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Space Station Human Factors Research Review

*Volume I: EVA Research
and Development*

JOE W. WILSON

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*Proceedings of a workshop held at
Ames Research Center
Moffett Field, California
December 3-6, 1985*



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Space Station Human Factors Research Review

*Volume I: EVA Research
and Development*

Edited by
Marc M. Cohen and H. C. Vykukal
NASA Ames Research Center
Moffett Field, California

Proceedings of a workshop held at
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Scientific and Technical
Information Division

1988

Space Station Human Factors Research Review

PREFACE

This conference proceeding is a compilation of the papers presented at the Space Station Human Factors Research Review held at NASA Ames Research Center from December 3-6, 1985. These presentations represent the first year of research supported by the Space Station Advanced Development program as well as on-going related research supported by other NASA programs.

Each day of this research review was dedicated to a different focus or discipline. The foci represent the various areas of expertise in the Space Human Factors Office and the Aerospace Human Factors Research Division at Ames Research Center. In general, the structure of the conference was to proceed from the more general topics to the more specific issues during each day and throughout the week.

Vic Vykukal, a specialist in advanced space suit design, chaired the first day's session, *EVA Research and Development*. After Vykukal presented an introduction to EVA Research and Development at Ames, representatives of each of the three aerospace contractors participating in the EVA Systems Study presented their views on Implications for Man-System Design. The final presentation related experiences in the deep-sea diving industry that are relevant to EVA.

Yvonne Clearwater, an environmental psychologist who is pioneering the quantitative modeling of human spatial habitability, chaired the second day, *Space Station Habitability: Behavioral Research*. After Clearwater presented an introduction to the Space Station Habitability Research Program within the Space Human Factors Office, contractors and grantees made presentations on habitability, productivity, operational simulation and aesthetics for space station design guidelines. The session concluded with a panel discussion consisting of the principal speakers.

Marc Cohen, an architect in innovative Space Station design, chaired the third day, *Space Station Habitability and Function: Architectural Research*. After Cohen presented an introduction to Ames Research Center Space Station Architectural Research, each of the contractor or grantee architects presented reports on the progress of their work in architectural design research. The session concluded with a panel discussion consisting of the principal speakers.

Trieve Tanner, Acting Assistant Chief for the Research for the Aerospace Human Factors Research Division, chaired the fourth day, *Inhouse Advanced Development and Research*. After Tanner gave a brief introduction, the members of the division's basic research discipline groups presented papers in their respective areas of expertise: Cognition and Perception, Workload and Performance, and Human/Machine Integration.

Each of these four sessions is published as a separate volume of NASA CP-2426, with each day corresponding to the sequentially numbered volume.

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TUESDAY AFTERNOON

December 3, 1985

- 12:30 Welcome and Overview of Advanced Development and Research at Ames**
Tom Snyder, Director of Aerospace Systems, NASA Ames
David Nagel, Acting Chief, NASA Ames Aerospace Human Factors Research
Division
Trieve Tanner, Chief, NASA Ames Space Human Factors Office

EVA RESEARCH AND DEVELOPMENT

Chair: Vic Vykukal

- 1:10 Introduction to EVA Research and Development**
Vic Vykukal, NASA Ames Space Human Factors Office

EVA PHASE A STUDY IMPLICATIONS FOR MAN-SYSTEMS DESIGN

- 1:30 Boeing:**
Joseph Thompson
- 2:30 Grumman:**
Fred Abeles
- 3:30 Break**
- 3:40 McDonnell Douglas:**
Tom Wood
- 4:40 Diving Industry Approaches to Work Systems Development**
Michael Gernhardt, Ocean Systems Engineering
- 5:40 Closing Remarks: Vic Vykukal**

WEDNESDAY
December 4, 1985

SPACE STATION HABITABILITY: BEHAVIORAL RESEARCH

Chair: Yvonne A. Clearwater

- 8:30 Introduction to the Space Station Habitability Research Program**
Yvonne Clearwater, NASA Ames Space Human Factors Office
- 9:00 Human Performance and Productivity Study**
Wayne Gonzalez, Lockheed, Astronautics Division
- 9:30 Space Station Functional Relationship Activity Analysis**
Al Steinberg, McDonnell Douglas Astronautics Co.
- 10:30 Break**
- 10:45 Space Station Operational Simulation Computer Model**
Al Globus and Rick Jacoby, Informatics General Corporation
- 12:00 Lunch**
- 1:00 Quantitative Modelling of Human Spatial Habitability**
James Wise, University of Washington
- 2:00 Privacy and Interpersonal Distancing Study**
Albert Harrison, University of California at Davis
- 3:00 Break**
- 3:15 Space Station Interior Color Study**
Mary Edwards, San Francisco Academy of Art
- 4:15 Human Adaptation Studies: Analogous Environments**
Yvonne Clearwater, NASA Ames Space Human Factors Office
- 4:30 Panel Discussion: Research Implications for Space Station Design**
Gonzalez, Steinberg, Globus, Wise, Harrison, Edwards

THURSDAY
December 5, 1985

**SPACE STATION HABITABILITY AND FUNCTION: ARCHITECTURAL
RESEARCH**

Chair: Marc M. Cohen

- 8:30 Introduction: Ames Space Station Architectural Research**
Marc M. Cohen, Architect, NASA Ames Space Human Factors Office
- 9:30 Space Station Architectural Elements Model Study**
Tom Taylor and Associates (TAI), with Ethan Clifton, Eyoub Khan and John
Spencer
- 10:30 Break**
- 10:40 Space Station Architectural Elements Model Study**
Michael Kalil Design Studio
- 11:40 General Discussion**
- 12:00 Lunch**
- 1:00 Space Station Group Activities Habitability Module Study**
David Nixon and Terry Glassman, Southern California Institute of Architecture
- 2:00 Full Scale Architectural Simulation Techniques for Space Station**
Colin Clipson, University of Michigan, Architectural Research Lab
- 3:00 Break**
- 3:10 Social Factors in Interior Furnishings**
Galen Cranz and Alice Eichold, U.C. Berkeley, College of Environmental Design
- 4:10 Panel Discussion: Research Implications for Space Station Design**
Cohen, Nixon, Taylor, Kalil, Clipson, Cranz

FRIDAY MORNING

December 6, 1985

INHOUSE ADVANCED DEVELOPMENT AND RESEARCH

Chair: Trieve A. Tanner

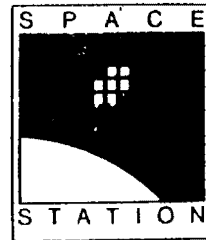
- 8:00 Cognition and Perception**
Andrew Watson, NASA Ames ASHFRD
- Space Station Proximity Operations and Windows**
Richard Haines, NASA Ames ASHFRD
- Prox-Ops Perspective Display: Spatial Displays – VERT**
Steve Ellis, NASA Ames ASHFRD
- Image Management**
Andrew Watson, NASA Ames ASHFRD
- 9:15 Workload and Performance**
Sandra Hart, NASA Ames ASHFRD
- Space Suit Workload Experiment**
RMS Workload Prediction/Assessment
Cursor Control in Zero-G (Flight Experiment)
- 10:30 Break**
- 10:40 Human/Machine Integration**
Everett Palmer, NASA Ames ASHFRD
- Spatial Cognition**
Mary Kaiser, NASA Ames ASHFRD
- Virtual Environment**
Scott Fisher, NASA Ames ASHFRD
- Fault Diagnostics in Orbital Refueling Operations**
Guy Boy, NASA Ames ASHFRD
- Error Tolerance/Procedure Aids**
Everett Palmer, NASA Ames ASHFRD
- 12:00 Closing Remarks**
Trieve A. Tanner
- 12:20 Tour of Mock-up Facility**

EXECUTIVE SUMMARY

The purpose of this review is to report the status of the Aerospace Human Factors Research Division's Space-Station-Oriented Research. This division's research program is directed toward human factors issues in both space and aviation.

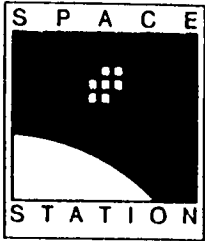
NASA Ames Research Center is not in the main development line for the Space Station. Therefore, it is important that we disseminate our research and development products in workshops like this one, as well as in less formal meetings between ourselves and the NASA Space Station Program office, development centers, and Space Station contractors.

Volume I of the Space Station Human Factors Research Review Workshop opened with an overview of EVA Research and Development activities at Ames. The majority of the program was devoted to presentations by the three contractors working in parallel on the EVA System Phase A Study, focusing on Implications for Man-Systems Design. The final presentation described Diving Industry Approaches to Work Systems Development.



EVA Mission Results Summary

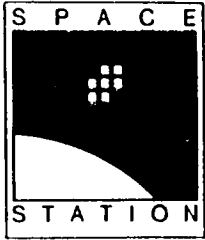
Joe Thompson



Advanced EVA System Design Requirements Study Final Review: EVA Mission Results Summary

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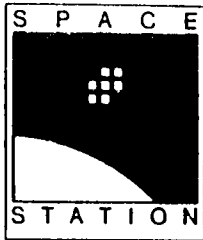
- EVA missions identified, categorized, and prioritized
- EVA missions analyzed
 - Mission description
 - Functional flow analysis
 - Baseline generic task list defined
 - Task versus mission matrix—summary
 - Workstation equipment and tools
 - EVAS equipment, restraint, and task parameters
 - Space Station support equipment
- EVAS mission timeline summary
 - Total EVA mission time
 - EVA mission scenario
 - Langley data base recommendations
- DOD EVA requirements assessment
- Space Station phase B requirements comparison to mission requirements (RFP) and trade study recommendations



EVA Mission Results Summary Mission Categories

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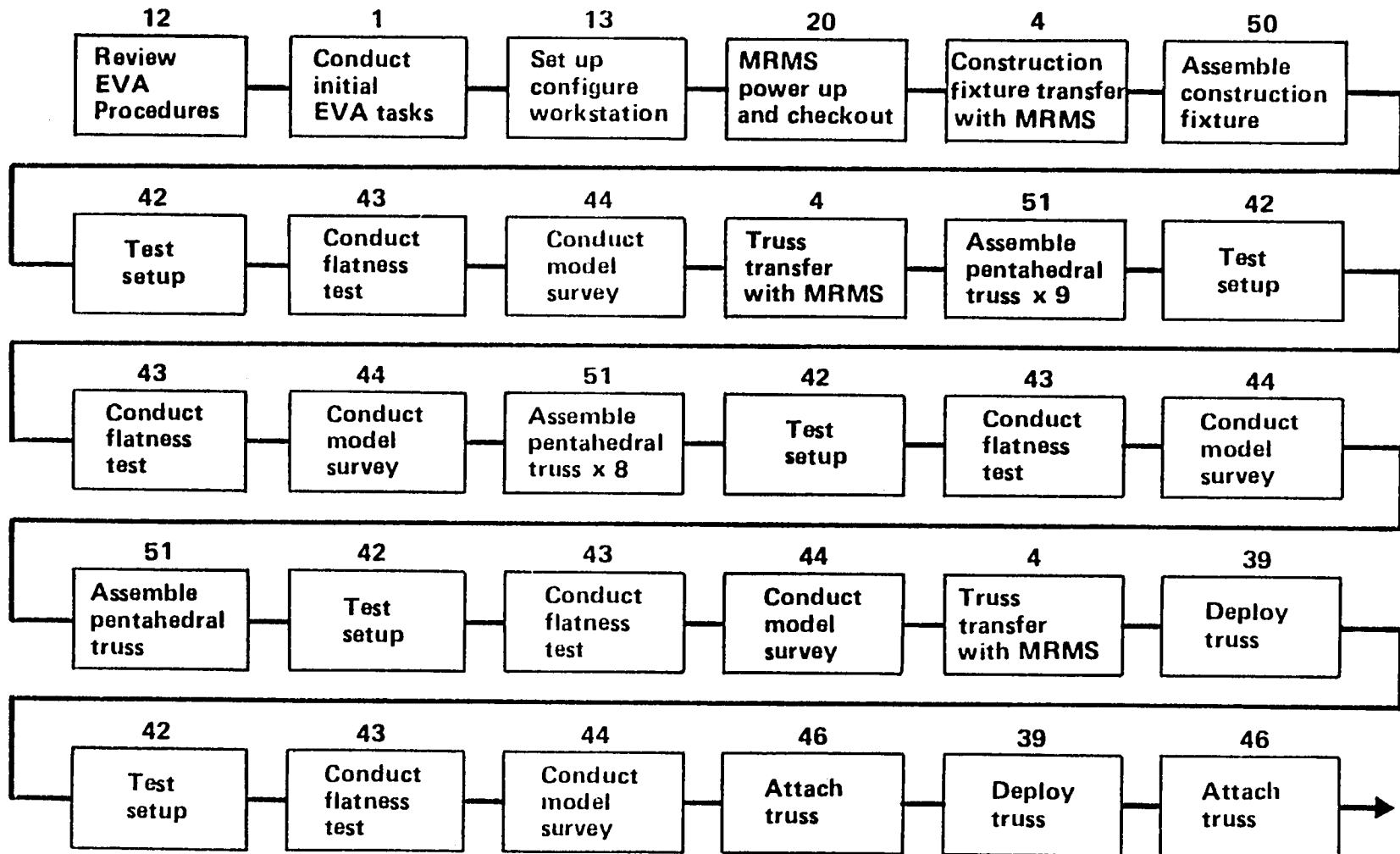
- Large satellite servicing
- Small and medium satellite servicing
- Large satellite launch (solids)
- Large satellite launch (liquid)
- Small and medium satellite launch
- Platform servicing at LEO
- Platform servicing at GEO
- Platform servicing at Polar
- Large space structure assembly
- On station installation and servicing
- Test and evaluation

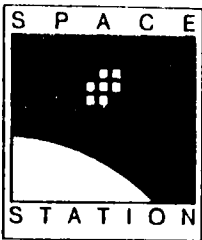


EVA Mission Results Summary

Advanced Antenna Assembly/Performance

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EVA Mission Results Summary

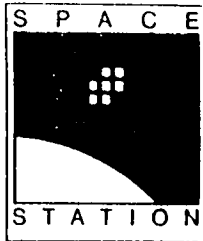
COMM Task Versus Mission Matrix

(Sheet 1 of 2)

BOEING

COMM	TIME	1280	1281	1285	1290	1291	1292	1304	1309	1312	1318	
*** GENERIC TASKS ***												
INITIAL EVA TASKS	50	1	1	1	1	1	1	1	1	1	1	0
FINAL EVA TASKS	80	1	1	1	1	1	1	1	1	1	1	0
INSTALLATION OF EIP PKG/MODULE	180	1	1	1	1	1	1	0	0	0	0	0
CARGO TRANSFER WITH MRMS	75	1	1	1	1	1	1	3	3	3	3	0
TRANSLATION & ATTACHMENT	75	1	1	1	1	1	1	3	3	3	3	0
INITIAL POWER UP AND TEST	65	1	1	1	1	1	1	0	0	0	0	0
IN-SITU CONFIB. CHANGE/SERVICING	30	0	0	0	0	0	0	1	1	1	1	0
REMOVE AND REPLACE AMPULES/SAMPLES	40	4	4	4	4	4	4	0	0	0	0	0
DMV/DTV MAIN ENGINE REMOVAL	71	0	0	0	0	0	0	1	1	0	0	0
DMV/DTV MAIN ENGINE REPLACEMENT	76	0	0	0	0	0	0	1	1	0	0	0
PROPELLANT TRANSFER SYSTEM (PTS)	51	0	0	0	0	0	0	1	1	0	0	0
REVIEW EVA PROCEDURES	240	1	1	1	1	1	1	1	1	1	1	0
WORKSTATION CONFIGURATION SETUP	35	1	1	1	1	1	1	1	1	0	0	0
WORKSTATION TEARDOWN AND STOW	35	1	1	1	1	1	1	1	1	0	0	0
INSPECTION/TROUBLE-SHOOTING	35	1	1	1	1	1	1	1	1	1	1	0
REMOVE/REPLACE ELECT COMPONENTS	49	0	0	0	0	0	0	1	1	1	1	0
REMOVE/REPLACE MECH COMPONENTS	44	0	0	0	0	0	0	1	1	1	1	0
SYSTEM TEST AND CHECKOUT	20	1	1	1	1	1	1	1	1	1	1	0
CLOSEOUT AND SECURE INSTALLATION	25	1	1	1	1	1	1	1	1	1	1	0
MRMS POWER-UP AND CHECKOUT	19	1	1	1	1	1	1	0	0	1	1	0
MRMS PARKING AND SHUTDOWN	15	1	1	1	1	1	1	0	0	1	1	0
MMU PREFLIGHT/DONNING/LAUNCH	18	0	0	0	0	0	0	1	1	1	1	0
MMU DOCK/PWR DWN/RECHARGE/SERVICE	9	0	0	0	0	0	0	1	1	1	1	0
PRESSURE VERIFICATION TEST AND PURGE	31	0	0	0	0	0	0	2	2	0	0	0
REMOVE FUEL FILL AND DRAIN VALVE	17	0	0	0	0	0	0	1	1	0	0	0
INSTALL FUEL FILL AND DRAIN VALVE	53	0	0	0	0	0	0	2	2	0	0	0
MANUAL APPENDAGE DEPLOYMENT	20	0	0	0	0	0	0	1	1	0	0	0
MANUALLY RETRACT APPENDAGES	26	0	0	0	0	0	0	0	0	1	1	0
JETTISON APPENDAGE	20	0	0	0	0	0	0	1	1	0	0	0
INSTALL ANTENNAS/SOLAR PANELS	38	0	0	0	0	0	0	0	0	0	0	0
ATTACH SATELLITE TO FSS CRADLE	20	0	0	0	0	0	0	0	0	1	1	0
REMOVE THERMAL COVER/SHROUD/DOOR	25	1	1	1	1	1	1	1	1	0	0	0
PREPARE/INSPECT DOCK/BERTH PORT	30	0	0	0	0	0	0	0	0	1	1	0
DOCK/BERTH MATE VERIFICATION	29	0	0	0	0	0	0	0	0	0	0	0
DOCK/BERTH DEMATE VERIFICATION	8	0	0	0	0	0	0	0	0	0	0	0
STOW DOCKING BERTHING PORT	19	0	0	0	0	0	0	0	0	0	0	0
OVEN COOLDOWN & FLUIDLINE PURGE	5	1	1	1	1	1	1	0	0	0	0	0
TRANSLATE SMALL PACKAGES	60	0	0	0	0	0	0	0	0	0	0	0

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EVA Mission Results Summary EVAS Mission Timeline Summary (Continued)

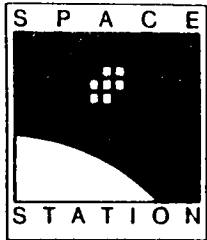


Total EVA Mission Time—JSC Data Base (From Langley May 1985)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Operational	84		12	46	22	43	44	32	38	32
Approved	163	67	154	178	114	247	318	300	481	438
Planned	895	851	1819	1459	1547	1500	1537	1403	1046	1133
Candidate	1638	2739	2707	2679	2555	2657	2705	2736	2695	2368
Opportunity	84	251	105	50			29	6	6	42
Total	2864	3908	4797	4412	4238	4447	4633	4477	4266	4013

Note 1 - Does not include NOAA (27 polar) or foreign missions

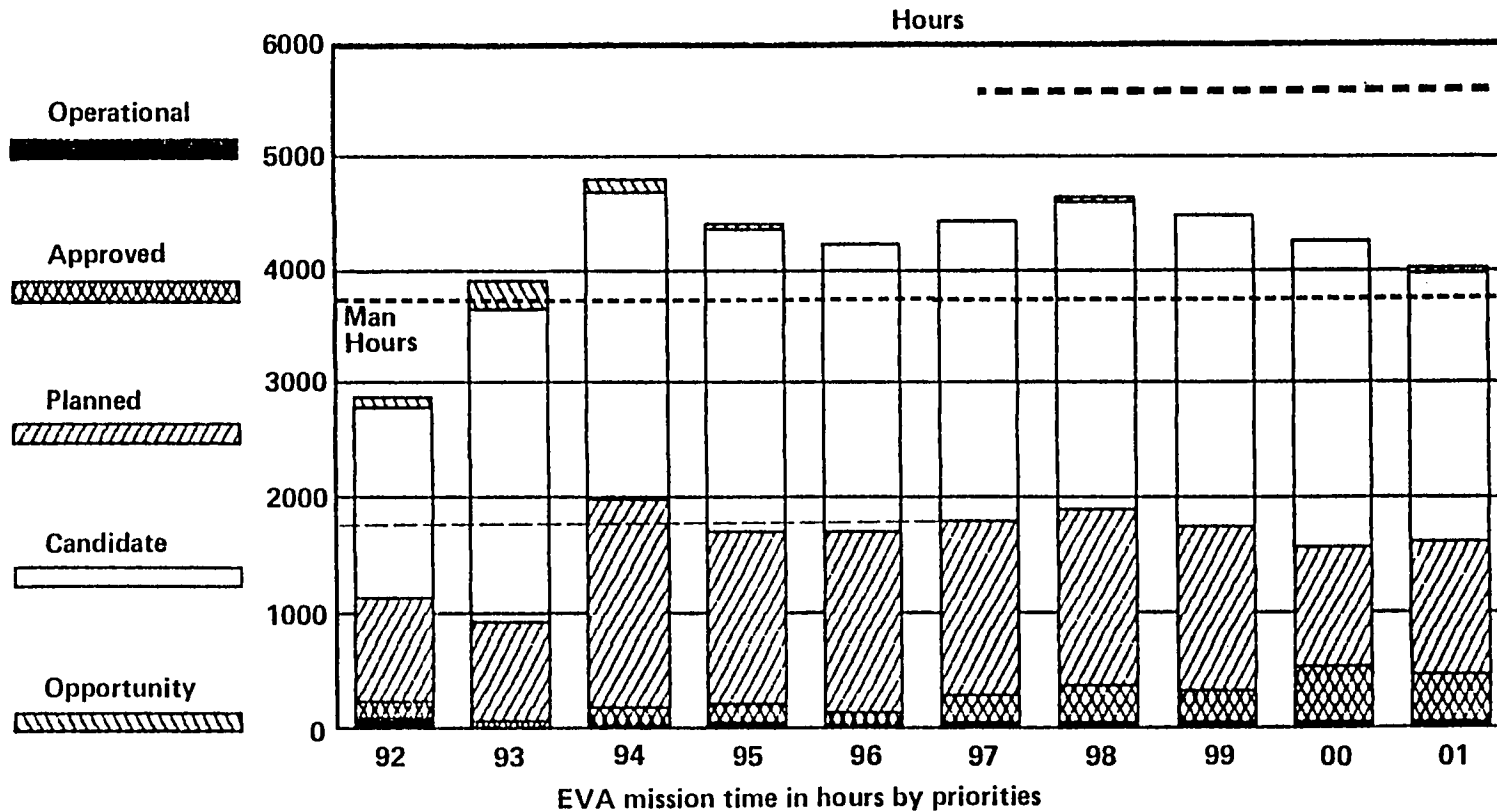
Note 2 - Does include Space Station construction (not in Langley data base) and OMV OTV time



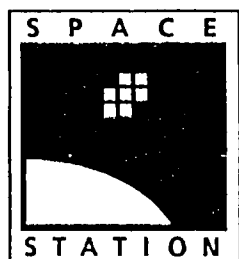
EVA Mission Results Summary

Total EVA Mission Times

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- IOC - - - - - 1872 EVA elapsed hours per year at 6 hours a day, 6 days per week 2 crews (3744 Man Hours)
- Growth - - - - - 3774 EVA elapsed hours per year at 6 hours a day, 6 days per week 4 crews (7488 Man Hours)
- Growth - - - - - 5616 EVA elapsed hours per year at 6 hours a day, 6 days per week 6 crews (11232 Man Hours)



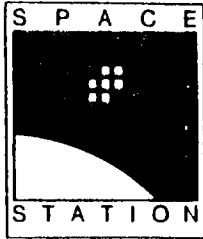
EVA Mission Results Summary

EVAS Mission Timeline Summary (Continued)

Total EVA Mission Times at Space Station –JSC Data Base (From Langley May 1985)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Space Station less Polar COML, TDMX, SAAX	2274	3806	4512	4209	3938	4260	4444	4271	4080	3891
Space Station maintenance and repair hours	1200	1200	1200	1200	1800	2400	2400	3000	3600	3600
Total EVA serial mission hours	3474	5006	5712	5409	5738	6660	6844	7271	7680	7491
Overhead	200 + 225	200 + 741	200 + 727	200 + 628	300 + 445	400 + 487	400 + 572	500 + 435	600 + 476	600 + 495
Productive mission* hours required	3049	4065	4785	4581	4993	5773	5872	6336	6604	6396
Number of crews	2	2	2	2	4	4	4	6	6	6
Crew effectiveness index	1.333	1.471	1.563	1.613	1.486	1.568	1.615	1.538	1.592	1.627
EVA manhours**	2712	3704	3988	3668	4105	4568	4608	5055	5224	5026
Available hours Surplus/Def.	3744 + 1032	3744 + 40	3744 - 244	3744 + 76	7488 + 3383	7488 + Large	7488 + Large	11232 + Large	11232 + Large	11232 + Large

- * NOTE 1: IOC crew of two; first growth crew of four; second growth crew of six
- ** NOTE 2: EVA manhours = (Productive mission hours required ÷ crew effectiveness) x number of crews + overhead
 100% crew effectiveness = 2 for a crew of two; 0% effective = 1 for a crew of two
 Scheduling efficiency = 100%. No contingencies. No EVA equipment downtime. No sickness. No mistakes.



EVA Mission Results Summary

EVA Mission Scenarios

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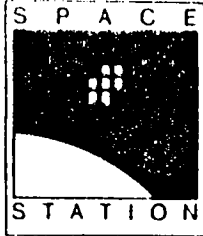
IOC

- Space Station proximity EVA transported by elevator/MRMs/MMU
- Co-orbiting low-Earth-orbit (LEO) satellites EVA transported by shuttle or satellites returned to station by OMV for EVA service
- Polar orbiting LEO satellites via shuttle and OMV retrieval

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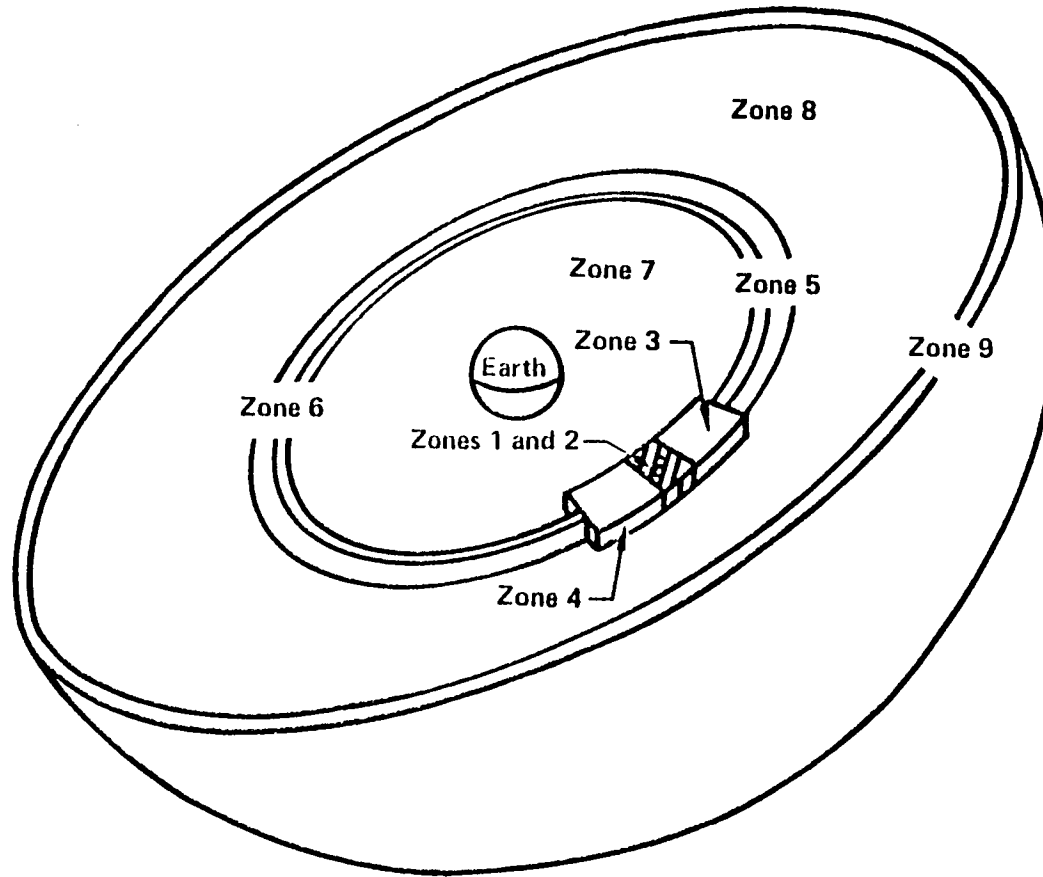
Growth

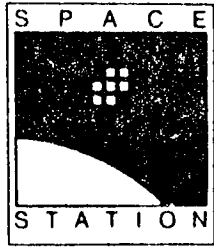
- Space Station proximity EVA transported by elevator/MRMs/MMU (no change)
- Coorbiting LEO satellites EVA transported by OMV/OTV
- Polar-orbiting LEO satellites EVA transported by shuttle and OMV/OTV or OTV from Space Station
- Geodetic-Earth-orbit (GEO) satellites EVA transported by OTV



Cutaway View of Operational Control Zones (Hemispherical Cutaway)

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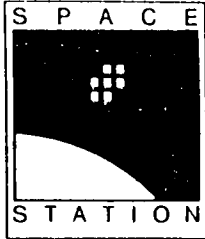


EVA Mission Results Summary

Space Station Phase B Requirements Comparison to Mission Requirements

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- **Agree with most requirements of Space Station RFP**
- **Items requiring further analysis – current recommendations**
 - **Duty cycles – 6 hours of EVA per day, 8 hours later**
 - **EVA time allocation – could be increased with new EMU**
 - **Operational control zones – reduce distances**
 - **Restraint systems design – open for more general purpose type**
 - **MRMS usage and availability – multiple, remote EVA operation**



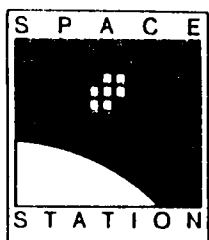
Advanced EVA System Design Requirements Study

Recommended Trade Studies – Phase B

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- **Internal versus external air lock** [Program decision for external]
 - EVAS size
 - Fixed versus movable
 - Volume requirements
 - Emergency conditions
 - Module commonality

- **Space Station pressure versus operational/design considerations**
 - Leakage
 - Meteoroid/space debris puncture
 - Entry - exit needs
 - Shell thickness and structure
 - Consumables losses
 - Pre/post EVA time
 - EVA duty cycle and duration
 - EVA crew size
 - Baseline versus growth
 - EVAS pressure (9.5 psi to 1 ATM)
 - Shuttle pressure (1 ATM)
 - Emergency conditions
 - EVA work location versus air lock location
 - EVA - IVA human productivity[Program decision for 14.7 or 1 ATM]

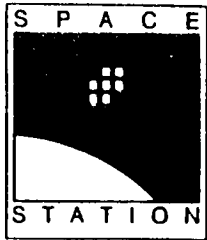


Advanced EVA System Design Requirements Study

Recommended Trade Studies – Phase B (Continued)

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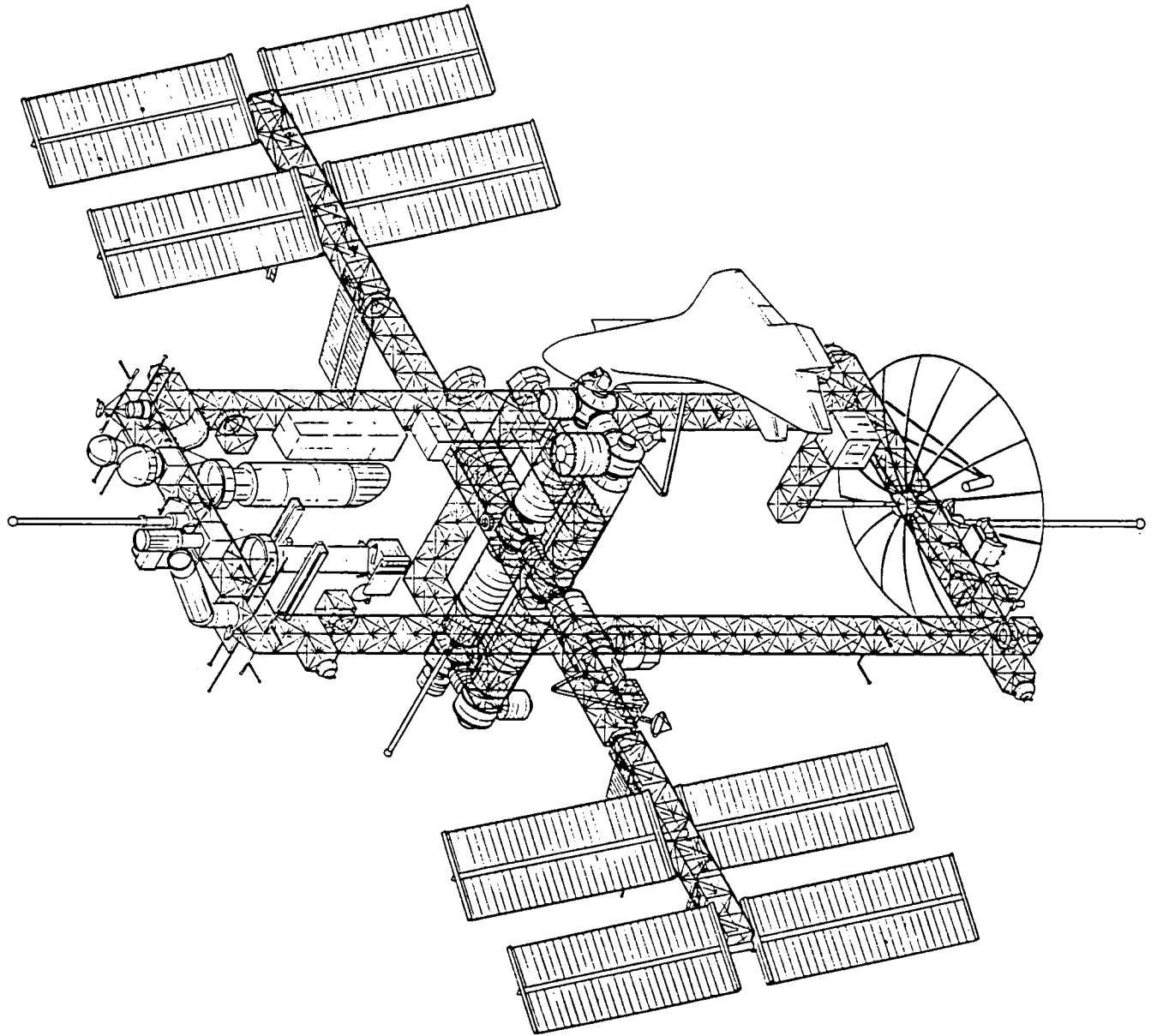
- **Number versus portable versus fixed/location**
 - **Hand holds versus translation rails/wires**
 - **Workstations**
 - **Foot restraints**
 - **Lights for both translation and workstation**
 - **Closed circuit TV**
 - **External equipment hold down points**
 - **EVAS servicing stations**
 - **Utility outlets for propellants, fluids, gases, data and electric power**
 - **Powered translating devices**
 - **Micrometeoroid protection**

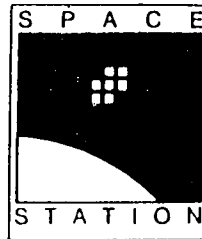


Advanced EVA System Design Requirements Study Recommended Trade Studies — Phase B (Continued)

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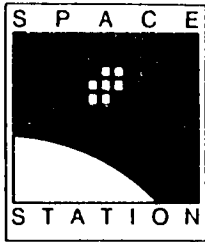
- **Facilities number and location /degree of automation**
 - Refueling facility
 - Maintenance facility, enclosed versus open platform
 - Attached construction platform
 - Storage facility/platform
 - External decontamination facility
 - OTV and OMV storage and maintenance facility
 - Experiment mounting platforms
- **Altitude and orbital inclination versus flux and distribution of partial radiation exposure**
- **Passive versus active radiation protection**





EVA System Design Requirements Summary

Paul Meyer

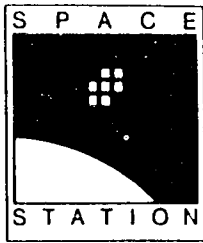


Advanced EVA System Design Requirements Study

EVA System Design Requirements Summary

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- **Consideration of issues**
- **Technology survey**
- **EVAS Requirements Recommendations**
- **Shuttle orbiter – EVAS interfaces**



EVA System Design Requirements Summary Issues and Conclusions

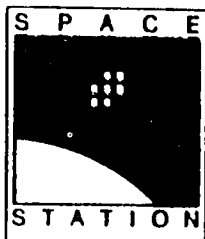
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Issue List

- Space Station EMU pressure select
- Suit design loads, operating life and safety factors
- Requirements and test criteria for high energy radiation
- Astronaut anthropometrics
- Contamination limits
- Definition of micrometeorite/space debris threat
- Accident profiles
- Environmental protection requirements

Conclusions

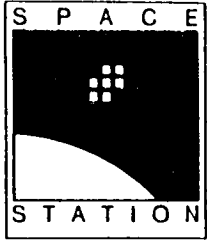
- Pressure selected as one atmosphere SS 9.5–10.2 psia or higher EMU
- Shuttle EMU short opn life—Design for on-orbit maintenance
- Need 1.62 gm/cm² hard suit—need additional for GEO
- Use 95% U.S. male/25% U.S. female at IOC and full scale range at FOC
- Design/require low leakage (< 25 cc/min)
- Require/design non-venting PLSS
- Cover sensitive instruments
- Design instruments to be cleaned
- Establish an experiment to better define the threat
- Most likely serious accident is suit puncture/decompression
- Need portable rescue bag/device at work site
- Require rapid puncture detection warning
- Improved EMU suit and LSS design



Technology Criticality Category Table

BDEIND

Level	Call-out	Definition
1	Basic principles	Basic principles have been observed and reported
2	Concept designed	Conceptual design has been formulated
3	Concept validated	Conceptual design has been validated or tested analytically or experimentally
4	Critical function demonstrated	Critical function or characteristic has been demonstrated
5	Breadboard lab tested	Component or breadboard has been tested in relevant environment
6	Model lab tested	Prototype/engineering model has been tested in relevant environment
7	Space tested	Prototype/engineering model has been tested in space
8	On-the-shelf	Item is on-the-shelf and is qualified or is qualifiable with minor modifications



EVA System Design Requirements Summary

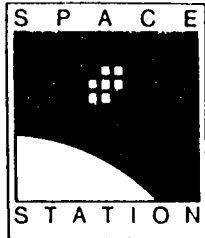
Technology Survey Area Recommendations

BOEING

Technology area

Recommendation

- High pressure suit technology (level 5)
 - Configuration for rapid don/doff (level 4)
 - High mobility, long term wear (level 5)
 - Improved data display, storage and command (level 5)
 - Hard structure thermal insulation (level 6)
 - Design for on-orbit repair, maintenance and servicing (level 4)
 - On-orbit fit check/resizing (level 8)
 - Automatic pre-EVA servicing and checkout (level 1)
- Increased emphasis on high pressure glove development
Build/require high pressure suit
 - Top/back closure entry
 - Joint/glove wear development
Use arms-in—philosophy
 - Develop high density portable read write device—in-suit voice control
 - Require reflective polished surface
 - Emphasize modularity, component placement and sizing
 - Limit IOC population
 - Develop automatic servicing and checkout procedures—system with in-suit BITE



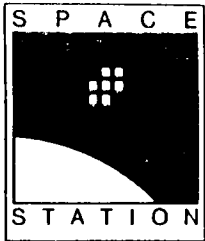
EVA System Design Requirements Summary Technology Survey Area Recommendations (Continued)

BOEING

Technology area

Recommendation

- | | |
|--|--|
| • Automation in-suit thermal control (level 6) | • Require automatic thermal control with set point control |
| • Controlled effluent EMU (level 3) | • Require and develop 8 hour non-venting thermal loop and minimum suit leakage |
| • Basically regenerable EMU (level 2) | • Require regenerable CO ₂ loop and develop |
| • Mechanical end-effector/suit interface (level 4) | • Develop end effector/tools |
| • Generic workstation (level 8) | • Require generic work station |
| • MMU caution and warning (level 8) | • Require adequate C&W |
| • Modular/integrated LSS (level 4) | • Require modularity and component replacement |
| • Space suit glove performance (level 2) | • Develop high pressure glove
Require dual pressure suit |



EVA System Design Requirements Summary

EVA System/Requirements and Concepts

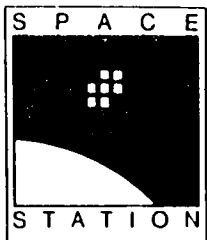
BOEING

Requirements

- Projected Space Station Mission Requirements will use all available EVA time.
- Recommend EVAS—Space Station interface shall include specified level of automation
- EMU shall be a hard enclosure
 - Modular for on orbit fit
 - Dual pressure 9.5 psia and 10.2 psia
 - Thickness for radiation and puncture protection
- EMU Life Support System (LSS) shall be regenerable, non-venting modular and flexible of construction
 - Full backpack
 - Backpack + carry pack
 - Backpack + umbilical
- EMWU or Pod shall be developed and operated for growth Space Station

Ref. Program Benefit/Impact

- | | |
|--------------------------------|---|
| Task 1
WP-6 | Clarifies the need and importance to Space Station of Automation and the Advanced EVAS |
| Task 3 | Provide a systems approach to interface and subsystem development |
| Task 2
WP-4
WP-2
WP-1 | Provide high astronaut EVA protection EVA protection and EVA and Space Station productivity |
| Task 2
WP-5 | Minimize consumables and contamination; tailor EMU to task, support on orbit maintenance, accommodate future growth |
| Task 2
WP-4 | Provide a bridge to robotic operation; higher EVA protection and productivity |



EVA System Design Requirements Summary

EVA System/Requirements and Concepts (Continued)

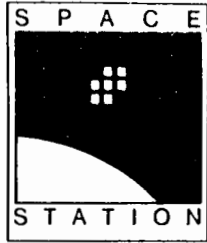
BOEING

Requirements

- Develop a high pressure glove and in parallel an end effector/tool combination with settable grip pressure.
- Develop an autonomous EVA airlock/work station for remote EVA operations in conjunction with OTV
- Recommend hyperberic chamber to 2.8 A rather than 6 atmospheres.
- Develop on-suit data storage/display device; and voice control of BMU
- Recommend use of industrial standards for radiation limits.
- Recommend anthropometric sizing range at IOC to 95% U.S. male to 25% U.S. female and growth to 5% oriental female

Ref. Program Benefit/Impact

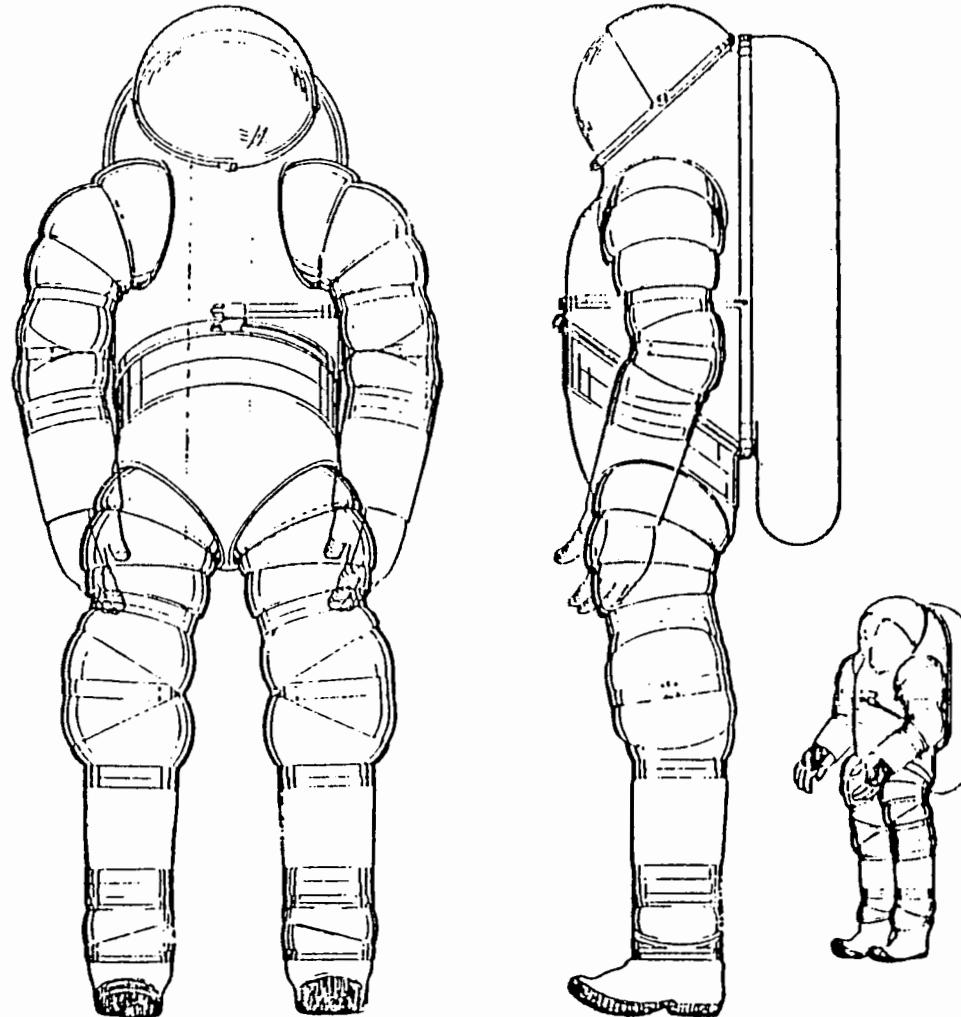
- Task 2
WP-9 Improved crewman productivity in operating at the higher pressure.
- Task 2
WP-10 Provide operational flexibility and a module for EVA support anywhere.
- Task 2
WP-10 Eliminates a nonrequirement based on deep sea technology
- Task 2
WP-4
WP-10 Provide reduced load on communications; link, more reusable data; support two handed operation.
- Task 2
WP-2 Provide longer crew life for Space Station
- Task 2
WP-3 Provides reduced initial logistic problems with smaller crew size

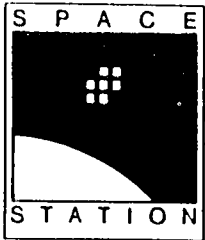


EVA System Design Requirements Summary

Advanced EMU Hard Suit Concept

BOEING





EVA System Design Requirements Summary

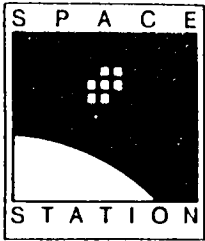
EMU Suit Concept Comparison

BOEING

Suit characteristic	Shuttle suit	Hybrid suit**	Hard suit
High pressure mobility	No	Yes	Yes
Zero pre-breath SS pressure data	No	Yes	Yes
Rapid don/doff	No	Yes*	Yes
Radiation protection	Limited	Partial	Full
Micro-meteoroid/ space debris protection	Yes w/TMG	Yes w/TMG	Yes
Thermal insulation	Yes w/TMG	Yes w/TMG	Inherent with polish
Contamination protection—hydrazene	None	Some	Yes
Decontamination	Hard	Easier	Easiest
On-orbit fit check and resizing	No*	Yes	Yes
On-orbit maintenance	No*	Design to	Design to
Operational life	Limited*	Yes	Yes
Automatic checkout	Limited*	Design to	Design to
Development costs	No*	Yes	Yes
Recurring costs	High	Less	Least

*Could meet requirement with new development and then development cost would be more

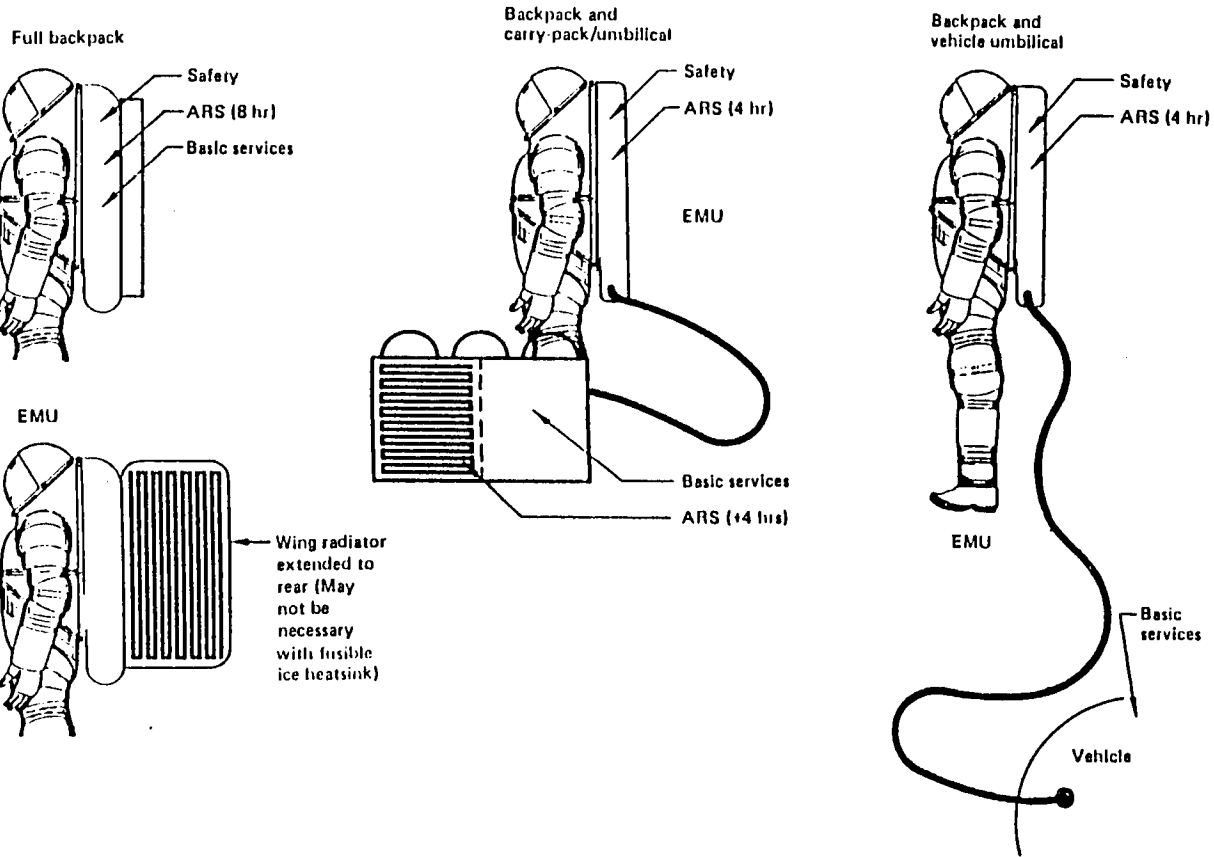
**Hybrid suit has fabric joints

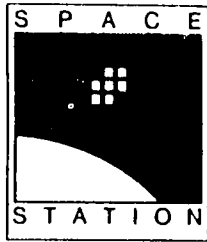


EVA System Design Requirements Summary

EMU Modular Configurations

BOEING

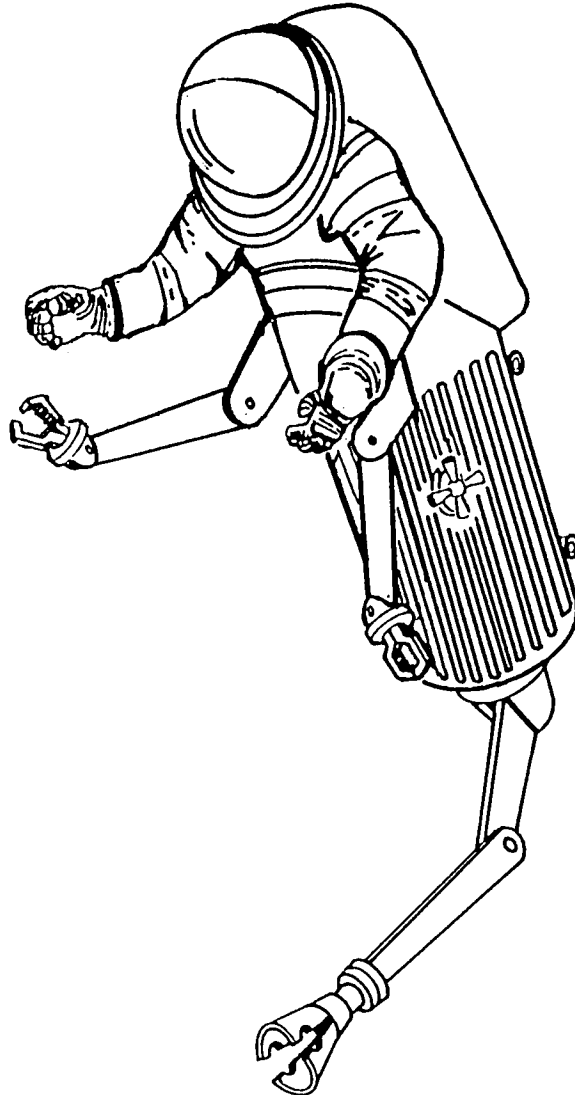


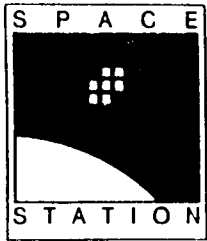


EVA System Design Requirements Summary

EMWU or Pod

BOEING

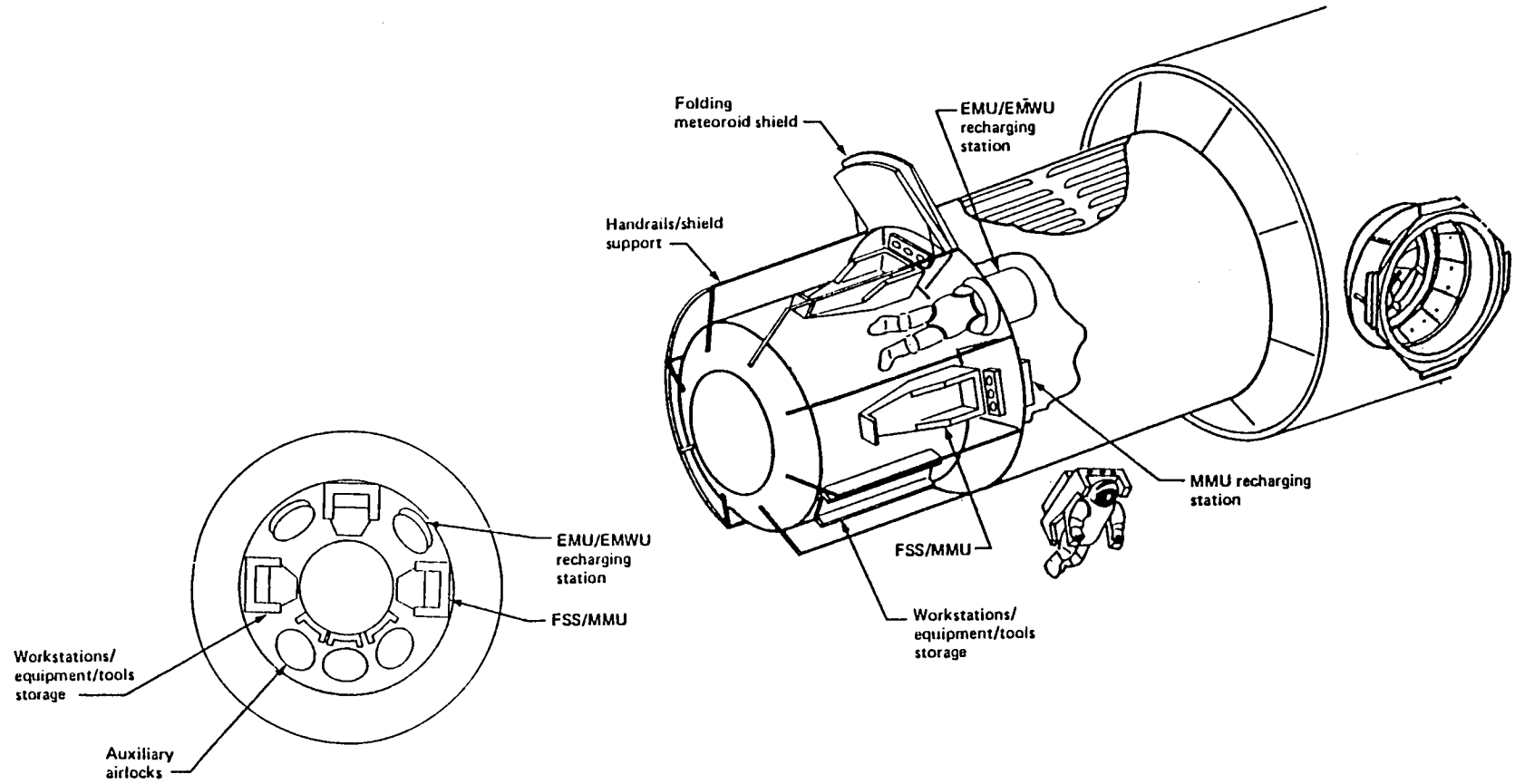


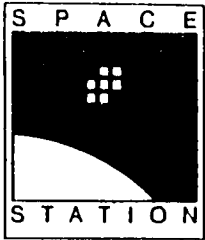


EVA System Design Requirements Summary

EVA Airlock

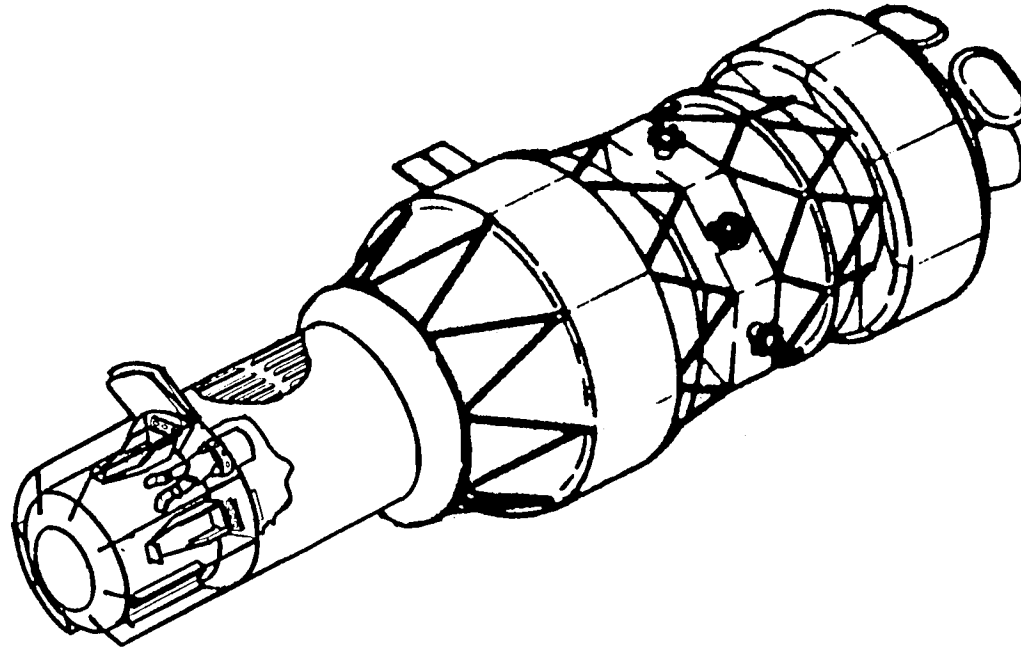
BOEING





EVA System Design Requirements Summary OTV with EVA Airlock

BOEING



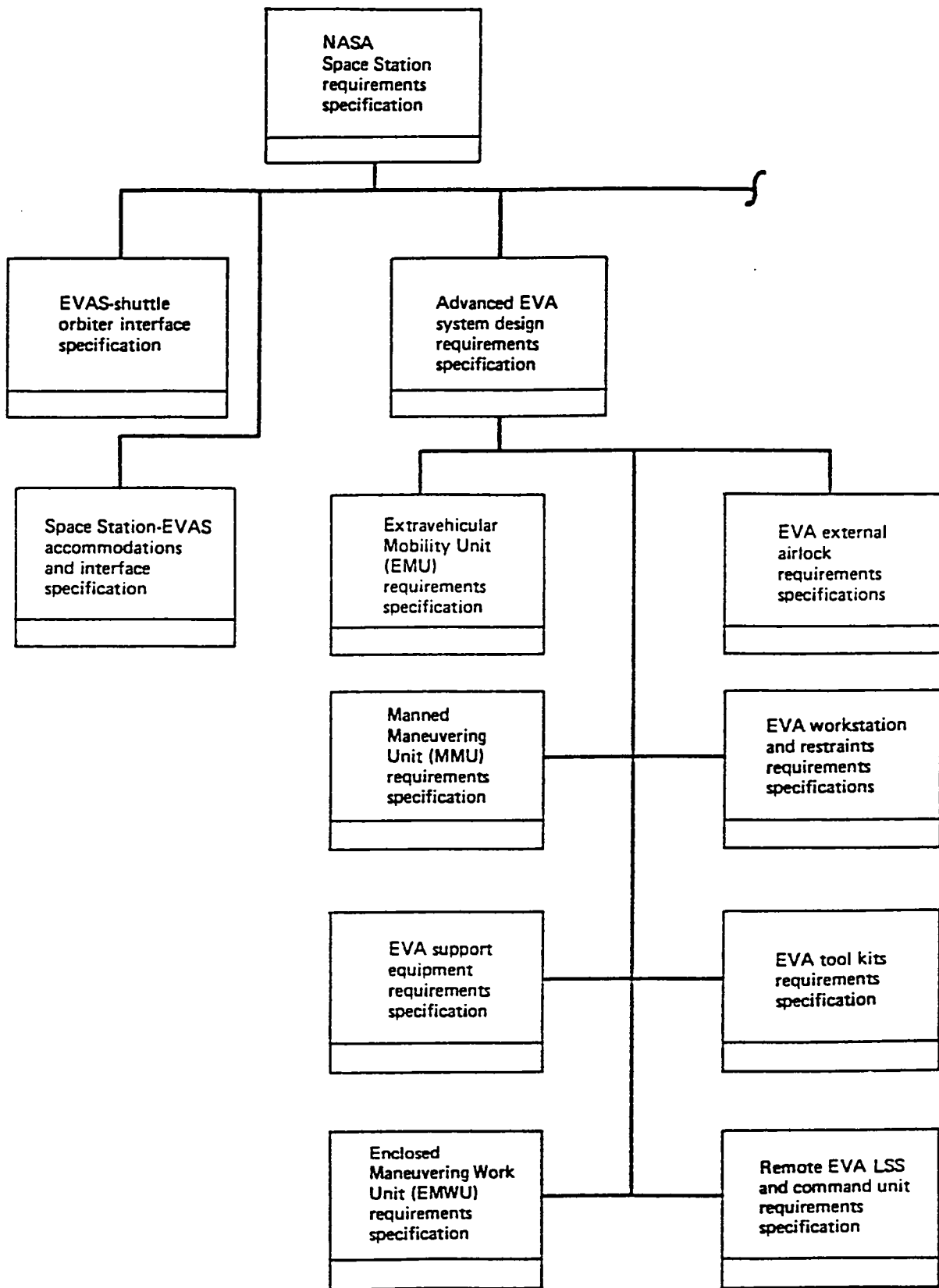
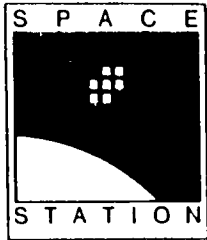


Figure 3.1.4-2. EVA System Specification Tree

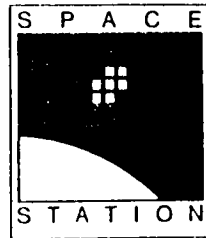


EVA System Design Requirements Summary

Shuttle Orbiter-EVAS Interfaces

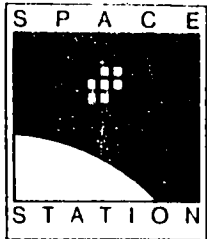
BOEING

- Shuttle orbiter modifications to accommodate advanced EVAS
 - Airlock modification to accommodate advanced EMU automatic servicing checkout and storage
 - Addition of digital voice communications and digital data transmission capability to the EMU during EVA
 - Software modifications to accommodate data management requirements of advanced EVAS for
 - Caution and warning trend data
 - Mission related procedures and technical data



Space Station EVA Requirements and Interface Accommodations Summary

Joe Thompson



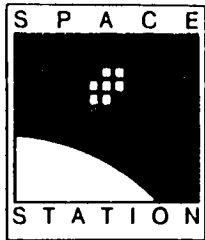
Advanced EVA System Design Requirements Study Midterm Review: Space Station EVA Requirements and Interface Accommodations Summary

BOEING

Space Station/EVA interface requirements

- Atmosphere composition and pressure selection [Selected]
- Communications compatibility
- Data management effectiveness
- Logistics requirements *
- EVA safe haven provisions—interior and exterior *
- Autonomy for Space Station and EVA systems *
- Space Station interior compatibility with EVA systems *
- Space Station exterior relationship for EVA missions *
- Airlock configuration—compatibility with EVA systems

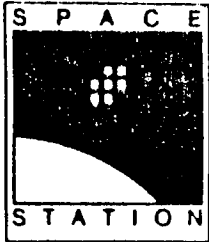
* Same as RFP



Space Station EVA Requirements and Interface Accommodations Communications Compatibility

BOEING

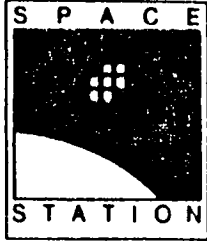
- **Space Station requirements (range 1 km, 0.54 nmi) (zone 1)**
 - **Line-of-sight communication and tracking**
 - **Voice conferencing (IVA/EVA/manned vehicles/ground)**
 - **One-way (freeze frame, compressed, slow scan) TV from EMU**
- **EVA system requirements**
 - **Integration of more than two EVA crewmembers**
 - **Identify voice level and quality requirements**
 - **Integral helmet microphone-speaker system versus “snoopy” communication CAP system**
- **Identified problems—existing system**
 - **Response delay—voice-triggered microphone**
 - **Position shift of snoopy communication CAP system**
 - **Line-of-sight requirements limits mission capability**
- **Potential options**
 - **Integral bone microphone-receiver**
 - 40-dB attenuation—background noise
 - Potential use for heartbeat and respiration measurement
 - Commonality potential for IVA application
 - **EMU helmet-mounted microphone speaker**
 - Atmosphere diving-suit application
 - Voice control/recognition



Space Station EVA Requirements and Interface Accommodations Data Management Effectiveness

BOEING

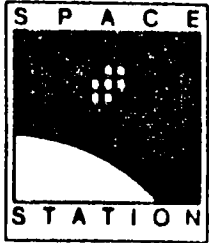
- **Space Station requirements**
 - Support for both EVA and IVA operations
 - Support for crew training
- **EVA system requirements**
 - Integration of more than two crewmembers
 - Quantify limits of usable data as displayed
 - Identify control documentation and data requirements for on-orbit autonomy
 - Identify viable EVA training techniques—faster training turnaround
- **Identified problems**
 - Need for reduced on-ground training time and equipment
 - Accrued radiation exposure data—individual EVA crewmember
- **Potential options**
 - On-job-training in orbit
 - IVA videotape task review prior to EVA
 - EVA TV procedure presentation (workstation only)
 - More generic ground training



Space Station EVA Header Requirement and Interface Accommodations EVA/Airlock Interface

BEING

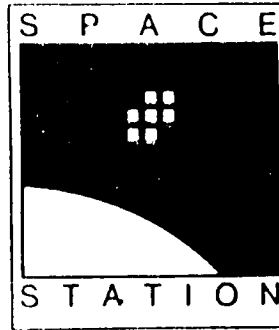
- **Space Station Requirements**
 - **Two EVA Airlocks will be provided.**
 - **Each airlock will accommodate 2-crew member transfer**
 - **EMUS shall be stowed inside airlocks**
 - **Airlocks shall accommodate donning/doffing unaided**
 - **EMU capable of being resized in airlock**
 - **ECLSS service equipment (critical functions for EVA) continuously verified**
 - **One airlock shall have two-crewman hyperbaric chamber capability**
 - **90% of airlock gas recovered by pumping gas into space station**
 - **Life support umbilicals available outside pressurized areas for umbilical EVA operation**
 - **EVA equipment and spares stowage inside space station and outside of EVA airlock**
- **EVA System Requirements**
 - **Volume, hatch size, location of controls, lighting, umbilical operations, requirements for multi-crew utilization and location with respect to traffic patterns and optimum parallel use of all space station volume**



Space Station EVA Requirements and Interface Accommodations EVA/Airlock Interface (Cont'd)

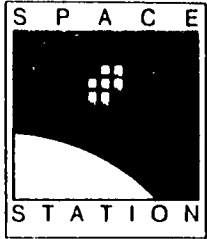
Recommendations to date

- Extensive EVA mission baseline and repair potentials indicate semiautonomous external (movable) airlock best satisfies missions (power, status monitoring, ECLSS recharge)
 - External airlock to include the following:
 - Two-chamber configuration
 - One chamber minimum volume—egress/ingress only
 - Second chamber internal configuration to include:
 - Suit don/doff
 - Maintenance facility—suit spares storage
 - Tool storage
 - Internal EMU recharge station
 - External MMU recharge station
- Hyperbaric capability for 2.8 atmospheres
- Incorporate as part of EVA system



Human Productivity Study Cross-Task Coordination

Joe Thompson



Advanced EVA System Design Requirements Study Midterm Review: Human Productivity Study Cross-Task Coordination

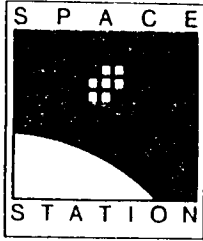
BOEING

Received from human productivity study

- Human productivity elements & subelements
- Human productivity requirements and candidate solutions for EVA interfaces
- Space Station—EVAS interface definitions
- Issues considered with EVAS impact

Provided to human productivity study

- Preliminary interface definitions
- EVAS study planned products
- EVA task parameters, equipment, and tools
- Comments on human productivity study issues



EVA System Design Requirements Summary

EVAS Technology Advanced Development Program

BOEING

- Group A **Suit Architecture:**
 - Hard suit top entry closure plane
 - Automatic servicing and checkout
 - LCVG operational life

- Group B **Gloves and End Effectors Dexterity:**
 - High pressure long-life dextrous glove
 - End effector with setable grip pressure
 - End effector sensor development

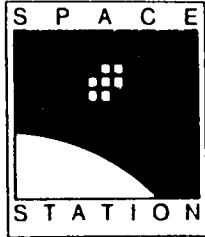
- Group C **Translation Technology:**
 - Investigate non-contaminating translation technology
 - EMWU development

- Group D **Data Display, Control, and Storage:**
 - Portable high density storage device for EVA
 - Display development
 - Voice control

- Group E **Work Station Technology:**
 - Generic work station

- Group F **Life Support:**
 - Regenerable CO₂ sorbent development
 - Ice pack heat sink development
 - Automatic thermal controls for LSS

- Group G **Packaging for on-orbit maintenance:**
 - Develop approaches to ORU development



Advanced EVA System Design Requirements Study Final Review

BOEING

- **Introduction – Joe Thompson**
- **EVA mission survey results final summary (task 3.1) Joe Thompson**
- **EVA system baseline design requirements final summary (task 3.2) – Paul Meyer**
- **Space Station EVA requirements and interface accommodations summary (task 3.3) – Joe Thompson**
- **Human productivity study cross-task coordination (task 5.0)– Joe Thompson**
- **Recommended EVAS Technology Advanced Development Program Joe Thompson**

**ADVANCED EVAS PHASE A STUDY
IMPLICATIONS FOR MAN-SYSTEMS DESIGN**

FRED ABELES

**SPACE STATION HUMAN FACTORS RESEARCH REVIEW
NASA Ames Research Center**

December 3, 1985

OBJECTIVES

PRIMARY

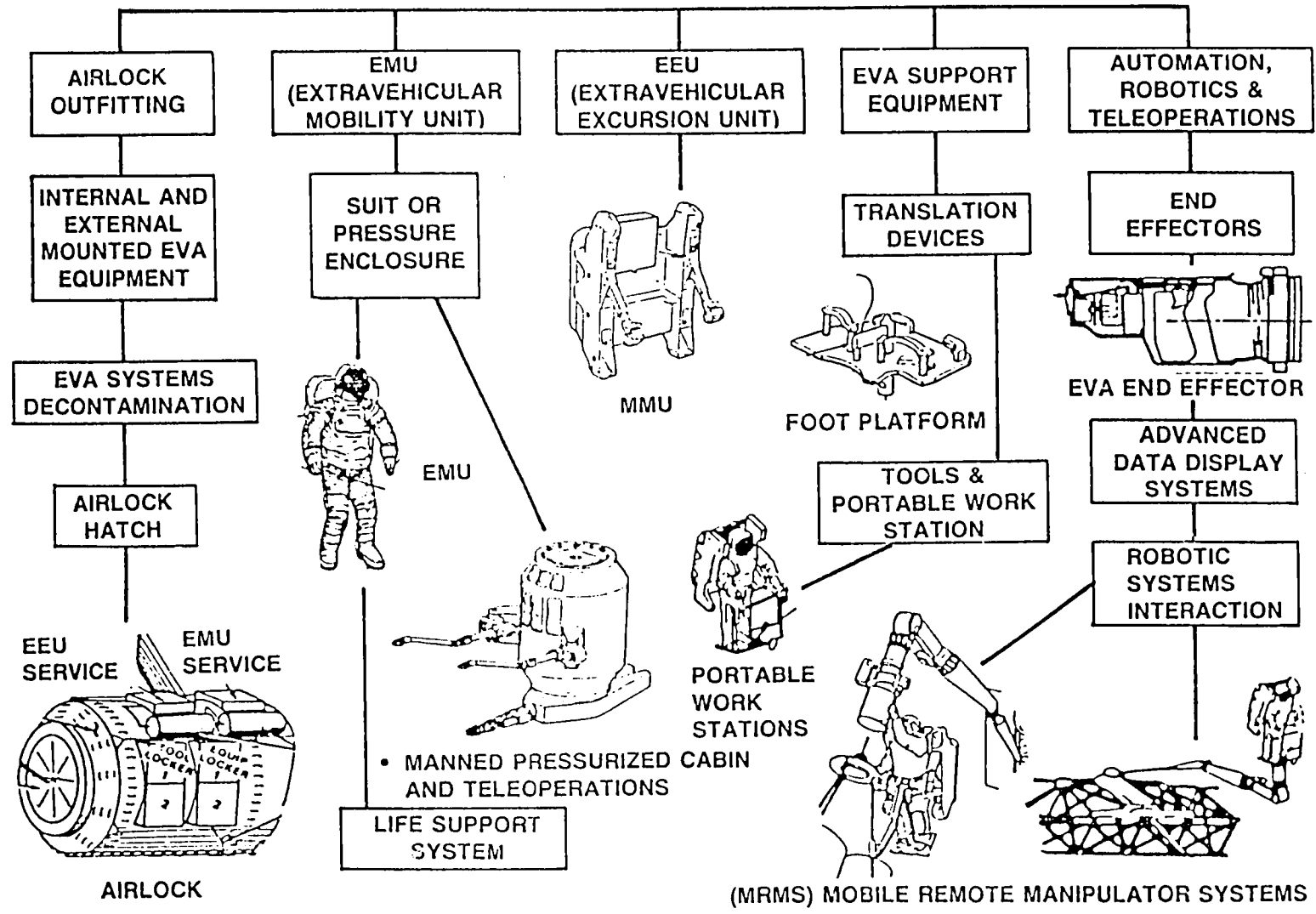
- ESTABLISH EVA HARDWARE SYSTEMS AND COMPONENT DESIGN REQUIREMENTS (STRAWMAN)
- ESTABLISH SPACE STATION EVA ACCOMMODATION REQUIREMENTS AND EVA INTERFACES (STRAWMAN)
- DEFINE TECHNOLOGY AND ADVANCED DEVELOPMENT EFFORT REQUIRED TO SATISFY ESTABLISHED DESIGN REQUIREMENTS

OBJECTIVES (CONT'D)

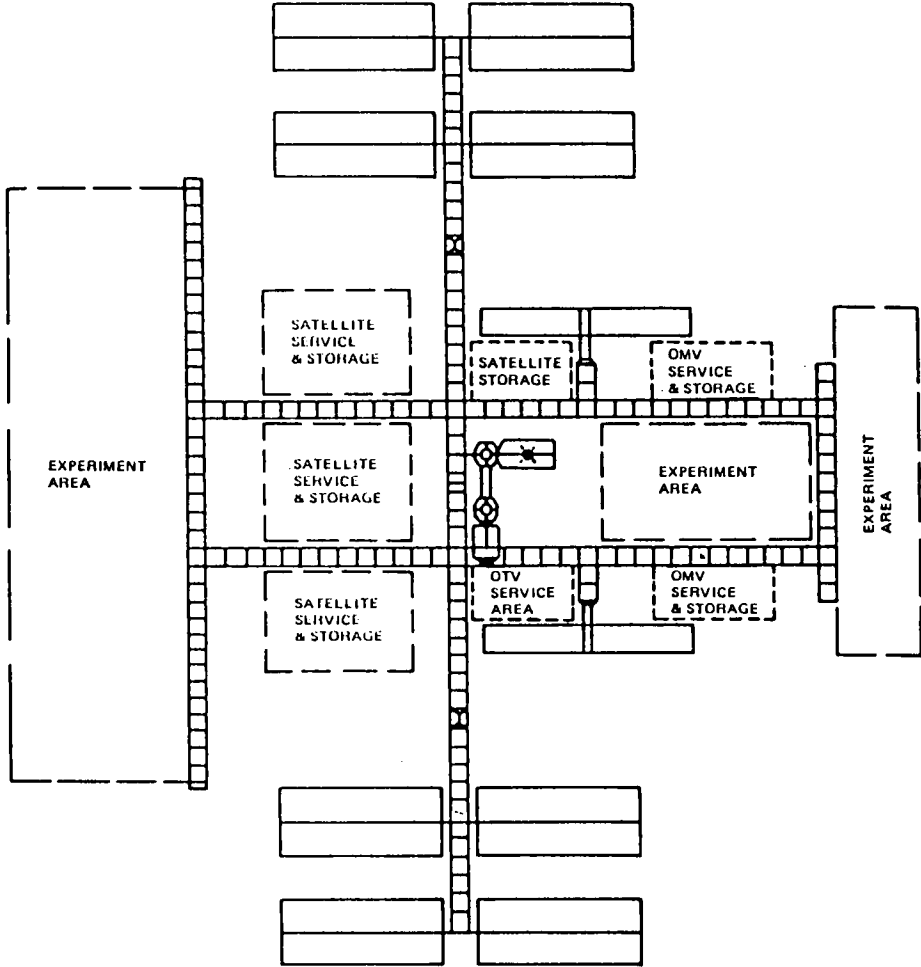
RELATED

- **IDENTIFY SHUTTLE INTERFACE REQUIREMENTS TO ACCOMMODATE ESTABLISHED EVA SYSTEM CHANGES**
- **DEFINE EVA MISSION AND SPECIFIC EVAS TASK AND EQUIPMENT NEEDS**
- **DEFINE AN EVAS DESIGN REFERENCE MISSION FOR A REPRESENTATIVE 90-DAY TIME PERIOD**

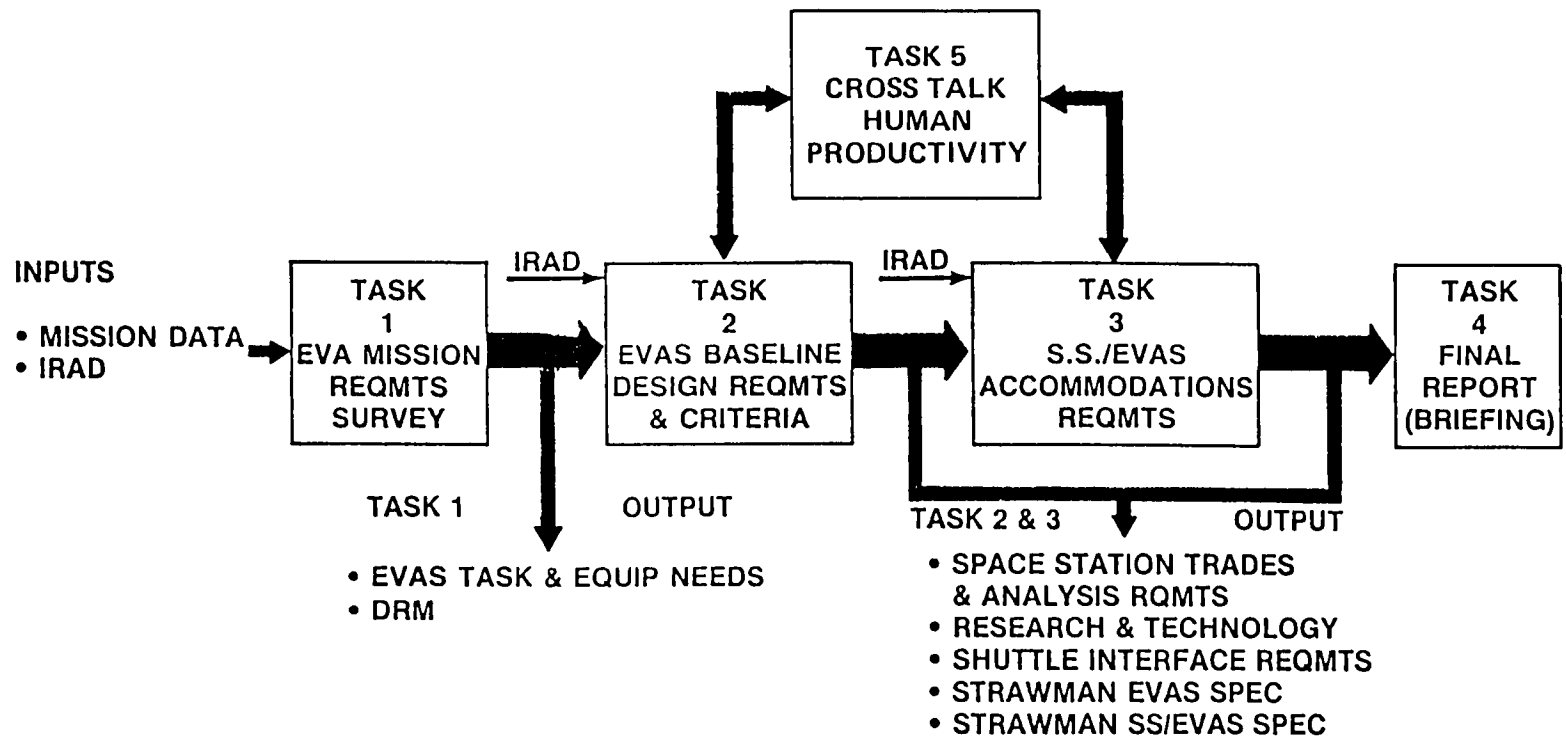
EVA SYSTEM HARDWARE ELEMENT COMPOSITION



SPACE STATION STORAGE & SERVICING AREAS



STUDY FLOW METHODOLOGY



STUDY APPROACH

TASK 1 EVA MISSION REQMTS SURVEY

- DEFINE EVA TASKS

TASK 2 HUMAN & EQUIPMENT REQMTS

- DEFINE HUMAN CAPABILITIES & LIMITATIONS
- DEFINE EQUIPMENT CAPABILITIES & LIMITATIONS
- BASELINE ADVANCED EVA SYSTEM

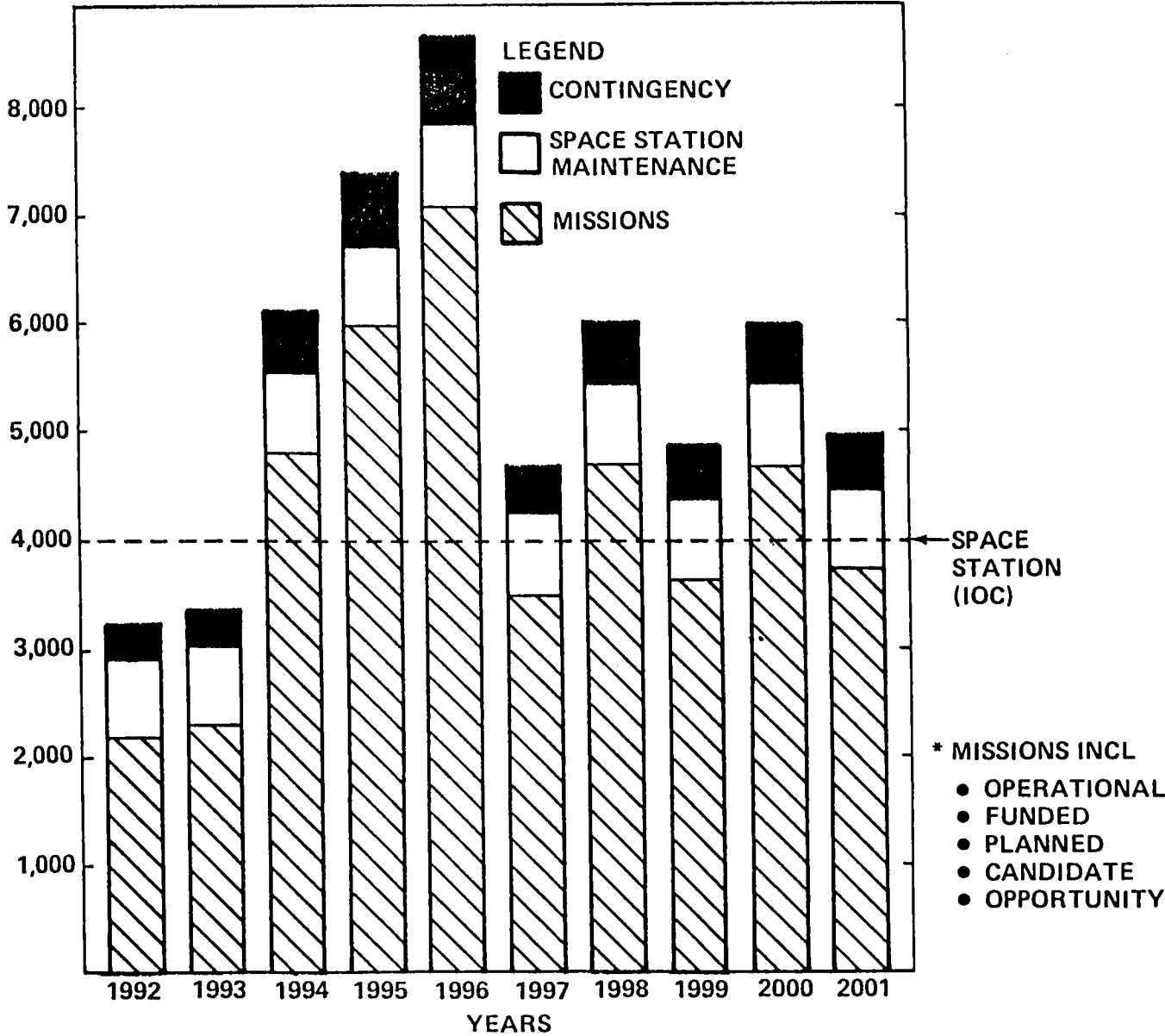
TASK 3 SPACE STATION ACCOMMODATIONS REQMTS

- DEFINE SS INTERFACES/ACCOMMODATIONS
REQUIRED FOR THE AEVAS

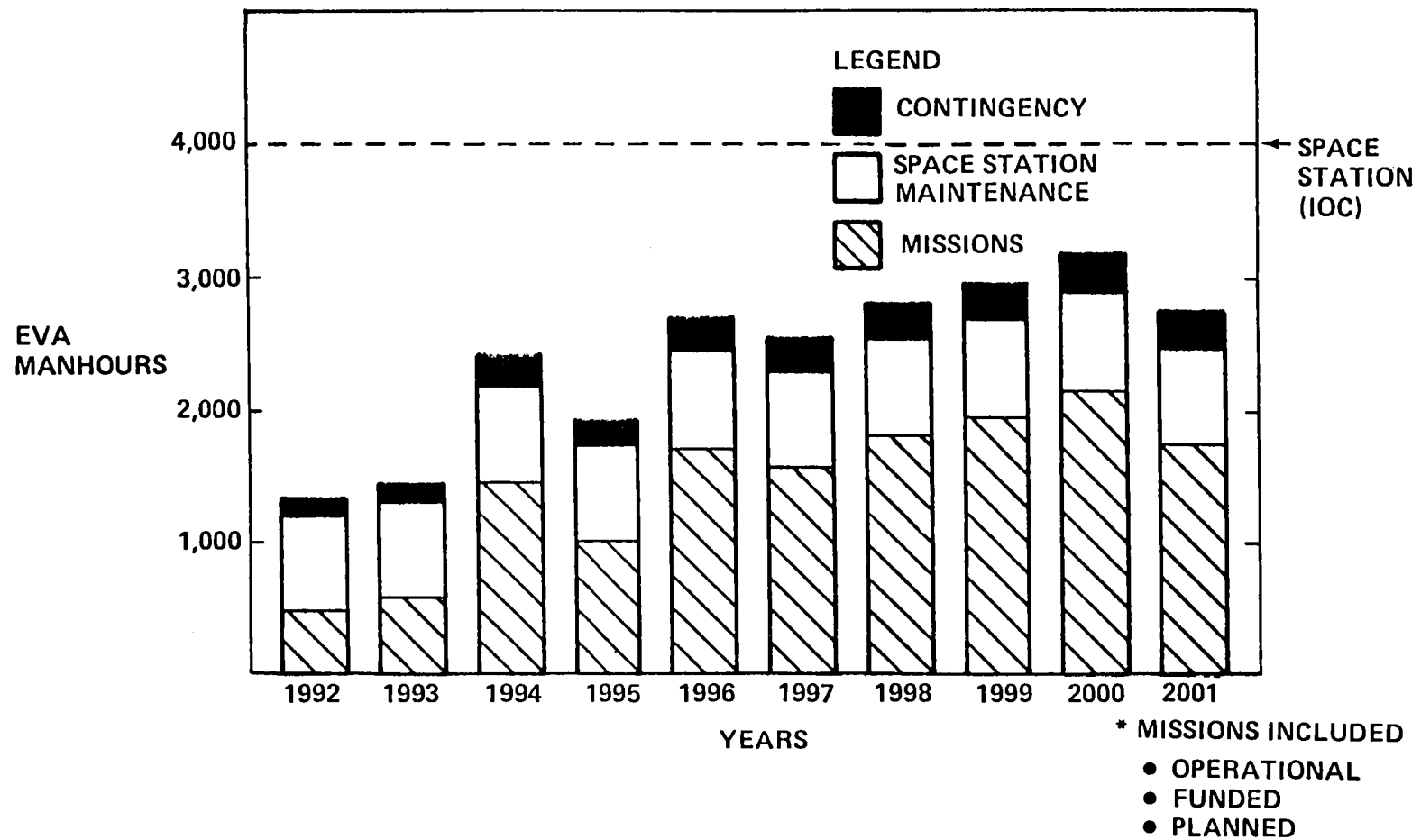
EVA REQUIREMENTS PROCESS

- **ANALYZE MISSIONS TO DERIVE DATA THAT IDENTIFIES:**
 - **REQUIRED FUNCTIONS & TASKS**
 - **BEHAVIORS REQUIRED TO PERFORM TASKS**
- **CONVERT TASK & BEHAVIORAL DATA INTO INFORMATION THAT DESCRIBES:**
 - **EVA SYSTEM REQUIREMENTS**
 - **EVA SUPPORT REQUIREMENTS**

EVA MANHOURS PER YEAR (MAX)*

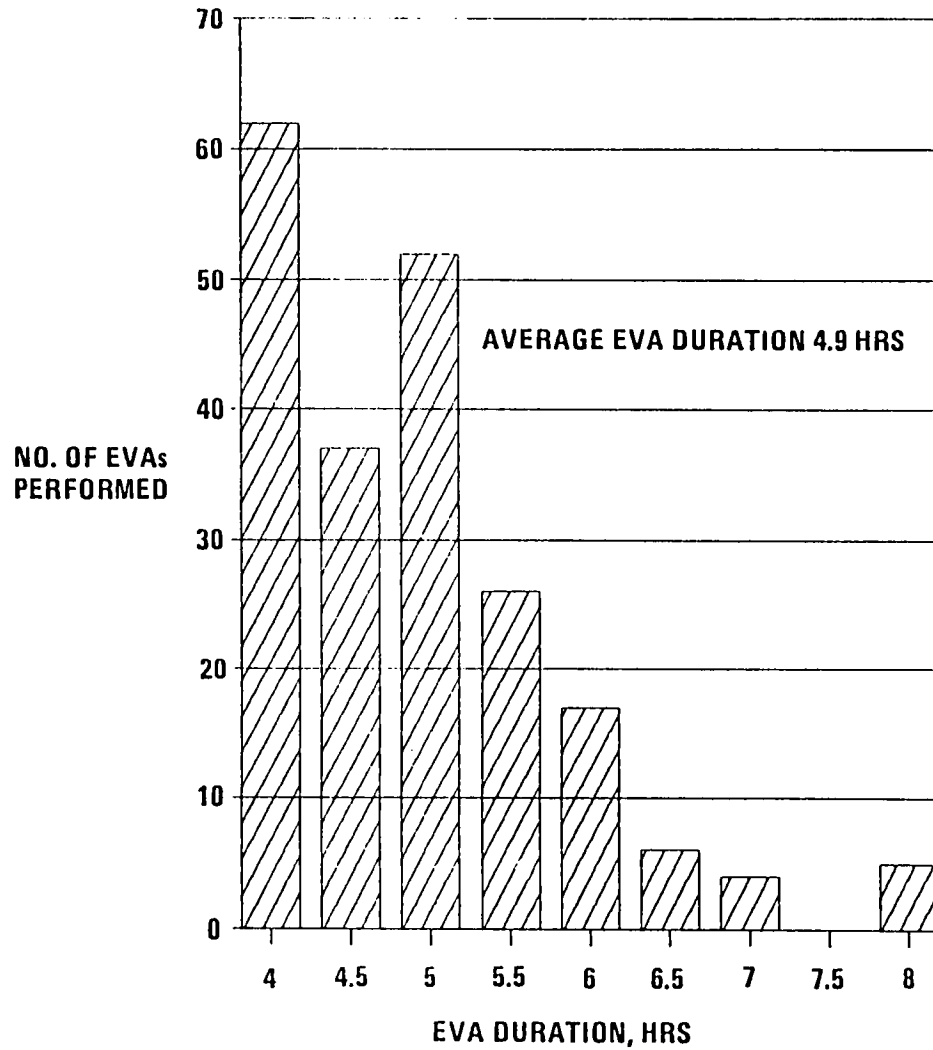


EVA MANHOURS PER YEAR (FIRM)*



EVA HISTOGRAM

DURATION (HRS) VS FREQ. (# PERFORMED)



EVA DESIGN REFERENCE MISSION (DRM)

- 90 DAYS BETWEEN CREW REPLACEMENT
 - 1000 MANHOURS EVA PERFORMED (4000 MAN-HOUR PER YEAR)
 - 4 PEOPLE PERFORM ALL EVA OPERATIONS
 - NO SOLO EVA ALLOWED
 - EVA HOURS DIVIDED EQUALLY
 - MAXIMUM OF 4 PERSONS EVA AT ONE TIME
 - 80 HOURS EVA FOR SS PER WEEK (FLEXIBLE)
 - *MAXIMUM OF 8 HOURS EVA PER PERSON PER DAY
 - *MAXIMUM OF 24 HOURS EVA PER PERSON PER WEEK (FLEXIBLE)
- *TIME ON PLSS

***TYPICAL EVA SPECIALIST WORK DAY (24-HOUR PERIOD)**

ON-DUTY HOURS (12 HOURS)

- A. 9 HOURS – CUSTOMER OPERATIONS (6 EVA, 3IVA; OR 9 IVA)**
- B. 1 HOUR – LUNCH**
- C. 1/2 HOUR – TRAINING**
- D. 1/2 HOUR – REPLANNING**
- E. 1 HOUR – UNSCHEDULED**

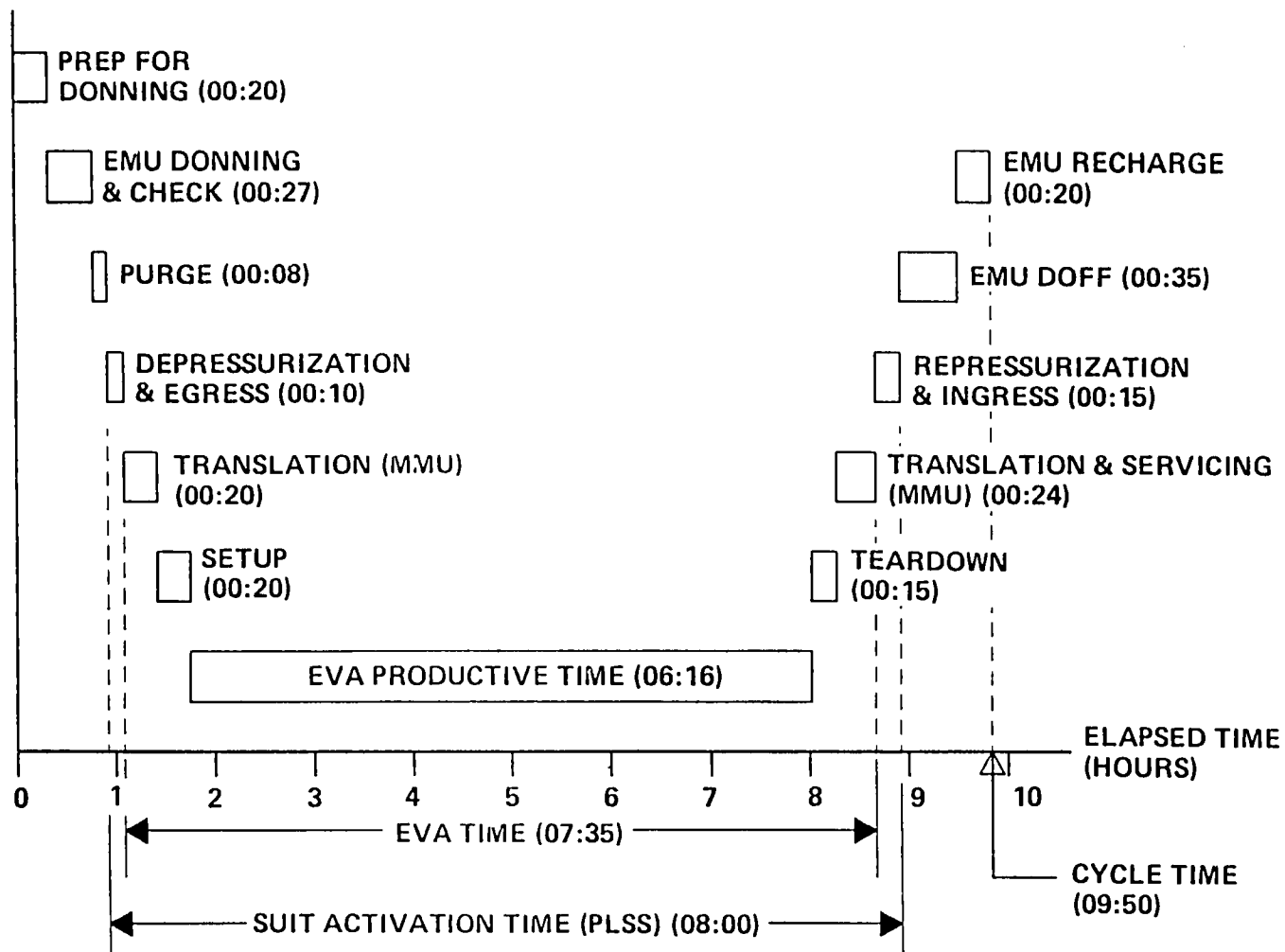
OFF-DUTY HOURS (12 HOURS)

- A. 8 HOURS – SLEEP**
- B. 1 HOUR – PERSONAL HYGIENE**
- C. 1 HOUR – EXERCISE/RECREATION**
- D. 1 HOUR – DINNER**
- E. 1/2 HOUR – BREAKFAST**
- F. 1/2 HOUR – SHIFT HANDOVER**

***SS RFP**

MAXIMUM EVA PRODUCTIVE TIME WITH 8 HR PLSS CAPABILITY & ZERO PREBREATH

56



EVA CYCLE OVERHEAD SUMMARY (8 HR. PLSS CAPABILITY)

<u>SYSTEM</u>	<u>STS 14.3 PSI CABIN</u>	<u>STS 10.2 PSI CABIN</u>	<u>ZPS/AXS 8.3 PSI</u>	<u>ZPS/AXS*</u>
● PREBREATHING	04:00	00:40	00:00	00:00
● AIRLOCK PREPARATION	00:36	00:36	00:36	00:36
● EMU SETUP/TEARDOWN	00:49	00:49	00:49	00:49
● AIRLOCK DEPRESSURIZATION/REPRESS:	00:25	00:25	00:25	00:25
● AIRLOCK EGRESS/INGRESS	00:25	00:25	00:25	00:25
● TRANSLATION REQUIREMENTS (MMU)	00:44	00:44	00:44	00:24
● WORKSITE SETUP/TEARDOWN	<u>00:35</u>	<u>00:35</u>	<u>00:35</u>	<u>00:00</u>
TOTAL	07:34	04:14	03:34	02:39

* DEDICATED TROLLEY DEDICATED WORK STATION

MAXIMUM EVA PRODUCTIVE TIME SUMMARY*

SYSTEM	1	2	3	4
OVERHEAD	07:34	04:14	03:34	02:39
MAX EVA PT	06:16	06:16	06:16	07:11
CYCLE TIME	13:50	10:30	09:50	09:50

*8 HR PLSS CAPABILITY

OVERHEAD REDUCTION

- EVA OVERHEAD CAN BE REDUCED BY;
 - ELIMINATING PREBREATHING REQUIREMENT
 - LOCATING DEDICATED WORK STATIONS AT HIGH USAGE WORK SITES
 - PROVIDING A DEDICATED TROLLEY FOR TRANSLATING TO & FROM HIGH USAGE WORK SITES
 - PROVIDING AN AUTOMATIC SERVICING/CHECKOUT SYSTEM

INCREASING EVA PRODUCTIVITY

- EVA PRODUCTIVITY CAN BE INCREASED BY SATISFYING HUMAN REQUIREMENTS; MAINTAINING SUIT ENVIRONMENT AT CONDITIONS CONDUCTIVE TO COMFORT AND PRODUCTIVITY
- APPLYING GOOD HUMAN FACTORS DESIGN CRITERIA TO THE DESIGN OF ALL EQUIPMENT AND TOOLS USED FOR EVA
- MAKING PROVISION FOR ASTRONAUT TO TAKE AN IN-SUIT REST BREAK AND INGEST FOOD AND DRINK
- MAKING PROVISION FOR IN-SUIT DEFECATION AND URINATION
- SELECTING EVA CREWS BASED ON JOB PERFORMANCE CRITERIA
- HAVING EVA CREWS UNDERGO TRAINING PROGRAMS FOCUSED ON JOB PERFORMANCE REQUIREMENTS

EVA SKILL REQUIREMENTS

- 1. NO TASKS REQUIRING SCIENTIFIC OR ADVANCED DEGREES**
- 2. EVA TASKS CHARACTERIZED BY HIGH LEVELS OF PHYSICAL ENERGY AND PSYCHOMOTOR SKILLS**
- 3. EVA TASKS NON-TECHNICAL IN NATURE**

INCREASING EVA PRODUCTIVITY

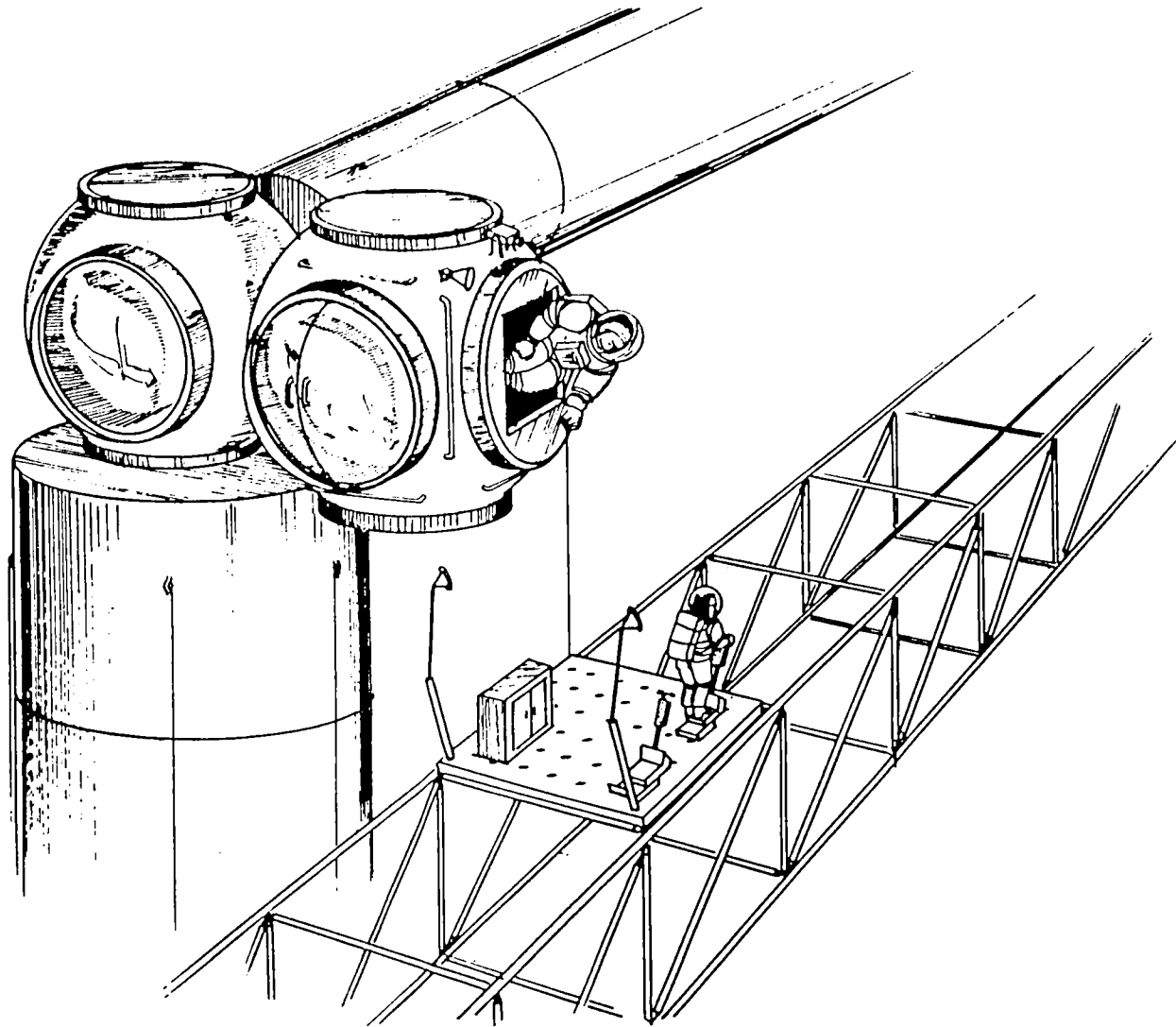
EVA PRODUCTIVITY CAN BE INCREASED BY PROVIDING WORK AIDS:

- INCORPORATING HELMET MOUNTED DISPLAY INTO EMU
- INTEGRATING RESTRAINTS SYSTEMS INTO HIGH USAGE AREAS
- LOCATING TOOLS AT HIGH USAGE AREAS
- DESIGNING PAYLOADS TO BE SERVICED BY EVA

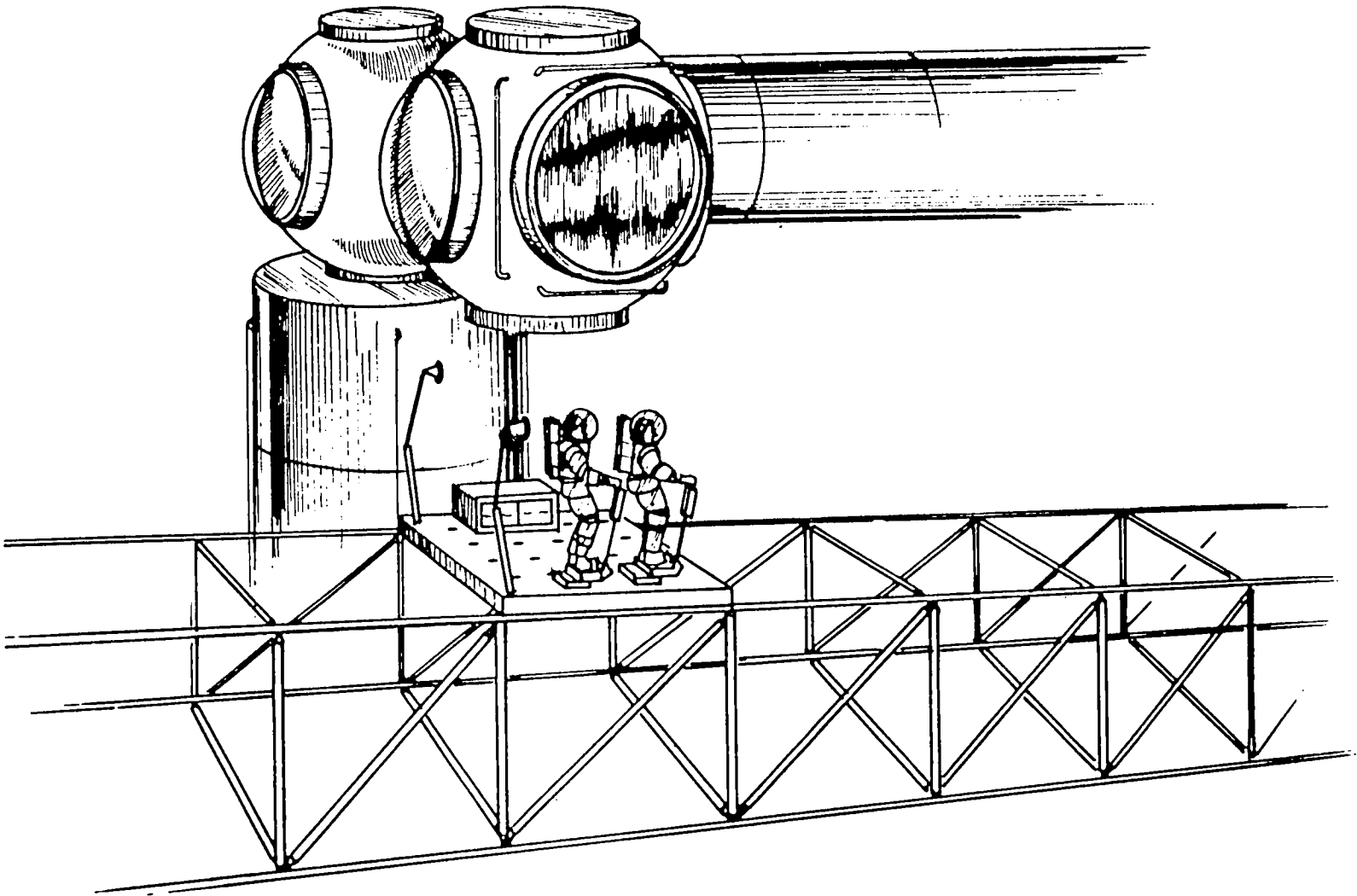
CONCLUSIONS REGARDING HMD

1. DECREASE TRAINING TIME
2. INCREASE AUTONOMY
3. INCREASE HUMAN PRODUCTIVITY

EVA OPERATIONS SCENARIO – AIRLOCK EGRESS

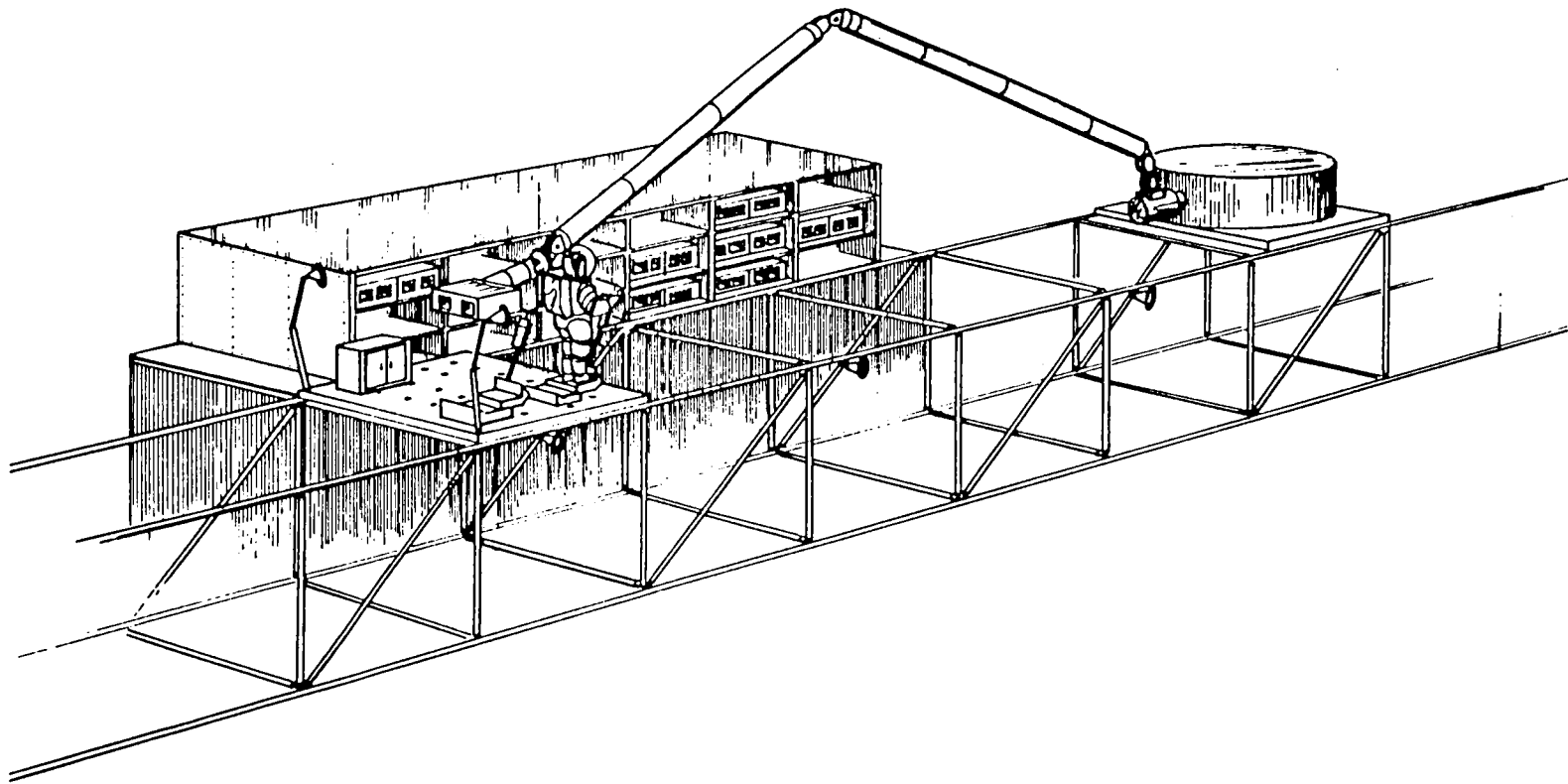


EVA OPERATIONS SCENARIO – TROLLEYING TO THE WORKSITE

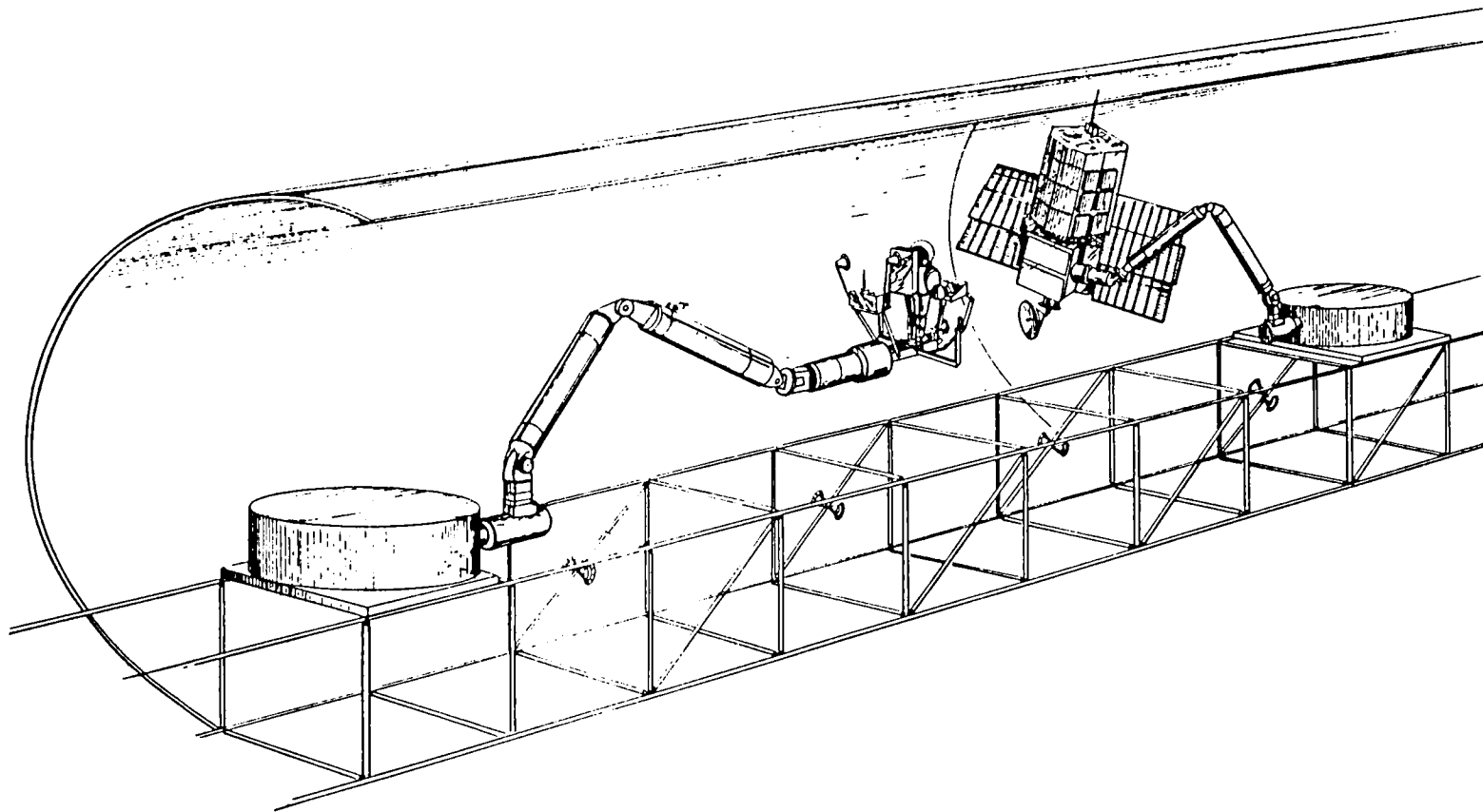


EVA OPERATIONS SCENARIO – ORU SELECTION

66



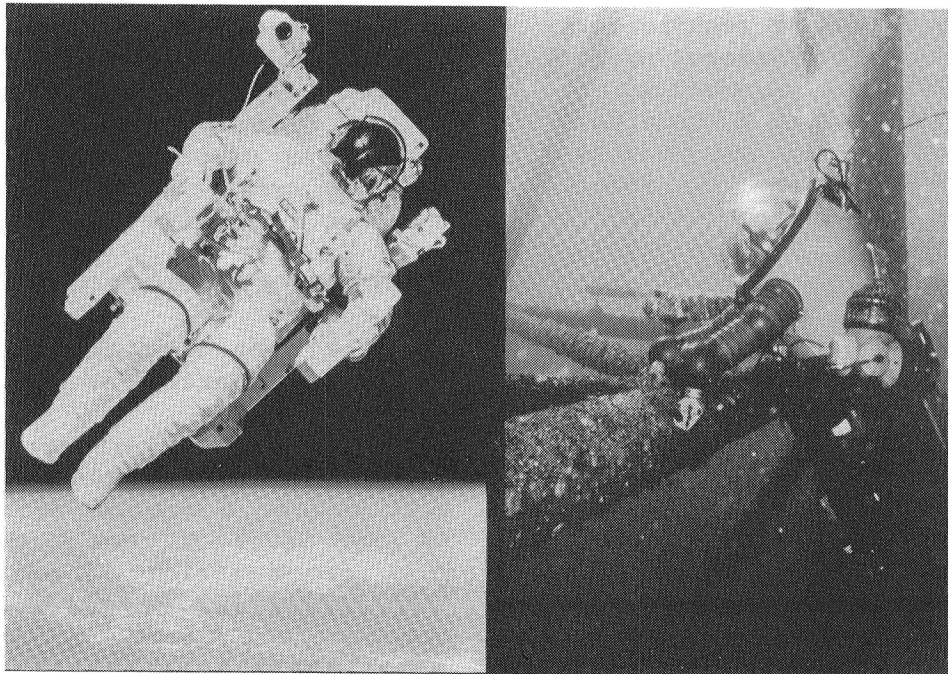
EVA OPERATIONS SCENARIO – ORU CHANGEOUT



SUBSEA APPROACH TO WORK SYSTEMS DEVELOPMENT

by

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Oceaneering International
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SUBSEA APPROACH TO WORK SYSTEMS DEVELOPMENT

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INTRODUCTION

The requirement for subsea work capabilities to support offshore oil production in increasing water depths has led to the evolution and development of a variety of work systems. These work systems range from hands-on divers to manned atmospheric diving suits with end effectors and a variety of tele-operated manipulator work systems.

Selection of the optimum work system to perform an operation depends on the work task requirements, the environmental conditions, physiological limitations, logistical requirements and economic considerations. The resulting selection may be a single work system with special modifications or a combination of work systems exploiting the strong points of each.

The commercial diving industry has more than twenty-five years experience in work systems development resulting in several million hours of underwater operations.

This paper will briefly overview the working environment, physiological limitations, work task requirements and work systems in the subsea industry.

WORKING ENVIRONMENT

The commercial underwater working environment to date is characterized by the following parameters:

- pressure: 0-3350 psi (0-7500 ft)
- temperature: 32-92° F
- visibility: 0-200 ft
- waves: 0-30 ft
- currents: 0-4 kts

In many respects, the underwater environment is a more hostile environment to work in than outer space. This is particularly true with respect to visibility and current/wave forces. The underwater environment is also dynamic and capable of radical changes over short time periods, imposing greater operating ranges on the work systems.

PHYSIOLOGICAL LIMITATIONS

The main physiological limitations are summarized as follows:

Decompression - After working underwater at increased pressures, divers must undergo a gradual decompression to sea level to avoid the bends. This decompression time can range from minutes to days, depending on the depth and duration of the dive.

Inert Gas Narcosis - For air diving below approximately 150 ft, the increased partial pressure of nitrogen creates a narcotic effect on the cen-

tral nervous system. To eliminate this effect, helium/oxygen (heliox) breathing mixes are used for deeper dives.

High-Pressure Nervous System - HPNS is associated with rapid compression on heliox to deeper depths. It can cause dizziness, disorientation and mild convulsions.

Gas Toxicity - Oxygen and carbon dioxide toxicity are critical and must be carefully controlled during diving operations.

Thermal Limitations - Temperature and humidity must be maintained within narrow limits, particularly with the greater heat capacity of heliox breathing mixtures.

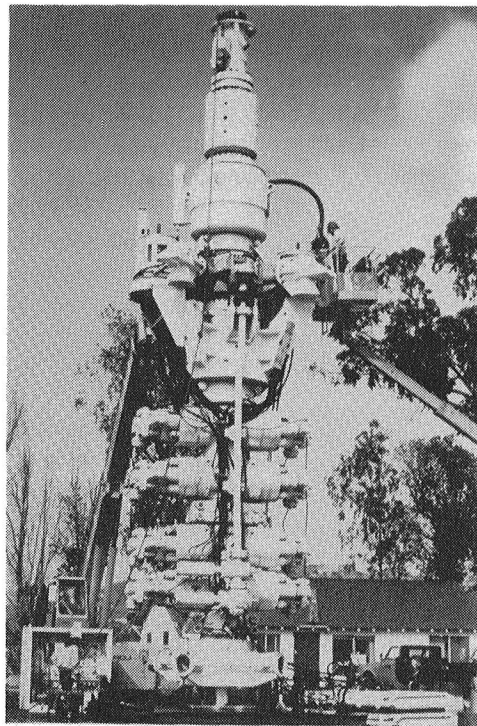
WORK TASK REQUIREMENTS

The work task requirements can be broken down into the following phases relative to the evolution of a producing oil field.

- Drilling Support
- Construction & Maintenance
- Inspection
- Repair

Drilling Support - The work requirements for this phase are primarily related to the installation, observation, maintenance and recovery of the subsea blowout preventer and associated equipment.

The basic work tasks are simple attachments, observations, vertical alignments, valve actuation, debris removal and changeouts of hydraulic hoses, electrical cables, connectors and modules.



Typical Subsea Blowout Preventer

Construction - This phase is primarily involved in the installation and hookup of offshore platforms and pipelines. The platforms are typically fabricated onshore and then towed to the offshore location.

The work task requirements in the construction phase involve complex rigging and alignments, assembling mechanical connectors, burning, welding, water jetting, special tooling and frequently onsite fabrication and modifications.

Inspection - The work requirements for inspection are primarily involved with the cleaning and inspection of in-service platforms and pipelines.

The work tasks required are observation, water jetting, cleaning with power tools, closeup photography, detailed measurements and non-destructive testing.

Repair - The work requirements for repair are primarily involved with mechanical and hyperbaric welded structural repairs of platforms and pipelines.

The work task requirements associated with repairs are detailed measurements, complex rigging and alignments, burning, welding, special tool operation and on-site fabrication and modifications.

WORK SYSTEMS

This section will overview the various types of work systems. These work systems can be classified as follows:

- Hyperbaric Diving
- Atmospheric Work Systems (Manned)
- Tele-Operated Work Systems
- Hybrid Systems

Where applicable, each type of work system will be outlined in the following format:

- Work Capabilities
- Special Interface Requirements
- Limitations

HYPERBARIC DIVING

Hyperbaric diving involves divers working in an ambient pressure, "hands-on" environment. In order to work at ambient pressures, high-pressure breathing gases must be inspired to maintain a pressure equilibrium across the lungs. This leads to tissue absorption of inert gases and a decompression requirement. Diving can be classified into three types with respect to decompression:

Surface Diving - For surface diving, divers will descend to depth, perform a task within a limited amount of bottom time, and then decompress back to the surface in accordance with a predetermined decompression schedule. This type of diving applies up to depth of 300 ft.

Bell Bounce Diving - For bell bounce diving, divers will descend to depth (300-600 ft) in a diving bell at one atmosphere. After analyzing the job requirements, the bell is rapidly compressed to ambient pressure, at which point the divers lock out and

GENERIC WORK TASKS

<p><u>DRILLING SUPPORT</u></p> <p>OBSERVATION VERTICAL ALIGNMENTS COMPLEX ALIGNMENTS HOSE CHANGEOUTS CONNECTOR CHANGEOUTS MODULE REPLACEMENTS DEBRIS REMOVAL CABLE CUTTING PLACING EXPLOSIVES</p>	<p><u>INSPECTION</u></p> <p>OBSERVATION SIMPLE ATTACHMENTS DEBRIS REMOVAL POWER TOOL USE SPECIAL TOOL USE NDT WATER JETTING MEASUREMENTS</p>
<p><u>CONSTRUCTION MAINTENANCE</u></p> <p>OBSERVATION VERTICAL ALIGNMENTS COMPLEX ALIGNMENTS DEBRIS REMOVAL CABLE CUTTING METAL BURNING WELDING RIGGING POWER TOOL USE SPECIAL TOOL USE WATER JETTING ASSEMBLING ONSITE FABRICATION MEASUREMENTS</p>	<p><u>REPAIR</u></p> <p>OBSERVATION VERTICAL ALIGNMENTS DEBRIS REMOVAL CABLE CUTTING METAL BURNING WELDING RIGGING POWER TOOL USE SPECIAL TOOL USE WATER JETTING ASSEMBLING ONSITE FABRICATION MEASUREMENTS</p>

perform the work task within a limited excursion time.

After completing the job, the diver returns to the bell and makes a pressure seal. The bell is then brought to the surface and mated to a deck decompression chamber, where the diver completes the decompression requirement. The principal limitation with this type of diving is the low working time to decompression time ratio. For 30 minutes bottom time at 500 ft, approximately 28 hours decompression is required. If a job requires long bottom times, then saturation diving will be used.

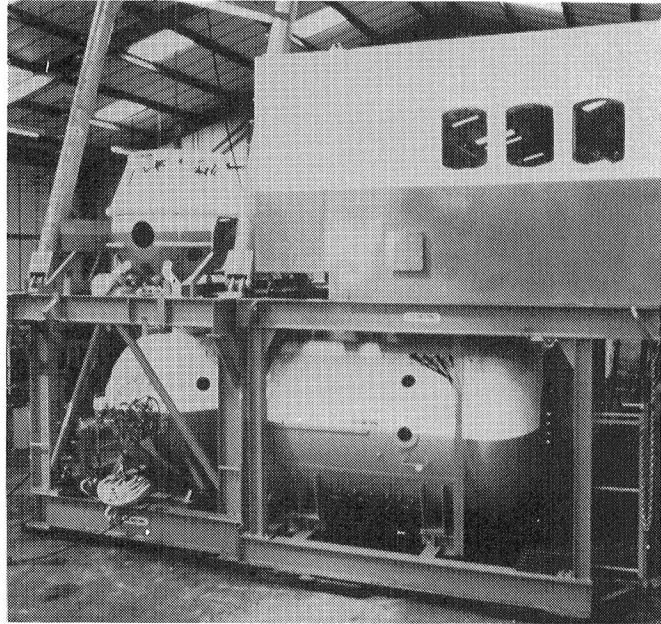
Saturation Diving - For saturation diving, the divers will remain at a pressure equivalent to their working depth for up to 40 days. Once the body is saturated with inert gas at a given depth (approximately 8 hours), then the decompression requirement is fixed, regardless of the time spent at that depth.

Saturation diving requires the use of a special modular diving system made up of the following components:

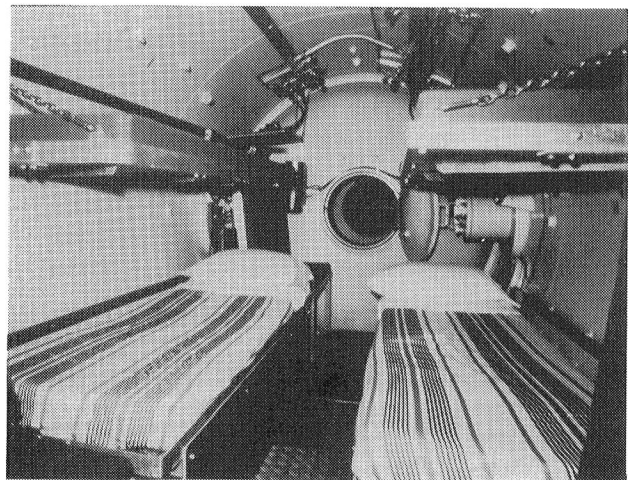
Diving Bell: The diving bell is a pressure vessel designed to be mated to a deck decompression complex, allowing diver transfer under pressure between the deck complex and the worksite.

Deck Decompression Complex: The deck decompression complex consists of two or more pressure vessels, the primary purpose of which is to provide safe living quarters for the divers while under pressure between working dives, or decompressing upon completion of the job. As the deck chambers are modular, any number can be bolted together to accommodate various crew sizes.

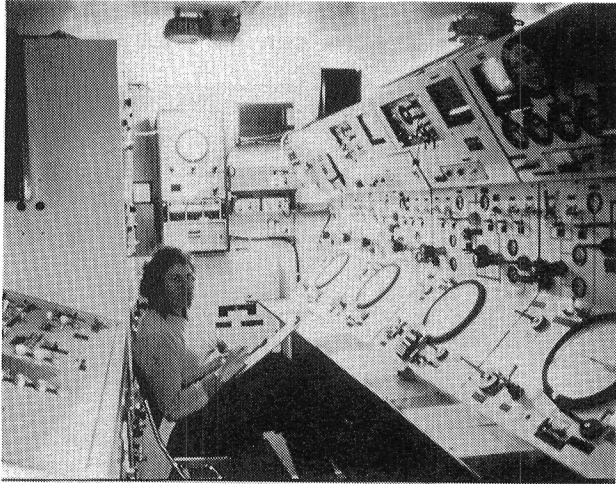
Control Van: Power, communications, gas control, gas monitoring and environmental control for the deck complex and the diving bell are all housed in a single control van. The life support systems are all modular so that in an emergency, any pressure vessel of the system can be isolated.



Six-Man Saturation Diving System



Inside View of Living Chamber



Control Van Showing Modular Life-Support Control Panels

Work Capabilities

Hyperbaric diving, because of human perception, judgment and dexterity, provides the most complete and versatile work system in the sub-sea industry. Divers were the original work system and have performed efficiently all of the underwater tasks required for offshore oil production. This baseline experience with man has provided the knowledge required to design alternate work systems, some of which can perform certain tasks more effectively than man.

Special Interface Requirements

Special man/equipment interfaces are usually not provided. Typical offshore structures are constructed from tubular trusses from 10 to 36

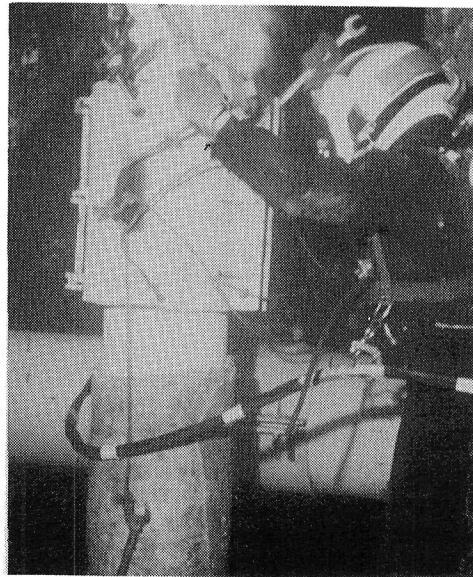
in. diameter. This makes it possible to attach to the structure in a variety of body positions using arms and/or legs. On larger-diameter tubulars, work restraint stations are fashioned from rope tethers and other items of opportunity.

Occasionally, on special projects, diver work stations are designed into the structure at key locations. This approach has proved to be cost-effective but tends to be the exception.

Limitations

The following are some of the limitations associated with hyperbaric diving:

- Human safety
- Depth limitations
- Dive duration limitations
- Decompression penalties
- Support crew and space requirements
- Reduced accessibility to hazardous areas



Diver Using an Impact Wrench to Tighten Bolts on a Riser Clamp. Note Use of Legs as Attachment Point



Diver Attaching Come-Along to Secure Underwater Welding Habitat

ATMOSPHERIC WORK SYSTEMS (AWS)

Atmospheric work systems utilize man in a one-atmosphere shirtsleeve environment and can be subdivided into atmospheric diving suits (ADS) with end-effectors, and manned submersibles with manipulators.

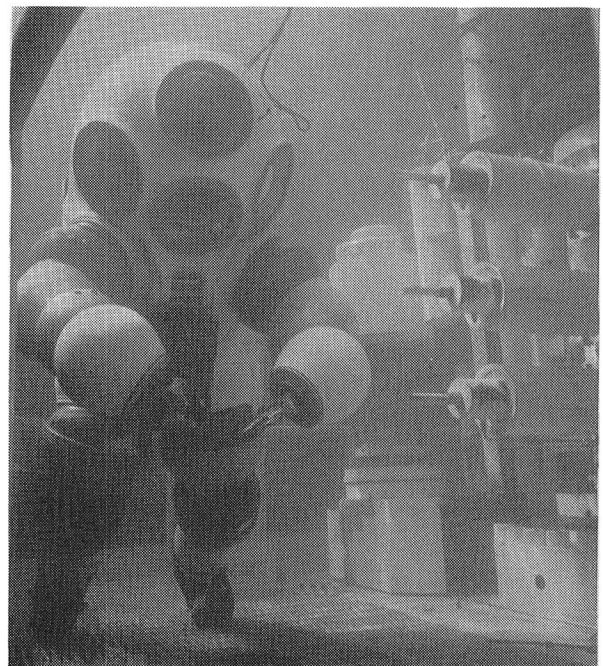
Atmospheric Diving Suits (ADS)

JIM: JIM is an atmospheric diving suit with articulated arms and legs, the limbs being neutrally buoyant so that operator effort is only required to overcome the friction of the articulated pressure balanced joints. The JIM suit receives no power from the surface with its lift umbilical containing only a communications cable.

Life support up to 72 hours is provided through onboard oxygen bottles. Since the suit does not leak, the nitrogen initially in the suit serves as a dilutant inert gas

throughout the dive, eliminating the requirement for a two-gas life support system. Carbon dioxide removal is provided through an oral-nasal lung-powered scrubber.

The end-effector assemblies work via a through-hull solid shaft penetration operated by the hand motions of the pilot. They can be continuously rotated in either direction and locked in position. The end-effectors have standardized grip surfaces and a rope hook used for sliding down guidewires. These end-effectors are able to interface with pre-engineered tools and work stations and have remained essentially unchanged throughout the entire commercial life of the suit.



JIM Working on Subsea Wellhead

WASP: The WASP is a free-flying atmospheric diving suit which utilizes the same articulated arms as JIM, but has no legs. The WASP receives power and communications through an umbilical to the surface. Translation and

station-keeping are provided through four foot-controlled thrusters.

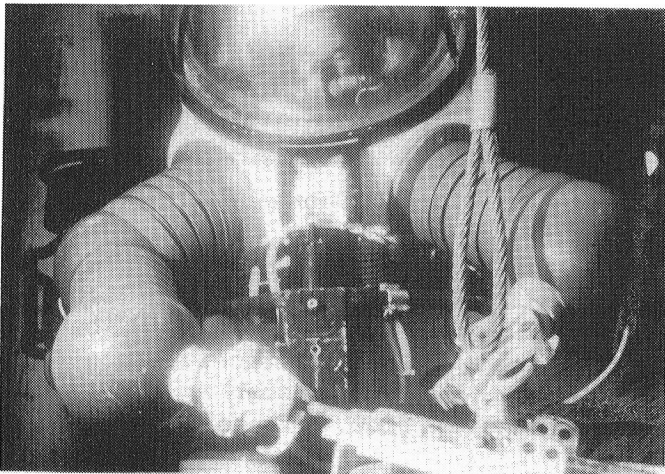
Life support is provided by an oxygen makeup system similar to JIM; however, fan-powered scrubbers are used for carbon dioxide removal.

Work Capabilities - The JIM suit is used primarily on drilling support. It has successfully performed inspections, attachments, debris removal, replaced valve assemblies and other tasks associated with drilling support.

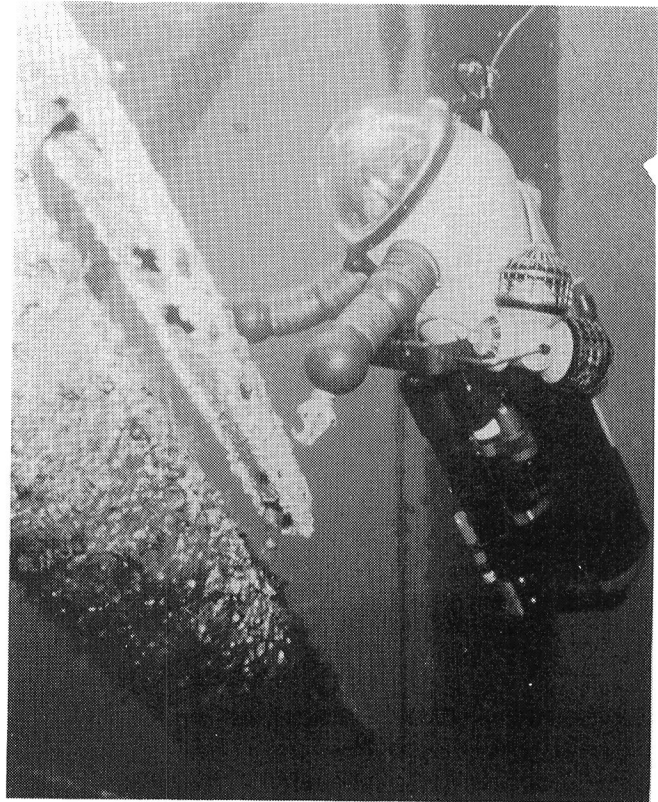
Tasks performed with JIM require interface engineering between the end-effectors and the equipment, and typically require a longer time than a hyperbaric diver.

The WASP has similar capabilities to JIM with respect to drilling support. It can also be used for mid-water work such as general platform inspection, cathodic protection measurements, waterblasting and other simple manipulative work tasks.

The WASP has been used successfully on some specially-interfaced midwater construction and repair projects such as mechanical clamp and anode installations.



JIM Operating a Lifting Jack
Using Both End-Effectors



WASP Performing Platform
Inspection

Special Interface Requirements

JIM needs a pre-installed walk deck to translate around the subsea equipment. Due to the limited ability to translate the bulk of the suit, and anthropomorphic limbs length limitations, some of the subsea equipment must be extended to JIM's work envelope. The equipment must also be designed for interfacing with the jaws of the end-effector. There are a variety of hand tools used by the JIM, each having a standardized end-effector interface, allowing multiple tools to be used without changing the end-effectors.

The WASP requires standardized equipment and tool interfaces similar to JIM. Also, depending on the job, special work-restraint systems and equipment extensions are utilized.

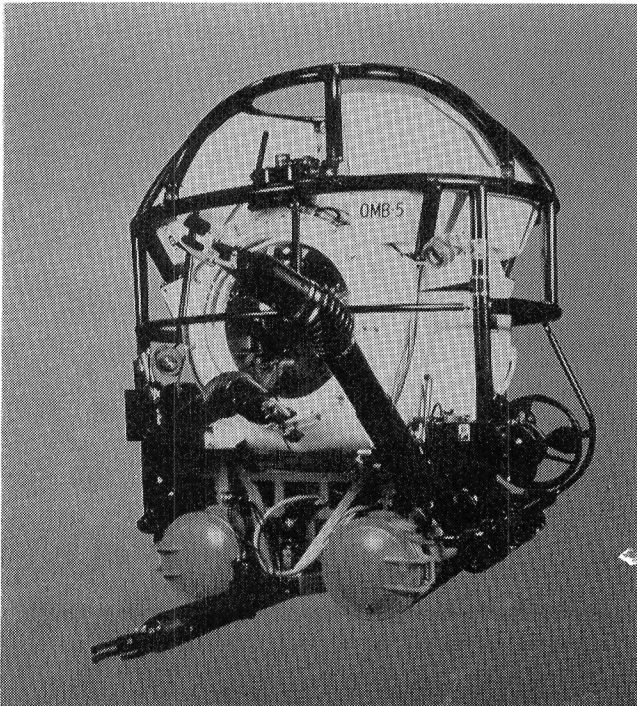
Limitations

- Human safety
- Depth
- Dive duration
- Reduced accessibility/work envelopes
- Restricted to bottom work (JIM)
- Stationkeeping when performing certain tasks in free-flying mode (WASP).

MANNED SUBMERSIBLES WITH MANIPULATORS

ARMS Bell

The ARMS bell has an interior maintained at one atmosphere, and is designed to support a two-man crew for 6 hours mission time plus 84 hours reserve. Observation of the work site is provided through a wide-angle plexiglass viewport. The bell is equipped with thrusters to provide lateral translational capabilities about the worksite.



ARMS Bell

The ARMS Bell will have up to three manipulators. The manipulator in the center of the bell has two degrees of freedom and typically is used as a work restraint system. On the left and right are either two seven-function manipulators or a seven- and five-function manipulator. The manipulators have standardized locking jaw end-effectors. Typically, the five-function manipulator is used as a grabber to initially align the work task, while the seven-function (six degrees of freedom) manipulator performs the dextrous work task. The five- and seven-function manipulators are usually spatially correspondent, utilizing a master/slave relationship. The work restraint manipulator is typically rate feed.

On some submersibles, the seven-function manipulator is equipped with force feedback, greatly enhancing the work capabilities.

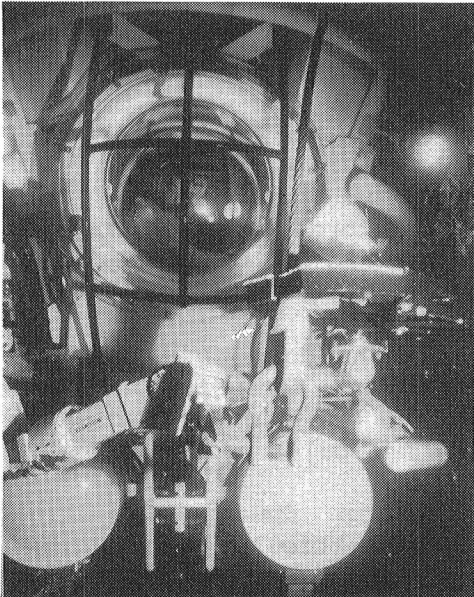
Typically, the manipulators are used only one at a time for the following reasons:

- In order to effectively use two manipulators simultaneously, both must have force feedback and dynamic compliance in order to optimize the resultant force vectors.
- Most jobs do not justify the expense of two force-feedback manipulators and can be performed using the various manipulators sequentially.
- Operator demands are greater. This is particularly true in the tele-operated systems where spatial perception is restricted by camera viewing angles and the inability of pan-and-tilt mechanisms to scan as quickly as the human eye.

In addition to the ARMS Bells, there are a variety of one-manned tethered submersibles with similar manipulator arrangements and work capabilities. These include the Mantis, Wrangler and an untethered version of the Deep Rover.

Work Capabilities

The human in a comfortable shirtsleeve environment provides high visual awareness and interpretive capability. With longer manipulators, these systems have a greater working envelope than the ADS suits, whose work envelopes are limited by anthropomorphic limbs. These capabilities have combined to produce an excellent track record in performing all the work tasks associated with drilling support. Because of size, translational capabilities and mobilization requirements, these systems are not frequently used in the other work phases.



ARMS Bell Aligning a Shackle Pin

Special Interface Requirements

- Standardized end-effector/equipment interface similar to the ADS suits
- Work restraint attachment points

Limitations

- Human safety
- Depth limitations
- Dive duration limitations
- Increased size, space, crew
- Reduced accessibility and translational capabilities

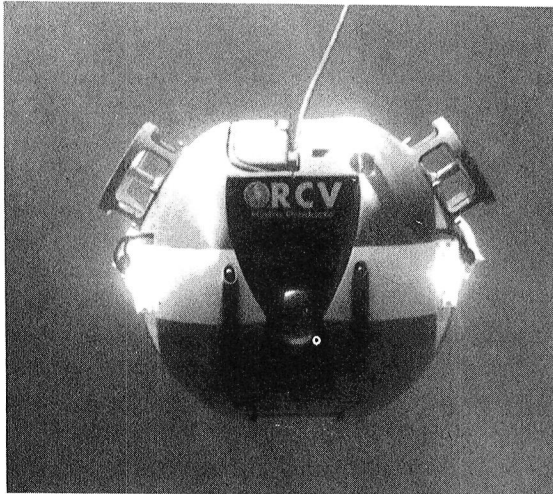
TELE-OPERATED WORK SYSTEMS

Tele-operated work systems are controlled by humans viewing television monitors remote from the work-site. The various types of systems can be classified as follows:

- Inspection Vehicles
- Light Work Vehicles
- General-Purpose Full Work Vehicles
- Modular Work Vehicles
- Special-Purpose Vehicles/Machines

INSPECTION VEHICLES

This class of tele-operated work system consists of a variety of small, tethered, remote-controlled, self-propelled observation vehicles. They have onboard video cameras typically mounted on a pan-and-tilt mechanism. This, combined with superior mobility, allows the inspection vehicle to observe underwater operations from a variety of orientations and in confined areas.



Inspection Vehicle

Work Capabilities

These vehicles are used extensively throughout all phases of oil production. In drilling support, they serve as flying eyeballs to allow surface crews to observe the underwater operation of subsea equipment and potentially identify or prevent problems.

In construction, they are used to monitor subsea operations and to locate and pre-inspect work sites, allowing the divers or other work systems to identify and plan job requirements prior to diving.

For platform inspection, they are used to perform the general visual inspection of the platform. In this role, they can be more effective than hyperbaric divers because of superior translational capabilities, depth-independent operations (within design limits), and longer dive duration capabilities. They also produce

a permanent, annotated video documentation of the entire inspection.

For platform inspection, typically the divers will be performing the detailed cleaning and inspection work, while the inspection vehicle does the general "flyby" inspection. This simultaneous operation reduces the total job time requirements. These vehicles are also used to monitor diver performance and safety.

Special Interface Requirements

There are no work interface requirements, as these vehicles do not have manipulators. On some subsea equipment, location reference systems are provided to orient the pilot.

Limitations

- Limited visual awareness
- Low interpretive capability
- No manipulative capabilities
- Limited payload capabilities
- Inadequate real-time response to changing environment

LIGHT WORK VEHICLES

This class of vehicles is similar to the inspection vehicles; however, they have increased payload capabilities and are capable of utilizing small, limited manipulators.

Work Capabilities

These vehicles can perform the same role as an inspection vehicle, with some loss of mobility and accessibility. Additionally, they can carry instrument packages, tools and can perform very simple manipulative tasks, such as attachments and placements. They play a bigger role in diver support in that they are capa-

ble of transporting tools to and from the diver at the worksite. They can also be used as a temporary tool storage platform.

Interface Requirements

- Standardized end-effector/equipment interface
- Location reference systems for pilot orientation

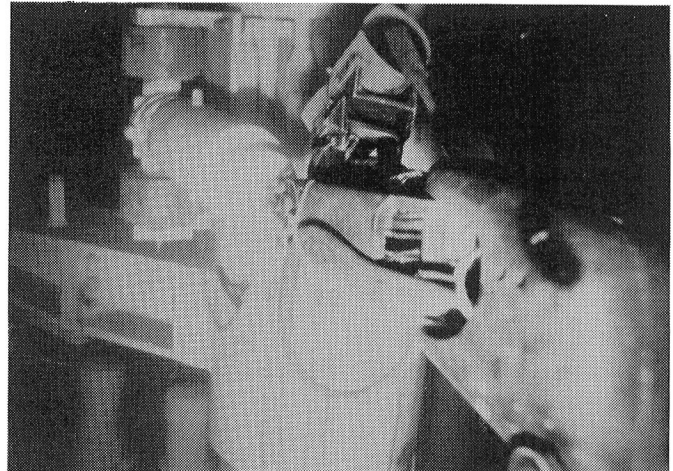
Limitations

- Can perform only simple manipulative tasks
- Other limitations same as inspection vehicle.

GENERAL PURPOSE WORK VEHICLES

These are larger vehicles designed to perform manipulative work. They are usually equipped with a five-function and seven-function spatially correspondent manipulators. These manipulators utilize a master/slave control with the speed of the slave proportional to the master. In some cases, the seven-function manipulator is enhanced with force feedback and dynamic compliance, which allows the operator to feel imposed loads. This capability greatly increases work performance due to increased sensitivity and awareness of the work task.

The manipulators are typically used sequentially with the five-function initially aligning the work task, which is then completed using the more dextrous seven-function manipulator.



View from Manipulator-Mounted Camera
of Work Vehicle on Subsea
Blowout Preventer

Work Capabilities

Although vehicles of this type are used in all phases of oilfield production, their primary application is in drilling support. The main reason for this is that most of the required tasks and subtasks have been well defined and are capable of being reduced to exactly the functions performed optimally by manipulators.

General purpose work vehicles are also used in construction for observation, diver support and pre-defined work tasks.

Interface Requirements

- Standardized manipulator/equipment interfaces
- Work restraint attachment points
- Location references

Limitations

- Limited visual awareness due to restricted camera viewing angles, inadequate scanning capabilities of pan-and-tilt mechanisms, and surface viewing monitor limitations
- Low interpretive capability
- Inadequate real-time response to changing environments
- Limited manipulative capability compared to the human hand
- Requirement for standardized manipulator/equipment interfaces
- Generally inflexible to unpredicted changes

MODULAR WORK VEHICLES

Modular work vehicles consist of a basic vehicle that provides propulsion, telemetry and control. The basic vehicle is capable of carrying, controlling and operating a number of special work packages that address specific tasks. Modular work vehicles are large systems with excess power and control functions in order to accommodate a number of add-on packages, including contingencies for future expansion.

Work Capabilities

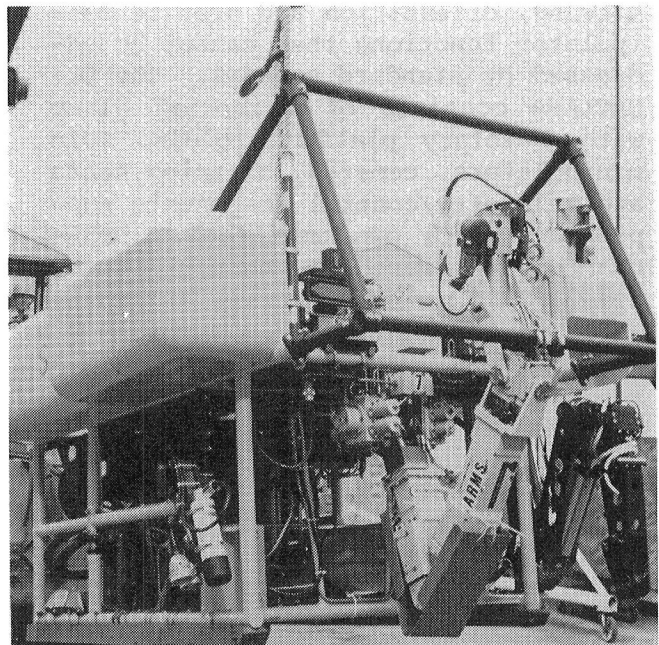
The modular work vehicle's capabilities are based on the propulsion and control characteristics available on the basic vehicle. The work packages can be tailored to drilling activities, as well as support, inspection and maintenance tasks. The success of the modular work vehicle is dependent on the functional specifications and the tradeoffs of a wide range of requirements within a single basic vehicle. If necessary, opposing requirements can be eliminated from the basic unit by incorporating their characteristics within the work package itself.

Interface Requirements

- Same as General Purpose Full Work Vehicle.

Limitations

- Basic unit size and complexity increased to support range of work packages
- Accessibility limitations due to overall system size
- Other limitations same as General Purpose Full Work Vehicle



Typical Modular Work Vehicle
with Force Feedback Arm

SPECIAL-PURPOSE WORK SYSTEMS

These units are designed from the outset to carry out a specific set of tasks. The power, telemetry, configuration, manipulation, tooling, etc. are selected and/or developed to support the defined scope of work.

Special purpose systems are extremely effective in carrying out the required work, and represent a highly productive and reliable method of performing work. Two examples of special purpose vehicles are DYNACLAMP and RIG BANDIT.

Dynaclamp: The DYNACLAMP is a special purpose machine designed to carry out the cleaning, photographing and detailed inspection of the welds found at the nodal joints of tubular members. This highly complex work imposes constraints on accessibility, viewing, orientation and precise manipulator functions that cannot be addressed by standard systems. The DYNACLAMP consists of a special clamp with a rotary platform holding twin manipulators, cameras, cleaning heads and telemetry/control components supported by its own umbilical. DYNACLAMP is delivered to the worksite by diver, ADS or ROV, greatly expanding their work capabilities.

Rig Bandit: The RIG BANDIT is a passive work system designed for guidewire-supported drilling support. The RIG BANDIT consists of a frame holding manipulators, lighting and cameras that is attached to guidewire and lowered from the surface. The RIG BANDIT can be clamped to the guidewires at the working depth to provide a stable platform. This configuration restricts translational capabilities. However, the system carries out certain tasks effectively with a less complex system than would result from adaptation of a general-purpose unit.

HYBRID WORK SYSTEMS

Operational experience with the various work systems has led to sufficient understanding of their work capabilities to allow hybrid work

systems to be designed. This section will briefly describe some of the hybrid work systems used in the subsea industry.

Mobile Diving Unit (MDU): The MDU is a combination of an ARMS manipulator bell and a saturation diving system. This combination provides the crew member the opportunity to complete the work task in a one-atmosphere environment without incurring any decompression penalty.

If the job cannot be completed using manipulators, then the diver can compress the bell to ambient pressure, lock out and perform the task in a hands-on environment.

Mantis Duplus: This vehicle is a combination of a manned submersible with manipulators and a tele-operated work system. It can be used in either the manned or remote-operated mode, depending on the difficulty of the task and the requirement for human perception and judgment. This type of system has the secondary advantage of allowing the submersible to be piloted remotely from the surface, while the crew member concentrates on the manipulative work task.

Dynaclamp: The DYNACLAMP is specially designed for performing detailed cleaning, inspection and maintenance tasks in restricted nodal areas. For this reason, it can perform these tasks much better than any other work system except possibly hyperbaric divers.

The DYNACLAMP can be delivered to the work site by a general purpose work system such as a WASP or general work vehicle. The DYNACLAMP then works through tele-operated control, while the delivery work system performs other, less complicated tasks

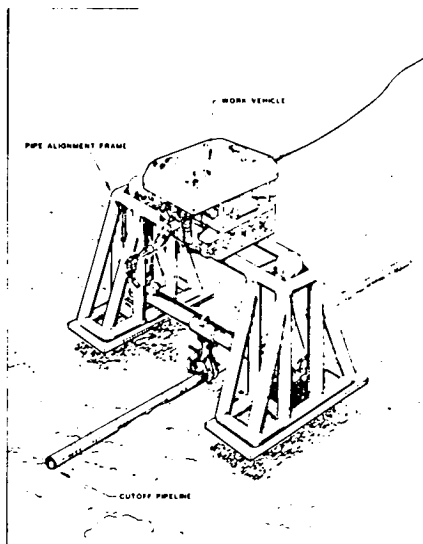
simultaneously. This combination greatly extends the work capabilities of general-purpose systems.

DEEPWATER PIPELINE REPAIR SYSTEMS

The deepwater pipeline repair system is a combination of a modular work vehicle and a variety of special purpose work systems.

This system was designed to address one major task - the remote repair of deepwater pipelines. Within this task are multiple subtasks that are individually addressed by special purpose work packages which are interchangeable on the modular work vehicle.

The integrated system can carry out a range of specific inspection, installation and work tasks, including the precision alignment of mechanical connectors, the lifting and alignment of pipe sections, the cutting and bevelling of pipe faces and a number of measurement tasks.



Deepwater Pipeline Repair System
Showing a Modular Work Vehicle
Operating a Pipeline Alignment Frame

The system uses a combination of sensors, manipulators, special tools and work packages to carry out the designated work.

OPERATIONAL PHILOSOPHIES

Through operational experience, a number of very clear lessons have been learned. Some of these lessons are as follows:

- Design Equipment for Intervention - This has proven to be cost-effective. The small increase in initial cost is paid for the first time the equipment breaks down. Triple-redundant fail-proof systems cost more up front and more to repair when they do break down.
- Standardize End-Effector/Equipment Interfaces - This can make pre-planning and job execution a lot easier. It is also a more sensible approach than changing end-effectors for each task or designing complex multi-finger end-effectors.
- Design Simple Job Requirements - A job can be done in a number of ways and with a variety of methods. It is important not to over-engineer the job.
- Documentation - Poor documentation of subsea equipment can lead to inadequate planning, useless tool design and ineffective operations. When possible, equipment should be documented extensively with photographs and scale drawings.
- Select the Most Effective Work System - A number of work systems may be able to do the job, but how productive and cost-effective? In selecting the optimum work system, it is important to start at the task and work backwards as opposed to trying

to fit the wrong work system where it does not apply.

A sensible approach to this process is as follows:

- Define the work tasks
- Determine work envelopes
- Determine required functions
- Incorporate operational considerations
- Select/design optimum work systems
- Perform interface engineering
- Design/manufacture special tooling
- Perform testing and optimization

For many work tasks, the answer may be hands-on divers or gloved astronauts. In other cases, hybrid work or special-purpose systems would be more effective.

CONCLUSIONS

The evolution of work systems in the subsea industry has been the result of direct operational experience in a competitive market. This experience should help to make the evolution of work systems more efficient for space operations.

ADVANCED EVA SYSTEM DESIGN REQUIREMENTS STUDY

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January 1986

PREFACE

The Advanced EVA System Design Requirements study was a twelve month effort to identify specific criteria regarding Space Station EVA hardware requirements by analyses of EVA missions, environments, operations, procedures, and Space Station and STS interfaces. The study began in January of 1985 and was completed in January, 1986.

This executive summary report has been prepared in accordance with the Statement of Work for the subject study, contract NAS9-17299, and summarizes the data and analyses from which all the study results were derived. A detailed report has also been prepared for distribution as determined by the contract monitors.

The study results are intended to provide information and guidelines in a form that will assist NASA program managers in evaluating and substantiating EVA system requirements to support a productive EVA capability for the Space Station Program.

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SECTION 1

Introduction and Study Overview

Introduction

The purpose of this document is to report on the technical work accomplished on the Advanced Extravehicular Activity System Study, Contract NAS-9-17299. The study was performed to define and establish design requirements and criteria for the Space Station Advanced Extravehicular Activity System (EVAS) including crew enclosures, portable life support systems, maneuvering propulsion systems, and related EVA support equipment. The study considered EVA mission requirements, environments, and medical and physiological requirements, as well as operational, procedures and training issues.

1.1 Team Organization

The MDC EVAS Study Team was organized to take advantage of a unique mix of experience and expertise in defining and developing EVA systems, as well as in planning and conducting successful EVA operations. (Figure 1-1). The Houston Division of the McDonnell Douglas Astronautics Company provided overall study management and expert task leadership dedicated to incorporating in this study all the relevant lessons learned while helping NASA develop and exercise the NSTS EVA capability which has been so spectacularly demonstrated in recent years. To this invaluable understanding of EVA operations were added the skills and experience of the Huntington Beach division of MDAC (for physiology, productivity, system integration and compatibility with Space Station architecture); the Hamilton Standard Division of United Technologies (for life support system technologies); ILC-Dover (for crew enclosure, materials and ancillary equipment); and Martin Marietta (for maneuvering propulsion technologies). Corporate EVA experience bases dating back to Gemini IV were thus applied to the purpose of defining EVA system requirements for the Space Station.

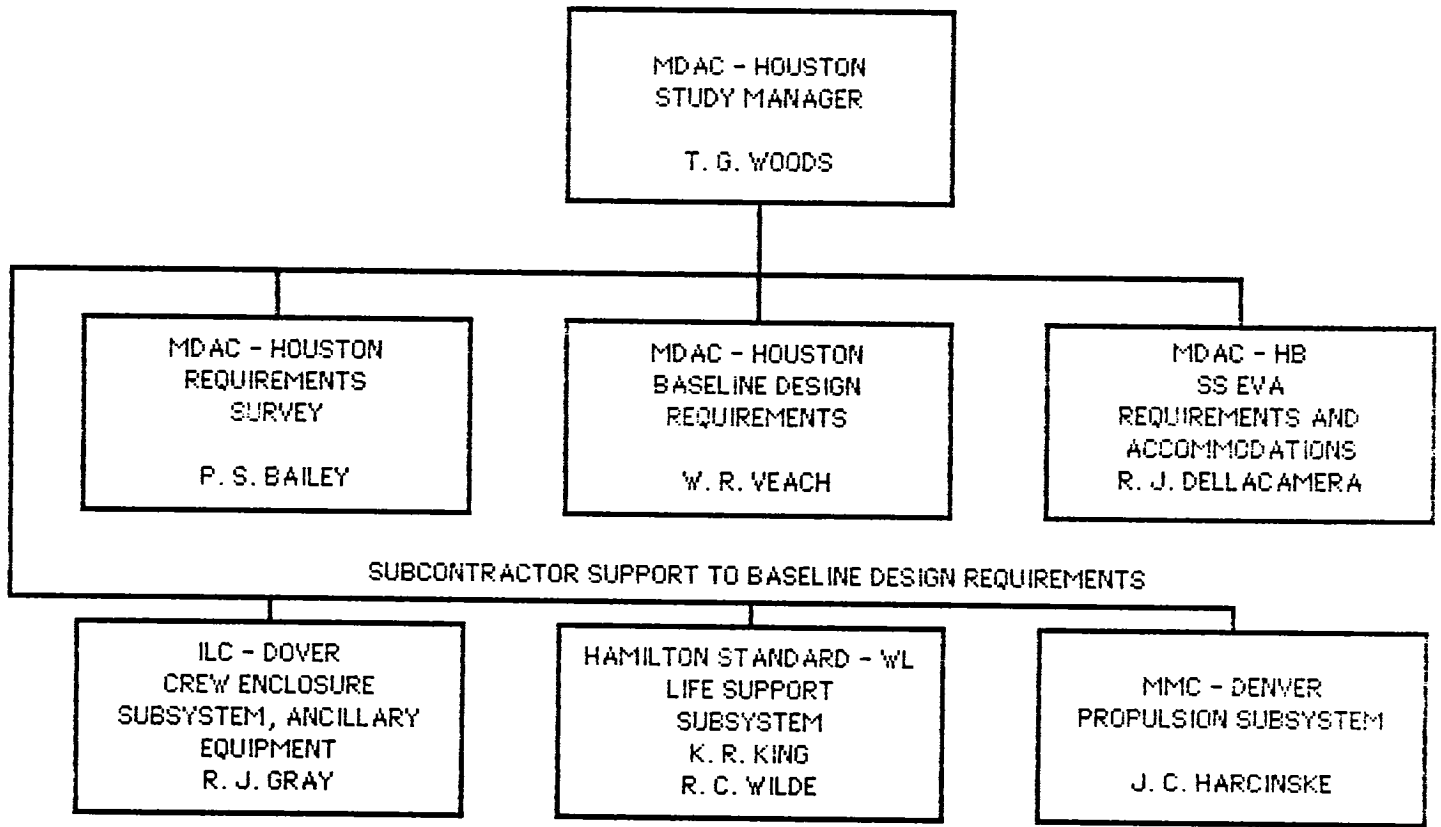


FIGURE 1-1
TEAM ORGANIZATION

1.2 Study Organization

The methodology chosen for this study was a classic Phase A approach of survey, analysis, synthesis and definition as shown in Figure 1-2.

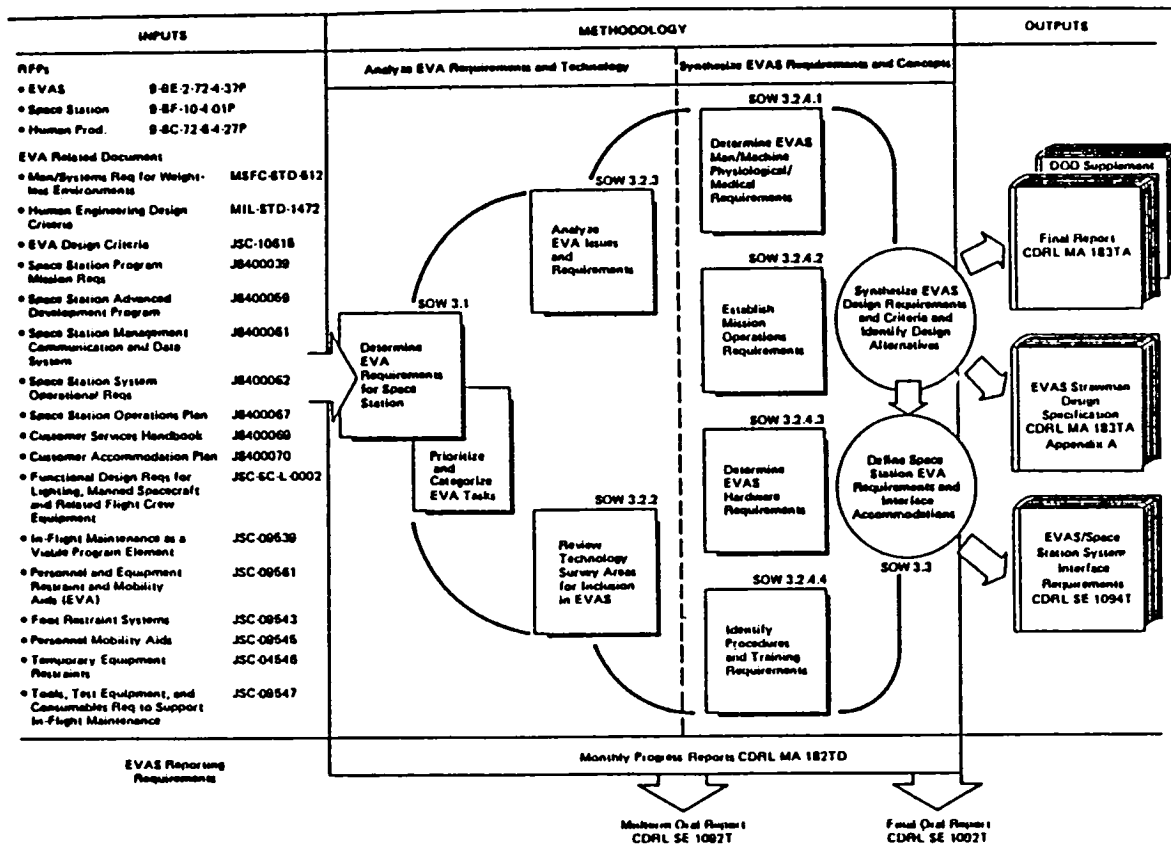


FIGURE 1-2
STUDY ORGANIZATION

The primary activity was organized into three major tasks corresponding to the contract Statement of Work (SOW). From numerous sources, the EVA Requirements Survey, Task 1, attempted to identify and quantify all the routine and contingency EVA mission requirements for assembly, servicing, maintenance, and repair of satellites and attached payloads, as well as for the Space Station itself. Using the identified mission requirements as one of several inputs, EVAS Baseline Design Requirements and Criteria - Task 2, analysed numerous environmental, physiological, man/machine, operational and hardware considerations to identify specific design requirements for systems that would maximize human productivity in EVA. In Task 3, Space Station EVA Requirements and Interface Accommodations, we identified the EVAS interfaces and EVA peculiar accommodations and support requirements to be incorporated into the SS systems and architecture. The detailed Work Breakdown Structure (WBS) is illustrated in Figure 1-3.

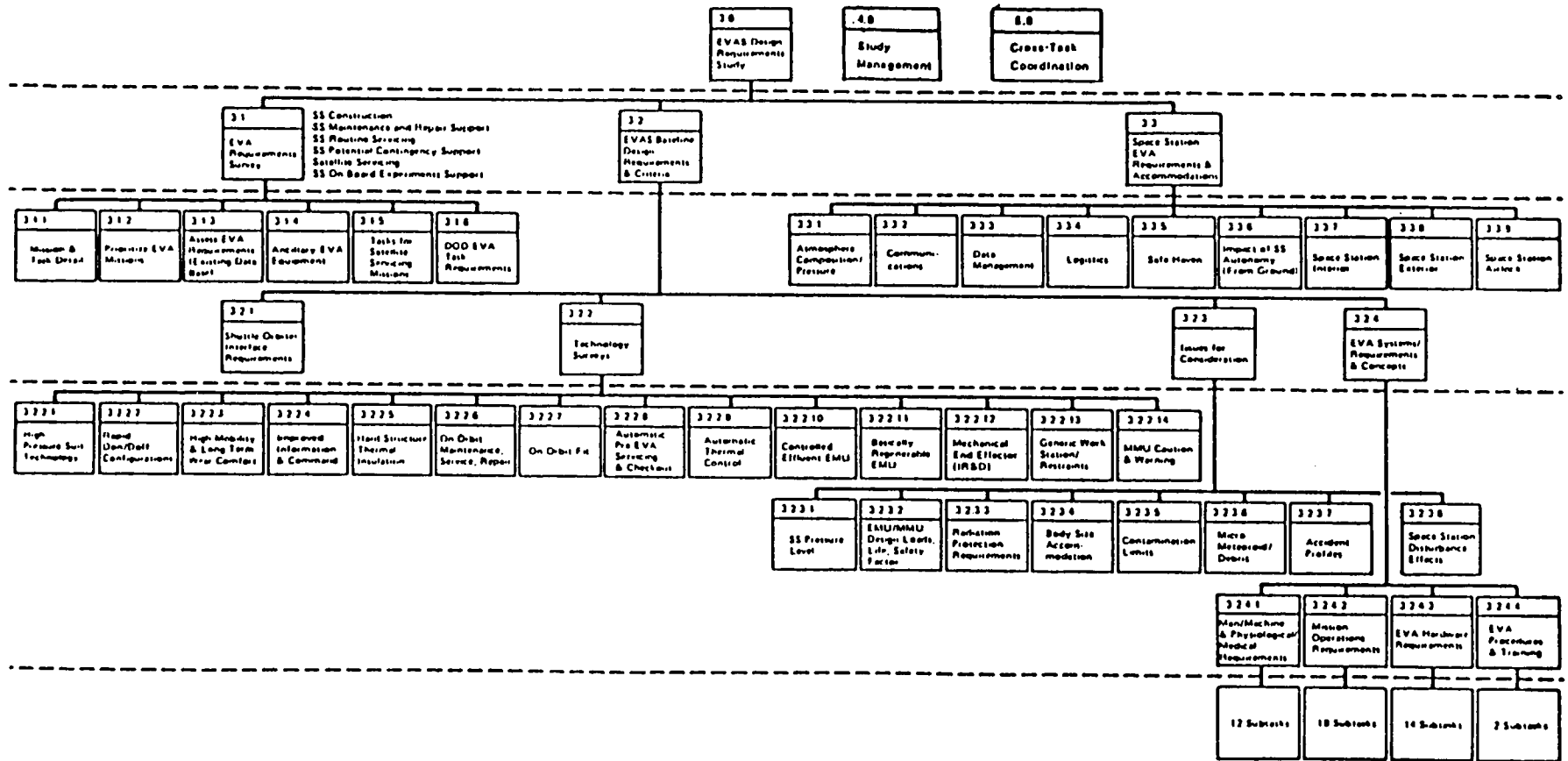


FIGURE 1-3
WORK BREAKDOWN STRUCTURE

1.3 Key Issues and Drivers

Specific EVA system requirements and their rationale are summarized in the ensuing sections of this report. There were several issues and driving considerations developed in the course of the study that affected more than one system and which combined with some unique characteristics of the Space Station to effect many of the EVA design considerations.

1.3.1 Unique Space Station Characteristics

When compared to previous programs, the Space Station crews will be routinely on-orbit for far longer periods, and the vehicle itself and many of its systems will be there virtually indefinitely. From this factor alone were derived several other key characteristics of the Space Station.

-
- O ORBIT STAY TIME GREATLY INCREASED OVER PREVIOUS PROGRAMS
 - O OPERATIONAL TEMPO RELATIVELY BENIGN
 - O MISSION PLANNING MORE LONG TERM, LESS PRE-MISSION DETAIL
 - O TRAINING MORE GENERIC, MORE TASK-ORIENTED, LESS MISSION SPECIFIC
 - O ON-ORBIT TRAINING REQUIRED FOR PROFICIENCY IN CONTINGENCY/ EMERGENCY SITUATIONS
 - O LONG US SHORT TERM PHYSIOLOGICAL FACTORS AND ENVIRONMENTAL PROTECTION REQUIREMENTS

FIGURE 1-4
UNIQUE SPACE STATION CHARACTERISTICS AFFECTING EVA

The tempo of operations will be relatively benign with regard to meeting most mission objectives in critical time periods. For instance, an EVA task that takes longer than anticipated can be rescheduled for completion in the next planned EVA event. This takes advantage of the more permanent nature of the manned presence than that afforded by the STS and also alleviates the potentially deleterious effect of less mission specific training available to SS crews. Mission planning itself will be more of a long-term nature on the ground with much less pre-mission daily detail than is required for Shuttle. For the same reasons, and due to the wide variety of EVA mission requirements, pre-mission training will emphasize development of the generic EVA skills that will be required to accomplish them. On-orbit EVA training opportunities will also be utilized to compliment limited ground simulations with an abundance of on the job training to achieve true profi-

ciency. Additional on-orbit training requirements in emergency procedures and off-nominal EVA systems operations are required by the length of crew cycles and by the need to maintain proficiency in safety critical areas.

While much has been learned about adapting man to the orbital environment, there are new, different, and perhaps unknown risks associated with long term exposures. The statistical probability, however small, of a hazardous event or exposure occurring to a crewman takes on a whole new meaning when the opportunities are significantly increased. Thus, for Space Station there is special emphasis on such areas as bends risk, radiation exposure, and micrometeoroid protection.

1.3.2 Key EVA Design Issues

With the considerations expressed above and with the key applicable lessons learned from the STS EVA experience, several issues emerged from the many considered in the study as having pervasive effects on EVAS design requirements (Figure 1-5).

-
- O EVAS MAINTAINABILITY
 - O EVAS TECHNOLOGY READINESS
 - O EVA LSS VOLUME VS EVA TIME AVAILABLE
 - O SUIT PRESSURE/CABIN PRESSURE RELATIONSHIP AND PRODUCTIVITY EFFECTS
 - O EVA CREW AUTONOMY
 - O INTEGRATION OF EVA AS A PROGRAM RESOURCE
 - O STANDARDIZATION OF TASK INTERFACES

FIGURE 1-5
KEY EVA DESIGN ISSUES

Maintainability is far and away the most important issue in EVAS design and the main reason why the STS EMU will not satisfy SS requirements.

Technology Readiness and risks associated with advanced EVAS technologies must be carefully considered in evaluating their benefits to EVA productivity. An assessment of technology readiness for the EVAS is provided in Section 4 of this report.

EVA LSS Volume vs EVA Time Available. There are several factors combining to drive the EVAS to an overall larger volume. While the STS constraints on volume are not expected to exist for Space

Station, this growth could be controlled by taking advantage of the Station's ability to provide dependent life support capability (i.e. via umbilicals) at remote worksites.

Suit Pressure/Cabin Pressure Relationship and Productivity Effects. Operating space suits at the pressure levels attendant to a sea level cabin with minimum prebreathe means that unless there is significant improvement in the glove technology the crewman will bear the brunt of having to perform manipulative tasks with very stiff hands. Recent tests have provided insufficient quantifiable data to back up this key feedback from our system operations. Further development efforts must concentrate on improving glove mobility and/or getting the suit pressure down.

EVA Crew Autonomy is an issue which was found to affect many areas of the EVAS and the SS EVA interfaces and accommodations. To maximize the overall productivity of the crew they need to be provided with all the resources to operate independently from the ground, as well as to allow the EVA crew to operate independently from the IV crew. This issue affects EVAS design, including reliability and maintainability aspects, the Data Management System, the Communications System, provisioning, and training and makes a strong case for implementation of IVA automation and EVA robotics.

Integration of EVA as a Program Resource is no less important than integration of other SS user services such as heat transfer, power distribution, pointing accuracy or data handling. This program appears well on its way to achieving this critical perspective and it must be maintained during the SS development.

Finally the Standardization of Task Interfaces must be promoted to increase EVA productivity, enhance the probability of mission success and reduce the overhead burdens associated with performing EVA. If EVA is to be relied upon for SS assembly, maintenance, servicing, and repair and as a resource to be applied to user needs, then properly designed work interfaces are required.

SECTION 2

TASK 1 - MISSION REQUIREMENTS SURVEY

2.1 MISSION AND TASK DETAIL

The study was begun by establishing as much detail as possible about the missions and tasks of the Space Station EVAS. This effort was hindered to some extent by the paucity of reliable information about missions which are 7 to 15 years in the future. Design details were usually sketchy or totally non-existent and quite often the viability of the actual mission was in doubt. Still, enough information existed to derive mission requirements for the Station EVAS.

Several different sources of information were consulted in the search for requirements. For detail on payload servicing missions Langley Data Bases dated March 1984 and May 1985 were consulted. These data bases began in 1991 and 1992, respectively, with the implied assumption that Space Station Initial Operational Capability (IOC) would occur on that initial date. While actual IOC is still unknown, the information derived from the Langley Data Bases should still provide reasonable estimates if referenced to IOC rather than a specific calendar date. As many as possible of the principal investigators or payload sponsors listed in the data bases were questioned. From the latest, perhaps more accurate, Langley Data Base it was determined that, of the 324 total missions, 141 would require some sort of EVA support. These were a mixture of domestic and foreign payloads. All American sponsors were contacted to verify and update the data in the data base. Generally it was found that the information was a sponsor's "best guess" at a very early date on what might fly.

Using the initial data on likely missions for the Space Station EVAS, a list of generic missions was generated which it was believed would describe the things the EVAS would be required to do and which would, by simplifying the analyses and reducing the data to a manageable size, give a clear picture of those EVAS requirements. Fifteen such generic missions were identified. (Figure 2-1) Time estimates were made for each generic mission and these estimates were used to estimate times for each of the missions derived either from the Langley Data Bases or other Space Station documentation. These estimates were then summed to arrive at estimates of EVA time required per year for customer

support. Figure 2-1 presents the results of this process.

1. ALIGNMENT OF XMITTER/RECEIVER ELEMENTS
2. DEPLOY/RETRACT SOLAR ARRAY
3. TRUSS STRUCTURE CONSTRUCTION
4. SATELLITE SERVICE TECHNOLOGY
5. LARGE MODULE MANIPULATION
6. SMALL/MEDIUM MODULE MANIPULATION
7. LARGE MIRROR CONSTRUCTION
8. CONSUMABLES RECHARGE VIA TRANSPORT
9. ORBIT LAUNCH OPERATIONS
10. SUBSATELLITE OPERATIONS
11. SPACE STATION RADIATOR CONSTRUCTION (ORBITER SUPPORTED)
12. ORBITER SUPPORTED LARGE MODULE MANIPULATION
13. ORBITER SUPPORTED TRUSS CONSTRUCTION/DEPLOYMENT
14. RADIATOR CONSTRUCTION-FULL UP SPACE STATION
15. EVA RESCUE

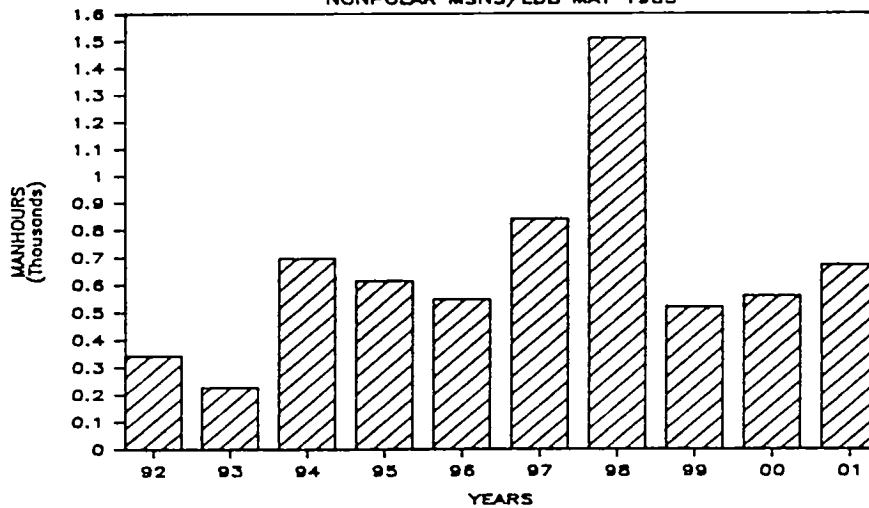
FIGURE 2-1
GENERIC EVA MISSIONS

Our analyses yielded the information that a minimum of slightly more than 1000 manhours of EVA time per year will be required at Station IOC and that within two years approximately 4500 manhours of EVA time will be required per year for all the missions in the Langley Data Base.

To arrive at a reasonable estimate of the actual SS EVA requirements, the data were further analysed as to mission firmness and locations. It was arbitrarily decided to include only those missions which had firmness ratings in the data base of 1,2, and 3, and 20 percent of firmness rating 4. After also removing all polar missions, the results were as depicted in Figure 2-2.

As indicated, 346 manhours of EVA time are estimated to be required in the first year of Space Station operation, increasing to a maximum of 1512 manhours required in the seventh year of Station operation. Two cautions go with these estimates. First, these are only estimates, heavily dependent on guesswork about missions as far as fifteen years in the future. Second, related to the first caveat, a "tail-off" phenomenon exists after the third year of Station operation, indicating that few experimenters and payload sponsors wish to guess about events so far in the future. This yields what is probably a false tail-off in required EVA hours in the latter years covered by the estimates and causes such estimates as exist to consist heavily of firmness 4 missions, yielding a further reduction due to our weighting procedure.

FIRMNESS 1+2+3+20% OF 4
NONPOLAR MSNS/LDB MAY 1985



YEAR	92	93	94	95	96	97	98	99	00	01
EVA MHRS/YR	346	229	700	617	551	842	1512	522	562	674
EVA MHRS/WK	7	5	14	12	11	17	30	10	11	13

FIGURE 2-2

Estimated EVA Mission Manhour Requirements for Space Station Core

It must also be pointed out that the experience of Skylab and Shuttle indicates that unplanned EVA mission requirements tend to exceed planned requirements by approximately 2 to 1 and for this reason our mission model is thought to be extremely conservative. Regardless of the amount of EVA determined by whatever means, program managers will likely have to allocate EVA crew time as a program resource, with limits determined by crew size, systems design capabilities and overall program priorities. This allocation may then determine which missions may be accommodated. The Functional Requirements Envelope, promulgated by NASA in May 1985 established an allocation of EVA time for users which very coincidentally approximated our user requirements model.

Space Station construction time estimates were also derived by assigning times based on the Generic 15 Missions to construction tasks and plans presented in the Space Station Reference Configuration Description (JSC 19989) and to tasks and plans developed by MDAC Phase B Space Station personnel for the dual-keel configuration. While Station construction may have significant impacts on Space Shuttle EVA support requirements, it does not seem to drive Space Station EVAS requirements, except to the extent of possibly driving the point at which the Station airlock is brought up for assembly with the rest of the Station. Otherwise, there is insufficient data to properly integrate SS construction with the time phased SS EVA mission requirements.

To complete the SS EVA mission model, an assessment of maintenance requirements for the Station was required. With little credible data to support such an analysis, an extrapolation from on-going Phase B studies was made. Various levels of maintenance estimates were derived based on the number of EVA and IVA orbital replaceable units (ORUs) and several values of Mean Time Between Failures (MTBF) were used. An allocation of 1192 EVA manhours per year was made, which resulted from the definition of one manhour MMTR for a properly designed EVA ORU, and reflecting the use of scheduled or planned EVA maintenance to enhance SS maintainability overall. It is important that continuing evaluations be made of SS EVA requirements for maintenance as the systems definition efforts proceed.

Total SS EVA missions requirements, then, are as shown in Figure 2-3. It shows that a minimum requirement of about 1400 manhours per year in the neighborhood of IOC grows to a requirement for approximately 2700 manhours per year at IOC + 6.

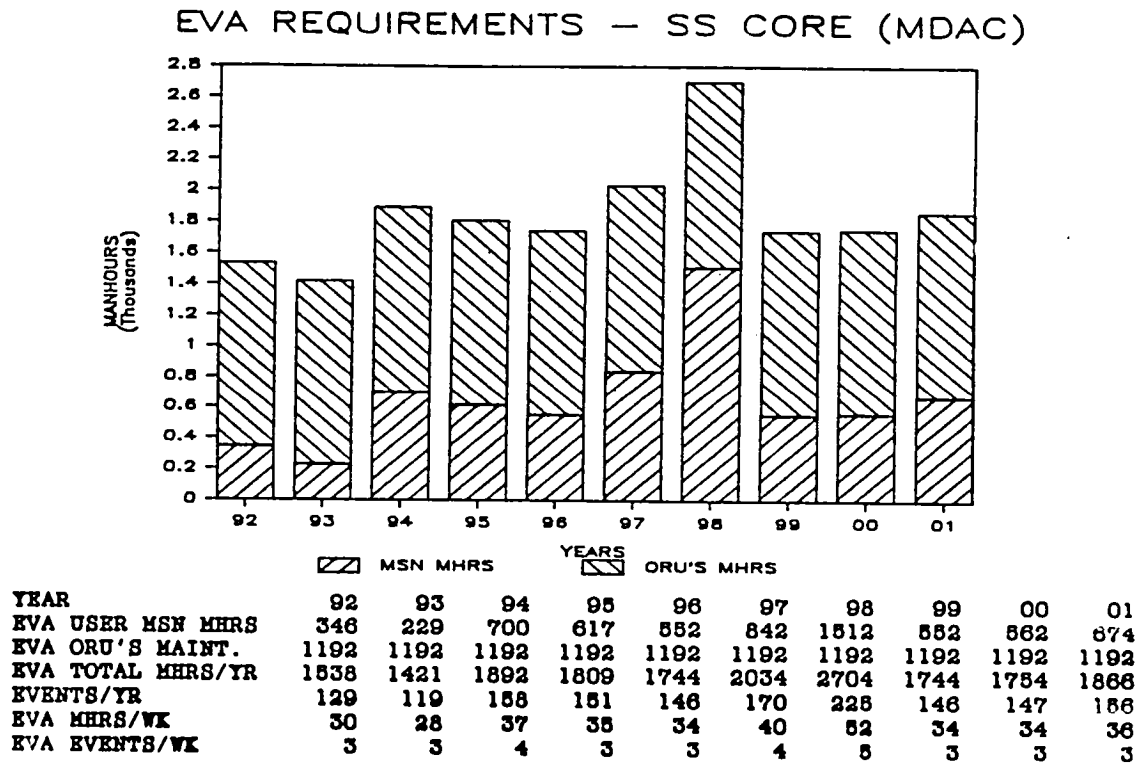


FIGURE 2-3
Total EVA Missions Plus ORU Manhours

2.2 ASSESS REQUIREMENTS AGAINST AN EXISTING DATA BASE

The Space Station EVAS requirements were compared on a task-by-task basis with current Shuttle EVAS capabilities. The general conclusion was that all requirements were well within the capabilities of a suited crewmember to perform. That is, no specific EVAS hardware requirements or capabilities were driven by the information on missions and tasks which were obtained. When the EVAS capabilities were considered in light of likely 90 day mission models, two basic problem areas were identified.

First, EVA operational impacts to Shuttle flights could not be tolerated on the Space Station. This was particularly true in the case of three specific impacts. The frequent large pressure changes in cabin atmosphere incurred as a normal part of Shuttle EVA's could not be tolerated on the Station with its sensitive scientific experiments. Similarly, all Station operations could not be driven by EVA support requirements as they are on the Shuttle. EVA must be a routine, minimum impact part of day-to-day Station operations, not a special case requiring maximum attention from all hands. Finally, the heavy task-specific pre-launch training encountered in preparing Shuttle crews for EVA tasks will not be possible for Station crewmembers. Too many nominal and far too many contingency tasks are possible during the course of a 90 day mission to specifically train for them on the ground prior to flight. These operational impacts, then, require different handling on Space Station than they did on Shuttle.

The second major difficulty arising from considering the entire EVA mission model instead of just individual tasks is the problem of EVAS maintenance. Currently, all EVA equipment undergoes a maintenance cycle after every flight. For most equipment this involves an extensive tear-down, test, and component replacement with subsequent reassembly and complicated test and certification for re-flight. Such procedures are not possible on the Space Station due to time, personnel, operational, and material limitations. A stronger emphasis on maintainability in the design philosophy is thus called for, leading to an EVAS which requires very little maintenance per hour of operation, fails in a safe manner when it does fail, and which can be easily and quickly repaired or serviced when required.

The actual hardware impacts associated with these findings will be discussed in depth in the detailed study report, but the above considerations constitute the drivers for the requirements embodied therein.

2.3 ANCILLARY EQUIPMENT REQUIREMENTS

Partly as a result of the assessment of EVAS requirements against an existing database of EVA experience and knowledge, and partly as a result of a dedicated analysis effort based on the Generic 15 Missions and the various mission models, a list of approximately 120 pieces of EVA ancillary equipment was derived.

Two broad categories of equipment, Generic Equipment and Special Equipment were included in the list. Generic Equipment would be provided as a normal part of the EVAS in standard equipment/tool kits, arranged most likely into a nominal tool kit and supplementary kits. Special Equipment would be provided by individual payload sponsors as required to service their particular payloads, assuming that equipment from the generic kits would not suffice.

It should be noted that the ancillary equipment list currently contains both off-the-shelf hardware and hardware requiring various amounts of development. Often a significant portion of such hardware development consists solely of making an otherwise off-the-shelf item compatible with EVA operations. As a general guideline in EVA operations design, it is desirable to minimize new hardware development by avoiding the use of Special Equipment and by maximizing the use of the Generic Equipment already provided. However, the primary emphasis should be on minimizing all loose equipment (Generic or Special) by proper design of the subject equipment's interface with the EVAS. For instance, use of captured butterfly latches on access ports is much to be preferred over the use of bolts or screws requiring wrenches or screwdrivers. While wrenches and screwdrivers are very much off-the-shelf equipment, the butterfly latch dispenses with all loose equipment (insofar as it's own operation is concerned) and is therefore better than bolts and screws requiring tools to operate them.

2.4 DOD EVA REQUIREMENTS

DOD EVA requirements were coordinated through the USAF Space Division in El Segundo, California. The DOD identified no mission specific EVA requirements, but instead, expressed twelve "concerns" which must be addressed by the EVAS in order for it to be usable on defense-related missions. Of these concerns eleven were already included as considerations in this study. The twelfth concern - an expressed desire for a two minute EMU don/doff capability - was not a requirement for the Space Station EVAS.

-
- o IMPROVED MOBILITY
 - o MAINTAINABILITY
 - o RADIATION PROTECTION
 - o STATIC CHARGING HAZARD
 - o IMMEDIATE EVA CAPABILITY
 - o CONTAMINATION CONTROL
 - o SIZING
 - o HEADS-UP DISPLAY
 - o MICROMETEOROID PROTECTION
 - o COMFORT
 - o CONTINGENCY TRANSLATION AIDS
 - o RAPID DOWNING/DOWING

FIGURE 2-4
DOD EVA SYSTEMS ISSUES

CONCLUSIONS

The central conclusion of the mission requirement survey is that, while mission data base detail is insufficient for accurate determination of specific task requirements, all EVA mission requirements can be described in terms of the Generic 15 EVA Missions. Because of this, it is felt that the capability to accomplish the 15 Generic EVA Missions is mandatory and should be the focus of future work until such time as greater mission specific detail is available.

A second key conclusion is that, while individual tasks can be accomplished by any suited crewmember, the current Shuttle EVAS would not be satisfactory when examined in the light of the overall mission model. Current EVAS impacts on Shuttle operations could not be tolerated on the Space Station, both in the area of EVA operations and in the area of EVAS servicing and maintenance. Therefore, a much improved EVA System must be provided for the Space Station.

A final conclusion, based on the overall mission model, is that, while a two man EVA crew will suffice for the first years of Space Station operations, within four to six years of Station IOC a four man EVA crew will be required.

RECOMMENDATIONS

1. The EVAS should be designed so that EVA time is crew limited, not hardware limited.
2. The capability should be developed to perform all 15 Generic Missions including development of all Generic Ancillary Equipment.
3. The EVAS must be maintainable on-orbit with continuous operations for 90 days on a 50% duty cycle as a minimum.

4. All payload sponsors should be made familiar with the JSC 10615A document and be encouraged to use it in their design efforts. For time estimate purposes, they should be made familiar with the Generic 15 Missions.

5. All payload sponsors should be provided with a Generic Tool Kit description and a Specialized Tool Kit description. They should be encouraged to use a design requiring minimal loose equipment with such equipment as required being chosen from the Generic Tool Kit if possible. They should be encouraged to identify any required specialized tools as quickly as possible.

SECTION 3

TASK 2 - EVAS BASELINE DESIGN REQUIREMENTS AND CRITERIA

3.1 OPERATIONS

In order to develop realistic design requirements, a general understanding of EVA operations is necessary. EVA by its very nature provides the flexibility to change the way we operate in space on a day-to-day basis, but certain functions are required to be performed regardless. The key elements of any EVA operation from a mature Space Station are:

3.1.1 PLANNING/SCHEDULING: EVA tasks to be performed are scheduled by the master crew scheduling system, along with any other (IV) tasks to be performed for a particular day. Tasks are prioritized according to criticality, proximity to one another, launch windows, etc., then a group of tasks is selected to be performed in the course of an EVA event. EVA is nominally scheduled to be conducted during the 9 orbits/day which do not pass through the South Atlantic Anomaly in the Van Allen radiation belts. At least two crewmembers on each shift have been trained to perform EVA, allowing mission planners maximum flexibility.

3.1.2 EVAS HARDWARE: Each EVA crewmember normally is assigned an Extravehicular Mobility Unit (EMU) consisting of a Life Support System and Crew Enclosure, and is responsible to insure that all required checks have been performed on his unit prior to EVA, whether manually or automatically. On-orbit resizing capability is required in order to permit changes in crewmember/EMU assignment, changes in sizing preference, and maintainability (modularity) of the EMU crew enclosure joints, but resizing is not normally accomplished on a routine basis. Four complete EMUs (1/crewmember, 2 crewmembers/shift) will provide the flexibility and redundancy needed to support the number of EVA hours predicted.

3.1.3 TYPICAL SCENARIO

3.1.3.1 PRE-EVA: Donning of cooling garment and waste collection device(s) is not discussed here; we have assumed that this would take place in the crewmember's personal quarters, much as a workman on earth decides when he gets up whether to wear work clothes or a business suit for a particular day's activities. The day's mission is reviewed among the crew and/or

ground support personnel. Checks equivalent to preflight inspection of an aircraft are performed on the EMU. These checks consist primarily of confirmation of completion of servicing (battery recharge, CO2 media regeneration or replacement, heat sink regeneration or recharge, and oxygen recharge), followed by a visual inspection of the hardware. Each EMU has an associated "logbook" in the Station Data Management System (DMS) which keeps track of accumulated time on the EMU components as well as any minor anomalies which do not preclude system operation, but may possibly cause degraded performance of one or more subsystems. This "logbook" is also reviewed as a part of the checks. Functional checks are performed in conjunction with system donning and activation, assuming no major maintenance has been performed since the last use. If any of these checks reveal a condition which cannot be corrected on the spot, the EVA is postponed unless it is time-critical, in which case a spare EMU is utilized for that particular EVA event, with the failed unit being restored to an operational condition in one duty cycle or less (approximately two days initially, one day or perhaps even one shift as the tempo of operations picks up in later years).

3.1.3.2 EVA: The conduct of the EVA consists of some amount of overhead--translation to worksite, trash stowage, etc.--and performance of some combination of the generic EVA tasks/missions identified in section 2 for a total time at reduced pressure up to 7 hours, with up to 6 hours of that being dedicated to useful EVA tasks. (An additional hour of reserve capacity is available from the Life Support System, but this capability is not normally used except in an emergency.) Translation requirements can be satisfied by a number of approaches (hand-over-hand, propulsion, "dumbwaiter" or trolley concepts, etc.); flexibility can be most enhanced by not precluding any of these methods. For example, a trolley is likely the most efficient means of translation along a keel, while access to solar panels or the like for inspection, and especially rendezvous with/retrieval of free-fliers will require some sort of maneuvering propulsion. Upon arrival at the worksite, restraint is required for the crewmember and for any tools or other ancillary equipment in use. Permanent workstations will be provided in areas of intensive EVA activity, probably along with Station services such as power, hardline communications, and cooling. Some sort of portable, temporary workstation will be required which attaches to most any part of the Station, probably to the truss structure, for use in areas which do not have prepared worksites.

3.1.3.3 POST-EVA: After repressurization of the airlock and EMU doffing, the crewmember initiates recharge and performs a visual inspection of the EMU. The recharge systems located in the airlock automatically shut off upon completion of the recharge. Optionally, this recharge can be accomplished by module replacement to enable rapid turnaround of the EVAS.

3.1.4 EVA SYSTEMS AND TASK TRAINING

Considering the sheer number of EVA hours required annually and the necessity of devising operational techniques and procedures between infrequent Shuttle flights, the impact of extensive mission-specific ground training associated with STS EVA clearly cannot be tolerated for Station operations. The following training philosophy is therefore recommended.

3.1.4.1 GENERIC TRAINING (ground): EVA crewmembers receive training roughly equivalent to that provided for STS flights without a planned EVA. This is currently broken into two distinct areas:

- o System operation fundamentals such as activation and troubleshooting of the Primary Life Support Subsystem (PLSS), donning/doffing of the Space Suit Assembly (SSA), and activation, piloting techniques and troubleshooting of the Manned Maneuvering Unit (MMU). Normal servicing and maintenance tasks are taught as a logical outgrowth of this training.
- o Performance of certain identified contingency EVA tasks required for safe return of the Orbiter after a given set of failures. Corrective actions for these failures, however credible, provide practice in the required basic skills such as position maintenance, translation, teamwork, and tether protocols, as well as familiarization with mobility limitations associated with pressure suits.

3.1.4.2 TASK SPECIFIC TRAINING: This training will be conducted on-orbit, primarily by the use of OJT. Unusually complex tasks may require special augmentation via video/CAI presentations, but for the most part rely on an awareness of EVA considerations during the design of the component/payload or during mission planning to enable application of generic training to the particular task.

3.1.4.3 RECURRENT TRAINING: Emergency procedures and system refresher training will need to be conducted regularly in order to insure maximum crewmember proficiency and safety. This is partially a subset of task-specific training, in that rescue of an incapacitated EVA crewmember, for instance, differs only in criticality, not in task performance, from the translation of any large object or module. System emergency procedures training could best be accomplished by use of the EVAS DMS in concert with the Station DMS to simulate various system failures.

3.1.5 EVA SYSTEMS MAINTENANCE

On-orbit maintenance of the EVAS is, for all practical purposes, completely new ground for the U. S. space program. The relatively short duration of missions to date, along with the relatively small number of EVA hours required and the philosophy that EVA is a backup to other methods of mission accomplishment,

have relegated on-orbit maintainability to the status of an unnecessary luxury, one that we could ill afford in an era of decreasing NASA budgets. With the dependence expected to rightfully be placed on EVA for mission accomplishment in the Station environment, on-orbit maintainability ceases to be a luxury and becomes instead an absolute necessity. Incorporation of maintainability features in the EVAS at the outset not only increases the probability of success for any payload exterior to the pressurized compartments of the Station, but provides a built-in capability to upgrade the system as will inevitably be required after well-meaning (and in all likelihood, necessary) budget cutting at the front end of the program forces acceptance of a less than optimum initial configuration.

3.1.5.1 SCHEDULED MAINTENANCE: For STS, scheduled maintenance has consisted of approximately 3000 hours of ground turnaround between each mission. This will have to be reduced to no more than annual refurbishment of systems, and ideally to repairing only inoperative components. There is no apparent reason why the hardware should not continue to operate indefinitely, just as aircraft continue to provide reliable service after many years of operation.

3.1.5.2 UNSCHEDULED MAINTENANCE: Provisions will have to be made aboard the Station to troubleshoot the EVAS and to isolate failures to the ORU level. Definition of this level is premature at this point, as it is circularly dependent on system design, which in turn depends on ORU level definition. This iterative process is best accomplished during the preliminary design phase. Considerations will include tool requirements for disassembly of components, cleanliness requirements, crew training, and many others. As a general rule, design of any system should not preclude any subcomponent being designated as an ORU unless this unnecessarily complicates design or increases cost (procurement or operations).

3.1.5.3 MAINTENANCE DOCUMENTATION:

The Documentation System ("logbooks") has access terminals at all maintenance locations (primarily the airlock).

The EVAS components (crew enclosure, life support system, propulsion system, and support equipment) are subdivided into ORUs, at which level all maintenance documentation will be recorded.

3.2 EVA SYSTEMS REQUIREMENTS

The basic configuration of the EVAS is driven by the environment. That is, any configuration developed will have to provide life support services, environmental protection, and probably propulsion.

The configuration and system sizing are driven by operational considerations. Due to the lack of detailed definition of missions, we feel that the best approach is to try to maximize the advantage from having a man present, which means enhancing his flexibility at every opportunity. In doing this, several overall EVAS issues come to light:

- O MAINTAINABILITY--The elements of maintainability (modularity and accessibility) go further toward permitting design flexibility than any other concept. That is, any ORU that can be removed and replaced during maintenance can just as easily be replaced by an updated version for growth or a less advanced system for fall-back in the event of technical or funding problems in advancing technology.
- O SUBSYSTEM FUNCTIONAL INTEGRATION--Closely related to maintainability, frequently competing. Should be minimized in favor of maintainability. NOTE: This does not apply to physical integration such as putting the radio in the backpack, rather to such concepts as tying the humidity control system to the feedwater system as in the STS EMU PLSS. While this effectively minimized the PLSS volume as required by STS considerations, it precludes upgrade of one of these systems without a complete system redesign.
- O AUTONOMY--Every opportunity to provide autonomy of the Station from the ground or the EVA crewmember from the Station should be capitalized upon, thus providing a host of operational (flexibility) benefits.
- O ACCEPTABLE PHYSIOLOGICAL RISK--Since so little is known about the physiology of decompression sickness, we feel the best approach is to not try to determine some boundary level of denitrogenation, rather a cabin/suit pressure ratio should be adopted which negates the need for prebreathe. (According to current thinking, this means $R = 1.22$ or less, where R is the ratio of alveolar nitrogen to the final suit pressure.) For the sake of EVA productivity, this combination should be as low as possible consistent with fire hazards, experiments, etc. From an EVA standpoint, a cabin pressure of 70 kPa (10.2 psi) with 30% O₂, along with an EVAS operating pressure of 40 kPa (5.8 psi) would seem to be the optimum.

- U NOMINAL AND MAXIMUM LENGTH OF EVA--While longer EVA duration capability means a larger LSS, the overhead associated with getting outside on a "per event" basis dictates that the system be sized according to practical upper size limits and physiological (fatigue) considerations.

Different disciplines have a different view of this. From an operational standpoint, we should provide 6 hours per crewmember per day available to users. From an equipment design standpoint, 8 total hours of life support available including reserve. From a logistics standpoint, 3 two-man EVA events per week.

- O REDUNDANCY--No single, credible failure should result in the loss of a critical function (though it may possibly result in function degradation and/or premature termination of EVA).

In summary, the correct approach to defining design requirements for a productive EVAS is to strive to provide the maximum flexibility in order to enable future operations planners, design engineers, and most of all EVA crewmembers to apply the advantages of human presence with minimum restrictions. EVAS requirements were developed based on this premise, and are summarized in Sections 3.2.1 through 3.2.12. Discussions of rationale for each requirement are contained in the detailed study report.

3.2.1 LIFE SUPPORT REQUIREMENTS

The Life Support System (LSS) must provide the following functions in Low Earth Orbit (LEO) space vacuum during performance of tasks identified in Section 2.

- O PRESSURIZATION/PRESSURE CONTROL
 - O ADJUSTABLE PRESSURE FROM 30-66 kPa (4.3-9.5 psi)
 - O REDUNDANT REGULATORS
 - O EMERGENCY MANUAL BACKUP
- O BREATHING OXYGEN--TOTAL 6 KG
 - O 6 HOURS OF USEFUL WORK @ 300 W (1000 BTU/HR) AVG
 - O 2 HOURS OF COMBINATION OVERHEAD/RESERVE @ 300 W
 - O 45 MIN OF CONTINGENCY OPERATIONS W/ 6 KG/HR LEAK

3.2.1 LIFE SUPPORT REQUIREMENTS (continued)

- O ATMOSPHERE REVITALIZATION
 - O CO2: SIMILAR TO SHUTTLE REQUIREMENTS--PERMIT HIGHER LEVEL DURING HIGH METABOLIC ACTIVITY AND LATE IN EVA
 - O HUMIDITY: 40-70% RELATIVE HUMIDITY, MAX 90%
 - O TRACE CONTAMINATES: IDENTICAL TO SHUTTLE REQUIREMENTS
- O THERMAL CONTROL--Collect, store, and/or reject heat.
 - O 100-600 WATTS (340-2000 BTU/HR)
 - O NO OVERHEATING BELOW 450 W
 - O AUTO CONTROL DESIRABLE

3.2.2 ENVIRONMENTAL PROTECTION REQUIREMENTS

The EVA crewmember and EVAS must be protected from the surrounding environment.

- O RADIATION
 - O IONIZING
 - O PROTON
 - O MAINTAIN TOTAL MISSION DOSE @ ACCEPTABLE LEVELS
 - O SCHEDULE ALL NON-EMERGENCY EVA AROUND SAA
 - O RF
 - O CONTROL OPERATIONALLY
 - O NON-IONIZING: PROTECT EYES, HELMET FROM UV
- O MECHANICAL DANGERS
 - O MICROMETEORIDS/SPACE DEBRIS > 95% PROB OF NO PUNCTURE BASED ON DEBRIS MODEL
 - O SHARP CORNER/EDGE SAME AS SHUTTLE SINCE STS EMU USED FOR CONSTRUCTION
- O ATOMIC OXYGEN: CONTROL WITH MATERIALS SELECTION/SHIELDING

3.2.2 ENVIRONMENTAL PROTECTION REQUIREMENTS (continued)

0 STATIC CHARGING

- 0 CREWMEMBER: LEVELS DO NOT PRESENT A DIRECT THREAT
- 0 EVAS/PAYLOAD: PROPERLY GROUND, SHIELD ALL ELECTRONICS; USE GROUND STRAP WHEN APPROACHING PAYLOADS

3.2.3 MOBILITY/ANTHROPOMETRIC SIZING REQUIREMENTS

Mobility considerations produce a requirement for an anthropomorphic crew enclosure with maximum torque and minimum joint range equivalent to a Shuttle EMU at 30 kPa (4.3 psi).

Range of crew size to be accommodated should be specified so as to fit the largest possible percentage of the target population with the minimum number of components. Attempts to fit an arbitrarily defined range of male and female percentiles for STS resulted in a system which cost far too much, compromised fit for all but a few, and ultimately failed to fit the specified range due to the technology limitations of building gloves for the small end of the anthropometric range while retaining sufficient mobility to allow the crewmember to perform useful tasks.

3.2.4 COMMUNICATIONS REQUIREMENTS

- 0 ALL RF LINKS REQUIRE ENCRYPTION CAPABILITY
- 0 VOICE
 - 0 FULL DUPLEX BETWEEN ALL PARTIES AT ALL TIMES
 - 0 DESELECTION OF STATIONS ON NET CAPABILITY FOR EVA CREWMEMBERS
 - 0 CONSIDERED SUBSET OF DATA COMMUNICATIONS SINCE DIGITAL SYSTEM IS ANTICIPATED
- 0 DATA
 - 0 SS --> EVAS
 - 0 RELATIVE STATE VECTOR (1/SECOND) DURING UNTETHERED OPERATIONS
 - 0 PROCEDURAL TEXT AND GRAPHICS (1 SCREEN/5 SECONDS)
 - 0 EVAS --> SS
 - 0 COMPLETE SYSTEM STATUS (1/SECOND)
 - 0 CONTINUOUS CARRIER ("KEEP-ALIVE")

3.2.4 COMMUNICATIONS REQUIREMENTS (continued)

- 0 VIDEO
 - 0 NOMINAL ATTACHED OPS COVERED BY STATION CCTV SYSTEM
 - 0 STATION --> EVAS
 - 0 ONE SCREEN/5 SECONDS
 - 0 HARDLINE CONNECTOR ON EVAS (FULL MOTION FROM STATION, PREVIEW CAMERA TRANSMISSIONS)
 - 0 EVAS --> STATION
 - 0 FULL-MOTION REQUIRED DURING EEU FREE FLIGHT

3.2.5 DATA MANAGEMENT REQUIREMENTS

- 0 I/O DATA HANDLING FUNCTION
 - 0 PROVIDE INTERFACES TO EVA CREWMEMBER, EVAS DISPLAY, EVAS SYSTEMS, EVAS COMMUNICATIONS SYSTEM
 - 0 VALIDATE RECEIVED DATA ACCORDING TO CRITICALITY
- 0 SYSTEMS MANAGEMENT FUNCTION
 - 0 SAMPLE ALL BIO, EMU, EEU INSTRUMENTATION, DISTRIBUTE DATA
 - 0 DETERMINE HEALTH, MISSION STATUS, ISSUE C & W
 - 0 MANAGE DISPLAYS (SOURCE, TYPE)
 - 0 EEU GUIDANCE AND CONTROL
- 0 APPLICATIONS PROGRAMS
 - 0 FIRMWARE REQUIRED FOR SAFETY-CRITICAL FUNCTIONS
 - 0 STANDARDS/SPECS SIMILAR AS POSSIBLE TO THOSE FOR SS INTERGRATED DMS
 - 0 STANDARDIZED CREWMEMBER INTERFACE

3.2.6 MANEUVERING PROPULSION REQUIREMENTS

- 0 MMU-CLASS VEHICLE (EEU) REQUIRED FOR CREWMEMBER RESCUE SCENARIO, HIGHLY DESIRABLE FOR ROUTINE MISSION OPERATIONS
- 0 REMAINDER OF REQUIREMENTS DEVELOPED ASSUMING EEU WOULD BE DEVELOPED AND BUILT
 - 0 OMV-CLASS VEHICLE (TUG) HIGHLY DESIRABLE FOR LARGE OBJECT MANIPULATION
 - 0 COLD GASEOUS NITROGEN FOR PROPELLANT EXCEPT FOR REMOTE TUG OPS
 - 0 50 M/SEC (150 FT/SEC) DELTA-V REQUIRED FOR EEU
 - 0 SAME ACCELERATION (TRANSLATIONAL AND ROTATIONAL) AS SHUTTLE MMU
 - 0 REDUNDANT PROPULSION AND CONTROL SYSTEMS AS ON SHUTTLE MMU
 - 0 NAVIGATION/TARGETING INFORMATION FOR RENDEZVOUS W/ CEP < 10 M AT < 2 KM
 - 0 AAH CAPABILITY W/ SELECTABLE INHIBIT OF UP TO 2 AXES
 - 0 SELECTABLE CG OFFSET COMPENSATION
 - 0 ATTACHMENT PROVISIONS FOR ROBOTIC/TELEOPERATOR CONTROL
 - 0 UNIVERSAL GRAPPLE FIXTURE
 - 0 CREWMEMBER RESCUE INTERFACE FOR CREWMEMBER W/ OR W/O EEU
 - 0 VARIABLE THRUSTER SELECT LOGIC TO MINIMIZE PLUME IMPINGEMENT
 - 0 AUTO SERVICING W/ MINIMUM CREWMEMBER INTERVENTION

3.2.7 CREWMEMBER SUPPORT REQUIREMENTS

- O HAND-IN CAPABILITY HIGHLY DESIRABLE TO ENHANCE ALL FUNCTIONS
- O 750 CALORIES OF FOOD FOR EVA CONSUMPTION
- O 1.2 LITERS (40 OZ) OF WATER FOR EVA CONSUMPTION
- O WASTE MANAGEMENT
 - O HYGIENICALLY COLLECT 1.5 LITERS (51 OZ) OF URINE
 - O FECAL/VOMITUS CONTROL NOMINALLY ACCOMPLISHED THROUGH DIET AND PERSONAL HABITS

3.2.8 MAINTENANCE/MAINTAINABILITY REQUIREMENTS

- O MODULAR DESIGN W/ EASY ACCESS, QUICK DISCONNECTS FOR FLUID AND ELECTRICAL CONNECTORS
- O MINIMIZE REQUIREMENT FOR PERIODIC MAINTENANCE AND TESTING--MAINTAIN ON CONDITION
- O FAIL-SAFE DESIGN ALLOWING SAFE RETURN TO A PRESSURIZED ENVIRONMENT AFTER COMPONENT FAILURE
- O IV MAINTENANCE WORKSTATION WITH APPROPRIATE RESTRAINT/POSITION AIDS AND FLUID, ELECTRICAL, AND ELECTRONIC INTERFACES
- O EVA MAINTENANCE STAND FOR EEU, INCLUDING PROVISIONS FOR PROPELLANT VENTING IN THE EVENT THE EEU OR SOME COMPONENT THEREOF MUST BE BROUGHT INSIDE

3.2.9 SERVICING REQUIREMENTS

- O ROUTINE SERVICING AUTOMATED TO MAXIMUM EXTENT PRACTICAL
- O IF REGENERATIVE LSS SYSTEMS USED, IN-PLACE REGENERATION IS DESIRABLE

3.2.10 LOGISTICS REQUIREMENTS

- 0 SUFFICIENT CONSUMABLES AND SPARE PARTS FOR 120 DAYS W/ THREE TWO-MAN EIGHT-HOUR EVAs/WEEK
- 0 STORAGE CAPABILITY FOR ONE YEAR'S SUPPLY OF EEU PROPELLANT HIGHLY DESIRABLE
- 0 MINIMIZE QUANTITIES OF SPARE PARTS REQUIRED THROUGH USE OF RUGGED, HIGH-RELIABILITY PARTS
- 0 MINIMIZE REQUIREMENT FOR TOOLS (ESPECIALLY UNIQUE TOOLS)

3.2.11 OPERATIONAL LIFE REQUIREMENTS

- 0 MINIMUM ONE YEAR ON-ORBIT BETWEEN GROUND RESERVICING
- 0 MINIMIZING COMPONENT MASS SHOULD BE SECONDARY TO SIMPLICITY AND RUGGEDNESS
- 0 OPERATIONAL CYCLES SHOULD BE MINIMIZED (E.G., CHECKOUT IN CONJUNCTION W/ NORMAL DORNING AND ACTIVATION)

3.2.12 EXTERNAL CONFIGURATION REQUIREMENTS

- 0 ANTHROPOMORPHIC CREW ENCLOSURE
- 0 EMU SIZED FOR 95th PERCENTILE CREWMEMBER SHALL PASS THROUGH SHUTTLE AIRLOCK HATCH
- 0 EEU SHALL ACCOMMODATE CREWMEMBER IN SHUTTLE EMU

SECTION 4

TASK 1 - SPACE STATION/EVA SYSTEM INTERFACE REQUIREMENTS AND EVA ACCOMMODATIONS

The Space Station/EVAS interface requirements fall into eight different categories:

1. Atmosphere Composition/Pressure
2. Communications
3. Data Management
4. Logistics
5. Safe Haven
6. SS Exterior Requirements
7. SS Interior Requirements
8. SS Airlock

4.1 ATMOSPHERE COMPOSITION AND PRESSURE

Several issues impact the choice of Station cabin atmosphere and pressure. EMU pressure should be as low as possible to provide the least productivity impact due to glove and suit joint mobility impairment or to pre-breathe requirements. Feasible maximum suit pressures drive feasible maximum cabin pressures because of the necessity for denitrogenation as the delta between the two increases. Figure 4-1 illustrates the relationship between EMU and cabin pressure with the area inside the lines defining possible combinations of pressures based on various assumptions. The parameter R is defined as the ratio of partial pressure of nitrogen in the crewmember's tissues to final (EMU) pressure. Note that zero pre-breathe is assumed, which means that, according to current medical research, an R of 1.22 and no higher is desired to prevent an occurrence of bends. The glove mobility limit line indicates the highest pressure at which current technology provides reasonable glove mobility.

Based on this analysis, a Station cabin pressure of 10.2 psi would be recommended, which together with an R value of 1.22 and a suit pressure of 6 psi would give acceptable EVAS performance with no pre-breathe. However, the Phase B programmatic decision has been made, due to other, global, Space Station considerations, to set cabin atmosphere at 14.7 psi Earth normal. This shifts all impacts, then, to the EVAS, pushing us beyond current glove technology for high pressure mobility or beyond acceptable bends risk without denitrogenation.

As Figure 4-1 indicates, due to the 14.7 psi cabin atmosphere either a high technological risk is incurred by requiring a suit pressure of 9.5 psi (with no pre-breathe), or productivity impacts are generated by requiring pre-breathe to achieve the lower suit pressure. The option of higher R values on a regular basis is not recommended due to increased crewmember risk of bends. The possible requirement for pre-breathe could force an impact on the Space Station by generating a further requirement for an intermediate pressure in the EVA prep area.

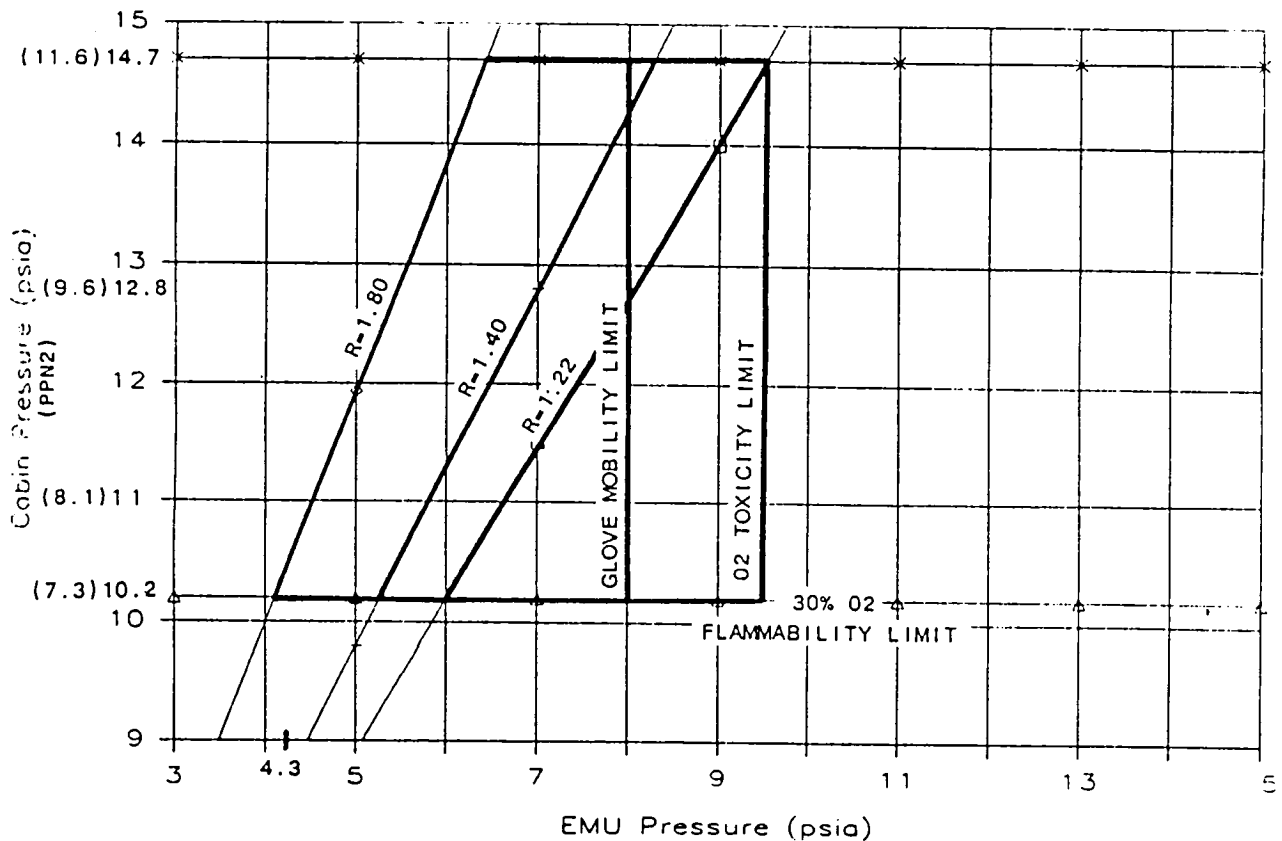


FIGURE 4-1
CABIN/EMU PRESS FOR ZERO P/B

4.2 COMMUNICATIONS

Three types of communication are desired to support EVA operations. They are:

1. Full Duplex Voice Communications
2. Data Uplink/Downlink
3. Video Uplink/Downlink

where uplink/downlink refers to Station to EVAS communications.

Full duplex voice communications would have to be provided for up to four EVA crewmembers simultaneously with the added provision to allow different teams of crew members, both IV and EV, to carry on separate conversations without interference from the other team.

Data uplink/downlink would consist of communication of system status data, alarms, and crew health data and possibly navigation information for a free-flying crewmember. Note that information would travel both ways, from Station to EVAS and vice-versa.

Video communications would provide freeze frame television to the EV crewmembers for transmission of procedural/task aids, and full motion television from the crewmember to the Station for worksite/task data to the Station and ground.

All issues associated with the Communications interface are straightforward design issues such as selection of the method of navigation of a free-flyer or degree of integration of the EVAS communications system with the station communications system. A list of all issues is presented in Figure 4-2.

-
1. FULL INTERGRATION OF EVAS COMM. WITH STATION COMM.
 2. DIRECTIONALITY OF SIGNAL
 3. POWER REQUIREMENTS
 4. COMPATIBILITY WITH SHUTTLE
 5. MAINTENANCE REQUIREMENTS
 6. METHOD OF NAVIGATION

FIGURE 4-2
EVA/SS COMMUNICATIONS ISSUES

4.3 DATA MANAGEMENT SYSTEM

The Space Station/EVAS Data Management System (DMS) would be responsible for all data handling and for the associated data systems management. The EVAS and associated EVAS DMS should appear to the Station DMS as merely another user with, possibly, some peculiar Input/Output requirements.

The DMS would be responsible for input/output data handling, interfacing the Station and EVAS processors to the full duplex telemetry system.

The DMS would be responsible for monitoring it's own systems and would also be responsible for monitoring EVA systems, providing EVAS monitoring and control (including alarms and procedures), free-flyer navigation and targeting information, and general displays management. The DMS could act as residence for an EVA monitor expert system.

Issues associated with the DMS are questions of allocation of functions to the EVAS or Station DMS, and questions of allocation of functions to software or firmware.

4.4 LOGISTICS

Upon analysis, five general EVA logistics requirements categories were discovered. These are:

1. Scheduled Maintenance Items
2. Regenerable EVAS ORUs to Support Quick Turnaround
3. Single Use and/or Low MTBF Items
4. Select Damage Prone Items
5. Select Random Failure Items

These group into two classes of resupply items:

1. On-Board Spares - One Time Delivery, Replenish as Required
2. Resupply Items - Resupply Every 90 Days

After determining initial quantities of EVAS items from operational considerations and the mission model, spares and resupply cycle data were derived from STS experience and extrapolations from technology development programs. Tables such as Table 4-1 were derived for each major EVAS end-item and overall logistics requirements were determined as shown in Table 4-2.

ON-ORBIT EMU SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
EMU LSS	2	378 (834)	382 (13.5)
SCU	2	10 (22)	57 (2.0)
Phase Change Heat Exchanger	2	20 (43)	28 (1.0)
CO2 Removal Canister CWS	2	98 (216)	

TABLE 4-1
PROJECTED EMU SPARES REQUIREMENTS

	MASS (KG)	VOL (LITERS)
ON ORBIT EMU SPARES Resupply as required	520	555
EMU RESUPPLY 90 DAYS	414.5	537
ON ORBIT SERVICE EQUIPMENT SPARES Resupply as required	47.2	46.9
SERVICE EQUIPMENT RESUPPLY	0.3	6
EEU SPARES Resupply as required	190.6	125.1
ANCILLARY EQUIPMENT SPARES	54.1	361.6

TABLE 4-2
LOGISTICS REQUIREMENTS SUMMARY

Logistics issues stem from the uncertainty currently present in all EVAS designs. ORU definition is configuration dependent and actual MTBFs will drive sparing provisions, as will the maintenance philosophy adopted and implemented. Additionally, all EVAS use models, especially the EEU use model, are fairly soft.

4.5 EVA SAFETY HAVEN

The EVA Safety Haven would have two practical uses:

1. As a shielded refuge from harmful radiation environments
2. As a pressurized refuge in cases of EVA crew emergency at a remote worksite requiring rapid pressurization

Two basic radiation threats present themselves to the EVA crewmember at LEO: the South Atlantic Anomaly in the Van Allen belts and sudden intense solar flares. The South Atlantic Anomaly is a downward bulge of the Van Allen belts towards the surface of the earth which subjects any unshielded crewmember passing through it to higher than normal radiation fluxes. Over a period of 90 days, the expected average crew stay time, these exposures could add up to harmful levels. While a safe haven could be used to shield the EVA crew member for the 15 minutes of a pass through the Anomaly, the problem can be avoided entirely simply by scheduling the EVA to coincide with orbits which miss the SAA. This means that the EVA crew shift would have to be changed, say from first to second shift, as orbital precession moved SAA passes into EVA periods. This is preferred to use of a safety haven.

Sudden intense solar flares could also pose a threat to the EVA crew. While an EVA safety haven could be used to protect them, in all cases sufficient warning of the arrival of a flare (at least 8 minutes) should exist to allow the crew to return to the Station interior and seek shelter there. This latter approach is preferred. Such events are not expected to occur more than once or twice in the eleven year solar cycle.

The EVA safety haven could be used to provide a pressurizable volume at a remote worksite in case of some emergency requiring rapid pressurization. Such an emergency might be a large leak in the EMU pressure garment or extreme injury or illness of the crewmember requiring immediate attention. The safety haven would need to be transportable in this case, both to be emplaceable next to the current worksite and to allow its transportation to the Station airlock once used. The safety haven would need to interface with the Station airlock to allow transfer of the affected crewmember in a pressurized environment to the Station interior. While this capability is desirable, it is not justified as a requirement and the decision to implement it will have to be made by weighing probability of need versus the cost of implementation.

4.6 SPACE STATION EXTERIOR

The Space Station exterior architecture must provide for:

1. Access to Worksites
2. Compatible and Efficient Workstations
3. Stowage of EVA Tools and Equipment
4. Remote Dependent Life Support Capability
5. Crewmember Safety

Access to worksites is provided by translation aids and restraints. Two types of translation aids, handrails and supplemental aids, are required. Handrails should be provided at all points on the Station exterior to allow manual translation by EVA crewmembers. Exceptions are locations where Station primary structure provides sufficient handholds for such translation. A supplemental aid or aids should be provided to allow rapid crewmember translation over long distances on the Station. Such aids would perform the functions of an elevator or dumbwaiter and would allow the crewmember to move quickly about the Station exterior either unencumbered or while carrying cargo equivalent to a medium module (up to 250 kg. and/or 1 cubic meter). A second type of supplemental aid would also be required, this one to move large modules from point to point on the Station in approximately 20 minutes or less.

Exterior restraints would be required comprising tether points and workstations. Tether points could either be fixed, probably an integral part of each handhold, or mobile, either as the working end of a safety line or slidewire or as part of a supplemental translation aid.

Workstations can either be fixed or mobile, that is, transferrable from worksite to worksite. They should not only firmly restrain the crewmember during work, but should also firmly hold the piece being worked on and any tools and parts required as well.

Sufficient lighting should be provided the crewmember on the Station exterior and at worksites (workstations) to allow unimpaired task performance during both day and night cycles. A tentative minimum of 50 foot-candle area lighting should be provided with the capability to perform 200 foot-candles of spot lighting.

External Stowage is required to permit convenient access to tools, equipment and ORUs, etc., while EVA.

A Dependent Life Support System (umbilical) may be required to provide support for a limited capability EMU Life Support Subsystem, to allow extension of a critical EVA, or to provide closed-cycle operation in the vicinity of sensitive instrumentation.

Safety of EVA crewmembers must be provided for on the Station exterior first by providing standards for exterior equipment design and second by the provision of required safety equipment. In the first case, a design criteria document similar to JSC 10615A "EVA Description and Design Criteria" should be provided for the Space Station to guide Station and payload designers with proper design standards. In the second case, an autonomous capability to retrieve stranded free-floating crewmembers (and debris) must be provided.

NUMBER AND TYPE OF AUXILLIARY TRANSLATION AIDS
OPERATIONAL SPECIFICATIONS: CARGO MASS, TRANSLATION TIMES,
ACCESS DESIGN CONCEPTS/SPECIFICATIONS

NUMBER AND TYPE OF WORKSTATIONS
FIXED AND PORTABLE
LOCATIONS

SITTING OF STOWAGE FACILITIES
OPTIMAL LOCATION

NEED FOR UMBILICAL
SOFT REQUIREMENTS VS COST

SAFETY DESIGN STANDARDS
WHAT ARE THE REQUIREMENTS?

DESIGN CONCEPTS FOR STRANDED CREWMEMBER RESCUE
FREE-FLYER VS SELF-CONTAINED

FIGURE 4-3
SPACE STATION EXTERIOR ISSUES FOR EVA ACCOMMODATIONS

As shown in Figure 4-3, most issues associated with Space Station exterior interface requirements are design issues. Two exceptions exist. The need for a Dependent Life Support System is soft and may not justify the cost. And stranded crew member rescue might possibly be accomplished by some method other than by a free-flying maneuvering unit, at a much smaller cost, but the free-flying unit is the only method in which confidence currently exists.

4.7 SPACE STATION INTERIOR

Space Station interior EVA interfaces must provide:

1. Stowage for EMUs, Support Equipment and Spares
2. An EVA Preparation Area
3. An EVA Servicing, Maintenance and Checkout Area
4. An EVA Planning/Training Area

Examination of various impacts and considerations allows allocation of the four functions above to Station modules. The impacts and considerations are:

1. Volume Required
2. Utilities and Systems Interfaces Required
3. Proximity of Related Functions

The functions, then, are allocated as shown in Table 4-3.

	STOWAGE	PREP/POST	SERVICING	MAINT.	CHECKOUT	PLANNING
AIRLOCK/EVA MODULE	PREFERRED	MANDATORY	MANDATORY	PREFERRED	MANDATORY	OPTION
HAB MODULE	OPTION			OPTION		PREFERRED
LOG MODULE	OPTION (SPARES)					

TABLE 4-3
ALLOCATION OF INTERIOR REQUIREMENTS TO AREAS

The Airlock/EVA module is the only logical location which satisfies EVA requirements in that it minimizes volume impacts to other SS modules and integrates operational requirements with utilities and system interface locations. However, some assembly, sub-assembly or component maintenance tasks may require a specialized maintenance environment depending on actual ORU definition, trouble shooting and post maintenance test requirements and cleanliness requirements. This might take the form of a "cleanroom" - like area in a Hab module.

4.8 SPACE STATION AIRLOCK

The primary function of the Station airlock is to provide a safe, efficient means of transferring men and equipment to and from the vacuum of space without imposing any adverse effects on Station operations. As noted above, it must also have provisions for storage of EVA equipment and must provide EVA system servicing and maintenance equipment including automatic servicing and

checkout equipment. It is highly desirable to minimize the amount of gas lost with each cycle to vacuum. Therefore airlock depressurized volume should be kept to a minimum and as much atmosphere as possible and cost-effective should be retained and recycled.

A programatic requirement for a hyperbaric chamber has also been levied with the airlock being the preferred location for this chamber. It must accommodate two crewmen and such medical equipment as required during hyperbaric treatment, as well as specified biomedical monitoring apparatus. It must be capable of operation at six atmospheres for two hours, thereafter following a standard Navy decompression profile back to cabin atmosphere.

SECTION 5

SUMMARY

5.1 STUDY OBJECTIVES ACHIEVED

As they were defined by the Statement of Work, our study objectives were achieved by survey and research, analyses and trade studies. We have developed what we consider to be a comprehensive set of design requirements for the Space Station EVAS and its interfacing and supporting systems.

In addition to the study contract objectives, the McDonnell-Douglas team had several other objectives in mind. First, we were determined to assist NASA in justifying a productive EVA capability for the Space Station program. As adamant EVA advocates we were strongly motivated to see that EVA and its attendant systems and accommodations received the programmatic attention they deserved. Secondly, we were fresh from our experiences in developing and conducting the STS EVA missions and eager to apply the lessons learned to the Space Station development effort. We were confident that as a continuing part of the NASA-led SS development team, we would share in the downstream benefits of a strong front end effort. Finally, and taking our cue from a theme consistent throughout the SOW, we wanted to make sure that all EVA system definition and development efforts were sensitive to human productivity aspects and impacts which are so often expressed in non-quantifiable terms.

Our first objective was shown to have been naively conceived as our mission requirements survey resulted in an EVA mission model which demands EVA services on a sustained and routine basis. Even with peak needs exceeding 3000 manhours in a year, the model must be considered conservative, since the SS maintenance, servicing, and repair requirements are poorly defined at this time and there is virtually no data to support the unplanned or contingency requirements which have been responsible for so much of the STS recent EVA requirements. We must continue to recognize that our mission model, as well as those we are aware of being utilized in SS Phase B trade studies, are indeed conservative and may not represent the full scope of EVA requirements for the Space Station.

Throughout the study we were careful to apply the lessons learned from the STS EVA experience base to our analyses and trade studies and found this background useful in identifying truly useful

advancements, in weighting trade-off criteria or in assessing all the ramifications of a new requirement or concept. Extrapolating from this base also enabled us to characterize the key differences in EVA capabilities and limitations between the STS and the SS. While we feel we were thus successful in meeting our second objective we recognize that there is a continuing need for NASA and the Space Station contractors to pursue this goal in the development of EVA systems.

With regards to the emphasis placed on human productivity aspects of EVA designs, we made a concerted effort to bias our trades in favor of productivity, even to the point of ignoring development cost as a discriminator between design options. So far, our conviction that maximizing the use of the crew as the most critical SS resource was the highest priority is being borne out by the EVAS cost trades being performed in the Phase B arena. We will have a continuing concern, though, that there will be productivity impacts resulting from priorities established for distributing limited SS development funds and minimizing those impacts will be a major challenge to the program. The savings in operational costs will be the future dividend of that effort.

5.2 AREAS REQUIRING FURTHER STUDY

Phase B studies will continue to refine EVAS requirements during the SS preliminary design phase, and both contractor and NASA Advanced Development programs will continue to develop the necessary technologies. We strongly recommend that emphasis be placed in the following areas as the program advances (Figure 5-1).

5.2.1 KEY ISSUES

The SS program has already recognized the importance of the radiation exposure issue as it affects the SS as a whole. We feel that this is the proper perspective to take considering the frequency, duration, and dose rate of the possible crew exposures, both IV and EV.

So long as space suit mobility remains affected by suit pressure, we must look for ways to improve the technology or lower the suit pressure. This is especially true for the gloves where even a technology breakthrough would be enhanced even further by lowering the operating pressure. However difficult it is to measure the impacts of this problem on overall EVA productivity, we are convinced that it will significantly affect the productive utilization of EVA as a valuable program resource.

While we are convinced that a maneuvering propulsion capability should be a part of the advanced EVAS, we recognize that the justification for it is not as firmly rooted in mission requirements as are the justifications for other systems. The cost of providing this capability should be carefully balanced against

KEY ISSUES

- 0 RADIATION EXPOSURE LIMITS
- 0 GLOVE DEXTERITY/SUIT MOBILITY REQUIREMENTS US TECHNOLOGY LIMITS
- 0 EEU JUSTIFICATION
- 0 IMPLEMENTATION OF ROBOTICS

DESIGN TRADE STUDIES FOR PHASE B/C/D CONTRACTORS

- 0 HAND-IN-SUIT CAPABILITY FOR CREW ENCLOSURE US SUIT FIT, DEXTERITY, EVAS VOLUME IMPACTS
- 0 CREW ENCLOSURE JOINT DESIGN SELECTION
- 0 BODY SIZE ACCOMMODATION RANGE US COST OF IMPLEMENTATION
- 0 DUAL PRESSURE EMU
- 0 EXTENDED EVA DURATION US EVAS VOLUME GROWTH
- 0 THERMAL CONTROL SYSTEM PERFORMANCE

FIGURE 5-1
AREAS REQUIRING FURTHER STUDY

prioritized program needs, regardless of the benefits of having it. Maneuvering propulsion does remain the only practical solution to the potential problem of crew rescue.

We have identified a number of areas which would benefit from advancing technologies in expert systems, teleoperations and other automation or robotic-type applications. While the implementation of such advances is still premature in many cases, the productive benefits warrant continued emphasis.

5.2.2 DESIGN TRADES

The hand-in-suit capability, while offering some significant benefits for crew health and comfort, must be evaluated for the potential impacts to suit fit in general, and especially to the critical glove fit relationship to hand dexterity. The overall crew enclosure may then tend to grow which may also be a problem.

While actual selection of the joint designs was not a Phase A issue, several concepts were evaluated and appear workable. To prevent development from being hindered, premature selection of one concept should be avoided. The modularity afforded by all the current design concepts supports this.

Just as it was for the STS program, the actual crew size range to be accommodated by the SS program, regardless of the range accommodated by the EVAS design, will have to be a carefully considered decision, based heavily on program cost.

A dual pressure EMU must be considered as an option until the suit pressure can be maintained at a level that satisfies both human physiological and productivity considerations. Our requirement for a variable suit pressure reflects the current dilemma posed by the sea level cabin. This will definitely require further study.

Several factors (maintainability, regenerative system efficiency, reliability) continue to conspire to increase the overall volume of the EVAS. This concern may result in a need to reduce the LSS volume allocated for time dependent functions which must be traded off against allowable independent life support time.

The EVAS thermal control system, which was overdesigned for the STS environment, should benefit even more from the more thermally benign SS environment, and thus reduce its volume as the performance requirements are relieved.

There are numerous other design options to be considered as EVA systems and subsystems develop. As cost driven compromises have an effect on crew productivity, continuing effort must be applied to carefully assess those effects to be sure that negative impacts are properly justified.



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16. Abstract The first day of the Research Review opened with an overview of EVA Research and Development activities at Ames. The majority of the program was devoted to presentations by the three contractors working in parallel on the EVA System Phase A Study, focusing on Implications for Man-Systems Design. The final presentation described Diving Industry Approaches to Work Systems Development.					
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