

# OAST Technology For the Future

Volume III—Critical Technologies, Themes 5–8

BEST AVAILABLE COPY

IN-SPACE TECHNOLOGY EXP

Best Available Copy

*distro same as*  
ADA 338 267 PLEASE RETURN TO: *U 2607*

BMD TECHNICAL INFORMATION CENTER  
BALLISTIC MISSILE DEFENSE ORGANIZATION  
7100 DEFENSE PENTAGON  
WASHINGTON D.C. 20301-7100

*U 2607*

## IN-STEP 88 WORKSHOP

### FOREWORD

At the workshop, Dr. Harrison H. Schmitt emphasized that the nations which effectively exploit the advantages of space will lead human activities on earth. The major space goal of the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology (OAST) is to provide enabling technologies, validated at a level suitable for user-readiness, for future space missions in order to ensure continued U.S. Leadership in space. An important element in accomplishing this goal is the In-Space Technology Experiments Program whose purpose is to explore and validate in space advanced technologies that will improve the effectiveness and efficiency of current and future space systems. OAST has worked closely with the aerospace community over the last few years to utilize the Space Shuttle, expendable launch vehicles, and, in the future, the Space Station Freedom for experimentation in space in the same way that we utilize wind tunnels to develop aeronautical technologies. This close cooperation with the user community is an important, integral part of the evolution of the In-Space Technology Experiments Program which was originated to provide access to space for technology research and experimentation for the entire U.S. aerospace community.

On December 6 through 9, 1988, almost 400 researchers, technologists, and managers from U.S. companies, universities, and the government participated in the OAST IN-STEP 88 Workshop. The participants reviewed the current in-space technology flight experiments, identified and prioritized the technologies that are critical for future national space programs and that require verification or validation in space, and provided constructive feedback on the future plans for the In-Space Technology Experiments Program. The attendees actively participated in the identification and prioritization of future critical space technologies in eight major discipline theme areas. These critical space technologies will help focus future solicitations for in-space flight experiments. The material within these four volumes is the culmination of the workshop participants' efforts to review the planning for the future of this program.

#### DISTRIBUTION STATEMENT A

Approved for Public Release  
Distribution Unlimited

Dr. Leonard Harris  
Chief Engineer  
Office of Aeronautics and  
Space Technology, NASA

20040817 051

BALLISTIC MISSILE  
DEFENSE ORGANIZATION  
7000 ...

**OAST IN-STEP 88 WORKSHOP  
Critical Technologies (Themes 5-8)**

**VOLUME III**

	<u>Page</u>
Foreword	i
Contents	ii
Introduction to Volume III	1
Presentation of Critical Technologies for Themes 5-8	3
<b>5. Automation and Robotics</b>	<b>4</b>
Background and Objectives - Dr. Antal K. Bejczy, JPL	5
<b>5.1 Robotic Systems</b>	<b>25</b>
Robotics - Al Meintel, LaRC	27
Robotics - T.M. Depkovich, Martin Marietta Space Systems Co.	33
Robots in Space - Delbert Tesar, The University of Texas at Austin	36
<b>5.2 Teleoperations</b>	<b>45</b>
Space Teleoperations, Now and Future - Charles R. Price, JSC	47
Teleoperation - Paul B. Pierson, G.E. Aerospace	53
Teleoperation: multimode operator interfaces, intelligent displays, hierarchical control, communication time delay, visual perception systems - Thomas B. Sheridan, MIT	59
<b>5.3 Artificial Intelligence</b>	<b>64</b>
In-Space Experiments in Artificial Intelligence - Dr. Peter Friedland, ARC	65
Artificial Intelligence: An Industry View - David A. Rosenberg, ISX Corporation	71
Artificial Intelligence - Dr. Robert Cannon, Stanford University	77
Critical Technology Requirements - Dr. Antal K. Bejczy, JPL	83
<b>6. Sensors and Information Systems</b>	<b>94</b>
Background and Objectives - John Dalton, GSFC	95
<b>6.1 Sensors</b>	<b>99</b>
In-Space Experiments in Remote Sensing Systems - Martin M. Sokoloski, NASA HQ	101
In-Space Sensor Technology Experiments - E. David Hinkley, Hughes Aircraft Company	109
LIDAR/Laser Sensors - Dr. Denis Killinger, University of South Florida	117
<b>6.2 Communications</b>	<b>125</b>
In-Space Experiments in Communication Systems - Martin M. Sokoloski, NASA HQ	127
Space Laser Communication Experiments - M. Ross, Laser Data Technology, Inc.	133
Coherent Optical Intersatellite Crosslink Systems - Vincent W. S. Chan, MIT	141
<b>6.3 Information Systems</b>	<b>149</b>
In-Space Experiments in Information Systems - John T. Dalton, GSFC	151
Information System Panel DMS Perspectives - George Nossaman, IBM	159
In-Space Experiments in Information Systems - Neil R. White, University of Colorado	167
Critical Technology Requirements - John Dalton, GSFC	175

7.	In-Space Systems	187
	Background and Objectives - Jon B. Haussler, MSFC	189
7.1	Materials Processing	198
	Materials Processing - Larry Spencer, NASA HQ	199
	Floating-Zone Crystal Growth in Space - John T. Viola, Rockwell International Science Center	207
	Materials Processing - Cells and Cellular Products - David W. Sammons, University of Arizona	213
7.2	Maintenance, Repair, and Fire Safety	220
	Maintenance, Servicing, & Repair in Space - Ed Falkenhayn, GSFC	221
	Spacecraft Fire Safety for Advanced Spacecraft - Wallace W. Youngblood, Wyle Laboratories	227
	Maintenance, Servicing, and Repair in Space - Bob Dellacamera, McDonnell Douglas Space Systems Company	233
7.3	Payload Operations	239
	Payload Operations from the Perspective of Manned Space flight - Dr. Jeffrey A. Hoffman, JSC	241
	Orbit Assembly Node - Tom Styczynski, Lockheed Missiles and Space Company	249
	In-Space Systems: Space Construction and Payload Operations - George W. Morgenthaler, University of Colorado	257
	Critical Technology Requirements - Jon B. Haussler, MSFC	265
8.	Humans In Space	272
	Background and Objectives - Remus N. Bretoi, ARC	273
8.1	EVA/Suit	288
	EVA Technology - Dr. Bruce W. Webbon, ARC	289
	Humans in Space (Extra-Vehicular Activity/Suit) - H.T. Fisher, Lockheed Missiles and Space Company	295
	EVA and Pressure Suit Technology - David L. Akin, MIT	303
8.2	Human Performance	309
	Crew and Environmental Factors - Dr. Barbara G. Kanki, ARC	311
	Artificial Gravity - Larry G. Lemke, ARC	317
	Human Performance - William R. Ferrell, University of Arizona	323
8.3	Closed-Loop Life Support Systems	329
	Physical/Chemical Closed Loop Life Support - R. D. MacElroy, ARC	331
	Closed-Loop Life Support, Industry Presentation - Thomas J. Slavin, Boeing Aerospace	337
	Physical/Chemical Closed-Loop Life Support - Martin W. Luttges, University of Colorado	343
	Critical Technology Requirements - Remus N. Bretoi, ARC	349

## INTRODUCTION TO VOLUME III

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on the In-Space Technology Experiments Program (IN-STEP) December 6-9, 1988, in Atlanta, Georgia. The purpose of this workshop was to identify and prioritize space technologies which are critical for future national space programs and which require validation in the space environment. A secondary objective was to review the current NASA (In-Reach) and Industry/University (Out-Reach) experiments. Finally, the aerospace community was requested to review and comment on the proposed plans for the continuation of the In-Space Technology Experiments Program. In particular, the review included the proposed process for focusing the next experiment selection on specific, critical technologies and the process for implementing the hardware development and integration on the Space Shuttle vehicle. The product of the workshop was a prioritized listing of the critical space technology needs in each of eight technology disciplines. These listings were the cumulative recommendations of nearly 400 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification and prioritization of the critical space technology needs were initiated by assigning NASA chairpersons (theme leaders) to the eight major technology disciplines or themes requiring consideration. These themes were as follows:

- space structures
- space environmental effects
- power systems and thermal management
- fluid management and propulsion systems
- automation and robotics
- sensors and information systems
- in-space systems
- humans in space

In order to provide further structure within each theme, the chairpersons divided their themes into three theme elements each. The theme element concept allowed focused technical discussions to occur within the broad discipline themes. For each theme element, the theme leader selected government, industry, and university experts to present the critical space technology needs of their respective organizations. The presentations were reviewed and discussed by the theme audiences (other members of the aerospace community), and prioritized lists of the critical technologies which require verification and validation in space were established for each theme element. The comments and conclusions for each theme were incorporated into a summary listing of the critical space technology needs and associated flight experiments representing the combined inputs of the speakers, the audience, and the theme leader.

The critical space technology needs and associated space flight experiments identified by the participants provide an important part of the strategic planning process for space technology development and provide the basis for the next solicitation for space technology flight experiments. The results of the workshop will be presented to the IN-STEP Selection Advisory Committee in early 1989. This committee will review the critical technology needs, the funding available for the program, and the space flight opportunities available to determine the specific technologies for which space flight experiments will be requested in the next solicitation .

These proceedings are organized into an Executive Summary and four volumes: Executive Summary; In-Reach/Out-Reach Experiments and Experiment Integration Process (Volume I); and Critical Technology Presentations (Volumes II and III).

Volume III contains the theme introduction given by the chairperson, the critical technology presentations for each theme element, and the summary listings of critical space technology needs for each theme. The introduction for each theme includes the chairperson's overview of the theme and its theme elements, along with instructions for the participants. The critical technology presentations are as described above, and the summaries are the listings of critical space technology needs and associated flight experiments as discussed above. This volume contains the documentation for the following four themes: automation and robotics, sensors and information systems, in-space systems, and humans in space.

**PRESENTATION OF CRITICAL TECHNOLOGIES FOR THEMES 5-8**

## **5. AUTOMATION AND ROBOTICS**

# **AUTOMATION AND ROBOTICS BACKGROUND AND OBJECTIVES**

**ANTAL K. BEJCY  
JET PROPULSION LABORATORY**

# ORGANIZATION

## THEME LEADER:

ANTAL K. BEJCZY, JPL

## COMMITTEE:

THOMAS S. DOLLMAN, MSFC

HENRY LUM, ARC

ALFRED J. MEINTEL, JR., LaRC

CHARLES R. PRICE, JSC

LLOYD R. PURVES, GSFC

DOUGLAS A. ROHN, LeRC

JAMES P. JENKINS, NASA HQ, OAST/RC  
(EX OFFICIO)

## SUBTHEMES & THEME GROUPS:

1. ROBOTICS
2. TELEOPERATION
3. ARTIFICIAL INTELLIGENCE

## **THEME SESSION OBJECTIVES**

### **PURPOSE**

- IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR AUTOMATION & ROBOTICS, BY CONSIDERING SUBTHEME DETAILS, WHICH
  - ● ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS
  - ● REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
- GENERATE COMMENTS AND SUGGESTIONS FROM AEROSPACE COMMUNITY ON OAST IN-STEP PLANS

### **PRODUCT**

- PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS, RECOMMENDED BY AEROSPACE COMMUNITY

## **THEME DESCRIPTION**

### ● **SCOPE**

FULL SPECTRUM OF TELEOPERATION, ROBOTICS AND ARTIFICIAL INTELLIGENCE COMPONENTS, SUBSYSTEMS AND SYSTEMS AS THEY RELATE TO SPACE MISSIONS, INCLUDING HUMAN OPERATOR FUNCTIONS IN THESE SYSTEMS

### ● **GOAL**

PROVIDE THE TECHNOLOGY AND UNDERSTANDING OF ALL THREE SUBTHEMES NEEDED TO ENSURE PRODUCTIVE AND SAFE APPLICATION OF INCREASINGLY AUTOMATED ROBOTIC AND SYSTEM CAPABILITIES IN SPACE MISSIONS UNDER REMOTE HUMAN OPERATOR SUPERVISION, INCLUDING THE UNDERSTANDING OF HUMAN PERFORMANCE CAPABILITIES IN THESE SYSTEMS

# DESCRIPTION OF SUBTHEME 1: ROBOTICS

## TECHNOLOGY ELEMENTS

- ROBOT MECHANISMS AND ACTUATORS
- ROBOT SENSING
- ROBOT CONTROLS
- ROBOT PROCESSING AND ITS ARCHITECTURE
- ROBOT SYSTEM CONCEPTS AND DESIGNS

INCLUDING REDUNDANCY IN ROBOTIC SYSTEMS, TOGETHER WITH RELIABILITY AND FAULT TOLERANCE REQUIREMENTS IN SPACE SYSTEMS

## SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR ABOVE ELEMENTS, TAKING INTO ACCOUNT SPACE APPLICATION AND SPACE ENVIRONMENTAL CONDITIONS AND MISSION CONSTRAINTS

# DESCRIPTION OF SUBTHEME 2: TELEOPERATION

## TECHNOLOGY ELEMENTS

- MULTI-MODE OPERATOR INTERFACES TO TELEROBOTS
  - INTELLIGENT DISPLAYS
  - HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES
  - VISUAL PERCEPTION SYSTEMS
  - COMMUNICATION TIME DELAY
- INCLUDING SUPERVISORY COMMAND LANGUAGES, TRADED/  
SHARED MANUAL/COMPUTER CONTROLS AND THE USE OF  
EXPERT SYSTEMS BY HUMAN OPERATORS

## SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR EFFICIENT  
AND SAFE UTILIZATION OF HUMAN OPERATOR CAPABILITIES IN  
DIRECT OR SUPERVISORY CONTROL OF TELEROBOTS, TAKING  
INTO ACCOUNT THE EFFECTS OF SPACE CONDITIONS  
(MICROGRAVITY, ETC.) AND COMMUNICATION TIME DELAYS ON  
OPERATOR BEHAVIOR AND PERFORMANCE, AND ALSO  
CONSIDERING THE HANDLING OF SINGULAR OR UNEXPECTED  
TASKS

# DESCRIPTION OF SUBTHEME 3: ARTIFICIAL INTELLIGENCE

## TECHNOLOGY ELEMENTS

- OPERATIONS AND CONTROL PLANNING/COORDINATION
- PERFORMANCE MONITORING OF COMPLEX SYSTEMS
- ERROR DETECTION AND RECOVERY
- MULTI-SENSOR DATA INTERPRETATION
- OPERATOR INTERACTION WITH EXPERT SYSTEMS

USING EXISTING AND EVOLVING CAPABILITIES OF ARTIFICIAL OR MACHINE INTELLIGENCE TECHNIQUES

## SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR INCREASED LEVEL OF INTELLIGENT AUTOMATION APPLICABLE TO SPACE MISSIONS AND OPERATIONS, INCLUDING TELEROBOTIC MISSIONS AND OPERATIONS, TAKING INTO ACCOUNT SPACE OPERATIONS CONSTRAINTS

# **BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT**

- **SUMMARY OF A&R THEME FROM 1985 WILLIAMSBURG, VA  
WORKSHOP (SEE APPENDIX)**
  
- **ACCOMPLISHMENTS SINCE 1985**
  - **IN-REACH ACTIVITIES**
  - **OUT-REACH ACTIVITIES**
  - **EXPERIMENTS IN PREPARATIONS**
    - **SHUTTLE RMS FTS/DEXTROUS MANIPULATION**
    - **TRIFEX/ROTEX**
    - **S/S FTS**
    - 
    - 
    -

# THEME SESSION AGENDA

## SPEAKERS & PANEL

1. A. MEINTEL, LARC
  2. T. DEPKOVICH/J. SPOFFORD, MARTIN MARIETTA SPACE SYSTEMS
  3. PROFESSOR D. TESAR, UNIVERSITY OF TEXAS, AUSTIN
- PANEL: SUBTHEME SPEAKERS AND:  
 PROFESSOR J. DUFFY, UNIV. OF FLORIDA; PROFESSOR G. SARIDIS, RPI; F. GARCIA, IBM; S. HARRIS, ODETTICS.

1. C. PRICE, JSC
  2. P. PIERSON, GENERAL ELECTRIC
  3. PROFESSOR T. SHERIDAN, MIT
- PANEL: SUBTHEME SPEAKERS AND: L. JENKINS, JSC; PROFESSOR L. STARK, UC BERKELEY; PROFESSOR J. STAUDHAMMER, UNIVERSITY OF FLORIDA.

1. N. SLIWA/P. FRIEDLAND, ARC
  2. D. ROSENBERG ISX, INC.
  3. PROF. R. CANNON, STANFORD UNIV.
- PANEL: SUBTHEME SPEAKERS AND: R. SIMPSON; DARPA; J. DICKERSON, MCDONNELL-DOUGLAS SPACE DIV.

<b>SUBTHEME: ROBOTICS</b>
SPEAKER 1. (30 min)
SPEAKER 2. (30 min)
SPEAKER 3. (30 min)
DISCUSSION (30 min)

9:45 A.M.



11:45 A.M.

<b>SUBTHEME: TELEOPERATION</b>
SPEAKER 1. (30 min)
SPEAKER 2. (30 min)
SPEAKER 3. (30 min)
DISCUSSION (30 min)

1:00 P.M.



3:00 P.M.

<b>SUBTHEME: ARTIFICIAL INTELLIGENCE</b>
SPEAKER 1. (30 min)
SPEAKER 2. (30 min)
SPEAKER 3. (30 min)
DISCUSSION (30 min)

3:15 P.M.



5:15 P.M.

## **THEME DISCUSSIONS**

- **AFTER EACH SUBTHEME SESSION**
  - OPEN 30 min DISCUSSION WITH AUDIENCE & THEME LEADER/SPEAKERS/PANEL
    - QUESTIONS & ANSWERS
    - IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE
  - AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES
- **JOINT THEME DISCUSSION, THURSDAY 8:30-10:45 A.M.**
  - DISCUSSION BETWEEN AUDIENCE & ALL THEME ELEMENT SPEAKERS
  - RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME

# **PRIORITIZATION CRITERIA**

**(LISTED IN ORDER OF IMPORTANCE)**

## **1. CRITICAL ENABLING TECHNOLOGIES**

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS

## **2. COST REDUCTION TECHNOLOGIES**

- TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (e.g., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

## **3. BROAD APPLICATION TECHNOLOGIES**

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

## **4. REQUIRE IN-SPACE VALIDATION**

- TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION

# APPENDIX

## SUMMARY OF AUTOMATION & ROBOTICS THEME FROM 1985 WILLIAMSBURG, VA, IN-SPACE RT&E WORKSHOP

— QUOTED FROM WORKSHOP EXECUTIVE SUMMARY —

AUTOMATION AND ROBOTICS  
OBJECTIVES/CAPABILITIES

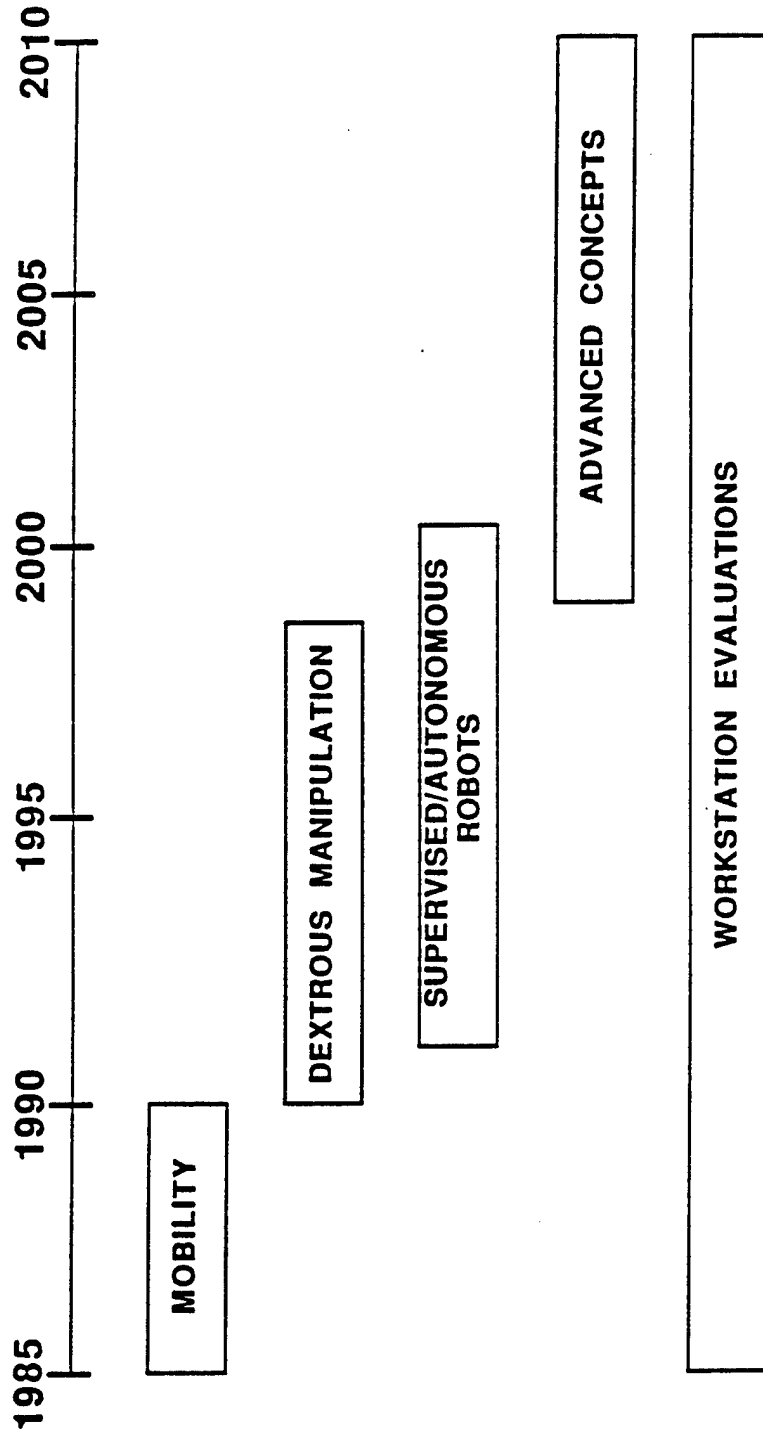
- o VALIDATE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - DOCKING - 1988
  - SATELLITE SERVICING - 1990
  - STRUCTURAL ASSEMBLY - 1992
  - IVA ASSISTANT - 1996
  - EVA ASSISTANT - 2000
- o EVOLVE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - TELEPRESENCE - 1990
  - SUPERVISORY CONTROL - 1994
  - AUTONOMOUS OPERATIONS - 1998
- o SYSTEM AUTONOMY CAN BE DEMONSTRATED ON GROUND

## WHY IN-SPACE EXPERIMENTS

- o EVALUATE ZERO "G" VS. ONE "G" DYNAMICS FOR:
  - MECHANICAL CONFIGURATIONS
  - PROXIMITY OPERATIONS
  - FLUIDS, SOLIDS, GASES
- o DEVELOP DESIGN/OPERATIONAL DATA BASE
- o VALIDATE PROTO FLIGHT HARDWARE/SOFTWARE/  
PROCESSES
- o EVALUATE MAN/MACHINE PERFORMANCE ON-ORBIT
- o EVALUATE GROUND MODELS/SIMULATIONS
- o EVALUATE LONG TERM SPACE EFFECTS ON SYSTEMS

QUOTES FROM 1985 WILLIAMSBURG, VA  
RT&E WORKSHOP

AUTOMATION AND ROBOTICS  
EXPERIMENT THRUSTS



QUOTES FROM 1985 WILLIAMSBURG, VA  
RT&E WORKSHOP

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
<ul style="list-style-type: none"> <li>● SINGLE ARM TELEOPERATOR</li> </ul>	<ul style="list-style-type: none"> <li>● DUAL ARM TELEOPERATOR COORDINATION</li> </ul>	<ul style="list-style-type: none"> <li>● MULTI-ARM COORDINATION</li> </ul>
<ul style="list-style-type: none"> <li>● TELEOPERATION FROM EARTH</li> <li>● COMBINED TRANSLATION/MANIPULATION</li> </ul>	<ul style="list-style-type: none"> <li>● TELEPRESENCE</li> </ul>	<ul style="list-style-type: none"> <li>● AUTONOMOUS ROBOTICS</li> <li>● MULTIPLE ROBOT COORDINATION</li> </ul>
<ul style="list-style-type: none"> <li>● FIXED ON-STATION RMS</li> <li>● DOCKING</li> </ul>	<ul style="list-style-type: none"> <li>● MOBILE ON STATION RMS</li> <li>● TELEOPERATED FREE-FLYING OPERATIONS</li> </ul>	<ul style="list-style-type: none"> <li>● FREE-FLYING AUTONOMOUS PROXIMITY OPERATIONS</li> </ul>
	<ul style="list-style-type: none"> <li>● FREE-FLYER AND DUAL-ARM COLLISION AVOIDANCE</li> </ul>	<ul style="list-style-type: none"> <li>● MULTIPLE ARM COLLISION AVOIDANCE</li> </ul>
	<ul style="list-style-type: none"> <li>● CAD-DRIVEN POSITION REGISTRATION (ON S/S)</li> </ul>	
<ul style="list-style-type: none"> <li>● END-EFFECTOR DEFINITION</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● MECHANICAL ASSEMBLY PROCESS</li> </ul>	<ul style="list-style-type: none"> <li>● JOINTING</li> </ul>	<ul style="list-style-type: none"> <li>● WELDING</li> </ul>
<ul style="list-style-type: none"> <li>● WORK STATION HW/SW/MM INTERFACES</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● SENSOR ACCOMMODATIONS</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● SPACE EFFECTS ON TELEOP. CAPABILITY</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
	<ul style="list-style-type: none"> <li>● ZERO G MATERIALS HANDLING</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>

QUOTES FROM 1985 WILLIAMSBURG, VA  
RT&E WORKSHOP

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
<ul style="list-style-type: none"> <li>● FAILURE DETECTION</li> <li>● FAILURE ISOLATION</li> <li>● FAULT TOLERANCE</li> </ul>	<ul style="list-style-type: none"> <li>● FAULT TOLERANT (EVOLVING)</li> <li>● FAULT REPAIR</li> </ul>	<ul style="list-style-type: none"> <li>● FAULT REPAIR (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● ADVANCED AUTOMATION SOFTWARE ALGORITHMS</li> </ul>	<ul style="list-style-type: none"> <li>● REAL-TIME PLANNING</li> <li>● INDEPENDENT EXPERT</li> </ul>	<ul style="list-style-type: none"> <li>● INTERACTIVE AI/EXPERT SYSTEMS</li> </ul>
<ul style="list-style-type: none"> <li>● IMPROVED SATELLITE SERVICING TOOLS</li> </ul>	<ul style="list-style-type: none"> <li>● TELEOPERATOR SATELLITE SERVICING</li> </ul>	<ul style="list-style-type: none"> <li>● AUTONOMOUS SATELLITE SERVICING &amp; REPAIR BY ROBOTS</li> </ul>
<ul style="list-style-type: none"> <li>● WORKLOAD POWER CONSUMPTION EXPERIMENTS</li> </ul>	<ul style="list-style-type: none"> <li>● ROBOTIC INSPECTION (SENSOR DEPENDENT)</li> </ul>	<ul style="list-style-type: none"> <li>● ROBOTS REPAIR BY ROBOTS</li> </ul>
<ul style="list-style-type: none"> <li>● ROBOTIC VISION AND IMAGERY OPTIMIZATION</li> </ul>	<ul style="list-style-type: none"> <li>● SPACE EFFECTS ON VISION SYSTEMS</li> </ul>	
<ul style="list-style-type: none"> <li>● AUTONOMOUS ORBIT TRANSFER</li> </ul>		
<ul style="list-style-type: none"> <li>● COMPLIANCE TECHNIQUES</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● MASS MOVEMENTS STUDIES</li> </ul>	<ul style="list-style-type: none"> <li>● MOMENTUM COORDINATION</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>● VOICE CONTROL/INTERACTION</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>● (EVOLVING)</li> </ul>

QUOTES FROM 1985 WILLIAMSBURG, VA  
RT&E WORKSHOP

AUTOMATION AND ROBOTICS

EXPERIMENT LIST

- |        |                                 |
|--------|---------------------------------|
| 1988   | PROXIMITY MANEUVERING           |
| 1989   | TELEOPERATED MANEUVERING (MMU)  |
| 1990   | SMART FRONT END TECHNOLOGY      |
| 1992   | SATELLITE SERVICING             |
| 1994/6 | SUPERVISORY STRUCTURAL ASSEMBLY |
| 1996   | IVA ROBOT                       |
| 2000   | AUTONOMOUS SPACE ROBOT          |
| 2010   | SPACE SPIDER                    |

CONTINUOUS WORKSTATION EVALUATION AND IN-SPACE WORKLOAD MEASUREMENTS

AUTOMATION AND ROBOTICS  
ACCOMMODATION ISSUES

- o "ROBOT FRIENDLY" INTERFACES FOR SERVICING, ASSEMBLY, AND DOCKING
- o STANDARD UTILITIES REQUIRED FROM MOBILITY SYSTEMS (RMS, MRMS, OMV, OTV, ETC.)
- o SAFETY
- o COMPUTING POWER, DATA STORAGE, SYSTEM ARCHITECTURES
- o STANDARDS FOR END EFFECTORS, ARMS, HOLDERS, ETC.
- o MASS/VOLUME MODEST
- o ASTRONAUT TRAINING REQUIRED
- o FORMATION FLYING REQUIRED
- o EVA NECESSARY IN SOME CASES
- o IVA ACTIVITY REQUIRED
- o HIGH BANDWIDTH VIDEO/ENCRYPTION COMMUNICATIONS SYSTEM

QUOTES FROM 1985 WILLIAMSBURG, VA  
RT&E WORKSHOP

RECOMMENDATIONS

- o ACCELERATE EXPERIMENT SCHEDULE - IMPACT SPACE STATION
- o ACTIVE FOLLOW-UP TO EMBED TECHNOLOGY ACCOMMODATION ISSUES WITH SPACE STATION
- o ESTABLISHMENT OF IN-SPACE TECHNOLOGY ADVOCACY COMMITTEE
- o WORK WITH ULTIMATE USER GROUPS
- o ENCOURAGE USERS TO COME FORWARD
- o EXPLORE CREATIVE WAYS OF COST SHARING
- o DEVELOP AND DISSEMINATE SPACE STATION IN-SPACE RESEARCH CAPABILITY
- o BROADEN RESEARCH USER LIAISON WITH STATION
- o COORDINATE BETWEEN PANELS - DISTRIBUTE TO PARTICIPANTS
- o ESTABLISH CONTINUING MAIL LIST AND FOCAL POINTS

## **5.1 ROBOTIC SYSTEMS**

**This page intentionally blank**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ROBOTIC SYSTEMS</b>
--------------------------------------	--	----------------------------

# **ROBOTICS**

**AL MEINTEL  
NASA LARC**

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

## **INTRODUCTION/BACKGROUND**

- **AUTOMATIC MACHINE  
SPECIAL PURPOSE MECHANISM**
- **REPROGRAMMABLE MULTIFUNCTIONAL MACHINE  
INDUSTRIAL ROBOT**
- **ADAPTIVE ROBOT  
SENSOR BASED**
- **TELEROBOT  
SUPERVISED MACHINE**
- **INTELLIGENT ROBOT  
GOAL DRIVEN**

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

**MISSION APPLICATIONS**

- ASSEMBLY**
- INSPECTION**
- SERVICING**
- EXPERIMENTATION**
- MANUFACTURING**
- REPAIR**
- CONSTRUCTION**
- EXPLORATION**

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ROBOTIC  
SYSTEMS**

## **TECHNOLOGY NEEDS**

- MECHANISMS**
- SENSORS**
- CONTROL**
- PLANNING**
- FAULT TOLERANCE**
- SYSTEMS ARCHITECTURE**

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- **MECHANISMS**  
  - REDUNDANT MANIPULATORS WITH LOW WEIGHT & POWER**
  - POSITIVE RETENTION OF END EFFECTORS/TOOLS**
  - MOBILITY**
  
- **SENSORS**  
  - END POINT DETERMINATION**
  - COLLISION DETECTION**
  - DATA CORRELATION**
  
- **CONTROLS**  
  - FLEXIBILITY**
  - DISTURBANCE COMPENSATION**
  - DYNAMIC INTERACTION**
  
- **OPERATOR INTERFACE**  
  - DYNAMIC SIMULATION**
  - MONITORING**
  - INTERACTIVE REPLANNING**

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ROBOTIC  
SYSTEMS**

## **SUMMARY/RECOMMENDATIONS**

- IN-SPACE EXPERIMENTS  
FLEXIBILITY  
DYNAMIC INTERACTIONS  
FLIGHT QUALIFIED HARDWARE  
MECHANISMS  
SENSORS  
COMPUTERS  
SYSTEM VALIDATION**
  
- STANDARDIZATION**
  
- EFFICIENT ROBOTIC PROGRAMMING**
  
- FAULT TOLERANCE/REDUNDANCY**
  
- TELEROBOTICS**

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ROBOTIC  
SYSTEMS**

## **ROBOTICS**

**T.M. Depkovich  
J.R. Spofford**

**MARTIN MARIETTA  
SPACE SYSTEMS CO.**

## **INTRODUCTION/BACKGROUND**

- R&D ACTIVITIES HAVE DEVELOPED AN ARRAY OF TECHNIQUES FOR ROBOTIC SYSTEM CONTROL
- MATURE AND NEAR-MATURE AREAS INCLUDE:
  - POSITION CONTROL
  - COMPLIANT CONTROL
  - COORDINATED DUAL ARM CONTROL
- FEASIBILITY DEMONSTRATIONS HAVE INCREASED CONFIDENCE IN TECHNOLOGY
- MISSION APPLICATION ASSESSMENT SUFFERS FROM "CHICKEN AND EGG" SYNDROME
  - MISSIONS UNWILLING TO COMMIT WITHOUT FIRM DEFINITION OF ROBOTIC CAPABILITY
  - ROBOTIC CAPABILITY ONLY GENERALLY DEFINED BECAUSE OF LACK OF MISSION SUPPORT
  - EXAMPLE: "DESIGN FOR SERVICING"
- BROAD RANGE OF POTENTIAL APPLICATIONS
  - EVA: CONSTRUCTION, INSPECTION, REFURBISHMENT, REPAIR, CONTINGENCY
  - IVA: HOUSEKEEPING, EXPERIMENTS

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ROBOTIC SYSTEMS</b>
--------------------------------------	--	----------------------------

## **TECHNOLOGY NEEDS**

- DEMONSTRATIONS PERFORMED OVER THE PAST SEVERAL YEARS HAVE SHOWN FEASIBILITY OF ALL MAJOR TECHNOLOGY ELEMENTS NECESSARY FOR ROBOTIC SERVICING PROGRAM
- MAJOR SHORTFALL AT THIS TIME IS A LACK OF CONSENSUS ON MEANS OF SPECIFYING MANIPULATOR SYSTEM PERFORMANCE REQUIREMENTS AND VALIDATING SYSTEM PERFORMANCE
- VIRTUALLY ALL CURRENT SPECIFICATIONS ARE STATIC; TO BE MEANINGFUL AND USEFUL, DYNAMIC SPECIFICATIONS ARE ALSO REQUIRED
- SOLUTION IS ACHIEVED THROUGH THE UNDERSTANDING OF RELATIONSHIP BETWEEN TASK FUNCTIONAL DESCRIPTION AND MANIPULATOR CLOSED-LOOP DYNAMIC IMPEDANCE
- EQUIVALENT TO ASSIGNING UNITS ON DEXTERITY
- THREE POTENTIAL APPROACHES TO ESTABLISHING THESE RELATIONSHIPS
  - ANALYTICAL (NOT LIKELY)
  - SIMULATION (LIKELY WITH ADVANCED CAD/CAE)
  - EMPIRICAL (BEST NEAR-TERM SOLUTION)

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- MAJORITY OF SPACE ISSUES CAN BE ANSWERED THROUGH GROUND BASED TESTING AND EXPERIMENTATION
- SPACE BASED EXPERIMENTS SHOULD BE VIEWED AS FINAL LINK IN CHAIN OF VALIDATION STUDIES NECESSARY PRIOR TO HANDOVER TO OPERATIONAL COMMUNITY
- DEDICATED EXPERIMENTAL TESTBED AVAILABLE TO RESEARCH COMMUNITY FOR GENERAL INVESTIGATIONS
  - MECHANISMS
  - SENSORS
  - CONTROL
  - PROCESSING
  - MMI
- KEY INITIAL EXPERIMENTS
  - CONTROL LAW VALIDATION
  - COMPLIANT CONTROL
  - CONTROL WITH LARGE PAYLOADS
  - COORDINATION
  - SUPERVISORY CONTROL
  - PERFORMANCE DATABASE FOR OPERATIONS ASSESSMENT

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

## **SUMMARY/RECOMMENDATIONS**

- ROBOTIC TECHNOLOGY NOW READY TO ADVANCE TO MATURE TECHNOLOGY STATUS
- THIS REQUIRES THE ABILITY TO UNAMBIGUOUSLY SPECIFY PERFORMANCE REQUIREMENTS; BOTH STATIC AND DYNAMIC
- THIS ABILITY ESSENTIAL TO DESIGN AND VALIDATION PROCESS; AN IMPORTANT FACTOR IN ACHIEVING COST EFFICIENCY
- CAPABILITY NOW EXISTS FOR EMPIRICAL DETERMINATION OF DYNAMIC REQUIREMENTS
- EXPERIMENTAL TESTBED REQUIRED TO SUPPORT ADVANCED RESEARCH
- KEY TO TESTBED SUCCESS IS FLEXIBILITY IN ACCEPTING NEW TECHNOLOGY
  - MECHANISMS
  - SENSORS
  - PROCESSING
  - ALGORITHMS
  - MMI
- LAST STEP IS FINAL VALIDATION OF TECHNOLOGY

**This page intentionally blank**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ROBOTIC SYSTEMS</b>
--------------------------------------	--	----------------------------

# **ROBOTS IN SPACE**

## **PROFESSOR DELBERT TESAR**

**Carol Cockrell Curran Chair in Engineering**

**THE UNIVERSITY OF TEXAS AT AUSTIN**

## INTRODUCTION / BACKGROUND TECH BASE ISSUES FOR ROBOTICS

- I. LIGHTWEIGHT
  1. ROBOTS ARE LIMBER
  2. MUST BE MADE ELECTRONICALLY RIGID
  3. REQUIRES COMPLETE PARAMETRIC MODEL
  4. LEVEL OF CONTROL FAR BEYOND PRESENT CAPABILITY
- II. PRECISION UNDER DISTURBANCE
  1. PRECISION LIGHT MACHINING
  2. REAL TIME DYNAMIC MODEL
  3. ADAPTIVE CONTROL
  4. FEEDFORWARD COMPENSATION
- III. MAN-MACHINE INTERFACE
  1. NEED INCREASES WITH BETTER TECHNOLOGY
  2. SHOULD BE KINESTHETIC (ANALOG)
  3. FORCE FEEDBACK ESSENTIAL
  4. GENERIC UNIVERSAL MANUAL CONTROLLER
- IV. DYNAMICS OF DOCKING
  1. SHOCK TO STATION UNDESIRABLE
  2. SATELLITE SPIN AND WOBBLE IS COMPLEX
  3. PRESENTLY REQUIRES 8 TO 10 hours
  4. SOPHISTICATED MANIPULATOR DYNAMICS REQUIRED
- V. LEVEL OF TECHNOLOGY REQUIRED
  1. FAR BEYOND TODAY'S INDUSTRIAL ROBOT
  2. GEOMETRY MUST BE MORE GENERIC (PARALLEL)
  3. DYNAMIC CONTROL TECHNOLOGY GROSSLY INADEQUATE
  4. BALANCE OF ELECTRICAL AND MECHANICAL ESSENTIAL

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ROBOTIC SYSTEMS
-----------------------	--	-----------------

## GENERIC TECHNOLOGY NEEDS / VOIDS

### NEEDS

1. MULTI-TASK CAPABILITY
2. LEVEL OF MACHINE INTELLIGENCE
3. TIME EFFICIENT OPERATION
4. UNSTRUCTURED TASK LEVEL
5. GEOMETRICAL DEXTERITY
6. PORTABILITY AND MOBILITY
7. PRECISION

### REMARKS

1. NUMBER OF DIFFERENT PHYSICAL TASKS FEASIBLE
2. LEVEL OF INTEGRATION OF COMPUTER HARDWARE, SOFTWARE, ARTIFICIAL INTELLIGENCE, ETC.
3. SPEED OF PERFORMANCE RELATIVE TO HUMAN ACTING ALONE
4. LEVEL OF NUMERICAL UNCERTAINTY IN TASK SPECIFICATION
5. EFFECTIVE MOTION RANGE (LINEAR AND ANGULAR) OF THE END-EFFECTOR
6. ABSOLUTE MOVEMENT OF SHOULDER BASE WITH WITH OR WITHOUT HUMAN ASSISTANCE
7. ABSOLUTE PRECISION OF POSITIONING OF END-EFFECTOR IN WORLD COORDINATES

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ROBOTIC  
SYSTEMS**

## **SPECIFIC TECHNOLOGY NEEDS / VOIDS REAL-TIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL**

### NEEDED DEVELOPMENT

- DEMONSTRATE MODEL REFERENCE CONTROL
  - RIGID LINK MODEL
  - COMPENSATE FOR APPLIED LOADS
  - COMPENSATE FOR INERTIA LOADS
- EXPAND TO INCLUDE DEFLECTIONS
  - LINK FLEXIBILITY
  - ACTUATOR FLEXIBILITY
- ESTABLISH OPERATIONAL SOFTWARE
- DEMONSTRATE IN ACTUAL MACHINING OPERATIONS

### TASK DESCRIPTION

- EXPAND RANGE OF APPLICATIONS
  - FOR GENERIC MANUFACTURING SYSTEMS
  - USE FEED FORWARD COMPENSATION
- ON LINE COMPUTATION
  - FULL MODELING MATRICES
  - REAL TIME (< 30 msec.)
- ARRAY PROCESSOR IMPLEMENTATION
  - PIPELINED COMPUTATION
  - RECURSION IN ALGORITHM

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ROBOTIC SYSTEMS</b></p>
---	---	-----------------------------------

## **ROBOT TECHNOLOGY NEEDS FOR SPACE**

- I. ASSEMBLY OF SPACE STRUCTURES
  - 1. HANDLING OF LARGE MODULES
  - 2. PRECISE SUB-ASSEMBLY TASKS
  - 3. PRECISION WELDING AND FORMING
  - 4. PRECISION LIGHT MACHINING
  
- II. SPACE STATION MAINTENANCE AND REPAIR
  - 1. CONTINUOUS INSPECTION REQUIRED
  - 2. 40% OF REPAIRS TO BE UNPLANNED
  - 3. UNSTRUCTURED TASK ENVIRONMENT
  - 4. PRECISION UNDER DISTURBANCE
  
- III. SATELLITE SERVICING AND REPAIR
  - 1. 75 MISSIONS/YEAR
  - 2. UNSTRUCTURED TASKS
  - 3. SOME PRECISION WORK UNDER DISTURBANCE
  - 4. DOCKING DYNAMICS CRITICAL
  
- IV. HAZARDOUS MANUFACTURING AND LABORATORY EXPERIMENTS
  - 1. CLUTTERED ENVIRONMENT IN MODULE
  - 2. CLEAN ROOM ATMOSPHERE
  - 3. ABSOLUTE STABILITY DESIRED
  - 4. FURNACE RENOVATION CRITICAL
  
- V. MAINTENANCE OF ROBOTS
  - 1. SOFTWARE ADAPTABILITY TO CHANGE IN PARAMETERS
  - 2. MODULARITY FOR MAINTAINABILITY
  - 3. MODULE REPLACEMENT FOR TECHNOLOGY UP-DATE
  - 4. DUALITY IN CRITICAL MAINTENANCE OPERATIONS

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ROBOTIC  
SYSTEMS**

## **IMMEDIATE RESEARCH NEEDS FOR SPACE STATION ROBOTICS**

- ARCHITECTURE OF ROBOTICS SYSTEMS
- UNIVERSAL MAN-MACHINE INTERFACE FOR ROBOTIC MANIPULATOR SYSTEMS
- CONTROL OF MULTIPLE ARM ROBOTIC SYSTEMS
- ROBUST CONTROL OF FLEXIBLE "CHERRY PICKER" ROBOTIC MANIPULATOR
- REALTIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL
- METROLOGY FOR ROBOTIC SYSTEMS

## 5.2 TELEOPERATIONS

**This page intentionally blank**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

# **SPACE TELEOPERATIONS, NOW AND FUTURE**

**Charles R. Price  
TELEOPERATOR SYSTEMS BRANCH  
JOHNSON SPACE CENTER**

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>TELEOPERATIONS</b></p>
---	---	------------------------------

## **INTRODUCTION/BACKGROUND**

- THE SPACE SHUTTLE DEPLOYMENT AND RETRIEVAL SYSTEM IS THE STATE OF THE ART FOR IN-SPACE TELEOPERATIONS
- THE PDRS CONSISTS OF THE REMOTE MANIPULATOR SYSTEM AND ITS ANCILLARY EQUIPMENT MOUNTED ON THE SPACE SHUTTLE ORBITER
- THE PDRS FUNCTIONALITIES ARE:
  - GRAPPLE, TRANSPORT, ORIENTATION, AND RELEASE OF A PAYLOAD
  - TRACK, CAPTURE, GRAPPLE, TRANSPORT, ORIENTATION, AND BERTHING OF A SATELLITE
  - EVA CREW TRANSPORT, POSITIONING, ORIENTATION VIA GRAPPLED MOBILE FOOT RESTRAINT
  - LOCAL ILLUMINATION VIA RMS-MOUNTED LIGHTS
  - DIRECTIONAL, AUGMENTED VIEWING VIA RMS-MOUNTED CCTV
  - FREESTREAM EXPERIMENT SENSOR POSITIONING
  - POWER AND DATA INTERFACE SERVICES FOR PAYLOADS
  - RESOURCE FOR CREATIVE SOLUTIONS TO UNPLANNED PROBLEMS

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

## NEAR TERM FUTURE TELEOPERATOR APPLICATIONS

- ON-ORBIT:
  - ORBITER-BASED SPACE STATION ASSEMBLY
  - SPACE STATION-BASED SPACE STATION ASSEMBLY
  - SATELLITE SERVICING
- TERRESTRIAL SPACE APPLICATIONS:
  - KSC TURN-AROUND OPERATIONAL COST REDUCTION APPLICATION, e.g.:
    - TILE INSPECTION
    - PAYLOAD BAY INSPECTION
  - NSTS TURNAROUND COSTS ARE \$250 MILLION/FLIGHT
  - SUCCESSFUL GROUND APPLICATIONS ENHANCE ON-ORBIT APPLICATIONS

## LONGER TERM TELEOPERATOR APPLICATIONS (WITH TRENDS TOWARDS TELEROBOTICS)

- EXPANDED ON-ORBIT SERVICING OF SATELLITES
- EXPANDED SHUTTLE TURNAROUND OPERATIONAL SUPPORT
- ON-ORBIT MAINTENANCE OF SPACE STATION
- ON-ORBIT SERVICING OF PLATFORMS, INCLUDING HARVESTING OF PRODUCTS
- ON-ORBIT ASSEMBLY OF LUNAR AND DEEP SPACE EXPLORATORY VEHICLES
- REMOTE LUNAR MINING OPERATIONS

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

**TECHNOLOGY NEEDS FOR SPACE SHUTTLE  
PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM  
SUPPORT TO SPACE STATION ASSEMBLY**

- **FORCE/TORQUE FEEDBACK**
- **CONSTRAINED MOTION CONTROL FUNCTIONALITY**
  - **RATE COMMAND TO CONTACT TRANSITION**
  - **RATE COMMAND WITH VARIABLE RESISTANCE LOADING**
  - **SPLIT AXIS MIXED MODES**
- **LOW SCAR GRAPPLE FIXTURE**
- **DISPLAY OF COMPLEX ASSEMBLY WORKSPACES TO CREW**
- **PRACTICAL COLLISION AVOIDANCE (INFERS LIMITED MACHINE VISION)**
- **SINGLE WORKSTATION CONTROL OF MULTIPLE, HIERARCHIAL (AND SOME PARALLEL) MANIPULATORS**
- **FAULT TOLERANCE BY DESIGN TO IMPROVE MISSION SUCCESS PROBABILITIES**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

## PERCEIVED VOIDS IN THE IN-SPACE EXPERIMENTS REGARDING TELEOPERATORS

- ON-ORBIT:
  - DISPLAY OF COMPLEX (ASSEMBLY) WORKSPACE UNDER ORBITAL LIGHTING CONDITIONS TO CREW
  - COLLISION AVOIDANCE SENSING, CALCULATION, AND DISPLAY TO CREW
  - SINGLE WORKSTATION CONTROL OF
    - HIERARCHIAL SETS OF MANIPULATORS
    - PARALLEL SETS OF MANIPULATORS
    - TOTAL DEGREES OF FREEDOM EXCEEDING FIFTY OR MORE
  - DEMONSTRATION/VERIFICATION OF MATH MODELED CONSTRAINED MOTION AND CONTACT DYNAMICS
  - FAILURE DETECTION, ISOLATION, AND AUTOMATIC RECONFIGURATION OF A TELEOPERATOR SYSTEM
  - DISTRIBUTED, JOINT-LEVEL REPROGRAMMABLE MICROPROCESSING FOR AN OPERATIONALLY ADAPTIVE TELEOPERATOR
  
- TERRESTRIAL RELATED:
  - FEEDFORWARD CONTROL FOR GROUND COMMAND OF ON-ORBIT TELEOPERATOR
  - SHUTTLE TURNAROUND COST SAVINGS APPLICATIONS

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>TELEOPERATIONS</b></p>
---	---	------------------------------

## **SUMMARY/RECOMMENDATIONS**

- **ASSEMBLY OF COMPLEX WORKPIECES IS THE MAJOR NEAR TERM TECHNOLOGY DRIVER FOR IN-SPACE TELEOPERATORS**
- **IN-FLIGHT EXPERIMENTS SUPPORTING ASSEMBLY WILL ALSO APPLY TO SATELLITE SERVICING TELEOPERATION**
- **RECOMMEND MORE EMPHASIS BE PLACED ON PRACTICAL COLLISION AVOIDANCE AND DISPLAY OF COMPLEX WORKSPACE TO CREW**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

# **TELEOPERATION**

**Paul B. Pierson  
GE AEROSPACE**

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>TELEOPERATIONS</b></p>
---	---	------------------------------

## **INTRODUCTION/BACKGROUND**

- **SPACE TELEOPERATION**
  - CANDIDATE MISSIONS DEFINED
  - COST EFFECTIVENESS UNDER REVIEW
  - TELEOPERATION IS POTENTIALLY A VIABLE OPTION
- **TECHNOLOGY BASE**
  - INDUSTRIAL ROBOTICS
  - UNDERSEA, NUCLEAR POWER PLANT TELEOPERATIONS
- **SPACE TELEOPERATION/SUPERVISORY CONTROL**
  - COMBINATION OF ROBOTICS AND TELEOPERATIONS
  - COMPLEX OPERATOR INTERFACE
  - HIERARCHICAL CONTROL/INFORMATION ARCHITECTURE
  - COMMUNICATION TIME DELAYS
  - MUST PERFORM PLANNED/UNPLANNED TASKS
  - SPACE CONDITIONS

## **CAPABILITIES REQUIRED FOR MISSION APPLICATION TASKS**

- **CAMERA/INSTRUMENT POSITIONING FOR INSPECTION**
- **HEAVY/LIGHT OBJECT MANIPULATION AND POSITIONING**
- **MANIPULATION IN FREE-SPACE AND WITH CONTACT CONSTRAINED MOTIONS**
- **APPLICATION OF FORCE**

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

## MISSION APPLICATIONS

- INSPECTION (ROUTINE OR DIAGNOSTIC)
- ORU/PAYLOAD EXCHANGE (PAYLOAD UPGRADE, EXPERIMENT REPLACEMENT)
- REFURBISHMENT/REPLENISHMENT OF EXPENDABLES (FUELS, CRYOGENS)
- ASSEMBLY OF LARGE SPACE STRUCTURES, COMPONENTS
  - SPACE STATION TRUSSES AND UTILITY TRAYS
  - LARGE ANTENNAS, NUCLEAR POWERED PLATFORMS
- COMPONENT REPLACEMENT
  - CONTAMINATED OR WORN PARTS
- INSTRUMENT ADJUSTMENT, CALIBRATION
  - SPACE TELESCOPE, EARTH OBSERVATION SYSTEM
- REPAIR/CONTINGENCY OPERATIONS (SOLAR MAX)
- TELESCIENCE
- MANUFACTURING

## MISSION PLATFORMS

- SPACE STATION
  - MASSIVE PLATFORM BASE
- EVA BACKUP: CONTINGENCY EVENTS, SERVICE THE SERVER
  - UNMANNED PLATFORM (e.g., POLAR, GEO)
- LOW MASS PLATFORM: CONTROL DYNAMICS ISSUES, INTERACTION WITH OTHER FLEXIBLE STRUCTURES
  - LONG PERIODS OF INACTIVITY
  - NO EVA BACKUP

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>TELEOPERATIONS</b></p>
---	---	------------------------------

## OPERATOR INTERFACE TECHNOLOGY NEEDS

- INTELLIGENT DISPLAYS
  - EYES/HANDS BUSY OPERATION
  - MUST (ONLY) PROVIDE CRITICAL INFORMATION
- VISUAL PERCEPTION SYSTEMS
  - POSITION
  - FORCE
- HAND CONTROLLERS
  - POSITION/RATE CONTROL
  - FORCE REFLECTION OPTION
- SPEECH RECOGNITION/SYNTHESIS
  - STRESS
  - ENVIRONMENT

## CONTROL SYSTEM TECHNOLOGY NEEDS

- STABILITY GIVEN WIDE RANGE OF MANIPULATION SPEEDS, OBJECT MASSES
- CONTROL PARAMETERS VARY WITH TASK/ENVIRONMENT
  - GAIN VALUES FOR POSITION/RATE CONTROL
  - PID GAINS FOR CLOSED LOOP FORCE CONTROL
  - FORCE LIMITS
- COMMUNICATION TIME DELAYS
  - WITHIN ON-BOARD CONTROL ARCHITECTURE
  - ROUND TRIP TO REMOTE OPERATOR
  - IMPACTS SPEED OF MANIPULATION, FORCE CONTROL SENSITIVITY, VIABILITY
- SIMULATION
  - GROUND HARDWARE LIMITED BY 1-G
  - SYSTEM NON-LINEARITIES DIFFICULT TO MODEL
  - VALIDITY OF EMPIRICALLY DERIVED PARAMETERS

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

## **TECHNOLOGY NEEDED IN HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES**

- MERGE MANUAL/PROGRAMMED TASKS
  - TASK SCRIPT AUTHORIZING TOOLS
- ENABLE GROWTH TOWARD INCREASING AUTONOMY
  - PLANNING/REPLANNING GIVEN INTERVENING HUMAN ACTIONS
- IMPLEMENTATION IN FLIGHT QUALIFIED PROCESSORS
  - CONSTRAINTS IMPOSED BY PLATFORM DATA COMMUNICATIONS
- SUPERVISORY COMMAND LANGUAGE

## **PROBLEMS ASSOCIATED WITH HUMAN CONTROL OF SPACE MANIPULATORS**

- LIMITED WORKSPACE VIEWS
  - CAMERA POSITIONS FOR OBJECT GRASPING, HIDDEN SURFACES
  - NEED STEREO OR MULTIPLE VIEWS FOR UNSTRUCTURED TASKS
- HUMAN INTERACTION WITH PLATFORM CONTROL DYNAMICS DURING TELEOPERATION
  - AVOIDANCE OF MANIPULATOR SINGULARITIES
  - DURING MANUAL CONTROL
  - STARTING PROGRAMMED TRAJECTORIES AFTER MANUAL POSITIONING
- COLLISION AVOIDANCE
  - ROBOT VERSUS WORKSPACE
  - CARRIED OBJECT VERSUS WORKSPACE
- REHEARSAL
  - GROUND AND IN-FLIGHT
  - CONTROL DYNAMICS
  - MANIPULATOR STIFFNESS, STRENGTH
  - TIME BETWEEN REHEARSAL AND ACTION
- MANY CONTROL PARAMETERS NEED TO BE SET WHEN UNPLANNED TASKS ARE TO BE PERFORMED

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS, MAN-MACHINE INTERFACE

- TELEOPERATION WITH OPERATOR IN MICROGRAVITY
  - FORCES EXPERIENCED WITH HAND CONTROLLERS
  - IMPACT ON VOICE ACOUSTICS FOR SPEECH RECOGNITION
- TELEOPERATION WITH OPERATOR ON GROUND
  - LIMITED COMMUNICATION BANDWIDTHS
  - TIME DELAYS
- CAMERA SYSTEM CONTROL/ADEQUACY
  - SELECTION, POSITIONING, POINTING, ZOOM, FOCUS, IRIS
  - LIGHTING GIVEN DYNAMIC SOLAR ILLUMINATION CONDITIONS
  - COMMUNICATION BANDWIDTH
- MANUAL SELECTION OF CONTROL PARAMETERS FOR UNPLANNED TASKS
- DYNAMIC INTERACTION BETWEEN PLATFORM, TELEROBOT/OBJECT, OPERATOR
- ACCURACY, STABILITY OF LIGHT MANIPULATOR
  - GIVEN WIDE RANGE OF OBJECT MASSES
- ACCURACY OF COMPUTER SIMULATION DYNAMIC MODEL
- VALIDITY/ACCURACY OF CONTROL PARAMETERS
  - DERIVED/DEMONSTRATED ON GROUND SIMULATION
  - HOW TO TEST PRIOR TO EXECUTING SINGULAR EVENT

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>TELEOPERATIONS</b>
--------------------------------------	--	-----------------------

**multimode operator interfaces  
intelligent displays  
hierarchical control  
communication time delay  
visual perception systems**

**Thomas B. Sheridan  
Man-Machine Systems Laboratory  
MIT  
Cambridge, MA 02139**

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	TELEOPERATIONS
--------------------------	--	----------------

### BACKGROUND

- Solid man-in-space successes in Mercury, Gemini, Apollo. Solid automation demonstrations in deep space, shuttle RMS. Some questions about need for man-in-space in the future, possibilities for remote control.
- Forty years of teleoperator experiments and operations. in nuclear plants, undersea, construction, and space.
- Steadily evolving capability of teleoperation and telerobotics. (Reality has lagged public and in some cases R&D rhetoric, but nevertheless is overtaking NASA's actual preparedness.)
- NASA tradition of attention to empirical human factors, but spotty development of human factors discipline outside.
- Fallacious tendency of Congress and US public to see human participation in space and automation/robotics as mutually exclusive. (They should be seen as symbiotic.)
- Legitimate conservatism re human life, resultant demand for reliable non-expendable hardware have inhibited progress where hardware could be expendable without endangering life.
- Growing competition from Europe and Japan in space technology.
- Current interest in commercial space vehicles.

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	TELEOPERATIONS
--------------------------	--	----------------

**TECHNOLOGY NEEDS IN  
TELEOPERATION AND TELEROBOTICS**

- Flexible, human friendly supervisory command languages which mix analogic and symbolic elements, and enhance computer understanding.
- means to control redundant degree-of-freedom kinematics (arms of  $\geq 7$  DOF, arms plus vehicles plus hands).
- Operator adjustable impedance between master and arm, slave and task.
- Video aids to enhance depth: stereo and other.
- Predictor instruments and other means to accommodate time delay in both video and force, and predict contact.
- Manipulator arms which are lighter, stiffer (adjustable), and of higher bandwidth and control precision.
- Smart end effectors having more dexterity (more degrees of freedom).
- Higher resolution and more robust touch and proximity sensors.
- Touch display to hands, eyes, ears or other parts of body.

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>TELEOPERATIONS</b></p>
---	---	------------------------------

**TECHNOLOGY NEEDS IN TELEROBOT DESIGN,  
MISSION PLANNING AND MONITORING.**

- Theory of telepresence, what it is and what it contributes.
- Theory and experimental measures of manual dexterity.
- Techniques for control of unpredictable dynamics.
- Computer understanding of operator queries and stated intentions (for expert systems and telerobot control aids).
- Real time simulation and associated graphics for on-line multiobjective control decisions and planning.
- Computer-based aids for telerobot failure detection, diagnosis and recovery.
- Theory of allocating, trading and sharing of telerobot control functions between human and computer.
- Techniques for simulating large-scale space teleoperation / telerobotics operations on the ground.

**PROPOSED EXPERIMENTS IN SPACE**

- Demonstrations of teleoperator (direct) and telerobot (supervisory) control in dynamic tasks, e.g., throwing and catching objects, rendezvousing with tumbling satellite and inspecting or inserting/removing module.
  - with and without force feedback.
  - with 6 and redundant degrees-of-freedom.
    - one arm-hand
    - two arm-hands
    - vehicle plus arm-hand simultaneously.
  - controlled from the ground.
  - using touch when vision is obscured.
- Demonstration of predictor instruments to accommodate time-delayed video and force feedback.
- Demonstrations of telepresence.
- Demonstrations of telescience by scientists on ground.
- Demonstration of failure recovery drills by various human and machine combinations.

### **5.3 ARTIFICIAL INTELLIGENCE**

<p>AUTOMATION AND ROBOTICS</p>	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	<p>ARTIFICIAL INTELLIGENCE</p>
--	--	------------------------------------

**IN-SPACE EXPERIMENTS IN  
ARTIFICIAL INTELLIGENCE**

Dr. Peter Friedland,  
BRANCH CHIEF, RIA  
NASA AMES RESEARCH CENTER

Nancy Sliwa  
RIA, NASA AMES RESEARCH CENTER  
ATB, NASA LANGLEY RESEARCH CENTER

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS
  - SYSTEMS AUTONOMY TECHNOLOGY PROGRAM (CSTI)
  - SPACE STATION FREEDOM ADVANCED TECHNOLOGY PROGRAM
  - PATHFINDER
- CURRENT CAPABILITIES:
  - INCO EXPERT SYSTEM IN MISSION CONTROL
  - \* HST SCHEDULER IN END-TO-END TESTING, SHARP, AUTOCLASS
- ARTIFICIAL INTELLIGENCE (AI) ELEMENTS
  - REASONING UNDER UNCERTAINTY
  - LEARNING
  - CAUSAL MODELLING
  - KNOWLEDGE ACQUISITION
  - ADVANCED PLANNING METHODS
  - COOPERATING KNOWLEDGE BASE SYSTEMS
  - VALIDATION TECHNOLOGIES
- DIFFERENCES BETWEEN GROUND- VS. SPACE-BASE AI SYSTEMS
  - AVAILABILITY OF SUFFICIENT PROCESSING POWER AND MEMORY
  - REALTIME CONSTRAINTS
  - RELIABILITY CONSTRAINTS
  - ENVIRONMENTAL UNCERTAINTY
  - PERCEIVED VS. REAL RISK

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## TECHNOLOGY NEEDS

- BUILDING AND USING VERY LARGE KNOWLEDGE BASES
  - AUTOMATIC KNOWLEDGE ACQUISITION
  - EFFECTIVE KNOWLEDGE COMBINATION FROM MANY SOURCES
  - REPRESENTATION AND OPERATIONALIZATION OF MASSIVE AMOUNTS OF KNOWLEDGE
- COLLABORATION
  - DISTRIBUTED PROBLEM SOLVING
  - MULTIPLE AGENTS
  - GRACEFUL INTERACTION WITH HUMANS
- CAUSAL REASONING
- UNCERTAINTY MANAGEMENT
  - REASONING ABOUT UNCERTAINTY
  - REACTIVE REPLANNING TO COPE WITH UNCERTAINTY
- VALIDATION AND VERIFICATION OF INTELLIGENT SYSTEMS

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## TECHNOLOGY NEEDS

- PLANNING/SCHEDULING IN REAL, COMPLEX SITUATIONS
- DESIGN
  - STATIC GROUND-BASED DESIGN
  - DYNAMIC FLIGHT-BASED REDESIGN
- MACHINE LEARNING
  - DISCOVERY
  - IMPROVEMENT OF PERFORMANCE WITH EXPERIENCE
  - ACQUIRING EXPERTISE
- SPACEBORNE SYMBOLIC PROCESSORS

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- FLIGHT TEST NEEDED FOR INTEGRATED HARDWARE/SOFTWARE SYSTEMS, e.g., PROCESSOR LIMITATIONS, ROBOTICS SYSTEMS
- IN GENERAL, AI SOFTWARE SHOULD BE TREATED LIKE ANY OTHER COMPUTER CODE - GROUND SIMULATION SHOULD BE SUFFICIENT FOR VALIDATION. BUT VALIDATION AND VERIFICATION OF AI SOFTWARE IS STILL A RESEARCH ISSUE
  - NEW TECHNIQUES MAY REQUIRE FLIGHT EXPERIMENTATION
  - PERCEIVED RISK MAY ADVISE FLIGHT EXPERIMENTATION

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## SUMMARY

- AI TECHNOLOGY WILL BE CRITICAL TO FUTURE SPACE MISSIONS FOR BOTH GROUND AND FLIGHT USE
- INTEGRATED HARDWARE/SOFTWARE FLIGHT TESTS WILL BE NECESSARY
- IN GENERAL, GROUND-BASED VALIDATION IS SUFFICIENT FOR SOFTWARE
- SOME FLIGHT VALIDATION MAY BE NECESSARY TO ESTABLISH A "TRACK RECORD" FOR AI SOFTWARE

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ARTIFICIAL INTELLIGENCE</b>
--------------------------------------	--	------------------------------------

# **ARTIFICIAL INTELLIGENCE: AN INDUSTRY VIEW**

**PRESENTED BY:**

**David A. Rosenberg,  
ISX CORPORATION**

**AUTOMATION  
& ROBOTICS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**ARTIFICIAL  
INTELLIGENCE**

## **INTRODUCTION/BACKGROUND**

- AI SPACE APPLICATIONS WILL CLEARLY BE HYBRIDS, INVOLVING CONVENTIONAL AND AI-BASED COMPONENTS TO SOLVE PROBLEMS THAT NEITHER COULD COPE WITH ALONE
- THESE PRODUCTS ARE GENERALLY KNOWN AS INTELLIGENT SYSTEMS. HERE, INTELLIGENCE IMPLIES THE USE OF EXPLICIT KNOWLEDGE (OFTEN META-KNOWLEDGE)
- INTELLIGENT AUTONOMOUS SYSTEMS UTILIZE EXPLICIT KNOWLEDGE OF A TARGET SYSTEM AND OF DESIRED GOALS TO EVALUATE OR CONTROL THE TARGET, WITH VARYING DEGREES OF AUTONOMY
- INTELLIGENT DECISION SUPPORT SYSTEMS EXPLOIT USER KNOWLEDGE, PLUS DOMAIN SPECIFIC KNOWLEDGE TO BETTER AID THE DECISION MAKER

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
--------------------------	--	----------------------------

## MISSION APPLICATIONS

- SHUTTLE. WHILE NOT "DESIGNED IN" INTELLIGENT SYSTEMS COULD PLAY AN IMPORTANT ROLE
- ADAPTIVE PLANNING TECHNIQUES COULD ASSIST CREW MEMBERS IN PERFORMING NUMEROUS ACTIVITIES, SUCH AS CONDUCTING EXPERIMENTS, OR PERFORMING PAYLOAD CHECKOUT
- GREATER AUTONOMY COULD BE GIVEN TO EXPERIMENTS. KNOWLEDGE GAINED FROM THE EXPERIMENT DESIGNERS COULD REDUCE CREW MONITORING AND PROVIDE BETTER, MORE EFFICIENT CREW INTERFACE WHEN INTERVENTION IS REQUIRED
- SPACE STATION. THE SAME TECHNIQUES DESCRIBED ABOVE COULD PROVIDE EVEN MORE LEVERAGE IF WELL INTEGRATED. SIGNIFICANT IMPROVEMENTS IN OPERATIONS PLANNING, RESOURCE ALLOCATION, AND FAULT DETECTION/CORRECTION COULD BE ACHIEVED. APPLICATION TO THE UNDERLYING DISTRIBUTED COMPUTATION ENVIRONMENT IS ESPECIALLY ATTRACTIVE
- TELEROBOTICS. AUGMENTATION TO THE HUMAN INTERFACE IS ESPECIALLY ATTRACTIVE
  - ADAPTIVE PLANNING COULD BE USED TO PROVIDE HIGH LEVEL TASK PLANNING AND REPLANNING IN CONCERT WITH ACTUAL PROGRESS. THE SELECTION OF VERY LOW LEVEL FEATURES SUCH AS GRIPPING FORCE, FORCE REFLECTION RATIOS, LIGHTING CONTROL, ETC., COULD BE AUTOMATICALLY SELECTED

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
--------------------------	--	----------------------------

## MISSION APPLICATIONS

- AUTONOMOUS ROBOTICS. HERE, INTELLIGENT AUTONOMOUS SYSTEMS ARE AN ENABLING TECHNOLOGY
  - FOR FULLY AUTONOMOUS OPERATION, GOAL-DIRECTED, HIGH LEVEL PLANNING IS EVEN MORE IMPORTANT
  - KNOWLEDGE OF THE SYSTEM BEING SERVICED, THE SERVER ITSELF, AND OF OVERALL GOALS WILL BE REQUIRED TO PROVIDE THE HUMAN SUPPLIED FEATURES DESCRIBED ABOVE: SITUATION ASSESSMENT, MACHINE VISION, TESTING, ETC. THIS COULD BE A VERY HARD PROBLEM
  - USER DIRECTED SPECIALIZATION OF SKELETAL PLANS COULD ALSO PROVIDE A POWERFUL MECHANISM FOR DEVELOPING NEW PLANS FOR BOTH INTELLIGENT AND DUMB AUTONOMOUS ROBOTS
  
- PLANETARY MISSIONS. HERE, THE MUCH GREATER NEED FOR AUTONOMY MAKES AI AN "ENABLING" TECHNOLOGY. ON UNMANNED MISSIONS, KNOWLEDGE OF MISSION OBJECTIVES AND OF THE STRUCTURE AND FUNCTION OF THE SPACE VEHICLE COULD BE ESSENTIAL TO ADAPTING PLANS AND OBJECTIVES TO UNFORSEEN EVENTS

<b>AUTOMATION &amp; ROBOTICS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ARTIFICIAL INTELLIGENCE</b>
--------------------------------------	--	------------------------------------

## **TECHNOLOGY NEEDS**

- IN GENERAL, PAST AI-BASED SYSTEMS HAVE BEEN BRITTLE, NOT WELL INTEGRATED AS COMPONENTS OF BROADER SYSTEMS, ISOLATED FROM CRITICAL DATA OVER WHICH TO REASON, OFTEN BUILT IN AN AD HOC FASHION, AND PRECLUDED FROM REAL-TIME APPLICATIONS DUE TO SEVERE PERFORMANCE CONSTRAINTS
- TOOLS AND TECHNIQUES ARE NEEDED TO SEEMLESSLY INTEGRATE KNOWLEDGE-BASED COMPONENTS INTO A BROADER SOFTWARE SUPPORT ENVIRONMENT
- COMMON LIFE-CYCLE TOOLS AND METHODOLOGY. TECHNIQUES SUPPORTING SOFTWARE RE-USE ARE ESSENTIAL. A UNIFIED VIEW OF DATA, ESPECIALLY SHARED INFORMATION ACROSS MODULES, GEOGRAPHY, AND HARDWARE. RUN TIME SUPPORT FOR HETEROGENEOUS HARDWARE/SOFTWARE, ALONG WITH APPROPRIATE STANDARDS TO MAKE THIS FEASIBLE
- QUALIFIED AND VALIDATED HARDWARE AND SOFTWARE TO SUPPORT AI SOFTWARE COMPONENTS DO NOT EXIST
- A FIRM COMMITMENT TO INTEGRATE AI INTO REAL WORLD SYSTEMS. RISK CAN BE REDUCED WITH A PHASED, INCREMENTAL APPROACH TO COMPETENCE, BEGINNING WITH DECISION SUPPORT AND WORKING TOWARDS GREATER AUTONOMY

<p><b>AUTOMATION &amp; ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ARTIFICIAL INTELLIGENCE</b></p>
---	---	---

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- IN A SENSE, AI TECHNOLOGIES ARE ORTHOGONAL TO OUR THEME AREAS, AND COULD BE APPLIED TO MOST OF THE ON-GOING EXPERIMENTS
- VALUABLE INTEGRATION EXPERIENCE COULD BE GAINED BY DEFINING, DESIGNING, BUILDING, AND FLYING AN INTELLIGENT DECISION SUPPORT SYSTEM TO AID CREW MEMBERS IN MANAGING SOME SET OF IN-SPACE EXPERIMENTS. A COMMON FRAMEWORK COULD LIKELY BE APPLIED TO SUPPORT A NUMBER OF SUCH EXPERIMENTS
- SPACE STATION FREEDOM REPRESENTS AN IDEAL OPPORTUNITY TO APPLY INTELLIGENT SYSTEMS IN BOTH CREW DECISION SUPPORT AND SEMI-AUTONOMOUS ROLES
- THE FTS PROVIDES AN OPPORTUNITY TO APPLY THE IDEAS DISCUSSED FOR HUMAN CONTROLLED AND AUTONOMOUS ROBOTICS

### **SUMMARY & RECOMMENDATIONS**

- A RELATIVELY NEW CLASS OF SYSTEM, THE INTELLIGENT SYSTEM, CAN BE EFFECTIVE WHERE CONVENTIONAL OR PURE AI-BASED APPROACHES ARE NOT
- IN THE LONG RUN, INTEGRATED AI WILL BE AN ENABLING TECHNOLOGY FOR AUTONOMOUS, OR VERY COMPLEX MANNED PLANETARY MISSIONS
- IN-SPACE EXPERIMENTS COULD PROVIDE A CRUCIAL, REAL WORLD INTEGRATION OPPORTUNITY

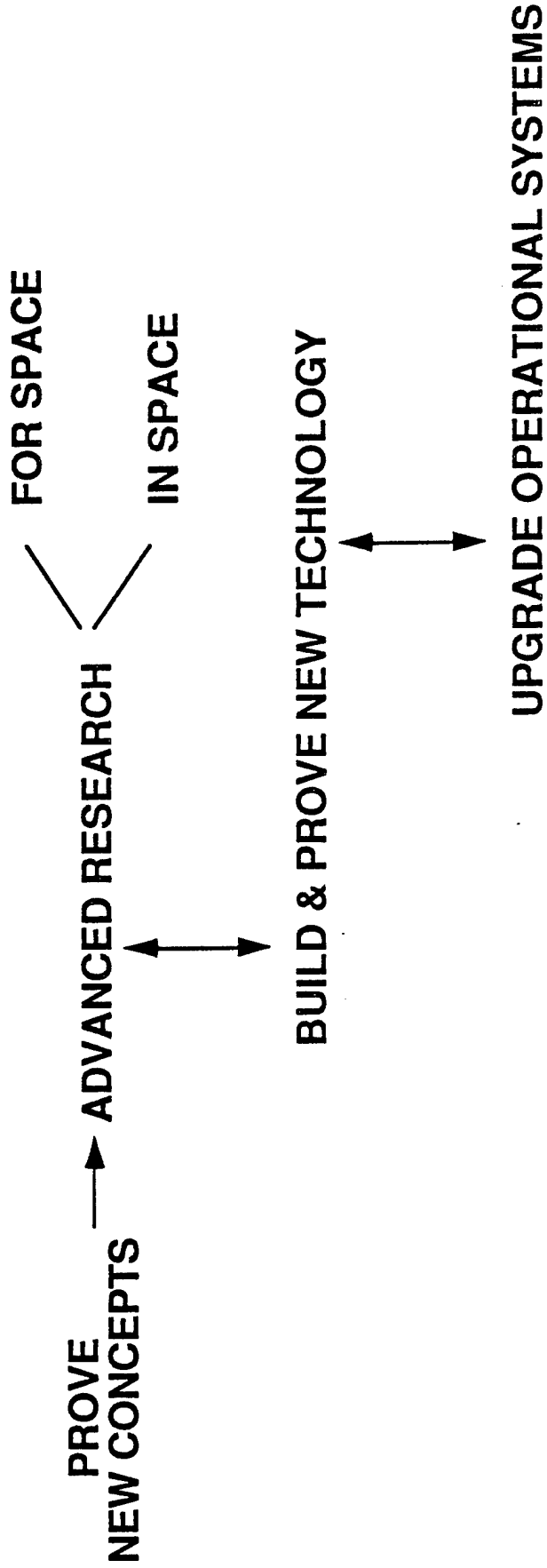
AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

# ARTIFICIAL INTELLIGENCE

DR. ROBERT CANNON  
STANFORD UNIVERSITY

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## INTRODUCTION/BACKGROUND



AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## TECHNOLOGY NEEDS

### o USER INTERFACE

GEOMETRIC  
OBJECT-LEVEL  
SIMPLE

### o MANIPULATOR CONTROL

LIGHTWEIGHT  
FLEXIBLE  
QUICK  
PRECISE  
ROBUST  
ADAPTABLE  
GRACEFUL  
WORK FROM A MOVING BASE

AUTOMATION AND ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
-------------------------------	--	----------------------------

## TECHNOLOGY NEEDS

### o COOPERATION

BETWEEN MANIPULATORS  
BETWEEN ROBOTS  
BETWEEN ROBOTS AND PEOPLE

### o NEW GENERATION OF ENGINEERS

GOOD YOUNG ENGINEERS  
GOOD ENGINEERING PROFESSORS/PROGRAMS/SCHOOLS  
LOOK AT RADICAL IDEAS

\* MEGASYSTEMS  
\* MICROSSYSTEMS

<p><b>AUTOMATION AND ROBOTICS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>ARTIFICIAL INTELLIGENCE</b></p>
---	---	---

## **IN-SPACE EXPERIMENTATION NEEDS**

- o ARTIFICIAL INTELLIGENCE NEEDS FLIGHT TESTING ONLY  
IN CONJUNCTION WITH DEPENDENT TECHNOLOGY, e.g. ROBOTICS**
- o NEED TO GET NEW GENERATION OF YOUNG ENGINEERS  
INVOLVED IN FLIGHT EXPERIMENTS**

**This page intentionally blank**

**AUTOMATION AND ROBOTICS  
CRITICAL TECHNOLOGY REQUIREMENTS**

**ANTAL K. BEJCZY  
JET PROPULSION LABORATORY**

	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	
--	--	--

## **TARGET NASA MISSIONS**

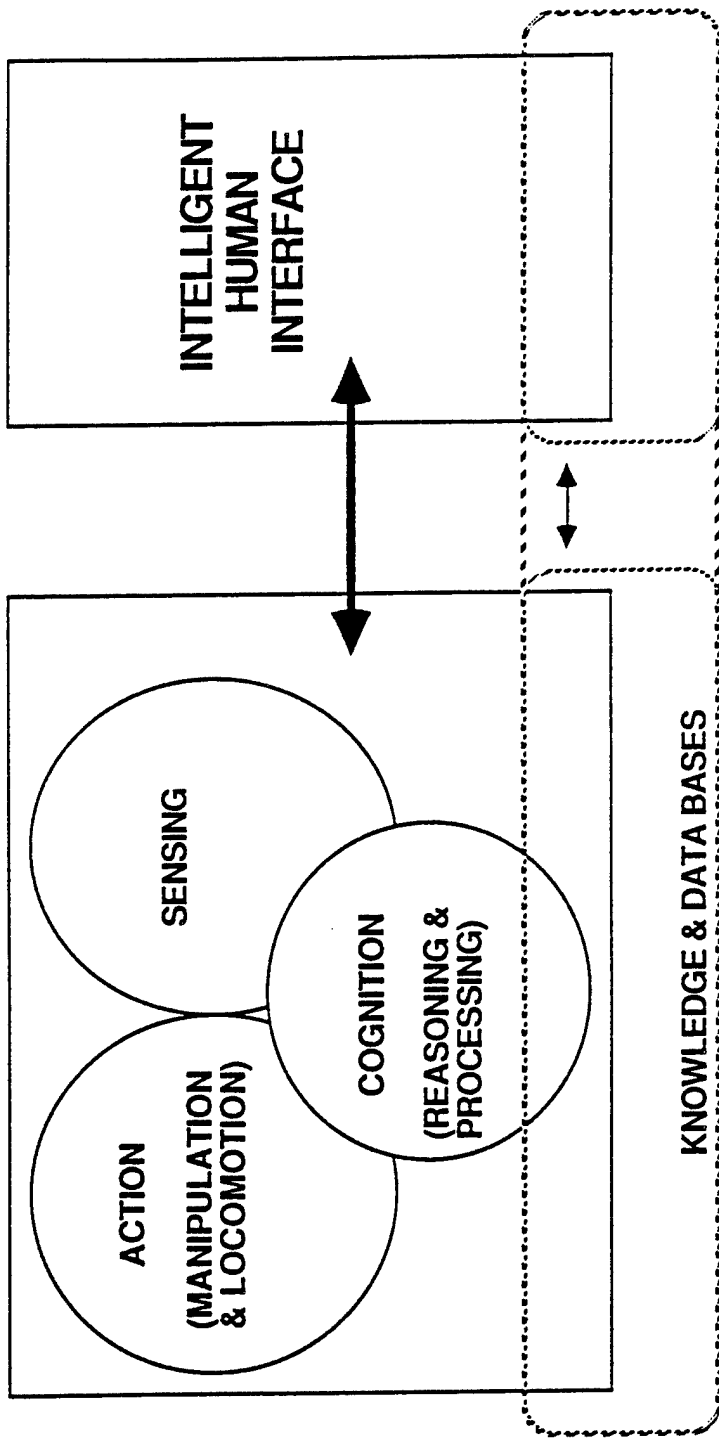
- o STS**
- o GREAT OBSERVATORIES**
  - HST
  - GRO
  - AXAF
  - SIRTf
- o SSFP**
- o FREE FLYERS (including POP)**
- o LUNAR OUTPOST**
- o MARS EXPLORATION**

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>
--	--

**USER NEED TASK DRIVERS**

- o IN-SPACE ASSEMBLY
- o MATERIALS PROCESSING
- o MATERIALS HANDLING
- o SYSTEMS MAINTENANCE AND OPERATIONS
- o SATELLITE SERVICING
- o EXPLORATION

INTEGRATED APPROACH FOR A & R ON A MULTI-DISCIPLINARY BASE



	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	
--	---	--

## **GENERAL THRUST**

**AUGMENT AND ENHANCE HUMAN RESOURCES/CAPABILITIES  
BY ENABLING HUMAN CONTROL OF COMPLEX SYSTEMS AT  
HIGHER & HIGHER LEVELS WHILE RETAINING CAPABILITY TO  
ENTER CONTROLLING PROCESS AT MULTIPLE LEVELS**

	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOPS</b> <b>DECEMBER 6-9, 1988</b>	
--	---	--

## **SPACE ROBOTICS TASK DOMAINS**

- o **WIDE RANGE OF OPERATING SCALES**
  - **LARGE / HEAVY (e.g. SATELLITE, PAYLOAD MANIPULATION)**
  - **SMALL / LIGHT (e.g. INSTRUMENT ADJUSTMENT, MATERIALS PROCESSING)**
  
- o **MECHANICAL COUPLING ENVIRONMENT**
  - **RIGID BASE**
  - **FLEXIBLY COUPLED**
  - **FREE FLYING**
  
- o **VARYING ILLUMINATION ENVIRONMENT**

## SPACE ROBOTICS TECHNOLOGY NEEDS

- o ROBUST AND SAFE MANIPULATION / LOCOMOTION
  - CONTROL LAWS
  - COLLISION AVOIDANCE
  - COMPLIANCE (ACTIVE OR PASSIVE)
  - USE OF TASK MODELS OR ADAPTIVE CONTROL
  - LOCAL AUTONOMY BASED ON SENSING
  - DYNAMICS OF COUPLING TO PLATFORM
- o FAULT TOLERANT HARDWARE / SOFTWARE ARCHITECTURES
  - MECHANISMS
  - ACTUATORS
  - SENSORS
  - SENSOR / CONTROL PROCESSORS
  - FAILURE DETECTION, IDENTIFICATION, AND RECOVERY

	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	
--	--	--

## TELEOPERATIONS, DOMAINS AND NEEDS

### o SUPERVISORY CONTROL FOR TELEROBOTIC OPERATIONS IN SPACE

- DYNAMIC TASK CONTROL
- ENHANCED VISUAL DISPLAYS WITH COMPUTATION  
(E.G. COLLISION AVOIDANCE)
- BIDIRECTIONAL M / M INTERFACES WITH  
HIERARCHICAL OBJECT-ORIENTED ARCHITECTURE  
AND MULTI-MODE CAPABILITIES
- MODELS FOR TELEROBOT AND ITS ACTIONS

	<p style="text-align: center;">IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	
--	--	--

**TELEOPERATIONS, DOMAINS AND NEEDS**  
(Cont.)

o CONTROL LOCATION

- ON ORBIT
- OPERATOR WITH FORCE FEEDBACK
- ROBOT ARM - VEHICLE INTERACTION
- ON GROUND
- COMMUNICATION DELAY / BANDWIDTH
- INTERACTING WITH MICROGRAVITY

o HIGH DEGREE-OF-FREEDOM SYSTEMS

- REDUNDANT ARMS
- MULTIPLE ARMS
- DEXTRIOUS END EFFECTORS AND TOOLS

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOPS DECEMBER 6-9, 1988</p>	
--	---	--

## ARTIFICIAL INTELLIGENCE TASK DOMAINS

- FAULT PROCESSING
  - AUTOMATED FAULT DETECTION, ISOLATION, RECOVERY / RECONFIGURATION
  - DIAGNOSIS OF UNANTICIPATED, MULTIPLE FAULTS
  - CONTINGENCY REPLANNING
- LARGE INPUT / OUTPUT SYSTEMS
  - SENSOR INTERPRETATION / FUSION
  - REAL-TIME IMAGE PROCESSING
  - SPEECH RECOGNITION AND SYNTHESIS

## **ARTIFICIAL INTELLIGENCE TECHNOLOGY NEEDS**

- o **INTEGRATED, REAL-TIME, FAULT-TOLERANT, COOPERATIVE INTELLIGENT SYSTEMS**
  - **PARALLEL, INTEGRATED NUMERIC / SYMBOLIC PROCESSING**
  - **ADVANCED, INTELLIGENT OPERATING SYSTEM**
  - **LARGE, DYNAMIC, DISTRIBUTED KNOWLEDGE BASE**
  - **INTEGRATION OF DATA AND MODEL INFORMATION**
  - **LAYERED, TRANSPARENT SOFTWARE**
  
- o **INTELLIGENT HUMAN INTERFACES**

## **6.0 SENSORS AND INFORMATION SYSTEMS**

# **SENSORS AND INFORMATION SYSTEMS BACKGROUND AND OBJECTIVES**

**MARTIN M. SOKOLOSKI  
NASA HEADQUARTERS**

**and**

**JOHN DALTON  
GODDARD SPACE FLIGHT CENTER**

## THEME SESSION OBJECTIVES

### PURPOSE

IDENTIFY & PRIORITIZE TECHNOLOGIES FOR SENSORS, COMMUNICATIONS, AND INFORMATION SYSTEMS WHICH

- ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS
- REQUIRE IN-SPACE TESTING AND VALIDATION

### PRODUCT

HIGH PRIORITY TECHNOLOGIES AND RATIONALE FOR IN-SPACE EXPERIMENTATION:

- TECHNOLOGY NEED
- IMPORTANCE TO SPACE MISSIONS
- IN-SPACE TESTING REQUIRED

## **THEME DESCRIPTION**

### **SENSORS**

- **DEVICES & OPTICS**
- **LASERS**
- **PRECISION POINTING**
- **THERMAL MANAGEMENT & CRYOGENICS**

### **COMMUNICATIONS**

- **OPTICAL & MICROWAVE**
- **POINTING, TRACKING, & ACQUISITION**

### **INFORMATION SYSTEMS**

- **SPACE QUALIFIED PROCESSORS , STORAGE & COMPONENTS**
- **IMAGE & SIGNAL PROCESSORS**
- **DATA NETWORKS & TELEMETRY SYSTEMS**
- **AUTOMATED SYSTEMS**

## **CRITERIA FOR PRIORITIZATION**

- 1. CRITICALITY OF TECHNOLOGY IN ENABLING FUTURE U.S. SPACE MISSIONS**
- 2. POTENTIAL OF TECHNOLOGY FOR REDUCING COST (DEVELOPMENT, OPERATIONS, OR LIFE CYCLE)**
- 3. DEGREE TO WHICH TECHNOLOGY HAS BROAD APPLICATION TO A VARIETY OF SPACE MISSIONS**
- 4. REQUIREMENT FOR IN-SPACE VALIDATION TO EXPERIMENT WITH OR VERIFY PERFORMANCE IN MICRO-GRAVITY / THERMAL / RADIATION ENVIRONMENT OR TO REDUCE RISK FOR OPERATIONAL APPLICATIONS**

## 6.1 SENSORS

**This page intentionally blank**

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------------	--	---------

## IN-SPACE EXPERIMENTS IN REMOTE SENSING SYSTEMS

Martin M. Sokoloski  
 Manager, Sensor & Communications Technology  
 Information Sciences & Human Factors Division  
 NASA/OAST  
 Washington, DC 20546

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS
  - Detector Arrays
    - Superconducting Bolometer Arrays
    - Impurity Band Conduction Detectors
    - III-V Material Arrays
    - Superlattice Detectors
  - Heterodyne Systems
    - Local Oscillators
    - Millimeter
    - Submillimeter
    - FIR
    - Mixers
    - Antennas (Radiometry)
      - 4M  $f > 100\text{GHz}$
      - 15-20M  $f < 100\text{GHz}$
    - Quasi-optics (Submillimeter)

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS (Continued)
  - DIAL/LIDAR
    - Lasers
    - Wavelength
    - Semiconductor Diode Array Pumps
    - CO2 Systems
    - Solid State Lasers (amps)
    - All Solid State Systems
    - Detectors
  - Coolers
    - Single Stage
    - Pulse Tube
    - Mechanical
    - Dilution
    - Flux Compression
    - ADM
    - Multi-Stage

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- DETECTORS
  - Radiation Effects on Arrays
  - Effects of Contaminants on Response of Detectors
  - System Demonstration under Low Background Conditions
  - Interaction of Coolers and Detector Systems
  - Retrofit on In-Reach LITE System with New Detector Arrays & Refly
  - Maintenance of Optical Surface Quality in Space with In-situ Cleaning Demonstration

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- **HETERODYNE SYSTEMS**

- UV, Protons, and Electron Radiation Effects on Components & Systems
- Effect of Contaminants on System Performance
- Modify LITE Experiment for Single or Dual Channel for IR Radiometer for OH Measurement Demonstration
- Space Test of Large Unfilled Synthetic Aperture Radiometer (Requires Large Structure ~20 M Arms) for Proof of Concept
- Space Test of 30 and 118 Micrometer Heterodyne Imaging Spectrometer

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- DIAL/LIDAR SYSTEMS
  - Retrofit LITE Platform with Tuneable Solid State Laser for DIAL Measurements Demo
  - Retrofit 2 Micrometer Doppler Wind Shear Detector on LITE
  - Demonstrate In-Space Operation of Semiconductor Diode Array Pumps
  - Test of Picosecond Laser Ranging and Altimeter System
  - In-Space Test of Laser System Stability

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- COOLER SYSTEMS
  - Microgravity Test of Liquid/Vapor Phase Separation in Joule-Thomson Refrigerators
  - Microgravity Test of 3He/4He Dilution Refrigerator Systems:
    - JPL System Concept
    - ARC System Concept
    - MSFC System Concept
  - Extended Microgravity & Vacuum Test of Mechanical Coolers (10 kelvin and Above)
  - Proof of Principle of Microgravity Operation of Subkelvin Coolers

## **SUMMARY/RECOMMENDATIONS**

- **REQUIREMENTS FOR SENSOR SYSTEM IN-SPACE EXPERIMENTS**
- **Test of Operation in Space Radiation Environment**
- **Functioning in Micro- or 0-g Environment**
- **Operation in Vacuum**
- **Survive Launch**
- **Survive Shuttle Contamination**

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------------	--	---------

# IN-SPACE SENSOR TECHNOLOGY EXPERIMENTS

109

*E. David Hinkley  
Hughes Aircraft Company  
El Segundo, California*



SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------------	--	---------

PURPOSE OF IN-SPACE  
SENSOR TECHNOLOGY EXPERIMENTS

---

TO DEMONSTRATE:

1. FEASIBILITY
2. RELIABILITY
3. ENVIRONMENTAL COMPATIBILITY

## UNIQUENESS OF SPACE ENVIRONMENT FOR SENSOR SYSTEMS

---

- NEAR-ZERO GRAVITY
- NONSTATIONARY PLATFORM
- SPECIAL SPACECRAFT ATMOSPHERES
- CONTAMINATION-INDUCED PERFORMANCE  
DEGRADATION
- STRONG RADIATION FLUX (UV, VIS, GAMMA)
- IN-VACUO WAVE PROPAGATION

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------------	--	---------

CATEGORIES FOR IN-SPACE SENSOR  
TECHNOLOGY EXPERIMENTS

---

1. THERMAL MANAGEMENT, CRYOGENICS
2. OPTICS CONTAMINATION/DECONTAMINATION
3. PRECISION POINTING & TRACKING
4. LASER OPERATION

SPACE APPLICATIONS  
*Thermal Management, Cryogenics*

---

1. SENSOR/ELECTRONICS CRYOCOOLING
2. HEAT SWITCH FOR REDUNDANT CRYOCOOLER
3. WASTE HEAT TRANSFER TO RADIATOR
4. OPTICS CRYOCOOLING

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------------	--	---------

SPACE APPLICATIONS  
*Optics Contamination/Decontamination*

---

1. OPTICS FOR UV, VIS, IR ASTRONOMY
2. CRYOCOOLED SENSORS & ELECTRONICS

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
---------------------------------	--	---------

SPACE APPLICATIONS  
*Precision Pointing & Tracking*

---

1. LASER REMOTE SENSING
2. HIGH-RESOLUTION ASTRONOMY
3. FAINT-TARGET ASTRONOMY (LONG INTEGRATION)
4. EARTH OBSERVATIONS FROM GEOSYNCH ORBIT
5. DEEP-SPACE OPTICAL COMMUNICATION



<b>SENSORS AND INFORMATION SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>SENSORS</b>
--	--	----------------

**SPACE APPLICATIONS**  
*Lasers*

---

1. WEATHER-RELATED MEASUREMENTS
2. ATMOSPHERIC CHEMISTRY MEASUREMENTS
3. HIGH-SPEED OPTICAL COMMUNICATIONS
4. IN-SPACE MANUFACTURING

<b>SENSORS AND INFORMATION SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>SENSORS</b>
--	--	----------------

## **LIDAR/LASER SENSORS**

**DR. DENIS KILLINGER  
UNIVERSITY OF SOUTH FLORIDA**

**SENSORS AND  
INFORMATION  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS**

**Table II. Selected List of Atmospheric Constituents and Parameters Measured by Lidar**

<b>Constituents</b>	<b>Laser Type</b>	<b>Accuracy*</b>	<b>Lidar Type</b>	<b>Range*</b>
Dust, Clouds Volcanic Ash Smoke Plumes	Ruby, Nd:YAG	1-10%	Atmospheric Backscatter	10-50 Km
H <sub>2</sub> O, O <sub>3</sub> , SO <sub>2</sub> NO, NO <sub>2</sub> , N <sub>2</sub> O C <sub>2</sub> H <sub>2</sub> , CH <sub>4</sub> , HCl, CO, Hg	Dye, CO <sub>2</sub> , OPO, Excimer Co:MgF <sub>2</sub>	Variable, 1 ppb to 100 ppm	DIAL, Raman	1-5 Km
OH, Na, K, Li, Ca, Ca <sup>+</sup>	Dye	10 <sup>2</sup> - 10 <sup>7</sup> atoms/cc	Fluorescence	1-90 Km
<b>Parameters</b>				
Temperature, Pressure	Dye, Nd:YAG	1 K <sup>o</sup> 5 mbar	DIAL, Raman	1-30 Km
Wind Speed	CO <sub>2</sub>	0.5 m/s	Doppler	15 Km

\* Accuracy and Ranges given are typical values and depend upon individual lidar measurements.

SPACEBORNE OPPORTUNITIES

• Global Laser Remote Sensing

1. Detection of  $[H_2O]$ ,  $[CO_2]$ ,  $[O_3]$

Temperature, wind speed from space;

LITE, LASA, EAGLE

2. Range/Altimeter for Surface and Ice Pack  
Profile, Fault Line Movement

• In-Situ Sensors

- High Altitude (In-Situ) Sensors  
for Trace Gas Contamination

**SENSORS AND  
INFORMATION  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS**

- Unique Spaceborne Problem Areas

- Power ( <10 kw, Eff. > 5%)  
Heat Dissipation (Primary, A/O Modulators)
- Weight ( < 2000 kg)
- Zero Gravity (Liquids/Dye Lasers, Cooling)
- Size
- Lifetime (Consumable, Laser H.V.)
- Eye Safety ( $\lambda > 1.4 \mu\text{m}$ )

- Critical Technology

- 1) Laser Development

- Diode Laser Pumping of Existing Lasers

- New Tunable (MID-IR) Laser Sources

- Ho:YAG

- Nd:Glass/Raman Shift

- Ti:Sapphire

- Single-Frequency (Nd, etc.)

- Er:YAG/OPO

- Local Oscillator  
(cw/Rapid Wide Tunability)

- Lifetime Issues

- CO<sub>2</sub>/Catalyst

- H.V./Electrodes

**SENSORS AND  
INFORMATION  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS**

2) LIDAR Deployment

LITE (Laser In-Space Technology Exp.)

- Nd:Y AG (2x, 3x)

1st Spaceborne LIDAR

- Phase II; Ti:Sapphire

LASA/EOS

- LIDAR (use to correct passive)

- DIAL

- Altimetry

LAWS (WINDSAT)

- CO<sub>2</sub>/Doppler (Lifetime)

- Nd:YAG (L.O. Tracking)

Ozone (Excimer/Raman Shift)

Pointing/Tracking Accuracy

- Small Footprint (more severe than Radar)

(Laser/Telescope Overlap)

- Push-Broom Scan

- Effect of Atmospheric Turbulence

(Motion /Tracking)

3) Laser Sensor

Absorption/Fluorescence Sensors

(Trace Species In-Situ)

- Fiber/Optical Coupling

- Tunable Microlaser Sensors

- Road Map (LIDAR/SENSORS)

LIDAR Development

1. Space Shuttle Test of Simple LIDAR (Nd:YAG): LITE
2. Spaceborne LIDAR/Diode Pumped Nd:YAG
  - Direct & Coherent Detection (Limited power)
3. Coherent Doppler (Nd & CO<sub>2</sub>)
  - L.O. Tracking
4. Atmospheric Density/H<sub>2</sub>O for Passive Corrections
5. Altimeter/Surface Profiler LIDAR

LASER Development

1. Long-Life Nd:YAG
2. Diode-Laser Pumped Nd:YAG
3. Ho:YAG
4. Tunable Tl:Al<sub>2</sub>O<sub>3</sub>
5. Tunable Local Oscillator

## **6.2 COMMUNICATIONS**

**This page intentionally blank**

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

**IN-SPACE EXPERIMENTS IN COMMUNICATION SYSTEMS**

**Martin M. Sokoloski**  
**Manager, Sensor & Communication Technology**  
**Information Sciences & Human Factors Division**  
**NASA/OAST**  
**Washington, DC 20546**

<p style="text-align: center;"><b>SENSORS AND INFORMATION SYSTEMS</b></p>	<p style="text-align: center;"><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p style="text-align: center;"><b>COMMUNICATIONS</b></p>
---	---	--

## INTRODUCTION/BACKGROUND

- Optical Communication System Elements
  - Lasers & Laser Systems
  - Modulation Techniques
  - Detection (Coherent, Non-coherent)
  - Optics
  - Electronics
- Space Qualification
  - Space Radiation Environment/Energetic Particles
  - Vacuum
  - Microgravity
  - Spacecraft Charging and Outgassing
- Laser Systems Not Space Demonstrated

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

## INTRODUCTION/BACKGROUND (CONT'D)

- NASA R&D Programs
  - Laser Sources
    - AlGaAs
    - Semiconductor Diode Laser Array  
Pumped Solid State Laser Rods & Slabs
  - Detection
    - Coherent
    - Non-coherent
  - Modulation Techniques
  - Electronics

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

## MISSION APPLICATIONS

- Mission to Planet Earth
  - GEO/GEO for Geoplat
  - GEO/LEO for Geoplat & Eos
  - GEO/Earth
- Planetary
  - Mars Rover
  - Cassini
  - Others
- Solar Physics
  - Star Probe (Enabling)

<p style="text-align: center;"><b>SENSORS AND INFORMATION SYSTEMS</b></p>	<p style="text-align: center;"><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p style="text-align: center;"><b>COMMUNICATIONS</b></p>
---	---	--

## TECHNOLOGY NEEDS

- Free-Space Optical Communications "Revolutionary" Technology
- Breadboard In-space Demo Needed
- Component Space Qualification
  - Laser & Laser Power
  - Pointing & Control (Closed and Open Loop)
  - Modulation Rate Demo
  - Demo of Space/Ground Link
  - Demo Space/Space Link

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------	--	----------------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- In-space Breadboard Demo of "Revolutionary" Technology
  - Space-Space
  - Space/Ground
  - Closed & Open Loop Acquisition
  - Coherent/Non-coherent Links

<b>SENSORS AND INFORMATION SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>COMMUNICATIONS</b>
--	--	-----------------------

**SPACE LASER COMMUNICATION EXPERIMENTS**

**M. ROSS  
LASER DATA TECHNOLOGY, INC.**

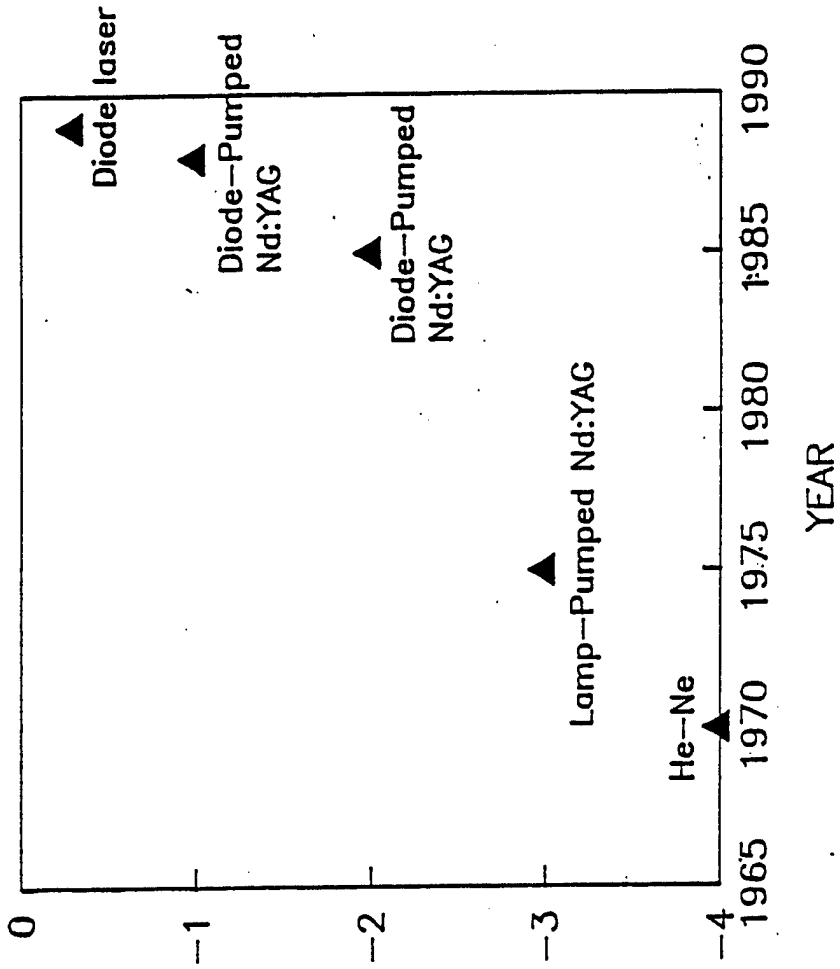
SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

SEMICONDUCTOR LASER BREAKTHROUGH

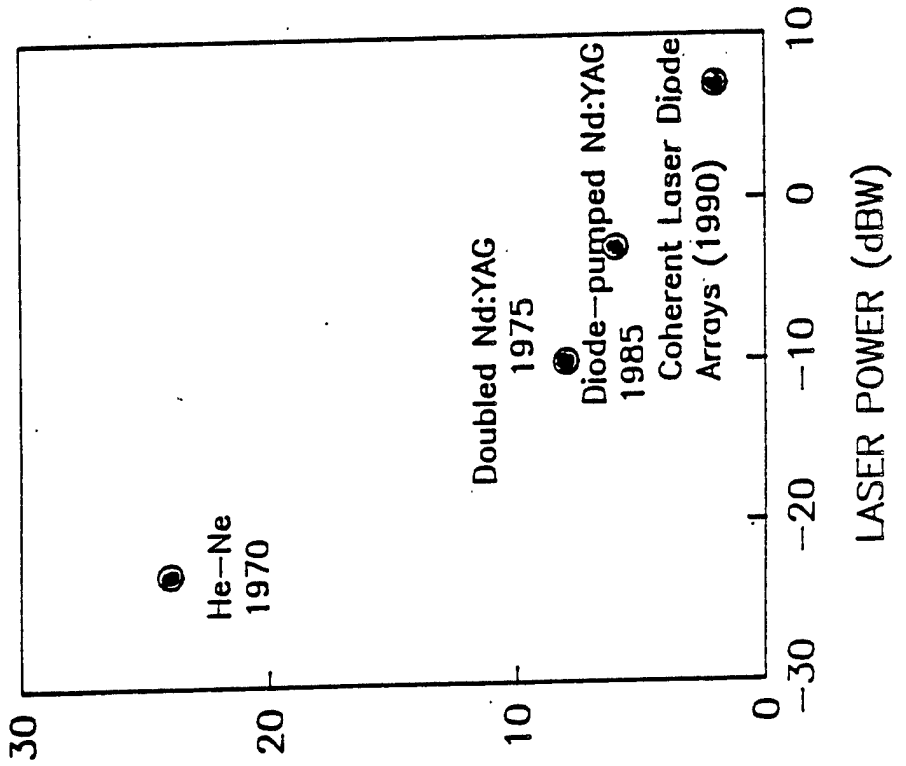
- HIGH EFFICIENCY
- GREATER THAN 50% ACHIEVED
- UNIFORMITY ACHIEVED
- ARRAYS FEASIBLE
- MULTI-WATT OUTPUTS ACHIEVED

## EFFICIENCY TRENDS FOR VISIBLE AND NEAR IR LASERS

LOG OF LASER EFFICIENCY



**LASER POWER/OPTICS SIZE TREND FOR SPACE LASERCOM**  
**(Direct Detection)**  
 REQUIRED OPTICS DIAMETER TO CLOSE LINK (INCHES)



SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

## TECHNOLOGY TREND

Photonics Capabilities Advancing Rapidly

Greater Solid State Laser Power Achievable at Higher Efficiency and Lower Cost

Enables Use of More Tolerant Designs in Rest of System

- Smaller, Less Precise Optics
- Easier Tracking Systems
- Less Integration and Test Costs

Enables Lower Weight, Lower Power, Lower Cost Laser Communication Systems

- 100lb, 100 watt Systems Will Become Achievable for Long-Distance Satellite-to-Satellite Links

SUMMARY

POTENTIAL OF LASER COMMUNICATIONS UNTAPPED

HISTORY OF SPACE LASERCOM EXPERIMENTS

- MANY STARTS, NO FINISHES
- LACK OF GOVERNMENT COMMITMENT TO FOLLOW THRU

TECHNOLOGY STATUS

- ABLE TO SUPPORT EXPERIMENTS
- SPACE EXPERIMENT NEEDED FOR VALIDATION

HARDWARE

- RELIABILITY
- CONCEPTS

SPACE LASERCOM EXPERIMENTS

<u>LINK</u>	<u>DATA RATES</u>	<u>NOTES</u>
ONE-TO-ONE	1 to 5 Mbps > 200 Mbps	SCIENTIFIC PAYLOADS; IMAGES; SENSOR DATA REAL TIME HIGH RESOLUTION IMAGERY
MANY-TO-ONE	1 to 5 Mbps	MULTIPLE ACCESS
ONE-TO-MANY	< 20 Kbps	COMMAND CONTROL

RECOMMENDATIONS

- DON'T TRY AND DEMONSTRATE TOO MUCH
  - NASA SPONSOR ONE LOW-COST SIMPLE SPACE EXPERIMENT THAT
    - VALIDATES CONCEPT
    - DEMONSTRATE COMPONENT RELIABILITY
    - DEMONSTRATES BASIC SUBSYSTEMS SUCH AS
      - ACQUISITION
      - TRACKING
      - LASER TRANSMITTER
      - LASER RECEIVER
  - RANGE NOT CRITICAL; COULD BE SHORT RANGE
- EXAMPLE: SHUTTLE TO FREE FLYER

**This page intentionally blank**

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

# COHERENT OPTICAL INTERSATELLITE CROSSLINK SYSTEMS

VINCENT W.S. CHAN

MIT LINCOLN LABORATORY  
LEXINGTON, MASSACHUSETTS 02173

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------	--	----------------

## LASERCOM CROSSLINK TECHNOLOGY

- CANDIDATE SYSTEM TECHNOLOGIES
  - DIRECT DETECTION (Incoherent)
  - HETERODYNE (Coherent)
- HETERODYNE RECEIVER 15 dB MORE SENSITIVE THAN DIRECT DETECTION
- HIGH ANTI-JAM CAPABILITY
- SMALLER APERTURE ALLOWS EASIER SPACECRAFT INTEGRATION
- USE OF HIGH EFFICIENCY (15%) GaAIAs SEMICONDUCTOR LASERS
- LINCOLN LABORATORY LASER INTERSATELLITE TRANSMISSION EXPERIMENT (LITE)

## **LASER CHARACTERISTICS FOR COHERENT SYSTEMS APPLICATIONS**

- **HIGH OUTPUT POWER**
  - **SIZE, WEIGHT, POINTING, MARGIN**
- **SINGLE SPATIAL MODE**
  - **USEFUL POWER IN FAR FIELD**
- **SINGLE FREQUENCY**
  - **HETERODYNE RECEIVER**
- **TUNABLE WAVELENGTH**
  - **WAVELENGTH MATCH, TRACKING**
- **DIRECT MODULATION**
  - **EQUALIZABLE FM TRANSFER FUNCTION**
- **NARROW LINEWIDTH**
  - **SPECTRAL SPREADING IMPACT ON BER**
- **STABLE, RELIABLE LIFE**
  - **>50,000 hr GOAL**

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------	--	----------------

## OPTICAL/MECHANICAL/THERMAL DESIGN ISSUES

- OPTICAL DESIGN
  - MAINTAIN THROUGHPUT, WAVEFRONT QUALITY
  - PROVIDE ACCURATE POINTING
- MECHANICAL DESIGN
  - PROVIDE STIFFNESS, STABILITY TO MAINTAIN OPTICAL ALIGNMENT, POINTING ACCURACY
  - ISOLATE AGAINST SPACECRAFT DISTURBANCES
- THERMAL DESIGN
  - MINIMIZE AND STABILIZE TEMPERATURE GRADIENTS UNDER VARYING THERMAL SCENARIOS

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

## HETERODYNE RECEIVER TECHNOLOGY

- LOW-NOISE/WIDEBAND FRONT END
  - NEAR-QUANTUM-LIMITED 1 GHz FRONT END DEMONSTRATED (LITE)
  - FURTHER DEVELOPMENT REQUIRED TO EXTEND BANDWIDTH AT QUANTUM LIMIT
- FREQUENCY-LOCKING
  - DONE ROUTINELY FOR FSK (LITE)
- PHASE-LOCKING
  - DIFFICULT WITH PRESENT LASER LINEWIDTHS

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------	--	----------------

## SPATIAL ACQUISITION

- LARGE INITIAL POINTING UNCERTAINTY
  - DOMINATED BY SPACECRAFT ATTITUDE CONTROL ERROR (~1 mRAD Typical)
  - SMALL COMMUNICATIONS BEAMWIDTH (4  $\mu$ rad In LITE)
- SEARCH OVER MANY SPATIAL "CELLS" REQUIRED
- CCD TECHNOLOGY WILL PERMIT RAPID ACQUISITION (Few Seconds)

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------------	--	----------------

---

## CONCLUSIONS

---

- COHERENT TECHNOLOGY IS READY FOR SPACE  
CROSSLINK APPLICATIONS
- IT OFFERS SMALL APERTURE SIZE, MODEST WEIGHT  
AND POWER
- WITH COMMERCIALY AVAILABLE COMPONENTS,  
SEVERAL HUNDRED Mbps CAN BE SUPPORTED WITH  
20 cm TELESCOPES

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
---------------------------------	--	----------------

**CRITICAL TECHNOLOGY DEVELOPMENT NEEDS FOR  
SPACE LASER COMMUNICATION SYSTEMS**

---

- ASSESSMENT OF STATE-OF-THE-ART TECHNOLOGY
- EXAMINE INTERPLAY BETWEEN TECHNOLOGY AND SYSTEM DESIGNS
- SOUND FLEXIBLE DESIGN
- ON-ORBIT DEMONSTRATION AND EXPERIMENTATION
  1. SPATIAL ACQ / TRACK EXECUTION AND EXPERIMENTATION
  2. OPTICAL / MECHANICAL / THERMAL DESIGN VERIFICATION
  3. USE OF EXPERIENCE GAINED FOR THE DESIGN OF OPERATIONAL SYSTEMS

### **6.3 INFORMATION SYSTEMS**

**This page intentionally blank**

**SENSORS AND  
INFORMATION  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION  
SYSTEMS**

**IN-SPACE EXPERIMENTS IN INFORMATION SYSTEMS**

**JOHN T. DALTON  
CHIEF, DATA SYSTEMS TECHNOLOGY DIVISION  
CODE 520  
NASA/GODDARD SPACE FLIGHT CENTER  
GREENBELT, MD 20771**

INFORMATION SYSTEMS	<p style="text-align: center;"><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP</b>  <b>DECEMBER 6-9, 1988</b></p>	SENSORS AND INFORMATION SYSTEMS
---------------------	---	---------------------------------

## INTRODUCTION/BACKGROUND

### o INFORMATION SYSTEMS ELEMENTS:

- SPACE-QUALIFIED PROCESSOR SYSTEMS AND COMPONENTS
- HIGH-SPEED IMAGE AND SIGNAL PROCESSING
- HIGH CAPACITY STORAGE
- ON-BOARD LOCAL AREA NETWORKS AND DATA HANDLING SUBSYSTEMS
- AUTOMATED SYSTEMS AND FAULT TOLERANT SYSTEMS

### CURRENT NASA CAPABILITY

#### • PROCESSORS:

NSSC-1, SHUTTLE COMPUTERS, 1750A PROCESSORS, HARRIS 80C86 (MARS OBSERVER)

PLANNED : SPACE STATION FREEDOM INTEL/IBM 80386, CRAF/CASSINI SANDIA 32016

#### • IMAGE PROCESSING:

NONE

#### • HIGH CAPACITY STORAGE:

LONGITUDINAL TAPE RECORDERS, VHS-BASED HELICAL SCAN(MANNED MISSIONS)

#### • ON-BOARD DATA HANDLING:

MISSION-UNIQUE

#### • AUTOMATED SYSTEMS:

PRIMARILY LIMITED TO PROCESS CONTROL PROCEDURES, WITH SOME AUTOMATED FAULT PROTECTION

**INTRODUCTION/BACKGROUND (CONTINUED)**

**NASA R&D PROGRAMS**

- **PROCESSORS:**
  - FAULT TOLERANT MULTIPROCESSOR SYSTEM (LaRC, JPL)
  - FLIGHT SYMBOLIC PROCESSOR WITH RH32 NUMERIC PROCESSOR (ARC)
- **IMAGE PROCESSING:**
  - G8As BIT SLICE PROCESSOR PIPELINE (GSFC)
  - MULTISPECTRAL IMAGE COMPRESSION/PROCESSING (JPL, GSFC)
- **HIGH CAPACITY STORAGE:**
  - SPACE OPTICAL DISK RECORDER - 160 Gbit capacity, 300 Mbps (LaRC)
  - ROTARY HEAD TAPE RECORDER HEAD LIFE TESTING (GSFC)
  - MEDIUM RATE (20 Mbps) LONGITUDINAL RECORDER (GSFC)
- **ON-BOARD DATA HANDLING:**
  - FIBER OPTIC TRANSCEIVERS (LaRC)
  - HIGH RATE ARCHITECTURE (GSFC)
  - CCSDS STANDARD FORMAT DATA HANDLING SYSTEMS (GSFC)
- **AUTOMATED SYSTEMS:**
  - SYSTEMS AUTONOMY DEMONSTRATIONS FOR SPACE STATION FREEDOM (POWER AND THERMAL SYSTEM CONTROL) - (ARC, JSC, LeRC)

INFORMATION SYSTEMS	<p align="center"><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	SENSORS AND INFORMATION SYSTEMS
---------------------	--	---------------------------------

## MISSION APPLICATIONS

- o ON-BOARD SYSTEM AND SENSOR CONTROL AND DATA PROCESSING APPLICATIONS  
GENERALLY APPLICABLE TO MOST SPACE MISSIONS:
  - INTELLIGENT SENSORS FOR LONG TERM MONITORING OF PHENOMENA AND FOR ADAPTIVE OBSERVATION OF SCIENTIFICALLY INTERESTING EVENTS
  - ON-BOARD SENSOR CALIBRATION AND PROCESSING
  - ON-BOARD CONTROL OF COORDINATED MULTI-SENSOR OBSERVATIONS
  - ON-BOARD FAULT DETECTION AND RECONFIGURATION OF SPACECRAFT SYSTEMS
  - COMPRESSION, BUFFERING, AND ON-BOARD PROCESSING FOR HIGH RATE IMAGING INSTRUMENTS
  - DATA DRIVEN TELEMETRY SYSTEMS (USING PACKET TELEMETRY STANDARDS)
  - ON-BOARD RESOURCE CONTROL TO IMPROVE RESPONSIVENESS OF SCIENCE OPERATIONS
  
- SUPPORTING PROCESSOR TECHNOLOGY FOR ROBOTICS:
  - TASK PLANNING
  - SENSING AND REACTIVE CONTROL
  - MACHINE VISION

## TECHNOLOGY NEEDS

- o SPACE-QUALIFIED PROCESSORS:
  - HIGHER PERFORMANCE 32-BIT PROCESSORS TO SUPPORT COMPLEX CONTROL OPERATIONS
  - PROCESSOR MEMORY CAPACITY (4 TO 32 MBYTES):
    - REDUCE FLIGHT SOFTWARE DEVELOPMENT COST
    - SUPPORT ON-BOARD SENSOR CALIBRATION AND DATA COMPRESSION
    - REDUCE TDRS CONTACT TIME REQUIRED FOR PROCESSOR LOADS
  
- o IMAGE AND SIGNAL PROCESSING:
  - IMAGE COMPRESSION DEVICES TO REDUCE TELEMETRY BANDWIDTH
  - PROCESSORS TO SUPPORT FEATURE AND INFORMATION EXTRACTION
  - COMPRESSION OF TIME SERIES OF HIGH RESOLUTION IMAGES (MICRO GRAVITY EXPERIMENTS)
  
- o HIGH CAPACITY STORAGE:
  - DIRECT ACCESS STORAGE (50 MBYTES TO 10 GBYTES)
    - ON-BOARD MANAGEMENT AND PRIORITY PLAYBACK OF ENGINEERING DATA, CONTROL PROGRAM LOADS, IMAGE STORAGE FOR NEAR-REAL TIME PROCESSING
  - HIGH RATE STORAGE (250 MBYTES @ 20 Mbps to 31GBYTES @ 300 Mbps)
    - LINK BUFFERING OF IMAGING SENSORS

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------	--	---------------------

## TECHNOLOGY NEEDS (CONTINUED)

### o NETWORKS AND DATA HANDLING SYSTEMS:

- FAULT-TOLERANT, ADAPTABLE ON-BOARD DATA SYSTEMS THAT ARE OPERABLE (UPGRADABLE, MAINTAINABLE) ON-LINE FROM GROUND CONTROL CENTERS
- PACKET TELEMETRY INTERFACES
- SYSTEM CONTROL INTERFACES FOR RESOURCE ENVELOPE ENFORCEMENT

### o AUTOMATED SYSTEMS:

- REAL-TIME EXPERT SYSTEMS FOR SENSOR AND SYSTEM CONTROL
- ON-BOARD RESOURCE MANAGEMENT AND CONTROL

## ISSUE

LARGE GAP EXISTS BETWEEN PERFORMANCE CAPABILITY OF GROUND-BASED INFORMATION SYSTEMS AND SPACE QUALIFIED SYSTEMS:

- SPACE ENVIRONMENT REQUIREMENTS: RADIATION, THERMAL, LAUNCH STRESS
- POWER AND WEIGHT CONSTRAINTS

ADVANCED MISSION CONCEPTS TEND TO BE BASED ON TECHNOLOGY CAPABILITY OF GROUND SYSTEMS, AND MUST BE SUBSTANTIALLY DESCOPE TO BE IMPLEMENTABLE IN PROVEN FLIGHT TECHNOLOGY.

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- o PROCESSORS:
  - DEMONSTRATE SPACE-QUALIFIED, FAULT TOLERANT PROCESSORS AND MEMORY SYSTEMS
    - WITH ACCEPTABLE POWER AND WEIGHT CHARACTERISTICS
    - SUFFICIENT SPACE ENVIRONMENT OPERATION TO VERIFY PERFORMANCE
- o IMAGE PROCESSORS:
  - DEMONSTRATE SPACE-QUALIFIED PROCESSORS FOR HIGH RATE LOSSLESS IMAGE COMPRESSION
  - DEMONSTRATE SPACE-QUALIFIED PROCESSORS PROGRAMMABLE FOR MULTISPECTRAL IMAGE FEATURE EXTRACTION
- o STORAGE:
  - DEMONSTRATE LAUNCH SURVIVAL AND IN-SPACE OPERATION OF MOVING MEDIA STORAGE DEVICES
  - LONG DURATION EXPOSURE OF MATERIAL AND COMPONENTS TO RADIATION ENVIRONMENTS (LASERS, WRITE-ONCE AND ERASABLE MEDIA, ETC.)
- o NETWORKS AND DATA HANDLING SYSTEMS:
  - DEMONSTRATE SOFTWARE AND SYSTEM RECONFIGURATION WHILE MAINTAINING RELIABLE OPERATIONS
  - DEMONSTRATE SPACE-QUALIFIED COMPONENTS FOR TELEMETRY GENERATION AND HANDLING SUPPORTING CCSDS PACKET TELEMETRY STANDARDS
- o AUTOMATED SYSTEMS:
  - DEMONSTRATE IN-SPACE OPERATION OF AUTOMATED EXPERIMENT AND SUBSYSTEM OPERATIONS
  - DEMONSTRATE OPERATION OF AUTOMATED RESOURCE MANAGEMENT SUBSYSTEMS (E.G., RESOURCE ENVELOPE ALLOCATION, RESOURCE CHECKING, COMMAND CHECKING, INTERLOCKS)

SENSORS AND INFORMATION SYSTEMS	<p align="center"><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP</b>  <b>DECEMBER 6-9, 1988</b></p>	INFORMATION SYSTEMS
---------------------------------	--	---------------------

**SUMMARY/RECOMMENDATIONS**

- o **REQUIREMENTS FOR INFORMATION SYSTEMS IN-SPACE EXPERIMENTS**
  - **SUCCESSFUL LONG DURATION EXPOSURE TO AND OPERATION IN RADIATION ENVIRONMENT**
  - **ACCEPTABLY LOW POWER AND WEIGHT REQUIREMENTS**
  - **LAUNCH SURVIVAL AND ZERO-G OPERATION PRIMARILY FOR MOVING MEDIA STORAGE DEVICES**
  - **SMART SENSOR SYSTEMS TESTED IN OBSERVATIONS FROM SPACE**
  - **AUTONOMOUS SYSTEMS: SUFFICIENT TESTING TO ELIMINATE PERCEIVED RISK**

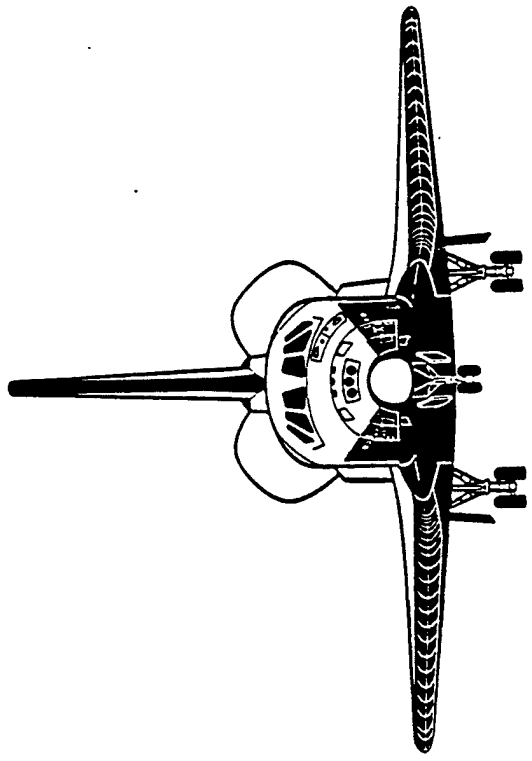
**SENSORS AND  
INFORMATION  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION  
SYSTEMS**

**INFORMATION SYSTEM PANEL  
DMS PERSPECTIVES  
DECEMBER '88**

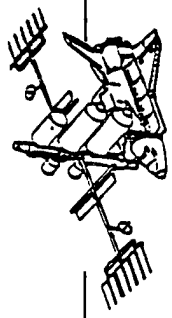
**GEORGE NOSSAMAN**



**space systems**



**Federal Systems Division  
3700 Bay Area Blvd., Houston 77058**



RATIONALE FOR IN-SPACE TECHNOLOGY EXPERIMENTS

"DMS PERSPECTIVES"

- SPACE TESTING GENERALLY EXPENSIVE
- ENVIRONMENT CAN NOT BE ACCURATELY SIMULATED IN GROUND LABS

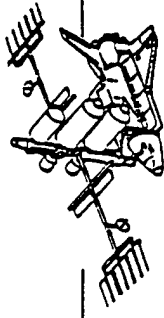
GROUND-SUFFICIENT

THERMAL  
VACUUM  
EMC  
VIBRATION  
RADIATION (PARTIAL)

IN-SPACE

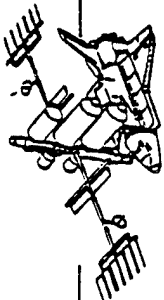
ZERO-G  
RADIATION (COMPLETE)  
MULTIPLE EFFECTS

- CONFIDENCE - BUILDING
  - ON-ORBIT TESTING RAISES CONFIDENCE IN SYSTEM APPROACH
  - DOES NOT COVER ALL PROBLEM AREAS



RATIONALE FOR IN-SPACE TECHNOLOGY EXPERIMENTS (CONTINUED)

- SOME OPERATIONAL INTERACTIONS - INVOLVING HUMANS CANNOT BE ACCURATELY SIMULATED
  - TELEOPERATIONS W/ROBOTS
  
- SPACE TESTING:
  - SHOULD VERIFY TECHNIQUES, SYSTEM APPROACHES WHICH CANNOT BE TESTED ON THE GROUND
  
  - SHOULD NOT BE USED AS BASIS FOR DEVELOPMENT OF NEW CONCEPT, OR PRIMARY TESTING APPROACH



## TRENDS IN SPACE DATA SYSTEMS

### • SYSTEM ARCHITECTURES

- MOVING TOWARD DISTRIBUTED APPROACHES
- MERGING WITH GROUND-BASED SYSTEMS - GENERAL PURPOSE H/W
- INCREASING USE OF STANDARDS FOR LCC REDUCTION
- DIFFERING MILITARY/CIVILIAN APPROACHES

### • NETWORKS

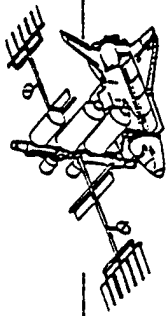
- EMERGING NEED FOR HIGH SPEED (>50 Mb/s)
- CONTINUING NEED FOR SIMPLE INSTRUMENTATION BUSES, LOCAL I/O
- EMERGING NEED FOR 10 Mb/s LAN
- FIBER OPTICS REPLACING CABLE/WIRE BUSES

### • PROCESSORS

- HIGH SPEED, SINGLE BOARD → SINGLE CHIP PROCESSORS (32 BITS)
- LOOSELY-COUPLED ARRAYS OF PROCESSORS
- TIGHTLY COUPLED SYSTEMS (MILITARY/SENSOR SYSTEMS)
- ON-BOARD HIGH-SPEED VECTOR PROCESSING
- SILICON MEMORY WITH ECC & SCRUB
- USE OF COMMERCIAL/MILITARY SYSTEMS IN SPACE
- USE OF COTS S/W, GENERAL PURPOSE OS

### • MASS STORAGE

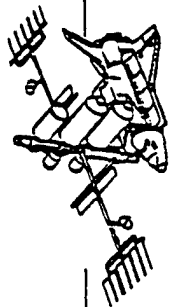
- MOVING TOWARD WINCHESTER-DISK MASS STORAGE
- OPTICAL MEMORY
- INTEGRATED DATA BASE APPROACHES



## RADIATION EFFECTS ON DIGITAL ELECTRONICS

### BACKGROUND

- FAILURE MODES
  - SINGLE-EVENT UPSET SEU
  - LATCH-UP
  - TOTAL DOSE
- VARIATIONS IN SPACE ENVIRONMENT
  - ORBITAL HEIGHT
  - ORBITAL INCLINATION
  - SOLAR CYCLES
  - RANDOM EVENTS (FLARES, ETC)
  - MAN-MADE EVENTS (NUCLEAR EFFECTS)
  - SHIELDING
  - PARTICLE FLUX CHARACTERISTICS
- GROUND TESTING LIMITATIONS
  - RADIATION SPECTRA
  - MODELING ACCURACY
  - CIRCUIT COMPLEXITY
  - EFFECTS REPORTING

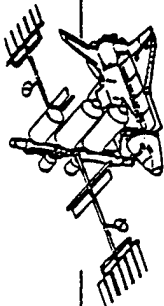


IN-SPACE TECHNOLOGY TESTING NEEDS

IN-SPACE TESTING RATIONALE

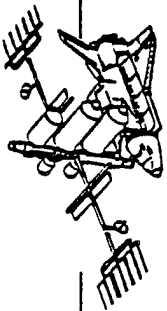
SPACE DATA SYSTEM NEED EXAMPLES

COMPONENTS	ZERO-G ENVIRONMENT	SINGLE-EVENT EFFECTS	TOTAL-DOSE EFFECTS	OPERATION COMPLEXITY	CONFIDENCE
VHSIC PROCESSES "COMMERCIAL" PROCESSES-SILICON "NEW COMPONENT" TECH-e.g. OPTICAL (DRIVES)	X X X	X X X	X X X		X X X
PROCESSORS NEW ISA SYSTEMS ARRAY PROCESSORS HIGH-SPEED BACKPLANES FAULT-TOLERANT ARCHITECTURES		X	X		X X X X
NETWORKS NEW MEDIA ROTATING JOINT MISSION NETWORK SYSTEMS DRIVER/RECEIVER TECHNOLOGIES		X X	X X		X X X X
MASS STORAGE ROTATING SYSTEMS OPTICAL DRIVERS/RECEIVERS MEDIA STABILITY	X	X X	X X		X X X
SOFTWARE OPERATING SYSTEMS DBMS's NETWORK OS AI SYSTEMS					X X X X
SYSTEMS TELE OPERATIONS AUTOMATED SYSTEMS				X X	X X



IN-SPACE TESTING NEEDS GENERAL

- INEXPENSIVE WAY TO TEST COMPONENTS IN SPACE FOR SEE
- INEXPENSIVE WAY TO VERIFY SYSTEMS FOR SEE, INTEGRATED EFFECTS
- LONG DURATION TEST FACILITY FOR LIFETIME TESTING - TOTAL DOSE, INTEGRATED EFFECTS
- COORDINATED GROUND TEST, MODELING PROGRAM
- PROGRAM AND FACILITY FOR MULTIPLE EFFECTS
- ORGANIZED APPROACH TO SELECT TECHNOLOGIES WHICH REQUIRE, RECEIVE TESTING
- SIMPLE WAY TO FLY "COMMERCIAL" AND/OR "MILITARIZE" ELECTRONICS FOR QUICK EVALUATION



SPECIFIC SUGGESTIONS

- ESTABLISH COMPONENTS & SYSTEMS TESTING PROGRAM
  - COMPONENTS & SYSTEM TEST STANDARDS
  - USE STATION AS A PATHFINDER
- DEVELOP A CONCEPT FOR LONG DURATION "COMPONENTS & ELEMENTS" TEST FIXTURES
  - PERHAPS SEVERAL AT VARIOUS DURATION AND ORBITS
- EXPAND INEXPENSIVE SORTIE-LEVEL TESTING CAPABILITIES
  - TEST COMPONENTS
  - VERIFY SYSTEM ELEMENTS
  - FLY UNMODIFIED COMMERCIAL/MILITARY TECHNOLOGY

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------------	--	------------------------

# IN-SPACE EXPERIMENTS INFORMATION SYSTEMS

NEIL R. WHITE  
UNIVERSITY OF COLORADO  
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS  
5525 CENTRAL AVENUE  
BOULDER, CO 80301  
(303)492-7959

SENSORS AND INFORMATION SYSTEMS	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP</b> <b>DECEMBER 6-9, 1988</b>	INFORMATION SYSTEMS
---------------------------------------	--	------------------------

**UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS**

- THE CATCH-22 OF SPACE INSTRUMENTATION
  - PROPOSALS ARE OFTEN AWARDED BASED UPON CONSERVATIVE 'CANNOT FAIL' DESIGNS. AT THE SAME TIME COSTS MUST BE HELD DOWN AND DELIVERY BASED UPON SUCCESS ORIENTED SCHEDULES.
    - POWER, WEIGHT, AND ENVIRONMENTAL CONSTRAINTS AFFECT SCIENTIFIC OBJECTIVES, TYPICALLY REDUCING OVERALL SCIENTIFIC RETURN.
    - H/W SHOULD BE 'OFF-THE-SHELF', USING PARTS PREQUALIFIED FOR SPACE ENVIRONMENTS. THIS FORCES USING TECHNOLOGIES AND PARTS WHICH ARE FIVE OR MORE YEARS BEHIND COMMERCIALY AVAILABLE PARTS, AGAIN LIMITING SCIENTIFIC RETURN.
    - S/W IS LIMITED BY PROCESSOR, TECHNOLOGY (CMOS, LSTTL, HCMOS, ETC.), MEMORY SIZES, ETC., FORCING ROUTINES TO BE WRITTEN IN ASSEMBLY LANGUAGE. ALSO LIMITS CAPABILITIES TO SIMPLE CONTROL ALGORITHMS AND LOW DATA RATES.
  
- YET WE LIVE IN A COMPLEX UNIVERSE, FORCING THE INSTRUMENTATION TO GROW IN COMPLEXITY AND SIZE.
  - EACH GENERATION MUST BE MORE SENSITIVE, HAVE A LARGER DYNAMIC RANGE, AND HIGHER PRECISION AND RESOLUTION THAN ITS PREDECESSOR
  - SHORT AND LONG TERM DRIFT (OVER TIME, TEMPERATURE, RADIATION, ETC) FORCE THE DEVELOPMENT OF COMPLEX, IN-FLIGHT, CALIBRATION SEQUENCES
  - DATA VOLUME IF UNINTERESTING PHENOMENA IN A 'SIT AND WAIT' MODE IS EXCESSIVE. INSTRUMENTATION NEEDS TO BE ABLE TO FIND THE HIGH QUALITY DATA THAT WILL ENHANCE SCIENTIFIC DISCOVERIES

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------	--	---------------------

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS  
(CONTINUED)

- MISSION APPLICATIONS FOR FUTURE SPACE QUALIFIED INFORMATION SYSTEMS
  - ON-BOARD SENSOR-BASED 'EVENT' DETECTION AND S/C MODE RECONFIGURATION FOR 'EVENT' OBSERVATION
    - SOLAR PHYSICS (FLARES, CORONAL MASS EJECTION, CORONAL HOLES, ETC)
    - ATMOSPHERIC PHYSICS (AURORA, POLAR MESOSPHERIC CLOUDS, ETC)
    - COMETARY PHYSICS (DETECTION, COMPOSITION)
    - PLANETARY EXPLORATION (VOLCANOS, RINGS, ETC.)
    - ASTROPHYSICS (SUPERNOVAS)
  - RESOURCE MANAGEMENT
    - POWER
    - TEMPERATURE
    - DISTURBANCE TORQUES
    - DATA (COMPRESSION, BUFFERING, RATES, PACKETIZING)
  - SENSOR CALIBRATIONS
  - FAULT DETECTION AND CORRECTION
  - POINTING, ATTITUDE, AND MOTION CONTROL AND COMPENSATION

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------------	--	------------------------

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS  
(CONTINUED)

- DIFFICULTIES EXPERIENCED RELATING TO DEVELOPMENT AND QUALIFICATION OF NEW FLIGHT TECHNOLOGIES
  - LIMITED PERSONNEL / EXPERIENCE BASE
  - AOS OFTEN PRECLUDE THE DEVELOPMENT OF NEW TECHNOLOGIES
  - NO PROFIT MOTIVE OR INTERNAL R & D FUNDING SOURCES
  - MOST FLIGHT PROGRAMS ARE UNWILLING TO ACCEPT THE RISKS ASSOCIATED WITH THE DEVELOPMENT OF NEW TECHNOLOGIES. SEPARATE GRANTS MUST BE OBTAINED PRIOR TO S/C FUNDING FOR DEVELOPMENT PROGRAMS
  
- UNIVERSITIES SUFFER FROM POOR OR CONFLICTING DATA PERTAINING TO SPACE QUALIFIED PARTS
  - EACH NASA CENTER USES DIFFERENT APPROVED PARTS AND FABRICATION TECHNIQUES
  - NEWER TECHNOLOGIES IN THE PROCESS OF QUALIFICATION ARE NOT WIDELY PUBLISHED
  - DOD SPACE QUALIFIED PARTS CANNOT BE OBTAINED

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------	--	---------------------

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS  
(CONTINUED)

- LITTLE OR NO STANDARDIZATION OF S/C INTERFACES, BUS STANDARDS, ETC. THUS EVERY INSTRUMENTS DESIGN IS UNIQUE EVEN THOUGH MANY INCORPORATE SUBSYSTEM COMMON TO ALL
  - MICROPROCESSOR / BUS
  - ECC MEMORY
  - TELEMETRY INTERFACE
  - STANDARD INTERFACES (MULTICHANNEL A/D'S AND D/A'S, ETC)
  - SOFTWARE

UNIVERSITY SCIENTISTS AND ENGINEERS WILL PUSH AVAILABLE FLIGHT DESIGNS AND TECHNOLOGIES TO THEIR LIMITS. HOWEVER, THEY WILL NOT PROPOSE INSTRUMENTATION REQUIRING THE DEVELOPMENT OR QUALIFICATION OF NEWER, COMMERCIALY AVAILABLE PARTS AND TECHNOLOGIES, UNDER S/C ANNOUNCEMENT OF OPPORTUNITIES.

SENSORS AND INFORMATION SYSTEMS	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	INFORMATION SYSTEMS
---------------------------------------	--	------------------------

### TECHNOLOGY NEEDS

- INTELLIGENT (NETWORKED) INSTRUMENTATION AND S/C
- ON-BOARD CALIBRATION SEQUENCING
  - S/C MANEUVERING
  - INSTRUMENT CONFIGURATION
  - SENSOR DATA CALIBRATION ANALYSIS
  - STORAGE OF CALIBRATION DATA
- REAL-TIME DATA PROCESSING
  - APPLICATION OF CALIBRATION DATA
  - BACKGROUND REMOVAL
  - ANALYTICAL ANALYSIS (MIN / MAX, FFT, MODEL FITTING, ETC)
  - DATA COMPRESSION
- DATA ANALYSIS
  - 'EVENT' DETECTION AND FEATURE RECOGNITION
- 'EVENT' BROADCAST AND RECONFIGURATION
  - INSTRUMENT
  - S/C
  - OTHER (OTHER S/C, GROUND INSTRUMENTATION, SS INSTRUMENTATION, ETC.)
- RESOURCE MANAGEMENT

TECHNOLOGY NEEDS (CONTINUED)

- SPACE-QUALIFIED PARTS / SYSTEMS
- STANDARDIZED BUS PROTOCOL(S)
  - 'OFF-THE-SHELF' SPACE-QUALIFIED COMPONENTS
    - 8, 16, & 32 BIT FAULT TOLERANT MICROPROCESSOR CARDS
    - ECC MEMORY (PROM, EPROM, SRAM, AND DRAM)
    - TELEMETRY INTERFACE CARDS (SHOULD COMPLY WITH COMMERCIALY AVAILABLE STANDARDS LIKE RS-232, IEEE-488, ETHERNET, ETC.)
    - CONTROL I/F CARDS (DIGITAL I/O, A/D, D/A, ETC.)
    - LITERALLY SPACE QUALIFIED PC'S, MAC II'S, MICROVAX'S, ETC. WITH PLUG IN PERIPHERAL CARDS
- SOFTWARE UTILITIES SUPPORTING HARDWARE SYSTEMS
  - REAL-TIME MULTITASKING KERNEL
  - PACKET GENERATION UTILITIES
  - DATA COMPRESSION UTILITIES
  - COMMAND ERROR CHECKING AND PARSING UTILITIES
  - GROUND BASED COMPLEMENTS TO THE ABOVE UTILITIES
  - RESOURCE MANAGEMENT UTILITIES

SENSORS AND INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
---------------------------------	--	---------------------

TECHNOLOGY NEEDS (CONTINUED)

- NATIONAL NASA APPROVED PARTS AND SOFTWARE DATABASE
  - CONTINUOUSLY UPDATED
  - DISCRETE PARTS AND MATERIALS
  - COMPONENT LEVEL CARDS / BOARDS
    - SPECIFICATIONS
    - QUALIFICATION LEVEL (MIL-STD-883, MIL-M-38510, ETC.)
    - RADIATION HARDNESS
    - VENDOR
    - PRICE
  - SOFTWARE UTILITIES
  - CURRENT R & D EFFORTS
  - USER FEEDBACK / WISH LISTS

**SENSORS AND INFORMATION SYSTEMS  
CRITICAL TECHNOLOGY REQUIREMENTS**

**MARTIN M. SOKOLOSKI  
NASA HEADQUARTERS  
and**

**JOHN DALTON  
GODDARD SPACE FLIGHT CENTER**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS IMPORTANCE**

**MISSION TO PLANET EARTH**

- EOS**      **Laser Active Sensing of Winds**  
**Laser Active Sensing of Trace Species**  
-      **Ozone, Acid Rain, H<sub>2</sub>O, CO<sub>2</sub>, Others**  
**Laser Altimetry**  
-      **Plate Tectonic Movements**

- GEOPLAT**      **Fixed Focus with Large Format Arrays**  
**Multi-Spectral Imagers**  
**Spatial Imagers**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS IN-SPACE TESTING REQUIRED**

- o IN-SPACE POINTING, CONTROL & STABILIZATION TEST BED FOR  
DETECTORS & LASERS REMOTE SENSING SYSTEMS**
  
- o IN-SPACE TESTING, DEMONSTRATION, AND VERIFICATION OF  
PROTOTYPE COOLERS & COOLER SYSTEMS**
  - Mechanical Refrigerators**
  - Magnetic Refrigerators**
  - He3/He4 Dilution Refrigerators**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS TECHNOLOGY NEEDS**

- 0 **PRECISION POINTING, CONTROL & STABILIZATION FOR PASSIVE AND ACTIVE (DIAL/LIDAR) REMOTE SENSING**
  - 0 **Passive Sensing (Detector Arrays)**
    - "Earth Looking"
    - "Out Looking"
  - 0 **Active Sensing**
    - **Differential Absorption LIDAR**
    - **Coherent Doppler LIDAR [Laser Atmospheric Wind Sounder]**
  
- 0 **SPACE - QUALIFIABLE COOLERS & COOLER SYSTEMS OPERATING IN 0-G ENVIRONMENT ~ 3-5 YEARS LIFETIME**
  - 0 **Cooling Sensor Arrays to Tens of Kelvin**
  - 0 **Cooling Sensor Arrays to Millikelvin <T <10ok**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**COMMUNICATIONS IMPORTANCE**

- o MISSION TO PLANET EARTH**
  - **Optical (>500 Mbps) GEOPLAT/GEOPLAT Links**
  - **GEOPLAT/EOS Links**
  - **Coherent Links [Two or More Platforms Employed as a Single Observational Instrument]**
  - **Optical Link Direct to Ground**
  
- o MARS EXPLORATION**
  - **Mars Rover (Eliminate Large Antenna)**
  - **Manned Missions**
  
- o LUNAR BASE**
  - **LaGrange Point / Earth -GEO / Far Side Optical Link**
  
- o OTHER MISSIONS**
  - **Enables Star Probe (Communication in and Thru Sun's Plasma)**
  - **TAU (Thousand Astronomical Unit)**
  - **Planetary - High Data Rate**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**COMMUNICATIONS TECHNOLOGY NEEDS**

**o EXPERIMENTAL TEST DATA ON OPTO-THERMO-STRUCTURAL  
MECHANICAL INTERACTIONS OF SPACE-BASED "OPTICAL  
BENCH" FOR OPTICAL COMMUNICATIONS**

- **Laser Power & Cooling**
- **Acquisition (Closed & Open Loop)**
- **Pointing and Tracking**
- **Communications Links**
- **Very Large Baselines (> 40,000 Km)**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**COMMUNICATIONS IN-SPACE TESTING REQUIRED**

- o Obtain Experimental Test Data to Obtain and Validate Complex Analytical Models to Enable Overall Laser Communications Systems Optimization**
  
- o The In-Space Environment:**
  - Platform Vibration**
  - Thermal Distortion**
  - Radiation**
  - Natural Background Sources**
  - S/C Glow**
  - Long Baselines**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION SYSTEMS TECHNOLOGY NEEDS**

- o Intelligent Information Systems to Support Automated Operations, On-Board Processing, & Robotics
  - Special Purpose Processors: Image, Symbolic, Neural Network
  - High Performance General Purpose Processors
  - High Volume Storage

**IMPORTANCE**

- o **MISSION TO EARTH:**
  - On-Board Feature Extraction & Processing Required to Reduce Large Volume of Global Monitoring Data and Enable Manageable Communications and Ground Processing Costs
- o **MICROGRAVITY:**
  - On-Board Selection of Features of Interest From High Rate/Volume Image Sequences. Required to Meet TDRS Communication Limit
- o **PLANETARY ROVERS:**
  - On-Board Science Analysis & Autonomous Vehicle Operation

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION SYSTEMS TECHNOLOGY NEEDS**  
**(CONT.)**

**IN-SPACE TESTING REQUIRED**

- o System-Level Validation:**
  - Adaptive Response to Real-Time Observations
  - Performance and Reliability in Space Radiation Environment
  
- o Space Environment Testing**
  - Space-Borne VHSIC Multiprocessor System
  - CSTI High Rate Data Systems

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION SYSTEMS IN-SPACE TECHNOLOGY  
NEEDS**

- o Space Qualified Components with Performance Comparable to Ground System Capability**
- o Confidence Testing of Commercial-Grade Components to Provide Low-Cost, Low-Risk Applications**
- o Zero-G Testing of Storage Systems**

**IMPORTANCE:**

- o Reduce Cost of Space Experiments**
- o Modular, Standard Processing Elements for Multi-Mission Applications**
- o Mission Enabling for Some Applications (Eg. On-Board Instrument Calibration, Automation of Operations)**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**INFORMATION SYSTEMS IN-SPACE TECHNOLOGY  
NEEDS (CONT.)**

**IN-SPACE TESTING REQUIRED:**

- o Laboratory for On-Going Testing of New Components
  - Shuttle/SSF Low Inclination Orbit
  - Polar & Geo Radiation Environment
- o Build on CRRES Experience
- o Improve Model of Radiation Environmental Effects
- o Incorporate as Last Step of Ground Modeling & Testing Process

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**SENSORS & INFORMATION SYSTEMS IN-SPACE  
TECHNOLOGY NEEDS**

**SENSORS**

- o Precision Pointing, Control, and Stabilization
- o Coolers

**COMMUNICATIONS**

- o High Rate Optical Communications
- o Closed and Open Loop Acquisition
- o Pointing and Tracking

**INFORMATION SYSTEMS**

- o Intelligent Systems For In-Space Observations, Automated Control, and Robotics
- o Effective Space Application of Processor and Storage Technology Advances

## **7. IN-SPACE SYSTEMS**

**This page intentionally blank**

# **IN-SPACE SYSTEMS BACKGROUND AND OBJECTIVES**

**JON B. HAUSSLER  
MARSHALL SPACE FLIGHT CENTER**

# **THEME SESSION OBJECTIVES**

- **PURPOSE**
  - IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR EACH THEME WHICH:
    - ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS
    - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
  - OBTAIN AEROSPACE COMMUNITY COMMENTS & SUGGESTIONS ON OAST IN-STEP PLANS
- **PRODUCT**
  - AEROSPACE COMMUNITY RECOMMENDED PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS

# **IN-SPACE SYSTEMS**

## **THEME ELEMENTS (*SUBTHEMES*)**

**MATERIAL PROCESSING**

**MAINTENANCE, REPAIR AND FIRE SAFETY**

**PAYLOAD OPERATIONS**

# 1985 WORKSHOP THEME

## IN-SPACE OPERATIONS

- ADVANCED LIFE SUPPORT SYSTEM
- BIOMEDICAL RESEARCH
- TETHERS
- MAINTENANCE AND REPAIR
- ORBITAL TRANSFER VEHICLE
- SYSTEM TESTING
- PROPULSION
- MATERIAL PROCESSING

# THEME SESSION AGENDA

## • **THEME ELEMENT SESSIONS**

### - **CRITICAL SPACE TECHNOLOGY NEEDS FOR THEME ELEMENT.**

#### **FROM PERSPECTIVE OF:**

##### - **INDUSTRY, UNIVERSITIES & GOVERNMENT**

(BRIEF PRESENTATIONS OF MAJOR TECHNICAL PROBLEMS/CONCERNS/NEEDS IN THIS THEME ELEMENT AREA FROM THE PERSPECTIVE OF THE SPEAKER'S ORGANIZATION)

### - **OPEN DISCUSSION WITH THE AUDIENCE & THEME ELEMENT SPEAKERS/THEME LEADER**

#### - **QUESTION & ANSWER WITH SPEAKERS**

#### - **IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE**

### - **AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES**

(INCLUDING THOSE TECHNOLOGIES DISCUSSED BY THE AUDIENCE)

(NOTE: AUDIENCE SHOULD USE PRIORITIZATION CRITERIA PRESENTED ON VIEWGRAPH)

## • **COMBINATION & PRIORITIZATION OF THEME TECHNOLOGIES**

### - **DISCUSSION BETWEEN AUDIENCE AND ALL THEME ELEMENT SPEAKERS**

### - **RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME**

# **IN-SPACE SYSTEMS**

## **MATERIAL PROCESSING SPEAKERS**

- **DR. ROBERT J. NAUMANN, MSFC**
- **DR. DAVID W. SAMMONS, UNIVERSITY OF ARIZONA**
- **DR. JOHN T. VIOLA, ROCKWELL INTERNATIONAL**

# **IN-SPACE SYSTEMS**

## **MAINTENANCE AND REPAIR SPEAKERS**

**- MR. ED FALKENHAYN, GSFC**

**- MR. BOB  
DELLACAMERA, McDONNELL DOUGLAS**

## **FIRE SAFETY SPEAKER**

**- MR. WALLACE W. YOUNGBLOOD, WYLE LABORATORIES**

# **IN-SPACE SYSTEMS**

## **PAYLOAD OPERATIONS SPEAKERS**

- **DR. JEFFREY A. HOFFMAN, JSC**
- **PROF. GEORGE MORGENTHAUER, UNIVERSITY OF COLORADO**
- **MR. LEE LUNSFORD, LOCKHEED**

# PRIORITIZATION CRITERIA\*

## 1. CRITICAL ENABLING TECHNOLOGIES

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS

## 2. COST REDUCTION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY  
(E.G., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

## 3. BROAD APPLICATION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

## 4. REQUIRE IN-SPACE VALIDATION

- TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR  
VALIDATION OR EXPERIMENTATION

\* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1. = HIGHEST)

## **7.1 MATERIALS PROCESSING**

**OFFICE OF SPACE SCIENCE AND APPLICATIONS  
MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION  
NASA HEADQUARTERS**

**IN SPACE TECHNOLOGY EXPERIMENTS PROGRAM  
1988 WORKSHOP**

**MATERIALS PROCESSING**

**DECEMBER 7, 1988**

**LARRY SPENCER**

## **WHY MICROGRAVITY?**

- **ELIMINATE BUOYANCY-DRIVEN CONVECTION**  
ESTABLISH DIFFUSION-CONTROLLED CONDITIONS  
VASTLY SIMPLIFIES TRANSPORT ANALYSIS  
SUPPRESSES THERMAL AND COMPOSITION FLUCTUATIONS  
ELIMINATES UNWANTED MIXING  
UNMASKS OTHER, MORE SUBTLE FLOWS
- **ELIMINATE SEDIMENTATION**  
MAINTAIN HETEROGENEOUS MIXTURES OR SUSPENSIONS  
PREVENT UNWANTED PHASE SEPARATION  
INVESTIGATE SECOND-ORDER FORCES ON PARTICLES OR DROPLETS  
OBJECTS CAN BE FREE-FLOATED
- **ELIMINATE HYDROSTATIC PRESSURE**  
LIQUID CAN BE CONSTRAINED BY THEIR SURFACE TENSION  
DEPLOY LIQUID BRIDGES TO RAYLEIGH LIMIT  
EXTEND FLOAT ZONE PROCESS TO LOW SURFACE TENSION MATERIALS  
ELIMINATE PRESSURE VARIATIONS IN CRITICAL POINT EXPERIMENTS

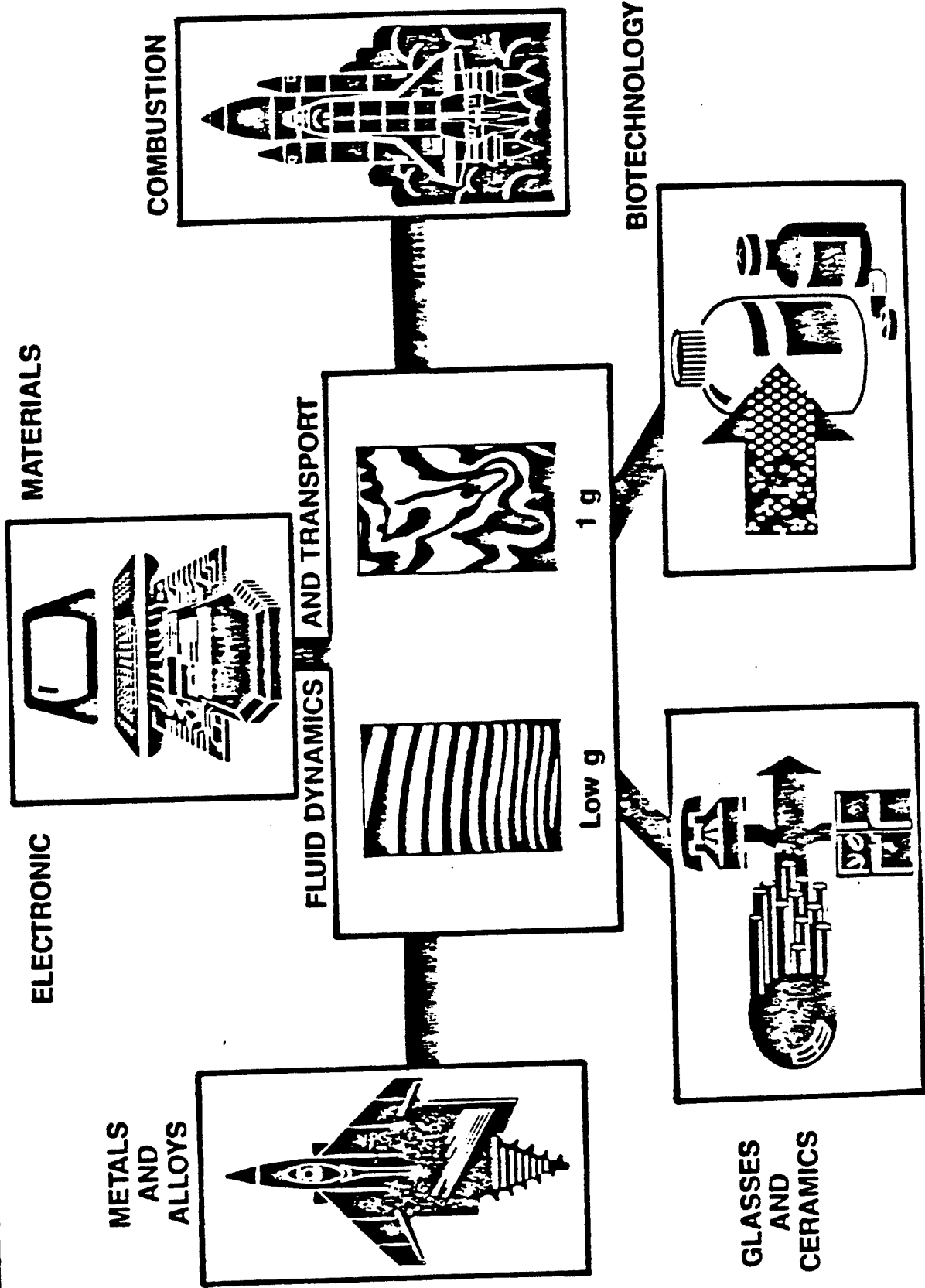
### **BONUSES**

ULTRAHIGH VACUUM —  $\sim 10^{-14}$  TORR BEHIND WAKE-SHIELD  
HIGH PUMPING SPEED — VIRTUALLY INFINITE SINK  
HIGH HEAT REJECTION —  $\sim 4$ K RADIATION BACKGROUND  
FLUX OF ATOMIC OXYGEN — COLLIMATED BEAM OF 5 eV O ATOMS  
UNFILTERED SUNLIGHT — SOURCE OF V.U.V. ESPECIALLY 121.6 nm.

**GOALS**

- o USE THE MICROGRAVITY ENVIRONMENT AS A LABORATORY TO:
  - 1) OBTAIN UNDERSTANDING OF BASIC PHYSICAL PHENOMENA AND PROCESSES
  - 2) QUANTIFY LIMITATIONS/EFFECTS IMPOSED BY GRAVITY ON THESE PHENOMENA AND PROCESSES
  - 3) APPLY THIS BASIC KNOWLEDGE TO BOTH EARTH BASED AND SPACE BASED PROCESSES OR PRODUCTS
  
- o DISSEMINATE THE RESEARCH DATA BASE TO THE U.S. PRIVATE SECTOR TO ENHANCE U.S. COMPETITIVENESS IN THE WORLD MARKET

# MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION



## **MICROGRAVITY SCIENCE AND APPLICATIONS DISCIPLINES**

### **FLUID DYNAMICS AND**

#### **TRANSPORT PHENOMENA**

- CRITICAL POINT PHENOMENA
- SURFACE BEHAVIOR
- CHEMICAL REACTION
- RELATIVITY
- TRANSPORT PHENOMENA
- SOLIDIFICATION MODELS

#### **GLASSES AND CERAMICS**

- NEW GLASS COMPOSITIONS
- FINING
- SPHERICAL SHELLS
- NUCLEATION/CRYSTALLIZATION

#### **ELECTRONIC MATERIALS**

- VAPOR GROWTH
- MELT GROWTH
- SOLUTION GROWTH
- FLOAT ZONE

### **METALS AND ALLOYS**

- MONOTECTICS
- EUTECTICS
- UNDERCOOLING
- SOLIDIFICATION FUNDAMENTALS
- THERMOPHYSICAL PROPERTIES

### **BIOTECHNOLOGY**

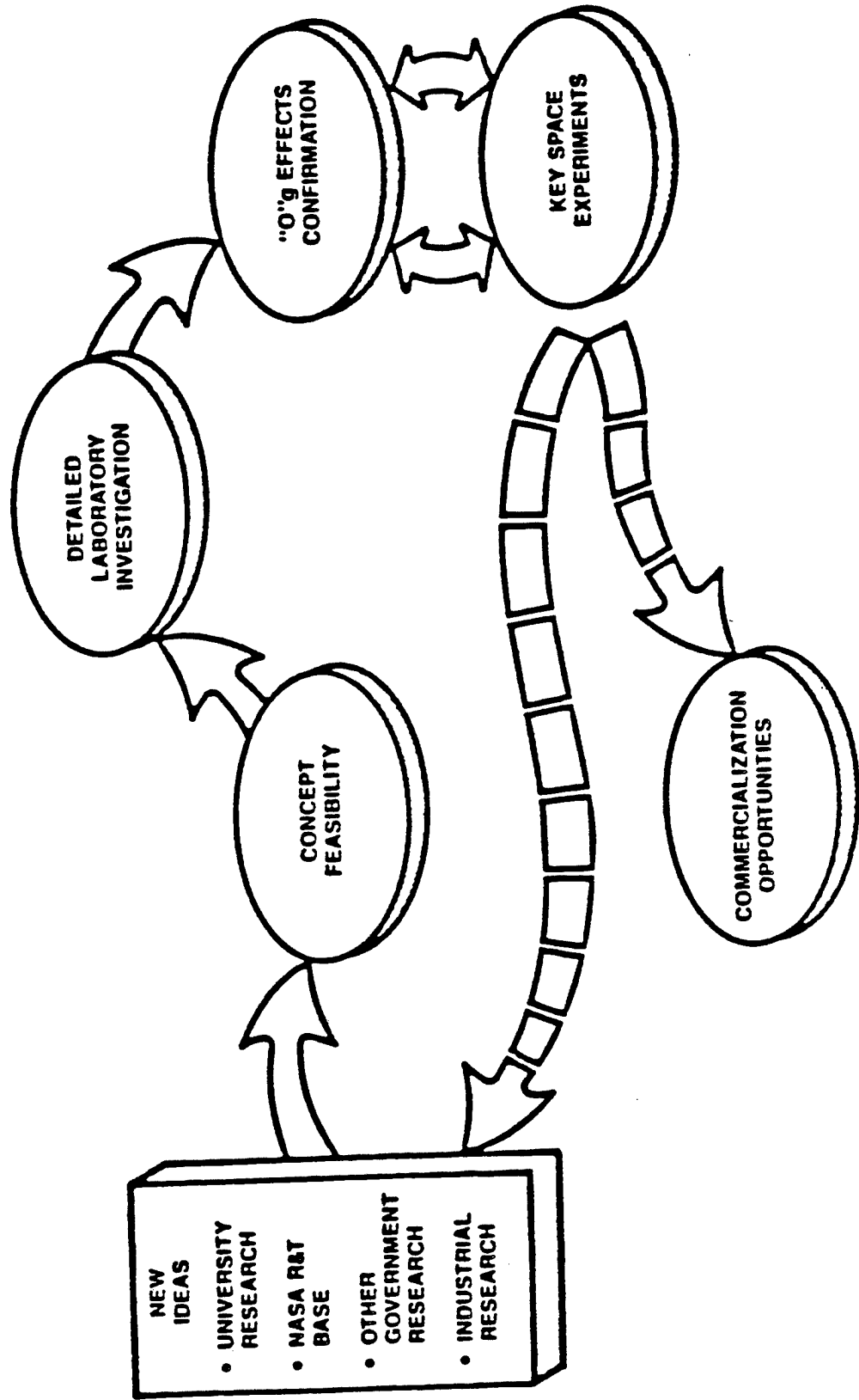
- NEW TECHNIQUE DEVELOPMENT
- EVALUATION OF CFES
- PROTEIN CRYSTAL GROWTH
- BIOREACTOR

### **COMBUSTION SCIENCE**

- SOLID SURFACE
- POOL BURNING
- PARTICLE CLOUD
- DROPLET BURNING

**NASA OFFICE OF SPACE SCIENCE AND APPLICATIONS  
MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION**

**THE APPROACH**



## MICROGRAVITY SCIENCE AND APPLICATIONS TECHNOLOGY DEVELOPMENT

---

- VIBRATION ISOLATION SYSTEMS ( $10^{-8}$  g,  $10^{-3}$  Hz)
- REACTIONLESS ROBOTICS
- ADVANCED HIGH-TEMPERATURE FURNACES
- HIGH-TEMPERATURE MATERIALS FOR FURNACES (3000°C)
- HIGH-FRAME RATE/HIGH-RESOLUTION VIDEO (100 microns, 1000 FPS)
- CRYSTAL GROWTH NUCLEATION DETECTION (10Å)
- NON-CONTACT TEMPERATURE MEASUREMENT CAPABILITY (5°K TO 2500°K)
- ELECTRONIC CRYSTAL GROWTH MEASUREMENT TECHNOLOGY
- FLUID AND COMBUSTION DIAGNOSTICS
- ACCELERATION MEASUREMENT ( $10^{-8}$  g)

## **IN-SPACE TECHNOLOGY VALIDATION NEEDS**

- **CHARACTERIZATION, MEASUREMENT, AND CONTROL OF THE MICROGRAVITY ENVIRONMENT**
- **ULTRAHIGH VACUUM TECHNOLOGY**
- **MEASUREMENT AND CONTROL OF FLUIDS**
- **REACTIONLESS ROBOTICS**
- **IN-SPACE SAMPLE PREPARATION AND ANALYSIS**
- **HANDLING OF MATERIALS AND WASTE PRODUCTS**
- **COMBUSTION DIAGNOSTIC TECHNOLOGY**

IN-SPACE SYSTEMS

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988

MATERIALS  
PROCESSING

FLOATING-ZONE CRYSTAL GROWTH IN SPACE

JOHN T. VIOLA

ROCKWELL INTERNATIONAL SCIENCE CENTER

IN-SPACE SYSTEMS

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988

MATERIALS  
PROCESSING

## INTRODUCTION / BACKGROUND

- 0 ELECTRONIC COMPONENTS AND SUBSYSTEMS FOR DEFENSE AND COMMERCIAL APPLICATIONS  
IN DEVELOPMENT
  - GaAs SIGNAL PROCESSORS, INFRARED FOCAL PLANE ARRAYS, NON-LINEAR OPTICS AND PHOTONICS
- 0 HIGH QUALITY, DEFECT-FREE MATERIAL IS NEEDED FOR THESE APPLICATIONS
- 0 CURRENT TECHNOLOGY LIMITS SINGLE CRYSTAL SIZE AND IMPOSES UNWANTED DEFECT CONCENTRATIONS (TWINS, DISLOCATIONS, PRECIPITATES, GRAIN BOUNDARIES)

**INTRODUCTION / BACKGROUND - CONTINUED**

- 0 FLOAT ZONE CRYSTAL GROWTH IN MICROGRAVITY CAN YIELD LARGER CRYSTALS WITH LOWER DEFECT CONCENTRATIONS.
- 0 REDUCED CONTAMINANT CONCENTRATION AND SPURIOUS NUCLEATION BY ELIMINATION OF INTERACTION WITH AN AMPOULE
- 0 LARGER DIAMETER ZONE IS POSSIBLE SINCE SURFACE TENSION NEED NOT SUPPORT THE WEIGHT OF THE MELTED ZONE
- 0 ELIMINATION OF PLASTIC DEFORMATION FROM CRYSTAL'S OWN WEIGHT.
- 0 FLOAT ZONE EXPERIMENTS IN SPACE ARE NEEDED TO DEMONSTRATE FEASIBILITY

## TECHNOLOGY NEEDS

- 0 EXPERIMENTAL FACILITY NEEDED TO PERFORM CONTROLLED CRYSTAL GROWTH OF HIGH MELTING ELECTRONIC MATERIALS WITH HIGH CONSTITUENT VAPOR PRESSURES.

### REQUIREMENT

SAMPLE SUPPORT AND CHANGEOUT  
FURNACE TEMPERATURES UP TO 1500C  
HOT WALL FURNACE  
VARIABLE SPEED ZONE HEATER  
POWER BUDGET MANAGEMENT

### PURPOSE

CONTACTLESS PROCESSING; MULTIPLE EXPERIMENTS  
ELECTRONIC MATERIALS OF INTEREST  
ELIMINATE VAPOR LOSS BY CONDENSATION  
ESTABLISH AND MOVE MOLTEN ZONE  
ESTABLISH AND MAINTAIN PROPER  
TEMPERATURE PROFILE

MOLTEN ZONE DIMENSIONAL SENSING  
(LENGTH, SOLID-LIQUID INTERFACES  
FLUID FLOWS)  
OPTIMIZE CRYSTAL GROWTH CONDITIONS

# TECHNOLOGY NEEDS

REQUIREMENT

PURPOSE

FURNACE AND GROWTH SYSTEM TEMPERATURE

OPTIMIZE CRYSTAL GROWTH CONDITIONS

SENSING

CONTROLLABLE POWER AND POSITIONAL

ESTABLISH AND MAINTAIN PROPER

SETTINGS

TEMPERATURE PROFILE

EVENTUAL EXPERT SYSTEM CONTROL

AUTONOMOUS OPERATION

PROVE FOR IN SITU OBSERVATION OF

EXPERT SYSTEM CONTROL OF GROWTH PROCESS

GROWING CRYSTAL QUALITY

(ULTRASOUND?)

ROBOTIC MANIPULATION

AUTONOMOUS OPERATION/TELESCIENCE

## IN-SPACE EXPERIMENTATION NEEDS / VOIDS

- 0 FLOATING-ZONE CRYSTAL GROWTH OF HIGH-MELTING SEMICONDUCTOR COMPOUNDS TO DEMONSTRATE LARGE SIZE, HIGH PURITY, LOW DEFECT, SINGLE CRYSTAL MATERIAL.
- 0 "CONTAINERLESS" PROCESSING TO DEMONSTRATE ADVANTAGES OF CONTACTLESS CRYSTAL GROWTH.
- 0 SENSING AND IMAGING SYSTEM FOR FLOATING-ZONE CRYSTAL GROWTH TO DEMONSTRATE CONTROL OF MOLTEN ZONE SIZE, LENGTH, SHAPE AND RELATIVE MOTION AND FLOW.
- 0 EXPERIMENTS TO INVESTIGATE FLUID DYNAMIC PHENOMENA, SUCH AS THERMOCAPILLARY FLOW, THAT ARE OF CRITICAL IMPORTANCE IN EARTH-BASED PROCESSES, BUT CANNOT BE STUDIED ON EARTH BECAUSE OF GRAVITATIONAL EFFECTS; RESULTS CAN BE APPLIED IN BOTH EARTH AND SPACE-BASED PROCESSES.

**MATERIALS PROCESSING --  
CELLS AND CELLULAR PRODUCTS**

**DAVID W. SAMMONS  
UNIVERSITY OF ARIZONA**

# **INTRODUCTION / BACKGROUND**

**EXPERIMENTS WITH CELLS UNDER MICROGRAVITY ARE**

**IMPORTANT TO:**

- O BASIC SCIENCE**
- O COMMERCIALIZATION OF BIOTECHNOLOGY**
- O SPACE MEDICINE AND HUMAN ADAPTATION**
- O TRANSFER OF SPACE TECHNOLOGY TO TERRESTRIAL APPLICATIONS**

## **TECHNOLOGY NEEDS**

- 0 HARDWARE FOR CELL MAINTENANCE & GROWTH**
- 0 HARDWARE FOR PROLONGED CELL STORAGE AND ACTIVATION**
- 0 VISION SYSTEMS FOR COUNTING, MEASURING AND EVALUATING CELLS**
- 0 AUTOMATED FLUID TRANSFER SYSTEMS THAT MAINTAIN STERILE ENVIRONMENTS**
- 0 SEPARATION SYSTEMS UTILIZING CELLULAR & BIOPHYSICAL CHARACTERISTICS OF TARGET CELLS**

## **TECHNOLOGY NEEDS**

- O ANALYSIS & QUALITY CONTROL INSTRUMENTATION**
- O TELECOMMUNICATION & EXPERT SYSTEMS TO MONITOR & ADJUST IN-SPACE EXPERIMENTATION**
- O MAINTENANCE & CONTINUED GROWTH INSTRUMENTATION FOR NEW IN-SPACE GENERATED PRODUCTS**
- O RECOVERY AND ANALYSIS SYSTEMS OF IN-SPACE GENERATED CELL PRODUCTS**

# **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

## **SAMPLE PREPARATION AND PROCESSING**

- O SAMPLE INJECTION**
- O LIQUID MIXING DEVICES**

## **MAINTENANCE AND/OR CULTURE**

- O GAS & TEMPERATURE CONTROLLED INCUBATORS**

## **SEPARATION OF CELLS (POPULATION & SINGLE)**

- O ELECTROKINETIC**
- O CELL SORTING**
- O AFFINITY**

# **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

## **TRANSFER OF FLUIDS & CELLS INTO REACTOR AND OUT OF REACTOR**

- O VALVING**
- O PUMPING OF FLUIDS**

## **REACTION CHAMBERS**

- O ELECTROFUSION/ELECTROPERMEATION**
- O CELL ACTIVATION**
- O HOLDING TANKS FOR SECRETION OF PRODUCTS**

## **IN-LINE SEPARATION OF CELLS AND PRODUCTS**

- O ELECTROKINETIC**
- O CELL SORTING**
- O AFFINITY**

# **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**RECYCLE UNREACTED CELLS TO MAINTENANCE AND/OR CULTURE**

- O VALVING**
- O PUMPING OF FLUIDS**

**SPECIALIZED CLONING AND GROWTH CHAMBERS**

- O AUTOMATIC DILUTORS**
- O GELS AND SPECIAL GROWTH CHAMBERS**

**ANALYSIS OF CLONES & ESTIMATION OF YIELDS**

- O COLORIMETRIC, FLUOREMETRIC & RADIOACTIVE**

**RECOVERY OF CELL PRODUCT FOR RETURN OR FURTHER PROCESSING**

- O INCUBATORS**
- O AFFINITY RESIN MATERIALS OF HIGH CAPACITY**

## **7.2 MAINTENANCE, REPAIR, AND FIRE SAFETY**

<p><b>IN-SPACE SYSTEMS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>MAINTENANCE, REPAIR, AND FIRE SAFETY</b></p>
------------------------------------	---	--

**MAINTENANCE, SERVICING & REPAIR IN SPACE**

**Ed Falkenhayn**

**SATELLITE SERVICING PROJECT  
GODDARD SPACE FLIGHT CENTER  
GREENBELT, MARYLAND**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

INTRODUCTION/BACKGROUND

CURRENT/PLANNED MAINTENANCE & REPAIR CAPABILITY

0 PAYLOADS PLANNING ON STS, SPACE STATION OR OMV DOCKING WILL DOCK TO

FSS THREE LATCH BERTHING RING

0 FSS BERTHING RING PROVIDES ELECTRICAL UMBILICAL SERVICES:

- POWER

- DATA

- COMMAND

0 FSS BERTHING RING PROVIDES MECHANICAL POSITIONING

- PIVOTS 0 TO 90°

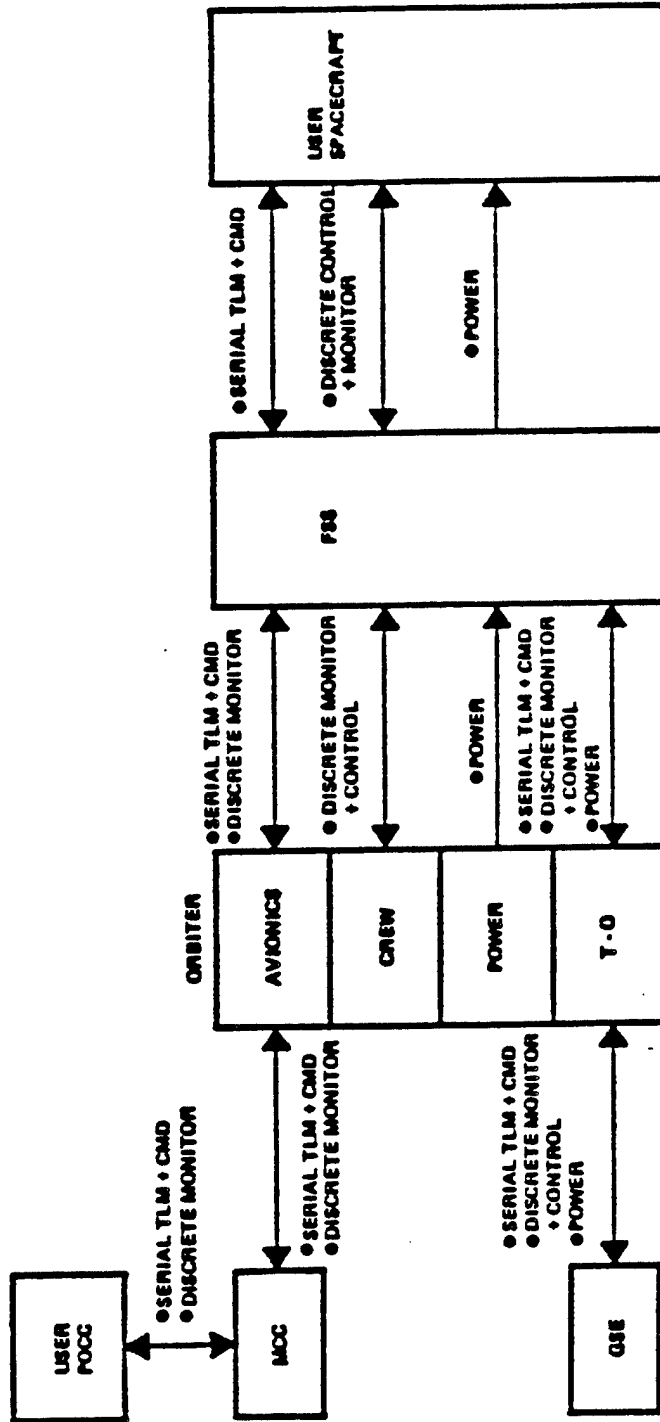
- ROTATION ±175°

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

OPERATIONS/FUNCTIONS

- O POSITIONING FOR INSPECTION AND EASE OF ACCESS
- O TOTAL OR SELECTIVE POWER-OFF TO PERMIT REPAIR AND/OR MODULE EXCHANGES
- O INDEPENDENT HEATER POWER TO MAINTAIN THERMAL LIMITS ON COMPONENTS/  
INSTRUMENTS/SYSTEMS
- O COMMAND & TELEMETRY LINKS PERMIT SPACECRAFT/PAYLOAD CHECKOUT
  - FROM ORBITER AFT FLIGHT DECK
  - FROM USER'S POCC VIA ORBITER AVIONICS
- O AFTER SMM REPAIR IN 1984, DURING NIGHT, BETWEEN REPAIR DAY & RELAUNCH DAY,  
FULL SPACECRAFT FUNCTIONAL CHECK WAS PERFORMED

## FSS ELECTRICAL AND AVIONICS SERVICES



IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

DIAGNOSTIC SYSTEMS

THE ON-BOARD COMPUTER - NSSC-1

- O ON-BOARD MANAGEMENT, AND UPDATING OF SPACECRAFT PERFORMANCE STATISTICS & TREND DATA
- O AUTOMATIC RESPONSES TO PREDEFINED SPACECRAFT ANOMALIES/HARDWARE FAILURES - SAFE HOLD
- O ALLOWS IN-FLIGHT TELEMETRY FORMAT MODIFICATIONS FOR DIAGNOSTICS AND RECONFIGURATION FOR OPTIMUM SCIENCE RETURN AS HARDWARE/INSTRUMENTS AGE AND DEGRADE

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

REMOTE SERVICING - THE NEXT STEP

- MANY SPACECRAFT OPERATE BEYOND STS/OMV AND SPACE STATION/OMV ALTITUDE AND

INCLINATION

- REMOTE SERVICING WILL USE ELV LAUNCHED SERVICING OPERATIONS; ENGINEERING

STUDIES NEED TO ADDRESS:

- O INVESTMENT IN ELV LAUNCHED, EXPENDABLE SERVICER CAPABILITY
- O PROGRAMMATICS/LOGISTICS/ECONOMICS OF A SPACE BASED SERVICING FACILITY
- O SERVICER/SPACECRAFT INTERDEPENDENCY; SHUT DOWN/TRANSFER OF SPACECRAFT FUNCTIONS
- O MANIPULATOR SYSTEM REQUIREMENTS/CAPABILITIES
- O TELEOPERATOR VS SUPERVISED AUTONOMOUS VS AUTONOMOUS OPERATIONS

<b>IN-SPACE SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>MAINTENANCE, REPAIR, AND FIRE SAFETY</b>
-----------------------------	--	---

# **SPACECRAFT FIRE SAFETY FOR ADVANCED SPACECRAFT**

**WALLACE W. YOUNGBLOOD  
WYLE LABORATORIES  
HUNTSVILLE, ALABAMA**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

**BACKGROUND**

- EARLY SPACECRAFT (MERCURY THROUGH APOLLO) UTILIZED A PURE OXYGEN ATMOSPHERE AT 5 PSIA
- SKYLAB UTILIZED AN ATMOSPHERE OF 65% OXYGEN, 35% NITROGEN AT 5.2 PSIA
- STS SHUTTLE & SPACELAB ADOPTED A SEA LEVEL AIR ATMOSPHERE
- FIRE DETECTORS (UV SENSORS) FIRST USED ON SKYLAB
- A PORTABLE FOAM FIRE EXTINGUISHER WAS PROVIDED ON THE APOLLO CSM
- FIXED AND PORTABLE HALON 1301 EXTINGUISHANT SYSTEMS ADOPTED FOR STS SHUTTLE
- DESIGN IS NOT FIRM FOR SPACE STATION
- ALL ASPECTS OF SPACECRAFT FIRE SAFETY MUST BE REVISITED:
  - MATERIAL SELECTION/CONFIGURATIONS
  - MATERIAL FLAMMABILITY/FLAME SPREAD
  - FIRE DETECTION/SUPPRESSION
  - HUMAN EFFECTS
  - ATMOSPHERES (NOMINAL/OFF-NOMINAL)

**TECHNOLOGY NEEDS**

**DATA BASE NEEDS FOR LOW GRAVITY IGNITION/FLAME SPREAD:**

- CRITICAL HEAT FLUX REQUIRED FOR IGNITION
- EFFECT OF RADIATION ENVIRONMENT
- FLAME SPREAD RATE AND EXTINCTION LIMITS
- FLAME CHARACTERISTICS: FLAME SHAPE, TEMPERATURE AND COLOR; RADIANT ENERGY; SOOT GENERATION

**UPGRADED MATERIAL FLAMMABILITY STANDARDS:**

- EXPANDED DATA BASE NEEDED FOR MATERIAL IGNITION AND FLAME SPREAD IN LOW GRAVITY
- STANDARDS NEEDED FOR CONFIGURATION MODELING
- DEVELOPMENT OF CORRELATIONS FOR LOW GRAVITY FLAMMABILITY
- UNIFORM FLAMMABILITY TESTS FOR NASA, ESA, NASD...

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

**TECHNOLOGY NEEDS**

**FIRE DETECTION DEVICE NEEDS:**

- FIRE DETECTION IS REQUIRED AT EARLIEST STAGE OF EVENT
- RAPID RESPONSE OVERHEAT AND INCIPIENT CONDITION DETECTORS
- LOW-GRAVITY DATA BASE NEEDS:
  - FLAME CHARACTERISTICS
  - SMOKE PARTICLE SIZE AND SIZE DISTRIBUTION
  - DETECTABLE AEROSOLS DUE TO OVERHEAT
- MEANS FOR MINIMIZATION OF FALSE ALARMS:
  - EXPERT SYSTEMS REQUIRED
  - SPECIAL SYSTEMS FOR CREW ALERTING
  - ARTIFICIAL FIRE SIGNATURE GENERATORS

**FIRE EXTINGUISHANTS AND SYSTEMS:**

- MUST BE COMPATIBLE WITH SPACECRAFT SYSTEMS
- MUST BE EFFECTIVE ON ALL FIRE SCENARIOS INCLUDING HYPERBARIC REGIONS
- DATA BASE REQUIRED FOR EXTINGUISHANT USE:
  - SEVERITY OF TOXIC PRODUCTS RESULTING FROM VARIOUS FIRE INTERACTION SCENARIOS
  - EFFECTIVENESS OF EXTINGUISHANTS VERSUS FLAME TEMPERATURE AND OXYGEN CONCENTRATION

**IN-SPACE  
SYSTEMS**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**MAINTENANCE,  
REPAIR, AND FIRE  
SAFETY**

**IN-SPACE EXPERIMENTATION NEEDS**

**LOW-GRAVITY IGNITION AND FLAME SPREAD:**

- INVESTIGATE MATERIAL IGNITABILITY
- FOR SELECTED MATERIALS, DETERMINE FLAME SPREAD RATES AND EXTINCTION LIMITS FOR VARIOUS ENVIRONMENTS
- ASSESS POTENTIAL HAZARD FOR SPONTANEOUS COMBUSTION OF PARTICLE CLOUDS
- ASSESS FIRE HAZARDS ASSOCIATED WITH FLAMMABLE LIQUID SPILLS

**FIRE DETECTION IN LOW GRAVITY:**

- DEVELOP A DATA BASE OF FIRE SIGNATURES IN LOW GRAVITY:
  - INVESTIGATE FLAME CHARACTERISTICS
  - EVALUATE LOW-GRAVITY EFFECTS ON SMOKE PRODUCTION
- TEST NEW DETECTORS IN LOW-GRAVITY USING REAL AND ARTIFICIAL FIRE SIGNATURES

IN-SPACE  
SYSTEMS

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988

MAINTENANCE,  
REPAIR, AND FIRE  
SAFETY

IN-SPACE EXPERIMENTATION NEEDS

FIRE EXTINGUISHMENT:

- INVESTIGATE EFFECTIVENESS IN LOW-GRAVITY
- ASSESS EFFECTIVENESS/HAZARD WHEN USED IN HYPERBARIC REGIONS
- SAFE FOR CREW AND COMPATIBLE WITH SYSTEMS?
- ESTABLISH DATA BASE FOR FIRE/EXTINGUISHANT INTERACTION
- MAP EXTINGUISHANT EFFECTIVENESS VERSUS FLAME TEMPERATURE
- EVALUATE EFFECTIVENESS ON SMOLDERING COMBUSTION

POST-FIRE CLEANUP:

- DEVELOP MEANS FOR EFFECTIVE PICK UP OF SMOKE PARTICLES AND AEROSOLS REMAINING AFTER AN EVENT
- EVALUATE EFFECTS OF COMBUSTION/EXTINGUISHANT PRODUCTS ON ELECTRONIC GEAR

FIRE SAFETY EXPERIMENT CONCEPTS:

- EXPERIMENTS GENERALLY NEED TO BE COMPACT/MULTI-PURPOSE
- ATTEMPT TO MAXIMIZE DATA OBTAINED
- PLAN TO ATTEND NASA LEWIS SPONSORED WORKSHOP:
  - INTERNATIONAL MICROGRAVITY COMBUSTION WORKSHOP
  - DATE: JANUARY 25 & 26, 1989

<p><b>IN-SPACE SYSTEMS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>MAINTENANCE, REPAIR, AND FIRE SAFETY</b></p>
------------------------------------	---	--

**MAINTENANCE, SERVICING & REPAIR  
IN  
SPACE**

**BOB DELLACAMERA**  
TELEPHONE: (714)896-5224  
**MCDONNELL DOUGLAS**  
**SPACE SYSTEMS COMPANY**

<p><b>IN-SPACE SYSTEMS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>MAINTENANCE, REPAIR, AND FIRE SAFETY</b></p>
--------------------------------	---	--

## **INTRODUCTION/BACKGROUND**

- **MAINTENANCE, SERVICING & REPAIR HAS BEEN DONE IN SPACE**
- **MANNED MAINTENANCE & REPAIR SO FAR**
- **EXTREMELY PLANNED OR UNPLANNED**
- **NOT NORMALLY BASELINED**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

## MISSION APPLICATIONS

- ALL MISSIONS CAN BENEFIT FROM INCLUDING MAINTENANCE  
SERVICING AND REPAIR PROVISIONS
  - SOFTWARE
  - HARDWARE
  - REPLENISHMENT
  
- EVA IS NOT THE ONLY THE ONLY METHOD OF MAINTENANCE,  
SERVICING & REPAIR
  
- MAINTENANCE, SERVICING & REPAIR REQUIRES A SUPPORT  
INFRASTRUCTURE FOR FULL IMPLEMENTATION

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

## TECHNOLOGY NEEDS

### DEVELOP TECHNOLOGIES FOR SUPPORTING INFRASTRUCTURE

- ROBOTICS
  - COGNITIVE CAPABILITIES
  - SERVICE ROBOTS
- COMPOSITE REPAIR
  - TRUSS
  - PRESSURE SHELLS
- TECHNICAL DATA
  - FORMAT/ACCESS
  - PRESENTATION/STORAGE
  - UPDATES
- EVA SUITS
  - SPACE BASING
  - MORE HARDNESS
  - LESS MAINTENANCE
- CONSUMMABLES
  - CRYO PUMPING
  - CRYO STORAGE
    - \* INSULATION
    - \* RELIQUIFICATION
  - TOXIC FLUIDS
  - DECONTAMINATE THE REFUELER

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

## IN-SPACE EXPERIMENT NEEDS/VOIDS

- INSTITUTIONALIZE MAINTENANCE, SERVICING & REPAIR BY DEMONSTRATION
  - MANNED
  - ROBOTIC
  - COMBINATION
  
- MAINTAIN,SERVICE & REPAIR AT HIGH INCLINATION AND POLAR ORBITS
  
- DEMONSTRATE MAINTENANCE, SERVICING & REPAIR HARDWARE FOR:
  - REFUELING
  - SELF-CONTROLLED ROBOTS
  - MANNED POLAR OPERATIONS

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
------------------	--	--

## IN-SPACE EXPERIMENT RECOMMENDATION

- ALL SPACE SYSTEMS SHOULD DEMONSTRATE MAINTENANCE, SERVICING & REPAIR CONCEPTS AS PART OF DEVELOPING THE BASIC MISSION CONCEPT
- APPLY ROBOTICS TO MAINTENANCE, SERVICING & REPAIR PROBLEMS SOON
- MAINTAIN AND REPAIR A ROBOTIC SERVICER ON-ORBIT
- FLY A PROTOTYPE HARD SUIT AT HIGH INCLINATIONS
- DEVELOP A SMALL-SCALE LONG DURATION REFUELING PILOT PLANT(CRYO,STORABLE)
- REFUEL SPACECRAFT ON-ORBIT

### **7.3 PAYLOAD OPERATIONS**

**This page intentionally blank**

<p><b>IN-SPACE SYSTEMS</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>PAYLOAD OPERATIONS</b></p>
--------------------------------	---	--------------------------------------

**PAYLOAD OPERATIONS  
FROM THE PERSPECTIVE OF  
MANNED SPACEFLIGHT**

**DR. JEFFREY A. HOFFMAN  
ASTRONAUT OFFICE  
NASA-JOHNSON SPACE CENTER  
HOUSTON, TX**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	--------------------

### INTRODUCTION

- HISTORICALLY, THE BUSINESS OF ASTRONAUTS WAS TO GET THEIR SPACECRAFT TO ITS DESTINATION AND BACK AGAIN.
- SINCE SKYLAB, ASTRONAUTS HAVE HAD TIME IN ORBIT TO CARRY OUT EXTENSIVE PAYLOAD-ORIENTED OPERATIONS.
- SPACE STATION WILL CONTINUE THIS TRADITION.
- SPACE SHUTTLE FLIGHTS CARRY SUFFICIENT NUMBER OF CREW MEMBERS TO ALLOW SOME ASTRONAUTS TO BE DEVOTED TO PAYLOAD ACTIVITIES.
  - EVA
  - RMS
  - DEPLOYMENTS
  - SCIENTIFIC INVESTIGATIONS

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	-----------------------

## MISSION APPLICATIONS

### HIGH GROUND

- VIEW DOWN
- METEOROLOGY
- EARTH RESOURCES
- OCEANOGRAPHY
- ETC.
- SYNERGISM BETWEEN SATELLITES AND CREW PHOTOGRAPHY
- SPACE STATION LIMITED BY 28° ORBIT
- VIEW UP - IR, UV, X, GAMMA RAY ASTRONOMY
- BEST SUITED FOR UNMANNED VEHICLES
- FOR FUTURE PAYLOAD OPERATIONS, NEED HONEST TRADE STUDY BETWEEN COST OF MAINTAINABILITY AND COST OF FAILURES
- VIEW AROUND - PLASMA, AURORAL AND IONOSPHERIC STUDIES
- COMBINE GEO, LEO AND GROUND STUDIES
- TETHERS, UP AND DOWN, OFFER NEW METHODS OF STUDY

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	-----------------------

## TECHNOLOGY NEEDS

### HIGH GROUND

- 1) ABILITY TO DEAL WITH EVER-INCREASING AMOUNTS OF DATA
- 2) TEST TETHER TECHNOLOGY
- 3) DEVELOP SATELLITE REPAIR, REFURBISHMENT AND REFUELING

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	-----------------------

## MISSION APPLICATIONS

### MICROGRAVITY

- HUMAN RESPONSE TO SPACE
  - THE ENVIRONMENT CREATES ITS OWN FIELD OF STUDY
- FUNDAMENTAL RESEARCH
  - FLUID PHYSICS
  - MATERIAL PROPERTIES
  - CRYSTAL GROWTH
  - BOTANY/ZOOLOGY
- APPLICATIONS
  - FIRE RESEARCH
  - EVENTUAL PRODUCTION PROCESSES

OVERWHELMING TECHNOLOGICAL NEED: **ABILITY TO USE SPACE AS A UNIQUE LABORATORY**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	-----------------------

## TECHNOLOGY NEEDS

### USE OF SPACE AS A LABORATORY

- MUST BALANCE UNIQUENESS OF ENVIRONMENT AGAINST OUR ACCUMULATED KNOWLEDGE OF HOW TO OPERATE IN A LAB.
- INTERACTIVE CREW OPERATIONS VS. AUTOMATION
  - USE OF HUMANS IS MOST VALUABLE DURING EARLY STAGES OF INVESTIGATIONS.
  - INCREASED UNDERSTANDING OF  $\mu$ -g PHENOMENA ALLOWS INCREASED USE OF AUTOMATION TO CREATE GREATER EFFICIENCY.
- EFFICIENT USE OF CREW TIME IS UNIQUE TO SPACE ENVIRONMENT
  - SPACE STATION MAY HAVE LESS CREW TIME THAN SHUTTLE
  - OBSERVE EXPERIMENTS IN PROGRESS
  - CHANGE PROTOCOL WHERE NECESSARY
  - REPAIR OR ALTER HARDWARE
- CLOSE UNION OF SCIENTIFIC ACTIVITIES ON GROUND AND ORBIT IS ESSENTIAL

—→ TELESCIENCE

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	--------------------

## TECHNOLOGY NEEDS

### TELESCIENCE

- HIGH DENSITY DATA AND COMMAND LINKS FOR GROUND OPERATIONS
  - VARIABLE FORMAT TV: RESOLUTION VS. SPEED VS. COLOR.
- EXPERIMENT DESIGN TO ALLOW EFFICIENT USE OF ONBOARD CREW
  - VISIBILITY
  - ACCESSIBILITY
- MAXIMIZE ABILITY TO REPEAT EXPERIMENTS AND ALTER VARIABLES.
- EXPERT SYSTEMS TO ASSIST CREW AND GROUND.
- FOR MATERIALS SCIENCE, SAMPLE RETURN CAPABILITY (SPACEMAIL).

<b>IN-SPACE SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>PAYLOAD OPERATIONS</b>
-------------------------	--	-------------------------------

### **SUMMARY**

- **BALANCE BETWEEN SCIENTIFIC RESEARCH AND SPACEFLIGHT OPERATIONS**
- **EARLY INVOLVEMENT OF CREW CAN ENHANCE EXPERIMENTS**

<p>IN-SPACE SYSTEMS</p>	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 8-9, 1988</p>	<p>PAYLOAD OPERATIONS</p>
-----------------------------	--	-------------------------------

**ORBIT ASSEMBLY NODE**

**TOM STYCZYNSKI  
LEE R. LUNSFORD**

**LOCKHEED MISSILES & SPACE CO., INC.  
SUNNYVALE, CA.**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	--------------------

## INTRODUCTION / BACKGROUND

**OBJECTIVE:** ASSEMBLY, VERIFICATION, SERVICING, REPAIR & CORRECTION, AND REFURBISHMENT.

**MISSIONS:**

- \* PLANETARY EXPLORATION MISSIONS - UNMANNED: PRECURSOR MISSION TO PLANETS AND MOONS WITHIN THE SOLAR SYSTEM.
- \* PLANETARY EXPLORATION MISSIONS - MANNED: LARGE TRANSIT VEHICLES, REFUELING & REFURBISHMENT STATIONS, etc.
- \* MISSION TO PLANET EARTH - ASSEMBLY AND TRANSFER OF VEHICLES TO SYN-EQ.
- \* LARGE SOLAR ELECTRIC ENERGY SYSTEMS.
- \* SPACE BASED MANUFACTURING & SERVICE FACILITIES.

## TECHNOLOGY NEEDS ORBIT ASSEMBLY AREA CONCEPT

### CRITICAL FUNCTIONS

- \* PRECISION SCHEDULING.
- \* SELF-CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
- \* AUTONOMOUS STABILIZATION FOR ASSEMBLY OF ADDITIONS COMPONENTS, ETC. - docking, berthing, positioning, orientation.
- \* PRECISION PLACEMENT: MICRO NAVIGATION, PRECISION ALIGNMENT AND ORIENTATION
- \* VISION CONTROL - focus, alignment, field of view, and shielding from the sun.
- \* AUTONOMOUS ASSEMBLY (ROBOT ASSEMBLY), TELE-ROBOTIC ASSEMBLY, & EVA ASSEMBLY.
- \* FUELING OR TOPPING OFF - PROPELLANT DEPOT OR TANKER
- \* PROTECTION OR HARDENING OF ASSEMBLY FROM SPACE DERRIS AND SOLAR ILLUMINATION.
- \* VERIFICATION OF PROPER ASSEMBLY - PNEUMATIC, STRUCTURAL, etc.

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1986	PAYLOAD OPERATIONS
------------------	--	--------------------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

### AUTONOMOUS CHECK-OUT :

SELF CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS WITH CAPABILITY FOR AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT. CONCEPT SHOULD INCLUDE ACTIVATION OF THE AUTONOMOUS SYSTEM AT SHIPMENT FROM THE FACTORY. NETWORKING AND SOFTWARE SHOULD PROVIDE CONTINUOUS READOUT (i.e., 10 TIMES PER SECOND).

### CRITICAL TECHNOLOGIES: - SENSORS, NETWORKING, & SOFTWARE:

- \* SENSORS REQUIREMENTS INCLUDE: ELECTRICAL, ELECTRONIC, STRUCTURES, MECHANICAL (i.e., LOCKED OR UNLOCKED), POSITION, LEAKAGE, PRESSURE, EXPENDABLES AVAILABLE (i.e., ZERO "G" MEASURE OF REMAINING PROPELLANTS), TEMPERATURE, VIBRATION & SOUND/PRESSURE LEVELS, STRESS & STRAIN, AND SEQUENCE OF EVENTS.
- \* NETWORKING: POWER, DATA AND COMMAND NETWORKING WILL BE REQUIRED WITH CAPABILITY OF AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT UPON ASSEMBLY - BOTH HARDWARE AND SOFTWARE PROBLEM.
- \* SOFTWARE: COMMAND AND CONTROL, SENSOR DATA PROCESS & EVALUATION, REPORTING CRITERIA (i.e., RECORD EVENT, REPORT EVENT, OR SOUND ALARM).

IN-SPACE  
SYSTEMS

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1966

PAYLOAD  
OPERATIONS

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

### AUTONOMOUS PLACEMENT:

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR MATING, PRECISION PLACEMENT OR INSERTION AND ASSEMBLY.

### CRITICAL TECHNOLOGIES:

- \* VISION: ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, EVALUATION AND CONTROL
- \* AUTONOMOUS STABILIZATION FOR ASSEMBLY: STABILIZATION DURING DOCKING, BERTHING, POSITIONING, AND ORIENTATION FOR ASSEMBLY.
- \* MICRO-NAVIGATION: TO SUPPORT PRECISION PLACEMENT, INSERTION, OR LOCATION OF DEFECTIVE PART.
- \* PRECISION ATTITUDE DETERMINATION AND CONTROL: TO SUPPORT LOCATION AND IDENTIFICATION, PLACEMENT AND ORIENTATION.
- \* VERIFICATION: VERIFICATION OF ASSEMBLY TO INCLUDE MECHANICAL, ELECTRICAL, ELECTRONIC, PNEUMATIC, HYDRAULIC, STRUCTURAL, POSITION LOCATION & ORIENTATION.
- \* END EFFECTORS: FOR GRASPING, HOLDING, MANIPULATING, POSITIONING, ORIENTING, AND INSERTING.

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
------------------	--	--------------------

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

### AUTONOMOUS REPLACEMENT OF PARTS:

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR ATTACHMENT, OPENING OF COVER OR PANELING, LOCATION, GRASPING & REMOVAL OF DEFECTIVE PART, FOLLOWED BY INSERTION OF REPLACEMENT PART, CLOSING OF COVER OR PANEL, AND VERIFICATION OF PERFORMANCE. REPEAT FOR ELECTRICAL/ELECTRONIC PARTS, PNEUMATIC PARTS, HYDRAULIC (i.e., PROPELLANT) PARTS, AND MECHANICAL COMPONENTS.

### CRITICAL TECHNOLOGIES:

- \* DEVELOPMENT OF COMPATIBLE ASSEMBLY COMPONENTS AND ROBOT CONCEPTS.
- \* HIGHER LEVEL OF AUTOMATION, FORCE FEEDBACK END EFFECTORS, ETC.
- \* SELF-LOCATION, ORIENTATION, MICRO NAVIGATION.
- \* VISION SYSTEM CAPABLE OF SENSING PLACEMENT OR INSERTION ACTIVITY IN A CLOSED LOOP.
- \* POSITIONING AND ORIENTATION.
- \* VERIFICATION OF PERFORMANCE - i.e., UNLOCKING, & LOCKING.

SUMMARY / RECOMMENDATIONS

- \* SYSTEM TRADES:
  - ASSEMBLY FACILITY VS. ASSEMBLY AREA WITH ENHANCED SPACE STATION
  - ORBITAL PROPELLANT DEPOT VS. TRANSPORT WITH PROPELLANT & TOP OFF FROM TANKER
- \* CRITICAL TECHNOLOGIES:
  - NETWORKING, SOFTWARE, & SENSORS FOR AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
  - VISION CONTROL - CLOSED LOOP ACQ., RECOGNITION, LOCATION, & EVALUATION.
  - PRECISION PLACEMENT - MICRO NAVIGATION, PRECISION ATTITUDE CONTROL, AUTONOMOUS STABILIZATION TO SUPPORT PLACEMENT.
  - VERIFICATION OF ASSEMBLY FUNCTIONS.
- \* IN-SPACE EXPERIMENTATION
  - SELF CONTAINED CHECK-OUT AND HEALTH STATUS WITH CAPABILITY OF INTEGRATION INTO THE NEXT HIGHER UNIT.
  - AUTONOMOUS PRECISION PLACEMENT AND ASSEMBLY
  - AUTONOMOUS REPLACEMENT OF COMPONENTS & SUB-ASSEMBLIES

**This page intentionally blank**

**IN-SPACE SYSTEMS:  
SPACE CONSTRUCTION  
AND  
PAYLOAD OPERATIONS**

**George W. Morgenthaler  
Aerospace Engineering Sciences Department and  
Center for Space Construction  
University of Colorado  
Boulder, Colorado**

## INTRODUCTION/BACKGROUND

- Humanity is entering 2nd ERA of the Space Age:
  - 1st Era:
    - Space flight realization, 1957-1987
  - 2nd Era:
    - Space exploration and base activation, 1987-2027
  - 3rd Era:
    - Space colonization and utilization, 2027--
- Parallel to man's Arctic and Antarctic activities:
  - Visit the Poles; Establish scientific bases; Alaskan pipeline;  
Canadian Arctic Center
- Long-term Space Mission Planning--many destinations, many decades:
  - National Commission on Space Report, 1986
  - Dr. Sally Ride's Report, 1987
  - NASA's Pathfinder Program
  - President Reagan's National Space Policy, 1988
- Consensus: Explore and utilize the Solar System; develop space commercially.
- Space Program Philosophy:
  - Building Block Approach;
  - International participation;
  - Mission model optimization, not single mission optimization only.

### MISSION APPLICATIONS

- Mission Model Identified:
  - Large unmanned laboratories, antenna arrays, telescopes, etc.
  - Mission to Planet Earth (Remote Sensing)
  - Space Stations and Platforms
  - On-orbit Assembly of Manned Interplanetary Spacecraft
  - Lunar Base
  - Mars Base
- Demands for increased scientific data operations
- Space construction instead of delivering entire space structure at one launch
- Astronaut work limitations
- Astronaut environmental protection required

TECHNOLOGY NEEDS

- Orbital logistics needs - Determine optimum mix of launch vehicles:  
large vs small, unmanned vs man-rated
- Telecommunication needs:
  - Construction phase telecommunication
  - improve telecommunication for operations and experiment telescience (OASIS)
- In-space Construction and Operation needs:
  - Type and intelligence (autonomy) of robots?
  - Bionic devices for astronauts?
  - Optimum astronaut/robot mix?
- Space Environment protection needs:
  - meteoroid/debris
  - radiation
  - thermal
  - pressure

SPACE TELECOMMUNICATIONS EXPERIMENTS FOR CONSTRUCTION/OPERATIONS

- The time-delay problem
- The security blanket problem
- The Steady-State Telecommunications System design problem
- The emergency support problem: equipment failure/medical crisis--  
AI implications
- The Tower of Babel Problem

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- Telecommunications System
  - . Develop and test Telecommunications System for Space Construction Phase
  - . Experiment with time-delay command-control
- OASIS system development and test (for operating space experiments)
- ET Space Experiments:
  - . Lower-Thermosphere Density Experiment
  - . Space Meteoroid/Debris monitoring experiment
  - . Fluid vibration generation experiment
  - . Space thruster experiment
  - . Explosive fastening experiment
- Macro-Planning Model Development

### SUMMARY AND RECOMMENDATIONS

- Plans for Space Construction Needs as well as Space Operations Needs.
- Develop standardized Construction-Phase and Steady-State Telecommunications for transmission of voice, video, data, computer, teleoperators commands in presence of time delays.
- Develop and Test a 1990's, user-friendly, teleoperator/telescience work-station, e.g., OASIS.
- Utilize the ET as well as ELV's and Shuttle Orbiter to provide knowledge of Space Environment.
- Develop a Macro-Planning Model for optimizing planning of a multi-year, multi-destination Space Program Mission Model.

**This page intentionally blank**

**IN-SPACE SYSTEMS  
CRITICAL TECHNOLOGY REQUIREMENTS**

**JON B. HAUSSLER  
MARSHALL SPACE FLIGHT CENTER**

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	
--	--	--

**IN-SPACE SYSTEMS THEME**

**THEME ELEMENTS**

- MATERIALS PROCESSING
- MAINTENANCE, REPAIR, AND FIRE SAFETY
- PAYLOAD OPERATIONS

	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	
--	---	--

**MATERIALS PROCESSING**

**AN ALL ENCOMPASSING DEFINITION OF MATERIALS  
IS USED IN THIS ELEMENT.**

	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP</b> <b>DECEMBER 6-9, 1988</b>	
--	--	--

## **MATERIALS PROCESSING**

**PRIORITY:**

- 1. UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT**
- 2. DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES**
- 2. CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT**
- 3. DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS**
- 4. DEMONSTRATION OF AUTOMATION AND ROBOTICS APPLICATIONS TO MATERIAL PROCESSING SYSTEMS**

**CONSENSUS CONCERN:**

**WASTE PRODUCTS FROM MATERIAL PROCESSING**

## EXPLANATION OF MATERIALS PROCESSING NEEDS

- UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT, SPACE ENVIRONMENT INCLUDES MICRO-G AND / OR ULTRA HIGH VACUUM. WE ARE ESPECIALLY CONCERNED WITH UNDERSTANDING A RANGE OF DYNAMIC PROCESSES IN MICRO-G, INCLUDING (BUT NOT LIMITED TO):
  - THERMOCAPILLARY FLOW
  - GAS/LIQUID/SOLID PHASE SEPARATION AND INTERFACE BEHAVIOR
  - DIFFUSION AND PERMEABILITY
  - WETTING
- DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES, THESE SAMPLE ANALYSIS TECHNIQUES SHOULD FOCUS ON REDUCING THE SIZE, MASS AND/OR HAZARDS OF CONVENTIONAL TECHNIQUES SUCH AS SCANNING ELECTRON MICROSCOPE, X-RAY FLUORESCENCE, WET CHEMICAL PROCESSING AND THE LIKE.
- CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT, IN PARTICULAR THERE IS A CRITICAL NEED FOR IN SITU MEASUREMENT OF G LEVELS FROM  $10^5$  G TO  $10^{-8}$  G AT FREQUENCIES  $< 1$  Hz ; PASSIVE AND ACTIVE VIBRATION ISOLATION AT LOW FREQUENCIES, AND THE REALISTIC ASSESSMENT OF G-LEVEL REQUIREMENTS FOR BIOLOGICAL AND PHYSICAL EXPERIMENTS.
- DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS, WE NEED TO DEVELOP AND DEMONSTRATE ENABLING TECHNOLOGIES WHICH ALLOW FOR REAL-TIME MONITORING, NON-CONTACT TEMPERATURE MEASUREMENT, MINATURIZATION OF SENSORS AND IMPROVED IMAGE ANALYSIS.
- DEMONSTRATION OF AUTOMATION AND ROBOTIC APPLICATIONS TO MATERIAL PROCESSING SYSTEMS, THERE IS A NEED FOR DEVELOPMENT OF EXPERT SYSTEMS AND REACTIONLESS ROBOTS FOR MATERIALS PROCESSING.

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	
--	--	--

## **MAINTENANCE, REPAIR AND FIRE SAFETY**

**PRIORITY:**

- 1. DEMONSTRATION AND VALIDATION OF CAPABILITY TO REPAIR UNEXPECTED EVENTS**
- 1. INVESTIGATION OF LOW-G IGNITION, FLAMMABILITY/FLAME SPREAD AND FLAME CHARACTERISTICS**
- 2. DEMONSTRATION AND VALIDATION OF FLUID REPLENISHMENT TECHNIQUES**
- 2. UNDERSTAND BEHAVIOR OF FLAME EXTINGUISHANTS IN SPACE ENVIRONMENT**
- 3. DEMONSTRATE ROBOTIC MAINTENANCE AND REPAIR CAPABILITY**

**CONSENSUS INTERESTING IDEA:  
SIMULATED ACCIDENT SCENARIOS**

	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	
--	--	--

## **PAYLOAD OPERATIONS**

**PRIORITY:**

- 1. DEMONSTRATION AND VALIDATION OF TELESCIENCE TECHNIQUES**
- 2. DEMONSTRATION OF AUTONOMOUS CHECKOUT,  
PLACEMENT AND SPACE CONSTRUCTION**

**CONSENSUS CONCERNS:**

- RAPID SAMPLE RETURN**
- ORBITAL DEBRIS**

## 8. HUMANS IN SPACE

**HUMANS IN SPACE  
BACKGROUND AND OBJECTIVES**

**REMUS BRETOI  
AMES RESEARCH CENTER**

NASA Ames Research Center

## HUMANS IN SPACE

THEME OVERVIEW

THEME SESSION OBJECTIVES

DESCRIPTION OF THEME & THEME ELEMENTS

BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT

PROGRESS SINCE 1985 WORKSHOP

THEME SESSION AGENDA

PRIORITIZATION CRITERIA

SUMMARY

HUMANS IN SPACE

THEME SESSION OBJECTIVES

PURPOSE

- o Identify & Prioritize In-Space Technologies for Humans In Space Which:
  - Are Critical for Our Future Space Programs, & Need Development & In-Space Validation.
- o Obtain Aerospace Community Comments & Suggestions on OAST IN-STEP Plans

PRODUCT

Aerospace Community Recommended Priority Listing of Critical Space Technology Needs & Associated Space Flight Experiments

**NASA Ames Research Center**

**HUMANS IN SPACE**

**DESCRIPTION OF THEME & THEME ELEMENTS**

**EVA/SUIT**

**HUMAN PERFORMANCE**

**CLOSED-LOOP LIFE SUPPORT SYSTEMS**

HUMANS IN SPACE

EVA/SUIT

SUITS & EQUIPMENT

Pressure Suit Technology  
Glove Technology  
End-Effector Technology  
Mobility Aids  
Tools  
Displays & Controls  
Interfaces

PORTABLE LIFE SUPPORT SYSTEMS

Thermal Control  
Atmosphere Control  
Automated Control Technology  
Display Technology  
Regeneration Equipment

NASA Ames Research Center

**HUMANS IN SPACE**

**EVA/SUIT**  
(Continued)

**LOGISTICS & SUPPORT**

**Diagnostics**  
**Displays & Controls**  
**Maintenance & Repair**  
**Inventory Management & Supply**  
**Information Management**

HUMANS IN SPACE

HUMAN PERFORMANCE

CREW & ENVIRONMENTAL FACTORS

Organization and Management  
Crew Coordination  
Environmental & Mission Task  
Training and Intervention

HUMAN-MACHINE INTERACTION

Crew Support and Enhancement  
Human-Automation-Robotics (HAR)

HUMANS IN SPACE

HUMAN PERFORMANCE  
(Continued)

ARTIFICIAL GRAVITY & ADV. COUNTERMEASURES

ARTIFICIAL GRAVITY

Rotation Rate  
Intermittent G vs Continuous Exposure  
Partial G and G Threshold  
Structural Facility Impact

ADVANCED COUNTERMEASURES

Electromyostimulation  
Pharmacological Tests  
Autogenic Feedback  
Pre-Adaptation Training

NASA Ames Research Center

HUMANS IN SPACE

CLOSED-LOOP LIFE SUPPORT SYSTEMS

PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT

Water Reclamation  
Waste Management  
Thermal Control  
Monitoring & Control Instrumentation  
Air Revitalization

HUMANS IN SPACE  
THEME BACKGROUND  
TECHNOLOGY DEVELOPMENT

HUMANS IN SPACE was not a theme in the 1985 Workshop.  
It is a new addition to the IN-STEP / Outreach Program.

282

RELATED STUDY EFFORTS resulting from the 1985  
Workshop were:

Spatial Perception Auditory Referencing  
Microbiology Monitor  
Closed-Loop Nutrient Solution Delivery System  
Water Electrolysis Operation

HUMANS IN SPACE

AGENDA

Wednesday December 7th

CRITICAL SPACE TECHNOLOGY & IN-SPACE  
EXPERIMENTS NEEDS

(PRESENTATIONS and DISCUSSIONS)

EVA/SUIT PRESENTATIONS

Bruce W. Webbon / Bernadette Squire (NASA-ARC)  
H. Thomas Fisher (Lockheed Corporation)  
David L. Akin (MIT, Aeronautics and Astronautics Dept)

EVA/SUIT OPEN DISCUSSION

Questions & Answers With Speakers  
Identification of Additional Technologies/Experiments

NASA Ames Research Center

HUMANS IN SPACE

## AGENDA

WEDNESDAY DECEMBER 7th

### HUMAN PERFORMANCE PRESENTATIONS

Barbara Kanki (NASA-Ames Research Center)

Lawrence G. Lemke (NASA-HQ / Office of Exploration)

Wm. Russell Ferrell (University of Arizona, Tucson)

### HUMAN PERFORMANCE OPEN DISCUSSION

Questions & Answers With Speakers

Identification of Additional Technologies/Experiments

HUMANS IN SPACE

AGENDA

WEDNESDAY DECEMBER 7th

CLOSED-LOOP LIFE SUPPORT SYSTEMS PRESENTATIONS

Robert D. MacElroy (NASA - Ames Research Center)

Richard L. Olson/Thomas J. Slavin (Boeing Aerospace)

Marvin Luttgies (University of Colorado, Boulder)

CLOSED-LOOP LIFE SUPPORT SYSTEMS OPEN

Questions & Answers With Speakers

Identification of Additional Technologies/Experiments

NASA Ames Research Center

HUMANS IN SPACE

AGENDA

THURSDAY, DECEMBER 8th

PRIORITIZE CRITICAL TECHNOLOGIES (AUDIENCE)  
COMBINE & PRIORITIZE THEME TECHNOLOGIES

FRIDAY DECEMBER 9th

THEME LEADER PRESENTATIONS TO GENERAL SESSION  
WORKSHOP WRAP-UP

PRIORITIZATION CRITERIA\*

1. CRITICAL ENABLING TECHNOLOGIES  
Technologies critical for future space missions
2. COST REDUCTION TECHNOLOGIES  
Technologies which can decrease costs or complexity (e.g., development, opns, life-cycle)
3. BROAD APPLICATION TECHNOLOGIES  
Technologies which can improve or enhance a variety of space missions
4. REQUIRE IN-SPACE VALIDATION  
Technologies which require the space environment or micro-gravity for validation or experimentation

\* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1 IS HIGHEST)

**8.1 EVA/SUIT**

Humans In Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	EVA/Suit
--------------------	--	----------

**EVA TECHNOLOGY**

**DR. BRUCE W. WEBBON, Ph.D.  
BERNADETTE SQUIRE**

**NASA-Ames Research Center  
Crew Research and Space Human Factors Branch**

## INTRODUCTION/BACKGROUND

### CURRENT EVA SYSTEM LIMITATIONS

- Low working pressures (productivity impacts)
- Limited mobility
- Marginal crew comfort
- Marginal glove acceptability
- Large consumable mass
- Maintenance and servicing
- Protection from environmental hazards
- Bends risk
- High life-cycle costs
- Growth potential
- Working period limitations
- Sizing repeatability

Humans In Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	EVA/Suit
-----------------	--	----------

## TECHNOLOGY NEEDS

### SYSTEMS STUDIES

- **MISSION REQUIREMENTS DEFINITION**  
Environmental, Task, Design Reference Mission
- **HUMAN REQUIREMENTS DEFINITION**  
Human Factors, Physiological, Medical
- **EVA WORK SYSTEMS INTEGRATION**  
Modeling, Trade Studies, Interface Definition,  
Logistics, Support, Test Requirements

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	EVA/Suit
-----------------	--	----------

## TECHNOLOGY NEEDS

### PORTABLE LIFE SUPPORT SYSTEM (PLSS)

- **THERMAL CONTROL SYSTEMS**  
Heat Storage, Acquisition, Transport, Rejection
- **ATMOSPHERE CONTROL**  
O2 Supply, CO2 Control, Trace Contaminant Control, Humidity Control
- **MONITORING & CONTROL**  
Automated Control, Display Technology
- **SYSTEM INTEGRATION**  
Support Equipment and Interfaces

## TECHNOLOGY NEEDS

### EVA SUITS & EQUIPMENT

- **PRESSURE SUIT TECHNOLOGY**  
Materials, Structures, Components, Mobility  
Elements
- **GLOVES & END-EFFECTORS**
- **EVA ANCILLARY EQUIPMENT**  
Mobility Aids, Tools, Displays & Controls,  
Work System Interfaces
- **SYSTEM INTEGRATION & TEST**  
Logistics & Support

Humans In Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	EVA/Suit
-----------------	--	----------

## SUMMARY / RECOMMENDATIONS

### Determine (empirically):

EVA Physiological/Metabolic Parameters  
Thermal Environment Parameters

### Characterize:

EVA Biomechanics in Reduced-g  
g-Sensitivity of Phase Change Processes

### Demonstrate:

Radiation Protection (Mars Transit)  
Radiator/Refrigeration System  
Electrochemical Regeneration of CO<sub>2</sub>  
Voice Technology for Control Applications  
Countermeasures for Bearing Blocking, Cold Welding  
Advanced Pressure Suit Technology in Zero-g  
High Pressure Gloves  
End-Effector Use in EVA Tasks

# **IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP**

**DEC. 6-9, 1988**

**ATLANTA, GEORGIA**

**SPONSORED BY NASA-OAST**

***HUMANS IN SPACE  
(EXTRA-VEHICULAR ACTIVITY/SUIT)***

**Presentation By**

**H. T. Fisher**

**Space Station Program**

**Astronautics Division**

**Lockheed Missiles & Space Co.**

## INTRODUCTION/BACKGROUND

1. THERE IS NO DOUBT EVA IS A CRITICAL TECHNOLOGY TO NASA  
CURRENT SPACE ACTIVITIES AND FUTURE MISSION PLANS
2. EVA HAS UNIVERSAL APPLICABILITY & MULTI-MISSION UTILITY
3. PRESENT EVA TECHNOLOGY IS EVOLVING TO ENHANCE:
  - CREW PRODUCTIVITY
  - RISK REDUCTION
  - MISSION FLEXIBILITY
  - ALTERNATIVE PATHS
4. NASA & DoD MAY SHARE COMMON NEEDS - E.G., CANDIDATE DoD  
MILITARY MANNED SPACE OPERATIONS
5. CERTAIN EVA TECHNOLOGIES ARE WELL UNDERWAY WHILE OTHERS  
ARE LAGGING OR ARE NOT BEING WORKED
6. MOST ADVANCED EVA PROGRAM EFFORT IS WITHIN THE NASA  
WITH LITTLE AEROSPACE/COMMERCIAL INDEPENDENT VENTURES
7. LIMITED, BUT IMPORTANT ADVANCED EVA PLANETARY STUDY  
WORK IS JUST BEING INITIATED & MORE IS PLANNED (?) VIA  
PATHFINDER - NASA-JSC/AMES
8. *IT APPEARS PRUDENT TO RE-ASSESS WHERE EVA TECHNOLOGY IS HEADED*

**EVA TECHNOLOGY NEEDS - SELECTED****EVA ENCLOSURE & LIFE SUPPORT**

- EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION
- RAPID CREW 'IN-SITU' SUIT SERVICING
- PROTECTION AGAINST RADIATION HAZARDS
- RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C
- ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF

**EVA SUPPORT EQUIPMENT**

- SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT
- SMALL LT-WT PORTABLE AIRLOCK
- SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EV CREW/EQUIP)
- SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER
- MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- CREW & EQUIP TRANSPORTER & POSITIONING AID
- CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT
- ADVANCED MANEUVERING UNIT
- EMERGENCY SUIT 'LIFE JACKET'
- EMERGENCY EVA SURVIVAL GEAR
- SUIT CONTAMINATION DETECTION & CLEANING UNIT
- DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- ADVANCED POWER TOOLS FOR EVA
- PORTABLE EVA EXPER/SURVEY/SAMPLE KIT
- PORTABLE MULTI-PURPOSE AVIONIC UNIT

**EVA TECHNOLOGY NEEDS - DEVELOPMENT FACTORS**

DEVELOPMENT FACTORS DEVELOPMENT ELEMENTS	MISSION CRITICALITY		NEED DATE	STATUS
	FUNDING LEVEL			
<b>EVA ENCLOSURE &amp; LIFE SUPPORT</b>				
• EXTENDED LSS DURATION	L-M	H	96	R&D(P)
• RAPID CREW 'IN-SITU' SUIT SERVICING	L-M	H	96	R&D(P)
• PROTECTION AGAINST RADIATION HAZARDS	L	M-H	2000	R&D(P)
• RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C	L-M	H	96	R&D
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	L	M-H	95	R&D
<b>EVA SUPPORT EQUIPMENT</b>				
• SMALL LT-WT PORT. HYPERBARIC TREATMENT UNIT	L	H	2000	R&D
• SMALL LT-WT PORTABLE AIRLOCK	L-0	H	2000	STUDY
• SMALL LT-WT PORT. SURFACE TRANSPORTER	0	M-H	2005	STUDY
• SMALL LT-WT PORT. RAD/THERMAL/WIND SHELTER	0	H	2005	STUDY
• MULTI-PURPOSE EVA WORK STA. & MOTOR. FT RESTR.	L	H	95	R&D(P)
• CREW & EQUIP TRANSPORTER & POSITIONING AID	L	H	95	R&D(P)
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	L	H	95	R&D(P)
• ADVANCED MANEUVERING UNIT	0	H	98	STUDY
• EMERGENCY SUIT 'LIFE JACKET'	0	M-H	2005	STUDY
• EMERGENCY EVA SURVIVAL GEAR	0	M-H	2000	STUDY
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	L	H	95	R&D(P)
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOW. UNITS	L-0	L-M	98	STUDY
• ADVANCED POWER TOOLS FOR EVA	L	M	98	R&D(P)
• PORTABLE EVA EXPR/SURVEY/SAMPLE KIT	0	L-M	2005	STUDY
• PORTABLE MULTI-PURPOSE EVA AVIONIC UNIT	0	M	2005	STUDY

KEY: L = LOW    M = MODERATE    H = HIGH    PARTIAL = P

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

DEVELOPMENT FACTORS DEVELOPMENT ELEMENTS	TECHNOLOGY STATUS/VOIDS
<p><b>EVA ENCLOSURE &amp; LIFE SUPPORT</b></p> <ul style="list-style-type: none"> <li>• RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT.</li> <li>• RAPID CREW 'IN-SITU' SUIT SERVICING</li> <li>• EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION</li> <li>• PROTECTION AGAINST RADIATION HAZARDS</li> <li>• ENHANCED AUDIO/HEADS-UP DISPLAY &amp; WRIST CUFF</li> </ul>	<p>TECH IN WORK*</p> <p>TECH IN WORK*</p> <p>TECH IN WORK*</p> <p>TECH IN WORK*</p> <p>TECH IN WORK</p>
<p><b>EVA SUPPORT EQUIPMENT</b></p> <ul style="list-style-type: none"> <li>• CREW &amp; EQUIPMENT RECOVERY/RETRIEVAL UNIT</li> <li>• SUIT CONTAMINATION DETECTION &amp; CLEANING UNIT</li> <li>• ADVANCED MANEUVERING UNIT</li> <li>• MULTI-PURPOSE EVA WORK STA. &amp; MOTORIZED FOOT RESTRAINT</li> <li>• CREW &amp; EQUIP TRANSPORTER &amp; POSITIONING AID</li> <li>• SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT</li> <li>• SMALL LT-WT PORTABLE AIRLOCK</li> <li>• EMERGENCY SUIT 'LIFE JACKET'</li> <li>• EMERGENCY EVA SURVIVAL GEAR</li> <li>• ADVANCED POWER TOOLS FOR EVA</li> <li>• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STORAGE UNITS</li> <li>• SMALL LT-WT PORTABLE SURFACE TRANSPORTER-EVA CREW/EQUIP</li> <li>• SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER</li> <li>• PORTABLE MULTI-PURPOSE AVIONIC UNIT</li> <li>• PORTABLE EVA EXPER/SURVEY/SAMPLE KIT</li> </ul>	<p>SOME NEW TECH NEEDED</p> <p>TECH VOID</p> <p>TECH BUILD-ON/NO ONGO</p> <p>SOME NEW TECH NEEDED</p> <p>BREADBOARD-WK REQD</p> <p>TECH IN WORK*</p> <p>NO ONGO WK+TECH VOID</p> <p>NO ONGO WK+TECH VOID</p> <p>NO ON GOING WORK</p> <p>SOME NEW TECH-WK REQ</p> <p>NO SIG. ON GOING WORK</p> <p>MIN ON GOING WORK</p> <p>TECH VOID</p> <p>NO SIG ON GOING WORK</p> <p>NO ON GOING WORK</p>

\* TECH. IN WORK BUT NOT CONSIDERED FIRM FOR IMMEDIATE ELEMENT RDT&E GO-AHEAD

**IN-SPACE EXPERIMENTATION NEEDS****EVA ENCLOSURE & LIFE SUPPORT**

- DEMONSTRATE RAPID SUIT DON & EV EGRESS IN 14.7 PSIA ENVIRONMENT
- DEMONSTRATE & VALIDATE 'AUTOMATED' & SHORT-TURN-AROUND ON-ORBIT SUIT SERVICING
- DEMONSTRATE EXTENDED SUIT LIFE SUPPORT SYSTEM DURATION & UTILITY BENEFITS
- DEMONSTRATE ALTERNATIVES IN 0-G AGAINST RADIATION HAZARDS
- DEMONSTRATE BASIC &/OR ALTERNATIVES TO AUDIO/DISPLAYED INFORMATION TO THE CREW

**EVA SUPPORT EQUIPMENT**

- DEMONSTRATE & VALIDATE ZERO/LOW-G CREW/EQUIPMENT RECOVERY/RETRIEVAL UNIT
- DEMONSTRATE CONTAMINATION ACQUISITION, VALIDATE SPECIES IDENT., & EVAL. REMOVAL TECHNIQUES
- DEMONSTRATE & VALIDATE ZERO/LOW-G ADVANCED MANEUVERING UNIT
- DEMONSTRATE & EXAMINE RANGE OF MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- DEMONSTRATE, EVAL. UTILITY/RANGE, & ASSESS PWR/UNPOWERED CREW/EQUIP XPORTER/POSITION AID
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE HYPERBARIC TREATMENT UNIT
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE AIRLOCK
- EXAMINE & ASSESS ALTERNATIVES FOR A SUIT 'LIFE JACKET'
- DEMONSTRATE & ASSESS CAPABILITY & UTILITY OF EVA SURVIVAL GEAR
- DEMONSTRATE & ASSESS EVA POWER TOOLS, E.G., CUTTERS, DRILLS, WELDERS, BONDERS, ETC.
- DEMONSTRATE & ASSESS UTILITY & SAFETY OF DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- DEMONSTRATE & ASSESS UTILITY OF MULTI-TERRAIN SMALL LT-WT PORT. SURFACE TRANSPORTER
- DEMONSTRATE & ASSESS SET-UP/USE OF RAPID DEPLOY ZERO/LOW-G RAD/THERMAL/WIND SHELTER
- DEMONSTRATE UTILITY & VALIDATE PORTABLE MULTI-PURPOSE AVIONIC UNIT
- DEMONSTRATE UTILITY & FLEXIBILITY OF PORTABLE EVA EXPER/SURVEY/SAMPLE KIT

## EVA TECHNOLOGY ELEMENTS - PRIORITIZATION

### PRIORITY DEVELOPMENT ELEMENTS

#### EVA ENCLOSURE & LIFE SUPPORT

- RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT. 1
- RAPID CREW 'IN-SITU' SUIT SERVICING 2
- EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION 3
- PROTECTION AGAINST RADIATION HAZARDS 4
- ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF 5

#### EVA SUPPORT EQUIPMENT

- CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT 1
- SUIT CONTAMINATION DETECTION & CLEANING UNIT 2
- ADVANCED MANEUVERING UNIT 3
- MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT 4
- CREW & EQUIP TRANSPORTER & POSITIONING AID 5
- SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT 6
- SMALL LT-WT PORTABLE AIRLOCK 7
- EMERGENCY SUIT 'LIFE JACKET' 8
- EMERGENCY EVA SURVIVAL GEAR 9
- ADVANCED POWER TOOLS FOR EVA 10
- DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS 11
- SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EVA CREW/EQUIP) 12
- SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER 13
- PORTABLE MULTI-PURPOSE AVIONIC UNIT 14
- PORTABLE EVA EXPR/SURVEY/SAMPLE KIT 15

DECEMBER 6-9, 1988

## SUMMARY/CONCLUSIONS

### SUMMARY

1. NASA & CANDIDATE DoD MANNED MISSIONS PRESENTED & TECHNOLOGY NEEDS RELATED TO EACH AND TO NASA 'MODEL' SCHEDULE
2. TECHNOLOGY NEEDS IDENTIFIED AND DEVELOPMENT FACTORS INDICATED
3. RATIONALE FOR EVA SYSTEM HDWR DEVELOPMENT PORTRAYED

### CONCLUSIONS

1. TOTAL/ALL-UP SUIT TECHNOLOGY NOT YET IMMEDIATELY READY FOR FULL RDT&E PUSH
  - TECHNOLOGY IS BEING WORKED HARD AT NASA-JSC/AMES
2. MANY EVA EQUIP. ELEMENTS IN BRASSBOARD DEVELOPMENT STATE
3. CERTAIN EVA EQUIPMENT NOT BEING WORKED RELATIVE TO MISSIONS IMMEDIATELY BEYOND FREEDOM SPACE STATION ASSEMBLY
4. MANY STATION EVA ELEMENTS LEND THEMSELVES TO ORBITER PRECURSOR FLIGHTS
5. EVA TECHNOLOGY NEEDS A MORE VIGOROUS \$ INFUSION TO ASSURE AVAILABILITY, VERIFICATION, AND MULTI-USER NEEDS/DATES
  - OPPORTUNITY FOR NASA & DoD MUTUAL INVESTMENT BENEFIT

# **EVA and Pressure Suit Technology**

**Prof. David L. Akin  
Space Systems Laboratory  
Massachusetts Institute of Technology**

## Background

- **Gemini**
  - Free-floating mobility
  - Experiment collection
  - Investigation of restraints
- **Apollo**
  - Self-contained life support equipment
  - Retrieval of mapping camera film
  - Lunar surface operations
  - Surface transport infrastructure
- **Skylab**
  - Planned servicing of instruments
  - Contingency repairs
- **Shuttle**
  - Satellite retrieval
  - ORU changeout
  - Dexterous repair operations
  - Initial EVA/robotic cooperation
  - Untethered MMU operations
  - Large object handling
  - Unpracticed EVA
  - Structural assembly

## Research Needs

- Development and use of physiological workload measurement systems for neutral buoyancy simulation
- Correlation of physiological workloads between neutral buoyancy and flight
- Calibration of forces required internally to actuate suit joints
- Development of noninvasive neuromuscular instrumentation for quantifying fatigue in critical muscle groups (wrist and hands)
- Development of advanced computer models of EVA with correlation of force, kinematic, dynamic, and workload elements in neutral buoyancy and space flight
- Development of rule-based system for predicting EVA task performance for use as a simplified front-end to "CAD Astronaut" model

## Technology Needs

- **Gloves with better mobility, dexterity, tactility**
- **Simplified suit systems for on-site maintenance and refurbishment, extended operational lifetime**
- **Non-venting cooling system, zone heating and cooling**
- **Advanced controls and displays, particularly video**
- **Extended set of available hand and power tools**
- **Non-intrusive body joint position and force sensors for biomechanics data collection**
- **Maneuvering units with additional  $\Delta V$ , single-hand control, and autonomous navigational capability (leading up to astronaut support vehicle/EVA Retriever)**
- **In-space suit decontamination systems, particularly for hydrazine**

## In-Space Experimentation Needs

- **Conduct routine EVAs to build experience base and to allow for experimental opportunities**
- **Baseline the use of suits instrumented for biomechanics and workload measurements to expand quantitative data base on EVA operations**
- **Conduct a series of fiduciary experiments to determine the limits of human capability in EVA, with and without the use of EVA tools/aids/support systems**
- **Assess the use of AI technology to provide suit monitoring and error diagnosis, reducing or eliminating the need for mission control monitoring**
- **As telerobotic systems develop, investigate cooperative roles for EVA and robotics to enhance space operations**

## **In-Space Experimentation Needs (cont.)**

- **Evolve life support systems towards regenerative technology to allow for extended operations in space or on planetary surfaces**
- **Assess the use of bidirectional video for reducing crew training requirements**
- **Investigate the use of telepresence technology to replace neutral buoyancy training for long-duration space crew**
- **Develop "CAD Astronaut" to allow long-duration space crew to investigate trade-offs in EVA techniques, simplify EVA planning and training, reduce dependence on mission control**
- **Experimentally verify research applied to innovative high-payoff concepts, such as skinsuit technology**

## **8.2 HUMAN PERFORMANCE**

**This page intentionally blank**

<p><b>HUMANS IN SPACE</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>HUMAN PERFORMANCE</b></p>
-------------------------------	---	---------------------------------

**CREW AND ENVIRONMENTAL FACTORS**

**Barbara G. Kanki, Ph.D.**

**NASA-Ames Research Center  
Crew Research and Space Human Factors**

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## INTRODUCTION/BACKGROUND GOALS

- "To develop empirically-based scientific principles that identify the environmental, individual, group, and organizational requirements for long-term occupancy of space by humans."

— Report of the National Research Council  
Committee on Space Biology and Medicine  
("The Goldberg Report"), p. 169

- To develop useful and practical approaches to selecting, training, and organizing effective crews for long duration space missions in collaboration with operational organizations.
- To provide a scientific resource to organizations responsible for man-systems design, crew selection and training and missions operations.

<p><b>HUMANS IN SPACE</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>HUMAN PERFORMANCE</b></p>
-------------------------------	---	---------------------------------

**TECHNOLOGY NEEDS**

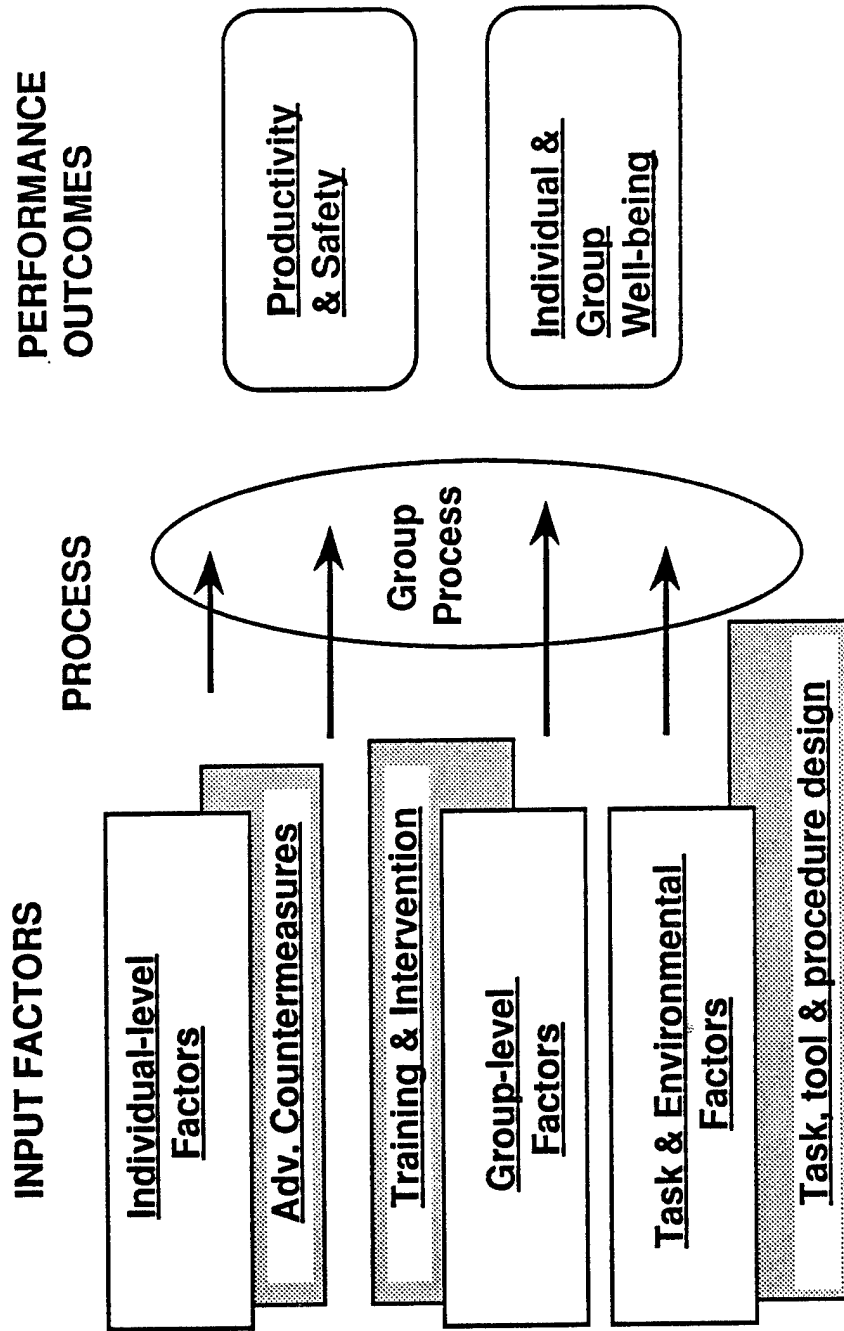
**Critical shortage of relevant research.  
No operational guidelines for spaceflight  
or long-term space occupancy.**

**PROBLEM AREAS**

- 1. Individual and Physiological**
- 2. Crew and Interpersonal**
- 3. Organization and Management**
- 4. Training and Intervention**
- 5. Environmental and Task**

## TECHNOLOGY NEEDS

Research for Optimizing Human Performance



### CONCEPTUAL FRAMEWORK

adapted from McGrath, 1984

<p><b>HUMANS IN SPACE</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>HUMAN PERFORMANCE</b></p>
-------------------------------	---	---------------------------------

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

### **Multi-phase Research Plan**

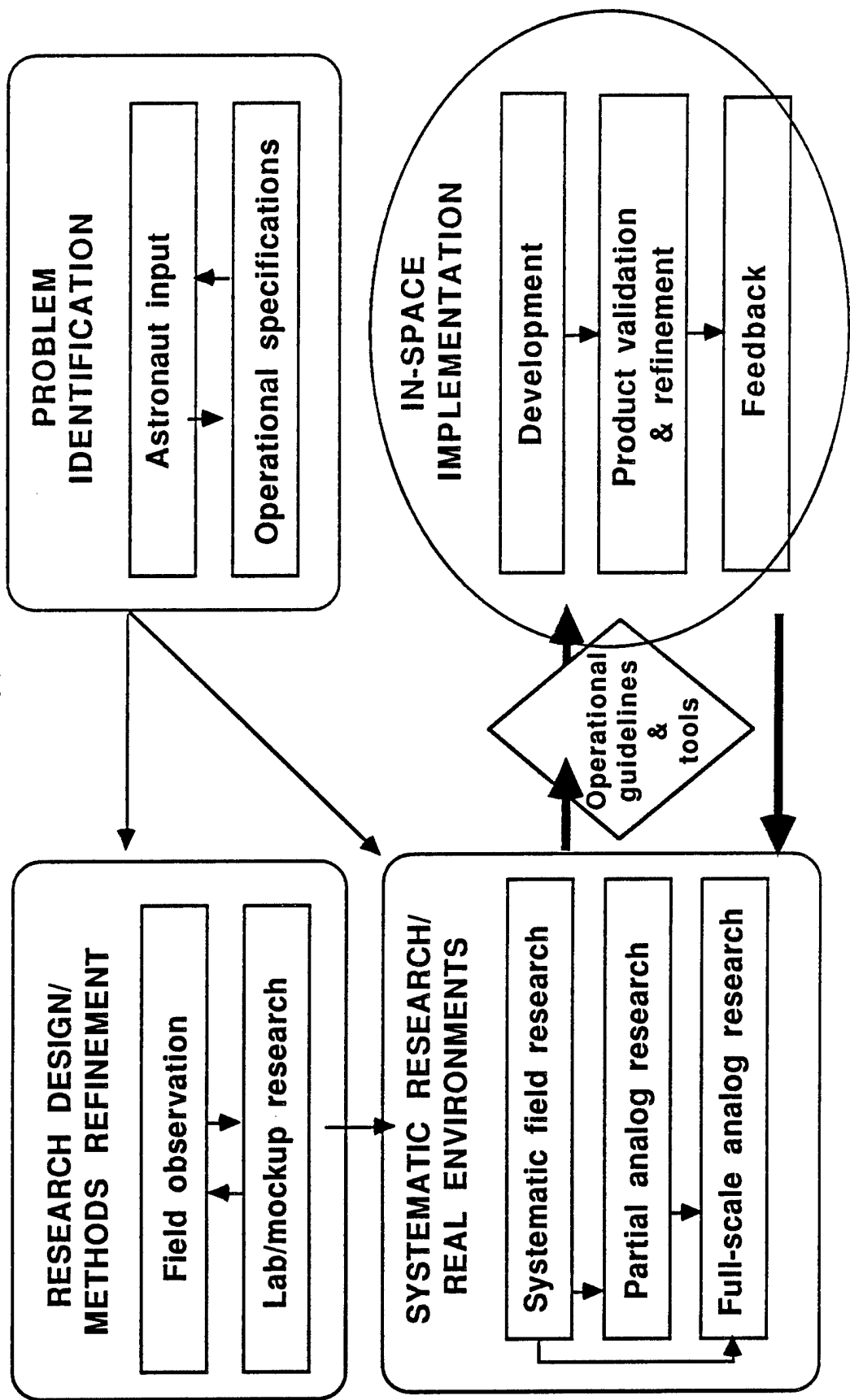
- Laboratory/Mockup Research
- Field Observation
- Systematic Field Research
- Partial Analog Research
- Full-Scale Analog Research

### **Relevant Analogous Environments**

- Space Vehicle Analog
- Space Station Analog
- Planetary Exploration Analog
- Astronaut/Mission Control  
Telescience Analog

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

An Integrated Approach



HUMANS IN  
SPACE

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988

HUMAN  
PERFORMANCE

## ARTIFICIAL GRAVITY

Larry G. Lemke  
NASA, Ames Research Center

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## INTRODUCTION/BACKGROUND

- "...THERE APPEARS TO BE A GENERAL PERCEPTION THAT THE ABSENCE OF LIFE-THREATENING MEDICAL PROBLEMS IN THE MANNED SPACE PROGRAM IMPLIES THAT THERE IS LITTLE NEED TO BE CONCERNED ABOUT HEALTH-RELATED ISSUES ON A MANNED SPACE STATION OR IN INTERPLANETARY MISSIONS OF SEVERAL YEARS DURATION. BASED ON WHAT WE KNOW TODAY, THIS ASSUMPTION OF CONTINUED SUCCESS CANNOT BE RIGOROUSLY DEFENDED".

--NATIONAL RESEARCH COUNCIL, COMMITTEE ON SPACE BIOLOGY & MEDICINE, 1987--

- "LONG-DURATION HUMAN HABITATION OF THE MOON AND MARS WILL REQUIRE PRIOR LONG-TERM STUDIES OF THE EFFECTS OF EXPOSURE TO 1/6 AND 1/3 G ON ANIMALS AND, EVENTUALLY HUMANS, INCLUDING STUDIES OF MULTIGENERATIONAL EXPOSURE TO VARIED G LEVELS"

### •RECOMMENDATION:

A TETHERED (> 10-METER DIAMETER) VARIABLE GRAVITY RESEARCH FACILITY FOR THE SPACE STATION THAT WOULD GREATLY REDUCE CORIOLIS/GRADIENT PROBLEMS ACROSS LARGE ANIMALS AND THAT WOULD BE OPERATIONAL BEFORE THE START OF ANY HUMAN SPACE MISSIONS OF EXTENDED DURATION"

--ROBBINS COMMITTEE REPORT, 1988--

## MISSION APPLICATIONS

### PROBABLE:

- HUMAN MARS EXPLORATION SCENARIOS

### POSSIBLE:

- LUNAR BASES
- ADVANCED SPACE STATIONS
- HUMAN ASTEROID RECONNAISSANCE

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## TECHNOLOGY NEEDS

- DESIGN STRATEGIES, CONTROL ALGORITHMS, & SPECIALIZED ACTUATORS TO ALLOW RELIABLE & SAFE CONTROL OF SPINNING, TETHERED DUMBBELL CONFIGURATIONS

### STRATEGIES,:

- OPTIMAL MASS DISTRIBUTION
- OPTIMAL ACTUATOR PLACEMENT
- OPTIMAL ACTUATOR TYPE

### ALGORITHMS,:

- END-BODY ATTITUDE CONTROL
- END-BODY PROPULSIVE THRUSTING CONTROL
- TETHER VIBRATION CONTROL
- TETHER LENGTH CONTROL

### ACTUATORS:

- END-BODY ATTITUDE CONTROL
- TETHER LENGTH CONTROL

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## IN-SPACE EXPERIMENTATION NEEDS

### EXPERIMENT HARDWARE:

- SMALL, (~ 1000KG) FREE-FLYING, REMOTELY CONTROLLED, TETHER-CONNECTED DUMBELL SPACECRAFT
- INSTRUMENTED TO MEASURE ALL IMPORTANT STATE VARIABLES
- ABILITY TO CONTROL SAME DEGREES-OF-FREEDOM AS HUMAN-RATED SPACECRAFT
- ROTATIONAL AND VIBRATIONAL EIGENVALUES CHOSEN FOR DYNAMIC SIMILARITY(TO ALLOW SCALING TO FULL-SIZE FACILITY)

### EXPERIMENT OBJECTIVES:

- MAINTAIN STEADY-STATE HABITAT G-LEVEL WITHIN +/- 1%, 3-AXIS ATTITUDE WITHIN +/- 1 DEG.
- STABILIZE COUPLED TRANSLATIONAL, ROTATIONAL, AND VIBRATIONAL MODES DURING SPIN-UP, SPIN-DOWN, TRANSLATIONAL THRUSTER FIRINGS
- CONTROL TRANSLATIONAL DELTA-V WHILE SPINNING TO < 1 m/s (INCLUDING PLANE CHANGES)
- DEMONSTRATE RECOVERY FROM FAILURES

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## SUMMARY/RECOMMENDATIONS

- HUMAN EXPLORATION MISSIONS MAY REQUIRE ARTIFICIAL GRAVITY
- VERY LARGE RADIUS ( $\approx 225$  m) CENTRIFUGE SEEMS MOST CONSERVATIVE FROM BIOLOGICAL PERSPECTIVE, MOST CHALLENGING FROM TECHNOLOGICAL PERSPECTIVE
- CONTROL OF LARGE, HIGHLY FLEXIBLE, ROTATING SYSTEMS MUST BE SHOWN SAFE AND RELIABLE PRIOR TO HUMAN-RATING
- EXPERIMENT OBJECTIVES CAN BE ACHIEVED WITH SUB-SCALE, FREE-FLYING DUMBELL CONFIGURATION:
- INITIATE FLIGHT EXPERIMENT DEFINITION AND DEVELOPMENT SOON TO BE CONSISTENT WITH OVERALL AGENCY SCHEDULE
  - LABORATORY RESEARCH, SIMULATION, & ANALYSIS
  - CONCEPTUAL DEVELOPMENT OF FLIGHT HARDWARE

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
--------------------	--	----------------------

## HUMAN PERFORMANCE

William R. Ferrell

Systems & Industrial Engineering Dept.  
University of Arizona  
Tucson, Arizona

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## INTRODUCTION / BACKGROUND

**HUMAN PERFORMANCE :** Human characteristics that affect the design of tasks, human-system interfaces, training

### NASA SUCCESS IN DESIGN FOR HUMAN PERFORMANCE

- Humans in space
- Ground control of remote operations

### ROLES OF HUMANS IN SPACE WILL CONTINUE TO CHANGE

- Passenger to Experimenter to Scientist / Engineer
- Passive to Active
- Sensory - motor skills to Decision - making / Problem - solving

### CURRENT BASES FOR DESIGN - will have to evolve

- NASA & Contractor experience
- Data & standards compilations, e.g. MSIS & MSRB
- Models for dynamic manual control
- Models for routine cognitive skills, motor skills, sensory function
- Simulation methods for crew activity and work load analysis
- Guidelines for computer - human interface design
- Beginnings of useful models for cognitive performance of specific tasks, e.g., debugging, transfer of procedural training

### HUMAN FACTORS FIELD

- Uneven development and too little basic research
- Focus on skills, task components

## MISSION APPLICATIONS

- Multi-way, interpersonal communication with voice, text and images
- High - dexterity manipulation
- Monitoring of intelligent monitoring systems
- Skill maintenance and training
- Data interpretation and analysis
- Information retrieval, storage and management tasks
- Intervention in and redirection of experiments
- Participation in revising old and devising new experiments
- Equipment repair
- Cooperative, creative problem solving and strategic decision making

## TECHNOLOGY NEEDS

### COMPUTER - BASED, INTELLIGENT SUPPORT FOR :

- Problem solving and diagnosis
- Decision making
- Information management
- Monitoring of systems and environments
- Skill maintenance and learning
- Cooperative work with voice, text and images

### ENABLING TECHNOLOGIES:

- Dynamic management of multi-media, multi-channel computer-human communication
- Language (and spoken language) understanding systems
- Intention inference
- Image and geometry understanding systems

### DESIGN TECHNOLOGIES:

- Task analysis and simulation
- Rapid prototyping
- Integrated human performance models incorporating responses to the space environment

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## IN - SPACE EXPERIMENTS NEEDS / VOIDS

Most of the technology for supporting human performance in space can be developed and tested without in-space experimentation.

In-space experimentation is important for:

- Design technologies, to determine / verify space environment effects on performance
- Specific interface design proposals, to assess interactions among task, interface, habitat, work-station and crew characteristics in the space environment -- early in the design process.

Need to begin early to develop the research base for design of effective support for distinctively human role in space.

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
-----------------	--	-------------------

## SUMMARY / RECOMMENDATIONS

**ROLES:** Science, Monitoring, Diagnosis, Intervention, Repair

**NEED KNOWLEDGE-BASED TECHNOLOGIES to support:**

- Creative Problem Solving
- Unforseen Activities
- Intervention and Repair
- Cooperative Planning & Decision

**SUBSTANTIAL SUPPORT FOR GROUND - BASED RESEARCH IS NEEDED TO DEVELOP THESE TECHNOLOGIES**

**IN - SPACE EXPERIMENTATION:**

- Physiological / Perceptual / Anthropometric modeling
- [Habitat & EVA experiments] (related sub - themes)
- [ TELEOPERATION experiments]
- Multi - operator, cooperative workstations
- Task / Interface simulations for testing interactions in context and for timely design feedback

**NEED FOR AN IN-SPACE FACILITY TO SUPPORT DESIGN**

**CRITICAL ISSUES:**

- Intelligent , dynamic interface management systems
- System integration -- a technical not a management--problem

### **8.3 CLOSED-LOOP LIFE SUPPORT SYSTEMS**

**This page intentionally blank**

**HUMANS IN SPACE**

**IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988**

**CLOSED LOOP  
LIFE SUPPORT**

# **Physical/Chemical Closed Loop Life Support**

**R.D. MacElroy  
NASA / Ames Research Center**

<b>HUMANS IN SPACE</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>CLOSED LOOP LIFE SUPPORT</b>
------------------------	--	-------------------------------------

## **Background. . .**

### **Closed-loop Life Support Focuses:**

- **Post-Space Station Life Support issues**
- **Efficient regeneration of life support materials**
- **Further development of existing technologies**
- **Promotion of innovative technologies**
- **Evaluation of new technologies**

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
-----------------	--	-----------------------------

## Technology Needs

### Life Support Functions / Technologies:

- Collection of CO<sub>2</sub>; adsorber regeneration
- Separation of gases
- Generation of O<sub>2</sub> from H<sub>2</sub>O, CO<sub>2</sub>
- Management and processing waste streams
- Purification of reclaimable water
- Process, sub-system and system sensing, monitoring and control
- Thermal control

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
-----------------	--	-----------------------------

## **In-Space Experimentation Needs:**

- \* Subsystems will be specifically designed to reduce reliance on gravity and low radiation levels**
- However, testing in the space environment will be essential because of long-term human reliance on life support devices**
- Physical integration of subsystem will be simulated; however, validation and verification of in-space behavior is required**
- Start-up, shut-down and operational transients must be evaluated in the space environment**

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
-----------------	--	-----------------------------

## **In-space Experimentation needs:**

- \* **A central issue: gas - liquid separation**
- \* **Related issues:**
  - **liquid behavior on surfaces in low gravity**
  - **changes in thermal behavior caused by differences in the convective behavior of fluids**
- \* **In general, subsystem designs that rely on forced fluid movements will obviate effects caused by decreased gravity**

**This page intentionally blank**

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
--------------------	--	-----------------------------

CLOSED LOOP LIFE SUPPORT  
INDUSTRY PRESENTATION

THOMAS J SLAVIN, P.E.  
LIFE SUPPORT ENGINEER  
BOEING AEROSPACE  
SEATTLE, WA

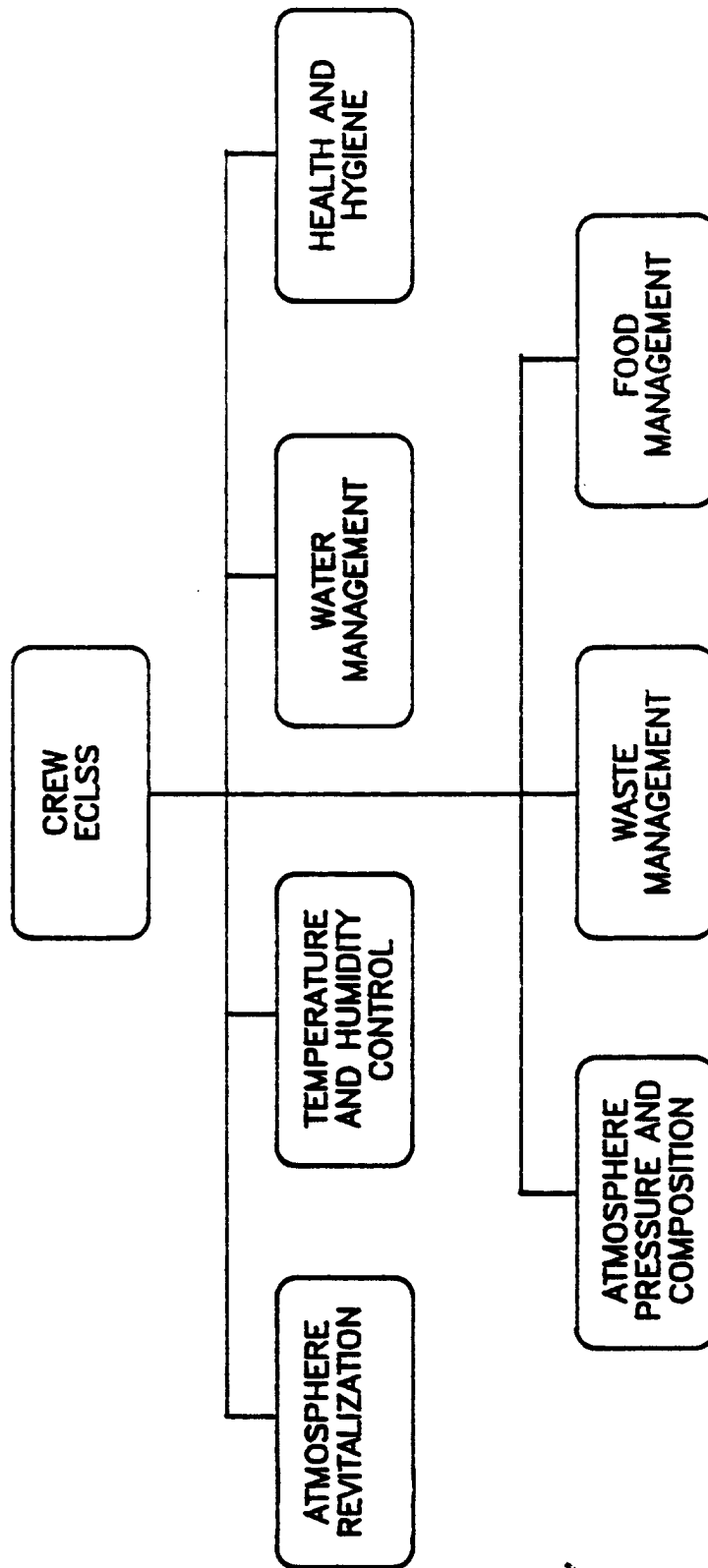
## SYSTEMS TESTS LESSONS LEARNED/ISSUES

- MATERIALS SELECTION/COMPATIBILITY
- CAREFUL DESIGN OF SYSTEM CLOSURE
- INTEGRATION OF SUBSYSTEMS
- ON-BOARD MAINTENANCE AND SERVICING

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
--------------------	--	-----------------------------

## TECHNOLOGY NEEDS

### LIFE SUPPORT FUNCTIONS



## LIFE SUPPORT TECHNOLOGY SELECTION DRIVERS

- OPERATING ENVIRONMENT
  - Gravity fields
  - Ambient pressures
- RELIABILITY/MAINTAINABILITY
- SAFETY
- POWER, MASS, VOLUME
- DEVELOPMENT COST AND SCHEDULE
- RESTRICTIONS ON RESUPPLY, EXPENDABLES, DISCHARGES

HUMANS  
IN SPACE

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP  
DECEMBER 6-9, 1988

CLOSED LOOP  
LIFE SUPPORT

## IN-SPACE EXPERIMENTATION NEEDS/VOIDS

### PHYSICAL-CHEMICAL LIFE SUPPORT TECHNOLOGY

<u>FUNCTION</u>	<u>TECHNOLOGY AREA</u>	<u>NEED</u>
<b>WATER RECLAMATION</b>	<ul style="list-style-type: none"><li>● Liq/Air Separation</li><li>● Solids Separation</li><li>● Fluid Transport</li></ul>	<ul style="list-style-type: none"><li>● Passive Separation Devices</li><li>● Filter Solids Accumulation</li><li>● Wicking Devices</li></ul>
<b>WASTE MANAGEMENT</b>	<ul style="list-style-type: none"><li>● Pre-Treatment</li><li>● Solids Reduction</li></ul>	<ul style="list-style-type: none"><li>● Effectiveness of Antifoam in 0 g</li><li>● Low Temp/Energy Processes</li></ul>
<b>AIR REVITALIZATION</b>	<ul style="list-style-type: none"><li>● Catalytic Reactors</li><li>● Electrochemical Cells</li></ul>	<ul style="list-style-type: none"><li>● Mixing &amp; Heat Dissipation</li><li>● Behavior of light gases &amp; thermal gradients</li><li>● Behavior of flames &amp; plasmas</li><li>● Change in efficiency</li></ul>

**CONTROLLED ECOLOGICAL/BIOREGENERATIVE LIFE SUPPORT TECHNOLOGY**

FUNCTION	TECHNOLOGY AREA	NEED
<b>FOOD, OXYGEN, &amp; WATER PROD.</b>	<ul style="list-style-type: none"> <li>● Lighting</li> <li>● Nutrients</li> <li>● Plant Growth</li> </ul>	<ul style="list-style-type: none"> <li>● Sun light collection, filtering, and distribution from orbiting platform</li> <li>● Nutrient solution delivery</li> <li>● Incremental Introduction of plants on Space Station program</li> </ul>
<b>FOOD PROCESSING</b>	<ul style="list-style-type: none"> <li>● Conversion</li> </ul>	<ul style="list-style-type: none"> <li>● Glycerol &amp; protein extraction</li> <li>● Biological conversion processes</li> </ul>
<b>WASTE PROCESSING</b>	<ul style="list-style-type: none"> <li>● Bioregeneration</li> </ul>	<ul style="list-style-type: none"> <li>● Biodigestion in 0 g</li> <li>● Gas/liquid/solid separation</li> </ul>
<b>AUTOMATION &amp; CONTROL</b>	<ul style="list-style-type: none"> <li>● Instrumentation Design</li> </ul>	<ul style="list-style-type: none"> <li>● Gravity independent sensor dev.</li> <li>● Struct dsn (minimize dead spaces)</li> </ul>

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Closed-Loop Life Support
-----------------	--	--------------------------

**PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT**

**MARVIN W. LUTTGES  
 LOUIS STODIECK  
 AEROSPACE ENGINEERING SCIENCES  
 AND  
 BIOSERVE SPACE TECHNOLOGIES  
 UNIVERSITY OF COLORADO, #429  
 BOULDER, CO 80309**

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Closed-Loop Life Support
-----------------	--	--------------------------

## INTRODUCTION/BACKGROUND

**LIFE SUPPORT RESUPPLY REQUIREMENTS SERIOUSLY  
CONSTRAIN MANNED SPACE MISSIONS.**

## CURRENT TECHNOLOGIES

- \* PROVIDE FOR LITTLE RE-USE
- \* ARE COSTLY
- \* INHIBIT SPACE MISSION FLEXIBILITY
- \* ARE NOT WELL-DEVELOPED
- \* HAVE TECHNICAL AND SAFETY DRAWBACKS

<p><b>Humans in Space</b></p>	<p><b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b></p>	<p><b>Closed-Loop Life Support</b></p>
-------------------------------	---	--

## **TECHNOLOGY NEEDS**

### **ORBITAL/TRANSIT NEEDS**

- \* REDUCED WEIGHT, POWER AND HEAT**
- \* EFFICIENCY**
- \* SAFETY**
- \* MICROGRAVITY-EFFECTIVE SUBSYSTEMS**
- \* INTEGRATION**

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Closed-Loop Life Support
-----------------	--	-----------------------------

## TECHNOLOGY NEEDS

### SURFACE NEEDS

- \* TRANSPORTATION
- \* SURFACE RESOURCE USE
- \* AUTONOMY AND RELIABILITY
- \* PRODUCT MANAGEMENT
- \* POWER

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Closed-Loop Life Support
-----------------	--	--------------------------

## IN-SPACE EXPERIMENTATION NEEDS

### ORBITAL/TRANSIT NEEDS

- \* FLUID SUBSYSTEM TESTS
- \* MASS VS. CONTAINMENT TRADES
- \* MICROGRAVITY SENSORS AND CONTROL
- \* SURFACE/CATALYTIC EFFICIENCIES
- \* RELIABILITY
- \* POWER AND HEAT REDUCTIONS

Humans in Space	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Closed-Loop Life Support
-----------------	--	--------------------------

## IN-SPACE EXPERIMENTATION NEEDS

### SURFACE NEEDS

- \* ON-SITE RESOURCE USES/TESTS
- \* LONG-TERM AUTONOMY AND RELIABILITY
- \* TRANSPORT AND DEPLOYMENT TESTS
- \* PRODUCT STORAGE, DISTRIBUTION AND USE
- \* POWER

**HUMANS IN SPACE  
CRITICAL TECHNOLOGY REQUIREMENTS**

**REMUS BRETOI  
AMES RESEARCH CENTER**

	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	
--	--	--

## **EVA / SUIT**

- o **DEVELOP THE TECHNOLOGY FOR MEASUREMENT OF EVA FORCES, MOMENTS, DYNAMICS, PHYSIOLOGICAL WORKLOAD, THERMAL LOADS AND MUSCULAR FATIGUE.**
- o **EVALUATE COOPERATIVE ROLES BETWEEN EVA AND TELEROBOTS AND FOR IVA AND ROBOTICS.**
- o **SUIT CONTAMINANTS DETECTION, IDENTIFICATION AND REMOVAL.**

	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	
--	--	--

## HUMAN PERFORMANCE

- o TECHNOLOGY FOR MEASUREMENT OF GRAVITY-RELATED ADAPTATION AND RE-ADAPTATION BEHAVIOR
- o TECHNOLOGY FOR IN-SPACE ANTHROPOMETRIC AND PERFORMANCE MEASUREMENT
- o VARIABLE - GRAVITY FACILITY AND APPLICATION TECHNOLOGY

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	
--	--	--

## CLOSED LOOP LIFE SUPPORT SYSTEMS

- IMPROVED PHASE SEPARATION SYSTEMS
- GRAVITY-INDEPENDENT SENSOR SYSTEMS
- WASTE-CONVERSION PROCESSES
- FLUID MIXING AND COMPOSITION CONTROL
- REACTOR PHENOMENA
- CHEMICAL SPECIES SEPARATION

	<p>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</p>	
--	--	--

**OTHERS TO CONSIDER - POSSIBLY  
BY OTHER THEMES**

- o FIRE AND SMOKE DETECTION SYSTEM
- o ZERO-G PHASE CHANGE PHENOMENA FOR EVA  
THERMAL MANAGEMENT
- o FOAMING COUNTERMEASURES