WORKSHOP PROCEEDINGS

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SPACE HUMAN FACTORS

VOLUME 2 OF 2

24 - 26 August 1982
Xerox Training Facility
Leesburg, Virginia

Editors:

Dr. Melvin D. Montemerlo
NASA Headquarters

Mr. Alfred C. Cron
General Research Corporation

Sponsored by:

National Aeronautics and Space Administration
Office of Aeronautics and Space Technology
Code RTH-6, Washington, D. C. 20546

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Workshop Proceedings

SPACE HUMAN FACTORS

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Dr. Melvin D. Montemerlo
NASA Headquarters

Editors

Dr. Melvin D. Montemerlo
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Washington, DC 20546

FOREWORD

The "Human Role in Space" Workshop was held at Leesburg, Virginia, on 24-26 August, 1982. The workshop was sponsored by the Office of Aeronautics and Space Technology (OAST) of the National Aeronautics and Space Administration (NASA). The goals of the workshop were:

- To provide a focus for, and a review of, technological opportunities and requirements for the human role in space.
- To brief outstanding American human factors specialists on the nation's space program plans, and on NASA's current technology for developing effective, efficient, and safe man-machine systems.
- To delineate a data-base of human factors methods, techniques, and technologies which may prove effective in the design and development of man-machine systems for use in the space program.
- To aid in planning OAST's space human factors program by identifying technological needs and promising research topics and approaches.
- To insure that all parties involved are aware of significant programs in industry, academia, the military and the government which may be helpful in determining optimal roles, tools, procedures, training and man-machine interfaces for current and future space missions.

The workshop served to open a dialogue between the human factors community and the space program's planners, researchers and operational staff. The focus for continuing this dialogue will be the space human factors research program which has been chartered by NASA's Office of Aeronautics and Space Technology (OAST) beginning 1 October, 1982. The goal of the space human factors research program is to develop an empirical data base for determining optimal roles, tools, procedures, training and man-machine interfaces for the space program. This includes ground operations as well as on-orbit operations.

This report contains copies of all the presentations given (Sessions I-V), the reports of the working group (Session VI), and a number of reports submitted for publication that were not presented at the meeting (Appendix A). In most cases, the presentations were made with overhead transparencies, and these have been published two to a page. The author's explanatory text is presented on the facing page.

Melvin Montemerlo

Melvin D. Montemerlo
Workshop Chairman

Alfred C. Cron

Alfred C. Cron
Workshop Coordinator

November 1, 1982
Washington, D.C.

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SESSION V

HUMAN FACTORS IN RELATED AREAS

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

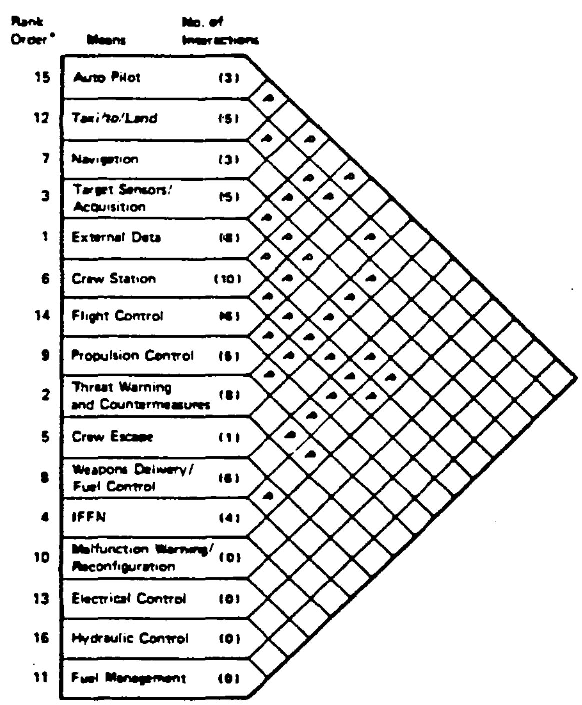
IDENTIFIED IMPORTANT MISSION FUNCTIONS AND OPPORTUNITIES FOR AUTOMATION

II. TECHNOLOGY

IDENTIFIED WHAT COULD BE ACCOMPLISHED THROUGH AUTOMATION

III. HUMAN FACTORS

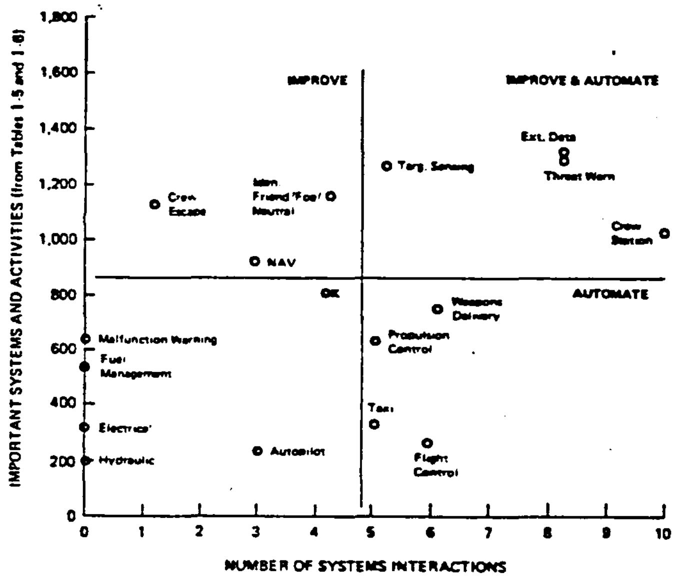
IDENTIFIED WAYS IN WHICH AUTOMATION CAN BE USED TO LESSEN PILOT WORKLOAD



*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.

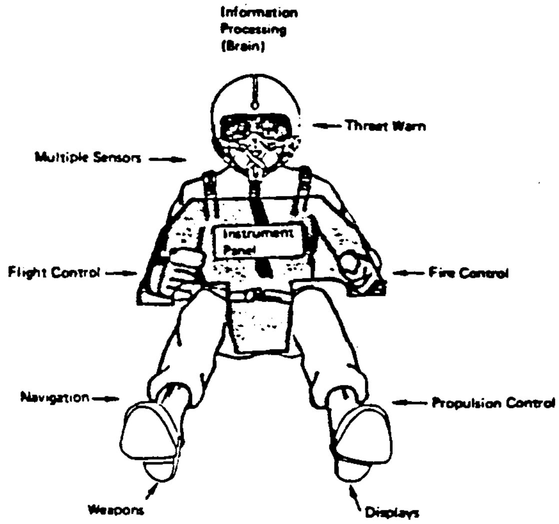


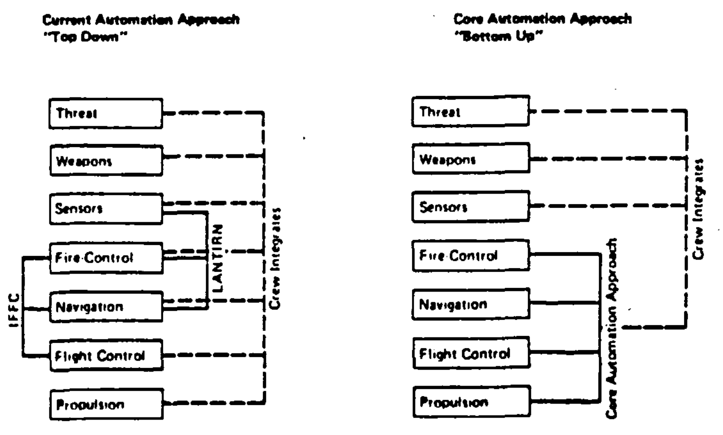
Systems and Activities
Crew Escape
Crew Station
External Data
IFFN
Navigation
Target Sensing/Acquisition
Threat Warning/Countermeasures

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.

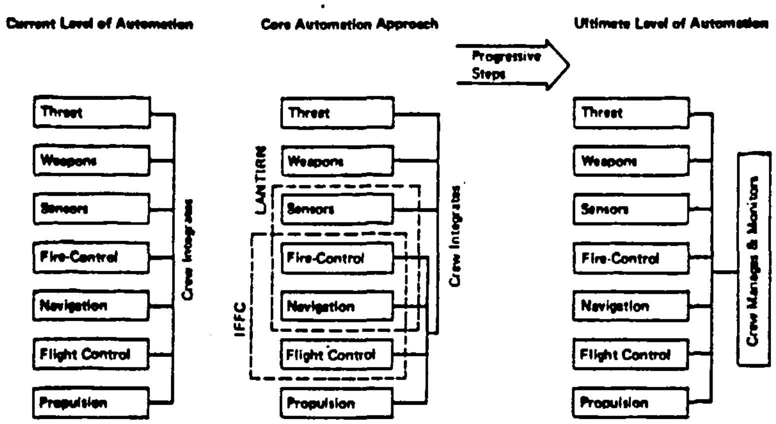
In the current automation approach (left side of figure), the LANTIRN programs links together weapons delivery, target sensing and acquisition, fire control, and navigation. The IFFC program links together fire control, navigation, and flight control. In both programs, the crew integrates all of the 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
IFFC
LANTIRN
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?

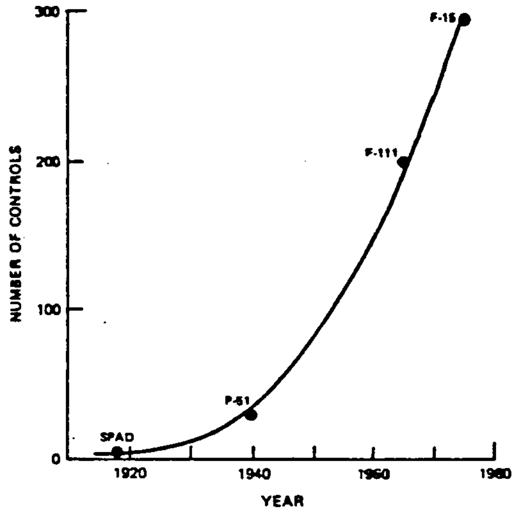
- Reduce Excessive Workload
- Reduce Errors
- Improve Performance
- Add New Capabilities

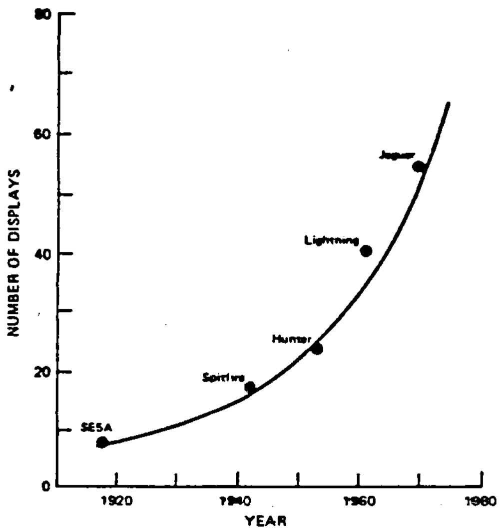
ALTERNATIVES TO AUTOMATION

- 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
F-15
F-111
P-51
SPAD
NUMBER OF CONTROLS
1920
1940
1960
1980
YEAR


80
60
40
20
0
Lightning
Hunter
SE5A
NUMBER OF DISPLAYS
1920
1940
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.

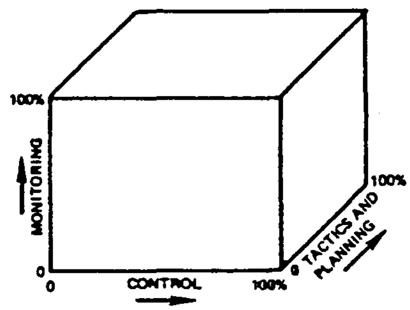


TABLE 2-4. Automation Guidelines For Combat Aircraft

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.

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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.

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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

HE-81-10-85

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.

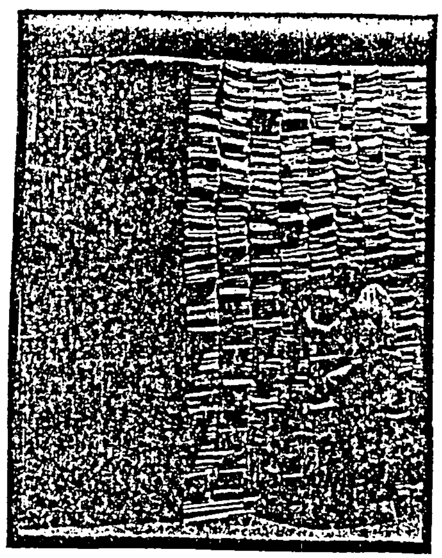
IPID PROGRAM

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

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

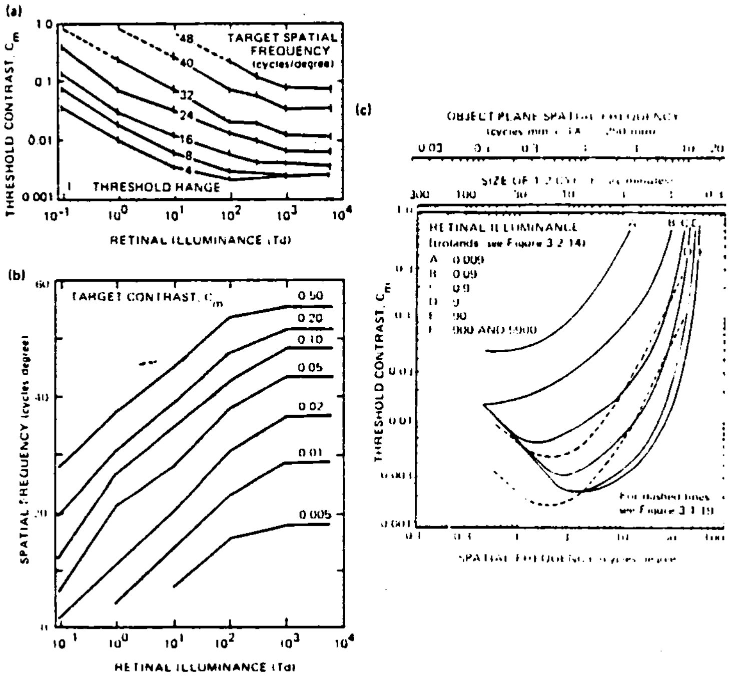


Figure 3.2.33. Effect of Luminance on Contrast Sensitivity. The test conditions for this study [illegible] were

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

[illegible]

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

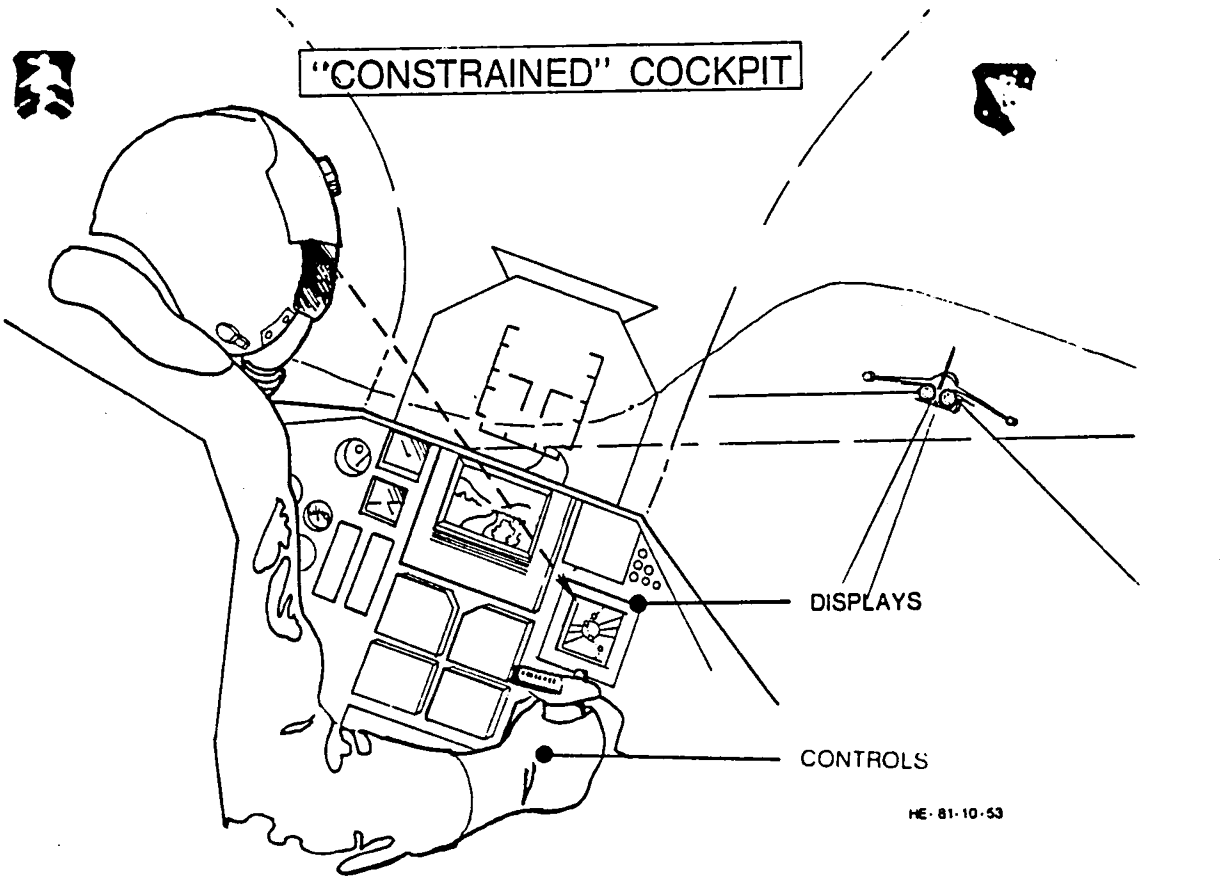
IPID PAYOFF

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 <u>NATURAL</u> PSYCHOMOTOR CONTROL INPUTS
    HEAD/EYES/HAND/VOICE
- AUTOMATION

TACTICAL AIRCRAFT COCKPIT DEVELOPMENT AND EVALUATION PROGRAM (TACDEP) FACILITIES

DESCRIPTION OF FACILITY

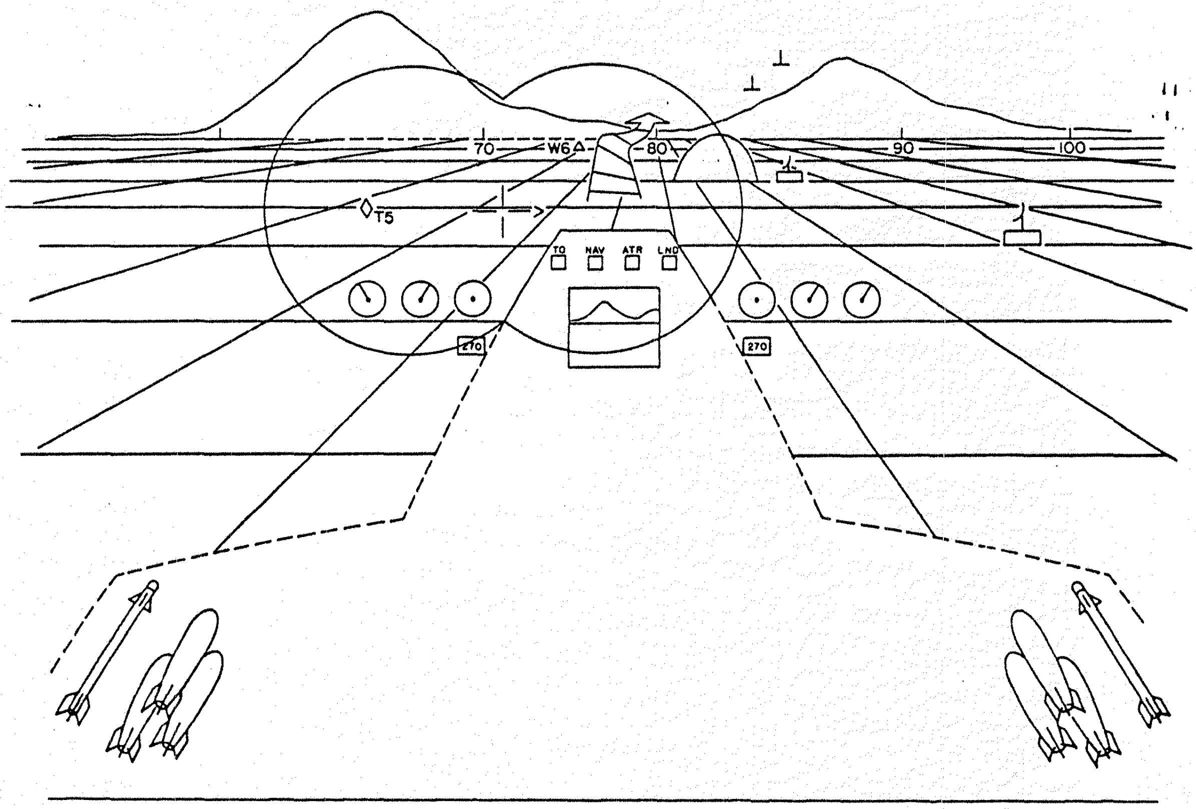
The existing TACDEP facility consists of a fixed base two seat (F-15 type) cockpit with selected instrumentation and controls. Six central processors linked through a multiport memory provide flight dynamics, weapon delivery dynamics, target dynamics and performance scoring. Visual presentations are 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

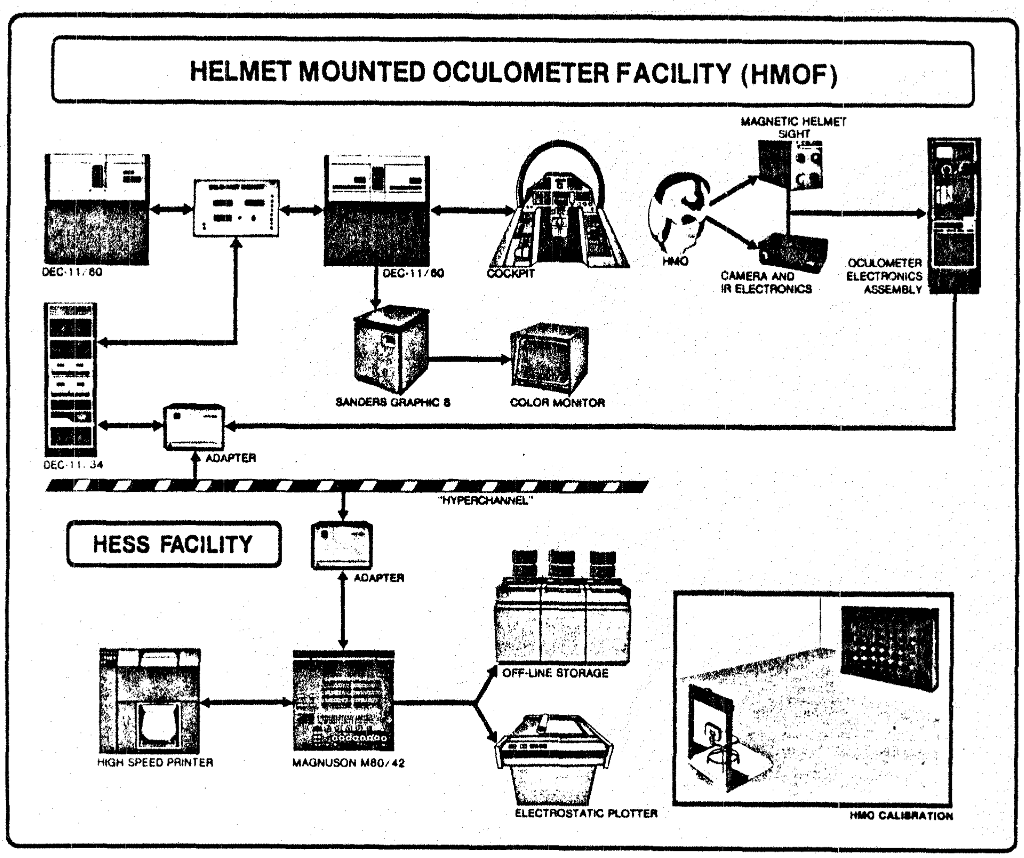
The purpose of this facility is to provide a flexible research tool for investigating crew interface factors in the design of advanced cockpits. The facility will permit the development and evaluation of advanced control/display concepts while performing measure of crew workload and performance. Additionally,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

PLANS

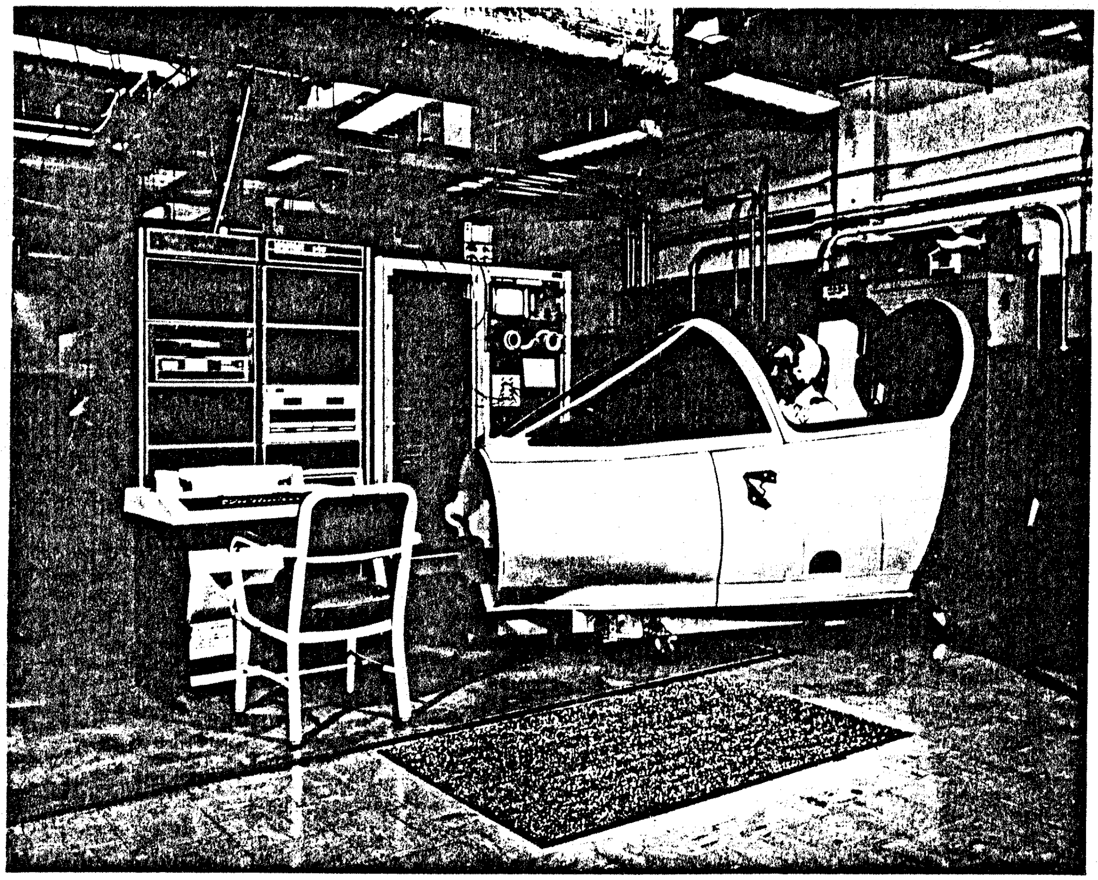
During FY 82-83, a helmet-mounted oculometer (eye position measuring system) will be incorporated into this facility. Future plans include upgrading the visual scene generators to provide color raster/computer generated imagery. The facility will also be interfaced to the Manned Threat Quantification (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.

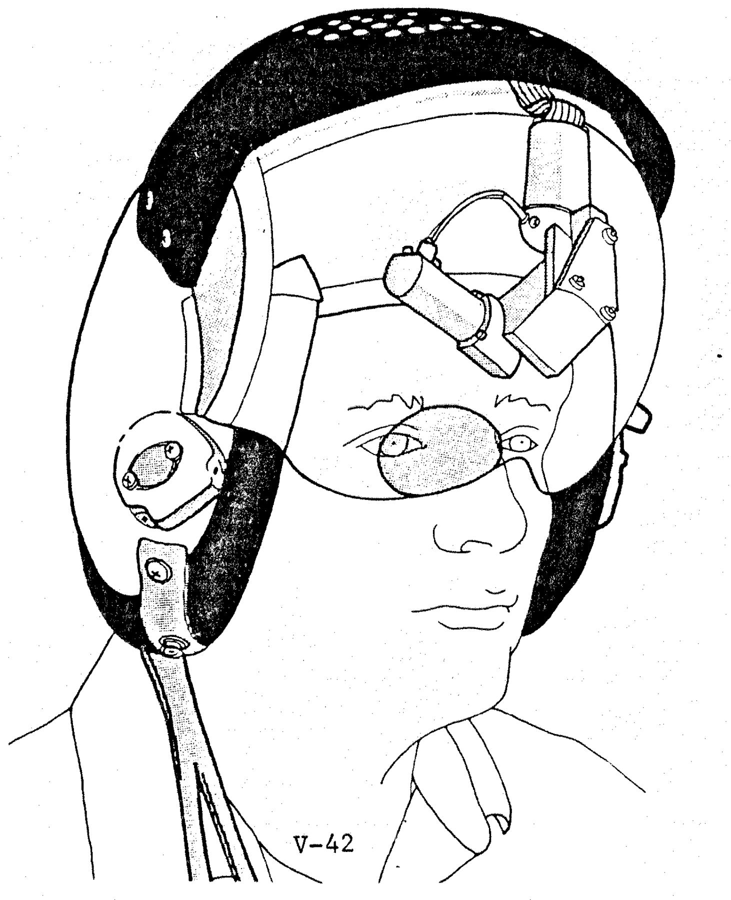


70
W6
80
90
100
T5
TO
NAV
ATR
LND
270
270



HELMET MOUNTED OCULOMETER FACILITY (HMOF)
MAGNETIC HELMET SIGHT
DEC-11/60
DEC-11/60
COCKPIT
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





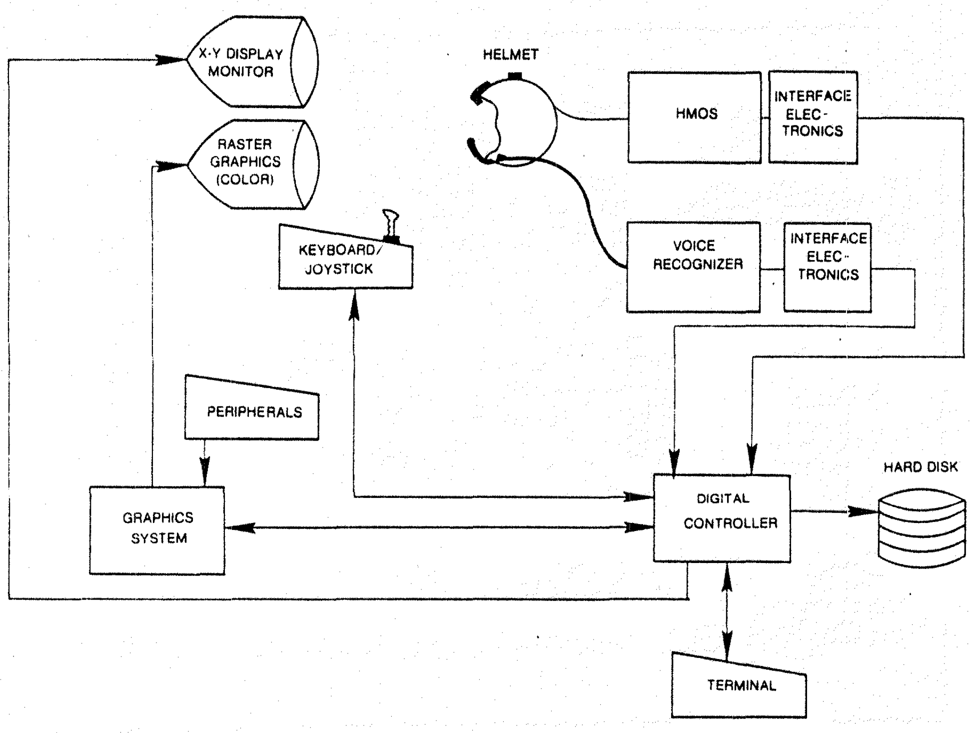
HELMET MOUNTED OCULOMETER SYSTEM

PERFORMANCE

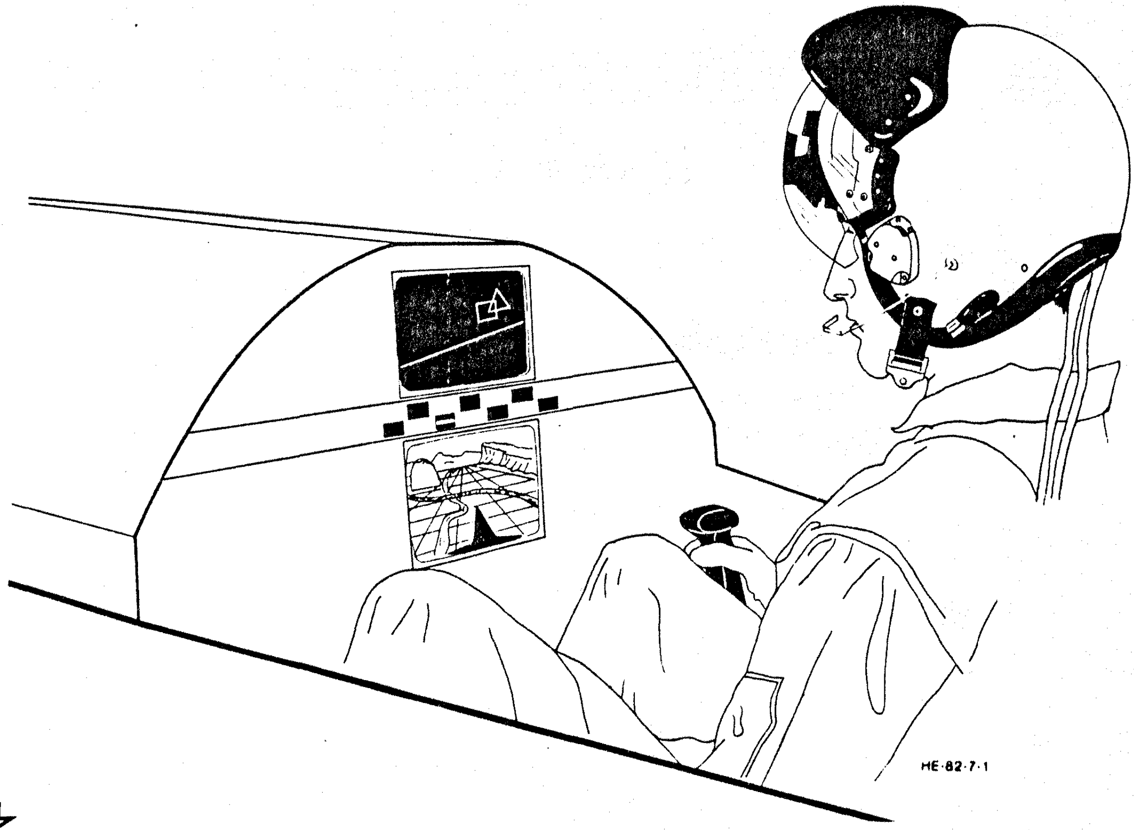
- MOTION BOX — $>2\ Ft^3$
- TRACKED EYE ACCURACY
  - $0°$ TO $50°$ Az, $0°$ TO $30°$ EL — $0.41°$ RMS
  - $50°$ TO $78°$ Az, $30°$ TO $60°$ EL — $0.72°$ RMS
- UPDATE RATE — 60Hz
- WEIGHT ADDED TO HELMET — 15 oz

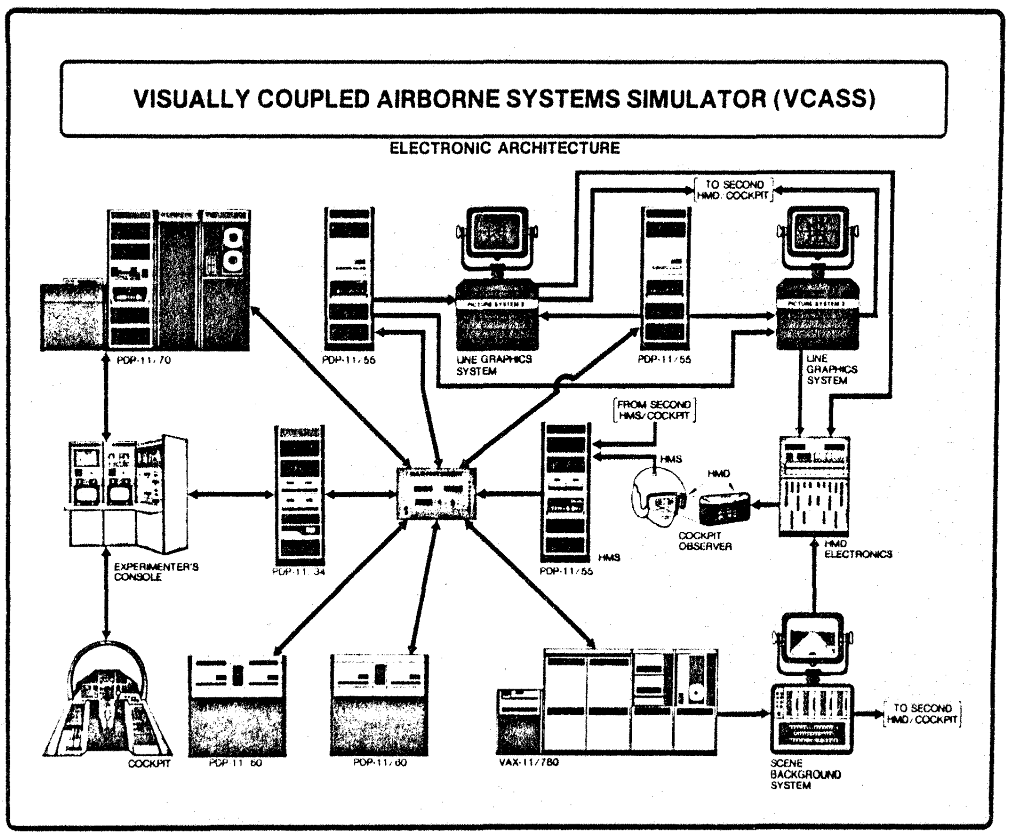
HE-82-1-60

EYE COUPLED VOICE CONTROL SYSTEM



HE-82-6-47

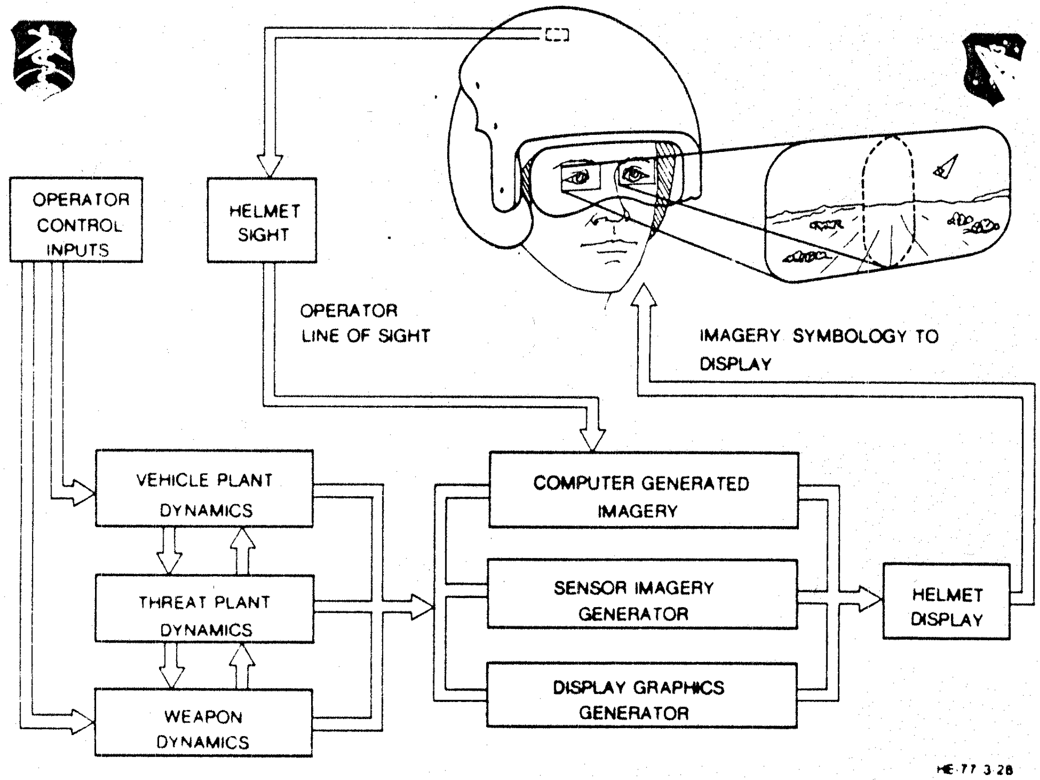

HE-82-7-1


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
COCKPIT OBSERVER
EXPERIMENTER'S CONSOLE
PDP-11/34
PDP-11/55
HMS
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

ADDENDUM

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

INTEGRATED PERCEPTUAL INFORMATION FOR DESIGNERS

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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.

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

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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

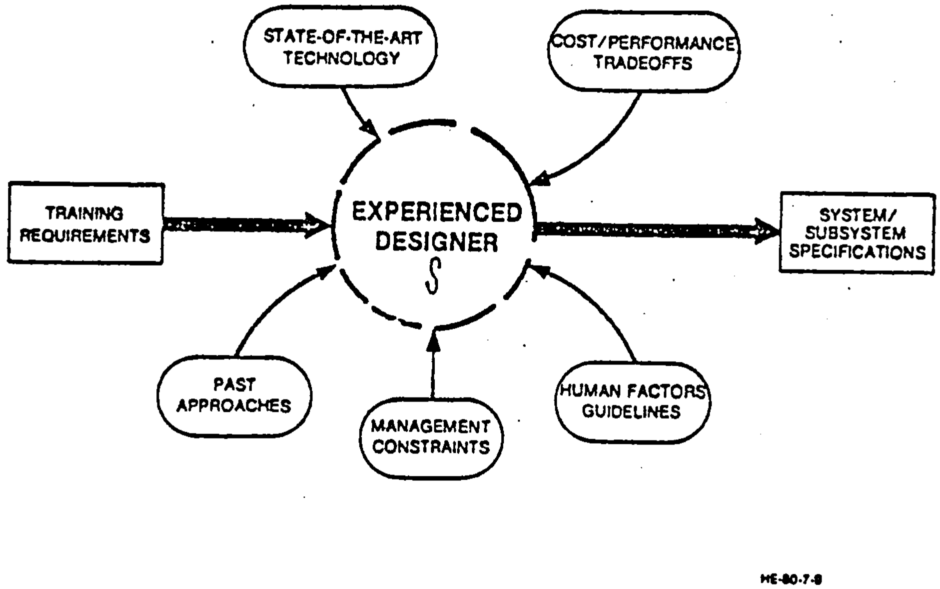

Figure 1

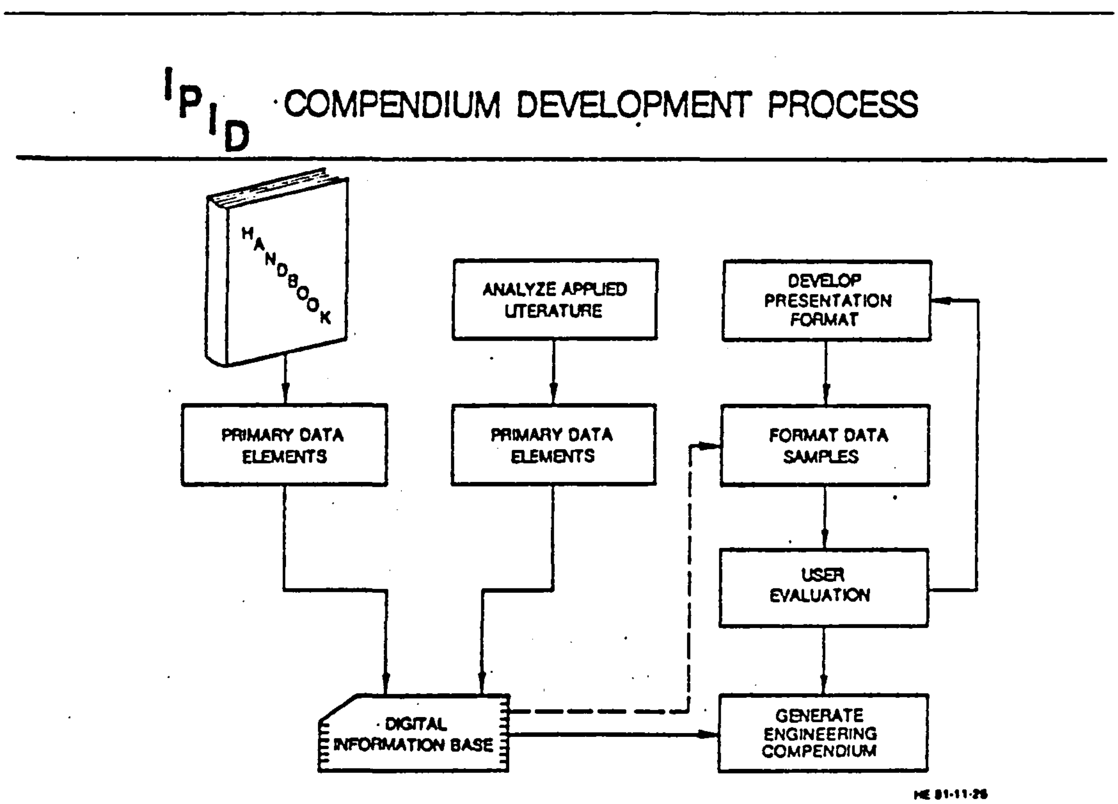

Figure 2

IPID HOW TO ACCESS THE DATA COMPENDIUM

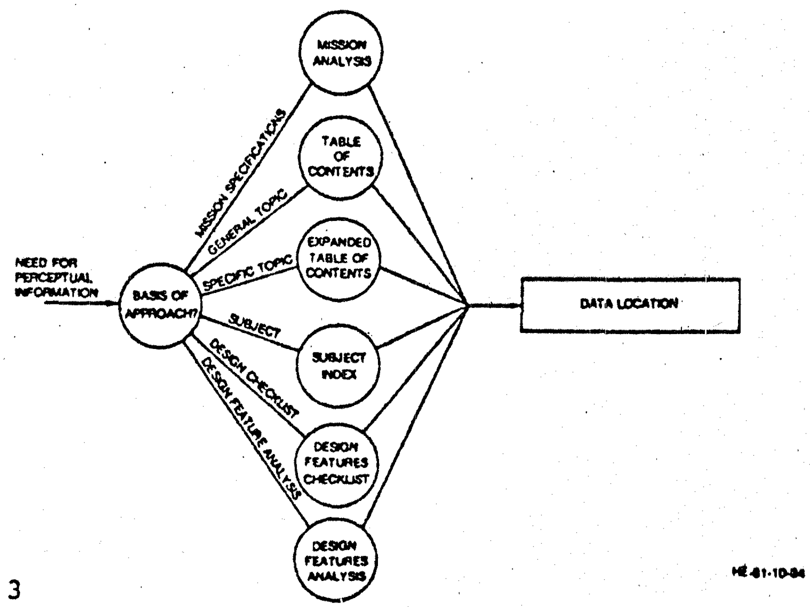

Figure 3

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IPID USER'S GUIDE: MISSION RELATED FEATURE ANALYSIS

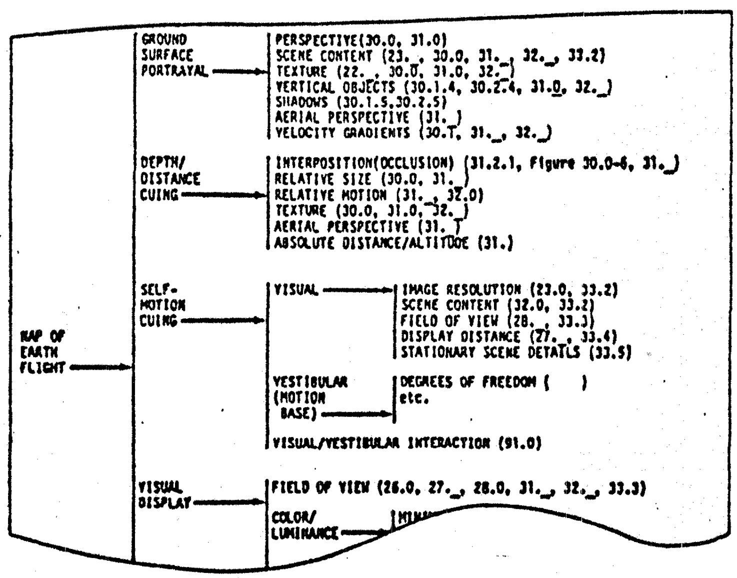


Figure 4

HE-81-10-78

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

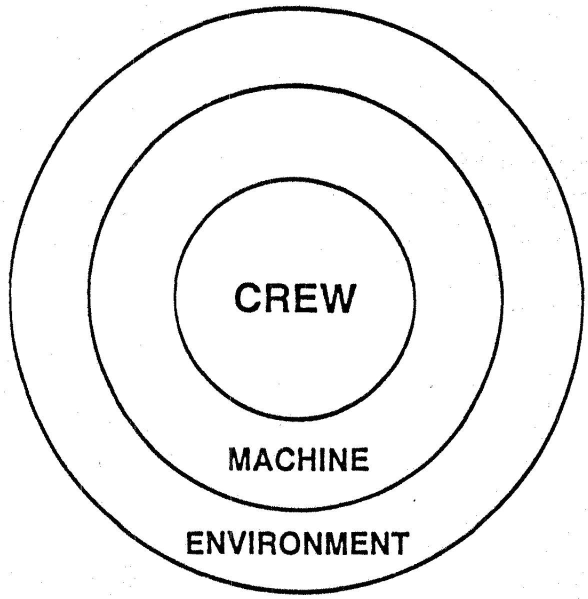
THE FLIGHT DECK DESIGN PHILOSOPHY HAS, FROM THE VERY INCEPTION, BEEN TO SYNTHESIZE A CREW CENTERED DESIGN.

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.

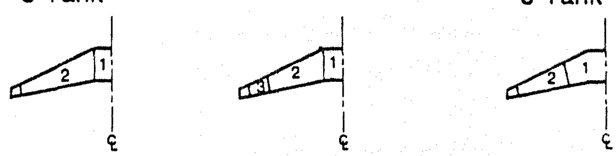
ACHIEVING DESIGN SIMPLICITY REQUIRES DETAILED ANALYSIS OF ALL RELEVANT FACTORS. CREW OPERATING PROCEDURES ARE GIVEN EQUAL CONSIDERATION WITH FACTORS SUCH AS WEIGHT AND RELIABILITY. IN THIS DESIGN REFINEMENT EXAMPLE, FUEL SYSTEM COMPONENT AND OPERATIONAL SIMPLICITY WERE MAINTAINED WHILE ACHIEVING THE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

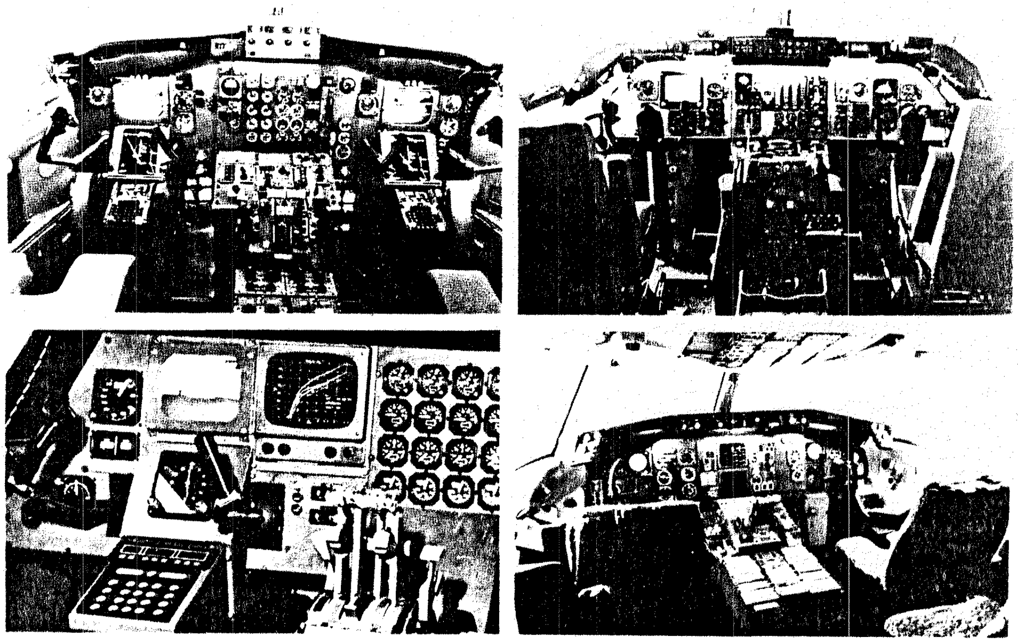
PICTURED CLOCKWISE FROM THE LOWER LEFT ARE THE COCKPITS OF THE UNITED STATES SST PROJECT (1969), THE NASA TCV BOEING 737 (1973 TO PRESENT) AND THE YC-14 (1976). THE BREAKTHROUGHS INTRODUCED IN THESE PROJECTS CULMINATED IN THE DESIGN OF THE 757/767 FLIGHT DECK SHOWN IN THE LOWER RIGHT AND ON THE RIGHT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

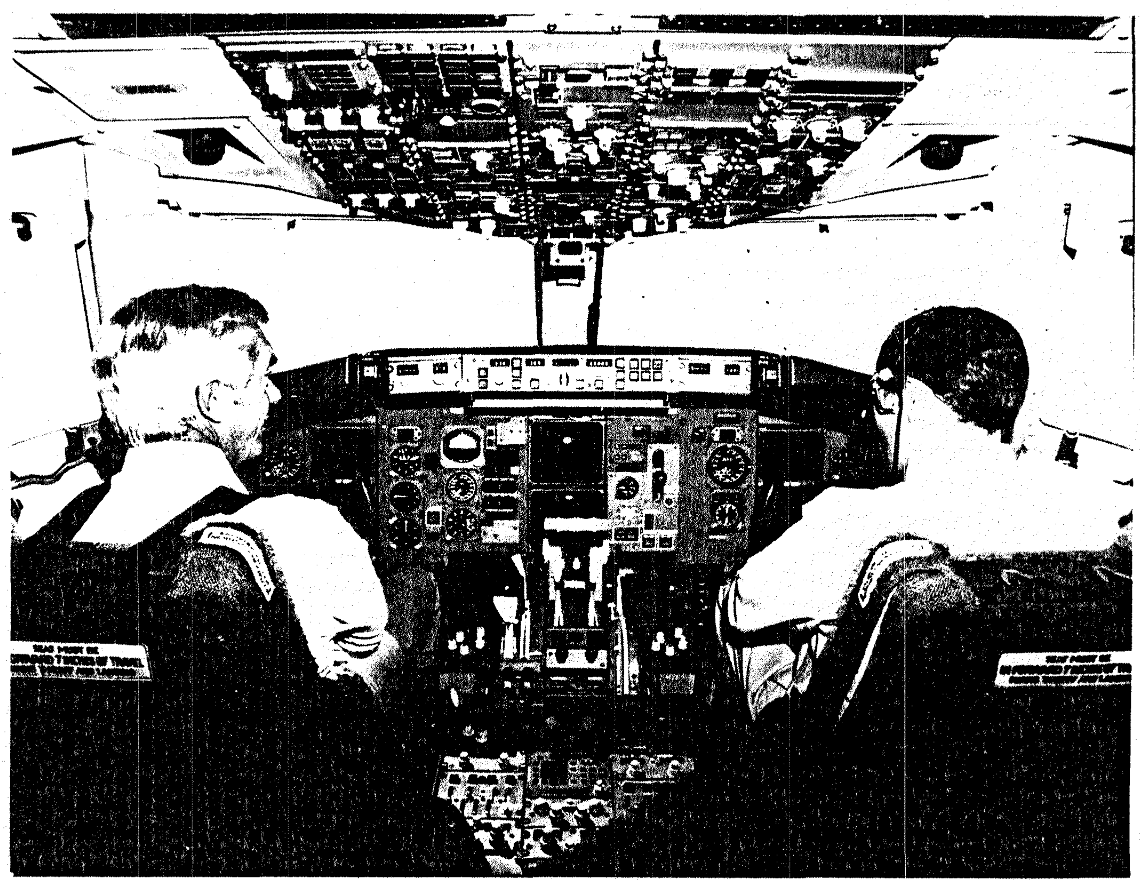
THE EFFICIENT AND COMFORTABLE DESIGN INCLUDES FLAT WINDSHIELDS FOR FORWARD VISION AND CURVED SIDE WINDOWS WITH A GEOMETRY THAT WILL PROVIDE A LOW NOISE, HEADSETS-OFF ENVIRONMENT WITH OPTIMUM INTERNAL AND EXTERNAL VISION CHARACTERISTICS. HIGH RESOLUTION COLOR CRTS, VISIBLE IN ALL LIGHTING CONDITIONS, 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.

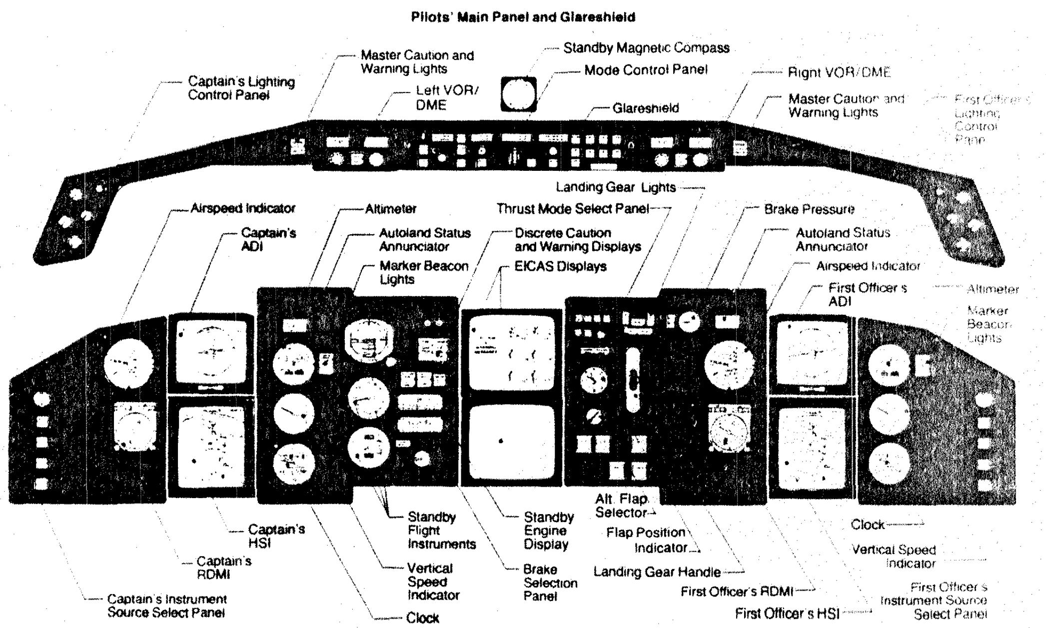
NOTE HOW UNCLUTTERED THIS CONTROL PANEL LAYOUT IS.

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



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

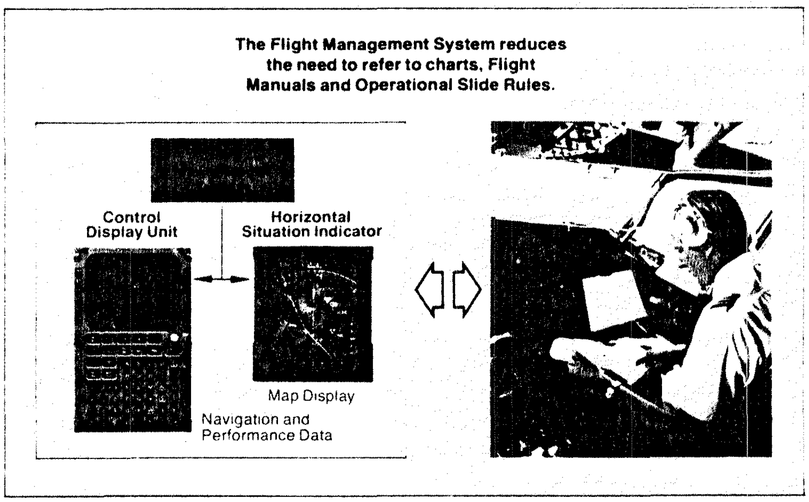
THROUGH THE FLIGHT MANAGEMENT SYTEM THE CREW OF A 757 OR 767 CAN ACCOMPLISH MORE EFFECTIVELY THE SAME TASKS REQUIRED IN OLDER GENERATION AIRPLANES, AND AT REDUCED WORKLOADS. AS A RESULT, THE CREW WILL HAVE MORE TIME FOR THE OPTIMIZED MANAGEMENT OF THE AIRPLANE AND THE FLIGHT, MORE TIME FOR IN-FLIGHT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



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

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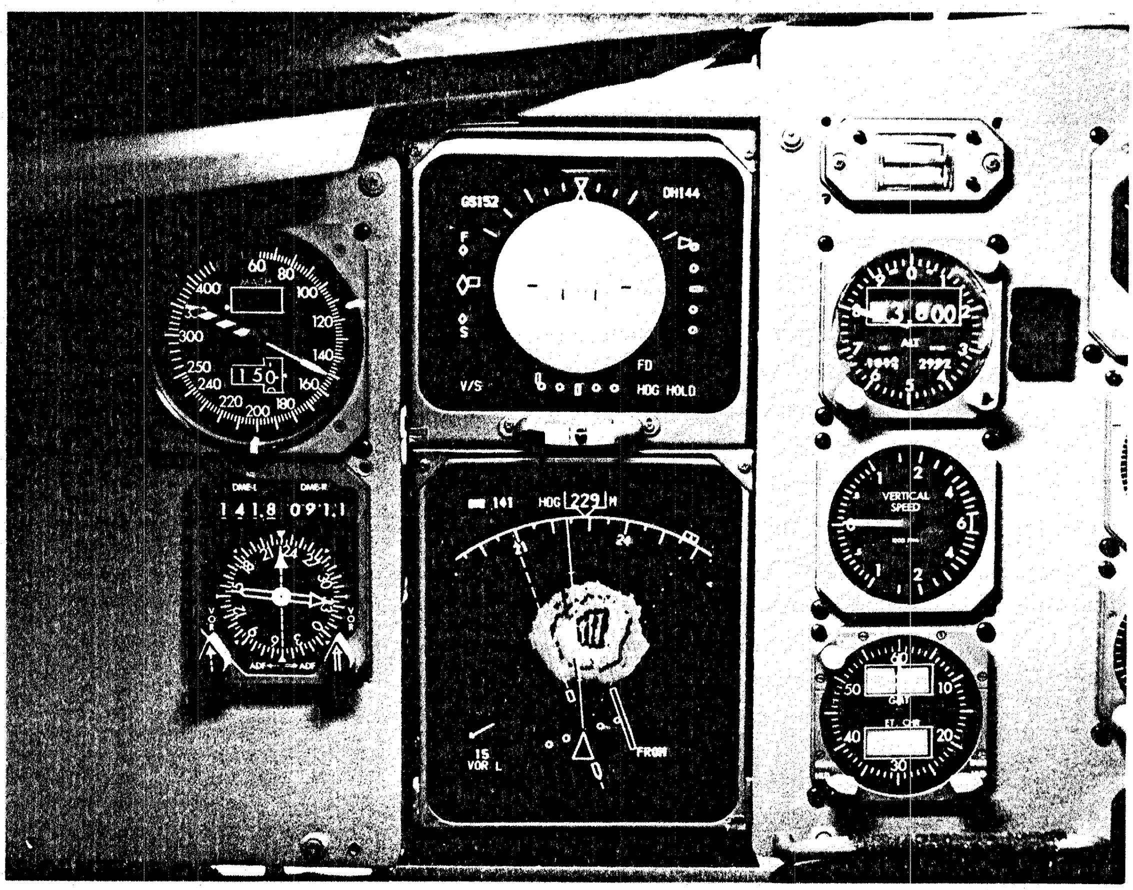
THE HSI INTEGRATES COMPASS, TRACK, WEATHER, AND MAP REFERENCES INTO A SINGLE DISPLAY WITH ALL ELEMENTS TO A COMMON SCALE. IN A MULTICOLOR FORMAT, IT DEPICTS THE HORIZONTAL POSITIONING OF THE AIRPLANE IN RELATION TO THE FLIGHT PLAN AND A MAP OF NAVIGATION FEATURES. THE AIRCRAFT TRACK, TURN PREDICTION 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.

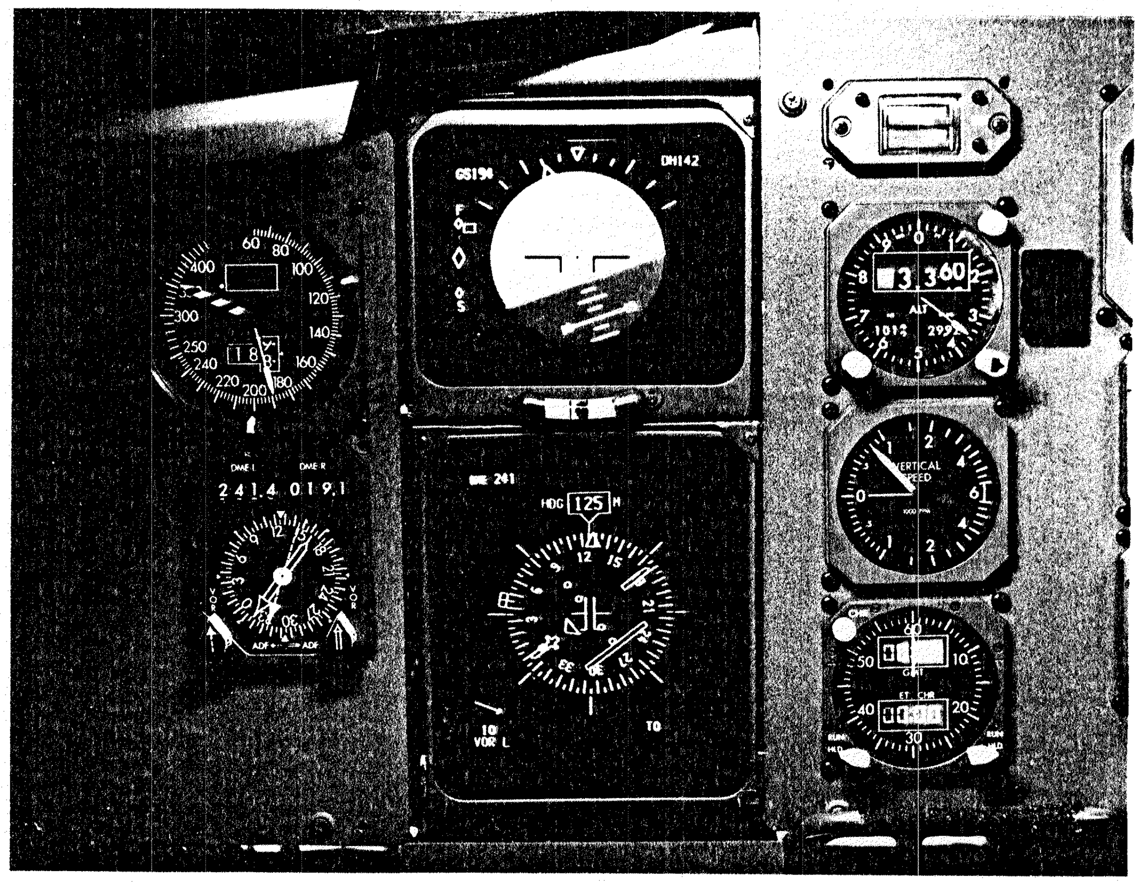
EACH PILOT MAY ADJUST THE COMPOSITION OF HIS HSI DISPLAY BY CHOOSING FROM A VARIETY OF SELECTABLE FEATURES. COLOR WEATHER RADAR RETURNS MAY BE SELECTED AND PRESENTED AT THE SAME SCALE AND ORIENTATION AS THE MAP. NAVAID, AIRPORT AND GROUND REFERENCE POINT SYMBOLOGY MAY BE ADDED TO THE MAP AT THE PILOT'S 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.





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

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.

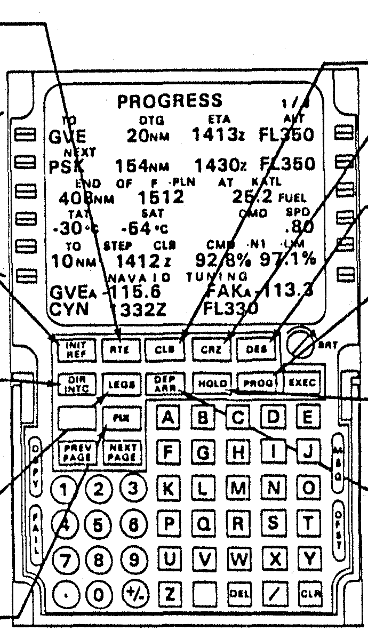
LINE SELECT KEYS
Provides for entry of data from verification line into selected line. Permits rapid manipulation of appropriate line data.

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.

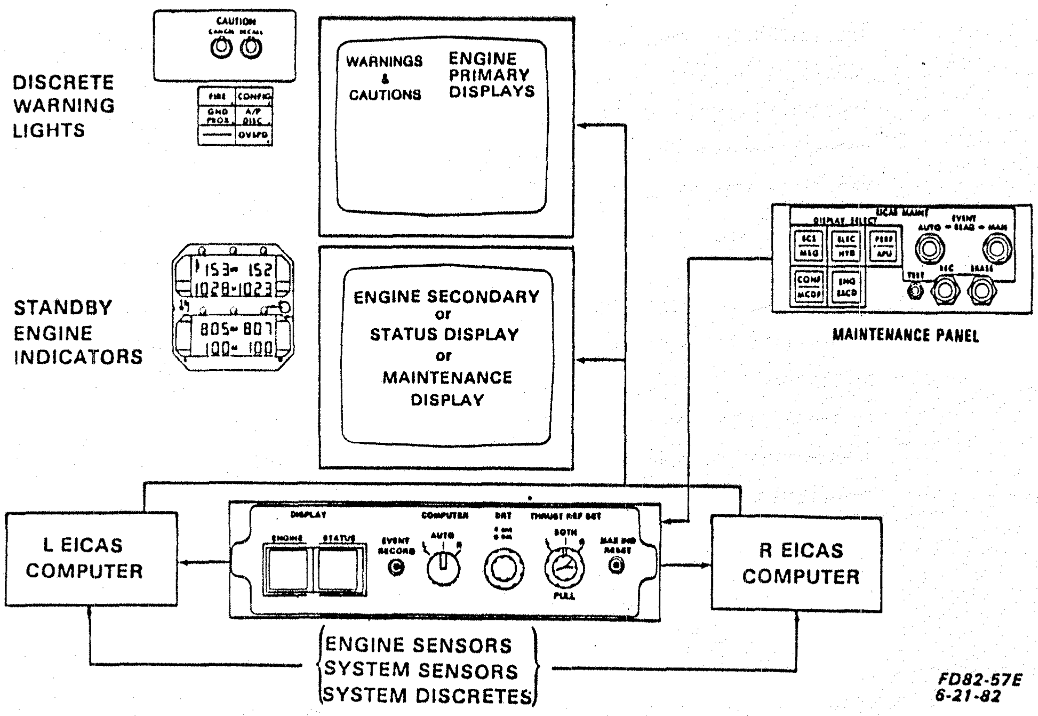
PROG (Progress)
Displays current dynamic flight information. Pages are for crew information only and require no crew inputs.

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
ENGINE INDICATION AND CREW ALERTING SYSTEM



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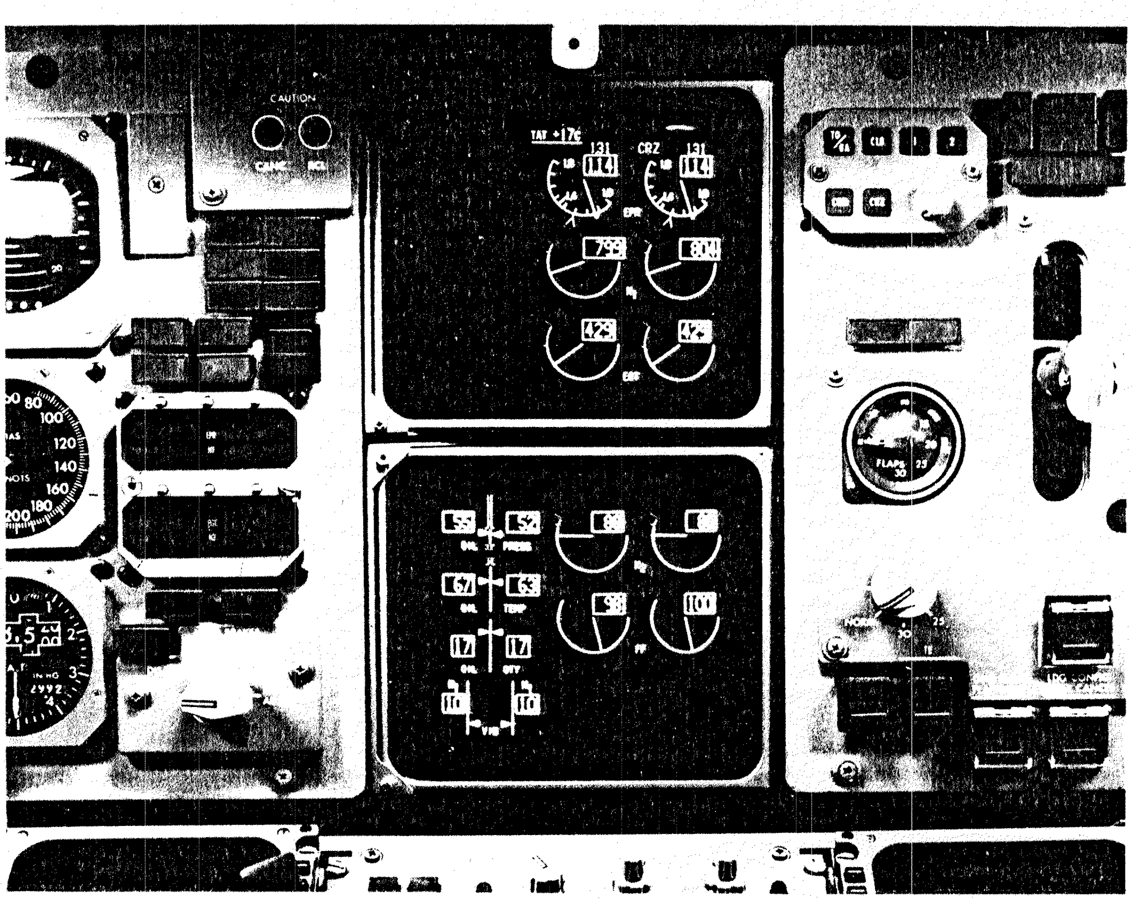
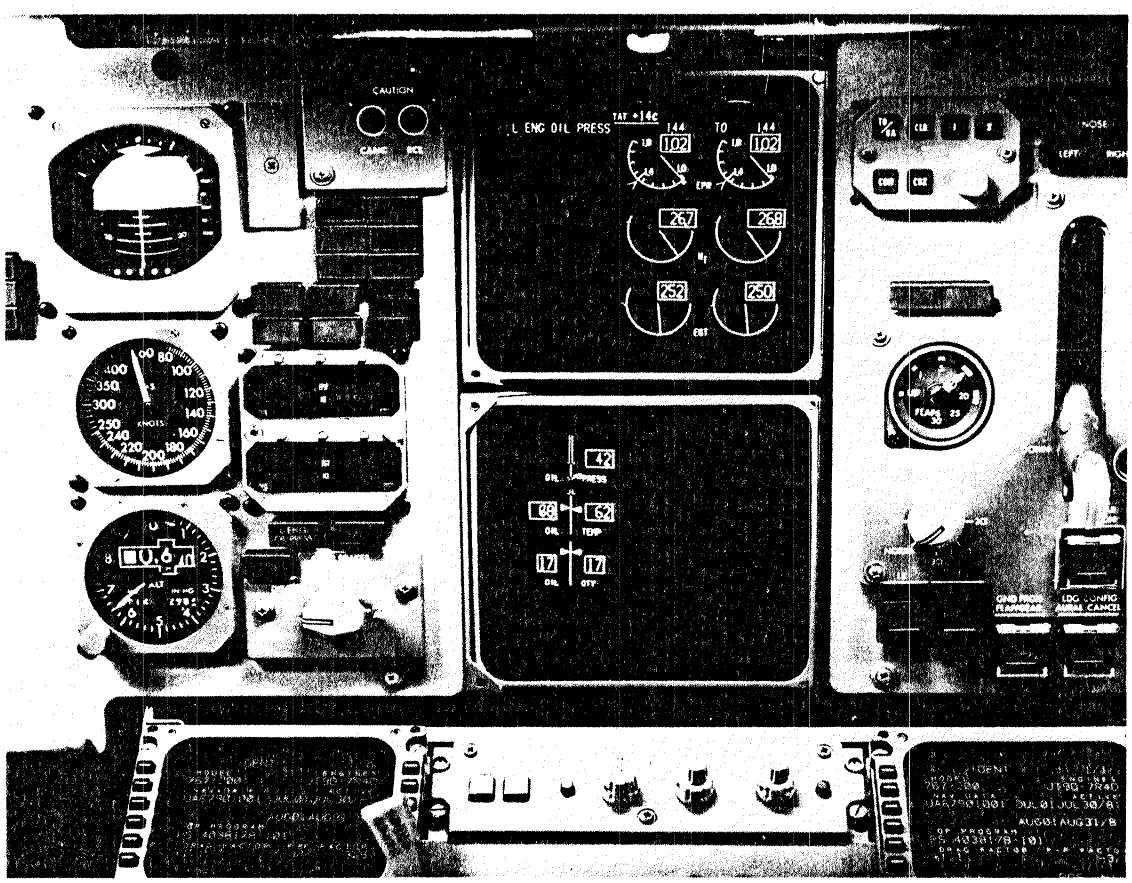
The full EICAS presentation can be displayed by pressing the ENGINE button on the EICAS control panel. Pressing the button a second time will return the display to the de-cluttered mode. In this mode only the primary engine instruments are displayed on the upper CRT. In a similar fashion the status display 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 abnormalities 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.



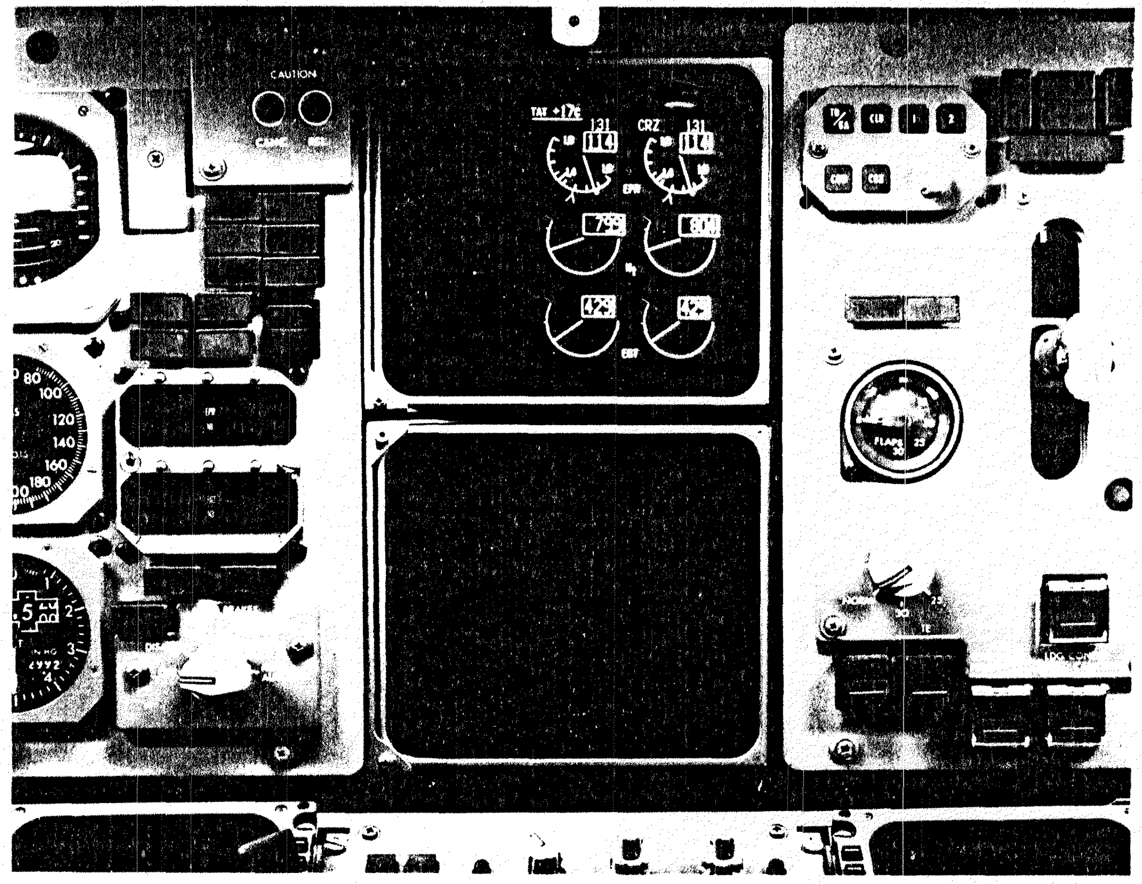


THE SYSTEM HAS TWO ADDITIONAL FUNCTIONS: STATUS AND MAINTENANCE. WHEN THE STATUS MODE IS SELECTED, THE LOWER CRT DISPLAYS DATA RELATING TO THE STATUS OF THE AIRPLANE, INCLUDING SUCH INFORMATION AS HYDRAULIC FLUID LEVELS AND CONTROL SURFACE POSITIONS. THREE MAINTENANCE MODE FORMATS ARE AVAILABLE ONLY 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
FLAPS

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

-Relevance to the Manned Space Program-

by
Harold E. (Smoke) Price
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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.

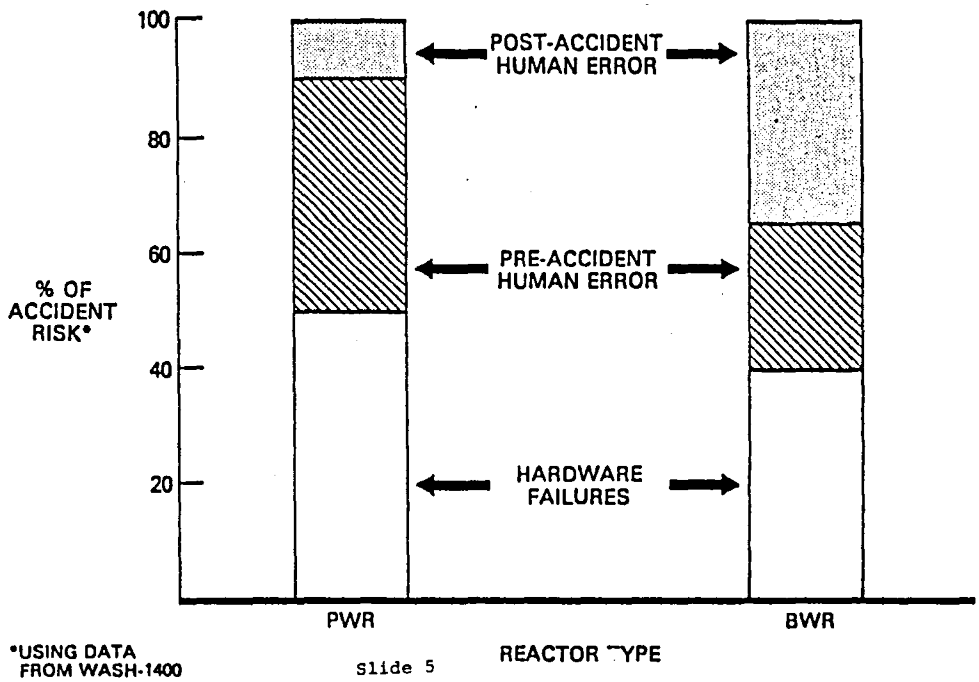
This chart was developed by summing the probabilities of all the sequences in WASH-1400, the renown Reactor Safety Study, which would constitute the total risk. The risk was then apportioned among human errors and hardware failures, and it can be seen that reducing the human error component can have 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

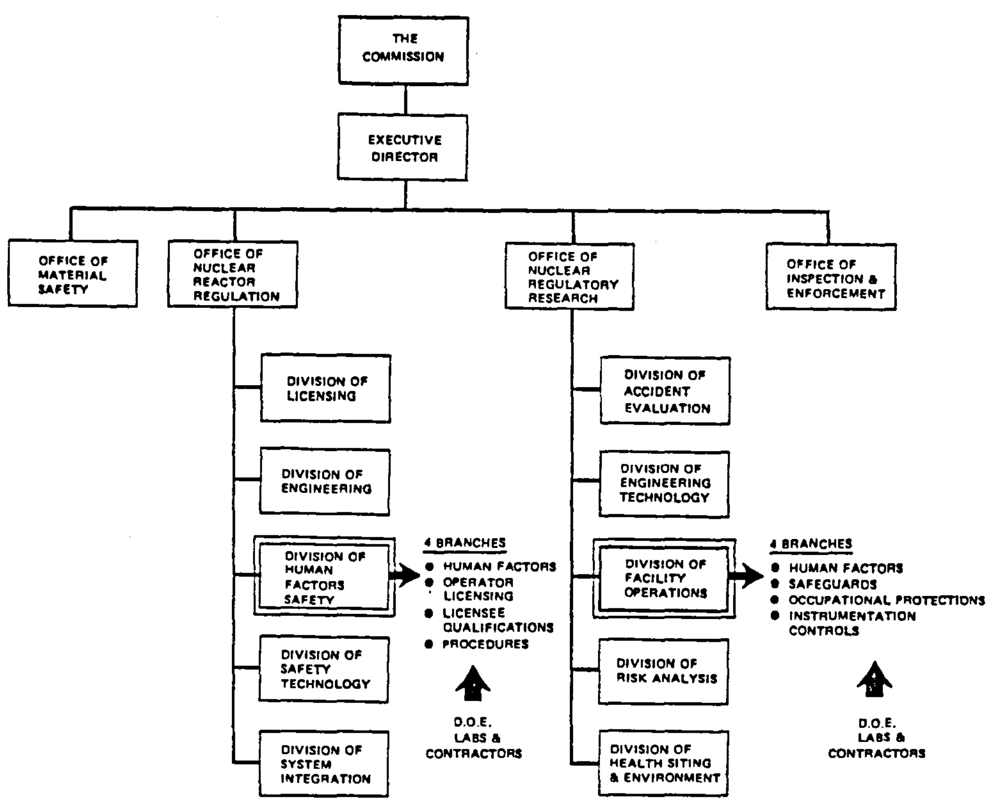
After TMI-2 and the ensuing investigations, the U.S. Nuclear Regulatory Commission (NRC) as well as the utilities began to make substantial changes to ensure consideration of human factors in present and future nuclear power plants. As indicated on this chart (double boxes), the NRC made two significant 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

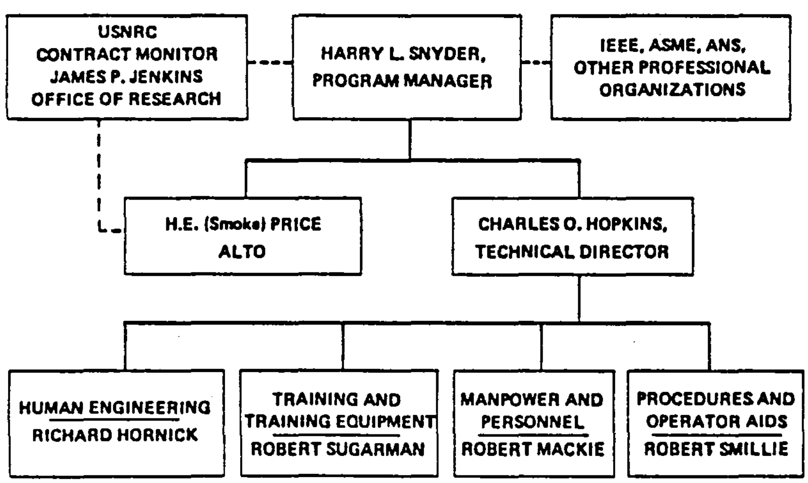
Project for

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.

<u>Selected References</u>

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

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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.

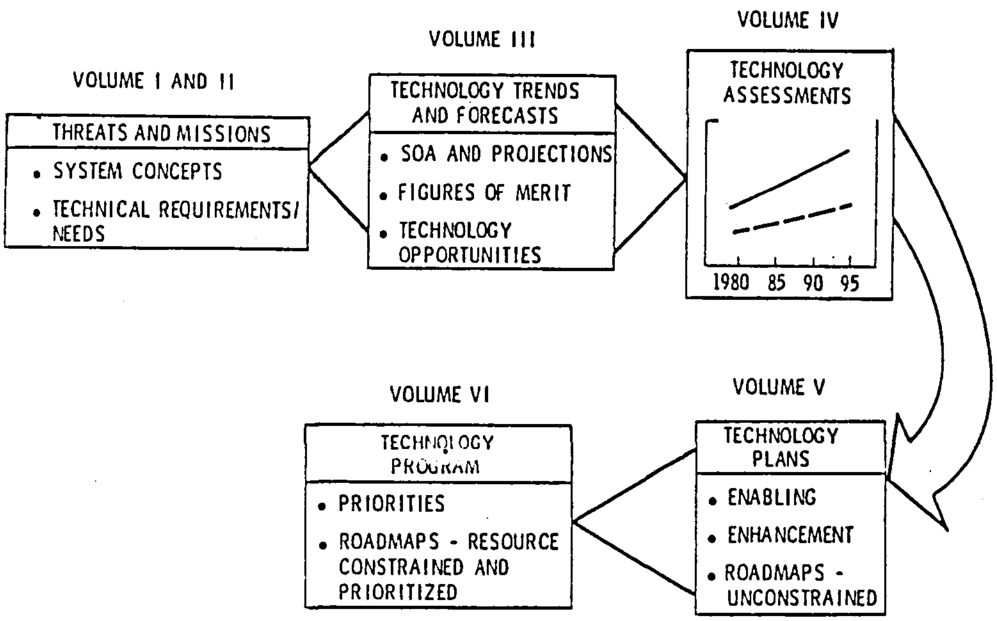
Military Space Systems Technology Model (MSSTM) Program Objectives

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.

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

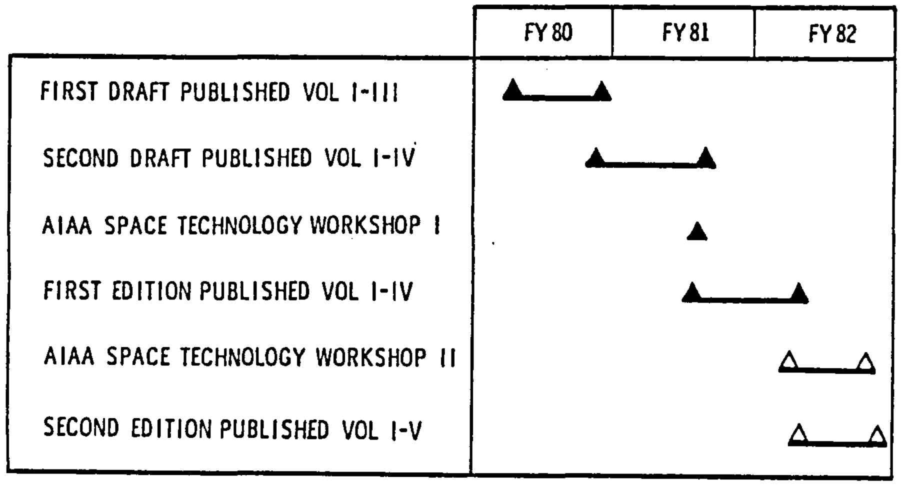
PERCENT	TOPIC
10%	8.0 SYSTEM/MISSION IMPACT ISSUES A. WHAT BASIC IMPACTS DO THESE CANDIDATE TECHNOLOGIES HAVE ON PLANNED SYSTEMS/MISSIONS/PROGRAMS • TIME TO DEVELOP VS AVAILABILITY NEED DATES • SIZE/MASS • POWER/FUEL/COOLING, ETC. • STOWED VS OPERATING ENVELOPE • DYNAMICS • CONTAMINATION • LOGISTICS/SERVICING • 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

NASA BACKGROUND TO EARLY WORKSHOPS OAST

- 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

NASA WORKSHOPS OAST

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 EXTRA-TERRESTRIAL 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 INTER-STELLAR 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, RADIO-ISOTOPES, 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 SUPER-VISION 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."

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

"<u>CONCLUSIONS</u>

- 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.

<u>RECOMMENDATIONS</u>

- 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

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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.

SESSION VI

WORKING GROUP REPORTS

This section includes the charts presented by each working group. When explanatory comments were provided, they appear in text after each chart.

REPORT OF THE CREW STATION DESIGN WORKING GROUP

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CREW STATION DESIGN KEY ISSUES SUMMARY

- ERGONOMIC MODEL OF THE HUMAN OPERATOR
- CREW STATION DESIGN AND DEVELOPMENT TECHNOLOGY
- NATURAL LANGUAGE INTERFACE
- PRIORITY AND INHIBIT LOGIC
- DATA ENTRY
- DATA STORAGE AND RETRIEVAL
- RESTRAINT SYSTEMS
- WORKLOAD EVALUATION METHODS--ZERO G
- OPTIMIZED CREW INTERFACE WITH INFORMATION MANAGEMENT SYSTEMS
- FACILITY HYGIENE
- BULK FOOD SYSTEMS

A summary of the key issues which will be discussed in more detail on the following charts.

ERGONOMIC MODEL OF THE HUMAN OPERATOR

ISSUE

SYSTEMATIC AND COMPREHENSIVE REPRESENTATIONS OF THE HUMAN OPERATOR AND HIS ENVIRONMENTS WHICH ARE INTERACTIVE IN THE DESIGN PROCESS ARE NOT AVAILABLE

APPROACH

- DEFINE DATA REQUIRED
- DEVELOP TECHNOLOGY FOR DATA ACQUISITION SYSTEMS
- DEFINE AND DEVELOP TECHNOLOGY REQUIRED FOR USAGE/ IMPLEMENTATION
- DEVELOP AND IMPLEMENT MODELING CRITERIA
  - ANTHROPOMETRIC MODEL
  - BIOMECHANICAL MODEL, WORK STATION AND ENVIRONMENTAL MODEL
  - INTERFACE AND INTERACTION MODELS

BENEFITS

- IMPROVED AND RESPONSIVE CREW STATION DESIGNS
- LOWERED COST, DECREASED CHANGE TRAFFIC
- IMPROVED CREW EFFICIENCY
- ENHANCED MISSION SUCCESS

We need systematic and comprehensive representations of three separate aspects of the human operator within a technological system:

(a) Model of body dimensions, "Anthropometric Model"

(b) Model of physical activity characteristics, "Biomechanical Model"

(c) Model of operator-equipment interactions, "Interface Model".

These submodels should be integrated for the "Ergonomic Model". This shall be a "proactive" (predictive) model, as compared to existing "reactive" (passive) models.

Many approaches for model subsystems or components of this overall problem exist. However, they do not fit into a common framework, and have different, often noncompatible outputs. Furthermore, the input requiremens are usually different (resulting from analytical or systematic approaches of different disciplines) and do not rely on a common data base.

The lack of a systematic, comprehensive, and quantitative ergonomic model brings about incomplete understanding of the human operator as a system component, who is often the main determiner of the system output. Thus, technological systems relying on the human as a system component may be laid out less than optimal with respect to system performance and, therefore, are suboptimal in their output.

Such systems are military or civilian. Typical examples in the military domain are aircraft cockpits, tank interiors, work stations on surface ships, or submarines. Search and rescue ships used by the US Coast Guard are notorious for the lack of human engineering in their design. Typical civilian applications are in the automobile industry, both in passenger vehicles or trucks, and very prominent in construction and agricultural equipment. Acute industrial problems relate to control rooms, or visual display terminals.

Thus, development of a comprehensive and systematic Ergonomic Model of the Human Operation would benefit military as well as civilian populations and applications.

CREW STATION DESIGN & DEVELOPMENT TECHNOLOGY

APPROACH

- DEVELOP A SYSTEMATIC PROCESS FOR ASSESSMENT OF IMPACTS ON GROUND CONTROL ELEMENTS OF DESIGN ALTERNATIVES WITH RESPECT TO MAN-MACHINE FUNCTIONS

BENEFIT

- YIELDS QUANTITATIVE DATA ON PERFORMANCE AND COMPARATIVE ASSESSMENT CAPABILITY

PLAN

- CONTINUE DEVELOPMENT OF TECHNOLOGY REPRESENTING COMPLEX SINGLE AND MULTIPLE COMPUTER MAN MODELS REPRESENTATIVE OF FLIGHT CREW FUNCTIONAL INTERACTION WITH SPACECRAFT SYSTEMS
- SIMULATOR MEASUREMENT SYSTEM DEVELOPMENT

A systematic process is needed that can be applied to various crew stations aboard the spacecraft/station and those control elements of the ground support system that interface with the spacecraft.

The crew station design technology described below is particularly appropriate for computer-based crew stations as exemplified by the 767 and F-18, as well as certain command and control systems. These systems are characterized by new multi-mode, multifunction displays/controls that are software driven, and thus, changes in logic and format can be introduced readily and without hardware changes.

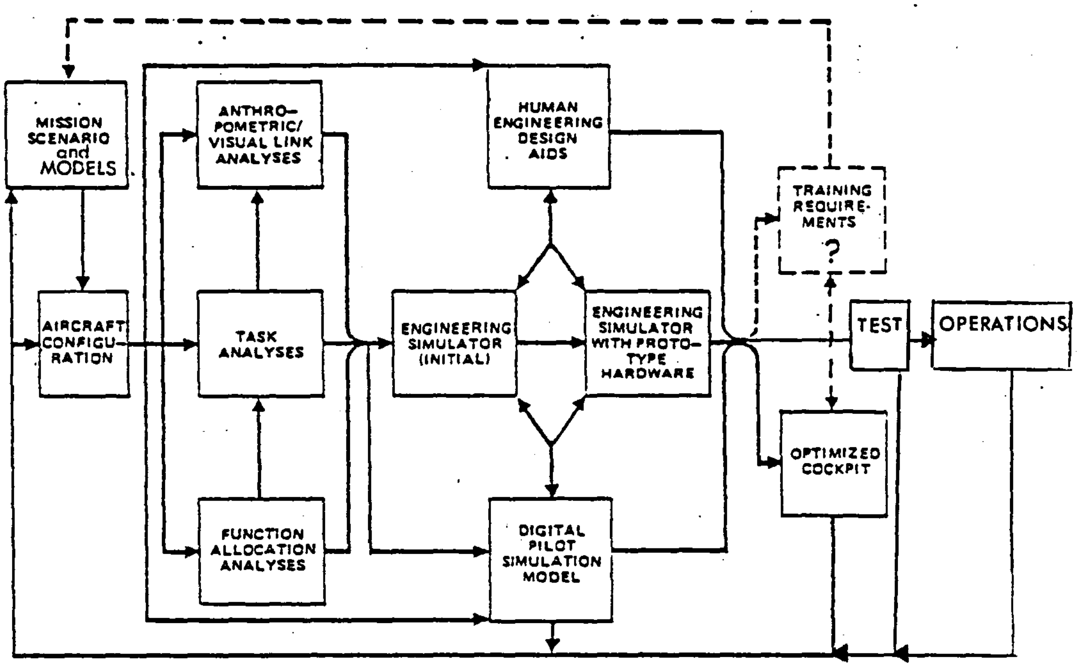
The crew station development process used for several aircraft is shown in the next chart. It should be noted that this process is probably the only way quantitative data can be obtained on the total effectiveness of a given crew station or the impact of a design (e.g., training, procedure, etc.) change on effectiveness. The issues are too complex and interactive to obtain "numbers" in any other way.

This process has been applied to the development of several fighter aircraft but further technology developments are needed to adapt this approach to NASA needs. Examples of further development needs are:

Digital Pilot (and Crew) Simulation Models
These are complex computer models that represent man's function in relation to a specific system. They consider discrete events, decision-making, and continuous control functions. Multiple runs of the models (Monte Carlo) can show the distribution of performance as a function of changes in variables such as a new display, stressors, and malfunctions. These can also interface with mission effectiveness models.

NASA needs require further developments in areas that include multi-man crews, mission control functions, duty cycles, and the effects of the environmental stresses found in space. Techniques must also be developed for inputing data from simulations and flight test and operational results.

Design Simulator Measurement Systems
The use of man-in-the-loop design simulators is an integral part of this process. However, the development of a science of crew station design requires the development of objective measurement systems. These do not exist now in a form that can generate quantitative data on a near real-time basis in a form that is meaningful for the design process. That is, a family of measures are needed that reflect new performance, system performance, and mission performance. They also should be developed in a way that human errors or poor performance basue of design (or training) limitations can be shown to impact safety of flight. Techniques for structuring missions and efficient "experimental" designs must also be developed to maximize data return.



HUMAN FACTORS USE OF ENGINEERING DEVELOPMENT SIMULATORS

Introduction - Simulators are used by many different engineering disciplines alone or in conjunction with other disciplines. These are chiefly the guidance and control mechanics, avionics, aerodynamics, flight test, computer software, operations analysis, and human factors groups. Most of the groups consider the man-machine interface, but the activities of the human factors group are probably most important in terms of impact on training system development.

Human factors studies, as a rule, use service or line pilots and focus on the cockpit to ensure that the aircraft is operable under a variety of mission conditions. Many cockpit configurations are examined during development. The ones used during the later stages of design are very close to the first aircraft. If human engineering has been effective, few changes will occur as a result of the flight test program because of crew operability problems. In the case of one recent fighter, the configuration of the cockpit is today essentially the same as the simulated cockpit established before the first flight.

Human engineering is the complement of training in that attempts are made to produce the most operable system possible in terms of crew use. Maximum operability is sometimes sacrificed in deliberate cost, complexity, and weight tradeoffs, and thus some tasks are identified for special emphasis during training. Consequently, an effective cockpit human engineering program should result in detailed and objective data regarding task difficulty and its various implications for training.

Approach - The iterative process used to develop a new cockpit is illustrated above. The key point is that analytical results are verified empirically in the context of mission scenarios. Current task analytic techniques are not powerful enough to identify, with the necessary certainty and precision, problems in operability. They seem particularly deficient in this regard for complex psychomotor tasks and for tasks involving new task elements found on emerging systems. The high capacity airborne computers and electro-optical displays utilized on newer aircraft led to an overabundance of pilot information presented in changing, complex formats.

Additionally, analytical results can be verified, corrected, and manipulated using digital pilot simulation models that do not require man-in-the-loop. Thus, better tools are now available to compensate for the weakness of the task analysis, particularly for complex interactive crew tasks.

During the concept design phase, preliminary crew functions are defined, operating procedures and tactics are developed, workload measured, the crew performance necessary to meet operational requirements established, and high risk training areas identified. At the same time computer software is being developed for the aircraft and for the engineering simulator.

After preliminary checkouts with engineers and test pilots, design verification is accomplished in the simulator with selected service pilots participating as test subjects and operational experts. Classroom training on the aircraft system is provided by the responsible engineer, and hands-on training is provided in the simulator.

Many planned and briefed mission segments are flown over a period of 5-10 days, with flight assignments based on experimental designs that maximize data utility. Sessions may be specific, such as air-to-air combat or carrier landings, or more encompassing depending on engineering needs. Normal operations and tactical situations are addressed with low and high workload imposed as a test condition. Numerical and graphic data and video recordings are obtained for each mission and detailed pilot debriefings provided.

The data necessary to assess the accuracy and quality of actual task performance is obtained. During early simulator flights, pilot performance is widely variable. The magnitude of this variability decreases, of course, as a function of practice. Tasks are identified which contribute to operating difficulty, such as crosschecking and the relation of switches to multifunction displays, and the use of new multifunction controls. Consequences of improper actions are identified. Target detection probability is examined as a function of mission conditions and display characteristics, and the precision required to meet operational requirements is defined.

Eye movements can be recorded to obtain information on frequency of instrument use, dwell time for each fixation, and scanning patterns. In special cases, physiological measures can be used as supplements to performance measures to indicate how difficult it is for the pilot to perform. In the future, for example, evoked brain potentials might be used in conjunction with eye-movement recordings for assessing workload.

All in all, simulation is a rich source of qualitative and quantitative data on the difficulty and performance requirements for perceptual-motor and cognitive tasks. The lessons learned and the information acquired in designing an aircraft can be of great value in identifying critical and difficult crew functions and defining training simulator configurations.

NATURAL LANGUAGE INTERFACE

ISSUE

- EXCESSIVE TRAINING REQUIRED

APPROACH

- DEVELOP CRITERIA FOR CREW INTERACTION WITH ON-BOARD SYSTEMS

BENEFITS

- REDUCED TRAINING
- GREATER PERFORMANCE ACCURACY
- SAFETY
- MISSION SUCCESS

Computer software should be developed so it does not require extensive operator training to interact with computer. Ideally the interaction with the computer will be "user friendly"--require no learning.

PRIORITY AND INHIBIT LOGIC

ISSUE

- AUTOMATION WILL REQUIRE MAN TO INCREASINGLY ASSUME THE ROLE OF MONITOR/DECISION MAKER/MANAGER--i.e., "THE FINAL REDUNDANCY"
- STRESS AND SYSTEM COMPLEXITY HIGH

APPROACH

- DEFINE CRITERIA FOR PRIORITY LOGIC FOR FAULT ANNUNCIATION
- DEFINE CRITERIA FOR INHIBIT LOGIC FOR RELEVANT TRAFFIC MANAGEMENT
- UTILIZE LOGICAL SYSTEMS ANALYSIS, EXPERT SURVEY AND EMPIRICAL TESTS

BENEFITS

- OPTIMAL USE OF MAN IN SPACE

As automation increases, man's role will become increasingly that of a monitor/decision maker/manager. He will probably always be retained as the final redundancy, reqhired to "take over" in the event of any unprotected system failure. Stress is apt to be high; mental set, familiarity skills are all apt to be low particularly with reliable systems. It is important, therefore, that the operator be unburdened from extraneous or redundant information. The warning system should provide clear, concise, unambiguous guidance for decision making and action. Priority logic would annunciate faults in the order of "most critical first", inhibit logic would not display caution or warning information that was unimportant at that time. Because, however, of the changing priorities resulting from differing phases of flight, environmental or other systems, many combinations of condition will have to be assessed including some requiring information not apt to be available to the computer. Some method of resolving this issue should be developed.

DATA ENTRY

ISSUE

- CURRENT METHODS (KEYBOARD, VOICE, MODE SELECTION, etc.) ALL HAVE SIGNIFICANT LIMITATIONS

APPROACH

- SYSTEMATIC REVIEW OF EXISTING DATA TO ESTABLISH GUIDE-LINES
- SYNTHESIS OF TECHNOLOGY TO SEEK BREAKTHROUGH

BENEFITS

- ERROR POTENTIAL REDUCED
- IMPROVED SAFETY AND MISSION SUCCESS

Interaction with computer requires human input. This can be done in any of a number of ways including keyboards, voice recognition, or mode selector keys. All of the existing methods have significant limitations. Keyboard entry, for example, is subject to high error rate when the operator is stressed, even with a scratch pad. Menu-select has been used to help overcome deficiencies but this approach may require significant time. Voice entry has a number of problems including a slow rate of input, erroneous and recognition or inadvertent activation potential. New methods and/or systematic guidelines of strengths, weaknesses, trade-offs of existing methods should be developed. A subsidiary problem is standardization of keyboard formats.

DATA STORAGE AND RETRIEVAL

APPROACH

- DEVELOP A STATE-OF-THE-ART SYSTEM FOR REPLACEMENT OF CURRENT FLIGHT DATA FILE BY ESTABLISHING CRITERIA AND METHODS FOR COMPRESSION, PRESENTATION, AND EFFECTIVE UTILIZATION OF DATA

BENEFIT

- WEIGHT } SAVINGS
- VOLUME } SAVINGS
- EFFICIENCY IMPROVEMENT

Current practice in spacecraft is to rely heavily on paper documentation for uplink information, experimental procedures, diagnostics, and emergency procedures. This practice, while providing relatively permanent records, is wasteful of crew time because of slow access. It may also be wasteful of space and weight.

A data storage and retrieval system could be substituted. It would probably require less space and would certainly reduce access time if properly diagnosed.

The storage and retrieval system must be optimized for space crew usage. An off-the-shelf approach to hardware or software would probably result in poor performance and poor crew acceptance. Formatting of information should be studied and developed specifically for efficient presentation and use by the crew. Diagrams, text, and data access procedures must be specifically tailored for viewing in the spacecraft environment. A research and development effort should be undertaken to determine the optimum formatting of information and the best types of data entry and display.

WORKLOAD EVALUATION

APPROACH

- DEVELOP METHODS FOR MEASUREMENT OF ZERO-G WORKLOADS, ESTABLISHING CRITERIA FOR ACCEPTABLE WORKLOADS AS A FUNCTION OF TIME
- DEVELOP METHODS FOR ASSESSMENT OF INTERACTION OF SPACEFLIGHT CREW WORKLOADS AS A FUNCTION OF STRESS

BENEFIT

- IMPROVED CREW EFFICIENCY
- AVOID POSSIBLE LOSS OF FLIGHT OBJECTIVES

Research is progressing on understanding and quantifying mental workload in a nominal 1 G environment. Several researchers are currently engaged in developing and validating procedures for aircrew workload assessment. These procedures will aid in determining the mental loads that aircrew stations impose on their operators.

It appears that no similar quantification effort for workload evaluation in spacecrew stations has been undertaken. Furthermore, any guidelines developed for 1 G environments probably could not be directly applied to zero-G environments. Unless procedures are developed, it is likely that spacecrew members may experience unacceptable mental loads, possibly resulting in mistakes and reducing the level of mission success.

Coupled with the problem of mental load is the problem of stress overtime. Acceptable mental load may decline as mission length increases, because of the possible interaction of stress with load. Physical load may also play a role in acceptable mental load.

In many cases, research should be undertaken to develop valid and reliable methods of workload measurement for space crew stations. These methods should then be used to specify acceptable load levels as a function of time in space. This problem will become more important as spacecrews begin to include more individuals not fully accustomed to the rigors of high performance flight.

RESTRAINT SYSTEMS

APPROACH

- ESTABLISH MULTIDISCIPLINARY RESEARCH TEAM TO EXAMINE ISSUES AND HISTORY
- INVESTIGATE ALL POSSIBLE APPROACHES

BENEFITS

- GENERIC SYSTEMS ELIMINATE INDIVIDUALIZED AND STYLIZED DESIGNS, REDUCE COSTS AND IMPROVE EFFICIENCY

While a great deal of effort has already been expanded on restraint systems, it appears that they still are not totally adequate. Restraints appear to fall into two major categories: foot restraints and body (torso) restraints. The need for these restraints arises because spacecrew members are routinely required to exert forces and torques, which must be counter-balanced to avoid unwanted body translations and rotations.

Because so much of the working time of future spacecrews will be spent in fixed, but unseated positions while performing some additional manipulation, efficient forms of restraints should be developed if possible, due to the wide variety of work sites in a Space Station.

A research team having multiple interdisciplinary backgrounds should re-examine the restraint problem. This group should not include those who have worked on the problem previously. However, the group should have access to them. The group should examine every conceivable approach to restraint including mechanical, pneumatic, electrostatic, electromagnetic, and various combinations. The research team should brainstorm prior to developing the most promising approaches, in hopes of achieving the greatest probability of success in evolving a new and better restraint system.

OPTIMIZED CREW INTERFACE WITH INFORMATION MANAGEMENT SYSTEMS

ISSUES

- CURENT I/Fs NOT OPTIMAL AND CAN BE IMPROVED
- SYSTEMATIC AND COHERENT APPROACH REQUIRED FOR SPACE STATION

APPROACH

- REVIEW AND APPLY CURRENT HF DATA BASE TO THE PROBLEM
- SYSTEMATICALLY CAPITALIZE ON DOD AND COMMERCIAL EXPERIENCE

BENEFIT

- IMPROVED CREW EFFICIENCY
- AVOID LOSS OF MISSION OBJECTIVES

Several assumptions stated upfront:

(1) Existing interfaces are not optimal with respect to the user.

(2) These may be optimized with respect to the variables which affect the operator's ability to acquire, process and utilize information from the system.

(3) Areas of concern may be:

a. Determination of what information is necessary to provide given the system, mission, task and previous training and experience of the operator.

b. Quality of information presentation (contrast, intensity, resolution, distortion, etc.) are operator fatique issues and related standards appropriate in zero-g.

c. Spatial/temporal configuration of the information within the display.

d. Spatial configuration of displays within cockpit suite with respect to subtask, task or mission requirements.

e. <u>Portrayal/coding of information</u> in displays. These relate to at least two sets of issues.

   1. Symbolic, pictorial, alphanumeric representations of information.

   2. Use of coping devices to prioritize or emphasize classes of information (issues of priority/inhibit logic and warning attentional directors will be treated elsewhere).

f. Definition of adequate metrics (probably including workload quantification) for system interface performance assessment.

(4) General Approach

a. Consult the existing human factors data base available in the general and technical report literature. Do not re-invent the wheel!

b. Systematically capitalize on the lessons learned from related experience internally and outside the organization.

(5) Less general considerations:

a. In the generally passive mission environment it may be possible to <u>reduce a number of discrete controls</u> and displays into a sort of adpative crewstation on either a "menu select" or automated screening basis. This may be task determined or based on individual operator differences.

b. Given issues of test paint, bi-dextral control requirements should probably be minimized. Use of biocybernetic control techniques involving heat, eye or voice control designation may be useful.

c. Consider deployment of integrated tactite, aural and visual displays.

d. <u>Eliminate/simplify highly coded information</u>. Consider pictorial and mimetic displays where possible. 3-D displays could be used to provide natural spatial analogs such that the location of information relative to the operator has meaning as well as the system symbology which is presented.

FACILITY HYGIENE

ISSUE

- LARGE ORBITAL FACILITY DECONTAMINATION ISSUE NOT HERETOFORE ADDRESSED

APPROACH

- STATUS REVIEW, STATE-OF-THE-ART CONSOLIDATION
- TECHNOLOGY DRIVERS IDENTIFIED
- DESIGN CRITERIA DEVELOPMENT

BENEFITS

- IMPROVED ON-ORBIT EFFICIENCY

Self Explanatory

BULK FOOD SYSTEMS

ISSUE

- BULK FOOD ACQUISITION, STORAGE, PREPARATION FOR LARGE SPACE STATIONS IS NEW TECHNOLOGY

APPROACH

- STATUS REVIEW, STATE-OF-THE-ART CONSOLIDATION
- TECHNOLOGY DRIVERS IDENTIFIED
- DESIGN CRITERIA DEVELOPMENT

BENEFITS

- IMPROVED ON-ORBIT EFFICIENCIES

Self Explanatory

REPORT OF THE
EVA
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EVA WORKING GROUP

ISSUE

- NASA DOES NOT HAVE A CLEARLY STATED POLICY ON EVA

APPROACH

- NASA MUST DEVELOP A POLICY WHICH ACTIVELY SUPPORTS EVA AS AN OPERATIONAL TOOL
- DEVELOP AN INTEGRATED EVA DESIGN GUIDELINE
  - WHAT CAN BE DONE WITH EVA?
  - HOW TO DESIGN PAYLOADS TO USE EVA
  - WHAT DOES EVA COST THE USER?

BENEFIT

- ELIMINATE EXISTING CONFUSION ABOUT EVA CAPABILITY
- SAVE PAYLOAD DESIGNERS MONEY
- IMPROVE SHUTTLE CAPABILITIES

EVA WORKING GROUP

ISSUE

- EVA TIMELINES IS INCREASED SIGNIFICANTLY DUE TO THE CREWMAN'S PRE-BREATH REQUIREMENT

APPROACH

- DEVELOP A HIGHER PRESSURE EMU $\approx$ 8 psi

BENEFIT

- REDUCE EVA OVERHEAD TIME
- ALLOW FOR QUICK CABIN EGRESS
- TECHNICAL IMPROVEMENTS ARE USEFUL AT ALL PRESSURES, i.e., 8 psi OR 4 psi

EVA WORKING GROUP

ISSUE

- SHUTTLE EVA EQUIPMENT DOES NOT INCLUDE THE CAPABILITY TO ANCHOR AN EVA CREWMAN AT AN UNPLANNED WORKSITE--EXTERIOR TO THE PAYLOAD BAY

APPROACH

- DEVELOP A UNIVERSAL WORKSTATION CAPABLE OF HOLDING THE EVA CREWMAN IN LOCATIONS NOT SPECIFICALLY DESIGNED FOR EVA

BENEFITS

- BETTER USE OF MAN AS A TOOL IN SPACE
- SALVAGE MECHANIZED PAYLOADS
- ALLOW EXTERIOR REPAIR OF ORBITER

EVA WORKING GROUP

ISSUE

- EVA TOOLS ARE NOT STANDARD--EACH USER BRINGS HIS OWN SPECIAL TOOLS

APPROACH

- ESTABLISH A STANDARD SET OF EVA TOOLS AND MAKE THEM AVAILABLE TO PAYLOAD DESIGNERS EARLY

BENEFIT

- CARRY LESS OVERHEAD WEIGHT AND STANDARDIZE PAYLOAD DESIGNS TO USE THE SAME TOOLS

EVA WORKING GROUP

ISSUE

- TECHNICAL IMPROVEMENTS IN EVA EQUIPMENT

APPROACH

- IMPROVE EVA GLOVES
- INTEGRATE COMMUNICATIONS IN HELMET
- PROVIDE "HEAD-UP" CWS DISPLAY FOR EMU
- DEVELOP NON-VENTING PORTABLE LIFE SUPPORT SYSTEM
- REGENERABLE CO_2 REMOVAL FOR PORTABLE LIFE SUPPORT
- DEVELOP LI BATTERY FOR LSS
- DEVELOP SUITS WITH QD TYPE ASSEMBLY
- AUTOMATE BETWEEN FLIGHTS, TEST AND CHECKOUT OF EMU

EVA WORKING GROUP

ISSUE

- SHUTTLE ORBITER NOT OPTIMIZED FOR EVA

APPROACH

- FOR THE NEXT NASA PROGRAM WE SHOULD:
  - ESTABLISH EVA AS A SPACECRAFT REPAIR TOOL EARLY
  - SIZE THE AIRLOCK ADEQUATELY (ORBITERS A/L IS TOO SMALL)
  - FACE FACTS ABOUT "CAN'T FAIL DESIGNS"
  - ESTABLISH EVA ENVELOP ROUTES EARLY IN THE DESIGN PHASE AND RETAIN THEM
  - STANDARDIZE GOOD DESIGN PRACTICES TO TAKE ADVANTAGE OF EVA LATER

REPORT OF THE
TELEOPERATION
WORKING GROUP

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TELEOPERATION IN SPACE

ISSUES

- GUIDANCE AND CONTROL
- SENSING AND PREPROCESSING
- DISPLAYS
- INFORMATION MANAGEMENT
- WORKLOAD
- SAFETY

APPROACH

- MODELING, SIMULATION, LAB EXPERIMENTS

BENEFITS

- DATA BASE, DEVICES, TECHNIQUES

This viewgraph summarizes the Teleoperator Working Group's views and recommendations. The subsequent viewgraphs present some details of the main topics and issues.

The Working Group's consensus was that, in future systems, the human operator in the teleoperator man-machine interface will require a greater sense of presence of the remote task ("telepresence"). This in turn requires advances in controllers, sensing, displays and information management. Control systems that allow the operator to interact in varying modes with the remote machine must be developed when the complexity of tasks and the complexity of teleoperator systems increases.

The Working Group endorsed an empirical approach to the R&D issues, supported with appropriate modeling and simulation studies to form a coherent frame for human factors data base development related to teleoperation in space. The consensus was that a space-specific human factors data base does not exist for teleoperation.

GUIDANCE AND CONTROL

- CONTROL MODES
  MANUAL/BILATERAL
  COMPUTER/INTERACTIVE/SUPERVISORY
- CONTROL REFERENCING
  SCALING (KINEMATIC AND DYNAMIC)
  INDEXING (PROPRIOCEPTION AND VISUAL FRAME)
- CONTROL LANGUAGES
  ANALOG
  SYMBOLIC
- COOPERATIVE CONTROL
  MULTI-ARM SYSTEMS
  MULTI-OPERATOR SYSTEMS
- GUIDANCE SENSORS
  VISUAL
  NON-VISUAL
- TIME DELAY--COMPENSATION

The break-down of the guidance & control issues expresses two major points:

(1) The development and evaluation of controls should be pursued by taking an operator-centered viewpoint.

(2) Relate the human operator's involvement in the control to the sensory (or guidance) information available to the operator.

The human involvement in the control under time-delay conditions was recognized as a major problem area.

SENSING

- VISUAL
  - DISTRIBUTED--COORDINATED
  - SCENE-ENHANCED/SCREEN-ENHANCED
  - STEREOSCOPIC
  - FRAMES FOR CONTROL, STATIC/MOBILE
- NON-VISUAL
  - GEOMETRIC-TYPE
  - FORCEC/TORQUES
  - CONTACT/TACTILE
- HAZARD DETECTION/WARNING
- "SMART" SENSORS
  - PREPROCESSING/COMPRESSING
  - FORMATTING
  - BANDWIDTH

The break-down of the sensing issues reflects two major points:

(1) The visual sensing instrumentation in teleoperation is primarily serving the interest of the human operator's visual perception of the remote task.

(2) For true "telepresence" and safe operation, the non-visual sensors are essential elements of the system.

DISPLAYS

- MULTIFUNCTION
  - FORMATS
  - INTEGRATION
- TASK-RELATED
  - OPERATOR-CONTROLLED
  - EVENT-DRIVEN
- COMPUTER GRAPHICS
  - REFERENCE FRAME
  - 3D-HOLOGRAPHY
- "SMART" DISPLAYS
  - CONTEXT-ORIENTED
  - UNBURDENING, e.g., AURAL, SPEECH-SYNTHESIS

The break-down of the display issues expresses two major points:

(1) The displays primarily convey non-visual information to the operator in visible or audible forms.

(2) The "intelligence" of the displays is a basic requirement in an information-rich control/decision environment.

INFORMATION MANAGEMENT

- TASK STRUCTURE
- STRATEGY/PLANNING
- PROTOCOL
- CONTINGENCIES
- PLAN MODIFICATIONS
- FAULT IDENTIFICATION/EVALUATION

USING APPLICATION OF AI TECHNIQUES

The break-down of the information management issues reflects the need to aid the operator and operation using AI techniques acting on a large data base.

WORKLOAD

- TASK ANALYSIS
- ASSESSMENT/MEASURES
- MANAGEMENT/OPTIMIZATION

The break-down of the workload issues are related to the physical, physiological and psychological conditions of the operator.

APPROACH

- GENERIC SET OF TASKS (INCLUDING TMS)

  COMPARATIVE PERFORMANCE OF BENCHMARK TESTS

  EVA VS. TSM
  TSM VS. TSC/I
  TSC/I VS. TSS/R

- MODELING

  STRUCTURES/PARAMETERS (INVOLVING OPERATOR)

  MATHEMATICAL SIMULATION

- LABORATORY

  EXPERIMENTAL SIMULATION
  1 G - NB - ϕG

  BENCH-MODELS; DEVICES

  TECHNIQUES; DEMOS

The development of generic set of tasks should consider the practical implications of conducting benchmark tests in order to compare task performance in alternative man-machine operation modes. The alternative operation modes are:

EVA: suited astronaut

TSM: teleoperator system, in fully manual control mode

TSC/I: teleoperator system, in man-computer interactive control mode

TSS/R: teleoperator system, in high-level supervised robot control mode.

The experimental laboratory work should consider all three working conditions:

Zero-g,

Natural buoyancy,

One-g,

REPORT OF THE
GROUND/SPACE OPERATIONS
WORKING GROUP

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TECHNOLOGY REQUIREMENTS FOR GROUND/SPACE OPERATIONS

- CONTROLS/DISPLAYS
- AUTOMATION
- ROLE OF MAN VS. MACHINE
- EXPERT SYSTEMS
- ASSEMBLY/INSTALLATION
- OPERATIONS PLANNING/SCHEDULING
- LEARNING TECHNOLOGIES

CONTROLS/DISPLAYS

- ADAPTIVE INTERFACES
- TEXT/GRAPHICS INTEGRATION
- VISUAL/NON-VISUAL SENSOR INTEGRATION
- VOICE INTERACTION

BENEFITS

- REDUCTION OF HUMAN ERROR
- ENHANCED SAFETY AND EFFICIENCY

RECOMMENDED APPROACH

- SURVEY THE STATE OF THE ART/PARTICIPATE IN OTHER STUDIES
- SPECIALIZED STUDIES

AUTOMATION

- ROBOTICS/REMOTE CONTROL FOR HAZARDOUS OPERATIONS EXAMPLES:
    - PROPELLANT SERVICING
    - UMBILICAL CONNECTIONS
- AUTOMATION FOR ROUTINE OR REPETITIOUS TASKS

BENEFITS

- ENHANCED SAFETY AND EFFICIENCY
- REDUCTION OF HUMAN ERRORS

RECOMMENDED APPROACH

- SURVEY THE STATE OF THE ART/PARTICIPATE IN OTHER STUDIES
- SPECIALIZED STUDIES

THE ROLE OF MAN VS. MACHINE

- SYSTEMS SUPERVISOR VS. OPERATOR
- ROUTINE/SPECIALIZED OPERATIONS
- MAN-TENDED VS. PERMANENTLY MANNED SPACE STATION
- MAINTENANCE OF CONTINGENCY SKILLS

BENEFITS

- EFFICIENCY--RESERVE MAN FOR WHAT HE CAN DO BEST
- ENHANCED SAFETY
- REDUCTION OF HUMAN ERRORS

RECOMMENDED APPROACH

- SPECIALIZED STUDIES

EXPERT SYSTEMS

- DECISION SUPPORT
  - TROUBLESHOOTING AND FAULT ISOLATION
  - CONTINGENCY/EMERGENCY OPERATIONS
  - LAUNCH "REDLINES"
- GENERATION/VERIFICATION OF SOFTWARE
- DATA/TREND ANALYSIS

BENEFITS

- ENHANCED EFFICIENCY AND SAFETY
- REDUCTION OF HUMAN ERRORS

RECOMMENDED APPROACH

- PUSH THE STATE OF THE ART FOR OPERATIONS
- SPECIALIZED STUDIES

ASSEMBLY/INSTALLATION

- SIMPLER, BETTER CONNECTIONS
  - MECHANICAL
  - ELECTRICAL
  - FLUID
- INTERFACE VERIFICATION
  - LEAK CHECKS
- HANDLING AND ALIGNMENT TECHNIQUES

BENEFITS

- SIMPLIFIED OPERATIONS
- PREPARATION FOR SPACE OPERATIONS

RECOMMENDED APPROACH

- SPECIALIZED STUDIES

OPERATIONS PLANNING/SCHEDULING

- PROBLEM TRACKING
- INVENTORY FORECASTING
- STATUS AND CONTROL

BENEFITS

- MORE EFFICIENT OPERATIONS
- HIGHER PROBABILITY OF MEETING MILESTONES

RECOMMENDED APPROACH

- SURVEY THE STATE OF THE ART
- SPECIALIZED STUDIES

LEARNING TECHNOLOGIES

- TRAINING TECHNIQUES
- INDIVIDUALLY ADAPTIVE CAPABILITIES

BENEFITS

- ENHANCED SAFETY AND EFFICIENCY
- REDUCTION OF HUMAN ERRORS

RECOMMENDED APPROACH

- SURVEY THE STATE OF THE ART
- SPECIALIZED STUDIES

GENERAL COMMENTS

- ALL TECHNOLOGY DEVELOPMENT MUST INCLUDE OPERATIONAL CONSIDERATIONS
- RESISTANCE TO CHANGE COULD IMPEDE INCORPORATION OF NEW OPERATIONAL TECHNIQUES
- SPECIALIZED STUDIES SHOULD INCLUDE QUANTIFICATION OF COSTS/BENEFITS
- ARE WE EXPECTED TOO MUCH FROM EXPERT SYSTEM TECHNIQUES?

REPORT OF THE
ROBOTICS/SUPERVISORY CONTROL
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HUMAN FACTORS ISSUES

ISSUE 1

- LACK OF USER ORIENTED LANGUAGE FOR OPERATION OF MACHINES (ROBOTS) IN SPACE

⇨ INVESTIGATE AND ESTABLISH HUMAN/MACHINE REQUIREMENTS

ISSUE 2

- MACHINE CONTROL WITH COMMUNICATION DELAY

⇨ EXTEND EXISTING RESEARCH TO DETERMINE REQUIRED LEVELS OF AUTONOMY

ISSUE 3

- NEED OF COMPUTER BASED MODELS AND GRAPHIC DISPLAYS TO:
  1. HELP OPERATOR TO PLAN AND TEACH MACHINE (ROBOT)
  2. ALLOW VISUAL SIMULATION
  3. ALLOW ANY VISUAL VIEWPOINT OR ZOOM
  4. CAN BE UPDATED RELATIVE TO REAL WORLD
  5. CAN BE USED DIRECTLY FOR MACHINE CONTROL

ISSUE 4

- NEED OF UNDERSTANDING/THEORY ON HOW HUMANS INTEGRATE AND INTERPRET SENSORY FEEDBACK FROM DIFFERENT KINDS OF SENSORS

ISSUE 5

- LEVEL OF SUPERVISION OF MACHINE SYSTEMS SUCH AS SPACE STATION AND/OR ROBOTS BY HUMAN OPERATOR(S)

⇨ DETERMINE THE SUBSYSTEM LEVEL THAT MUST BE REACHABLE

⇨ DETERMINE HUMAN TRAINING REQUIREMENTS

⇨ DETERMINE REQUIRED HUMAN CHARACTERISTICS

ISSUE 6

- VARIABLE/ADAPTIVE CONTROL ACCESS BY HUMAN OPERATOR(S)

⇨ INVESTIGATE AND DETERMINE HUMAN FACTOR REQUIREMENTS

HUMAN FACTORS ISSUES (CONT.)

ISSUE 7

- VARIABLE/ADAPTIVE FUNCTION ALLOCATION BETWEEN HUMAN(S) AND MACHINE(S) OR ROBOT(S)

⇨ INVESTIGATE AND DETERMINE HUMAN FACTOR REQUIREMENTS

ISSUE 8

- TRAINING REQUIREMENTS FOR TOTAL SYSTEM

ISSUE 9

- ORGANIZATIONAL STRUCTURE OF MAN-MACHINE (HUMANS-ROBOTS) SYSTEM CONSIDERING A SPACE STATION CREW OF UP TO 12 PEOPLE AND UP TO SEVERAL SUPERVISED ROBOTS

⇨ STUDY AND DETERMINE OPTIMAL MANAGEMENT (DECISION-MAKING) STRUCTURE

⇨ INVESTIGATE REQUIREMENTS FOR AND DEFINE AUTOMATIC PLANNING AND DECISION MAKING TOOLS TO COPE WITH TIME LIMITATIONS, SYSTEM COMPLEXITY, GROUP DYNAMICS, GROUP COORDINATION, AND GROUP/MACHINE BEHAVIOR

⇨ DEVELOP APPROPRIATE INTERACTIVE DISPLAY TECHNIQUES, BUILT-IN MODELS OF THE SYSTEM, EXPERT SYSTEMS, AUTOMATED PLANNING SYSTEMS, ETC.--DEVELOP HUMAN FACTOR REQUIREMENTS

⇨ DEVELOP STRATEGIES FOR FAIL SAFE AND/OR FAULT TOLERANT OPERATIONS

ISSUE 10

- SYSTEM PERFORMANCE AND VALIDATION

⇨ DEVELOP METHODOLOGY FOR ASSESSING SUPERVISORY SYSTEM PARAMETER SENSITIVITY INCLUDING HUMANS

⇨ DETERMINE SUPERVISORY SYSTEM PERFORMANCE CRITERIA

DEVELOP METHODOLOGY FOR "TEST BED" VALIDATION

⇨ INVESTIGATE APPROACHES FOR PROGRESSIVE VALIDATION OF SUPERVISORY/ROBOT SYSTEM (VALIDATING/LEARNING ON THE JOB)

⇨ ESTABLISH AND DEFINE MEANINGFUL FLIGHT TESTS SCENARIOS

REPORT OF THE
BEHAVIORAL INTERACTIONS AND HABITABILITY FACTORS
WORKING GROUP

Steward Nachtwey, Chairman (NASA/JSC)

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Stephan Cheston (Georgetown University)
Steve Hall (NASA/MSFC)
Dave Stephens (NASA/LARC)
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SPACE STATION WILL BE A COMPLEX SYSTEM
REQUIRING ADVANCES IN DESIGN AND OPERATIONS:

- HABITABILITY
- CREW SELECTION
- CREW TRAINING
- OPERATIONAL PROCEDURES

WHY ADVANCES ARE NEEDED:

- LARGER CREW SIZE
- LONGER DURATION
- INCREASED AUTONOMY
- MIXED CREWS
  - DISCIPLINES
  - SEXES
- NOT TEST PILOTS--CREW WILL BE PASSENGERS
- LESS GLAMOUR--LESS PUBLIC VISIBILITY

HABITABILITY

THAT WHICH INVOLVES THE NATURE AND QUALITY OF AN ENVIRONMENT, MEASURED IN TERMS OF HOW QUICKLY AND COMPLETELY HUMANS CAN ADJUST TO THEM AND HOW SUCCESSFULLY THEY SUPPORT OPERATIONAL EFFECTIVENESS, COMFORT, PERSONAL WELL-BEING, AND MORALE.

HABITABILITY CONSIDERATIONS

INTERNAL ENVIRONMENT
- TEMPERATURE AND HUMIDITY
- AIR MOVEMENT
- GAS COMPOSITION
- ACOUSTIC CHARACTERISTICS
- LIGHTING LEVELS

ARCHITECTURE
- VOLUME AND GEOMETRY OF COMPARTMENTS
- ACCESS AND EGRESS
- COLORS AND TEXTURES
- STOWAGE AND RETRIEVAL

MOBILITY
- LOCOMOTION AIDS
- RESTRAINT MODES
- MECHANICAL AIDS

HABITABILITY CONSIDERATIONS (CONT.)

FOOD

- VARIETY AND TYPES AVAILABLE
- STOWAGE AND RETRIEVAL
- MEAL PREPARATION AND SERVING
- MEAL CONSUMPTION

CLOTHING

- DUTY
- OFF-DUTY
- SLEEP WEAR

PERSONEL HYGIENE

- BATHING
- GROOMING
- BODY WASTE COLLECTION

HOUSEKEEPING

- CLEANING EQUIPMENT, PROCEDURES AND SCHEDULES
- REFUSE COLLECTION AND DISPOSAL

COMMUNICATIONS

- INTRAVEHICULAR (WITHIN FLIGHT CREW)
- OUTSIDE (FAMILY, FRIENDS, AND GROUND CONTROL)

CREW ACTIVITIES

- WORK/REST SCHEDULES
- OFF-DUTY ACTIVITIES
    - --LEISURE AND ENTERTAINMENT
    - --SLEEP
    - --EXERCISE

HABITABILITY ELEMENTS OF CONCERN

NOISE CRITERIA
- SLEEP
- COMMUNICATION
- HEARING IMPAIRMENT
- COMFORT

NOISE AND VIBRATION CONTROL

SPACE MOTION SICKNESS ENHANCERS/REDUCERS

RESTRAINTS/MOBILITY AIDS

ARTIFICIAL G

WASTE MANAGEMENT

ARCHITECTURE
- VOLUME
- PRIVACY
- TRAFFIC PATTERNS

CREW SELECTION CRITERIA

- TECHNICAL COMPETENCE FOR MISSION REQUIREMENTS
- ADAPTIVE SOCIAL COMPETENCE FOR EFFECTIVE INTERACTION WITH A SMALL, DIVERSIFIED GROUP OPERATING IN A STRESSFUL ENVIRONMENT

METHODS OF EVALUATION OF ADAPTIVE COMPETENCE

- PERSONAL DEVELOPMENTAL HISTORY
- FUTURE-SELF ATTITUDES
- STRESS TESTING
- PEER EVALUATIONS

CREW TRAINING

TECHNICAL TRAINING

SOCIAL SENSITIVITY TRAINING

- IMPROVE UNDERSTANDING OF OTHERS IN CIRCUMSTANCES THAT INTERMIX SEXES, EDUCATIONAL LEVELS, SOCIAL CLASSES, CULTURES, AND WORLD VIEWS

COMMUNICATION SKILLS

- TRAIN TO ARTICULATE ANXIETIES AND FRUSTRATIONS TO AVOID BUILD-UP AND DEVIANT BEHAVIOR

GROUP PERFORMANCE

- TRAIN LEADING, FOLLOWING, AND FACILITATING COMPROMISE

SIMULATIONS OF SPACE STATION GROUP DYNAMICS

CREW BEHAVIOR/OPERATIONS

- ON-STATION DURATION AND CREW ROTATION
- COMMAND ORGANIZATIONS/RESPONSIBILITIES
- WORK/REST CYCLES
- OFF DUTY ACTIVITIES
- MALE/FEMALE RELATIONS
- FAMILY RELATIONS
- INDIVIDUAL/GROUP COMMUNICATIONS AND SECURITY
- BEHAVIORAL CRISIS MANAGEMENT/STRESS REDUCTION
- GROUP DYNAMICS
- SENSORY MODALITIES MODIFICATION
- MAINTENANCE SUPPORT

APPROACHES

- REDUCE VOLUMINOUS LITERATURE TO USABLE HAND-BOOKS (SPACE STATION ORIENTED)

- INTERVIEW ASTRONAUTS

- SYSTEMATICALLY STUDY DURING SPACE SHUTTLE AND SPACELAB MISSIONS

- EARTH BASED SIMULATIONS

REPORT OF THE SIMULATION/TRAINING WORKING GROUP

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Ed Stark (Singer Corporation)
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Bob Sugarman (RCS)
Bob Hennessy (NRC)
Ed Shriver (Kinton, Inc.)
Dave Akin (MIT)

SIMULATION/TRAINING

- ASSUME 90-DAY TOURS; APPROXIMATELY 10-YR LIFETIME
- TRAINING INCLUDES GROUND AND FLIGHT
- SUGGEST UTILIZATION OF CAREER TRAINING TECHNOLOGISTS

- In order to scope the boundaries for simulation and training, we assumed a target of a Space Station mission with a 10-year lifetime, and crew rotations every 90 days.
- We further assumed that training considerations were for all people involved in a mission, including ground support, maintenance support, and flight and launch control personnel.
- It is recommended that, in order to fully perform training to the level required, it is beneficial to incorporate career training technologists.

SIMULATION/TRAINING

ISSUE	PROGRESS APPROACHES/ TECHNIQUES	BENEFITS
1. CURRENT SIMULATION/ TRAINING PROBLEM - SIM/TRG REQMTS INCREASING - SIM/TRG FACILITY TIME DECREASING	1. EVALUATE CURRENT TRG CAPABILITY (US) - MAXIMIZE UTILIZATION OF TRG/ENG FACILITIES - DEFINE TRG ALTERNATIVES	1. SIM/TRG DATA BASE - IMPROVE TRG EFFICIENCY
2. ARE WE USING STATE-OF-THE-ART TRG TECHNOLOGY?	2. SURVEY INDUSTRY - TECHNIQUES FOR ANALYSIS - SOLUTIONS	2. DEFINES TRG OPTIONS - SIM/TRG DATA BASE
3. CAN NASA TRG BE IMPROVED?	3. ANALYZE/SELECT FROM APPROACH (ITEM 2) AND APPLY	3. LOWER LIFE CYCLE COSTS - ABILITY TO MEET SCHEDULES - SIM/TRG DATA BASE

Item 1: The first issue identified was that we have a basic problem in simulation/training. That is that the simulation and training requirements are steadily increasing, while the available time on the various simulators is decreasing.

The approach or technique for making progress toward a solution includes a comprehensive evaluation of the current capabilities throughout the United States, in government, industrial, and academic facilities. To be addressed are those systems which may be incomplete or in moth balls.

Once identified, we must maximize the utilization of training and simulation facilities. This means to update or bring on-line facilities which are not up currently. Likewise, we must consider or use multiple shift operations.

In conjunction with the above, we must also creatively define training alternatives in order to work around those problems that the existing simulation/training capabilities do not meet.

The benefits of this approach will be to establish a simulation/training data base. It will also improve training efficiency for the current training system.

Item 2: The question was raised: Is NASA using state-of-the-art training technology? It is suspected that this is not the case due to procurement cycles, uneducated training personnel (due to intense involvement with ongoing simulation activities), and lack of available information from other training designs. This question can also be applied to developmental simulation.

The answer to the question may be found by performing a survey of industry (including industry, academia, other government agencies). The survey should address techniques for performing training analysis, and the determination of solutions for answering the question.

The benefit should be the provision of the training options that could be used by NASA based on training requirements. It will also add to the simulation/training base established from Item 1.

Item 3: The question was raised: Can NASA training be improved? The thought behind the question is self-evident. The approach for the answer is to analyze and then select an approach(es) from Item 2 and apply this technique to the future simulation and training requirements.

The benefits will be the reduction of simulator life cycle costs. It will likewise permit us to better meet mission and training schedules. Finally, it will add to the simulation/training base.

SIMULATION/TRAINING

ISSUE	PROGRESS APPROACHES/ TECHNIQUES	BENEFITS
4. PAYLOAD HARDWARE TRAINING REQMTS	4. CREATE GUIDELINES FOR PAYLOAD TRAINING: - CONCEPTS - HARDWARE	4. STANDARDIZE AND IMPROVE USER-SUPPLIED SYSTEMS
5. SPACE STATION SIMULATION AND TRG REQMTS - OPERATIONAL - SOCIAL	5. DEFINE PLAN FOR DEVELOPING TRG REQUIREMENTS	5. STATE-OF-THE-ART TRG OF MULTIPLE FOLLOW-ON CREWS: - CONSIDER SPACE STATION AS SIMULATOR/ TRAINER - HARMONIOUS CREW

Item 4: It was determined that there is a need to develop a comprehensive standard set of training requirements for the various payloads upcoming on Space Station, Spacelab, etc.

The technique recommended for correcting the problem is to create guidelines for payload training. The thrust should be for training concepts as well as for hardware.

Benefits to the payload and carrier personnel will be the standardization and improvement of user-supplied systems.

Item 5: There is a need to define Space Station simulation and training requirements, including operational and social requirements. Space Station provides a unique situation (for NASA) in that crews will be kept in a relatively small environment with a small group for relatively long time periods (up to 90 days). Further, the personnel may not be as homogeneous as previous crews and the motivation of work may not be astrong as on previous missions. This portion should be transferred to the Habitability Working Group.

The approach to define the Space Station requirements is to define a plan for developing training requirements as an initial start. It is required early in the program in order to best and most efficiently define the training portion of the mission. The program will then use this plan to develop simulation requirements.

The benefits will then provision state-of-the-art training of the various Space Station crews. It will also result in a more harmonious crew.

An additional benefit would be that with planning the Space Station itself might be used for both developmental simulation and training of flight personnel because it provides the best simulation environment.

REPORT OF THE
MAN/MACHINE FUNCTION ALLOCATION
WORKING GROUP

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MAN/MACHINE FUNCTION ALLOCATION

ISSUES	TECHNIQUES PROPOSED TO SOLVE	EXPECTED RESULTS
1. NO ACCEPTED PROCEDURE EXISTS FOR ALLOCATION OF MAN/MACHINE FUNCTIONS	1. FORMULATE DECISION TREE PROCEDURE TO CONSIDER ALTERNATIVES IN THE DESIGN OF A SYSTEM NEEDED TO PERFORM TASK	1. DESIGNS WILL BE MORE OBJECTIVE
2. CONSIDER TECHNOLOGY RISK/TRADE-OFF	2. FIND WAY TO QUANTIFY RISK FACTORS	2. ABILITY TO DEFINE BENEFITS BY A SYSTEM USING MAN-IN-THE-LOOP
3. A DATA BASE DOES NOT EXIST DETAILING THE "STATE OF THE ART" IN TECHNOLOGIES NEEDED FOR DESIGNER'S DECISION PROCESSES	3. COLLECT, INTEGRATE AND ADAPT DATA ON TECHNOLOGY CHARACTERISTICS - INVESTIGATE NATURAL LANGUAGE COMMUNICATION WITH DATA BASE MANAGEMENT SYSTEM	3. DEVELOP IMPROVED TECHNOLOGY AND PROVIDE STIMULUS TO RESEARCH

Q. Can any existing accepted techniques be used or improved?

A. No widely accepted procedure could be identified.

Q. Why are there no such procedures?

A. Knowledge of the "state of the art" in technology areas relevant to the decision making process was not readily available to those responsible for system planning.

Q. If such a data base system were available, what else would be needed by the system planner?

A. Some method of quantizing risks, trade-offs, performance of the various system alternatives in common units.

MAN/MACHINE FUNCTION ALLOCATION

ISSUES	TECHNIQUE PROPOSED TO SOLVE	EXPECTED RESULTS
4. DEVELOPMENT OF AUTOMATED ASSIST TO MAN OR DEVELOP WAY MAN CAN HELP MACHINES	4. DEFINE INFORMATION SYSTEM INTERCHANGE CHARACTERISTICS - NATURAL LANGUAGE COMMUNICATIONS	4. DEVELOP IMPROVED TECHNOLOGY
5. ADAPTIVE ALLOCATION OF FUNCTIONS IN REAL TIME	5. RESEARCH	
6. IMPACT OF AUTOMATION ON PERSONNEL TRAINING AND READINESS	6. INVESTIGATE ON-BOARD SIMULATION AND TRAINING EXERCISES	6. SYSTEM RELIABILITY AND RESPONSE TO UNEXPECTED EVENTS MAY BE ENHANCED

Q. Assuming that automated systems are all man/machine at some level, what issues need further examination?

A1. Methods are needed to facilitate automated assists to man and/also ways man can help machine (also cases in which either may be impaired).

A2. Examine the adaptive allocation of function in real-time.

A3. Examine the impact of automation on personnel training and readiness.

SESSION VII

CLOSING REMARKS

Implications for Developing a
Human Factors Research Program
for On-Orbit Operations

Dr. Melvin Montemerlo
Workshop Chairman

Two and a half days ago Dr. Ray Colladay initiated this workshop with an exciting invitation. He asked the discipline of Human Factors to help make America's space program plans a reality. We heard Dick Carlisle, Ed Gabris, and Bill Smith delineate those plans for a space station and for space transportation systems. We heard Joe Loftus and Jesco Von Puttkamer put an historical perspective on the space program and on the evolution of the astronaut role. We heard talks from NASA Center personnel on the state of the art in designing for the human in space. Astronaut Owen Garriott presented us with a personal perspective on astronaut capabilities in space. Finally we broke up into eight working groups and developed research recommendations which were just summarized by the working group chairmen.

In my closing comments, I will not attempt a review of those recommendations. Rather, I will summarize some key points that arose throughout the workshop, both during formal sessions, and during coffee breaks and meals.

1) The first is the need to take a fresh look at long-standing issues such as restraints, tools for extra-vehicular activity, and crew station design. There are people in this room who have revolutionized entire fields of endeavor by starting out with a fresh look. Duane McRuer and Ezra Krendall developed a new approach to the analysis of continuous control systems which is based on the human operator's perception of the task, and on how that perception changes as his skill level increases. Ed Shriver was one of the founders of the Job Performance Aid (JPA) movement which demonstrated that tasks previously performable only by experienced maintenance personnel could be performed by novices with proper documentation. Bold strokes such as these are not the sole province of yesteryear. You heard Ken Boff's presentation on IPID (Integrated Perceptual Information for Designers) which may well have a powerful effect on crew station design. It is fresh new looks like these that human factors specialists must take at technology issues for manned space flight.

2) The second is that to be effective, human factors specialist must work closely with the allied field of Life Sciences, Life Support, and Systems/Operations. While all three of these fields have reached a high degree of maturity, the third is not well documented.

3) The human/automation relationship is not a dichotomy. In considering function allocation to man and to machine, it must be kept in mind that it is humans who design, develop, use and maintain automated systems. Automation does not reduce the need for good man-machine interface, but rather changes this character of that interface.

4) Robots for space operations will not be capable of on-orbit assembly and servicing in the time-frame for which the space station is envisioned. The best route to their development is through teleoperators. Robots are actually nothing more than teleoperators that can perform a number of "subroutines" with little human supervision. As Ewald Heer pointed out, even highly autonomous robots will require some level of human supervisory control.

5) Since dexterous teleoperators for remote assembly and servicing will not be available in the time frame now envisioned for the space station, the only alternative is to use astronauts in the EVA environment. This will necessitate the development of improved tools and techniques.

6) Design decisions are based heavily on cost and weight tradeoffs. A working knowledge of that decision process is imperative if human factors research is to maximize its impact.

7) The astronaut population will change as space missions become more frequent and crews grow in size. This will necessitate changes in training, job aids, and in some man/machine interfaces.

8) The time available for training will decrease as space missions become more frequent. This will require improved training program design, and may require provision for on-orbit refresher training during long missions.

9) With the glamour of an orbit operations, it is easy to forget about human factors considerations in ground operations prior to launch, during launch, and ground control after launch. At present these functions are highly labor intensive and costly. The affordability of a space station may well depend on the feasibility of reducing human ground support. However, a highly autonomous space station will require quite different man/machine interfaces both on the ground and on-orbit. A particular challenge lies in developing methods for transferring the operations of assembly, check-out and launch from the ground to the space station.

10) The human factor in maintenance functions needs to be considered. There are significant issues not only for on-orbit maintenance but also for Earth-based servicing. On-orbit servicing may be accomplished from within the station or shuttle, or through EVA or teleoperations.

11) The discipline of human factors can have a greater impact if it develops design guidelines, standards, and practices which are generic rather than systems specific. Johnson and Marshall presently have human factors design guides, but they need updating.

12) International cooperation on programs like Spacelab is already being explored for the space station. Such a practice helps make a program affordable by spreading the cost, but it also introduces a myriad of problems in system design, test and operation. Human factors specialists may be able to analyze past effort of this sort to develop methods which avert or minimize such problems in the future.

The twelve points described above will be helpful in organizing and filtering the more detailed recommendations of the working groups into an integrated long-range human factors research program. The first two points (the need to take a fresh look, and to integrate with Life Sciences, Life Support and Systems/Operations) could be considered to be truisms. However, in the sometime hectic process of program planning and advocacy, it is necessary to raise such truisms to a higher state of consciousness. The final ten points encompass a larger research program that funds will permit in FY 1983. This points out the need to coordinate with the military. With respect to technology for man in space, the needs of the civil and military programs overlap. Joint research and a planned division of research responsibilities will be mutually beneficial.

The final point to be made is that the discipline of human factors has been given an entry to the space program. This decision is not without its skeptics. We will be under close scrutiny for a good while. In the zero-sum exercise of allocating limited research funds, those disciplines with a longer history and with vested interests will ask hard questions about the worth of spending money on human factors work which could have been allocated to them. Thus it behooves us to insure our program is responsive to the users. Our program must have a viable balance of short and long range payoffs which are well-defined. We must be able to state the deltas in technology that will be provided, and the benefits that will result.

The challenge of instituting a space human factors research program is truly exciting. Given the benefits that our discipline has brought to aviation, manufacturing, weapons systems, command and control, training, maintenance, and other fields, I am confident we can do the same for space.

Thank you very much for your participation.

APPENDIX A

ADDITIONAL PAPERS

SUMMARY OF MIT SPACE SYSTEMS LAB

EXPERIENCE IN EVA SIMULATIONS

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The MIT Space Systems Lab has been conducting an extensive series of tests on human construction operations in space. The primary questions addressed in this research are: what are the capabilities of humans working in weightlessness?; what is the best mix between man and machine in space?; and how much time will it take to perform the basic operations of space construction? To answer these questions, the Space Systems Lab has performed experiments at MIT, in the neutral buoyancy simulation facility at the NASA Marshall Space Flight Center, and in parabolic flight on board the KC-135 aircraft of Johnson Space Center.

In order to have confidence in the results of the neutral buoyancy simulations, a first goal of this research was to determine how well neutral buoyancy simulates true weightlessness. A computer model of the human body was developed for this purpose. This model predicted the dynamics of a person performing assembly-type tasks both underwater and in space, so that the two environments could be compared quantitatively. The model was validated using pressure suits in the Marshall neutral buoyancy tank, and in parabolic flight on board the NASA KC-135. KC-135 experiments included both linear translation of large masses (similar to the body dynamics tests underwater), and angular alignment of high moments of inertia. Results of this analysis showed that neutral buoyancy is a good simulation of true weightlessness when the masses manipulated underwater are large (greater than about 50% of the test subject's body mass).

Learning, productivity, and fatigue have all been identified as critical parameters for determining the capabilities of humans in EVA. In all of the MIT neutral buoyancy simulations of construction operations in space, learning rates have been shown to be consistently higher than expected. The average rate established was approximately 70%, with a low of 55% and a high of 80%. This compares with a typical 80% learning rate for aerospace assembly operations on earth, and represents both learning how to operate in the pressure suit (Skylab A7LB's), and learning how to assemble the structure. Productivities were established using a 36-element tetrahedral truss structure, and a variety of configurations of a 55-element "tinkertoy" type structure, assembled by a single test subject or a two person team. Productivities above 1000 kg/crew hour were demonstrated, with an average for extended operations around 500-600 kg/crew hour. Productivities for similar earth operations are typically 50 kg/crew hour. A fatigue estimate was established by having a single person perform a four hour neutral buoyancy run. This indicated that fatigue does degrade productivity over time, but an extrapolated rate of 400-450 kg/crew hour could still be maintained by a test subject working at a steady pace during an eight-hour EVA.

A study was also performed in the Marshall neutral buoyancy facility to determine how the hardware used in the assembly procedure affects learning and productivity. Similar structures were assembled both in foot restraints and without foot restraints. This indicated two important results: even after learning has bottomed out for a test subject working in foot restraints, he still has much to learn if he starts working out of foot restraints; and while productivity may be marginally higher for a subject in foot restraints, nevertheless, foot restraints are not necessary at all work stations. The structural hardware can also have an effect on productivity. Tetrahedral truss structures which rigidize themselves as each tetrahedral subcell is assembled, are easier to build than prismatic lattice structures which necessitate the use of cables on each square face for stability. It was also found that high-mass bulky equipment packages could be manipulated without too much difficulty. A parametric study of the effect of beam length and moment of inertia on productivity was performed with the following result: effective moment of inertia underwater, which includes the effect of both drag and true moment of inertia, is probably the single most important parameter affecting assembly time in neutral buoyancy simulations.

In order to investigate the optimum man/machine mix in EVA structural assembly, a variety of assembly aids have been tested in neutral buoyancy. A hand-held maneuvering unit was used as an aid to structural alignment tasks, and was satisfactory in that task. A "cherry picker" manned remote work station was constructed, and tested on the shuttle remote manipulator simulator at the Marshall Space Flight Center. It proved valuable as a mobile work platform, but was limited by the geometry of the RMS, and by difficulties in interfacing between the test subject and the RMS operator. A manned maneuvering unit was tested repeatedly at NASA Marshall, and proved to be an effective and useful tool for structural assembly. The presence of an MMU led to increased subject mobility, higher safety factors with less time impact (less requirements for work site restraints), and greater ease of supplying the assembly subjects with structural components. Tests were also performed on optimal hand controller placement and design, and on the use of a head-up display to provide MMU system status.

All assembly runs were videotaped, and time-and-motion data was collected from each of the test sessions. This data indicated that the task requiring the largest block of time for all assemblies (50%) was structural element alignment, but this is a strong function of connector design. Subject translation between work stations was performed by hand over hand maneuvering along previously assembled parts of the structure. This was not a problem either in terms of time required (20%) or because of applied loads. Loads applied to the structure during assembly were measured using strain gauges installed on one of the structural elements. Peak loads were generally found to be moments applied to a structural element after one end was attached and while the other end was being worked on.

After four years of research, it is the conclusion of the MIT Space Systems Lab that no significant human factors issues limit the utility of extravehicular activity, and that the use of crew members in EVA assembly of space structures is an effective and desirable use of the versatility of humans in space operations.

TECHNIQUES FOR SUCCESSFUL UTILIZATION OF EXTRAVEHICULAR ACTIVITY IN PAYLOAD OPERATIONS

by

Barry Boswell

McDonnell Douglas Technical Services Company
Houston Astronautics Division

The Space Transportation System (STS) offers a number of advantages over the use of expendable launch vehicles in payload operations. Paramount among these is the presence of a flight crew and the ability of the payload manager to use that crew. A prime example is the conduct of Extravehicular Activity (EVA) in support of payload operations (Figure 1). This is a very effective method of accomplishing tasks which heretofore required the use of complex automated mechanisms. The spectacular successes of the Apollo and Skylab programs clearly illustrate how man's capabilities as observer, mechanic, builder, and scientist can be utilized when extended beyond the confines of his space vehicle. The applications of EVA techniques are not limited to planned mission objectives, but include a capability to conduct unanticipated maintenance and repair operations as well. As demonstrated by the saving of Skylab, EVA can make significant contributions to a program.

The Shuttle Orbiter has EVA provisions which are baselined on all missions. These include two Extravehicular Mobility Units (EMUs), an airlock, translation and restraint aids, general purpose hand tools, and equipment stowage containers (Figure 2). Through proper planning and program development, the payload manager is able to take advantage of this existing STS service and increase reliability while at the same time reducing costs. The difficulty is in determining when and how to utilize EVA in payload operations. This issue can be divided into two areas:

- Cost effectiveness of accomplishing a task with EVA, and
- Proper development of EVA hardware and procedures.

Determining whether or not an EVA is the most effective method of accomplishing a task requires an understanding of the relative merits of using manned systems versus automated systems. Usually, this is a question of having an EVA crewmember operate a mechanism rather than designing a remotely operated device. In order to make a rational decision, the payload manager must conduct trade studies to weigh these alternatives. In basic concept, these trades are similar to those conducted to select other systems in the payload.

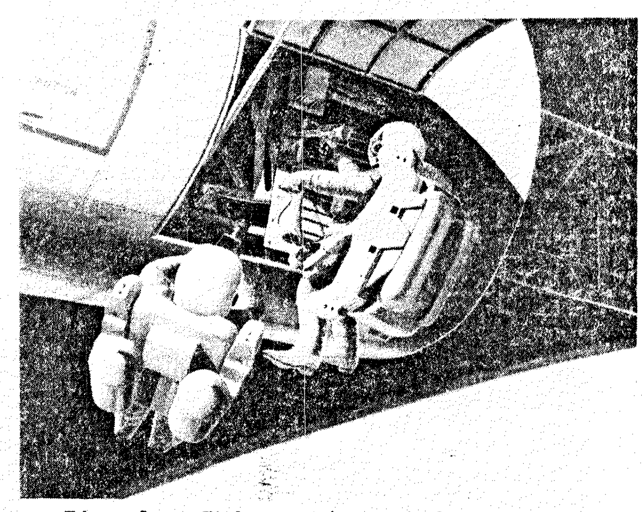
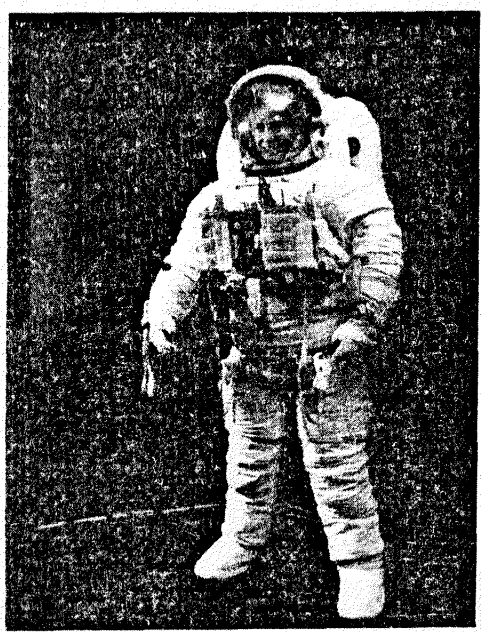
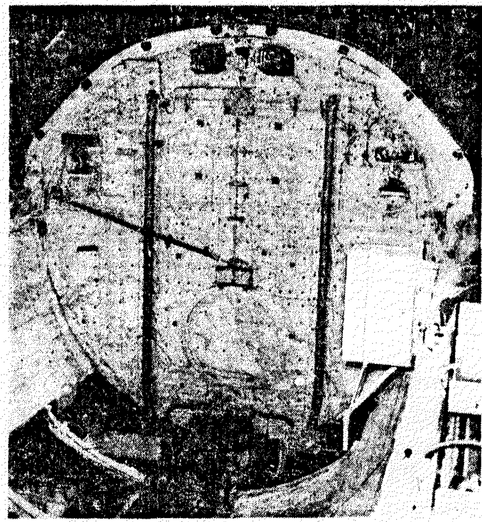


Fig. 1 - EVAs conducted for on-orbit maintenance of payloads

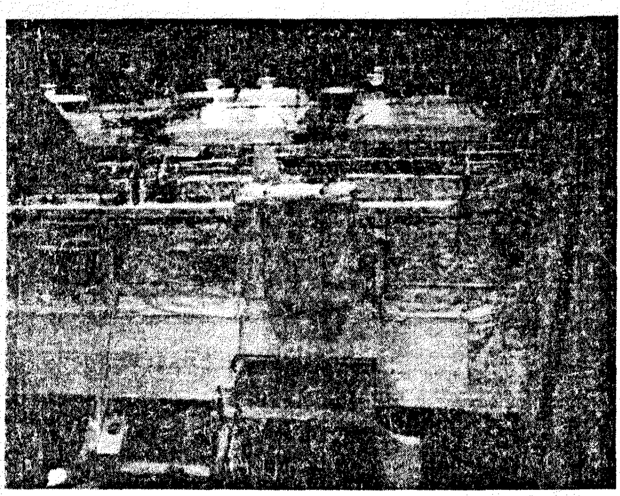
The most important point is that these trades be performed at the same time the other studies are being conducted. That is, during Phase A of the design and development process (Figure 3). The payload manager is then able to establish EVA design requirements early in the program and costly modifications or "add-ons" will be avoided later. Also, design funds are not expended on the normally more expensive automated devices. A Manned Activity Manager should be appointed early in Phase A with the



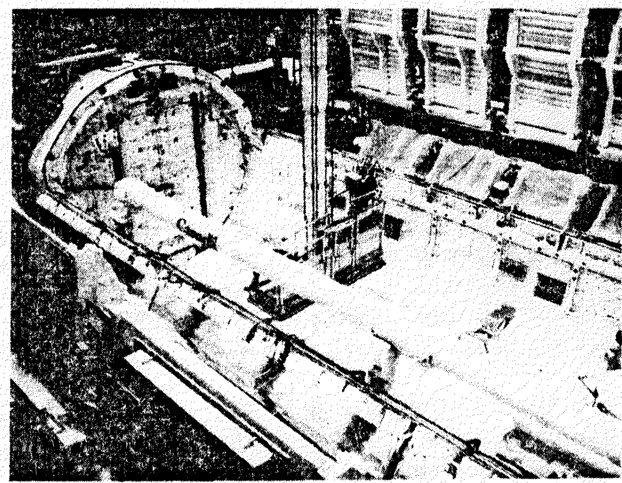
Extravehicular Mobility Unit (EMU)
Two are flown on each mission



Forward bulkhead showing handrails, airlock, CCTVs, and the Tool Box. The Portable Foot Restraint platform is mounted below the Tool Box



Tool Box mounted on sill longeron of payload bay. Slidewire standoff is visible above box



Overview of payload bay with RMS, hingeline handrails, RMS, and slidewires in place

Fig. 2 - Orbiter EVA Provisions

responsibility of insuring continued compliance with EVA design criteria through all phases of the program.

One example of a payload being developed for EVA maintainability is the Space Platform being proposed by the McDonnell Douglas Astronautics Company (MDAC). In defining this system, MDAC conducted numerous trade studies to arrive at the most effective maintenance approach for this low earth orbit satellite.

Trade studies considered the following:

- Costs of orbital maintenance
- Complementary ground logistics system requirements
- Ground-to-orbit transportation requirements
- Shuttle Orbiter revisit opportunities and cost-sharing possibilities with other payloads

PHASE 0	PHASE A	PHASE B	PHASE C	PHASE D
RESEARCH	CONCEPT STUDIES	CONCEPT SELECTION	DESIGN ▲ PDR ▲ CDR	PRODUCTION

Fig. 3 - Payload Design and Development Process

The common selection criteria used in each of these trade studies was the life-cycle cost of the alternatives. The approach selected is to design the Space Platform with sufficient reliability (through redundancy and and failure tolerance) that an autonomous back-up capability will maintain system operation until on-orbit maintenance can be performed (Figure 4). Although maintenance is accomplished during premium (EVA) mission time, analyses show the costs associated with conducting EVAs is minor compared to the alternative concepts of either extensive redundancy in all automated systems or ground servicing. Providing on-orbit servicing will extend the life of the Space Platform and substantially reduce total costs.

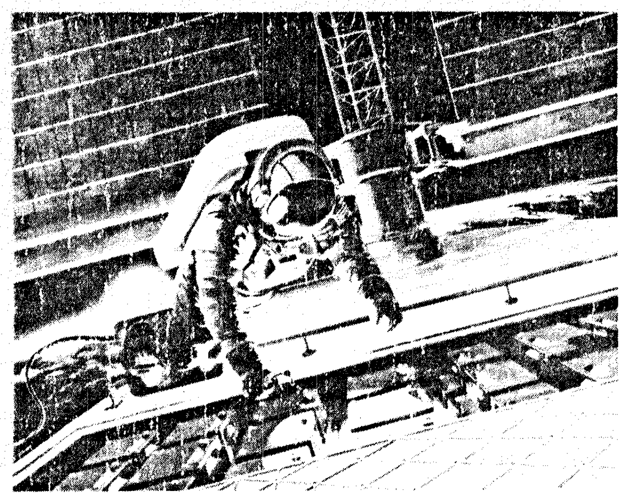


Fig. 4 - Space Platform EVA maintenance

In conducting the trade studies, the payload manager must keep two considerations in mind: (1) if a manually operated device is not the best primary system, it may still be the most effective back-up method, and (2) even though no specific EVA tasks are identified in the trade studies, the payload should still remain EVA compatible. In this case, compatibility would include: positioning mechanisms for accessibility by a suited crewmember, insuring all hazards (sharp edges, stored energy) are avoided or can be safed, and sizing fasteners, disconnects, fittings, and other hardware to be compatible with the EVA tools flown on the Orbiter and the force application capabilities of an EVA crewmember.

EVA compatibility in a non-EVA payload is a particularly sticky issue. However, a review of both past and present space programs will quickly underscore the wisdom of providing this compatibility. The exterior of the Skylab for example, was designed to MSFC STD 512, MAN/SYSTEM DESIGN REQUIREMENTS FOR WEIGHTLESS ENVIRONMENTS. Although no EVAs were planned in the vicinity of the Orbital Work Shop (OWS), the following are typical of the modifications MDAC made to insure EVAs were not precluded in that area.

- Round-off all corners
- Install caps on the end of all hat sections
- Remove sharp edges and corners on radiator panels

These modifications were responsible in part for allowing the conduct of ten EVAs during four Skylab missions which accomplished 15 repair objectives, 23 investigative activities, and enhanced 16 experiments (Figure 5). None of these EVAs were planned prior to the launch of Skylab, however they were the means by which the mission was saved.

More recently, a number of EVA tasks have been developed for the Shuttle Orbiter. These tasks are primarily designed to return the Orbiter to a safe configuration for entry and include: (1) closing the deployable radiators and payload bay doors, (2) latching the payload bay doors, and (3) restowing and securing the Remote Manipulator System. In

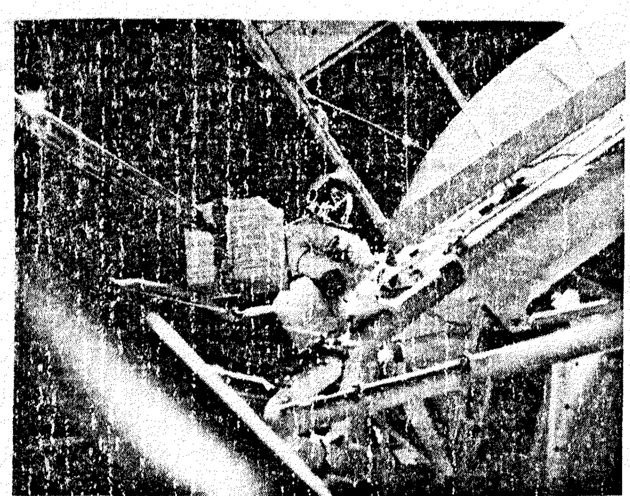


Fig. 5 - Skylab EVA

Fig. 6 - 3-Point Latch Tool installed on aft bulkhead of Orbiter

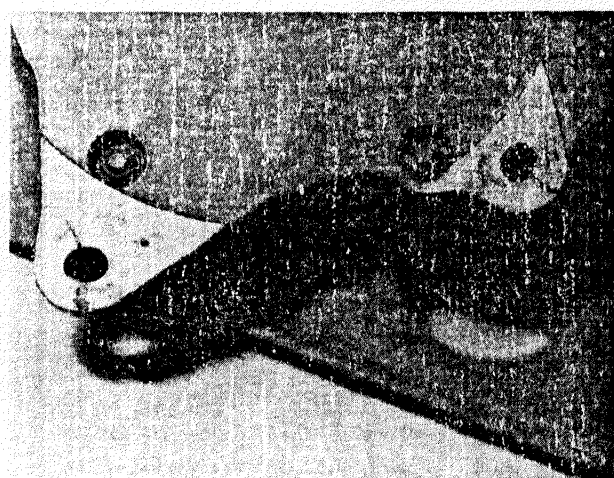


Fig. 7 - Port aft bulkhead latch gang power drive unit (STS-3)

each of these cases, the EVA was an "add-on" capability which involved significant costs not only in hardware development but also in training the crew for tasks which were not optimized for EVA (Figure 6). The importance of developing this EVA capability, however, was demonstrated on STS-3 when the port aft bulkhead latch gang failed. Fortunately, thermal conditioning allowed the latch gang to close, however, post-flight inspection revealed severe structural damage to the power drive unit mounting lugs (Figure 7). Had this system failed completely while on-orbit, the only way to bypass the failure would have been to conduct an EVA to install the tool shown in Figure 6. Although these systems were originally considered adequate without manual back-up, an EVA capability developed late in the program was very nearly required to bypass an actual flight failure. The really unfortunate aspect is that a back-up EVA capability could have been designed into the systems originally at no additional cost. This failure to remember lessons learned in previous programs has already proved to be very costly in developing "work-arounds" and bandaids.

If the trade studies show EVA to be the most effective approach to a task, then EVA compatibility must be considered a programmatic requirement with EVA design criteria set at the beginning of Phase B (Figure 3). Initially, design criteria will be general in nature and are intended to insure the various elements of the program do not establish system designs which will preclude the EVA. These criteria are contained in JSC 10615, EVA DESCRIPTION AND DESIGN CRITERIA DOCUMENT, and may be grouped into the following three areas:

- Access to the worksite - provisions must be made to get the EVA crew and any required equipment or tools safely to the worksite

- Worksite environment - the worksite must be safe and provide adequate volume, lighting, communications, and restraint for both the crew and and any necessary equipment

- EVA mechanism design - the crewmember interfaces and manually operated mechanisms must be designed and positioned so as to minimize the affects of zero-G and the pressure suit

These three groups also represent a decreasing order of impact to the overall payload program. Safe access to the worksite will probably affect most payload elements, while the actual environment at the worksite may only impact those systems in the immediate vicinity. The area of tool and mechanism is the most critical item in terms of EVA success but probably affects the fewest payload systems. This flow is in concert with most program design and development processes in that, as systems mature, design specifications become more firm. When the design is to provide an EVA back-up to an automated mechanism however, the manual capability must be developed from initial concept selection in Phase A in parallel with the remotely operated portion of the system.

Often, the automated section is designed without due consideration for the crewmember operated section. The EVA mechanism is added at a later date (usually one week prior to the PDR), and turns out to be a device which bypasses few if any of the creditable failures, requires excessive force to operate, and is virtually inaccessible. These problems can be avoided by developing both the automated and manual systems to compliment each other.

> For example, a power drive unit uses two redundant motors to drive a gear box via a differential. The gear box operates a push/pull rod. If analyses show the best EVA approach to be bypassing failures in the power drive unit, the wrong technique would be to simply provide a tool to manually operate the gear box. This device would only bypass electrical failures. A better technique would be to provide an independent means of turning the rotary actuator after disengaging the gear box. This system would then bypass both electrical and mechnical failures.

The important point is that this system cannot be designed piecemeal. The manual drive capability must be integrated into the system from the beginning. Other advantages of totally integrating the two systems include:

- Keeping force levels and throw distances low
- Utilizing optimum crewmember dynamics
- Incorporating the "tool" into the basic mechanism, or at worst being able to use an existing Shuttle EVA tool
- Minimizing "overhead time" (tool/equipment transfer, restraint set-up, repositioning)
- Causing the least impact to the baseline EVA crew training

At this point, it is apparent that manned activities are essentially no different from other elements in a payload program. The trade studies conducted to analyze the potential benefits of EVA operations are analogous to those conducted to select other payload systems. EVA compatibility is a programmatic requirement in EVA payloads, design criteria must be set early, and manually operated devices must be included in all system development phases. By doing so, the payload manager is able to consider more options in selecting systems, save money and weight while increasing reliability, and enjoy a high level of confidence in those payload activities which are being supported by Extra Vehicular Activity.

UNITED TECHNOLOGIES
HAMILTON STANDARD

SATELLITE SERVICES OVERVIEW

HUMAN ROLE IN SPACE WORKSHOP
OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

AUGUST 24-26, 1982

KENNETH R. KING
HAMILTON STANDARD

INTRODUCTION

The Space Transportation System (STS) is a developing national resource that will open a new era of space exploration, utilization and research. In view of the world's growing dependence on the use of space, particularly the use of satellites for communications, monitoring weather and earth resources, navigation, surveillance and astronomy, plans are being made to dedicate a substantial portion of future STS activity to deployment, service, and retrieval of earth orbiting satellites.

SATELLITE SERVICE

Satellite service is a generic term for STS orbital operations associated with satellite payloads. Satellite operations can be partitioned into three categories of orbital work activity:

Deployment - Operations involving delivery of Shuttle Orbiter satellite payloads to earth orbit, including reboost of satellites back to prescribed operational orbits.

Service - Operations associated with resupply, refurbishment, and repair of satellites. Examples include inspection, photography, film or module replacement, fluids replenishment, and antenna replacement.

Retrieval - Operations associated with returning free-flying space objects to the Shuttle Orbiter, stabilization of spinning or tumbling space objects, and satellite-to-Orbiter docking.

In the past satellites were not designed for orbital service because in-flight satellite servicing had not been available. Satellite system design philosophy to date has been to dictate stringent requirements for high reliability to satisfy mission life requirements. Already, the Space Telescope, Solar Max Mission, Long Duration Exposure Facility, Advanced X-Ray Astrophysics Facility and Space Platform, representing next-generation satellites, are designed for orbital service. With future development of reusable Space-Tugs and Teleoperators for transferring satellites between Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) virtually all earth orbiting satellites will become candidates for LEO service.

Satellite payload activation and servicing may be carried out by any combination of three operational modes:

Automation - This mode of operations requires that the vehicle or payload conduct operations automatically. This is the most common for satellite deployment and has been the form of all satellite on-orbit activity to date. This mode requires redundancy of actuators, components and subsystems so that any single failure will not incapacitate a satellite or the Shuttle Orbiter and jeopardize mission success.

EVA - Describes activities performed by the crewmember outside the pressurized spacecraft environment. There are three basic classes of EVA:

(Continued)

- Scheduled EVA - tasks included in the planned mission time line scheduled to support Shuttle or payload operations.

- Unscheduled EVA - an EVA task not included in scheduled mission activities, but which may be required to achieve payload operation success or to enhance overall mission success.

- Contingency - EVA required to effect the safe return of crewmembers.

<u>RMS, Teleoperators, Robotics</u> - Conduct tasks in which man directed artificial intelligence mechanisms approach a payload, dock to it, conducts remote from the Orbiter a preprogrammed set of tasks or returns the payload to the Orbiter for earth return or refurbishment.

In performing satellite servicing via the aforementioned methods, the mission planner is provided substantial flexibility in realizing benefits afforded by satellite servicing. These benefits impact all areas of program management, from financial (cost) to operations (extended mission life). To exploit satellite servicing capability fully, service provision should be designed into the satellite. Projected satellite serviceability design considerations are summarized in Table I.

- MECHANICAL LOADS
- SAFE SURFACES AND EDGES
- ACCESSIBLE MAINTENANCE AREAS
- REPLACEABLE SUBSYSTEM MODULES
  - PAYLOAD INSTRUMENTATION
  - ATTITUDE CONTROL AND PROPULSION
  - POWER
  - DATA PROCESSING AND TELEMETRY
- FLUID SUBSYSTEMS
  - REFUELING
  - SAFETY VENTING
  - FAIL-SAFE PRESSURE VESSELS
- DIAGNOSIS AND CHECKOUT CAPABILITY
- STANDARD INTERFACES
  - SAFETY INTERLOCKS
  - DIAGNOSTIC AND CHECKOUT CONNECTOR
  - DISCONNECTS, FITTINGS AND FASTENERS
  - REMOTE MANIPULATOR
  - CREWMEMBER RESTRAINTS AND HANDHOLDS

TABLE I. DESIGN CONSIDERATIONS FOR SATELLITE SERVICEABILITY

(Continued)

Proper inclusion of satellite service features are necessary for on-orbit maintenance time optimization. Table II lists projected service tasks for satellite subsystems and major components that appear practical to perform on-orbit.

- INSPECTION, PHOTOGRAPHY, AND POSSIBLE MANUAL OVERRIDE OF PAYLOAD SYSTEMS AND MECHANISMS
- INSTALLATION, REMOVAL, AND TRANSFER OF FILM CASSETTES, MATERIAL SAMPLES, PROTECTIVE COVERS, AND INSTRUMENTATION
- OPERATION OF EQUIPMENT, INCLUDING STANDARD OR SPECIAL TOOLS, CAMERAS, AND CLEANING DEVICES
- CLEANING OF OPTICAL SURFACES
- CONNECTION, DISCONNECTION, AND STOWAGE OF FLUID AND ELECTRICAL UMBILICALS WHEN SAFED
- REPLACEMENT AND INSPECTION OF MODULAR EQUIPMENT AND INSTRUMENTATION ON THE PAYLOAD OR SPACECRAFT
- REMEDIAL REPAIR AND REPOSITIONING OF ANTENNAS AND SOLAR ARRAYS
- ACTIVATING/DEACTIVATING OR CONDUCTING EXTRAVEHICULAR EXPERIMENTS
- PROVIDING MOBILITY OUTSIDE THE CARGO BAY AND IN THE VICINITY OF THE ORBITER USING MANNED MANEUVERING UNITS (MMU'S)
- MECHANICAL EXTENSION/RETRACTION/JETTISON OF EXPERIMENT BOOMS
- REMOVAL/REINSTALLATION OF CONTAMINATION COVERS OR LAUNCH TIEDOWNS
- TRANSFER OF CARGO
- LARGE SPACE STATION CONSTRUCTION
- ON-ORBIT SATELLITE SERVICING

TABLE II. SERVICE TASKS

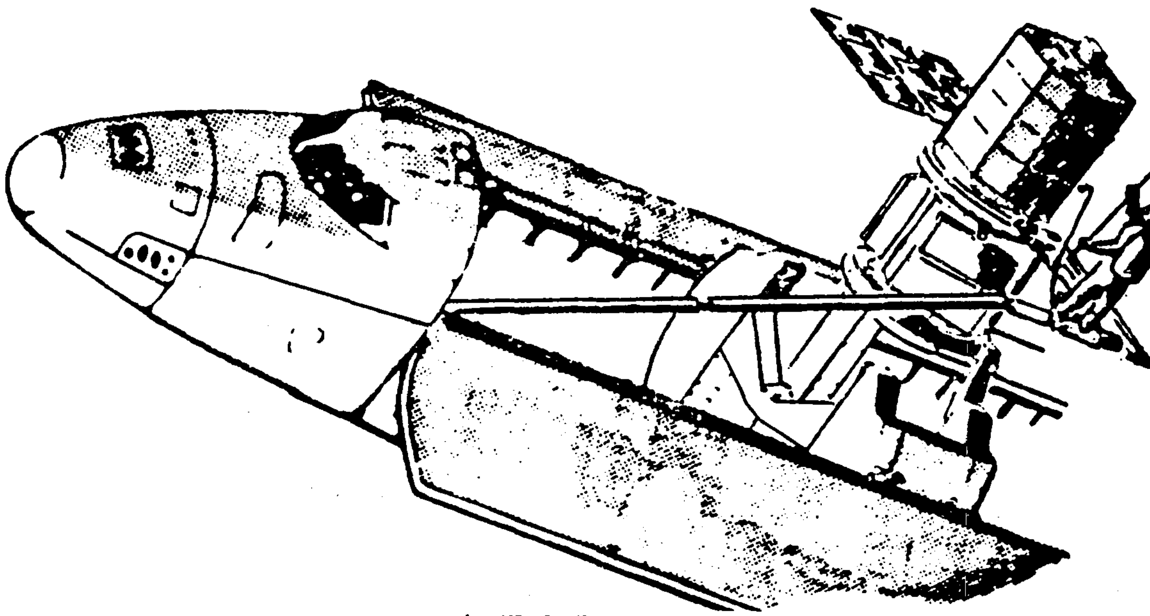
STS provides a baseline capability for performing a range of satellite servicing tasks. Baseline equipment includes the Shuttle Orbiter, Remote Manipulator System (RMS), Extravehicular Mobility Unit (EMU), Manned Maneuvering Unit (MMU), and an assortment of hand tools, foot restraints, handholds and storage capability for supporting satellite deployment, service and retrieval operations.

Deployment

Normal deployment of Shuttle Orbiter satellite payloads is expected to be automated, with crew activities conducted from the Orbiter cabin. The satellite to be deployed would first be elevated in the Orbiter payload bay by either a flight support platform or the Remote Manipulator System (RMS). Satellite antennas and solar panels would then be deployed by remote control actuators. Satellite systems would be checked out prior to satellite release from the flight support platform, with release effected by a spring actuator mechanism or using the RMS. Platforms could be designed to impart spin to spin-stabilized satellites. Following release, thruster activation would propel the satellite to the prescribed operational orbit.

(Continued)

Contingencies could alter the normal deployment sequence. For example, a satellite solar panel could fail to self-deploy requiring use of the RMS or EVA as contingency backup for panel release. EVA might be required for inspection, evaluation of anomalies, and repair activities prior to or following release of the satellites. Figure 1 depicts an EVA astronaut engaged in a deployment contingency operation. The astronaut is restrained by a foot restraint platform attached to the RMS. An Open Cherry Picker (OCP) (a portable work station which can be attached to the RMS) is being considered as a near term capability improvement for STS. The EVA astronaut shown is equipped with the Shuttle Extravehicular Mobility Unit (EMU) which provides environmental protection and life support.



PAYLOAD DAMAGE-CONTINGENCY

FIGURE 1. CONTINGENCY DEPLOYMENT

Service

Shuttle/Spacelab missions will fly with a baseline EVA capability supported by the Manned Maneuvering Unit (MMU). Figure 2 depicts an EMU-MMU equipped astronaut. The current MMU design uses a nitrogen cold gas which provides astronaut propulsion. The EMU equipped crewmember dons the MMU by backing into its latching mechanisms. The MMU will not be required if EVA is limited to the payload bay. In addition to the MMU, the EVA crewmember will have portable foot restraints, tools, and work aids to use to support satellite service tasks. These tasks range from payload inspections to module changeouts.

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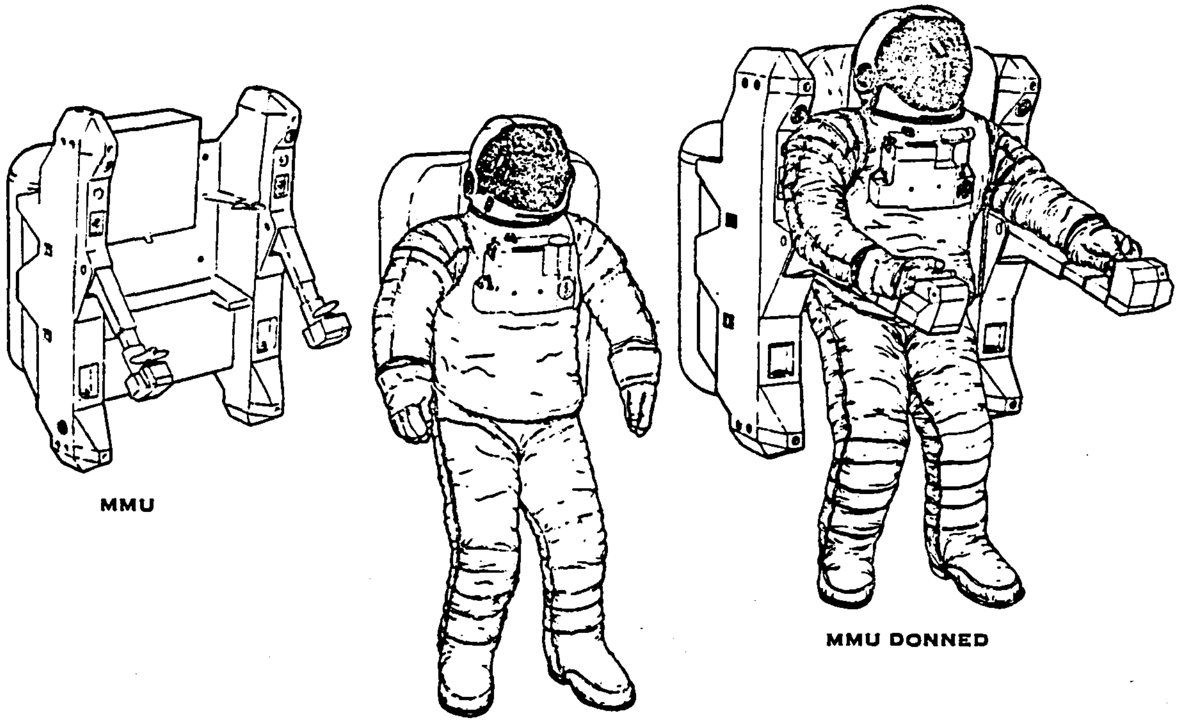

FIGURE 2. SPACE SHUTTLE MANNED MANEUVERING UNIT (MMU)

Retrieval

Present retrieval planning calls for berthing satellites to the support platform in the Orbiter payload bay using the RMS. Extensions of this technique under study include use of orbital transfer vehicles (access to GEO) and use of EVA for satellite guidance. In all retrieval techniques, chief among concerns are:

- Satellite/Orbiter/RMS approach and docking
- Orbiter thruster induced satellite translation
- Satellite dynamics and capture
- Satellite-Orbiter relative motion
- Mission time and propellant required
- Safety

SUMMARY

One of the objectives set forth for the Space Transportation System is the increased utilization of man in space. Projected manned activity encompasses such on-orbit operations as satellite deployment, service, and retrieval;

(Continued)

space construction; and Shuttle Orbiter repair. The effectiveness with which each of these operations is conducted will depend to a large extent on implementation of service design features in component, systems and operations.

The range of potential satellite servicing tasks and techniques available provides substantial flexibility to payload design and mission planning. Satellite servicing benefits include extended mission life and overall program cost savings.

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ERGONOMIC MODEL OF THE HUMAN OPERATOR

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Problem and Needs

We need systematic and comprehensive representations of three separate aspects of the human operator within a technological system:

(a) Model of body dimensions, "Anthropometric Model"

(b) Model of physical activity characteristics, "Biomechanical Model"

(c) Model of operator-equipment interactions, "Interface Model".

These submodels should be integrated for the "Ergonomic Model". This shall be a "proactive" (predictive) model, as compared to existing "reactive" (passive) models.

Many approaches for model subsystems or components of this overall problem exist. However, they do not fit into an common framework, and have different, often noncompatible outputs. Furthermore, the input requirements are usually different (resulting from analytical or systematic approaches of different disciplines) and do not rely on a common data base.

The lack of a systematic, comprehensive, and quantitative ergonomic model brings about incomplete understanding of the human operator as a system component, who is often the main determiner of the system output. Thus, technological systems relying on the human as a system component may be laid out less than optimal with respect to system performance and, therefore, are sub-optimal in their output.

Such systems are military or civilian. Typical examples in the military domain are aircraft cockpits, tank interiors, work stations on surface ships, or submarines. Search and rescue ships used by the U.S. Coast Guard are notorious for the lack of human engineering in their design. Typical civilian applications are in the automobile industry, both in passenger vehicles or trucks, and very prominent in construction and agricultural equipment. Acute industrial problems relate to control rooms, or visual display terminals.

Thus, development of a comprehensive and systematic Ergonomic Model of the Human Operator would benefit military as well as civilian populations and applications.

Background

The knowledge required to solve the problem extends over several scientific domains, e.g. anthropometry, physiology, psychology, biomechanics, computer science, and engineering. It includes the need to establish a common reference system, a convenient notation system, and the development of special research methods and of related measurement techniques.

Thus, the problem is mostly one of basic research, of data organization and primarily of establishing the conceptual framework. Development of work on computer software is also needed but does not seem to be a major problem. Application needs and possibilities are obvious.

A vast number of publications exist on this topic. Its collation and evaluation is a basic task of the model development. A first step towards the concept of an Ergonomic Model described here was discussed a decade ago by this author:

K. H. E. Kroemer. COMBIMAN-Computerized Biomechanical Man-Model. AMRL-TR-72-16, WPAFB, OH: Aerospace Medical Research Laboratory, 1972.

Review and detailed papers regarding anthropometric, biomechanical, and interface submodel are contained in:

R. Easterby, K. H. E. Kroemer, and D. B. Chaffin (eds.): Anthropometry and Biomechanics. Proceedings of the NATO Conference, July 1980, in Cambridge, England. New York, NY: Plenum (in press).

H. Schmidtke, K. H. E. Kroemer and P. L. Walraven (eds.): Ergonomic Data for Equipment Design. Proceedings of the NATO Advanced Research Institute, March 1982, in Munich, Germany. London: Plenum (in press)

Approach

Subsystem 1: Anthropometric Model

A comprehensive model of human body dimensions, particularly of the human body in motion, is lacking and needs to be developed.

The problem can be subdivided into four areas:

1. Lack of a reference system. For example, standard anthropometry relies on measurements taken in front view, side view, or top view, usually without interrelating the measurements taken in each plane.

2. Lack of a suitable measurement technology. For example, measurements are still generally taken with the clasical anthropometer, instead of using photography or other advanced techniques.

3. Lack of adequate notation. Standard medical terminology is gross, clumsy and ambiguous. Detailed systems such as used in choreography are cumbersome and non-scientific.

4. All of the above lead to a lack of information on human body dimensions, reaches, and mobility particularly of the human body in motion (dynamic anthropometry). One sub-problem is predicting unknown body dimensions from measured ones. The lack of information is particularly obvious with respect to civilian populations.

<u>Subsystem 2</u>: <u>Biomechanical Model</u>

Current models of physical performance characteristics of the human operator are largely restricted to three aspects:

1. Static measurements, as traditional in physical anthropometry, of body segments in common "frozen" postures.
2. Voluntary strength and power capabilities under laboratory conditions (physiology) or for extreme achievements (sports events).
3. Passive responses of the body to force fields, or impacts.

A systematic breakdown is missing that describes active voluntary physical performance characteristics needed as design inputs for manned systems. Such performance characteristics could refer to dynamic mobility including reach, to dynamic muscular strength, and to energy and power output capabilities. These variables should be subdivided into output capabilities of the whole body, or of trunk, limbs, or hands in particular. Furthermore, they should be described along the time axis, such as one-time all-out-efforts compared to short or medium time endurance. Finally, long term capabilities need to be described, which would take into account training, skill acquisition, and/or fatigue, in various environments.

Part of the problem is the determination of suitable assessment methods and techniques. Physiology has largely used oxygen consumption and heart rate. Psychology has developed various methods to assess mental and physical strain. Emerging psychophysiological (psychophysical) approaches combine several approaches.

<u>Subsystem 3</u>: <u>Interface Model</u>

Models are largely missing that determine how human operated equipment should be designed and arranged so that a best match between the operator, and hardware or software, is achieved for maximum output, safety, reliability, comfort, etc. This optimization of the operator-equipment interface requires a clear understanding of which variable or variables should be optimized, and of the optimization criteria.

Within limits, existing models indicate suitable approaches. The U of Nottingham SAMMIE model is used for workstation design. The USAF COMBIMAN establishes geometry interfaces betwen a seated operator and an aircraft cockpit. The USN CAPE and CAR models are crewstation design tools. NASA uses combinations of these models, and others such as PLAID in the design of space ship interiors.

Interface points used in various models are either the eye, the buttocks, or the feet (see, e.g., AFSC Design Handbook, Military Standard 1472, Military Handbook 759) Usually, these models are simply intercept or clearance models determining the space needed by the operator. They have implicit and often unclear optimization goals with respect to system performance. This is obvious if one considers the fact that the hands as the single most important interface links between operator and equipment are usually not part of the design models, or only in a very indirect sense, e.g. is using only the maximal reach envelope .

<u>The Integrated Ergonomic Model</u>

Obviously, the subsystems (the anthropometric, biomechanical, and interface models) are hierarchical in nature. Therefore they should follow a common concept, and use compatible inputs and outputs. This common framework will be provided by the Ergonomic Model. Thus, definition of objectives and design of the Ergonomic Model determine the subsystems. Hence, goals, strategies, approaches, and measurement techniques for the Ergonomic Model must be determined first so that the submodels can be adjusted to fit the common purpose. One the other hand, experiences made so far with the subsystems provide valuable information for the establishment of a feasible and efficient comprehensive model.

<u>Recommended Course of Action</u>

It is not useful to simply continue the peace-meal approach taken so far in which the branches of the armed forces, different universities, and various other research institutions work in separate areas, on separate topics, in separate ways, without a common guiding concept. While these approaches have lead to valuable information in selected areas, the results cannot be combined to yield an overall picture and model.

The statements regarding problems and needs in the preceding text indicate appropriate goals and strategies of this work. The solution requires:

First: An overall concept and framework, with common directions and strategies to be followed

Second: Detail research along common guidelines to develop the subsystems

Anthropometric Model
Biomechanical Model
Interface Model

Third: Integration of these into the Ergonomic Model of the human operator within a technical system.

The First Step:

It is proposed that an expert meeting be organized. It should consist of perhaps 10, certainly not more than 20 persons. This meeting can rely, at least in part, on the results of the 1980 NATO Symposium on Anthropometry and Biomechanics and on the 1982 NATO ARI on Ergonomics. Using the results of these meetings, a *steering panel* should develop a general concept, and guidelines.

The Next Step:

After the systematic approach has been established, parallel research can be stimulated to establish compatible models that describe human body dimensions (Anthropometric Model), physical performance characteristics (Biomechanical Model), and operator-equipment interactions (Interface Model).

SPACE HARDWARE

DESIGN AND DEVELOPMENT

INTEGRATING THE MANNED INTERFACE

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FOREWORD

Studies by NASA contractors and others over the last fifteen years have emphasized the potential benefits, including costs, of selected manned operations. A satellite servicing study in the late sixties summarized the problem:

> "Since so many aspects of space are dynamic, it should be clear that it would be foolhardy to expect that satellites could be manufactured so that they would never deteriorate, have a limitless useful life, be absolutely reliable, and be inexpensive and standardized instead of complex. . . ."
>
> "One possibility is to devote more of society's limited resources to greater pre-orbit efforts of design, manufacture, test, and launch. However, the incremental improvement in the listed problem area . . . would probably be very small relative to the effort involved."
>
> "An alternate way to improve the present situation would be to . . . launch the satellite, let it malfunction, run-down, deteriorate, or become partially obsolete, then take corrective actions while it is in orbit."
>
> "This technique has the tremendous advantage of pin pointing a problem for that specific satellite thereby creating a high probability that a specific relative improvement can be made . . . this improvement can usually be accomplished in a short time and with less expense relative to any pre-orbit effort."
>
> "The obvious superiority of the in-orbit correction method led space program planners to suggest the creation of a space vehicle that would be designed to perform the necessary corrections."

The Space Transportation System (STS) provides the basic tools required for an on-orbit servicing and maintenance capability. With man onboard the STS, he represents an STS subsystem that can be used to accomplish planned payload mission objectives, as well as contingency service and maintenance functions.

INTEGRATING THE MANNED INTERFACE

The manned interface is defined as the equipment and systems manipulated or used directly by man in performance of a payload function. Previous manned space flight experience has shown that the effective use of man's capabilities requires careful attention to integration of the manned interface. A variety of techniques have been used to facilitate the integration process. These techniques have included desk-top modeling and analysis; task simulations using part-task and full-scale models of task hardware; and space environment simulation using thermal vacuum and water immersion facilities. One of the techniques used early in the integration process is the "operations scenario." Development of the operations scenario enhances the analysis of manned operations. It is presented as an initial link between the hardware as conceptualized and the design required for successful manned operations.

An "operations scenario" may be defined as the end-to-end sequencing of all subtasks required to perform an operation. The development of an operations scenario involves the identification of all hardware and software systems, personnel, and other items required for each subtask to be accomplished. A sample format for developing an operations scenario is illustrated in Figure 1. This particular format was prepared for development of an Extravehicular Activity (EVA) function, but it could be modified and used for development of aft crew station or other Intravehicular Activity (IVA) functions. All items required for subtask performance are identified as operational support requirements. Other requirements should be added as needed to accomplish the subtasks. Development of the scenario begins with the identification of a potential manned task. Potential manned tasks can be identified from an analysis of system functions. Initially, the task may be a general statement of some operation to be performed. The operation should be broken into the lowest meaningful subtasks. The sequence of tasks is determined by the objective of the operation. Several iterations may be required to identify the lowest subtask and the most effective sequence.

As the performance of each task is considered, all items required for performance are identified. For example, if a subtask identified as "4.3 Power Switch - On" required performance from the aft crew station, the "perform 4.3" would be entered into the personnel column title "AFT C/S" (i.e., at Orbiter crew station). The location column identifies the position of the individual performing the particular subtasks. This data locates personnel during the performance of all subtasks, and it may be used to determine a more efficient subtask sequence. It may also be used to determine a more effective location of the subtasks. This column may also serve as a cue for documenting environmental requirements such as radiation protection, spacecraft attitude, or solar flux limits. Other columns for environmental requirements may be added if they are relevant issues.

POTENTIAL MANNED TASK / EVA FUNCTION				OPERATIONAL SUPPORT REQUIREMENTS										
TIME		TASK	SUBTASK	PERSONNEL				LOCATION/ ENVIRONMENT		TASK HARDWARE/ SOFTWARE	TASK SUPPORT HW/SW	TASK PERFORMANCE REQUIREMENT	CAPABILITY TECHNOLOGY STATUS	SPECIAL/ STOWAGE REQUIREMENTS
TOTAL	TASK			EVA 1	EVA 2	AFT C/S	GROUND	EVA 1	EVA 2					

FIGURE 1 – Operation Scenario Development

The task hardware/software column identifies the hardware/software required for direct performance of the task. In the aft crew station example, a power control switch may be required. If a unique control panel for the switch is required, it would also be entered in this column. Software or wiring may also be required to perform this subtask. The adjacent column identifies requirements for task support hardware/software. Support hardware facilitates the performance of the subtasks or contributes to maintaining the capability to perform the subtask. Examples of this hardware include body restraints, stowage devices, and portable lighting. Task performance requirements identify either performance limits or requirements for hardware/software. A performance limit on the rotation of a power control switch may be identified as "10 in-lbs." "Body restraint" in this column may identify the performance requirement for a handhold. The capability/technology status column may be used to qualify the performance of any subtasks. (A "check mark" may be entered to indicate that there is no capability or technology concerns relative to the subtask performance). The capability/technology status column may also be used to indicate that the subtask has been performed in the past or that a demonstration is required to verify its performance. The column could also identify a state-of-the-art technology concern or deficiency. The last column may be used to identify special requirements that may surface as a result of scenario development. The existence of off-the-shelf hardware is a note that could be entered. The column may also identify and track stowage requirements for loose equipment.

Once the operations scenario has been developed, each subtask should be reviewed to estimate the time required for its completion and this time should be entered in the time task column. If the subtask performance time is unknown, personnel familiar with the task or task performance records may provide an estimate. In some cases, a subtask demonstration may be required to determine the performance time. Once the subtask's performance times have been estimated or determined, the accumulated total provides a preliminary timeline for the scenario. Development of the scenario may be repeated as new data on potential manned tasks, task hardware, or task support hardware becomes available. A refined operations scenario provides a source of data for reference prior to the availability of hardware for demonstration and evaluation.

An analysis of the refined operations scenario will provide a source of preliminary data for program documentation, such as system design and performance requirements. The subtasks and timeline data will also provide an input into preliminary flight data file articles such as the flight plan and checklists. Preliminary training plans and training facility plans can be generated from the task data and the operational support requirements data. A sample matrix of operations scenario products referenced to preliminary program documents is shown in Figure 2. A subtask opera-

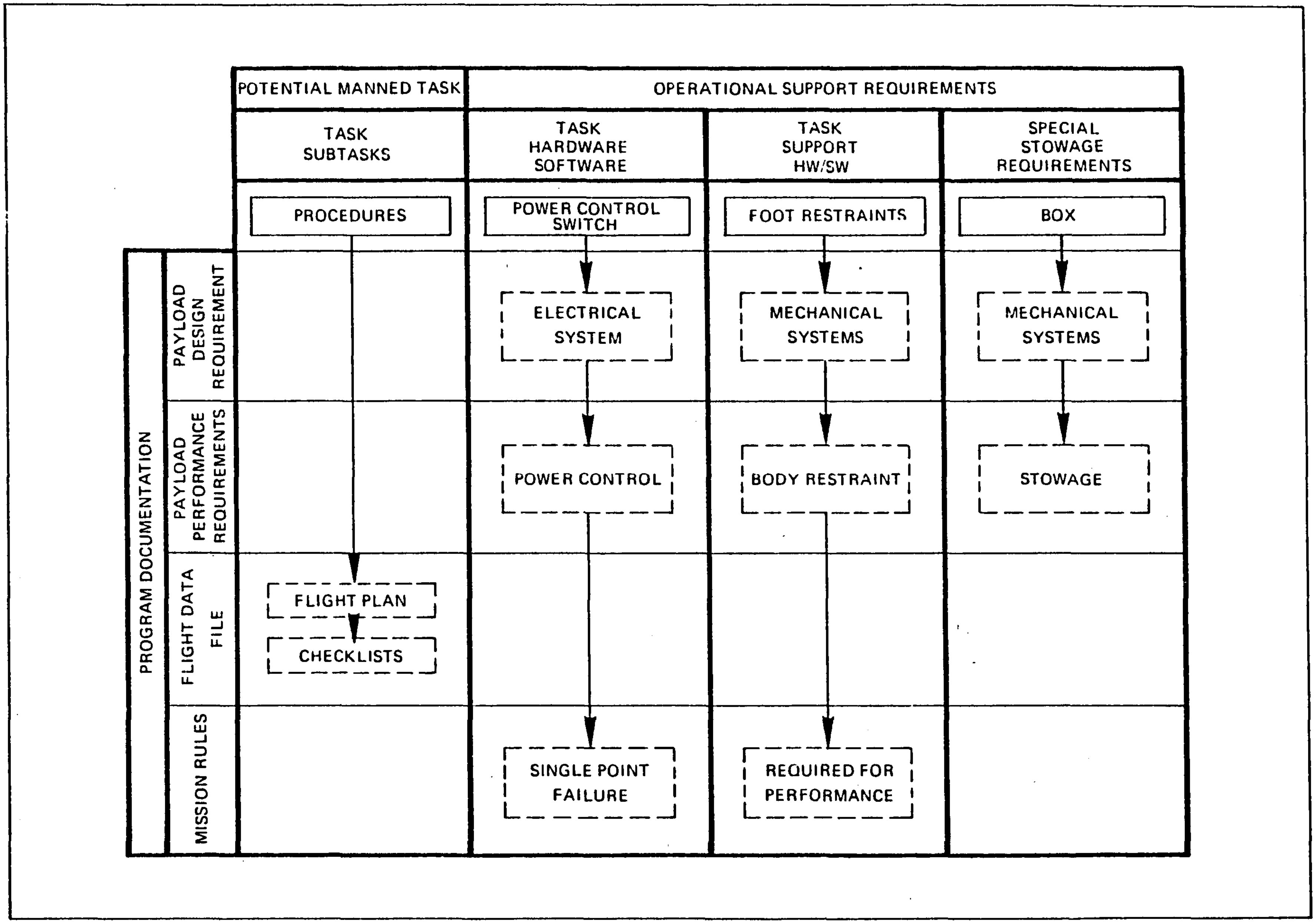


FIGURE 2 – Scenario Products Matrix

tional support requirement, such as foot restraints, provides an input into the payload program's preliminary design and performance requirements document. This input may affect the payload's mechanical systems requirements or the crew systems requirements depending upon the subdivisions of the requirements document.

The operations scenario data can be used to generate concept demonstration and evaluation plans. Low-cost mockups or prototype hardware may be used to refine and revise the operations scenario or the requirements generated by scenario development. The data generated by development of one operations scenario may be used in concept evaluation and development and trade-off studies with an alternate approach or another potential manned task.

The Allocation of Functions in Man-Machine Systems

by H.E. Price
and R. Pulliam

Space systems as they now exist would be impossible without automated control. We have become accustomed to systems which make maximum use of computer logic to control vehicles and ground systems. In such systems, at their best, computers are able to unburden the operator, to deal with complex computations, to organize information for display, and to act with great reliability and speed. Many control problems can be solved in no other way. But automated control is no panacea. Computers cannot set objectives, and they prove to be poor substitutes for man in processes such as pattern recognition and fault diagnosis. They cannot deal with the unexpected, nor can they construct innovative solutions to an emergency condition. Sometimes computer applications create, rather than solve, problems; and in operational situations we repeatedly observe that operators or pilots elect to defeat their automated systems, so that they themselves can assume manual control.

In many of these cases the problem is an improper allocation of functions between man and machine. Allocation decisions were cast in hardware or software during design, and may now permanently limit the usability of the system. When functions are automatic the human operators may be unable to see what is happening or to exercise useful control. On the other hand, when functions are manual, the users may be forced to perform unnecessary chores or to do tasks for which humans are poorly adapted. To some extent, such design errors happen because, during design, there has been no deliberate consideration of which functions should be allocated to man and which to the machine.

An Historical Study

This problem is widely recognized in military and industrial settings, as well as in the aerospace community. Our company, BioTechnology, Inc. (BTI), recently completed a study for the Department of Defense in which we examined the R&D literature and the histories of recent systems procurements. In spite of DOD regulations which specifically require allocation of functions as a step in the design cycle, we could not find a single case in which the allocation of functions was decided, system-wide, in a systematic way. This is true, we believe, because there is no recognized methodology for allocating functions. Accordingly, BTI recommended the development of a framework and a set of methodological tools which a design team could use in allocating functions to man or machine.

Developing a Method

BTI is now developing such a framework and tools for use in nuclear power plant (NPP) design. In an effort supported by Oak Ridge National Laboratories and the Nuclear Regulatory Commission, BTI has developed a conceptual method for allocating functions (or assessing existing allocations) in NPP control rooms. The method is applicable both to earlier technology using electromechanical process control and to later technology exploiting the computer.

BTI first examined the history of technology in this perspective, and then reviewed major models and methods which have been proposed for the allocation of functions. These begin with the "listing" approach. In 1951, Fitts proposed a table listing the differing capabilities of machines and man, to be used in support of decisions about automation. Since then, more elaborate lists have been suggested, for instance by Mertes and Jenny (1974), Edwards and Lees (1974), and Swain (1980). More elaborate simulations, procedural guides, and information support systems have also been developed, including HEFAM (Connelly & Willis, 1969), CAFES (Parks & Springer, 1967), SYSSIM (Ireland, n.d.), SAINT (Workman et al., 1975), HOS (Strieb & Wherry, 1979), and the Hypothetical-Deductive Model of Price and Tabachnik (1968). Several of these have features which might be applied in determining functions for nuclear power plant control, but most of them either were never developed in an operational form, or assumed the availability of large bodies of reference data which do not yet exist. In spite of widespread concern, there appears to be no instance of a proven methodology for allocating functions to man or machine.

Findings of this research included a recommended general, iterative procedure for allocating functions in the design of NPP control rooms, and some "lessons learned":

- There has been no successful system-wide use of an allocation method.
- Most methods for allocating functions are helpful for psychomotor tasks, but *not* for the cognitive tasks which are central to nuclear and aerospace operations.
- Allocation of functions is like engineering design: it is an iterative process that requires repeated cycles of preliminary design, test, and modification.
- Engineering design depends on an institutional memory, within the profession, of past successes and failures. We need such a memory for allocation (and for other human factors) decisions.
- Allocation decisions drive related requirements for training, procedure writing, and personnel selection.
- A major need in automated systems is for man-computer communications: a means by which (1) the operators can remain aware of system states, even when computers exercise control, and (2) the computer can be informed of human interventions, including what those interventions are expected to accomplish.

BTI proceeded to (1) elaborate a practical, step-by-step, reproducible method by which allocations can be made, and (2) identify criteria sets to be used in applying the method. The method will now be fully developed and applied to a selected real case in the NPP industry.

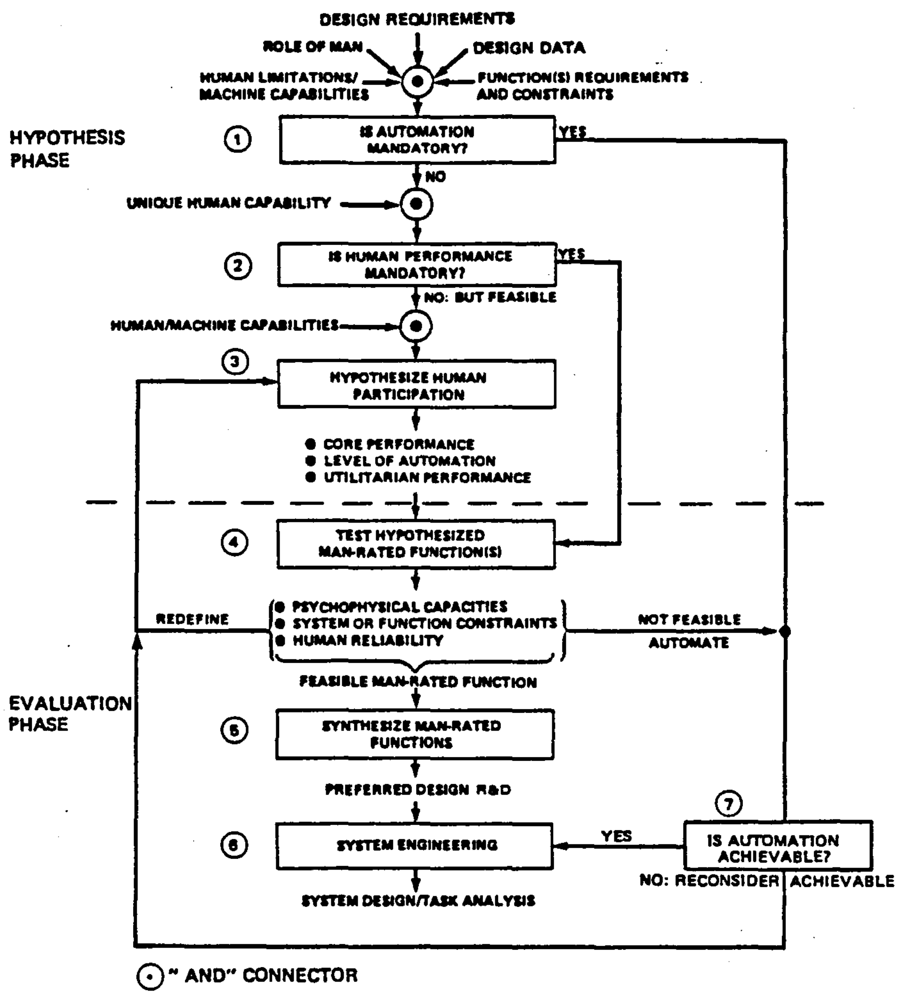
The Recommended Procedure—Hypothesis

A procedure was developed which differs from earlier schemes in at least one major feature: earlier procedures provided hypothetical solutions only. However sound they were, they provided only an untested hypothesis as to the correct allocation of functions. The BTI procedure added deductive (or empirical) tests of the hypothetical solution. Furthermore, specific tests were followed by closed feedback loops, so that the method can search heuristically toward an optimized man-machine interaction. The method is designed to be applied continuously, throughout the system design process, and to provide a series of iterative approximations approaching the goals expressed in a system requirements statement.

Exhibit 1 illustrates principal steps of the proposed method. Note the median dashed line, which separates an initial hypothetical analysis from the following evaluation phase. This second phase is called the "deductive" phase when deductive rather than empirical tests are employed, as must be the case during early (concept or preliminary) design phases.

Exhibit 1

The Allocation-of-Functions Process



In the procedure, initial decisions identify these functions which must be allocated to man or machine for obvious reasons. Such allocations must be made to automation (Step 1) for instance, when regulation or policy requires it, when hostile environments preclude the presence of man, or when the required system reaction times exceed human response limitations. Allocations to human control (Step 2) may be mandatory, for instance, when there is a requirement to develop strategies, to detect patterns or trends, or when meaning or values must be assigned to events. Additional tests are applied for economic and technical feasibility (Step 3), and in some cases a tentative decision may have to be fed back for reconsideration at the system requirements level.

Steps (1) and (2) are repeated first at the whole-system level, then for subsystems, and finally for portions of subsystems until those parts of the system which clearly must be controlled by man or computer have been partitioned off and allocated properly. Normally, this will leave substantial portions of the system, and of the operating procedure, which can reasonably be allocated *either* to man, to machine, or to some combination of the two. At Step (3), these functions are classified according to a performance taxonomy and allocated on a best-choice basis. This process is reported in detail in NUREG/CR-2623 (Price, Maisano, & Van Cott, 1982). At each point in this process decision aids are provided, but the actual decisions remain judgmental. It is suggested that the procedure be applied by a team including at least one experienced human factors engineer and one control engineer. The method provides an orderly decision procedure and a set of decision aids which includes some representative quantified human performance data. Most importantly, it provides for documentation of the decision process. This documentation makes it possible for allocations decisions to be communicated widely within the systems design organization. It provides a basis for the evaluation steps which follow. Finally, it provides a basis for iterative improvement and elaboration of detail in the man-machine relationship, and interaction with engineering design decisions as the system design evolves.

The Recommended Procedure—Evaluation

At this point in each cycle of the system design, an allocation of functions to man or machine has been hypothesized. In a design which has reached the mockup or prototype phase, an empirical test is appropriate. But a set of deductive tests are provided as well, which can be used during concept formulation and other early design phases.

First (Step 4), those functions hypothesized as "man-rated" are reviewed in detail against the known psychophysical capabilities of man, against system constraints, and against reliability requirements. If found feasible in these tests, a next step (Step 5) asks whether the human job, as it is emerging, is acceptable to an operator. Modifications are made at this point to ensure that operators will feel supported and important, that the job is coherent, and that it will fit into a reasonable authority and social structure. Finally, depending on outcomes of tests (Steps 4 and 5), elements of a preferred man-machine design are provided to systems engineering (Step 6) or are fed back to other steps of the design process.

Although the work discussed in this paper is being directed at nuclear power plant operations, the allocation-of-functions lessons learned, method, and criteria should be applicable to many design issues in space systems. In both cases, the key lesson to be learned is that man and machine should not be considered as competitors but as complementary components for achieving system performance.

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ESSEX

HUMAN FACTORS AND SPACE TECHNOLOGY:
Notes on Space Related Human Factors Research and Development, History, Faculties and Future Requirements

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H-82-04

FOREWORD

These notes on Human Factors Research and Space Technology are meant as a first step in documenting the history, capability and future requirements of space related human factors research and development. It is hoped that they will stimulate the progress of human factors in advanced space programs such as the space stations, large space structures, and future Spacelabs by describing the capability and advantages of integrating human factors in the conceptual stages of program definition.

These notes are not intended to be comprehensive nor complete at this time, but rather to serve as a guide for the collection of information. Comments, program descriptions, historical data, additions to the literature survey, and suggestions for the inclusion of human factors in advanced space programs should be addressed to Dr. Melvin Montemerlo, NASA Headquarters, telephone (202) 755-2494.

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ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control System
AEC	Atomic Energy Commission
AFD	Aft Flight Deck
ATM	Apollo Telescope Mount
AXAF	Advanced X-Ray Astrophysics Facility
DARPA	Defense Advanced Research Projects Agency
DDU	Data Display Unit
DOF	Degree(s) of Freedom
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
FY	Fiscal Year
IVA	Intravehicular Activity
JSC	Johnson Space Center
MIL STD	Military Standard
MMU	Manned Maneuvering Unit
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
ORU	Orbital Replacement Unit
PCTC	Payload Crew Training Complex
POCC	Payload Operations Control Center
RMS	Remote Manipulator System
SOC	Space Operations Center
SMRM	Solar Maximum Repair Mission
SRMS	Shuttle Remote Manipulator System
ST	Space Telescope
STS	Space Transportation System
TBD	To Be Determined
TMS	Teleoperator Maneuvering System
TRS	Teleoperator Retrieval System
WETF	Weightless Environment Training Facility
Zero-G	Zero Gravity

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1.0 INTRODUCTION

The history of manned spaceflight has had a substantial impact upon the human factors disciplines, microgravity anthropometry, life support systems, zero-G simulations, extraterrestrial work environments were all quite "foreign" to conventional ergonomics and a whole new branch of human factors began to develop to accommodate to the new and exotic requirements of space travel and orbital working environments. Some may argue that entrance into the space age had a greater impact on human factors than vice versa, but without question, considerable effort was made to broaden our research base and develop new techniques for studying human/system interactions. Now that we have gained skills and knowledge through our participation in the many space programs, we can make significant contributions to, and have an important influence upon, future programs.

1.1 BACKGROUND

Much of the early human factors research in space technology was undertaken to protect the human in space and to prepare for gathering data on human performance in a new environment. In preparation for the Mercury flights, safety and protection were foremost in the programs, and human factors research reflected this. With more experience through Gemini and Apollo flights, human factors research was able to expand its attention to deal with performance, comfort and habitatiblity. This culminated in the Skylab program where humans were supported in an orbiting work environment for extended periods. Not only did Skylab provide an opportunity for extensive application of human factors research, it also served as a laboratory for the collection of human factors data and the development of an empirical data base dealing with human concerns of space missions. The capabilities of EVA were extensively demonstrated; the medical and psychological consequences of space flight were examined; work and human performance were evaluated; and the stage was set to move permanently into our space environment.

1.2 SCOPE

This report was developed as a record of the authors' knowledge of the human factors research undertaken in support of space technology, the work currently being done at research centers in NASA, and how these apply to future space programs. They are notes to be shared among human factors specialists to facilitate communication and are not necessarily meant to be a comprehensive statement about research, facilities or future programs. Comments for inclusion in future revisions will be collected, and all comments are welcome.

2.0 STATUS OF HUMAN FACTORS RESEARCH

Very often appended to a specific program, and therefore difficult to identify, human factors research is being carried out through NASA and NASA contractor facilities. Pressure suit designs, extravehicular (EVA) workstations, EVA/remote manipulator system (RMS) symbiosis, remote systems technology, ground control stations and operations are some of the general areas of human factors concern. Specific research being conducted by NASA for advanced programs includes space station definition, large space systems (LSS) assembly, EVA servicing of spacecraft, and Spacelab payload crew training.

2.1 STATUS OF EVA RESEARCH AND DEVELOPMENT

Much of the early EVA research was performed to determine what crew restraints, mobility aids and tools the crew would need to perform simple spacecraft maintenance operations such as fastener removal and module changeout. Much of this research centered around the configuration of handrails, foot restraints and equipment restraint, tethers and the design of powered and manual hand tools. Pre-Gemini investigations into antirotation, low impact tools turned out to be unnecessary, and modifications to simple hand tools were determined to be adequate for most maintenance tasks as demonstrated many times on Skylab. Skylab also seemed to standardize handrail, foot restraint, and tether configurations.

Most of our knowledge about the capabilities of EVA crewmen has been acquired through development of specific spacecraft such as Skylab and Spacelab and payloads rather than through research. The current difficulties being experienced in the Space Telescope EVA operations as evidenced by difficult crew tasks and multiple simulations for design, development and verification do not indicate a lack of research data but a wholesale disregard of the lessons learned from Skylab and the existing EVA design standards. This body of knowledge and experience is adequate for most foreseeable EVA tasks such as instrument changeout, spacecraft maintenance, inspection, and contingency repair that may be required on Space Station and most STS EVA payloads. However, EVA will be used on some future missions in ways different from our current experience. An example of this is large space system assembly. Our knowledge of EVA assembly, large equipment handling and multiple shift EVA operations is insufficient to predict crew fatigue, suit and glove wear, and assembly timelines.

A description of EVA tasks performed to date and the status of EVA crew equipment and EVA design standards are presented below.

2.1.1 EVA Tasks

A brief history of EVA tasks performed on Gemini, Apollo, Skylab are presented in the following paragraphs. More detailed descriptions can be found in mission reports.

Gemini

During Gemini, an EVA crewman demonstrated a hand-over-hand translation technique using simple handrails, demonstrated the use of a "dutch shoe" foot restraint, and performed simple servicing simulations. The EVA lessons learned were that EVA servicing tasks can be performed if handrails are provided to the work site and if foot restraints are provided at the work site.

Apollo

During the Apollo transearth periods, an EVA crewman translated from the command module hatch to the service module and retrieved a camera. This activity verified that Skylab film changeout tasks could be easily performed.

Skylab

Skylab provided a wealth of spacecraft EVA servicing data. The Apollo Telescope Mount (ATM) film retrieval and D024 sample retrieval tasks were simulated many times in the MSFC Neutral Buoyancy Simulator and on the KC-135 zero-gravity aircraft. Tools, crew aids and servicing methods developed for the planned EVA tasks are still valid.

Only two of the contingency EVA tasks for which the crew was trained were required. The 22 unplanned, contingency EVA tasks performed by the Skylab crews kept the Skylab vehicle and its instruments alive and provided additional science capability. When planning the contingency EVA tasks before the flight, engineers and project personnel were too naive to think of all the things that could go wrong and underestimated what the EVA crews would be asked to do to correct the problems.

The planned, unscheduled and contingency tasks performed during Skylab are listed below, followed by the number of times each task was performed.

Film Retrieval - 28 Thermal Coatings Sample Retrieval - 2	Planned (7 EVA Tasks)
Solar Array Deployment - 1 Thermal Sail Erection - 1 XUV Camera Operations - 1 Particle Collection Experiment Materials Sample Installation & Retrieval - 2	Contingency or Unplanned (24 EVA Tasks, 2 Envisioned Prior to Mission)

Kohoutek Camera Operations - 2
Operations - 1
Sail Material Sample Installation & Retrieval - 4
Camera Door Latch Removal - 3
Occulting Disc Cleaning - 2
Camera Filter Wheel Repositioning - 1
Battery Charger Repair - 1
S193 Antenna Repair - 1
Rate Gyro Cable Installation - 1
Vehicle Exterior Inspection - 1 (Electrical shorts, blown fuses, coolant leak)
ATM Door Opening - 2.

Contingency or Unplanned (24 EVA Tasks, 2 Envisioned Prior to Mission)

These lessons learned from the Skylab EVA's which were determined to have beneficial application to future spacecraft were reported in the EVA section of MSFC-STD-512. The reader is strongly encouraged to study this design standard.

Future EVA Missions

Planned and unscheduled, contingency EVA anticipated for STS, Space Telescope, AXAF and the Solar Max Repair Mission are listed below.

- STS
  - Radiator stowage
  - Payload bay door latching
  - Airlock hatch closing

- Space Telescope
  - Camera changeout
  - Unplanned ORU changeout
  - Solar array operations
  - High gain antenna operations
  - Aperture door operations

- Solar Max Repair Mission
  - ACS module changeout
  - XRP vent cap installation
  - XHIS thermal cover installation
  - C/P MEB changeout

- Advanced X-Ray Astrophysics Facility (AXAF)

  - Planned and contingency EVA operations are TBD but are expected to be similar to the EVA tasks for Space Telescope.

2.1.2 EVA Equipment

Before STS, there were no tools developed for any EVA servicing task on any spacecraft. On Apollo and Skylab, all planned and potential EVA tasks were designed to be performed without tools. However, the

Skylab contingencies necessitated the real-time development of numerous EVA tools, either developed before or between the manned missions, or developed from onboard IVA servicing tools. These tools are listed below.

- Combination wrench
- Ratchet
- Allen attachment
- Hammer
- Screwdriver
- Lens cleaning brush
- Mirror
- Flashlight
- Electrical connector pliers
- Duct tape
- Safety wire.

Currently available tools and support equipment developed to date include foot restraints, tethers, handrails, ratchet wrench, allen attachment, extensions, and 7/16-in. sockets. Additional tools under development include a RMS-mounted foot restraint and a power ratchet.

2.1.3 EVA Design Standards

Three EVA design standards are in existence and provide different types of information to spacecraft designers and project office personnel. These standards are described below.

- JSC - 10615
  - This standard provides a good description of STS EVA provisions and what is planned for ST and SMRM
  - Very little useful information on past EVA tools and tasks, work envelopes, allowable forces and torques, and other specific data needed by the designer.
- MSFC-STD-512
  - This standard contains specific information on workstation layout, access requirements, tools, fasteners, connectors, equipment insertion guides, touch temperatures, and edges and covers needed by the spacecraft designer and should be a contract requirement for all spacecraft developers.
  - It does not include data and experience from LSS and Space Telescope EVA simulations.
- MSFC-STD-512A
  - This is a revised version of 512 (EVA section) but lacks most of the specific design information.

2.2 STATUS OF TELEOPERATOR RESEARCH AND DEVELOPMENT

NASA's interest in remotely manned systems has been long lived, being formalized in a joint AEC-NASA technology survey in 1967. Since 1971, MSFC has been involved in the Teleoperator Technology Development Program and is now investigating remote systems assembly technology for large space systems.

2.2.1 Teleoperator Technology and the Human Operator

Visual Systems - Vision is presumed to be the primary feedback mode for the control of teleoperators, and as a result, many investigations have been undertaken to determine the effects of various visual system parameters on operator performance. The recent summary of visual system investigations is found in Essex Corporation's Report H-82-01 and addresses findings for black and white, color, monoscopic, stereoscopic, analog, digital, slow frame rate, narrow band pass filtered TV systems in combination with environmental parameters such as signal-to-noise ratio, contrast, illumination, target shapes and angles and ranges. The point of contact for teleoperator visual systems is Daryl Craig, EC35, Marshall Space Flight Center, (205) 453-1575.

Manipulator Systems - For dexterous manipulation of the remote site, several classes of manipulator arms, end effectors, controllers and control schemes have been investigated as part of the Teleoperator Technology Development Program. General and special purpose systems, tool kit adaptors, bilateral and unilateral arms, anthropomorphic and non-anthropomorphic designs, discrete and integrated controllers, computer resolved control laws and direct drive controls are some of the parameters dealt with in manipulator system evaluations at MSFC. The point of contact for current manipulator evaluations is Keith Clark, EC25, Marshall Space Flight Center, (205) 453-3447.

Evaluations and simulations of operator performance using the Shuttle Remote Manipulator System (SRMS) have been carried out by the developer, SPAR, and the sponsoring agency, JSC. Data on large space manipulators and simulation capabilities can be obtained from Jeri Brown, Johnson Space Center Crew Systems, (713) 483-3774 and from Bryan Fuller, SPAR Aerospace, Ontario, Canada.

Mobility Systems - Remote mobility, through space, underwater or across a land mass is crucial for guiding the teleoperator to the task site. At JPL, work is on-going for planetary rovers; at MSFC, work has been going on since 1974 in the air bearing test facility on thruster propulsion for teleoperators. The point of contact at JPL is Ewald Heer, and the contact at MSFC is Ed Guerin, EC13, (205) 453-4635.

Integrated Teleoperator and Robotics Evaluation Facility - This facility is currently under construction at MSFC. It will provide a test environment for an extremely wide range of teleoperated activities. It contains a 4,000 sq. ft. air bearing epoxy flat floor, an automated orbital servicer simulator, two six degrees-of-freedom test beds for mounting mockups. There is a computer room for data analysis and test conduct, an electrical and mechanical shop for test apparatus, two remote control rooms and all the supporting equipment for communications, video, manipulation, etc. The completion data is late 1982. The point of contact for detailed information on this facility is Fred Roe, EC25, MSFC, (205) 453-3369.

2.2.2 Teleoperator Program Concepts

Several teleoperator concepts have been put forward in response to specific and general mission requirements. The Teleoperator Retrieval System (TRS), envisioned for boost/deboost of Skylab, is probably the best developed of these. Martin Marietta, under contract to MSFC, brought firm definition to the TRS, including engineering analyses, simulations, component flight items, and documentation. Another concept, pursued by Vought for MSFC, was the Teleoperator Maneuvering System (TMS) which has been designed with the delivery capability of the Shuttle in mind. The pancake shaped TMS is a departure from historical concepts, but this configuration is carried on in yet another teleoperator concept--Martin Marietta's Mark II propulsion module for the TMS. Each of these three teleoperator concepts has implications for human factors, and indeed, some limited human factors research has been conducted on these programs. The current status of teleoperator research and development is pressing toward a prototype for future flights and the point-of-contact for detailed information on teleoperator concepts is Jim Turner, PD21, MSFC, (205) 453-0367.

2.2.3 Other Remotely Manned Systems Research and Development

Programs outside NASA have particular interest in RMS research and development. Underwater research is being conducted by the Navy; nuclear energy management is being investigated at the Oak Ridge National Laboratories, and the Defense Advanced Research Projects Agency (DARPA) has research ongoing into remote system components. While not directly related to any NASA program, the research conducted at other agencies may have an impact on the research and development requirements of NASA.

2.3 STATUS OF CREW/VEHICLE INTERACTION RESEARCH AND DEVELOPMENT

Based upon experience gained in early manned missions and the extensive data gained in the Skylab missions, NASA has continued to accomplish human factors research in support of crew/vehicle interaction. Large Space Systems, Space Operations Center, Space platforms, teleoperators, satellite servicing and Spacelab are only some of the areas where this research will be applied.

2.3.1 Anthropometry for Crew/Vehicle Design

Several sources exist for crew vehicle design criteria. Many are NASA specific as is the case with MSFC-STD-512, Man/Systems Requirements for Weightless Environments, and others draw from more general anthropometric data bases such as NASA Reference Publication 1024, Anthropometric Source Book, Vols. I, II and III. Still others, like MIL

STD 1472C, have application to some NASA designs but were developed by other agencies. Current research has dealt with the new generation of space pressure suits (EMU), the flight control stations and the aft flight deck of the Shuttle, and the EVA service stations on serviceable payloads such as Space Telescope. Points of contact for anthropometric research are Allen Louviere, JSC Spacecraft Design Division, and Jack Stokes, EL15, MSFC Systems Analysis and Integration Laboratory.

2.3.2 Spacelab Experiment Control

The crew/vehicle interaction requirements for Spacelab are fairly complex and provide a good source of research data. The data requirements include EVA, DDU Display and Command Guidelines, crew procedures, crew training, and simulations.

The Spacelab Display Design and Command Usage Guidelines were developed to give standardized criteria for displaying experiment control and feedback information on an interactive video terminal. The point of contact is Ron Schlagheck, MSFC PCTC, (205) 453-1474.

2.4 STATUS OF ANALYSIS AND RESEARCH DESIGN TECHNOLOGY

A presumption that human factors research and technology is part of every complex system is usually made but is not always valid. In complex space systems, because of our short history and advanced technology, the requirement for user/system data is crucial to mission success, and this section briefly outlines current space related human factors technology development programs.

2.4.1 Research and Development Techniques and Resources

Human/Systems Simulations, Neutral Buoyancy Simulator. This facility is located at the Marshall Space Flight Center and provides a simulation environment for studying human task performance in zero gravity. The facility offers a large volume working environment in a 75 ft. wide by 40 ft. deep water tank. The facility can conduct full scale evaluations using two pressure suited subjects and preliminary concept evaluations using scuba subjects.

The facility has provided the environment for Skylab crew operations, Large Space Systems assembly and deployment, Space Telescope servicing, Shuttle RMS operations, MMU/EVA evaluations, and EVA contingency operations. It has a long history of EVA simulation activity and provides the largest earth-based environment for studying human performance in space suited operations.

The facility is currently equipped with a full size Shuttle cargo bay mockup, an operational SRMS, a MMU simulator for EVA mobility, and pallet and payload mockups for mission simulation.

For human performance simulations, the point of contact is Jack Stokes, EL15, MSFC, (205) 453-4430. He can provide information on past research, particular capabilities and requirements for human factors simulations, and information on use of the research facility.

Human/Systems Simulation, Weightless Environment Training Facility. Located at JSC, this facility also provides a zero-G simulation environment, used for astronaut training. The facility is outfitted with a cargo bay mockup and Shuttle bay pallets. The test tank is 78 ft. long, 30 ft. wide, and 25 ft. deep.

The point of contact for training studies at JSC is Carl Shelly, CG, JSC, (713) 483-2061; for the WETF, Ray Dell-osso, JSC, (713) 483-2541.

Human/Systems Simulation, KC-135 Weightless Environment. Flying from JSC, the KC-135 simulation facility allows 2-3 sec. periods of induced weightlessness through a flight profile of parabolas. Part task simulations and special applications can be conducted aboard the aircraft and by "stringing" tasks over successive parabolas, a task sequence can be studied in zero-G.

The point of contact is James W. Billodeau, CG, JSC, (713) 483-2061.

Manipulator Evaluation Criteria. A useful research technique, the evaluation criteria, employs a hierarchy of task modules with increasing degrees-of-freedom (DOF). In use at MSFC since 1973, it permits elimination of manipulator components such as end effectors, hand controllers, arm configurations, etc. from further test and evaluation if they fail to satisfy performance criteria at an elemental level (1 or 2 DOF). This procedure saves resources in that all possible combinations of manipulator components don't need to be extensively evaluated to find one or two complete systems which excel in typical task performance. The task modules typically measure tip position accuracy, orientation, stability, force/torque application, performance time and error rates.

The point of contact is Nicholas Shields, Essex Corporation, (205) 883-7471.

Teleoperation and Robotics Integrated Test Facility. Currently under construction, this test laboratory combines the capability of three existing laboratories: visual systems, manipulator systems and mobility systems. The completed facility (FY83) will provide a 4000-sq. ft. epoxy flat floor for air bearing vehicles. The vehicle stands provide 6 DOF for target motion. A remote workstation provides for evaluation of human performance during remote operations, such as satellite servicing, docking, inspection. The facility provides for a wide range of remote systems and robotics simulation in a simulated space environment.

The point of contact is Fred Roe, EC25, MSFC, (205) 453-3369.

Teleoperator Technology Development Program. This program provides a means of transferring and applying teleoperator and robotic technology to various space programs. Begun in 1971, the program is a laboratory based research program to develop design criteria for remote systems.

The conventional human factors criteria have assumed that the human operator and the controlled system occupy the same physical and temporal space, but this is not true for teleoperated systems. Consequently, performance data using remote support systems--manipulators, sensors, motion bases--had to be developed. This is an ongoing program for both basic and applied research issues.

The point of contact is Wayne Wagnon, EC31, MSFC, (205) 453-4623.

Six Degree-of-Freedom Motion Base and Crew Station and the Target Motion Simulator. These two complementary facilities provide for the simulation of rendezvous and docking in remote or local operations. The motion base provides proprioceptive/kinesthetic cues for user/system flight simulation and is equipped with a terrain table and visual system. The target motion simulator provides computer resolved vehicle approach and motion between two vehicles, one of which is controlled by the operator.

The point of contact for these facilities is Frank Vinz, EF93, MSFC, (205) 453-3991.

Analytical Techniques for Human Factors in Space Applications. Task analyses are still the most common means to derive system roles and responsibilities for humans in space, but other techniques are also in use. The SAINT program for integrated systems analysis is a more demanding analytical technique requiring substantial data for implementation but it also yields more data on performance of the system. The Man/Machine Assembly Analysis is a developmental technique for assessing appropriate modes of large space system assembly from manual, remote or automated alternatives. Conventional cost and engineering studies can generally be applied to human factors areas, but they tend not to provide human factors-specific information.

2.4.2 Control Station Design Data Base

There are ample volumes on control and display station design, but some of the unusual user/system requirements found in space applications require, and certainly the unusual environment has dictated, special designs for control stations.

Spacelab Experiment Control Station. This interactive station is designed for the command and control of experiments through a data display system consisting of a keyboard and video display unit. The requirements for command and control are derived from the hardware and software constraints, and the display protocols are presented in MSFC-PROC-711A. The display guidelines were derived from evaluations on the Experiment Computer Operating System and provide information on human performance in controlling remote software and hardware activity.

Teleoperator Control Station Design. Several models for teleoperator control stations have been investigated as the requirements for specific teleoperated systems have developed. Free flying teleoperator, teleoperator bay experiment, earth orbital teleoperator,

teleoperator retrieval system, teleoperator maneuvering system are some of the concepts that have been put forth, and with them control stations based on differing operational philosophies have also been proposed. Aft flight deck, Spacelab, TDRSS, ground station and POCC versions have been investigated. The level of investigations has not been such that there is any firm basis as yet for deciding on a "best" control station.

The point of contact for Integrated Teleoperator Control Station design is Ed Guerin, EC13, MSFC, (205) 453-4635. Work done for the integrated Orbital Servicer crew station design is included under teleoperator related research, and the point of contact is Don Scott, EC24, MSFC, (205) 453-5758.

3.0 TOPICS FOR FUTURE HUMAN FACTORS RESEARCH

In order that human factors data be an integral part of advanced space systems, it is desirable that programs in their conceptual stage be reviewed for areas of human factors applications. The review of advanced programs will enable human factors data to be part of the design basis for advanced programs rather than an add-on or system design afterthought. The responsibility for identifying human factors applications in advanced space systems is shared between the system designer and the human factors community. Additionally, the human factors applications are both generic and system specific in nature. Consequently, the aim of future research should be to assess the adequacy of generic human factors data in meeting the requirements of advanced systems and to contribute to the human factors data base by performing system-specific research not currently a part of the generic base as in MSFC-512A, JSC 10615, MSFC PROC-711A and similar technical documents.

3.1 ADVANCED SPACE SYSTEMS, GENERIC RESEARCH TOPICS

Habitability - Systems such as the Spacelab module provide for shirtsleeve operations on-orbit. Potentially missions of long duration, 90 days, can be carried out from a Spacelab type module attached to an orbiting large space structure. Habitability requirements for long duration human occupation of a module can be derived from a review of Tektite data, Skylab data, and from specific Spacelab simulations.

Output - Long duration human habitability requirements document.

Anthropometry - As those people involved in space based activities become more representative of the general population, the anthropometric data base for space system design criteria must also be expanded. Current data bases from military sources and the NASA-REF-1024 can be used as a foundation for future expansion of a representative anthropometric data base which is appropriate to space applications.

Output - Representative anthropometry for weightless environments.

Advanced Crew Station Design - More reliance upon multi-function, computer driven displays and multifunction command and control panels is apparent in aerospace and earth-based workstations. Using current data on human computer interaction and the expanded anthropometric data base, a set of crew station design standards for advanced space programs should be developed. The design standards should reflect the anticipated future space programs and the data already generated from programs such as the Apollo Telescope Mount (ATM) and Spacelab Experiment Control.

Output - Advanced crew station design standard.

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3.2 SPECIFIC RESEARCH TOPICS

3.2.1 Remote System Control/Supervision

Several distinct research efforts are coalescing and have significant implications for advanced space missions. Machine intelligence, teleoperation, space structure fabrication and assembly, large space systems, automated experiment management and long duration orbital repair and servicing are research programs which have been developing independently, but from a programmatic viewpoint have binding relationships with each other. What is needed is a research and development program which identifies the areas of human factors applications for specific remote system programs such as large space structures assembly, teleoperator servicing missions, and human interaction with intelligent machines; identifies the data which still need to be developed for human/remote systems technology; collects those data and then compiles them into remote system/human factors compendium. While this is a very large order for a specific research program, it can be broken out into component parts, as follow:

A. Human Interface with Intelligent Systems for Operations Management

1. Develop and evaluate intelligent computer programs for experiment control. Develop an intelligent system to assist in crew operations of complex science experiments. Perform evaluations on human alone experiment control, human/computer management, and computer alone management. Compare data return and accomplishment of science objectives using the three modes.

2. Evaluate the command/control feedback alternatives for operator/machine interaction and develop a set of optimal design standards for advanced experiment control, orbital activity management and other remotely managed tasks. Standards should address specific issues of AFD vs. POCC vs. specialized control/display station operations as well as command protocols, display arrangement, and uses of special visual and auditory displays.

3. Evaluate automated system control with the operator in a supervisory role and expert systems/artificial intelligence for system control for the purpose of defining the role of humans in highly automated systems, and providing adequate human control functions for contingency and off-nominal operating conditions, including emergencies.

B. Human Control of Remote System Mobility and Manipulation

1. Evaluate the effects on performance of utilizing a single controller system which serves to control both vehicle mobility and docking and post-docking manipulator control. Determine the performance differences between a single hand controller and dual hand controllers for such a system.

2. Evaluate operator performance on manipulative tasks where visual feedback is degraded but still available (< 20 dB S/N, 300 lines resolution, <.25 target background contrast). Determine performance baseline on degraded system and then employ augmentary feedback systems such as tactile displays, computer enhanced displays, computer generated displays, radar image displays to test for changes in task performance.

3. Develop concepts for specialized manipulator applications, including specialized controllers (as in a full torso exoskeletal controller for use at a ground station) and specialized end effectors (as in an inflatible end effector for use with beams, or a delicate claw for use with composite columns). Full sized controllers, while not desirable for Shuttle aft flight deck use, might be preferred for control via dedicated work stations.

C. Control Station Design

1. Current planning calls for zero-G and one-G operating environments for control of remote systems. The human factors requirements for the two environments are quite distinct as we discovered on ATM-Skylab. A research evaluation effort is required to identify what data bases and which design criteria apply specifically to one-G operator stations, to zero-G operator stations and which apply appropriately to either or both environments. Particular points of interest should be human restraint/support during mobility/manipulation activities, head movement and visual displays, multiple system operations from the same control station.

2. Simulation mockups for use in neutral buoyancy simulation and one-G simulations should be fabricated for use in operational simulations and concept verification.

3.2.2 EVA Applications During the Shuttle Era

The Shuttle will provide a broad opportunity for extravehicular activity in the next several decades. EVA servicing missions, satellite repair, experiment management, unscheduled and contingency operations are just some of the EVA tasks proposed for future space missions.

The new equipment available to the EVA crew members--EMU, MMU, SRMS--for support and maintenance of EVA tasks, and new equipment in the concept stages--power ratchet wrench, RMS-mounted cherry picker, large construction manipulator module, and mobile work stations--will greatly expand our current knowledge of the role of humans in space as well as expand our ability to use the human's unique capabilities in the space environment. In order to appreciate the full capabilities of EVA potential, human factors scientists should direct their attention to each of the following areas:

(1) Determine the effects on workstation design of the EVA mobility unit for the anthropometry represented by the 5th percentile female through the 5th percentile male.

(2) Determine the effects of MMU configuration on EVA workstation design. This should include MMU stand-off and positioning aids.

(3) Evaluate several standard module changeout designs for EVA and remote manipulator compatibility. Where are the effects of different changeout approaches on task times, task performance, EVA workload, and manipulator capabilities?

(4) Evaluate EVA performance changes using a three-axis EMU foot restraint. Current foot restraints must be egressed before reorienting them at the worksite in violation of MSFC-STD-512. What performance benefits can be gained by using a 3 DOF station which is manually adjustable while the EVA crew member remains in the foot restraint? What foot restraint design criteria must be met to assist the EVA crew in task performance?

(5) Determine potential cost savings associated with multiple crew, multiple shift EVA assembly and servicing operations for Space Station construction and maintenance tasks.

(6) Develop EVA cost data for tools, manual overrides and crew aids for comparison with conventional automated devices. Evaluate cost savings for potential Space Station servicing tasks.

(7) Evaluate system performance during spacecraft servicing tasks. This should include EVA workload, tool interface, glove wear, effects of manual vs. power tool on task performance, and generation of empirical data on which to base tool and workstation design criteria.

(8) Develop an EVA body positioning kit for use by system designers involved in EVA applicable programs. With new EMU configurations, tool packs and MMU's, our existing design data are out-of-date. The body positioning kit would be a suited subject model and would indicate the preferred and the worst case body positions for general categories of EVA tasks such as translation, assembly, module changeout, etc.

(9) Develop human factors/EVA design criteria for EVA restraint systems on advanced missions. These restraint systems would include EMU foot restraints, leg restraints, restraint systems for cargo bay servicing of payloads, RMS attached workstation restraints and assembly restraints. The requirement for further development of EVA restraint systems is derived from the anticipated expansion of the role of EVA in servicing, assembly, and mission support. These new EVA tasks will be

accomplished most effectively with equipment designed specifically to accommodate the EVA crew.

(10) Develop a standardized design specification for changeout requirements via EVA. The design specification should address workstations, restraints, EVA capability, stowage, transfer, access and safety for items such as electronics packages, fluid and power connectors, electrical and mechanical instruments, film and data packs, and similar EVA serviceable packages. The design specification should also address, as a secondary issue, design requirements for remote changeout via manipulator systems where these requirements do not interfere with EVA requirements.

(11) Design and develop an EVA power tool for on-orbit operations. The power tool should be generally applicable to common EVA activities and should include tool attachments such as grippers, cutters, screwers. The tool should be reversible in operating direction and have provisions for manual use in case of power failure. Additionally, evaluations on manual vs. power tool selection--in terms of performance times, task accuracy, support requirements--should be conducted to access the two tool modes. Space telescope servicing tests conducted in the neutral buoyancy simulator have indicated savings in time, restraints, glove wear and increased accuracy of task performance for some classes of EVA tasks.

(12) In conjunction with tool operations, a design standard for selection of fasteners and connectors should be developed for use in EVA tasks.

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4.0 LITERATURE SURVEY

Ref. Appendix A - Data Sources

A.1 EVA

MSFC-STD-512	Man/System Design Standard for Manned Orbiting Payloads
MSFC-STD-512A	Man/System Requirements for Weightless Environments
JSC-10615	STS EVA Design Guidelines and Criteria
NASA TMX-64825	MSFC Skylab EVA Development Report
Essex H-76-7	Design Guidelines and Criteria for Shuttle Payloads to Accommodate EVA
Essex H-80-4	Structural Attachments for Large Space Structures
CONT OPS 2102	Contingency Operations Training Workbook (STS EVA)
LS-005-003-24	Photographs of Skylab Inflight Tools and Equipment
Skylab Experience Bulletin No. 1	Translation Modes SI Bump Protection
No. 5	Inflight Maintenance of a Visible Program Element
No. 13	Tools, Test Equipment and Consumables Required to Support Inflight Maintenance
No. 27	Personnel and Equipment Restraint and Mobility Aids (EVA)
JSC-18201	Satellite Services Workshop (June 22-24, 1982)

A.2 TELEOPERATOR

ESSEX H-82-01	Human Operator Performance of Remotely Controlled Tasks
NASA/MSFC T/O Task Team	Teleoperator Maneuvering System Program Definition Activities, 1979

A.2 TELEOPERATOR (Continued)

Essex H-79-01	Earth Orbital Teleoperator Systems Evaluation
H-30093B, NBS	Proximity-Vision System for Protoflight Manipulator Arm
Machine and Machine Theory	Manipulator System Performance Measurements
Proceedings of the Sixth Congress of the International Ergonomics Association	A Method and Data for Video Monitor Sizing
Essex H-75-30953	Role of Man in Flight Experiment Payloads
NASA SP-5047	Teleoperators and Human Augmentation
NASA SP-5070	Teleoperator Controls
Martin Marietta Documentation on TRS, NAS8-32821	Teleoperator Retrieval System Program Documentation

A.3 CREW/VEHICLE INTERACTION

MSFC-PROC-711A	Spacelab Display Design and Command Usage Guidelines
VanCott and Kinkade	Human Engineering Guide to Equipment Design
NASA-CR-3285	EVA Manipulation and Assembly of Space Structure Columns
NASA SP-377	Biomedical Results from Skylab

A.4 ANALYSIS/DESIGN TECHNOLOGY

Essex H-82-02	Man Machine Assembly Analysis
NASA-RP-1024	Anthropometric Source Book
Proceedings of the 23rd Annual Meeting of the Human Factors Society	Lewis, J.L. Operator Station Design System: A Computer Aided Design Approach to Workstation Layout.

SOME RESEARCH ISSUES CONCERNING HUMAN PERFORMANCE IN COMPLEX SYSTEMS

Robert W. Swezey
Science Applications, Inc.

In the study of human performance, a topic which has received widespread attention is known as the Yerkes-Dodson Law. This law states that the quality of performance on any task is an inverted-U-shaped function of the level of arousal of the performing human, and that the range over which performance improves with increasing arousal varies with task complexity (Yerkes and Dodson, 1908). Thus, according to this proposition, as arousal (stress) is shown to increase, performance also appears to increase in linear fashion until a critical point is reached when further increases in stress result in rapid performance deterioration.

This law, although originally based on somewhat crude experimental procedures, has been demonstrated to be valid in a wide range of situations. (Duffy, 1957; Malmo, 1958; Hebb, 1949; Schlosberg, 1954; Stennett, 1957). An example of the validity of the Yerkes-Dodson Law is provided by the work of Stennett (1957). He investigated the relationship between performance on a tracking task and levels of GSR and muscle tension. He also introduced a new variable by manipulating the motivational level of his subjects with changing instructions. Presumably, instructions which demanded more effort of the subjects would result in higher levels of arousal and this would be reflected in the GSR and muscle tension measures. Stennett found that performance on the auditory tracking task was related to level of motivation by an inverted-U-shaped function. The finding held regardless of the measure used to indicate arousal. Figure 1 shows the classical Yerkes-Dodson relationship.

It has also been hypotehsized (Hebb, 1949) that sensory events are composed of cue functions (which guide behavior into a particular type of activity such as eating, drinking, etc.) and arousal functions which elicit the basic energy to propel the organism in a goal-oriented direction. According to this theory, without arousal, no cue function can exist.

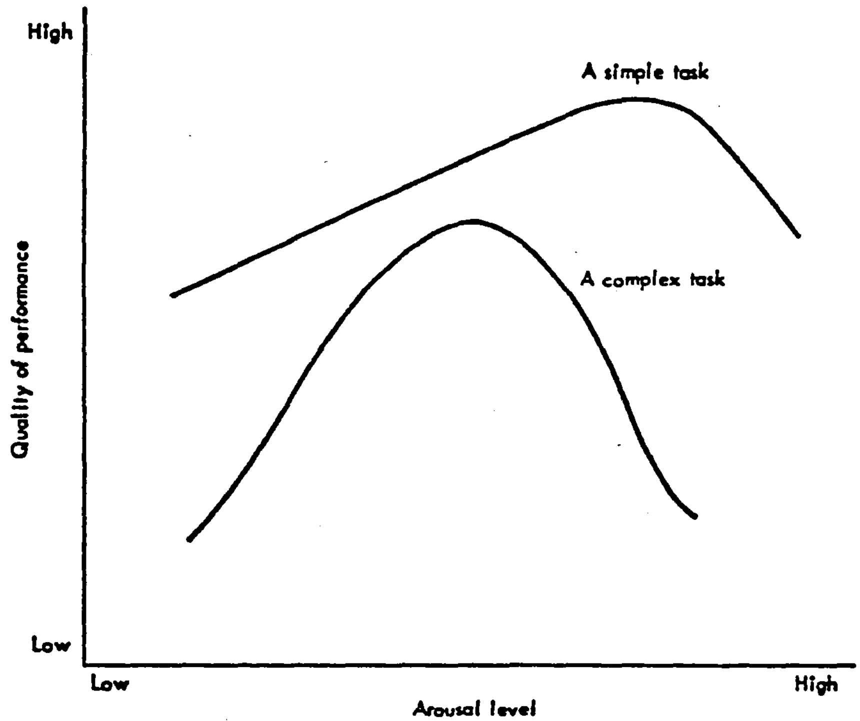

Figure 1 - The Yerkes-Dodson Law
as pictured by Kaneman (1973)

Hebb's concept of arousal is synonymous with the concept of general drive state and is also related to cue function via the inverted-U-shaped function. Hebb's conception is shown in Figure 2.

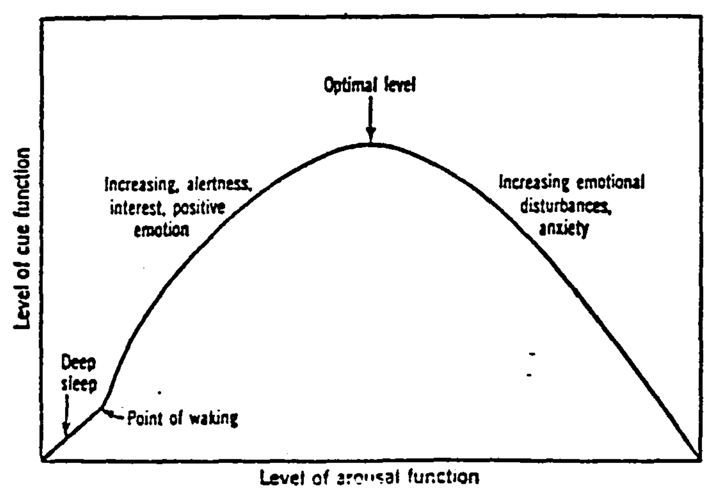

Figure 2 - Hypothetical "inverted U-shaped" relationship
between behavioral efficiency or level of cue function
and level of arousal as pictured by Hebb (1949).

More recently, Fineberg (1975) has shown that this function also describes aviator performance (reaction time and response accuracy) in a series of complex tasks involving manipulations of aircraft closing velocity and target distance.

Welford (1968) has postulated two explanations for such phenomena. One assumes that an individual's level of arousal varies with the strength of an incentive, such that a high level of incentive would have little effect on the performance of an easy task, but would have a much greater effect as the requirement for capacity increased. The second explanation presumes that tasks themselves induce a degree of arousal, and that this arousal rises with increasing task difficulty. This arousal is then added to the arousal produced by an incentive. If the optimum arousal level is the same for most degrees of task difficulty, the addition due to incentive that would produce this optimum, would fall as a task becomes more difficult.

The Yerkes-Dodson Law has been widely studied in the areas of stress and performance (c.f. Freeman, 1938; Stabler and Dyal, 1963; Anderson, 1976). It appears to have been adequately demonstrated, and exists as a respected component of the scientific literature.

Cognitive Tasks

Additionally, work has focused upon expanding the variable domain in this area. A series of studies by Swezey (summarized in a forthcoming book; Easterby and Zwaga, in press) have suggested that the inverted-U-shaped phenomenon can legitimately be extended to the cognitive domain. That is, when a variety of stimulus manipulations in several different contexts (primarily legibility studies) addressed the cognitive tasks of recalling and retaining presented alphanumeric data, an inverted-U-shaped function similar to the Yerkes-Dodson type effect, resulted. A cognitive processing explanation for this phenomenon was offered (Swezey, 1978) which suggested that as stimuli were degraded the effective result of the degradations was to force the user to concentrate harder on the presented material in order to compensate for the rapidly degrading stimulus conditions. This increased concentration resulted in improved recall and retention performance up to a point beyond which no amount of increased concentration on the user's part could compensate for the extreme stimulus degradation, and recall and retention thus deteriorated.

Interactive Complexity Theory

In a somehwat different domain, work by Streufert and associates (summarized in Streufert and Streufert, 1978) have postulated an interactive theory of cognitive complexity which, briefly stated, suggests that as the environmental complexity of a situation increases, the ability of individuals to demonstrate flexible differentiative and integrative performance in complex decision making tasks follows (you guessed it) a series of inverted-U-shaped curves.

According to Streufert (1982), the potential for multidimensional (differentiative/integrative) behavior is considered to be optimal at some intermediate level of environmental load. However, differential maximum elevations of the U-shaped curves at that optimal point reflect differential styles of information processing. That is, Streufert's theory postulates the existence of various styles of information processing. Current theory specifies nine such styles as follows: low unidimensional, normal unidimensional, general differentiative, closed-hierarchical differentiative, excessive differentiative, low integrative, high integrative, closed-hierarchical integrative, and non-closing integrative (Streufert and Swezey, 1982). Individuals employing such styles presumable show differently constructed inverted-U-shaped curves (c.f. Figure 3).

Complexity theory has been tested in basic laboratory experiments (e.g., Streufert, 1966), in organizational manned simulations (e.g., Streufert, 1970), and in a large number of real-world settings (summarized in Streufert and Streufert, 1978). The predictions of the theory have been confirmed for perceptual (e.g., Streufert and Driver, 1965), and complex decision-making tasks (e.g., Streufert and Schroder, 1965) among others.

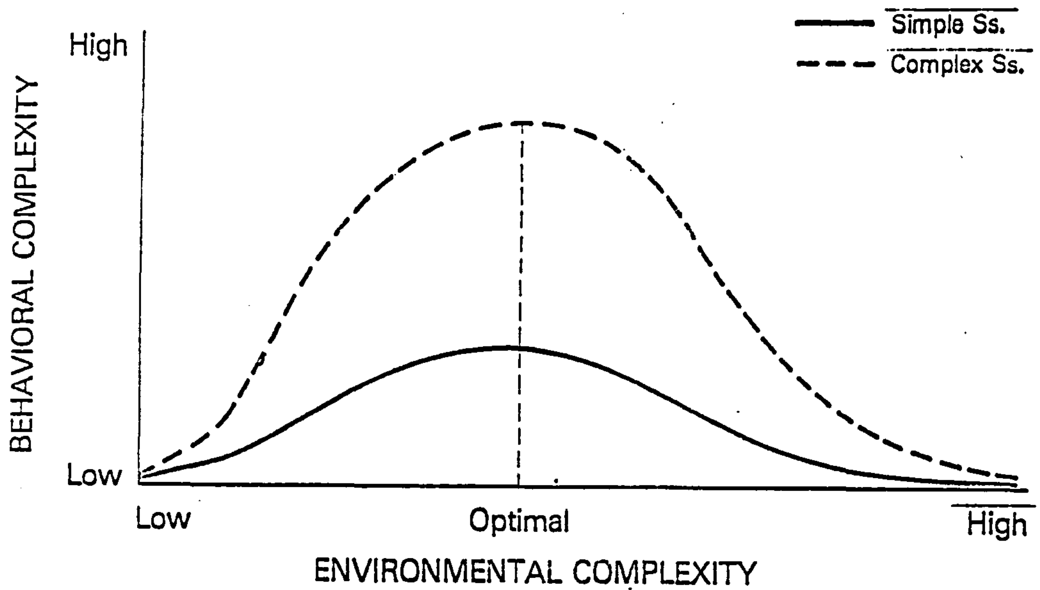

Figure 3 - Degree of flexible differentiation and integration in perception and performance as a function of environmental complexity (Revised theory: Streufert and Streufert, 1978)

Complex Systems Design

The previous discussion has introduced the notion that an inverted-U-shaped function applies widely to perceptual, retention, and decision-making tasks; and further, that individual decision styles may effect the specific shape and height of that function. Such a notion would argue that complex systems should be designed with these data in mind (i.e., should be designed to maximize user performance by employing optimal stressor levels). Here the term "stressor" is used generically to refer to such concepts as load, environmental complexity, stimulus degradation, etc. The point is that research may be conducted to determine ways to manipulate system design parameters in order to maintain the optimal (asymptotic) performance level on the inverted-U-shaped curves (c.f. Figure 4) for various individual cognitive styles (i.e., simple, complex, etc.).

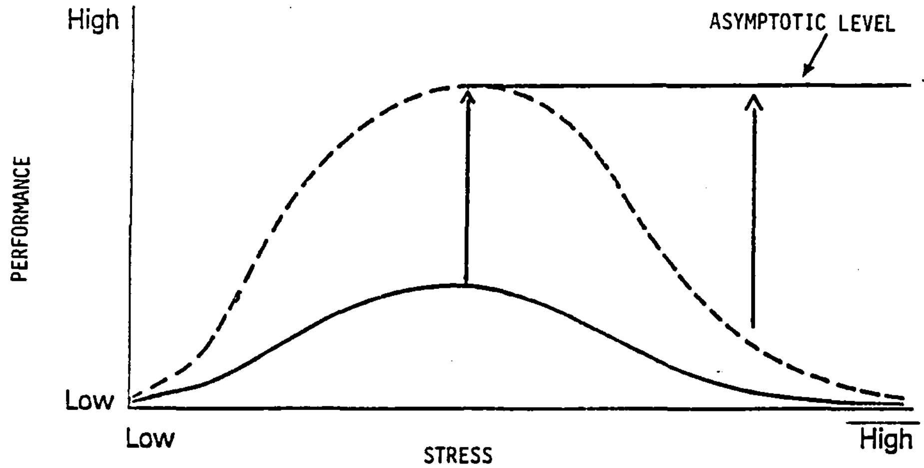

Figure 4 - Asymptotic level

One of the major human factors findings of the 1981 Air Force Studies Board panel on Automation in Combat Aircraft (AFSB, 1981) was that..."The effectiveness of automation depends (in large part) on matching the designs of automated systems to (users' cognitive) representations of their tasks. This requires an understanding of how (users) think about their tasks, as well as an understanding of the performance characteristics of the control and display components through which the (users) and the automated systems interact...(p. 59)."

"Further that panel issued the following recommendation..." Develop models of (user) behavior, for example, specific models of workload and menu selection, as well as general models of how (users) process information and make decisions...(p. 59)."

Recent studies in cognitive psychology appear promising but need to be codified into practical handbooks and models. Such an attempt has recently been made, for example, by Davis and Swezey (in press) in the area of human factors guidelines for computer graphics displays.

Practical research efforts are needed in these areas as follows:

- Determining and quantifying optimum stressor levels for various tasks and display parameters,
- Manipulating system designs and display parameters to achieve optimum stressor levels (and thereby determining ways to maintain asymptotic performance),
- Determining the effects of various individual cognitive styles on system performance,
- Studying cognitive models and expectations of system users,
- Synthesizing guidelines for complex system design,
- Employing Hunter, Schmidt, and Jackson (1981) type meta-analytic procedures to establish the current state of knowledge in the area of complex display design.

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APPENDIX B

SPACE HUMAN FACTORS WORKSHOP ATTENDEES

HUMAN FACTORS WORKSHOP
ATTENDANCE LIST

PROF. DAVID AKIN	MIT
MR. JOHN ANDERSON	NASA HQ
MR. WILLIAM BACHMAN	JPL
DR. SHELDON BARRON	BOLT BERANEK & NEWMAN
DR. ANTAL BEJCZY	JPL
DR. CHARLES BILLINGS	ARC
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DR. KENNETH BOFF	AFAMRL/HEA
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DR. ALLAN CHAMBERS	ARC
DR. RANDALL CHAMBERS	US ARMY RESEARCH LAB
DR. STEPHAN CHESTON	GEORGETOWN UNIVERSITY
DR. RAYMOND COLLADAY	NASA HQ
CAPT. DAN COLLINS	USAF
CAPT. WILLIAM CONNOR	AIRPLINE PILOTS ASSOCIATION
MR. ALFRED CRON	GRC
DR. STANLEY DEUTSCH	CONSULTANT
MR. MAX ENGERT	JSC
LTC. DAVE ENGLAND	USAF
MR. DELL FREEMAN	NASA HQ
MAJ. RUDY FEDERMAN	AF/SD
MR. KENNETH FERNANDEZ	MSFC
MR. H. TOM FISHER	LOCKHEED
DR. ALFRED FREGLY	AFOSR
DR. RICHARD GABRIEL	DOUGLAS AIRCRAFT COMPANY
MR. EDWARD GABRIS	NASA HQ
DR. OWN GARRIOTT	JSC
MAJ. LARRY GLASS	AF/SD
MR. JERRY GOODMAN	JSC
DR. CHARLES GOODWIN	GRUMMAN AEROSPACE

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MR. EWALD HEER	JPL
DR. ROBERT HENNESSEY	NRC
DR. WYCKLIFFE HOFFLER	KSC
DR. CARL HOFFMAN	AEROSPACE CORPORATION
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DR. EZRA KRENDALL	UNIVERSITY OF PENNSYLVANIA
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MR. FRED KEUNE	JSC
DR. RONALD LARSEN	NASA HQ
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DR. BYRON LICHTENBERG	MSFC (MIT)
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