK THAT IS THE MOST EFFICIENT AVAILABLE FOR ANY AIRLINER.

THIS CHART AMPLIFIES THE LIST OF AUTOMATIC FEATURES AVAILABLE TO THE CREW. THESE FEATURES ALLOW CREW MEMBERS TO CHOOSE THE LEVEL OF PHYSICAL AND MENTAL WORKLOAD THEY WOULD LIKE TO OPERATE WITH DURING NORMAL AND NON-NORMAL OPERATIONS.

Crew Efficiency Improvement

The Flight Management System reduces the need to refer to charts, Flight Manuals and Operational Slide Rules.



AUTOMATIC FLIGHT CONTROLS

SYSTEM FEATURES

- AUTOMATIC CLIMB, CRUISE, AND DESCENT
- CONTROL WHEEL STEERING
- FLIGHT DIRECTOR COMMAND INFORMATION
- AUTOMATIC THRUST MANAGEMENT
- OPTIMUM VERTICAL AND LATERAL NAVIGATION WHEN COUPLED TO THE FLIGHT MANAGEMENT SYSTEM
- ELECTRONIC COMMAND SPOILER AND SPEEDBRAKE CONTROL SYSTEM
- YAW DAMPER SYSTEM
- RUDDER RATIO SYSTEM
- STABILIZER/MACH SPEED TRIM AND ELEVATOR ASYMMETRY PROTECTION
- AUTOMATIC CATEGORY IIIB APPROACH, LANDING, ROLLOUT, AND GO-AROUND

FD82-61E
6-8-82

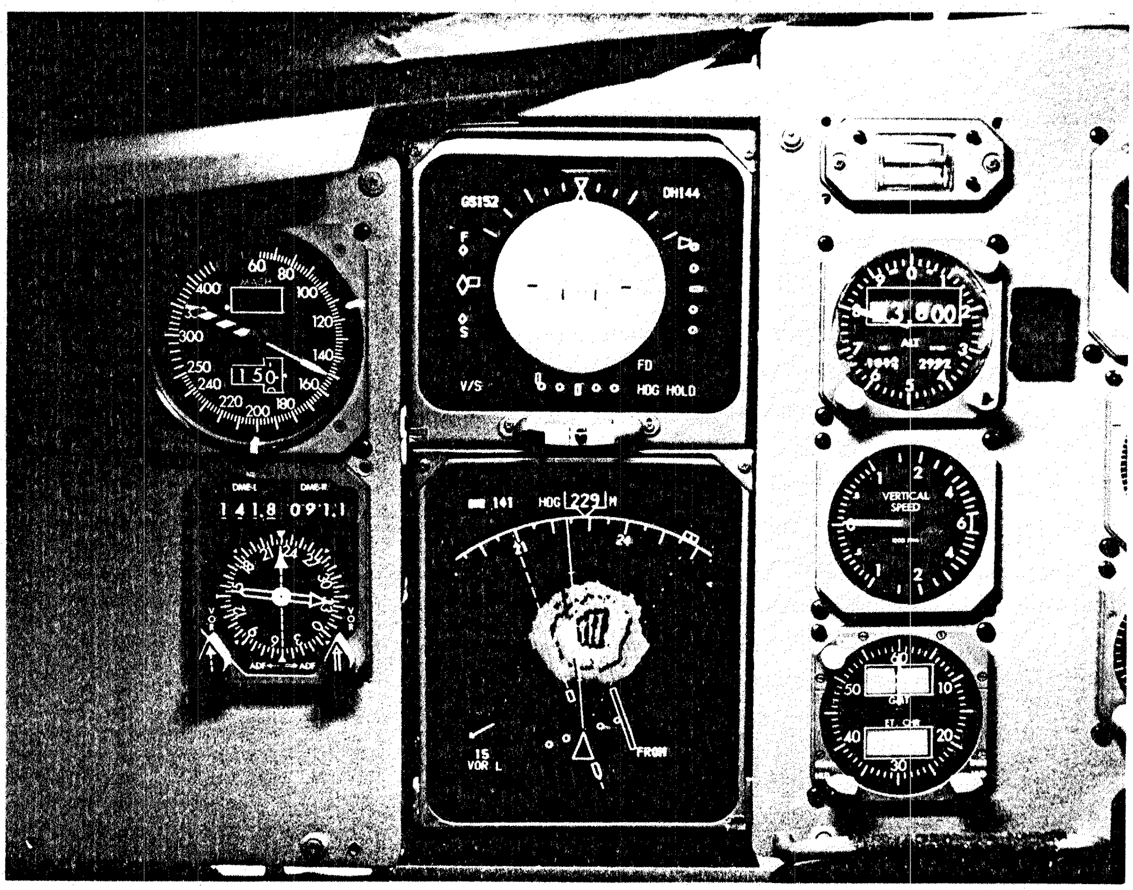
THE HSI INTEGRATES COMPASS, TRACK, WEATHER, AND MAP REFERENCES INTO A SINGLE DISPLAY WITH ALL ELEMENTS TO A COMMON SCALE. IN A MULTICOLOR FORMAT, IT DEPICTS THE HORIZONTAL POSITIONING OF THE AIRPLANE IN RELATION TO THE FLIGHT PLAN AND A MAP OF NAVIGATION FEATURES. THE AIRCRAFT TRACK, TURN PREDICTION INDICATION, AND DESIRED FLIGHT PLAN PATH INDICATE THE RELATION OF AIRPLANE POSITION TO DESIRED POSITION. THIS ALLOWS RAPID AND ACCURATE FLIGHT PATH CORRECTION AND MANEUVERING BY THE PILOTS. INDICATIONS OF OTHER DATA SUCH AS WIND SPEED AND DIRECTION, LATERAL AND VERTICAL DEVIATION FROM THE SELECTED FLIGHT PROFILE, DISTANCE TO WAYPOINT, ETC., ARE ALSO DISPLAYED AS REQUIRED.

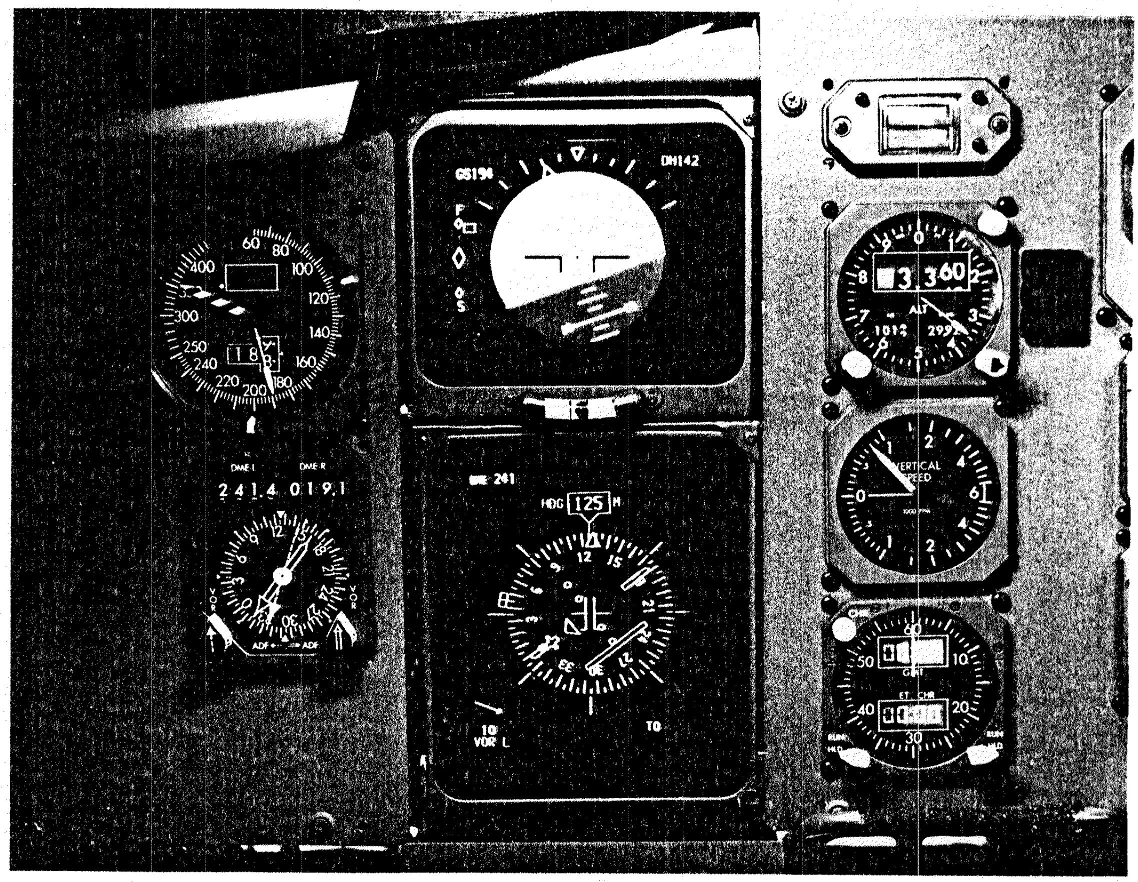
EACH PILOT MAY ADJUST THE COMPOSITION OF HIS HSI DISPLAY BY CHOOSING FROM A VARIETY OF SELECTABLE FEATURES. COLOR WEATHER RADAR RETURNS MAY BE SELECTED AND PRESENTED AT THE SAME SCALE AND ORIENTATION AS THE MAP. NAVAID, AIRPORT AND GROUND REFERENCE POINT SYMBOLOGY MAY BE ADDED TO THE MAP AT THE PILOT'S OPTION. SPEED, ALTITUDE, AND TIME OF ARRIVAL FOR EACH FLIGHT PLAN WAYPOINT CAN ALSO BE DISPLAYED.

THE ADI PRESENTS PRIMARY AIRPLANE ATTITUDE INDICATION, PITCH AND BANK STEERING INFORMATION, SPEED DEVIATION, AND ILS COURSE AND GLIDESLOPE. IN ADDITION, OTHER DATA IS DISPLAYED SUCH AS AUTOPILOT AND AUTOTHROTTLE MODES, GROUNDSPEED, AND RADIO ALTITUDE. THE ADI, IN CONJUNCTION WITH THE HORIZONTAL SITUATION INDICATOR (HSI), PRESENTS COMPLETE AIRPLANE ATTITUDE AND POSITION INFORMATION TO THE PILOTS IN ALL PHASES OF FLIGHT. THE PRESENTATION FORMAT MAKES USE OF THE BEST FEATURES OF PREVIOUS ELECTROMECHANICAL INSTRUMENTS WHILE INCORPORATING NEW FEATURES WHICH CAN ONLY BE ACCOMPLISHED ON A PROGRAMMABLE CRT DISPLAY. IN ADDITION, USE OF THE CRT ALLOWS FUTURE REQUIREMENTS FOR DISPLAY FUNCTIONS TO BE READILY RETROFITTED TO THE AIRPLANE.

THE HSI MAY ALSO BE OPERATED IN THE OPTIONAL COMPASS ROSE MODE AS WELL AS THE MAP, VOR OR ILS MODES. THIS MODE DEPICTS DEVIATION FROM SELECTED VOR OR ILS COURSE, DME DISTANCE, HEADING, AND WIND SPEED AND DIRECTION. GLIDESLOPE DEVIATION IS ALSO SHOWN, AS REQUIRED, WITH A SCALE AND POINTER ON THE RIGHT SIDE OF THE INSTRUMENT.

WEATHER RADAR DISPLAY IS NOT AVAILABLE IN THE COMPASS ROSE MODE OF THE HSI.


GS152
DH144
FD
HDG HOLD
V/S
HDG 229 M
VERTICAL SPEED
ALT
DME-L
DME-R
ADF
VOR
15
VOR L
FROM
ET CHR


DH142
HDG 125 M
VERTICAL SPEED
ALT
DME-L
DME-R
ADF
VOR
10
VOR L
TO
ET CHR
RUN
HLD

THE FLIGHT MANAGEMENT COMPUTER CONTROL DISPLAY UNIT (CDU) ALLOWS PROGRAMMING OF THE FLIGHT MANAGEMENT SYSTEM AND DISPLAY OF FLIGHT PLANNING, PERFORMANCE, AND NAVIGATION/GUIDANCE DATA. FLIGHT PLANNING DATA IN THE FORM OF WAYPOINTS (I.E., VORTAC, LAT., LONG., ETC.) COURSES, AND ALTITUDE PROFILES CAN BE LOADED AND DISPLAYED. PERFORMANCE DATA SUCH AS OPTIMUM PROFILES FOR CLIMB, CRUISE, AND DESCENT, AS WELL AS MINIMUM COST FLIGHT PARAMETERS CAN BE PROGRAMMED. THE COMPUTER THEN SENDS AUTOPILOT/FLIGHT DIRECTOR STEERING COMMANDS (TWO-DIMENSIONAL AND THREE-DIMENSIONAL) TO THE AUTOMATIC FLIGHT CONTROL SYSTEM (AFCS) AND SPEED/THRUST COMMANDS TO THE AUTOTHROTTLE SYSTEM. DISPLAY MAY BE SELECTED TO SHOW PERFORMANCE, FLIGHT PLANNING, NAVIGATION, GUIDANCE, OR NAVIGATION-AID DATA AS DESIRED.

THE EICAS SYSTEM IN THE 757 AND 767 AIRPLANES CONSOLIDATES ENGINE AND SELECTED SUBSYSTEM INDICATIONS AS WELL AS CAUTION AND WARNING FUNCTIONS. IT CONSISTS OF TWO HIGH RESOLUTION COLOR CRTs, TWO IDENTICAL COMPUTERS, A SUPPLEMENTARY CAUTION AND WARNING ANNUNCIATOR, AND A STANDBY LIQUID CRYSTAL ENGINE INDICATION DISPLAY. THESE SIX LRUs REPLACE OVER 40 LRUs IN TYPICAL NON-EICAS CONFIGURATIONS. TO REDUCE SPARES, THE CRTs ARE INTERCHANGEABLE WITH THOSE USED FOR THE HSI.

FLIGHT MANAGEMENT CONTROL DISPLAY UNIT

767

RTE (Route)
Access to flight plans entered in FMC. With an active flight plan, press of key will display current leg and continuation of flight plan.

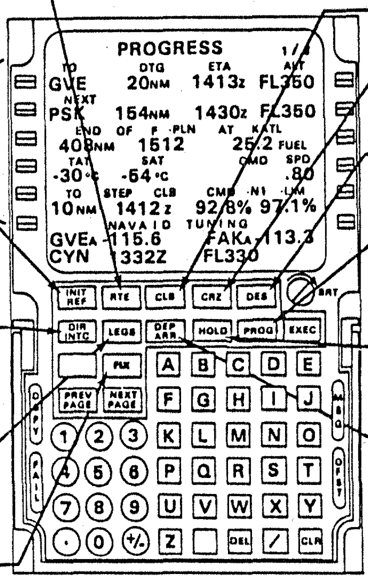
LINE SELECT KEYS
Provides for entry of data from verification line into selected line. Permits rapid manipulation of appropriate line data.

INIT/REF (Initialization/Reference)
Allows initialization of the FMCS and IRS for flight plus various categories of reference data.

DIR/INTC (Direct/Intercept)
Enables FMC guidance from present position direct to any designated geographic point or to intercept a selected course.

LEGS
Detailed data concerning every leg of a flight plan. Allows for detailed data entry of each leg of flight plan.

FIX
Displays range/bearing information from present position to entered fix. Enables radials from the fix to be displayed on the HSI.



CDU Key Functions

CLB (Climb)
Press of key will display current or planned climb mode.

CRZ (Cruise)
Press of key will display current or planned cruise mode.

DES (Descent)
Press of key will display current or planned descent mode.

PROG (Progress)
Displays current dynamic flight information. Pages are for crew information only and require no crew inputs.

HOLD
Allows for development of a holding pattern at any designated waypoint.

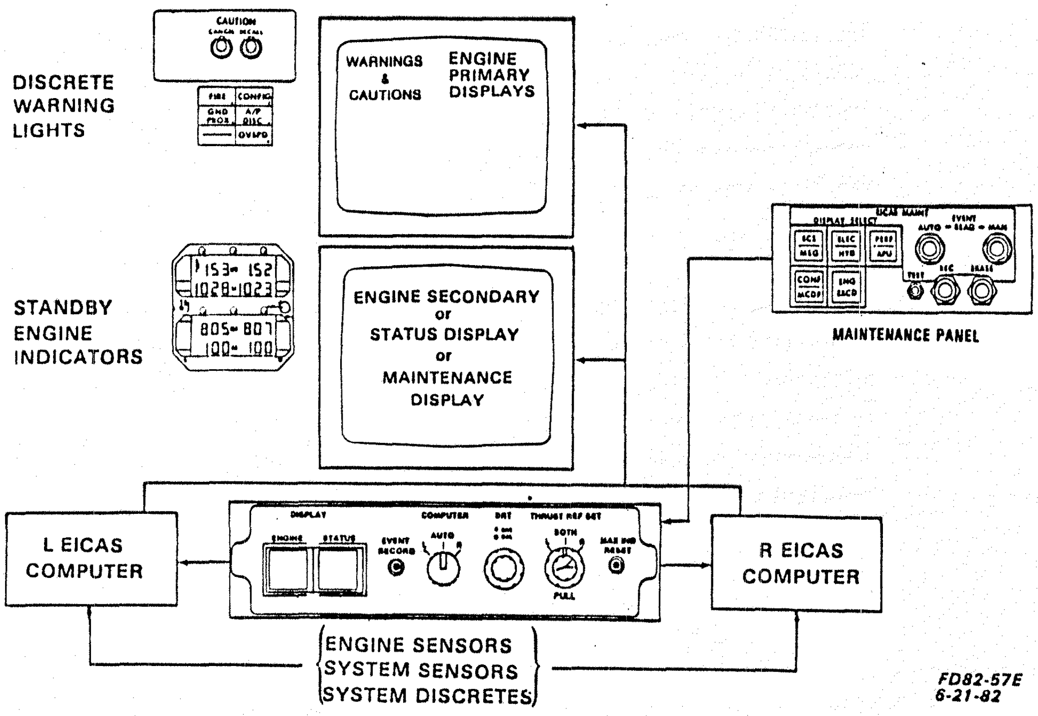
DEP ARR (Departure/Arrival)
Displays departure procedures from origin or arrival procedures at destination. Desired procedures can then be selected into flight plan.

FM82-20E
6-25-82

EICAS

767

ENGINE INDICATION AND CREW ALERTING SYSTEM

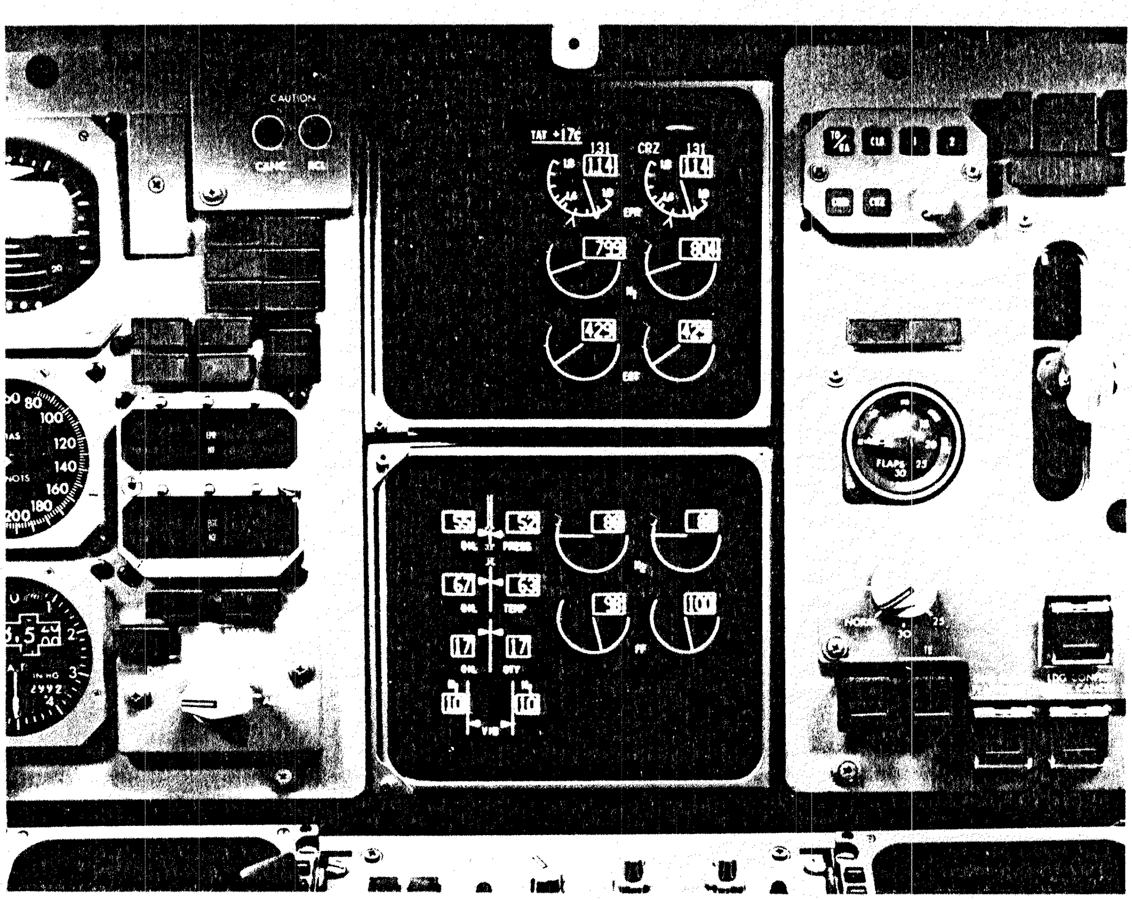


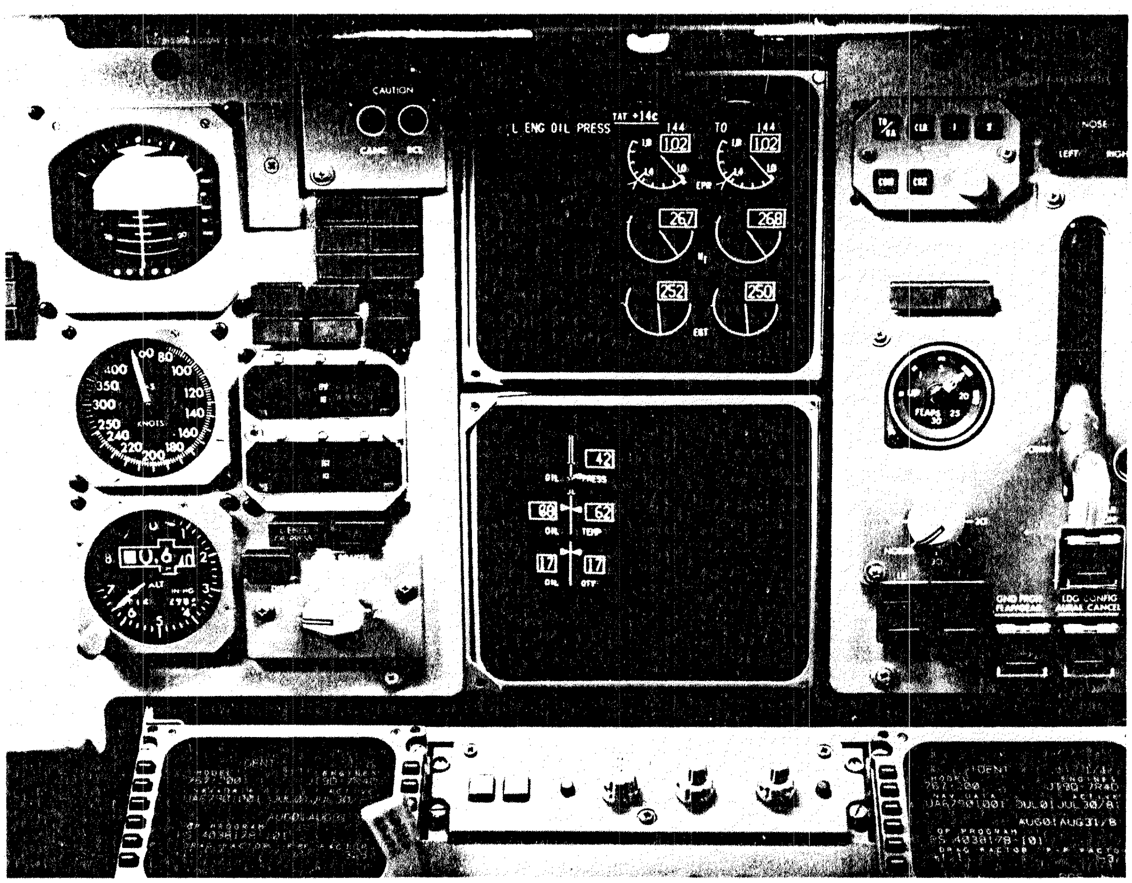
FD82-57E
6-21-82

THE FULL EICAS PRESENTATION CAN BE DISPLAYED BY PRESSING THE ENGINE BUTTON ON THE EICAS CONTROL PANEL. PRESSING THE BUTTON A SECOND TIME WILL RETURN THE DISPLAY TO THE DE-CLUTTERED MODE. IN THIS MODE ONLY THE PRIMARY ENGINE INSTRUMENTS ARE DISPLAYED ON THE UPPER CRT. IN A SIMILAR FASHION THE STATUS DISPLAY WILL APPEAR ON THE LOWER CRT WHEN THE STATUS BUTTON IS DEPRESSED. THRUST LIMITS ARE NORMALLY SET AUTOMATICALLY BUT MAY BE MANUALLY ADJUSTED BY MEANS OF THE THRUST SET KNOB. IN EITHER CASE THE LIMIT IS DISPLAYED BY REFERENCE "BUGS" ON THE UPPER EICAS ENGINE DISPLAYS.

THE SYSTEM CONTINUOUSLY DISPLAYS INFORMATION NEEDED FOR NORMAL OPERATION ON THE UPPER CRT. IT ALSO MONITORS OVER 400 INPUTS FROM ENGINES AND SUB-SYSTEMS TO ALERT THE CREW IN THE EVENT OF AN ABNORMALITY. SYSTEM AB-NORMALITIES ARE DISPLAYED AS WARNING, CAUTION, OR ADVISORY MESSAGES ON A DEDICATED AREA OF AN EICAS CRT.

AN ABNORMAL ENGINE PARAMETER CAUSES AN AMBER OR RED COLOR CHANGE ON THE APPROPRIATE EICAS GAUGE DISPLAY. IF THE FAULTY PARAMETER IS NOT ALREADY ON DISPLAY, IT APPEARS AUTOMATICALLY ON THE LOWER CRT, IN SOME CASES ACCOMPANIED BY OTHER, CLOSELY RELATED GAUGES. THESE LOWER-CRT INDICATIONS, NORMALLY NOT ON DISPLAY, CAN BE CALLED UP BY THE CREW WHEN DESIRED VIA THE EICAS CONTROL PANEL.


CAUTION
TAT +17c
CRZ
131
114
EPR
799
804
429
FLAPS
LDG CONFIG

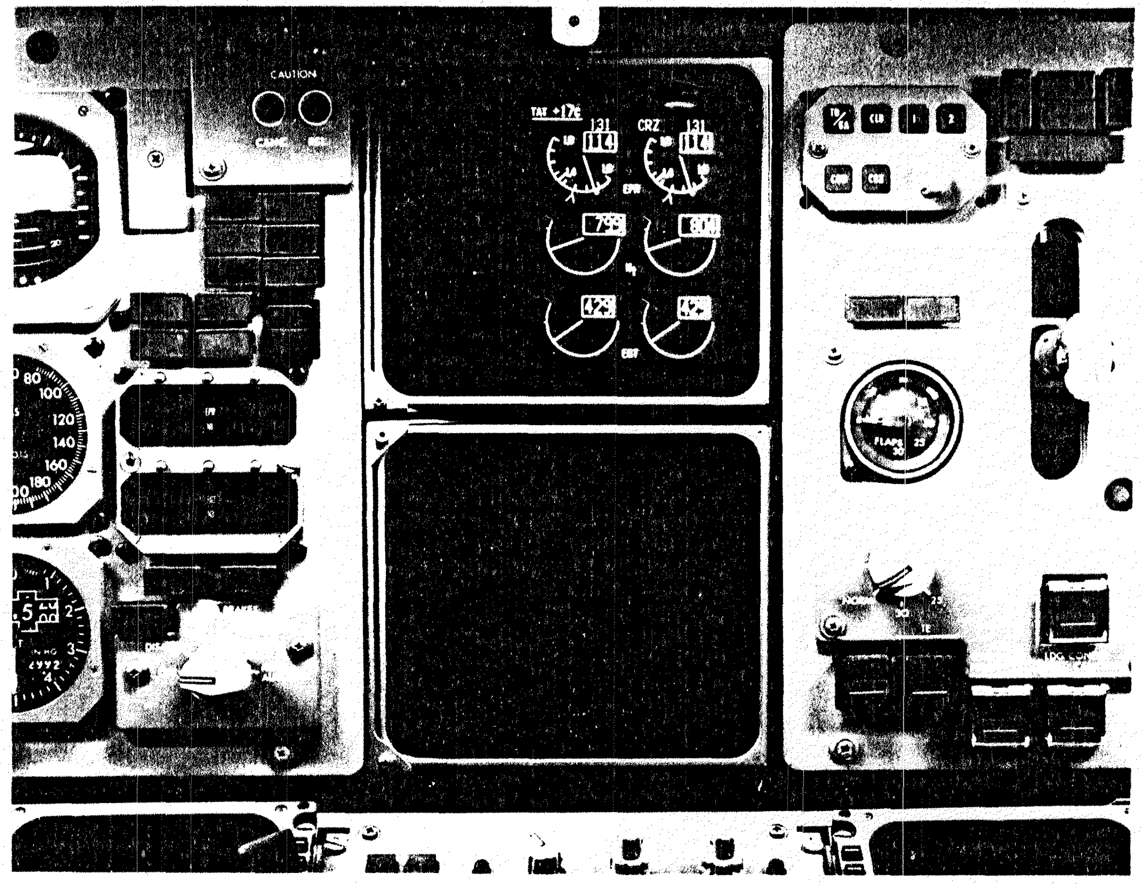

CAUTION
L ENG OIL PRESS
TAT +14c
144
TO
102
EPR
267
268
252
250
EGT
42
OIL PRESS
66
62
OIL TEMP
17
OIL QTY
KNOTS
ALT
FLAPS
NOSE
LEFT
GND PROX
LDG CONFIG

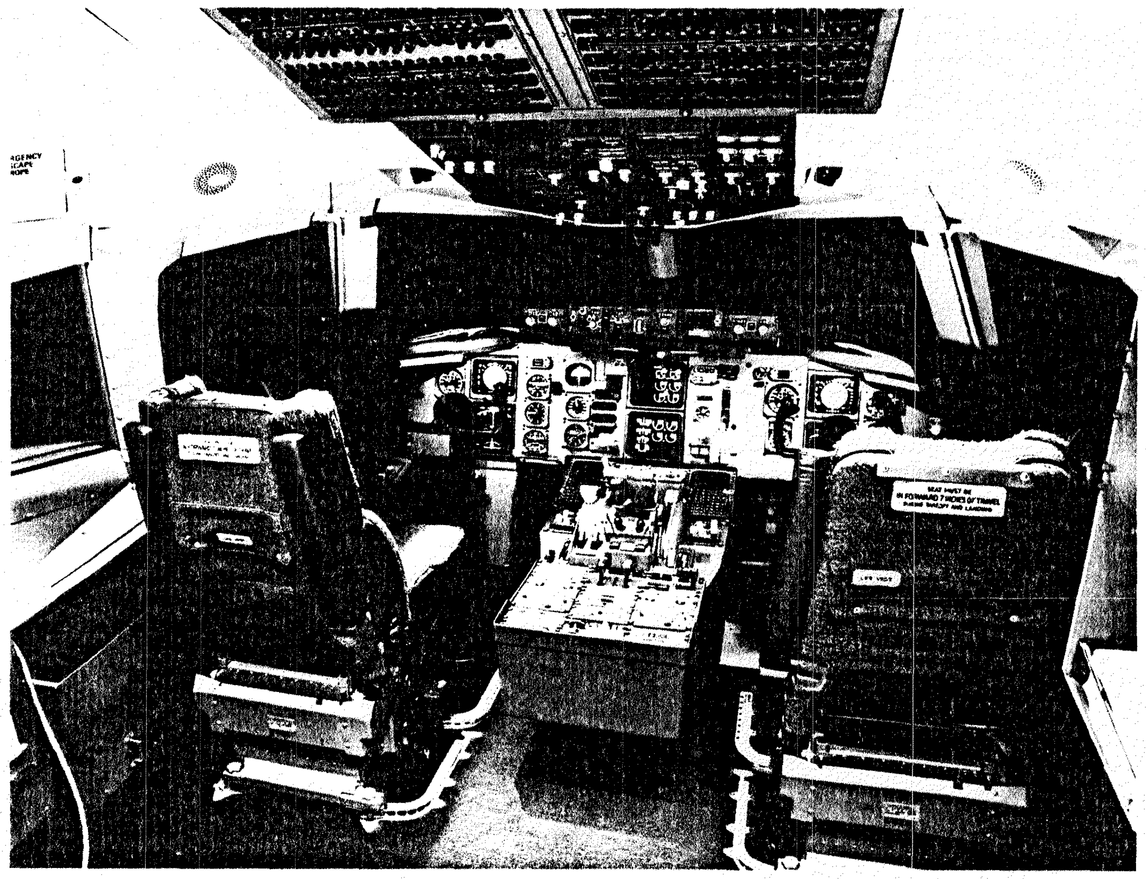
THE SYSTEM HAS TWO ADDITIONAL FUNCTIONS: STATUS AND MAINTENANCE. WHEN THE STATUS MODE IS SELECTED, THE LOWER CRT DISPLAYS DATA RELATING TO THE STATUS OF THE AIRPLANE, INCLUDING SUCH INFORMATION AS HYDRAULIC FLUID LEVELS AND CONTROL SURFACE POSITIONS. THREE MAINTENANCE MODE FORMATS ARE AVAILABLE ONLY ON THE GROUND. THEY DISPLAY INFORMATION ON CONDITIONS OVER WHICH THE FLIGHT CREW HAS NO CONTROL, SUCH AS ELECTRICAL FREQUENCY AND VOLTAGE. ALL EQUIPMENT FAILURES ARE LISTED WHETHER OR NOT THEY AFFECT DISPATCH.

TO ASSURE THAT ALL ENGINE PARAMETERS CAN STILL BE DISPLAYED IF A CRT FAILS, THE SYSTEM PROVIDES A COMPACT MODE IN WHICH PORTIONS OF THE GRAPHIC DISPLAY ARE CHANGED TO DIGITAL AND APPEAR ON THE REMAINING CRT. IN THE UNLIKELY EVENT THAT BOTH CRTS FAIL, OR THE PRIMARY ELECTRICAL SYSTEM FAILS, THE LIQUID CRYSTAL STANDBY ENGINE INSTRUMENTS ARE ACTIVATED.

THE 767-200 FLIGHT DECK IS A SPACIOUS, COMFORTABLE WORK AREA EQUIPPED WITH THE LATEST IN DIGITAL ELECTRONIC EQUIPMENT AND COMPUTERS. THE COMPUTERS ALLOW THE FLIGHT CREW TO OPERATE THE AIRPLANE MOST ECONOMICALLY (AND AUTOMATICALLY IF DESIRED) FROM TAKEOFF THROUGH APPROACH AND LANDING ROLLOUT.

THE LATEST IN AUTOMATIC GUIDANCE CONTROLS, AS WELL AS SYSTEM STATUS AND MALFUNCTION MONITORING PROVIDE AN ENVIRONMENT DESIGNED FOR SAFETY, EFFICIENCY, RELIABILITY AND COMFORT.


CAUTION
CRZ



HUMAN FACTORS ACTIVITIES IN THE NUCLEAR POWER INDUSTRY SINCE TMI-2

-Relevance to the Manned Space Program-

by
Harold E. (Smoke) Price
BioTechnology, Inc.
Falls Church, Virginia

Slide 1

When I was asked to make a presentation about human factors in the nuclear power industry and their relevance to manned space flight, I was initially concerned about the validity of transferring lessons learned from the nuclear power experience to the space human factors R&D program. My first thought was that the two areas are very different in terms of their technology and hardware, and that perhaps the human factors problems and solutions might also be different. However, as I began to work on this presentation some significant similarities became apparent.

Slide 2

There are probably many different factors or variables which offer a basis for comparing nuclear power and manned space flight, but I have chosen to highlight a few which I think will emphasize the significance of human factors. In making these comparisons, I have tried to illustrate the similarities with an example from the nuclear power area.

Safety. Both areas are extremely safety conscious. Nuclear power plants are designed so as to maintain the integrity of the systems and plants under extreme failure conditions. The primary mandate of the NRC is to see that the public's health and safety are protected.

Complexity. Both are complex man-machine systems. Many components and many people are involved in the design, construction/manufacture, operation, and maintenance of the systems. In nuclear power plants, for example, there are often more than 2,000 annunciators in the control room just for monitoring various parameters and conditions. There are also hundreds and even thousands of other controls and displays which are used in operating the plants.

Cost. Both programs require substantial investments in order to achieve an operational capability. In today's economy, the cost of a 1200-megawatt, triple-unit power plant, from start to commercial operation, is probably in the four-billion-dollar range.

Hostile Environment. Both programs require people to perform effectively in a hostile environment. Although some of the environmental factors are obviously quite different, the need for such things as protective clothing and equipment, special tools and procedures, and special training is common to both.

Continuous Operation. When performing their primary missions, both systems require continuous operation by some members of the crew. Consequently, problems of manning, shiftwork, and biological and social dysrhythms are always of concern.

Remote Control and Communications. Each system entails both local and remote control roles for personnel. While the local control roles are quite different, the remote control and communications requirements are similar. In nuclear power plants there are complex mechanisms for remote handling of radioactive material. There are also a great many technical communications that must take place between local and remote personnel and between man and machine.

Role of the Operator. As just mentioned, the specific roles of operators in both systems are quite different. However, both systems are highly automated and one of the key roles of the operator is to be available to manage those unforeseen and critical events that will inevitably occur. In the nuclear power industry and in the space program alike, the human is the last line of defense against catastrophe.

Consequences of Human Error. Fortunately, the consequences of human error in either case are not always catastrophic. Nevertheless, the ultimate or cumulative consequences of error in both cases can be catastrophic, so that reducing the potential for human error to its absolute minimum is a high-payoff endeavor.

HUMAN FACTORS ACTIVITIES IN THE NUCLEAR POWER INDUSTRY SINCE TMI-2

RELEVANCE TO THE MANNED SPACE PROGRAM

PRESENTED BY

HAROLD E. (SMOKE) PRICE

BIOTECHNOLOGY INC. Falls Church, Virginia

Slide 1

SOME COMPARISON FACTORS BETWEEN NUCLEAR POWER & MANNED SPACE FLIGHT

- SAFETY
- COMPLEXITY
- COST
- HOSTILE ENVIRONMENT
- CONTINUOUS OPERATION
- REMOTE CONTROL & COMMUNICATIONS
- ROLE OF THE OPERATOR
- CONSEQUENCES OF HUMAN ERROR

Slide 2

Slide 3

Everyone is well aware that the interest of the nuclear power community in human factors was precipitated by the Three Mile Island accident. There were many investigations into that accident, and most of them concluded that human factors or the lack thereof was a significant contributor to the overall process that resulted in the accident. In my opinion, the fundamental human error at TMI-2 was a lack of recognition that a nuclear power plant is a man-machine system, and that the design for man is as important as the design for machine. This original error was made ten years prior to the TMI accident, when the design was initiated, and it set the stage for the later events.

Slide 4

Although nearly all military and aerospace systems, and some industrial systems, have been developed with the benefit of human factors inputs, this seems not to have been the case in the process control and power industry. There were, of course, a few faint voices addressing the human factors issues in these systems well before TMI-2 brought them to the fore. For example, back in 1975, Steve Hanauer, though a nuclear physicist and not a psychologist or human factors engineer, was cognizant of the human factors problem. In an internal NRC memo on the important technical issues concerning reactor safety facing the Nuclear Regulatory Commission at that time or in the near future, Hanauer said, "Present designs do not make adequate provision for the limitations of people. Means must be found to improve the performance of the people on whom we depend and to improve the design of equipment so that it is less dependent on human performance."

THE HUMAN FACTORS ISSUE AT TMI-2

★ THE FUNDAMENTAL HUMAN ERROR AT TMI-2 WAS LACK OF RECOGNITION THAT A NUCLEAR POWER PLANT IS A MAN-MACHINE SYSTEM AND THE DESIGN FOR MAN IS AS IMPORTANT AS THE DESIGN OF MACHINE.

- NRC LESSONS LEARNED - "MOST IMPORTANT LESSONS LEARNED ..... OPERATIONAL SAFETY .... INCLUDES HUMAN FACTORS ENGINEERING ..... INTEGRATION OF THE HUMAN ELEMENT IN THE DESIGN, OPERATION, AND REGULATION OF SYSTEM SAFETY" (PAGE 1 - 2)

- KEMENY REPORT - "FUNDAMENTAL PROBLEMS ARE PEOPLE-RELATED" (PAGE 8)

- ROGOVIN REPORT - "PRINCIPAL DEFICIENCIES ARE MANAGEMENT PROBLEMS ... WILL BE SOLVED ONLY BY FUNDAMENTAL CHANGES IN THE INDUSTRY AND THE NRC..... (PAGE 89)

Slide 3

TMI MINUS 4 YEARS & 15 DAYS

IMPORTANT TECHNICAL REACTOR SAFETY ISSUES FACING THE NUCLEAR REGULATORY COMMISSION NOW OR IN THE NEAR FUTURE - Memo Dated March 13, 1975

"PRESENT DESIGNS DO NOT MAKE ADEQUATE PROVISION FOR THE LIMITATIONS OF PEOPLE. MEANS MUST BE FOUND TO IMPROVE THE PERFORMANCE OF THE PEOPLE ON WHOM WE DEPEND AND TO IMPROVE THE DESIGN OF EQUIPMENT SO THAT IT IS LESS DEPENDENT ON HUMAN PERFORMANCE"

STEPHEN H. HANAUER, NRC

Slide 4

Slide 5

Before discussing some of the human factors programs that have emerged in the nuclear power industry since TMI-2, I would like to briefly address one important question relevant to nuclear power plants. That question is: Can human factors reduce the risk of another TMI-2? I believe the answer is yes, and I believe that this single chart provides the rationale for that answer.

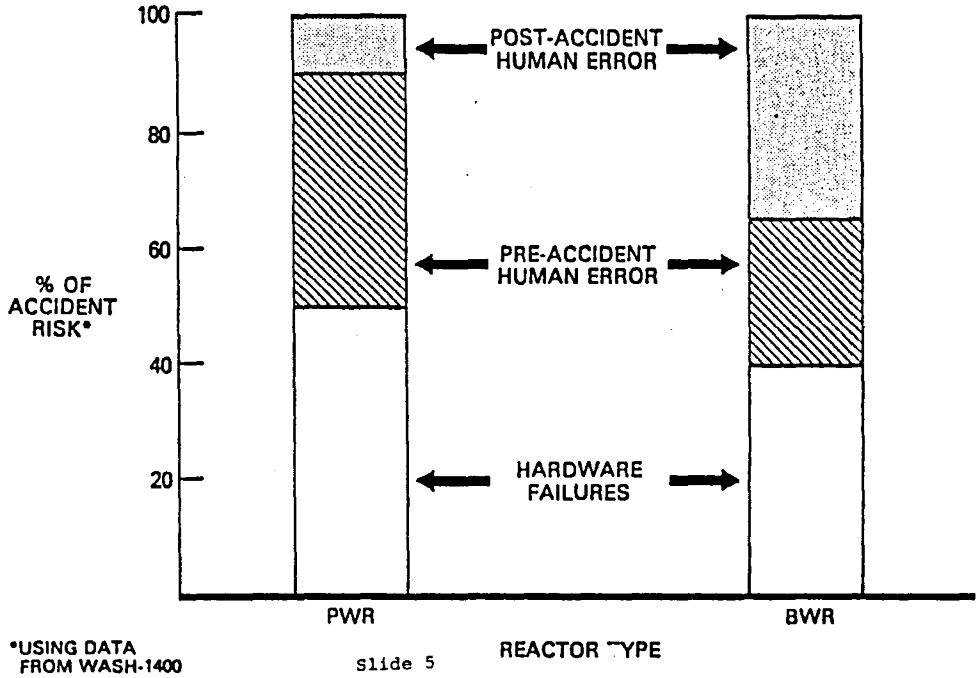
This chart was developed by summing the probabilities of all the sequences in WASH-1400, the renown Reactor Safety Study, which would constitute the total risk. The risk was then apportioned among human errors and hardware failures, and it can be seen that reducing the human error component can have a substantial impact on reactor safety. The pre-accident human errors are those made prior to initiation of the event. Typically this would be mispositioning of valves in safety systems or incorrect calibration of sensors designed to trigger safety systems. Thus, many of these errors are test and maintenance errors. The post-accident errors occur after the initiating event. For example, in some designs the emergency core cooling system comes on automatically and injects water into the core; but eventually the water source is depleted and the operator has to manually switch to another supply. Failure to do this would be a post-accident error.

The chart may in fact underestimate the contribution of human error, because human error is factored in only to the extent that it contributes to the unavailability of safety systems on demand. For example: A reactor trips; the Emergency Core Cooling System is required but is not available for some reason. In WASH-1400 the contribution of human error to the initiating event which caused the trip was not considered. It was simply assumed that some transient had occurred, and the possible contribution of human error was ignored.

Slide 6

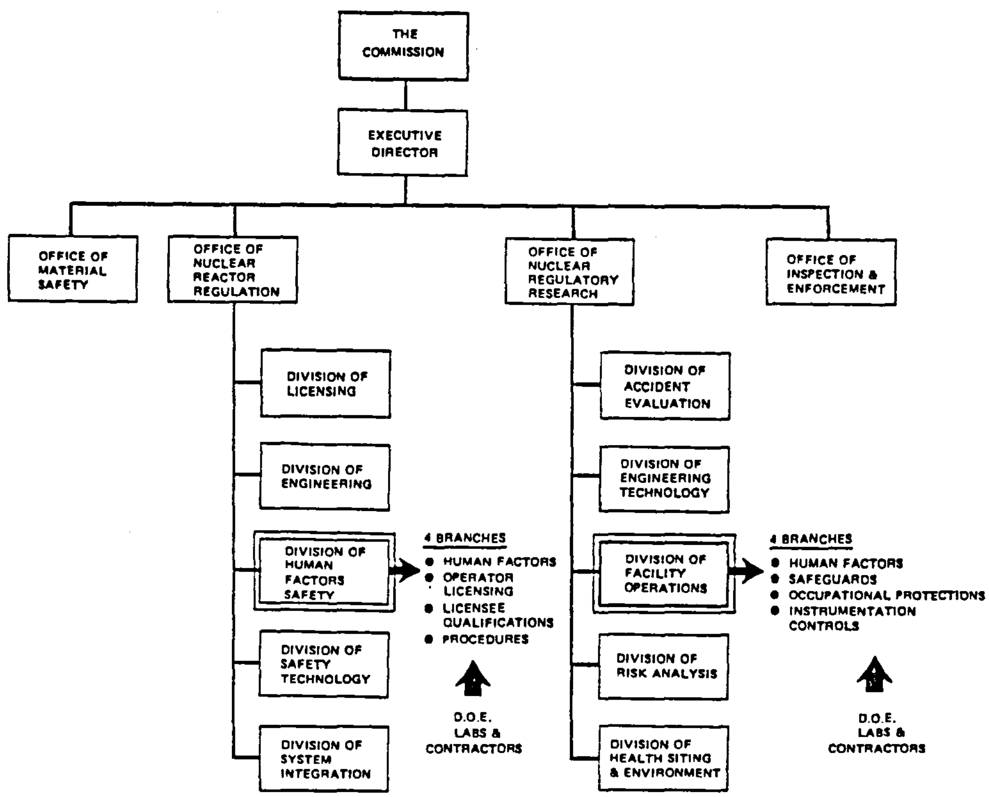
After TMI-2 and the ensuing investigations, the U.S. Nuclear Regulatory Commission (NRC) as well as the utilities began to make substantial changes to ensure consideration of human factors in present and future nuclear power plants. As indicated on this chart (double boxes), the NRC made two significant organizational changes to include human factors. In the Office of Nuclear Reactor Regulation (NRR) a separate Division of Human Factors Safety was created in May 1980 with four branches: human factors engineering, operator licensing, licensee qualifications, and procedures and test. In the Office of Nuclear Regulatory Research, a Human Factors Branch was created within the Division of Facility Operations. Concurrent with this organizational change the NRC immediately began an intensive recruiting campaign for human factors career professionals. As a result, I believe that there are now probably 20 to 25 human factors professionals in the NRC, whereas at the time of TMI-2 there were none. Human factors research or technical assistance efforts are probably funded by NRC at a level of 15 to 20 million dollars at present.

IMPROVING THE OPERATOR-MACHINE INTERFACE CAN SIGNIFICANTLY ENHANCE REACTOR SAFETY



Slide 5

NUCLEAR REGULATORY COMMISSION



Slide 6

Slide 7

Another significant step the NRC took in early 1980 was to ask the Human Factors Society, a professional organization of which many of us are members, to consider undertaking a contract for the development of a comprehensive human factors plan for nuclear reactor regulation. Discussions went on for almost a year, and in December 1981 the Human Factors Society was awarded a contract for approximately $500,000 to prepare a human factors plan.

Slide 8

Seven members of the Society were selected to participate in this project on a part-time basis, and I was one of them. Since I had had some previous experience in nuclear power human factors and I was located in the Washington, D.C., area, I was asked to be the Agency Liaison Technical Officer (ALTO), providing technical coordination between the NRC and the other members of the Human Factors Society project team.

human factors society

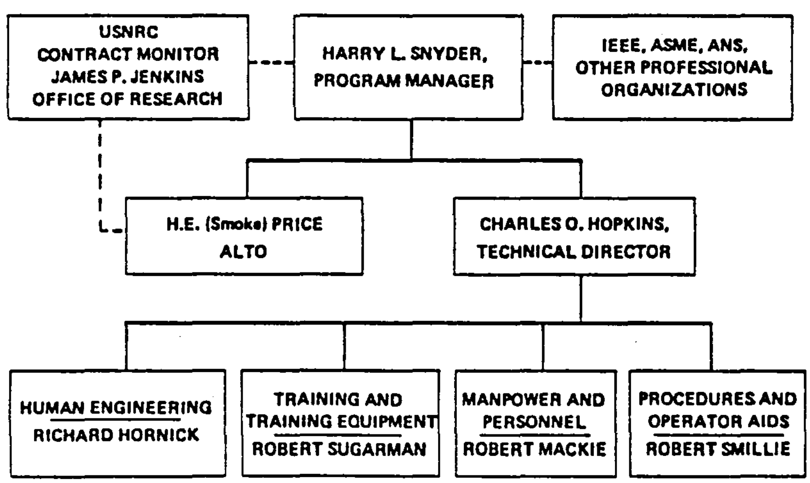
Project for

DEVELOPMENT OF A COMPREHENSIVE HUMAN FACTORS PLAN FOR NUCLEAR REACTOR REGULATION

U.S. Nuclear Regulatory Commission

Slide 7

HFS-NRC PROJECT TEAM



Slide 8

Slide 9

The project was conducted in three phases. The first task was to determine those aspects of nuclear power plant safety that have human factors implications. This was accomplished through a detailed survey of NRC program offices and through a study of relevant reports and documents. The second task was concerned with getting the industry side of the picture. Activities included visits to plants and meetings with representatives of utilities, the manufacturers of nuclear steam supply systems, A&E firms, and industry-sponsored organizations such as the Electric Power Research Institute and the Institute of Nuclear Power Operations. The third phase of the program consisted of an evaluation of each regulatory activity that had been defined as having a human factors impact, and, finally, the preparation of a recommended human factors long-range plan. The final report has been completed and is scheduled for publication by the NRC as NUREG/CR-2833 in August 1982.

Slide 10

One of the major reasons why I want to bring this report to your attention is that a large portion of it is devoted to a description and review of current (as of December 1981) human factors programs within the NRC and industry. I believe that many of these programs and the publications and products resulting from them have relevance to the manned space program. The Human Factors Society report is probably a good way to become familiar with those programs. This slide depicts the outline that we tried to follow in describing and evaluating each program. The next few slides will illustrate the types of human factors programs that are in effect or planned, and a few of these programs will be singled out for their potential relevance to manned space flight activities.

HFS-NRC PROJECT

SCOPE OF WORK

- TASK A SURVEY NRC PROGRAM OFFICES AND REPORTS TO DETERMINE THOSE ASPECTS OF NUCLEAR POWER PLANT SAFETY WITH HUMAN FACTORS IMPLICATIONS
- TASK B SELECTIVELY CHECK WITH THE NUCLEAR INDUSTRY REGARDING THE COMPLETENESS AND ACCURACY OF THE STUDY GROUP'S FINDINGS
- TASK C FOR EACH REGULATORY ACTIVITY WITH HUMAN FACTORS IMPACTS, EVALUATE WHAT IS BEING DONE AND RECOMMEND ACTION TO INSURE NUCLEAR POWER PLANT SAFETY

Slide 9

VOL. I
HUMAN FACTORS PROGRAMS

DESCRIPTION
- NEED
- OBJECTIVE
- WORK EFFORT

PERFORMING ORGANIZATION

STATUS
- SCHEDULE
- RESOURCES
- PRODUCTS/PUBLICATIONS

EVALUATION
- APPROPRIATENESS OF OBJECTIVES
- TIMELINESS
- COST/EFFECTIVENESS
- QUALITY OF WORK

Slide 10

Slide 11

This chart presents some of the programs being conducted in the Human Factors Engineering Branch and the Procedures and Test Review Branch of the Division of Human Factors Safety at the NRC. I would like to call your attention to a few specific ones which may be of interest.

- HUMAN ENGINEERING GUIDELINES FOR CONTROL ROOM REVIEW (NUREG-0700)--This publication was developed to provide guidance to utilities in conducting a human factors engineering review of the control rooms in their nuclear power plants. It contains an approach for a complete review, including functions analysis and task analysis, and an extensive collection of human factors engineering guidelines or criteria for use in assessing the man-machine interface in nuclear power plant control rooms. Much of the data originally came from military/aerospace documentation, but some new guidelines have been included. It is recommended as a useful reference--particularly for the review or design of ground support equipment.

- DEVELOPMENT OF HUMAN FACTORS ACCEPTANCE CRITERIA FOR THE SAFETY PARAMETER DISPLAY SYSTEM (NUREG-0835)--This document presents some criteria for reviewing the design of CRT-type displays used for presenting system status and safety information.

- ADVANCED DISPLAY TECHNOLOGIES--There are several projects underway in this area, most of them being conducted by the Idaho National Engineering Laboratory and the Lawrence Livermore National Laboratories. Several reports have been published relating to human factors design and evaluation of flat-panel displays.

- CRITERIA FOR PREPARATION OF EMERGENCY OPERATING PROCEDURES (NUREG-0899)--This publication and several others that preceded it present guidelines and criteria for preparing plant procedures in a format designed to reduce human error potential by increasing comprehension and readability.

Slide 12

This slide presents some of the programs being conducted in the Licensee Qualifications Branch and the Operator Licensing Branch of the Division of Human Factors Safety at NRC. These programs tend to be more specific to the nuclear power industry, and probably have less applicability to the manned space flight area than do the programs dealing with human factors engineering and procedures. Again, I would suggest that you refer to the Human Factors Society report, which gives more detailed descriptions of these programs and thus allows an independent judgment to be made regarding their usefulness for manned space missions. A few of these reports which, in my opinion, are worth perusing are:

- GUIDELINES FOR UTILITY MANAGEMENT, ORGANIZATION, AND STAFFING (NUREG-0731, NUREG/CR-1656, NUREG/CR-1280, and NUREG-1764)--The TMI accident suggested a need for a more thorough assessment of utility organizational effectiveness. Concerns were raised with respect to both management and operational personnel. Several studies and guidelines for this area have since been promulgated, covering a broad range of topics such as, for example, the assessment of utility management structures and the effects of various shiftwork practices on operator performance.

- PLANT OPERATOR QUALIFICATIONS--Several attempts have been made to establish appropriate educational, training, and experience requirements for licensed operators of nuclear power plants. While the content issue here is not relevant to the space program, the general human factors issue of qualifications required for personnel performing tasks with significant safety or operational consequences is relevant.

THE DIVISION OF HUMAN FACTORS SAFETY PROGRAMS - NRC

HUMAN FACTORS ENGINEERING BRANCH

- HUMAN ENGINEERING GUIDELINES FOR CONTROL ROOM REVIEW (NUREG-0700)
- HUMAN FACTORS CONTROL ROOM CASE REVIEWS
- DEVELOPMENT OF EVALUATION CRITERIA FOR DETAILED CONTROL ROOM DESIGN REVIEW (NUREG-0801)
- DEVELOPMENT OF HUMAN FACTORS ACCEPTANCE CRITERIA FOR THE SAFETY PARAMETER DISPLAY SYSTEM (NUREG-0835)
- SYSTEM STATUS VERIFICATION GUIDELINES
- ADVANCED DISPLAY TECHNOLOGIES
- ANNUNCIATOR SYSTEM GUIDELINES
- PLANT MAINTENANCE PROGRAM PLAN
- STANDARD REVIEW PLAN FOR HFEB

PROCEDURES AND TEST REVIEW BRANCH

- EMERGENCY PROCEDURES CONTROL ROOM CASE REVIEWS
- CRITERIA FOR PREPARATION OF EMERGENCY OPERATING PROCEDURES (NUREG-0899)

Slide 11

THE DIVISION OF HUMAN FACTORS SAFETY PROGRAMS - NRC

LICENSEE QUALIFICATIONS BRANCH

- GUIDELINES FOR UTILITY MANAGEMENT AND ORGANIZATION (NUREG-0731 AND NUREG/CR-1656)
- FEASIBILITY OF LICENSING NUCLEAR UTILITY MANAGERS AND OFFICERS
- INDEPENDENT SAFETY ENGINEERING GROUP ROLE AND RESPONSIBILITY
- MANPOWER AND STAFFING GUIDELINES (NUREG CR-1280 AND NUREG-1764)
- SHIFT TECHNICAL ADVISOR GUIDELINES
- ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS CONCERNING OPERATOR LICENSING (NUREG-1750)
- REACTOR OPERATOR AND SENIOR REACTOR OPERATOR EXAMINATION VALIDATION
- TRAINING AND EXAMINATION PROGRAM DEVELOPMENT
- PLANT OPERATOR QUALIFICATIONS
- OPERATOR FEEDBACK WORKSHOPS
- PLANT DRILL GUIDELINES

OPERATOR LICENSING BRANCH

- PROGRAM FOR THE ADMINISTRATION OF REACTOR OPERATOR (RO) AND SENIOR REACTOR OPERATOR (SRO) EXAMINATIONS (NUREG-0094)

Slide 12

Slide 13

The human factors research programs sponsored by the NRC may be of more interest and relevance to the manned space area than those programs just discussed, which are a part of the regulatory office of NRC. This slide identifies programs concerned with human factors engineering research and with personnel, staffing, and training research, some of which merit a closer look:

- OPERATIONAL AIDS FOR REACTOR OPERATORS AND THE ALLOCATION OF FUNCTIONS--This program is one which I think is relevant when considering the human role in space; it is one with which I am particularly familiar because my company is working in this program. Three principal publications have been issued. NUREG/CR-2587 deals with the functions and operations of nuclear power plant crews, in particular the development of the operator's role. Again, the substance is not relevant but many of the concepts should be of some value. NUREG/CR-2586 is a survey of methods for improving operator acceptance of computerized aids; this is a good review of the problem of user acceptance in dealing with automated systems. NUREG/CR-2623 is concerned with the allocation of functions in man-machine systems. It reviews recent literature on the subject and reports the development of a conceptual model. Incidentally, this is the portion of the program being carried out by BioTechnology. We are now also extending that research to areas such as dynamic and adaptive allocation of function designs.

- HUMAN ENGINEERING AND ADVANCED DISPLAYS--Several projects are underway to develop criteria for the design and evaluation of advanced displays. The Idaho National Engineering Laboratory has been in the forefront of this research, and numerous publications are available.

- SAFETY RELATED OPERATOR ACTIONS--This project is one wherein human performance data is being collected using a full-scale control room simulator. The method for developing and recording the operators' tasks, including a computerized performance measurement system, may have some general application.

- SPENT FUEL HANDLING--The refueling of nuclear reactors and the handling of spent fuel on-site and at independent storage facilities has required considerable technological development in remote-handling technology. The operator's role in these systems and the development of training requirements for these operators should be worthwhile for those of you concerned with robotics, tele-operations, and remote handling.

Slide 14

This slide presents some more of the human factors research programs being sponsored by the NRC.

- RISK ANALYSIS AND HUMAN RELIABILITY RESEARCH--Well before TMI-2, the NRC was sponsoring human reliability research to support the overall risk analysis program. The Sandia National Laboratory has been responsible for this research, and has issued several significant publications concerned with human reliability and performance prediction. NUREG/CR-1278 is a handbook of human reliability analyses, with emphasis on nuclear power plant applications. NUREG/CR-2254 is a workbook to guide the user in the development and application of human reliability data. Finally, some work has been done on the use of expert opinion to estimate human error probabilities; a recent publication (NUREG/CR-2255) contains a review of probability assessment and scaling. If human error estimation or probabilistic risk assessment is important in the space program, then certainly the work done by Sandia in these areas will be of interest.

- REACTOR OPERATOR TASK ANALYSIS--This research project will not, of course, be of interest from the content point of view. However, a substantial amount of effort has been devoted to the methodology of task analysis and, in my opinion, has resulted in a true advance in the state of the art in that area. No formal reports have been published, but a data collection plan which describes the task analysis methodology was delivered to the NRC in July 1982.

HUMAN FACTORS RESEARCH PROGRAMS - NRC

HUMAN FACTORS ENGINEERING RESEARCH

- PLANT STATUS MONITORING
- AUGMENTED OPERATOR CAPABILITY
- OPERATIONAL AIDS FOR REACTOR OPERATORS & THE ALLOCATION OF FUNCTIONS
- HUMAN FACTORS REVIEW
- CRT DISPLAY DESIGN AND EVALUATION
- HALDEN REACTOR PROJECT
- EVALUATION OF HUMAN FACTORS ENGINEERING DATA

PERSONNEL, STAFFING, AND TRAINING (LICENSEE QUALIFICATIONS) RESEARCH

- SAFETY RELATED OPERATOR ACTIONS
- PERSONNEL SELECTION AND TRAINING
- MANAGEMENT QUALIFICATIONS
- INDEPENDENT SPENT FUEL STORAGE INSTALLATION TASK ANALYSIS
- THE EFFECTS OF POST TMI REQUIREMENTS ON OPERATORS
- THE EFFECTS OF SHIFT WORK AND OVERTIME ON OPERATOR PERFORMANCE
- BEHAVIORAL RELIABILITY PROGRAM
- STANDARDS FOR PSYCHOLOGICAL ASSESSMENT

Slide 13

HUMAN FACTORS RESEARCH PROGRAMS - NRC

PROCEDURES AND OPERATOR AIDS RESEARCH

- OPERATING PROCEDURES EFFECTIVENESS TECHNICAL ASSISTANCE UPGRADING

RISK ANALYSIS AND HUMAN RELIABILITY RESEARCH

- HUMAN PERFORMANCE DATA BANK AND ANALYSIS
- HUMAN PERFORMANCE MODELING FOR NPP OPERATIONS
- MAINTENANCE ERROR MODEL
- HUMAN ERROR RATE ANALYSIS

GENERAL HUMAN FACTORS RESEARCH

- HUMAN FACTORS PROGRAM PLAN
- REACTOR OPERATOR TASK ANALYSIS
- HUMAN FACTORS RESEARCH FOR LIQUID METAL FAST BREEDER REACTORS
- HUMAN FACTORS RESEARCH REVIEW GROUP

LONG RANGE RESEARCH PLAN (FY 84 – FY 88)

OFFICE OF INSPECTION AND ENFORCEMENT

- EVALUATING MAINTENANCE, TEST, AND CALIBRATION PROCEDURES

Slide 14

Slide 15

The Federal Government is not the only organization performing human factors research in the nuclear power area. The Electric Power Research Institute (EPRI), which is supported by the utilities, also has a sizable human factors program for research and development in areas of broad interest to the member utilities. Again, it is interesting to note that their work in human factors began prior to Three Mile Island. Some of the key programs are:

- HUMAN FACTORS REVIEW, METHODS, AND GUIDANCE FOR IMPROVING NUCLEAR CONTROL ROOMS--EPRI began this series of studies in 1977. EPRI NP-309, Human Factors Review of Nuclear Power Plant Control Room Design, was completed in 1977 and identified many of the problems that are now the subject of intensive review by the industry and the NRC. This project was followed by a related project which resulted in a multi-volume series of publications (EPRI NP-1118) in 1979 concerned with human factors methods for nuclear control room design. In May 1982, EPRI NP-2411, Human Engineering Guide for Enhancing Nuclear Control Rooms, was issued. All of this work will be found to have general relevance to the problem of man-machine interface design in ground support systems.

- HUMAN FACTORS AND POWER PLANT MAINTAINABILITY--Most of the human factors studies and research in nuclear power have been operations-oriented. EPRI has sponsored work in maintainability, and two publications on this subject are available. EPRI NP-1567, Review of Power Plant Maintainability, examines the man-machine environment interfaces that influence performance, safety, effectiveness, and reliability of maintenance personnel. EPRI AF-1041, The Role of Personnel Errors in Power Plant Equipment Reliability, is also of value for those interested in the maintainability area.

Slide 16

This slide presents additional human factors programs being conducted by the Electric Power Research Institute. The programs identified here tend to be the latest EPRI efforts.

- TEST OF JOB PERFORMANCE AIDS FOR POWER PLANTS--This project, which has been underway for several years, is a test and evaluation of the application of JPA technology--primarily in the maintenance area. No final report is available as yet, but the results should be enlightening to those interested in job performance aids.

- WORK PERFORMANCE UNDER HEAT STRESS--The objective of this effort was to develop a cooling garment to increase a worker's tolerance to high-temperature environments. The general problems of working while wearing protective clothing are obviously relevant to the manned space program.

- ENHANCEMENT OF COMMUNICATIONS SYSTEMS--The first project under this program documented several problems which degrade internal nuclear power plant communications (EPRI NP-2035). A follow-on project is now underway to identify and evaluate approaches to upgrading communications in existing power plants. Results of this effort will be of value to those interested in reliability of communications, particularly in noisy environments.

ELECTRIC POWER RESEARCH INSTITUTE (EPRI)
HUMAN FACTORS PROGRAMS

- HF REVIEW OF NPP CR DESIGN
- HF REVIEW OF POWER PLANT MAINTAINABILITY
- THE ROLE OF PERSONNEL ERRORS IN EQUIPMENT RELIABILITY
- HF METHODS FOR NUCLEAR CR DESIGN
- PMS FOR TRAINING SIMULATORS
- EVALUATION OF PROPOSED CR IMPROVEMENTS THROUGH ANALYSIS OF CRITICAL DECISIONS
- SUMMARY AND EVALUATION OF SCOPING AND FEASIBILITY STUDIES FOR DASS
- HF REVIEW OF ENHANCEMENT APPROACHES FOR NUCLEAR CR
- SURVEY AND ANALYSIS OF COMMUNICATIONS PROBLEMS IN NPPs

Slide 15

ELECTRIC POWER RESEARCH INSTITUTE (EPRI)
HUMAN FACTORS PROGRAMS

- TEST OF JOB PERFORMANCE AIDS (JPA's) FOR POWER PLANTS
- HUMAN ENGINEERING GUIDELINES FOR OPERATIONS
- ALARM SYSTEM IMPROVEMENT GUIDE
- WORK PERFORMANCE UNDER HEAT STRESS
- SAFETY FUNCTIONS MONITORING CONCEPTS EVALUATION
- PHYSICAL ANTHROPOMETRIC SURVEY
- IDENTIFY AND EVALUATE COMMUNICATION SYSTEM ENHANCEMENT
- MAINTAINABILITY STUDIES
- WORK STRUCTURE AND PERFORMANCE
- DEVELOPMENT OF A GUIDELINE FOR USE OF CRT DISPLAY IN CONVENTIONAL CR

Slide 16

Slide 17

The Institute for Nuclear Power Operations (INPO) is another utility-sponsored organization, more recently established than EPRI, whose charter is to ensure a high quality of nuclear power operations. Its programs are probably less generalizable to the manned space operations area, as they intend to be quite specific to utility problems and needs. The INPO programs are also less research-oriented and more problem-solving in nature. Nevertheless, one program is underway which may have some relevance:

- EMERGENCY OPERATING PROCEDURES DEVELOPMENT--One result of TMI-2 is that all utilities will have to revise and upgrade their emergency operating procedures to be more symptom-oriented, rather than event-oriented. Concurrently with this, the organization, format, and other presentation issues relating to procedures documents and which have an impact on human performance will be enhanced. INPO is developing guidelines for use by the utilities; these guidelines include (1) a writer's guide and (2) techniques for verifying and validating the procedures. Both of these efforts will be valuable for those in the space program who are concerned with the development of technical procedures and the minimization of human error.

That's all I have to say about human factors activities in the nuclear power industry that may be relevant to the manned space program. I would like to remind you that the Human Factors Society report referred to earlier contains an extensive list of references as well as a more detailed description of the projects just discussed. I have also included a more limited bibliography at the end of this paper which will guide the reader to selected references.

Slide 18

Before I leave my topic I want to return to a theme that is a recurrent one in human factors work, and make a few observations. Throughout this presentation, references or inferences have been made to "human error." In case I have left the impression that human error is a significant problem in the manned space program, I want to clarify what I mean by human error and the contribution of human factors to the reduction of it.

"To err is human" is so deeply ingrained in our everyday speech and ways of thinking that it has, frankly, misled us for a long time. Accident statistics compiled for insurance companies concerning home, street, railway, and industrial accidents are full of causes such as carelessness, faulty attitude, and inattention. Although labels such as these appear to tell us something, they really don't. Everyone is inattentive at some time or other, and to say that an accident was caused by inattentiveness gives us no clue whatsoever to how it could have been prevented.

Human factors specialists were among the first to begin to reorient our thinking in regard to this problem, due primarily to problems that arose in the operation of the complex military machines produced in World War II. In a classic study of so-called "pilot-error" accidents carried out nearly 35 years ago, Fitts and Jones were able to show that a major part of the blame for these "pilot errors" was to be found in the way equipment was designed. Subsequent human factors research over the years has confirmed that people make many more mistakes with some kinds of equipment than with others, and that it is possible to redesign many pieces of equipment so that the "human errors" are greatly reduced or even eliminated. Indeed, I have referred to many designs as "error-provocative" because they almost literally invite people to make mistakes.

Have these lessons been applied in the nuclear power industry? The answer, unfortunately, is "No." In my experience, I have found almost every single kind of textbook human engineering deficiency that could possibly occur. Yet when I talk to many architects, designers, and operations managers, I consistently hear that human factors is just good common sense. As part of a training seminar my company gives to utilities, we deal with that response by showing some slides of absolutely atrocious human engineering discrepancies that exist in today's nuclear power plants and asking the seminar participants the question, "If human factors is really common sense, where was the common sense when these designs were conceived?"

INSTITUTE FOR NUCLEAR POWER OPERATIONS (INPO)

HUMAN FACTORS PROGRAMS

- EMERGENCY OPERATING PROCEDURES DEVELOPMENT
- CONTROL ROOM REVIEW
- OPERATOR AID DEVELOPMENT
- SEE-IN PROGRAM SUPPORT
- RISK ASSESSMENT TECHNIQUE DEVELOPMENT
- OCCUPATIONAL ANALYSIS
- MANPOWER SURVEY
- MONITORING AND REPORTING RESULTS OF NUCLEAR UTILITY
- HUMAN RESOURCES DEVELOPMENT
- ACCREDITATION OF NUCLEAR TRAINING
- JOB AND TASK ANALYSIS

Slide 17

TO ERR IS HUMAN - OR IS IT?

- OVER 50% OF ALL SYSTEM FAILURES (IN GENERAL) ARE CAUSED BY HUMAN ERROR
- ANALYSIS OF LER'S CONCLUDES THAT 20% ARE ATTRIBUTABLE TO HUMAN ERROR

BUT

- A SMALL PERCENTAGE OF HUMAN ERRORS ARE RANDOM OR HUMAN ORIGINATED (EXOGENOUS)
- THE MAJOR PART OF HUMAN ERROR IS DESIGN INDUCED OR SITUATION CAUSED (ENDOGENOUS)

Slide 18

Note: At this point in the presentation several slides which are not contained in this paper were presented to the audience to illustrate the lack of common sense in some present-day designs.

Designers, manufacturers, and operations personnel must realize that good human factors is not just a case of "proving the obvious" (i.e., that human factors is simply common sense). In most nuclear power plants and some aerospace systems today, a common-sense approach has produced marginally acceptable designs (from a human factors standpoint) because of the fact that the hardware and the technology associated with that hardware have been around for some time. Experience with it has produced a level of knowledge one might term "lessons learned"--which may really be what is referred to as common sense.

In periods involving quantum leaps in technology and hardware and software sophistication, this common-sense approach breaks down primarily due to the absence of the "lessons learned" that comes from long experience with a technology or method. Human factors personnel have the training and experience in a variety of systems that enables them to bring valuable knowledge and techniques to the space systems development process. Human factors personnel have obtained this knowledge largely by dealing with gaps in technology where common sense has broken down. In addition, operations analysis and research in fields such as system engineering, aviation medicine, applied physiology, experimental psychology, anthropometry, and sociology have contributed a great deal of basic design data, which human factors personnel know <u>where to find</u> and <u>how to interpret</u>. Perhaps most important of all is the fact that human factors personnel have the necessary motivation to search for optimal solutions where man is involved.

Selected References

NUREG-0700. Guidelines for Control Room Design Reviews. U.S. Nuclear Regulatory Commission, September 1981.

NUREG-0835. Human Factors Acceptance Criteria for the Safety Parameter Display System (draft report for comment). U.S. Nuclear Regulatory Commission, October 1981.

NUREG-0898. Guidelines for Preparation of Emergency Operating Procedures (draft). U.S. Nuclear Regulatory Commission, February 1982.

NUREG/CR-2623. The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review. Oak Ridge National Laboratory, June 1982.

NUREG/CR-2586. A Survey of Methods for Improving Operator Acceptance of Computerized Aids. U.S. Nuclear Regulatory Commission.

NUREG/CR-1970. Development of a Checklist for Evaluating Emergency Procedures Used in Nuclear Power Plants. U.S. Nuclear Regulatory Commission, May 1981.

NUREG/CR-1994. Technique for Displaying Miltivariate Data on Idaho National Engineering Laboratory, April 1981.

EG&G Idaho, Inc. Some Human Engineering Color Considerations Using CRT Displays: A Review of the Literature (SD-B-81-001). EG&G Idaho, Inc., January 1981.

EPRI NP-1118-SY, Project 501-3. Human Factors Methods for Nuclear Control Room Design (summary report). Lockheed Missiles & Space Company, June 1979.

EPRI NP-2441. Human Engineering Guide for Enhancing Nuclear Control Rooms. Electric Power Research Institute, May 1982.

AF/AIAA MILITARY SPACE SYSTEM TECHNOLOGY MODEL

Presentation To

HUMAN ROLE IN SPACE

NASA WORKSHOP

24-26 AUG. 1982

Dr. Stacy R. Hunt

General Electric Co.

(H. Tom Fisher)

Lockheed Missiles & Space Co.

The MSSTM basic program objectives (shown opposite) can appropriately be expanded to include three added specific objectives. The first is to present the Space Division corporate position on technology through the integration of technology requirements and the subsequent prioritization of technology needs. The second specific objective is to develop an advanced technology plan with associated rationale. Finally, it is strongly desired to provide guidance to and access technology support from:

- USAF and other DoD laboratories
- DARPA and NASA
- Industry

The initial MSSTM planning base evolved into six primary technical volumes as shown in the facing page. Approximately 15 major technology subjects are addressed therein. As envisioned, the original MSSTM workshop results and corresponding initial multi-volume output will be further definitized, more effort expended in Volume VI (particularly the technology roadmaps), and greater industry-agency interaction achieved as partially evidenced by this presentation to the NASA workshop participants.

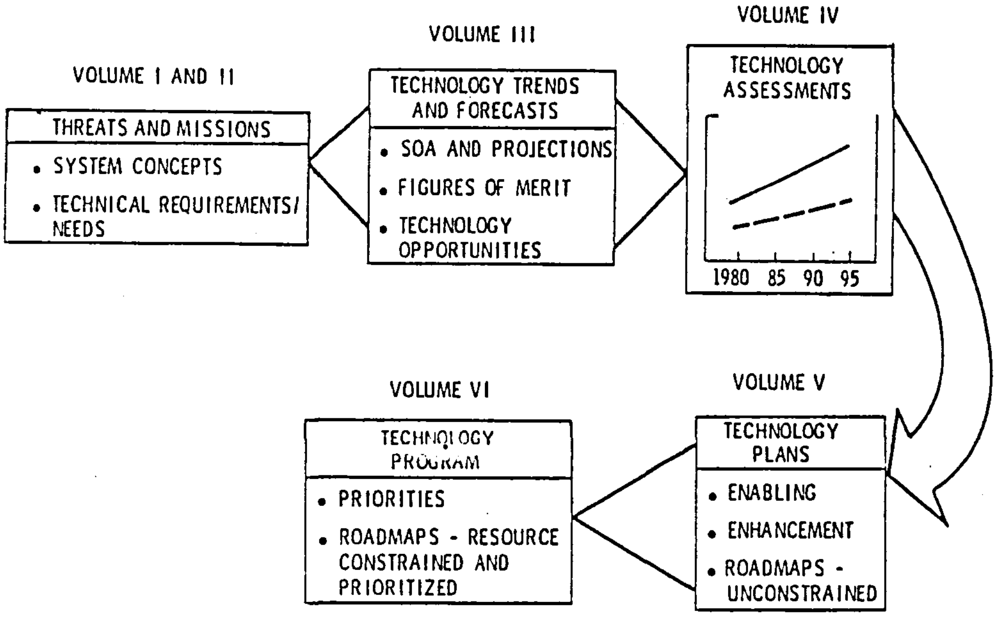
Military Space Systems Technology Model (MSSTM) Program Objectives

TO PROVIDE:

- A SYSTEMATIC PROCESS TO LINK FUTURE TECHNOLOGY NEEDS TO MILITARY MISSION REQUIREMENTS FOR SPACE
- A COMMUNICATIONS TOOL BETWEEN SD AND AIRSTAFF, HQ AFSC, MAJCOMs, AF LABS, NASA, AND DARPA
- A GUIDE TO INDUSTRY FOR IR&D

Long Range Space Technology Planning Process

MILITARY SPACE SYSTEMS TECHNOLOGY MODEL



The facing chart essentially portrays the nature of material considered in the 1st workshop. Although a good start, it was perceived as too limited in scope and not now fully representative of the rapidly emerging role of military man in space and the associated requirements, technology needs, and subsystem/hardware necessary to support and augment the STS ERA.

This second workshop "team" has received a series of excellent overviews by several arms of the DoD (e.g., USAF, Army, and Navy), and as indicated on the facing chart, a very fruitful exchange of ideas consummated. The establishment of some 15 technology panels has provided the basic vehicle for both inter and intra panel "education" and, has and is leading to the development of highly pertinent, synthesized, and multidisciplinary responses for input into Workshop II MSSTM final documentation.

Man in Space

ADVANCES SOUGHT BY THE MID-90's

- PHYSIOLOGICAL
  - REMEDIES FOR MOTION SICKNESS, HYPERVOLEMA, CALCIUM LOSS IN ZERO-G
- HABITAT
  - LIGHTWEIGHT EVA SUIT (e.g., 8 psi)
  - IMPROVED LIFE SUPPORT
    - LONG-LIFE (~1 yr)
    - RADIATION PROTECTION
    - LIGHT WEIGHT

POTENTIAL SYSTEM BENEFITS

- LOWER COST, HIGHER RELIABILITY, GREATER FLEXIBILITY IN MANNED APPLICATIONS

1982 AIAA / NSIA Space Systems and Technology Workshop

OBJECTIVES

- EXCHANGE IDEAS
  - PROVIDE INDUSTRY WITH A COHESIVE SUMMARY OF SPACE DIVISION'S SPACE SYSTEMS AND TECHNOLOGY DEVELOPMENT PLANNING
  - OBTAIN INDUSTRY AND TECHNICAL COMMUNITY EVALUATION OF SPACE CONCEPTS AND TECHNOLOGY SOLUTIONS (rationale, priorities, timeliness)
- EDUCATE
  - ESTABLISH A COMMON BACKGROUND FOR INDEPENDENT RESEARCH AND DEVELOPMENT
- DOCUMENT
  - REPORT WORKSHOP RESULTS FOR FOLLOW-UP EVALUATION AND ACTION

The basic 15 MSSTM technologies and corresponding panel chairmen are presented on the facing chart. Each panel is composed of a number of recognized experts in their corresponding field(s). Interestingly, over 70 different companies/agencies/organizations make up the panel team membership.

As shown on the opposite chart, Dr. Stacy Hunt is Chairman of the Man-in-Space Panel. He is assisted by 17 active panel members, each of whom has been assigned a cogent area of responsibility. Mr. Murry Gross backs up Dr. Hunt and also acts as Principal Technical Interface Liaison with the other 14 panels. Messrs. Al Brouillet and Tom Fisher are charged with the responsibility of "pulling together" the technical sections. Liaison with the NASA Human Role in Space Workshop has been through Dr. Montemerlo at NASA HQ.

Technologies and Panel Structure

TECHNOLOGIES AND PANELS	PANEL CHAIRMEN
COMMUNICATIONS	DAVID R. McELROY, JR
INFORMATION PROCESSING	RUSSEL E. WEAVER
NAVIGATION, GUIDANCE, AND CONTROL	KLAUS D. DANNENBERG
MATERIALS AND STRUCTURES	DONALD E. SKOUMAL
PROPULSION	ROBERT L. SACKHEIM
POWER AND ENERGY	JOHN SCOTT-MONCK
THERMAL CONTROL	W. RAY HOOK
WEAPONS	ROBERT C. OHLMANN
RADAR	FRED E. BRADLEY
ELECTRO-OPTICS	ROGER A. BRECKENRIDGE
MANUFACTURING	BART GEAR
SURVIVABILITY AND AUTONOMY	BENN MARTIN
NATURAL ENVIRONMENT	BILLY M. McCORMAC
FUTURE SPACE CONCEPTS AND OPERATIONS	JERRY J. FLOREY
MAN IN SPACE	STACY HUNT

AF/AIAA MAN-IN-SPACE PANEL

A. CHAIRMAN – DR. STACY R. HUNT
CONSULTANT, HUMAN FACTORS
GENERAL ELECTRIC CO. – VFSC
BLDG. A, ROOM 10A46
P.O. BOX 8555
PHILADELPHIA, PA, 19101
AC 215 962-5599

B. PANEL MEMBERS:

1. MR. ALFRED O. BROUILLET - HAMILTON STANDARD CORP.
2. DR. PAUL BUCHANAN - NASA/KSC
3. MR. CARL F. EHRLICH, JR. - ROCKWELL INTERNATIONAL
4. MR. JAMIE ERICKSON - ROCKWELL INTERNATIONAL
5. MR. H. TOM FISHER - LOCKHEED MISSILES AND SPACE COMPANY
6. DR. SHIRO FURUKAWA - MACDONNEL DOUGLAS (MDTSCO)
7. MR. MURRY GROSS - GENERAL ELECTRIC COMPANY
8. MR. RONALD J. HARRIS - NASA/MSFC
9. MR. JAMES L. HIEATT - TRW
10. DR. HERBERT KELLY, MACDONNEL DOUGLAS
11. MR. STANLEY MARCUS - ROCKWELL INTERNATIONAL
12. MR. JOHN MOCKOVCIAK - GRUMMAN AEROSPACE CORP.
13. DR. MELVIN D. MONTEMERLO - NASA/HDQ.
14. COL. L. RICHARD NORRIS - GENERAL DYNAMICS CORP.
15. MR. WILLIAM SMITH - NASA/HDQ.
16. DR. ROBERT E. STEVENSON - ONR/SCRIPPS INSTITUTE OF OCEANOGRAPHY
17. MR. GORDON WOODCOCK - BOEING AEROSPACE COMPANY

The principal man-in-space panel self-developed objectives are presented on the facing chart. Although ambitious in terms of scope and content, significant effort is being expended by the panel to increase the breadth of the initial workshop (I) and to provide substantial more intra-panel interaction.

The basic panel activities to date are shown on the facing chart. Not shown, but equally important is participation in this NASA workshop (Human Role in Space). Also of benefit to this man-in-space panel was the recent NASA-JSC Satellite Services Workshop (June 1982) wherein many of the panel members actively participated in this workshop including presentation of formally documented papers. The bottom-line objective of this panel is the input to and presentation of materials at the Workshop II final meeting at Kirtland AFB and the resulting panel interactions and final recommendations.

AF/AIAA MAN-IN-SPACE PANEL OBJECTIVES

A. ASSEMBLE A HIGHLY COMPETENT AND MULTI-DISCIPLINARY PANEL TEAM

B. PROVIDE A FULLY REPRESENTATIVE MANNED SYSTEM WORKSHOP INPUT FOR THE 1985 - 2005 TIME FRAME

C. EXPAND ON WORKSHOP I MANNED SYSTEM INPUT

D. EXPAND THE WORKSHOP I MISSION MODEL RELATIVE TO MANNED SYSTEM PARTICIPATION

E. DEVELOP A MORE BROAD AND DEFINITIZED MILITARY MANNED SYSTEM TECHNOLOGY MODEL

F. COORDINATE WITH OTHER 13 TECHNOLOGY PANELS TO EXTENT PRACTICAL/REQD

G. COORDINATE WITH NASA's "HUMAN ROLE IN SPACE" WORKSHOP AND PANELS / MEMBERS

AF/AIAA MAN-IN-SPACE PANEL ACTIVITIES TO DATE

A. ATTENDANCE AT WORKSHOP II WORKING SESSION 'KICK-OFF' – 18 FEBRUARY 1982

B. ATTENDANCE AND PARTICIPATION AT 2ND WORKSHOP HELD AT PENTAGON – 2 JUNE 1982

C. MAN-IN-SPACE PANEL MEETING (29/30 JULY 1982) AT GENERAL ELECTRIC COMPANY

D. PARTICIPATION BY ALL PANEL MEMBERS AND 'DRAFTED SUPPORT' IN THE PREPARATION OF DRAFT MATERIAL FOR WORKSHOP II FORMAL INPUT

E. PLANNING FOR AF/AIAA SPACE SYSTEMS TECHNOLOGY WORKSHOP II FINAL MEETING:
   1. KIRTLAND AIR FORCE BASE, ALBUQUERQUE, NEW MEXICO
   2. 20-23 SEPTEMBER 1982

The document will be organized as shown in the facing chart. The numerous panel member inputs will be synthesized and edited to provide a reasonably structured product. It is not planned at this time (August 1982) to have a classified supplement.

It was thought that Section 2 might be of interest to this NASA workshop due to some similarity in content. Thus, the 8 subsections of Section 2 are presented on the facing chart. Subsection 2.5 addresses more specifically the military missions providing the basis and interrelationships for subsections 2.4 and 6.8.

AF/AIAA MAN-IN-SPACE DOCUMENT CONTENT

1.0 INTRODUCTION
- 1.1 BACKGROUND
- 1.2 SCOPE/SUMMARY

2.0 ROLE OF MAN
(SEE EXPANDED OUTLINE)

3.0 SPACE SYSTEM REQUIREMENTS AND DESIGN
- 3.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS
- 3.2 HUMAN FACTORS
- 3.3 BIOMEDICAL/MEDICAL REQTS AND SUPPORT

4.0 SUMMARY

AF/AIAA MAN-IN-SPACE PANEL (SECTION 2 - ROLE OF MAN)

2.1 ANALYSIS OF MISSIONS AND UTILITY OF MAN-IN-SPACE

2.2 ON-ORBIT SERVICING - NEAR ORBITER

2.3 ON-ORBIT SERVICING - REMOTE FROM ORBITER

2.4 ON-ORBIT SERVICING - GEOSYNCHRONOUS

2.5 SPECIAL/SPECIFIC MISSION - SPACECRAFT/PAYLOADS

2.6 STATIONS AND PLATFORMS

2.7 TRANSPORTATION AND SUPPORT VEHICLES

2.8 ROBOTICS AND TELEPRESENCE

The following three charts present the suggested format wherein panel members addressed their respective sections. Also shown is the recommended extent (%) of effort for each subelement. Where practical, the outline has generally been followed with intent to standardize all subsections. As could be expected, the detailed technology roadmap has been most difficult to evolve, synthesize and integrate; as the workshop effort progresses and greater intra-panel interaction is achieved, it is expected that the basic technology roadmap will mature accordingly.

Continued

MILITARY MAN-IN-SPACE
SUGGESTED FORMAT - SECTION 2.0

PERCENT	TOPIC
1%	1.0 INTRODUCTION A. PURPOSE B. SCOPE C. RELEVANCE
5%	2.0 MISSION MODEL APPLICATION A. APPLICABILITY OF CURRENT MISSION MODEL (28+ X MISSIONS*) TO MANNED TECHNOLOGY B. UTILIZATION C. SUMMARY/RECOMMENDATIONS OR CONCLUSIONS
10%	3.0 REQUIREMENTS A. GENERAL MANNED TECHNOLOGY SUPPORT B. REQUIREMENT CATEGORIES • BASIC • DIRECT • DERIVED • REMOTE
10%	4.0 SYSTEM DEFINITION A. GENERAL SYSTEM(S) CONCEPT(S) THAT MANNED TECHNOLOGY SUPPORTS • IDENTIFICATION B. INTERRELATIONSHIPS OF SYSTEMS (e.g.) • MILITARY COMMAND POST & TRANSPORTATION • ROBOTIC SYSTEMS AND 'DIRECT' MANNED PARTICIPATION C. MATRIX OF GENERAL MANNED TECHNOLOGY(IES) VS SYSTEMS

MILITARY MAN-IN-SPACE
SUGGESTED FORMAT - SECTION 2.0 (Cont'd)

PERCENT	TOPIC
25%	5.0 TECHNOLOGY ITEMS A. IDENTIFICATION OF WHAT SPECIFIC MANNED TECHNOLOGY IS NEEDED TO SUPPORT WHAT SYSTEM(S) - (SECTION 4.0) B. CANDIDATE TECHNOLOGIES TO MEET NEEDS C. REPRESENTATIVE SELECTION CRITERIA TO APPLY AGAINST CANDIDATES D. RECOMMENDED TECHNOLOGY ITEMS
15%	6.0 GENERAL PERFORMANCE/CHARACTERISTICS A. IDENTIFICATION OF WHAT THE TECHNOLOGY FUNCTIONALLY DOES B. PERFORMANCE/CHARACTERISTICS • SIZE/MASS • OPERATIONAL RANGES • PERFORMANCE RANGES • SUPPORT (PWR/FUEL/SIGNAL, ETC.) • ENVIRONMENT • SENSITIVITIES/CONSTRAINTS/LIMITATIONS • OTHER
15%	7.0 TECHNOLOGY NEEDS/GOALS/OBJECTIVES A. WHAT DOES THIS TECHNOLOGY PROVIDE? • WHAT NEEDS FULFILLED FOR WHAT PROGRAMS/SYSTEMS • WHAT DISCRETE VS 'BIG PICTURE' GOALS/OBJECTIVES DOES THIS TECHNOLOGY MEET/ASSURE/AID B. MATRIX OF SPECIFIC TECHNOLOGY ITEMS VS PROGRAMS/SYSTEMS

Continued

The key MSSTM summary items are presented on the facing chart. Relative to the man-in-space panel, the following observations can be made:

A. The scope from Workshop I to II was increased greatly.

B. The role of military man-in-space is rapidly emerging; hence, requirements and needs are still evolving.

C. Security needs have frequently "slowed down" efforts, but these constraints were, are, and can be worked to facilitate development of meaningful outputs.

D. Greater I/F with the other panels would be even more beneficial.

E. There is a need (now and expanding) for military man-in-space and accordingly the associated technology.

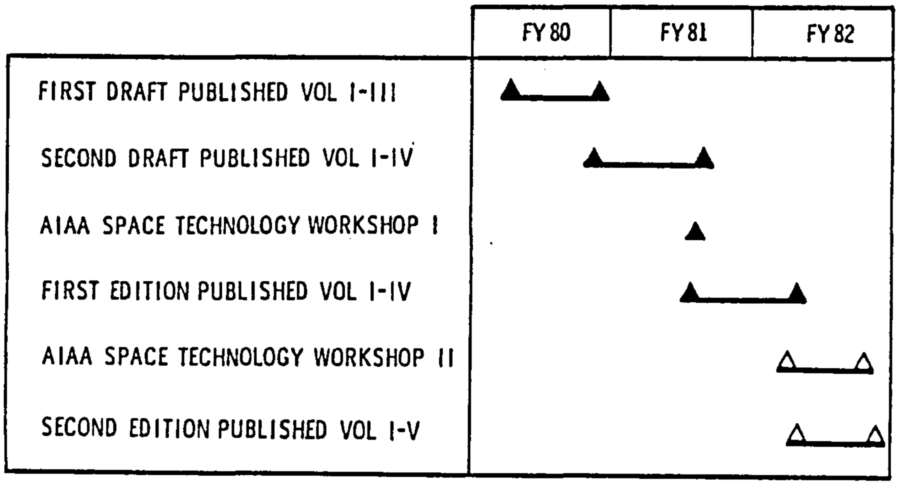
PERCENT	TOPIC
10%	8.0 SYSTEM/MISSION IMPACT ISSUES A. WHAT BASIC IMPACTS DO THESE CANDIDATE TECHNOLOGIES HAVE ON PLANNED SYSTEMS/MISSIONS/PROGRAMS • TIME TO DEVELOP VS AVAILABILITY NEED DATES • SIZE/MASS • POWER/FUEL/COOLING, ETC. • STOWED VS OPERATING ENVELOPE • DYNAMICS • CONTAMINATION • LOGISTICS/SERVICING • OTHERS B. MATRIX OF TECHNOLOGY ITEMS VS IMPACTS
10%	9.0 TECHNOLOGY ROADMAP A. TECHNOLOGY ITEM(S) FULL ROT & E SPAN B. MATRIX OF TECHNOLOGY INTERRELATIONSHIPS C. TECHNOLOGY ITEM(S) RELATED TO MAJOR NEEDS VS TIME (1985 - 2005) • SIMPLE BAR CHARTS D. TECHNOLOGY PRIORITIZATION • LIST • RATIONALE, IF APPLICABLE E. SUMMARY - 'BIG PICTURE'

Summary

- A MECHANISM (MSSTM) FOR ORGANIZED DEVELOPMENT OF TECHNOLOGY HAS BEEN PUBLISHED AND IS BEING REVISED AT SD
- MANY KEY TECHNOLOGIES ARE PURSUED VIGOROUSLY. NEW INITIATIVES ARE BEING ESTABLISHED
- CLOSE COOPERATION WITH AF LABS, DARPA, NASA, AND INDUSTRY
  - SD/AF LAB JOINT PLANNING GROUP
  - NASA/USAF SPACE RESEARCH AND TECHNOLOGY INTERDEPENDENCY WORKING GROUP
  - AIAA SPACE TECHNOLOGY WORKSHOPS
  - EIA SPACE ELECTRONICS CONFERENCE
- A SYSTEMATIC PROCESS INCORPORATING THE MSSTM IS BEING IMPLEMENTED AT SD FOR ESTABLISHING A STRONG TECHNOLOGY BASE FOR ADVANCED MILITARY SPACE SYSTEMS

As shown on the facing chart, Volumes I-IV have been published. The remaining volumes are at least in draft volume status and some 1st and 2nd editions are available. As illustrated, the second workshop is well underway. The initial man-in-space panel edited input will be submitted for the 20-23 September 1982 meeting at Kirtland AFB. Thus, inputs from this AF/AIAA panel will be available shortly-- possibly in time to be of value for this NASA (Human Role in Space) Workshop subsequent activities.

MSSTM Schedule



NASA OAST

PREVIOUS NASA WORKSHOP RECOMMENDATIONS

ON THE

ROLES OF AUTOMATION AND OF MAN IN SPACE

Stan Sadin

INCREASING COSTS AND MISSION COMPLEXITY LEAD NASA TO CONSIDER THE IMPACT AND NEED FOR AUTOMATION.

A LISTING OF NASA WORKSHOPS RELATED TO ROLES OF AUTOMATION AND MAN IN SPACE

BACKGROUND TO EARLY WORKSHOPS

- INCREASING MISSION COMPLEXITY AND DURATION CONTRIBUTES TO MAJOR INCREASES IN COST
- 1978 JPL STUDY SUGGESTS MAJOR SAVINGS IF TECHNOLOGY OF MACHINE INTELLIGENCE IS VIGOROUSLY RESEARCHED, DEVELOPED, AND IMPLEMENTED IN FUTURE MISSIONS
- AUTOMATION WOULD ALLOW NASA TO
  - REDUCE COST OF INFORMATION
  - ENABLE MORE COST EFFECTIVE MISSIONS
  - INCREASE OPERATIONAL PRODUCTIVITY
  - REDUCE COST OF SPACE TRANSPORTATION
  - ENABLE AFFORDABLE GROWTH IN SYSTEM SCALE

WORKSHOPS

NASA STUDY GROUP ON MACHINE INTELLIGENCE AND ROBOTICS	JUNE 1977 - DECEMBER 1978
WOODS HOLE NEW DIRECTIONS WORKSHOP #1 SELF REPLICATING SYSTEMS TOPIC	JUNE 1979
PAJARO DUNES SYMPOSIUM ON AUTOMATION AND FUTURE MISSIONS IN SPACE	JUNE 1980
ADVANCED AUTOMATION FOR SPACE MISSIONS WORKSHOP AT UNIVERSITY OF SANTA CLARA	JUNE 1980 - AUGUST 1980
WOODS HOLE NEW DIRECTIONS WORKSHOP #2 THE HUMAN ROLE IN SPACE SELF REPLICATING SYSTEMS CONTINUED	JUNE 1980

"FINDINGS

- GENERIC CHARACTERISTICS OF AN AGGRESSIVE SPACE EXPLORATION PROGRAM INCLUDE:

  - A MAJOR EARTH RESOURCES OBSERVATION PROGRAM
  - INTENSIVE EXPLORATION OF THE SOLAR SYSTEM AND BEYOND
  - MAJOR LOW-EARTH ORBIT ACTIVITIES REQUIRING THE CONTINUOUS PRESENCE OF MAN AS TROUBLESHOOTER, SUPERVISOR, AND OPERATIONS COORDINATOR
  - A SIGNIFICANT CAPABILITY FOR ACQUIRING AND UTILIZING NONTERRESTRIAL MATERIALS FOR PRODUCTS TO BE USED IN SPACE, SUCH AS LARGE STRUCTURES, POWER SYSTEMS, ANTENNAS, EXPENDABLES, AND SO FORTH
  - AN ADVANCED MOBILE COMMUNICATIONS SYSTEM (THE IMPORTANCE OF THIS PROGRAM ELEMENT WAS RECOGNIZED BY THE STUDY GROUP BUT WAS NOT ADDRESSED BY ANY OF THE SELECTED MISSION PROBLEMS SINCE THE AUTOMATION REQUIREMENTS WERE NOT CONSIDERED UNIQUE)

- ADVANCED AUTOMATION TECHNOLOGY IS ESSENTIAL FOR A MAJOR SPACE PROGRAM CAPABILITY"

"CONCLUSIONS AND RECOMMENDATIONS

- MACHINE INTELLIGENCE SYSTEMS WITH AUTOMATIC HYPOTHESIS FORMATION CAPABILITY ARE NECESSARY FOR AUTONOMOUS EXAMINATION OF UNKNOWN ENVIRONMENTS. THIS CAPACITY IS HIGHLY DESIRABLE FOR EFFICIENT EXPLORATION OF THE SOLAR SYSTEM AND IS ESSENTIAL FOR THE ULTIMATE INVESTIGATION OF OTHER STAR SYSTEMS.
- THE DEVELOPMENT OF EFFICIENT MODELS OF EARTH PHENOMENA AND THEIR INCORPORATION INTO A WORLD MODEL BASED INFORMATION SYSTEM ARE REQUIRED FOR A PRACTICAL, USER-ORIENTED, EARTH RESOURCE OBSERVATION NETWORK.
- A PERMANENT MANNED FACILITY IN LOW EARTH ORBIT IS AN IMPORTANT ELEMENT OF A FUTURE SPACE PROGRAM. PLANNING FOR SUCH A FACILITY SHOULD PROVIDE FOR A SIGNIFICANT AUTOMATED SPACE MANUFACTURING CAPABILITY.
- NEW, AUTOMATED SPACE MATERIALS PROCESSING TECHNIQUES MUST BE DEVELOPED TO PROVIDE LONG-TERM SPACE MANUFACTURING CAPABILITY WITHOUT MAJOR DEPENDENCE ON EARTH RESUPPLY.
- REPLICATION OF COMPLEX SPACE MANUFACTURING FACILITIES IS A LONG-RANGE NEED FOR ULTIMATE LARGE-SCALE SPACE UTILIZATION. A PROGRAM TO DEVELOP AND DEMONSTRATE MAJOR ELEMENTS OF THIS CAPABILITY SHOULD BE UNDERTAKEN.
- GENERAL AND SPECIAL PURPOSE TELEOPERATOR/ROBOT SYSTEMS ARE REQUIRED FOR A NUMBER OF SPACE MANUFACTURING, ASSEMBLY, INSPECTION AND REPAIR TASKS.
- AN AGGRESSIVE NASA DEVELOPMENT COMMITMENT IN COMPUTER SCIENCE IS FUNDAMENTAL TO THE ACQUISITION OF MACHINE INTELLIGENCE/AUTOMATION EXPERTISE AND TECHNOLOGY REQUIRED FOR THE MISSION CAPABILITIES DESCRIBED EARLIER IN THIS SUMMARY REPORT. THIS SHOULD INCLUDE A PROGRAM FOR INCREASING THE NUMBER OF PEOPLE TRAINED IN THE RELEVANT FIELDS OF COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE."

NASA SYMPOSIUM ON AUTOMATION AND FUTURE MISSIONS - PAJARO DUNES OAST

FINDINGS

- SIGNIFICANT AUTOMATED MISSIONS
  - VERY DEEP SPACE PROBES
  - ASTEROID RESOURCE RETRIEVAL
  - HAZARDOUS EXPERIMENT FACILITY
  - SELF-REPLICATING LUNAR FACTORY
- CRITICAL AUTOMATION TECHNOLOGIES
  - MACHINE VISION
  - MULTISENSOR INTEGRATION
  - LOCOMOTION TECHNOLOGY
  - MANIPULATORS
  - REASONING OR INTELLIGENCE
  - MAN-MACHINE INTERFACE

NASA NEW DIRECTIONS #1 - WOODS HOLE, 1979 OAST

CONCLUSIONS

- REPLICATING MACHINES MAKE POSSIBLE AMBITIOUS PROJECTS WITH REASONABLE RESOURCES
- IN PRACTICE AUTOMATED SYSTEMS OF DIVERSE COMPONENTS ARE NEEDED
- THE LONG R&D PROCESS WILL PRODUCE TECHNOLOGY FALLOUT FOR USE IN SPACE AND EARTH AT EACH STAGE OF DEVELOPMENT

RECOMMENDATION

- NASA SHOULD PROCEED WITH R&D IN
  - AUTOMATION
  - ROBOTICS
  - MACHINE INTELLIGENCE

" CONCLUSION 1. REPLICATING MACHINE SYSTEMS OFFER POSSIBILITY THAT NASA COULD UNDERTAKE AMBITIOUS PROJECTS IN SPACE EXPLORATION AND EXTRATERRESTRIAL RESOURCE UTILIZATION WITHOUT UNREASONABLE RESOURCES.

CONCLUSION 2. IN PRACTICE, APPROACH MIGHT NOT REQUIRE BUILDING TOTALLY AUTONOMOUS SELF-REPLICATING AUTOMATA, BUT RATHER ONLY A LARGELY AUTOMATED SYSTEM OF DIVERSE COMPONENTS WHICH COULD BE INTEGRATED INTO A PRODUCTION SYSTEM ABLE TO GROW EXPONENTIALLY.

CONCLUSION 3. SUCH SYSTEMS WOULD NECESSARILY COME AS THE RESULT OF A LONG PROCESS OF R&D IN ADVANCED AUTOMATION ROBOTICS AND MACHINE INTELLIGENCE WITH DEVELOPMENTS AT EACH STAGE FINDING WIDE USE ON EARTH AND IN SPACE.

RECOMMENDATION

BELIEVING THAT ROBOTICS, COMPUTER SCIENCE, AND THE CONCEPT OF REPLICATING SYSTEMS COULD BE OF IMMENSE IMPORTANCE TO THE FUTURE OF THE SPACE PROGRAM, THE WORKING GROUP RECOMMENDS THAT NASA PROCEED WITH STUDIES TO ANSWER FUNDAMENTAL QUESTIONS AND TO DETERMINE THE MOST APPROPRIATE DEVELOPMENT COURSE TO FOLLOW."

"FINDINGS

MISSIONS SIGNIFICANT TO NASA'S FUTURE AND DEVELOPMENT OF ADVANCED AUTOMATION TECHNOLOGY:

- VERY DEEP SPACE PROBE, HIGHLY AUTOMATED FOR SOLAR SYSTEM EXPLORATION, EVENTUALLY TO BE EXTENDED TO INCLUDE INTERSTELLAR MISSIONS CAPABLE OF SEARCHING FOR EARTH-LIKE PLANETS ELSEWHERE IN THE GALAXY.
- ASTEROID RESOURCE RETRIEVAL, INCLUDING ASTEROIDS, JOVIAN SATELLITES, AND LUNAR MATERIALS, USING MASS DRIVERS, NUCLEAR PULSE ROCKETS, AND SO FORTH FOR PROPULSION.
- HAZARDOUS EXPERIMENT ("HOT LAB") FACILITY, AN UNMANNED SCIENTIFIC LABORATORY IN GEOSTATIONARY ORBIT WITH ISOLATION NECESSARY TO SAFELY HANDLE SUCH DANGEROUS SUBSTANCES AS TOXIC CHEMICALS, HIGH EXPLOSIVES, RADIOISOTOPES, AND GENETICALLY-ENGINEERED BIO-MATERIALS.
- SELF-REPLICATING LUNAR FACTORY, AN AUTOMATED UNMANNED (OR NEARLY SO) MANUFACTURING FACILITY, CONSISTING OF PERHAPS 100 TONS OF THE RIGHT SET OF MACHINES, TOOLS, AND TELEOPERATED MECHANISMS TO PERMIT BOTH PRODUCTION OF USEFUL OUTPUT AND REPRODUCTION TO MAKE MORE FACTORIES.

CRITICAL ROBOTICS AND MACHINE INTELLIGENCE TECHNOLOGIES:

- MACHINE VISION CAPABILITIES, ESPECIALLY IN THE AREAS OF DEPTH PERCEPTION, MULTISPECTRAL ANALYSIS, MODELING, TEXTURE AND FEATURE, AND HUMAN INTERFACE
- MULTISENSOR INTEGRATION, INCLUDING ALL NONVISION SENSING SUCH AS FORCE, TOUCH, PROXIMITY, RANGING, ACOUSTICS, ELECTROMAGNETIC WAVE, CHEMICAL, AND SO FORTH
- LOCOMOTION TECHNOLOGY TO BE USED IN EXPLORATION, EXTRACTION PROCESSES AND BENEFICIATION, WITH WHEELED, TRACKED, OR LEGGED DEVICES UNDER TELEOPERATED OR AUTONOMOUS CONTROL
- MANIPULATORS, USEFUL IN HANDLING MATERIALS BOTH INTERNAL AND EXTERNAL TO THE MACHINE, GENERAL PURPOSE AND SPECIAL PURPOSE, TELEOPERATED OR FULLY AUTOMATIC
- REASONING OR INTELLIGENCE, INCLUDING LOGICAL DEDUCTIONS, PLAUSIBLE INFERENCE, PLANNING AND PLAN EXECUTION, REAL-WORLD MODELING, DIAGNOSIS AND REPAIR IN CASE OF MALFUNCTION
- MAN-MACHINE INTERFACE, INCLUDING TELEOPERATOR CONTROL, KINESTHETIC FEEDBACK DURING MANIPULATION OR LOCOMOTION, COMPUTER-ENHANCED SENSOR DATA PROCESSING, AND SUPERVISION OF AUTONOMOUS SYSTEMS."

MACHINE INTELLIGENCE AND ROBOTICS (SAGAN)

CONCLUSIONS RE NASA CAPABILITIES

- COMPUTER SCIENCE AND MACHINE INTELLIGENCE CONSERVATIVE AND UNIMAGINATIVE
- FIVE TO FIFTEEN YEARS BEHIND
- IMPORTANCE NOT APPRECIATED WITHIN AGENCY
- ADVANCES NEEDED FOR ECONOMICAL MISSIONS WILL NOT HAPPEN WITHOUT A MAJOR COMMITMENT

MACHINE INTELLIGENCE AND ROBOTICS (SAGAN)

RECOMMENDATIONS

- ADOPT POLICY OF VIGOROUS RESEARCH
- INTRODUCE ADVANCED COMPUTER SCIENCE INTO EARTH ORBITER AND PLANETARY MISSIONS
- DEVELOP A FLEXIBLE MISSION OBJECTIVE TO TAKE ADVANTAGE OF TECHNOLOGICAL OPPORTUNITIES
- INSTITUTE A PLAN OF ACTION
  - HEADQUARTERS FOCUS
  - ADVISORY AUGMENTATION
  - DOD LIAISON
  - TASK GROUP ON INTELLIGENT COMMUNICATIONS

THE NEXT SERIES OF CHARTS HIGHLIGHT THE RESULTS OF THE VARIOUS WORKSHOPS. THE HIGHLIGHTS ARE EXTRACTED FROM THE REPORTS OF THE WORKSHOPS. VERBATIM QUOTES FROM THE REPORTS ARE LISTED ON THE FACING PAGES BELOW:

"CONCLUSION 1. NASA IS 5 TO 15 YEARS BEHIND THE LEADING EDGE IN COMPUTER SCIENCE AND TECHNOLOGY.

CONCLUSION 2. TECHNOLOGY DECISIONS ARE, TO MUCH TOO GREAT A DEGREE, DICTATED BY SPECIFIC MISSION GOALS, POWERFULLY IMPEDING NASA UTILIZATION OF MODERN COMPUTER SCIENCE AND TECHNOLOGY. UNLIKE ITS PIONEERING WORK IN OTHER AREAS OF SCIENCE AND TECHNOLOGY, NASA'S USE OF COMPUTER SCIENCE AND MACHINE INTELLIGENCE HAS BEEN CONSERVATIVE AND UNIMAGINATIVE.

CONCLUSION 3. THE OVERALL IMPORTANCE OF MACHINE INTELLIGENCE AND ROBOTICS FOR NASA HAS NOT BEEN WIDELY APPRECIATED WITHIN THE AGENCY, AND NASA HAS MADE NO SERIOUS EFFORT TO ATTRACT BRIGHT, YOUNG SCIENTISTS IN THESE FIELDS.

CONCLUSION 4. THE ADVANCES AND DEVELOPMENTS IN MACHINE INTELLIGENCE AND ROBOTICS NEEDED TO MAKE FUTURE SPACE MISSIONS ECONOMICAL AND FEASIBLE WILL NOT HAPPEN WITHOUT A MAJOR LONG-TERM COMMITMENT AND CENTRALIZED, COORDINATED SUPPORT."

"RECOMMENDATION 1. NASA SHOULD ADOPT A POLICY OF VIGOROUS AND IMAGINATIVE RESEARCH IN COMPUTER SCIENCE, MACHINE INTELLIGENCE, AND ROBOTICS IN SUPPORT OF BROAD NASA OBJECTIVES.

RECOMMENDATION 2. NASA SHOULD INTRODUCE ADVANCED COMPUTER SCIENCE TECHNOLOGY TO ITS EARTH ORBITAL AND PLANETARY MISSIONS, AND SHOULD EMPHASIZE RESEARCH PROGRAMS WITH A MULTIMISSION FOCUS.

RECOMMENDATION 3. MISSION OBJECTIVES SHOULD BE DESIGNED FLEXIBLY TO TAKE ADVANTAGE OF EXISTING AND LIKELY FUTURE TECHNOLOGICAL OPPORTUNITIES.

RECOMMENDATION 4. NASA SHOULD ADOPT THE FOLLOWING PLAN OF ACTION:

(a) ESTABLISH A FOCUS FOR COMPUTER SCIENCE AND TECHNOLOGY AT NASA HEADQUARTERS FOR COORDINATING R&D ACTIVITIES.

(b) AUGMENT THE ADVISORY STRUCTURE OF NASA BY ADDING COMPUTER SCIENTISTS TO IMPLEMENT THE FOREGOING RECOMMENDATIONS.

(c) BECAUSE OF THE CONNECTION OF THE DEFENSE MAPPING AGENCY'S (DMA) PILOT DIGITAL OPERATIONS PROJECT WITH NASA INTERESTS, NASA SHOULD MAINTAIN APPROPRIATE LIAISON.

(d) NASA SHOULD FORM A TASK GROUP TO EXAMINE THE DESIRABILITY, FEASIBILITY, AND GENERAL SPECIFICATION OF AN ALL-DIGITAL, TEXT-HANDLING, INTELLIGENT COMMUNICATION SYSTEM."

NASA ADVANCED AUTOMATION FOR SPACE - SANTA CLARA OAST

FINDINGS

- ADVANCED AUTOMATION TECHNOLOGY IS ESSENTIAL
- MANY LOW EARTH MISSIONS REQUIRE CONTINUOUS PRESENCE OF MAN
  - TROUBLE SHOOTER
  - SUPERVISOR
  - OPERATIONS COORDINATOR
- A PERMANENT MANNED FACILITY IS AN IMPORTANT ELEMENT OF A FUTURE SPACE PROGRAM
- TELEOPERATOR/ROBOT SYSTEMS ARE REQUIRED FOR SPACE MANUFACTURING, ASSEMBLY, INSPECTION AND REPAIR TASKS

RECOMMENDATION

- AN AGGRESSIVE DEVELOPMENT COMMITMENT IN COMPUTER SCIENCE, MACHINE INTELLIGENCE, AND AUTOMATION

NASA ADVANCED AUTOMATION FOR SPACE - SANTA CLARA OAST

FINDINGS

- ADVANCED AUTOMATION TECHNOLOGY IS ESSENTIAL
- MANY LOW EARTH MISSIONS REQUIRE CONTINUOUS PRESENCE OF MAN
  - TROUBLE SHOOTER
  - SUPERVISOR
  - OPERATIONS COORDINATOR
- A PERMANENT MANNED FACILITY IS AN IMPORTANT ELEMENT OF A FUTURE SPACE PROGRAM
- TELEOPERATOR/ROBOT SYSTEMS ARE REQUIRED FOR SPACE MANUFACTURING, ASSEMBLY, INSPECTION AND REPAIR TASKS

RECOMMENDATION

- AN AGGRESSIVE DEVELOPMENT COMMITMENT IN COMPUTER SCIENCE, MACHINE INTELLIGENCE, AND AUTOMATION

"CONCLUSIONS

- THE PRESENCE OF HUMAN BEINGS IN SPACE IS INEVITABLE WHETHER PRESENT DEFINITIONS OF THEIR ROLE ARE CLEAR OR WHETHER CURRENT COST ESTIMATES TO USE THEIR UNIQUE CAPABILITIES IN SPACE MISSIONS CAN BE JUSTIFIED OR NOT.

- A NUMBER OF SPACE EVENTS COULD RAISE THE PUBLIC CONSCIOUSNESS TO ONE WHICH DEMANDED IMMEDIATE ACTION FROM THE SPACE COMMUNITY. WHETHER SUCH A REACTION, GENERATED FROM EXTERNAL EVENTS OR US SPACE ACCOMPLISHMENTS, PROVIDED A STRONG MOTIVATION OR NOT, NASA SHOULD CONCENTRATE ITS EFFORTS TO BE PREPARED TECHNOLOGICALLY FOR SUCH A RESPONSIBILITY.

RECOMMENDATIONS

- A PERMANENT ORBITING MANNED PLATFORM PROGRAM SHOULD BE DEFINED AND PURSUED IN INCREMENTS OR AS A TOTAL PROGRAM TO AUGMENT THE UTILITY OF THE CURRENTLY PLANNED SPACE TRANSPORTATION SYSTEM. THIS PLATFORM CAN PROVIDE A BASE FOR A MULTIPLICITY OF EXPERIMENTS, INCLUDING LARGE STRUCTURE ASSEMBLY, SATELLITE MAINTENANCE AND REFUELING, SUPPORT TO HIGH ORBIT AND OUTER SPACE MISSIONS, AND A DEPOT FOR PAYLOADS TO BE ORBITED OR TO BE RETURNED TO EARTH BY THE SHUTTLE.

- A STUDY SHOULD BE INITIATED, SUPPLEMENTED AS DEEMED FEASIBLE BY EARTH OR ORBITAL BASED EXPERIMENTS, TO DEFINE THE SIZE AND CHARACTER OF A SELF SUFFICIENT SPACE COMMUNITY BASED IN LOW EARTH OR SYNCHRONOUS ORBITING SPACE STATIONS, LUNAR ORBITING STATIONS, OR ON THE SURFACE OF THE MOON, THE OUTER PLANETS, OR ON A SUITABLE ASTEROID. THIS KIND OF STUDY COULD PROVIDE THE INCENTIVE AND DIRECTION FOR MANY MORE LIMITED EXPERIMENTS TO BUILD THE DATA BASE ON WHICH FUTURE MISSIONS COULD RATIONALLY BE PLANNED."

THE OVERALL IMPACT OF PRIOR WORKSHOPS

NASA HUMAN ROLE IN SPACE - WOODS HOLE OAST

CONCLUSIONS

- PRESENCE OF HUMANS IN SPACE IS INEVITABLE
- A NUMBER OF EVENTS COULD DEMAND ACTION AND NASA SHOULD BE TECHNOLOGICALLY PREPARED

RECOMMENDATIONS

- DEFINE A PERMANENT ORBITING MANNED PLATFORM PROGRAM

NASA IMPACT SUMMARY OF PRIOR WORKSHOPS OAST

- EARLY EMPHASIS ON AUTOMATION TO REDUCE COSTS WITH MINOR CONSIDERATION OF MAN'S ROLE
- RECONSIDERATION OF MAN'S ROLE IN SPACE SERVED AS A CATALYST FOR A MANNED PLATFORM THRUST
- AUTOMATION WILL FREE MAN TO DO MORE HUMAN TASKS
- WORKSHOPS SERVED AS A CATALYST FOR PROGRAM AND BUDGET INCREASES IN COMPUTER SCIENCE AND AUTOMATION

HUMAN BEHAVIOR IN SPACE ENVIRONMENTS:

A RESEARCH AGENDA

Joseph V. Brady, Ph.D.

Professor of Behavioral Biology

Johns Hopkins University School of Medicine

It is the purpose of this report to summarize the purposes, proceedings, and research perspectives which emerged as a result of a conference held at Williamsburg, Virginia in November, 1980 under the sponsorship of the Life Sciences Division of the National Aeronautics and Space Administration. The conference was organized in response to a perceived need to accelerate and expand behavioral and biological research in so far as such investigative initiatives were required to enhance an essential space science and technology support base. The participants, assembled largely from the ranks of academic and NASA life scientists, addressed their attention to the identification of critical knowledge areas and to the ordering of investigative priorities focused upon human behavior in space environments. The most tangible product of those interactions is a report entitled "Human Behavior in Space Environments: A Research Agenda", now completed, for all practical purposes, but not quite hot-off-the-press. In a matter of weeks, it should be ready for distribution.

The basic question-raising format of the meeting evolved as a consequence of group consensus, and an appropriate universe of analysis was delineated within the framework of three broad aspects of behavior-in-space inquiry. 1) Definition of the information domain - what knowledge is needed? 2) Assessment of the existing data base - how much knowledge is available? 3) Identification of the remaining knowledge gaps - where is additional knowledge needed? An empirical orientation was adopted with emphasis upon experimental questions framed in terms of operationally defined procedures and measurable outcomes as an essential prerequisite to the generation of new and generalizable knowledge. This vital first step of asking the right questions was considered a necessary basis for the development of an investigative agenda, and the ensuing discussions focused upon five substantive research areas of obvious relevance:

1. Selection, Training, and Organizational Functions

2. Physiological Adaptation and Stability

3. Operational Performance and General Living Requirements

4. Conceptual and Methodological Approaches to Long-Term Research Requirements

5. General Implementation Considerations

1. SELECTION, TRAINING, AND ORGANIZATIONAL FUNCTIONS

Along with unparalleled advances in the physical science and technology data base, the hallmark of space flight initiatives to date has been the thorough and comprehensive planning for human participation in these momentous events. A major feature of these preparations has been the broad and systematic efforts to investigate human capabilities and limitations with a view to appropriate selection of candidates for such space missions. The selection of military and test pilots during the first stage of this development predetermined the standards of physical health and behavioral adjustment judged appropriate on the basis of strictly "expert" opinion. Clearly, the success of these early missions testifies to the efficacy of this "space medicine" approach. But the demands of longer and more routine missions under conditions which do not provide the superordinate challenge to succeed in pioneering a new frontier will doubtless require a more scientifically based personnel assessment approach. Selection methodologies will have to be concerned not only with broadly defined physical and behavioral health characteristics but with those interpersonal factors which are certain to assume increasing importance as determinants of both individual and group performance effectiveness during extended space occupancy. Gurovskiy and Novikov (1981) have recently reviewed the Russian literature and research activities in the development of screening procedures for such purposes.

Of immediate importance and continuing concern, however, would seem to be the preselection problems associated with developing predictive indices differentiating between individuals with adaptive and maladaptive responses to zero gravity conditions. Contemporary approaches to the prediction of successful physiological adaptation to exercise training (e.g., in heart disease patients) may provide appropriate models for analyzing the complex behavioral-physiological interactions which are likely to be involved in predicting weightlessness adaptability. There is, of course, a somewhat broader concern with the prescreening of individuals whose physical and behavioral status will place them at high risk under stressful environmental conditions and interactive social circumstances. The obvious theoretical and practical importance of this problem has long been recognized, and despite extensive investigative attention in areas both related and unrelated to space flight needs, the development of valid and reliable predictive techniques remains an elusive goal.

Of potentially even greater complexity and broader long range significance would seem to be the problems associated with the selection, training, and organizational structure of individuals and groups involved in long-term space-related operations and performance functions. Unfortunately, there has been little in the way of systematic research either on group composition or performance evaluation from a behavioral perspective in this critical domain beyond the "screening out" of potentially aberrant individuals. But the contents of a recently translated volume on "Psychological Problems of Spaceflight" (Petrov et al., 1979) from Soviet sources suggest that concerns about behavioral matters may be more central, both from operational and research perspectives, in the USSR than in the USA space programs. One persistent problem of common interest to which the Soviets have obviously turned their attention as well, concerns the "command structure" and the merits of "strict distribution of duties and responsibilities" while "refraining from absolute emphasis on a hierarchical structure for a crew consisting of 2-3 people, and erasure of the concept of commander".

Under any circumstances, it now seems clear that the stage is set for extending a research analysis of interrelated selection, training, and organizational problems to include such issues as:

a) optimization of matches between specific tasks and assigned group members -- considerations regarding individual past histories, relevant strengths and weaknesses, detailed task analyses.

b) cross-training of individual group members -- considerations regarding redundancy and task criticality, compromise of individual proficiency on given tasks, trade-offs with regard to the time required for group readiness.

c) fixed or rotating assignment choices involving group members -- considerations regarding the maintenance of fixed group membership or rotating personnel among groups, common tasks with interdependent functions or groups with independent member assignments.

d) optimization of system automation (i.e., computerization) -- considerations regarding mission programming and/or manual control of space flight operations.

Over the past two decades, significant advances in two areas of major importance suggest that a timely marriage between basic and applied aspects of an existing knowledge base can markedly enhance selection and training capabilities in support of essential space-related performances. At a basic level, the experimental behavior laboratory has provided a more fundamental understanding of the conditions under which complex performance repertoires can be analyzed, generated and maintained in strength over extended time intervals. And from a more applied perspective, the developing sophistication in computer-based simulation research promises an experimental approach which replicates the requirements of operational settings with remarkable fidelity. Within the framework of these conceptual and empirical advances, a range of critical questions can be addressed experimentally and empirically as they relate to methodological refinements in procedures for analyzing task requirements, for rapid skill acquisition, and defining overload limits, for optimal group training to specified skill levels in differentiated tasks, and for determining criteria of maintenance under conditions which involve essential but rarely exercised skills (e.g., emergency performances).

2. PHYSIOLOGICAL ADAPTATION AND STABILITY

By far the most imminent and critical concerns in ordering research priorities related to human space flight and extended occupancy continue to be associated with the problems of short-term physiological and behavioral adaptation to zero gravity and the maintenance of long-term stability under such weightless conditions. Beyond the preselection of space flight participants for weightlessness adaptability and the development of physical preconditioning procedures, the broader concerns associated with maintaining in-flight adjustments and long-term stability would seem to require an investigative focus upon environmental and behavioral factors as they interact with such physiological adaptations. As a case in point, it can be assumed that we know considerably less than we think we know about the behavioral physiology of weightlessness in relationship to the identifying features and performance consequences of zero-gravity disturbances. The verbal reports of physiologically untrained (for the most part) observers, with an obvious stake in maintaining their "can-do" image in the eyes of the flight surgeons and ground controllers have evident limitations, particularly as they may reflect upon performance effectiveness. Under the circumstances, the first order of business in the space-related behavioral physiology research agenda would seem to be the development of more valid and reliable methods for observing and recording the effects of weightlessness upon such complex processes. Among the more promising approaches to be studied experimentally in this regard is the trained participant observer provided with a specifically operational language history appropriate to the required correlation tasks involving such behavioral-physiological interactions.

Second in importance only to the requirement for collecting valid and reliable information about the physiological and behavioral effects of zero-gravity environments is the research, development, and refinement of procedures for physiological self-regulation which presently appear to hold promise for providing some measure of control over the changes associated with weightlessness. Of perhaps great potential utility in this persistently troublesome area of space sickness may be the behavioral biofeedback procedures for developing active self-regulatory control of visceral, somatomotor, and central nervous system processes which are now being widely investigated in research laboratories throughout the world and broadly applied in a range of clinical settings. Current research applications of these biofeedback procedures in the control of motion/space sickness by Cowings at the NASA Ames Research Center in Moffett Field, California have shown that such training can suppress motion sickness symptoms under a range of challenge conditions (e.g., Coriolis acceleration, optokinetic stimulation, etc.), and that there are distinct differences in autonomic activity patterns between high and low motion-sickness susceptible individuals.

The relevance to space biology of developments over the past decade in the application of laboratory behavior analysis principles and procedures to the treatment, management, and prevention of medical disorders may also be worth emphasizing. The emergent field of "behavioral medicine", as this rapidly expanding interdisciplinary area has come to be known, can be seen to have its origins in the technological application of basic science advances in two major areas of direct relevance to space physiology and medicine. In the first instance, operational procedures have been specified for the interactive control of visceral, somatomotor, and central nervous system processes based upon explicity arranged relationships between observed physiological changes and programmed environmental events. And the second significant development of relevance to emerge from the basic science laboratory over the past two decades has provided operational definition of explicit learning procedures for the establishment, maintenance, and modification of behavioral interactions demonstrably related to individual and group health status (e.g., contingency management of medication compliance, exercise, diet, smoking cessation, etc.). In addition to the development of biofeedback interventions for the direct modification of potentially harmful physiological responses, the emergence of specialized techniques for enhancing self-control and self-management within the context of behavioral medicine applications would seem of considerable relevance to space physiology and space medicine.

The extent to which such behavioral interventions can be usefully applied in the treatment, management, and perhaps most importantly, the prevention of maladaptive physiological changes remains to be fully illucidated, but the evidence to date strongly suggests that at least with respect to these "risk-factor-reduction" efforts, advantageous alterations in health-related environmental interactions can be both effective and durable. Certainly, the importance of these developments and the need for an expanded research effort on the incorporation of appropriate health maintenance behaviors as an integral part of space crew performance requirements is emphasized by the limited availability of "on board" medical facilities for definitive management of physiological dysfunctions, on the one hand, and the serious ramifications of space mission effectiveness of illness-compromised crew capabilities, on the other. The recent closely-related focus on behavioral medicine applications in the area of adherence to prescribed treatment or maintenance regimens (now recognized as probably the single greatest deterrant to effective delivery of health care) can also be seen as directly related to potential biomedical problems in physiological adaptation to space environments. Clearly, research on the integration of these demonstrably effective behavior control methodologies for enhancing compliance within the context of ongoing space mission requirements will doubtless assume increasing importance as the heterogenity of space crews and the duration of space missions compound the remoteness in time and distance of ground control supervisors and care-givers.

In many respects, the potential of behavioral applications in space physiology and medicine may be most effectively and expeditiously assessed in so-called "stress" management, an area comprising aspects of both prevention and treatment. A variety of research initiatives in this critical "stress" managment area have suggested the importance of monitoring social interactions, physiological indicators (e.g., heart rate, skin conductance), and even vocal analysis, while biofeedback and relaxation techniques have been emplored either as treatment interventions or prophylactic countermeasures to reduce the risk of behavioral disruption. Clearly, however, the research data base in this crucial domain must be expanded to define more precisely the ways in which various physiological, and both verbal and non-verbal performance measures interrelate under such stressful conditions to disrupt ongoing behavioral interactions and to provide clues to effective countermeasures.

Two additional areas of currently active research investment involving biological rhythms and performance, in the first instance, and drugs and behavior, in the second, can be seen to bear importantly upon the development of effective approaches for enhancing physiological adaptation and stability in space environments. It is clear, for example, that careful circadian scheduling could be of the utmost operational significance, since a growing literature continues to document the intimate relationship between behavioral interactions and such biological rhythms.

And the extent to which pharmacological interventions can be of benefit in the management of these space-related adaptational problems remains to be empirically determined, though a rapidly expanding behavioral pharmacology data base suggests that judicious applications of selected drug-performance interaction principles, well-established in both laboratory and clinical settings, may have considerable potential for stabilizing adjustment levels under a range of difficult environmental circumstances.

3. OPERATIONAL PERFORMANCE REQUIREMENTS AND GENERAL LIVING CONDITIONS

Beyond the necessity of developing scientifically based personnel selection and training procedures as well as methods for insuring long-term physiological stability under conditions of extended space occupancy, questions regarding the optimal arrangement of environmental and behavioral factors influencing operational performance requirements (i.e., mission objectives) and general living accommodations (i.e., biological, personal, and social needs of human space-mission participants) must address perhaps the most complex and enduring range of unknowns to confront the research agenda for an expanding space age. The characteristics of the spacecraft imposes certain "givens" on the analysis of operational performance requirements and general living conditions while at the same time providing opportunities for design and construction in accordance with the continuing development of "human engineering" principles and knowledge. An evident priority in this regard is the design requirements imposed by the weightlessness burden, and the pronounced alteration of the environment in which humans ordinarily exist and perform caused by the absence of gravity. One of the most important research questions requiring early resolution in this regard concerns whether it is suitable to adapt to the absence of vertical orienting under such gravity-free conditions or whether it is more efficient from the performance perspective to provide for an artificial vertical in the spacecraft design. The broader relevance of the specific vertical orientation problem to operational performance requirements bears upon the ability of flight participants and long-term occupants to make sensory and perceptual discriminations in space environments, both inside and outside the transport vehicle, and upon the timeliness and accuracy of such behavioral interactions as a critical determinant of mission success.

As the focus of concern shifts from such basic sensory, motor and perceptual functions (and fundamental interactions involving the physical features of space environments) to more complex aspects of behavior commonly identified (though seldom operationalized) with the terms "cognition", "motivation", "emotion", and the like, considerations involving the social environment become critical. Interpersonal factors and group process considerations continue to loom large in prioritizing the research agenda as they relate to both the physical setting and the social milieu of space environments -- small, inescapable, and invariant, at least for the forseeable future. The interactions between "structural" and "social" factors is most likely to be manifest in considering such vital relationships as command and control functions among mission participants, and their determination by relative proximity and access to decision makers and vital instrumentation. The potential contribution of such physical arrangements to the social structure of the crew, group cohesion, morale, individual job satisfaction, and ultimately, successful mission accomplishment can not be overlooked, and must be considered in developing a research data base in support of both short- and long-term space initiatives. Of no less importance is the accomodation of leisure time activities and needs for individual privacy as they relate to flight durations, crew size, and physical living space as determinants of health and general well-being.

But perhaps the matter of highest priority in this operational performance and general living requirements domain for which emerging behavioral research technologies may hold the most promise for developing a substantive data base over the next two decades is the careful, systematic, and intensive experimental analysis of social structure in small groups or confined microsocieties. The range of pertinent issues encompasses such traditional problem areas as decision-making, leadership styles, disciplinary models, and group process, among others. The range of variables which have been shown to interact with such contingencies as they affect group social patterns, cohesion, and performance include the appetitive or aversive properties of controlling consequences, as well as the structural and functional properties of the group (e.g., composition, membership change, etc.) in relationship to such operationally relevant matters as individual rotation, substitution, and replacement. From the broader perspective of essential interactions between performance and living schedules in the confined small group residential setting dictated by at least the short-term requirements of space flight and occupancy over the next two decades, the immediate extension and application of existing behavior analysis principles would seem to represent an important operational research priority. Relevant applications of such research-based technologies would involve the development of empirical approaches to the structuring of viable systems for productive performance schedules and general living conditions within the necessarily confined microsocieties of at least near-term space missions. The pervasive issues which surround organization of the spacecraft internal "economy" clearly require an empirically testable, structured approach based upon principles which insure effective behavioral interactions even under conditions which require tedious or repetitious individual and group performance schedules. Under such circumstances, research on the refinement and application of contingency management procedures in accordance with emergent experimental analysis principles relevant to the behavioral programming of appetitive and aversive environmental consequences in confined microsociety settings would seem to take on ever increasing importance.

4. CONCEPTUAL AND METHODOLOGICAL APPROACHES TO LONG-TERM RESEARCH REQUIREMENTS

The nature and extent of long-term space initiatives are obviously problematic issues which involve important political, fiscal, and scientific/engineering considerations. Since specific requirements and time schedules are difficult to determine under such circumstances, the emergent imperatives of human behavior research in support of long-term space occupancy would seem best served by the development of conceptual and methodological approaches which are heuristic and productive of investigative innovation. Despite uncertainties associated with the behavioral requirements of space laboratories, work stations, interplanetary probes, and settlements beyond the earth's atmosphere, a common feature of these diverse endeavors will be extended time intervals involving confinement of human participants in extraterrestial habitats. A primary focus of conceptual and methodological concerns must then be upon the development of research-based technological, organizational, and sociological support of the human behavioral repertoire under such circumstances.

Beyond the somewhat narrower considerations of space craft design and specific scheduling of human performance and leisure requirements discussed in previous sections of this report, the interactive physical and behavioral features of the environment must provide for configuration of the sociopolitical organization of space-dwelling groups. The solution to this problem will doubtless depend upon input from many scientific disciplines and upon several levels of conceptual and methodological analysis. Initial expeditionary efforts have always been characterized by authoritarian structure because of serious environmental hazards, uncertainties, and minimum provisioning found in such undertakings. So it will probably be for the foreseeable future with space exploration. The frequent sequelae of such expeditions, however, are the establishment of extended or permanent settlements and the eventual evolution of independence. The evolving relationship between the "senders" and "sent" is the fountainhead for the evolution of social structure and governmental policy as it exists in empire, colony, and emergent independent states. The process has filled history books with a major portion of human activity and suffering throughout time. Formal programs of investigation to understand this evolution and the dynamics of social organization, as influenced by internal and external group contingencies, must be a major subject matter requiring extended research.

The complexities of such research initiatives which must take into account a wide variety of possible space settlements are obviously imposing. The conceptual and methodological problems associated with designing, establishing, and maintaining such functional human and ecological systems would seem to require, in the first instance, an approach at the most fundamental scientific level, with subsequent work moving toward more complex situations on the basis of accumulated data. What must ultimately be determined is how to maintain a synthetic behavioral ecosystem. This requires at a minimum a specification of how individuals' social and non-social environments control their behavior. Once specified, this can be used to synthesize an environment which will reliably produce and maintain appropriate repertoires with respect to other members of the social environment, life support systems, and work activities. The development of such a technology would be facilitated by a research methodology which provided for simulations of expected environmental conditions and the systematic experimental analysis of behavioral interactions over extended time periods. The conceptual framework and methodological approach to the management of behavioral ecology emerging within the context of such an analytic and synthetic orientation would be explicitly experimental in nature, dictated by both scientific and pragmatic considerations, and closely approximate procedures of established effectiveness in other areas of natural science.

Developments over the past several decades in the joint disciplines of experimental and applied analysis, which together have given detailed attention to the controlling relations between the environment and behavioral interactions, provide an operational approach to solving many, if not all, of the methodological problems which have constrained previous studies in this critical domain. The inductively derived principles which have resulted provide a generalized operational account of the observable, manipulable, and measurable antecedent and consequent environmental events that bear functional relations to the behavior of both individuals and groups. Such controlling antecedent and consequent environmental relations are termed contingencies of reinforcement and by their systematic manipulation, behavior can be demonstrated to change in orderly ways. Experimental analysis based upon these contingency management procedures has been shown to have widespread success in, and reliability for, the control of behavior across both phyletic lines and behavioral repertoires from the simple to the complex. Optimal control over important variables should be complemented with high accuracy of measurement under human laboratory conditions to pursue major research questions with widely varying goals using the species of primary interest without sacrifice of methodological rigor. An extensive research literature developed in several inter-related areas of behavior analysis over the past two or three decades can be seen to make contact with critical relations between the behavior of individuals and groups, with analysis of contingencies of reinforcement, with behavioral economies, response distribution, and with the effects of behavioral programs and their relations to economic systems. Initial success in space ventures will depend largely on a precise knowledge of what behaviors are required and how to occasion and maintain them within individuals. Without an experimentally derived functional account of individual behavioral variability, a natural science of behavior cannot exist . Without a natural science of behavior, the social sciences will necessarily remain in their current status as disciplines of less than optimal precision or utility.

Whatever the resolution of the methodological/technological research issues suggested by this account, a functional analysis of human performances as observable interactions between the environment and the individual is essential, and should provide an operational account of behavior change in a manner similar to the way in which Darwin's theory of natural selection accounted for the evolution of phylogenic lines (i.e., in discriptive, non-teleological terms). Similarly, as Darwin's account has been subsequently shown to be consonant with information obtained at the cellular level, so too should behavior principles ultimately prove to be in accord with an account of ontogenic adaptation at a biochemical level. Such a synoptic relational account suggests that there are common behavioral and environmental processes underlying both the active and reactive interactions between organisms and their environments and that these processes constitute the fundamental features of ontogenic behavioral selection at a functional level of analysis.

5. GENERAL IMPLEMENTATION CONSIDERATIONS

Perhaps the most fundamental and pervasive problems associated with the implementation of space research initiatives in general, and of a behavior-in-space research agenda in particular, emanate from the need to generate and maintain a strong societal support base for the substantial investment required. In more operational terms, this translates into the need for promoting, establishing, and enhancing a vigorous funding effort over the considerable time periods essential to the full realization of space exploration potentials in the face of year to year vagaries in budgetary commitments and the electoral temperament. Despite the overwhelming evidence of scientific and technological achievements which have provided strong foundations for space developments of great promise, we are confronted by deep doubts, timid commitments, and uncertain political priorities. Nothing less than a major educational research effort is required to bring to bear behavioral science expertise upon the enhancement of communication and assessment capabilities for stimulating and rewarding the citizenry for the contributions it will be required to make in this noble (and most certainly profitable) venture.

A second issue of no less import in view of the relative expense and difficulty involved in the implementation of a long-range behavioral research agenda in space environments is the requirement that investigative initiatives be of the highest quality and that they focus on broad issues of widespread interest to the scientific community. At present, the number of behavioral scientists prepared to take advantage of space environments as a setting for the advancement of generalizeable knowledge in this crucial field is relatively small compared, for example, to the physical sciences. And the number of investigators with skills and competences in the experimental analysis of behavior who are actually involved in space-related research efforts and who understand the problems and requirements for present and future studies of human behavior in space environments is even smaller. Clearly, strenuous efforts must be made not only to aquaint behavioral scientists with the opportunities presented by space research, but to formalize programmatic efforts to reward those whose initiatives must be the foundation for an accelerated and expanded effort to provide the essential space behavior science and technology support base.

Beside the obvious need for increased behavioral research funding support, provision must be made for a wider and more flexible base for scientific advice in the behavioral sciences by enlarging the responsibilities of advisory groups beyond the traditional process of grant review, and providing opportunities for informing such groups about the special problems of space research. An extension of the fuctional role of such advisory panels would envision not only the review and evaluation of individual research proposals, but participation in the assembly of larger collaborative studies involving multiple groups of investigators. Indeed, the most effective way to encourage broad support of space research efforts by the behavioral science community is to insure their participation in the planning, development, execution, and evaluation of all behavioral experiments, both in ground-base and space-flight settings, in the interest of optimizing the scientific yield and operational success of such investments.

To some considerable extent at least, the general lack of behavioral science impact on space research initiatives to date can be attributed to the characteristically narrow, oversimplified actuarial approach of the social and psychological disciplines with their traditional emphasis upon statistical significance, often at the expense of biological relevance. But there appear to be other factors as well which have compromised, and will continue to compromise, the potentially critical contributions of behavioral research to the long term requirements of human space environments unless countermeasures are considered. In the first instance for example, the very success of manned missions to date with little behavioral science input does not encourage operational integrations involving human performance and adjustment research outcomes even though higher levels of achievement might be obtained under such circumstances and, more critically, past success is no guarantee of future success in these regards. There is also the traditional reluctance of operational peronnel to look with favor upon the outcome of research they did not commission, particularly when the analyses in question suggest future problems in the absence of previous difficulty. And, the fact that not much behavioral research has been initiated directly by operational personnel compounds the ignorance of investigators within this domain as to just what space research issues and problems their experimental contributions may be relevant.

An effective response to these implementation problems would, of necessity, involve an integration of behavioral science concerns throughout the organizational fabric of the space program in order to insure the planning, accomplishment, and utilization of appropriate investigative initiatives in this important domain. Operations and managerial personnel, the ultimate consumers, should be party to the behavioral research planning, and there should be encouragement of direct communication between investigators and consumers throughout the course of the research. Channels of communication must be established and maintained between and among investigators so that the behavioral scientists involved can determine how their own work relates to that of others and to the entire programmatic effort. And finally, more formal communication mechanisms should be established between behavioral science investgators and operational personnel to review the outcomes and implications of completed research. Such formal mechanisms would ensure awareness of such research efforts and their outcomes, implications, and significance, while at the same time providing feedback to the behavioral science community about the perceived utility of such research and the fact that operational decisions must often be made on the basis of probability estimates from less than optimal amounts of data.

That some focal research sites must eventually emerge to accomodate the growing need for a behavioral science and technology data base in support of extended space occupancy by humans seems self-evident. Serious consideration should be given to establishing such behavioral research facilities (perhaps even in the form of a free-standing Institute for Human Behavior Research in Space Environments) in close proximity to such space flight operations as the activity at the Johnson Space Center in Houston, Texas. This would facilitate personal, day-to-day contact between investigators and operational staff as a vital link in the development of productive research interactions under conditions which enhance validity in more advanced, complex experimental settings. Such a dedicated investment in space-related behavioral research, appropriately located in an operational setting, could also be expected to accomodate the inevitable need for long-term experiments (e.g., a year or more in duration) under conditions which provide appropriate incentives, financial and otherwise, for carefully screened and appropriately prepared human volunteer participants.