NASA CR-
140364

(NASA-CR-140364) STUDY OF ROLES OF REMOTE MANIPULATOR SYSTEMS AND EVA FOR SHUTTLE MISSION SUPPORT, VOLUME 1 (Essex Corp.) 132 p HC $5.75 CSCL 22B

N75-12036

Unclas

G3/18 03607

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FINAL REPORT

STUDY OF ROLES OF REMOTE MANIPULATOR SYSTEMS AND EVA FOR SHUTTLE MISSION SUPPORT

VOLUME I

Prepared for:

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Under Contract NAS9-13710

October 1974

ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to the many people who assisted in the completion of this effort. Special thanks are extended to: Dr. Stanley Deutsch, Head, Bioengineering Division, NASA Office of Life Sciences; David C. Schultz, Chief of the Procedures Branch, Crew Training and Procedures Division, NASA JSC; and James L. Ellis, of the Procedures Branch.

In addition, the following individuals are acknowledged for having significantly contributed to the results of this effort:

Carl Janow, Bioengineering Division, Office of Life Sciences, NASA HQ

Raymond G. Zedekar, Procedures Branch, NASA JSC

John H. Covington, Procedures Branch, NASA JSC

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Glen C. Miller, Remote Manipulator Systems, Spacecraft Design Division, NASA JSC

ACKNOWLEDGMENTS, Continued:

Louis E. Livingston, Head, Analytical Support Section, Spacecraft Design Division, NASA JSC

Robert L. Bond, Head, Man-Machine Engineering Section, Spacecraft Design Division, NASA JSC

Jack C. Heberlig, Manager, Payloads Coordination Office, Space Shuttle Program Office, NASA JSC

Maj. Charles E. Whitsett, USAF STS Group, Space Shuttle Program Office, NASA JSC

Jerry R. Goodman, Orbiter Systems Integration, Space Shuttle Orbiter Project Office, NASA JSC

Dr. Ewald Heer, Advanced Technical Studies, JPL

Dr. Woo, Erectable Antenna Program, Communications/Navigation, JPL

B. C. Look, Shuttle IR Telescope Development Program, NASA Ames

Eugene Ehrlich, Chairman, Navigation Working Group, NASA HQ

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Charles S. Quantock, Code PS-06, NASA MSFC

W. T. Roberts, Code PS-02, NASA MSFC

ACKNOWLEDGEMENTS, Continued:

George W. Smith, Martin Marietta, Denver Division

H. T. Fisher, Lockheed Missile and Space Company, California

Nelson Brown, URS/Matrix, Houston, Texas

Graham D. Whitehead, Spar Aerospace, Toronto, Canada

Dr. Mark Kirkpatrick, Essex Corporation, Huntsville, Alabama

Sheldon W. Shenk, Essex Corporation, Alexandria, Virginia

Kathleen Sperry, Essex Corporation, Alexandria, Virginia

EXECUTIVE SUMMARY

This study was concerned with determining the relative effectiveness of alternate EVA and RMS configurations in performing an array of representative shuttle and payload support tasks. The EVA and RMS modes investigated were five: unaided EVA (comparable to EVA on prior manned space missions); EVA using the manned maneuvering system (MMU) for translation; shuttle attached remote manipulator system (RMS); EVA and RMS; EVA on RMS (Cherry Picker). The EVA and RMS systems investigated represented the current baseline system concepts.

The initial activity in the study was to perform a comprehensive analysis of payload and shuttle support missions required to be conducted exterior to a pressurized enclosure (Orbiter cabin or spacelab). A set of task selection criteria were established to ensure inclusion of tasks in the study which: (1) were representative of requirements associated with a wide range of shuttle and payload support missions; and (2) were amenable to RMS and EVA performance. A set of study tasks was then identified using the task selection criteria.

A problem area recognized early in the study was the availability of hard requirements for support tasks associated with payloads which themselves are still in early stages of development. This problem was alleviated by selecting baseline payloads for the tasks, which are furthest along in development (the Large Space Telescope, the Langley Advanced Technology Lab, the Ames Shuttle IR Telescope Facility, etc.). The problem of establishing realistic and representative requirements for shuttle and payload support tasks was further alleviated by identifying the range of variation in which tasks can be performed, and then by including alternate task conditions for each task which included the significant variables (type of failure, payload location, worksite location, number of modules to be handled, task operational requirements, etc.).

Requirements for selected tasks and conditions were identified from Level II Space Shuttle Payload Descriptions, Space Shuttle Program Requirements documentation, and personal contacts with payload working group personnel, and specific payload and shuttle system personnel within NASA and NASA contractors. Requirements included: operations to be performed within a task; required operational sequences; and support system (EVA or RMS) information requirements, performance requirements, and interface requirements, for each task and task condition.

Based on these requirements and on the established capabilities of each EVA and RMS mode, a decision was made as to the applicability of each mode for each task/condition. An operational sequence and timeline was then established for performance of each task/condition by each mode. A set of mode comparison criteria was established which accommodated task requirements for each task. Criterion areas included: basic capability, time to perform, performance capability, operational factors, flexibility factors, safety, support factors, and configuration factors.

For each task/condition the applicable modes were evaluated in terms of problems associated with each of the criterion factors. Based on the assessment of the problems of performing each task/condition with each mode, one mode (in some cases two modes) was selected as the recommended technique for the task/condition. During the mode comparisons problem identification was aided through the use of a 50th scale model of the shuttle, selected payloads, EVA crewmen, and the baseline RMS.

While one (or two) mode was selected as most effective for a given task/condition in terms of the degree of identified problems, other modes were identified as feasible for the task/condition. Feasible modes included those which were judged close enough to the selected mode in terms of identified problems so as not to be ruled out from task performance at this time. Thus, three decisions were made in determining the relative effectiveness of EVA and RMS modes for shuttle and payload support missions. They were: (1) Mode applicability (based on the correspondence of task requirements and mode capabilities); (2) Mode feasibility (based on the magnitude of problems identified with a mode not selected); and (3) Selected mode (the mode judged most effective in terms of problem magnitude).

For all applicable modes for each task/condition, problems of performing the task with each mode were identified. For feasible modes and the selected mode(s), requirements for performing the task were identified. Finally, requirements for research and technology development for each mode were identified.

The results of the study may be summarized as follows (Table 4-2):

- the unaided EVA mode was selected for 15 of the 35 task/conditions and was feasible for 24 of the 35 tasks/conditions
- RMS was selected for 9 tasks/conditions and was feasible for a total of 20
- EVA/MMU - selected on 10, feasible on 17 tasks/conditions
- EVA/RMS - selected on 7, feasible on 9 tasks/conditions
- Cherry Picker - selected on 2, feasible on 4 tasks/conditions

In examining the characteristics of tasks/conditions for which modes were selected, a set of guidelines were established for the application of each mode (Table 4-4):

- Use unaided EVA for in-bay tasks requiring high degrees of precision (dexterity and alignment), workspace confinement, and flexibility, and low levels of force application and mass handling

- Use EVA/MMU for out-of-bay and in-and-out tasks requiring high precision and flexibility, and low levels of worksite confinement, force application, and masses to be handled

- Use RMS for in-bay or out-of-bay tasks where only gross dexterity and alignment are required, where large (greater than 300 lbs.) masses need to be moved, or where time to perform the task is tightly constrained. (Use of RMS generally requires half the time required for EVA associated modes.)

- Use EVA/RMS for in or out-of-bay tasks requiring either transfer of modules exceeding 100 lbs., or multiple transfer of modules of any mass, with high precision requirements

- Use the Cherry Picker for tasks in or out of the bay where manual activation is not required, and where high levels of dexterity and flexibility are required

Conclusions of the study included:

- Unaided EVA is required for shuttle and payload mission support

- EVA/MMU is required for shuttle and payload mission support

- RMS is required for mission support

- EVA/RMS is desirable for mission support where both high precision and module transfer are required

- Cherry Picker is not recommended for mission support; further consideration of this mode for shuttle and payload support should be discontinued

The rationale for these conclusions, and the requirements and recommendations for each mode, are presented in detail in Section 4.4.

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1.0 INTRODUCTION

As the Space Shuttle program proceeds through development increasing attention is being focused on mission support requirements and techniques. This acceleration in emphasis on mission support is observed in orbiter systems development as well as in payload definition and development activities. Shuttle mission support can be generally defined as the array of activities and technologies required to ensure satisfaction of mission objectives, which activities and technologies are provided by means other than and separate from the specific orbiter system or payload involved in the mission. The rationale of providing low cost, standardized transport systems (the orbiter) and payloads applies equally to development of minimum cost and standard support systems which have the versatility to effectively support a wide range of different missions and orbiter and/or payload systems.

Two candidate approaches for providing versatile standardized systems for shuttle mission support include the use of astronaut extravehicular activity (EVA) and the application of remote manipulator system (RMS) technology. EVA is an established method of accomplishing mission support operations, dating back to June 1965 when Edward H. White, II made the first "spacewalk" during the mission of Gemini IV. The benefits of having a man on-board a spacecraft were emphatically demonstrated by the report that of NASA's first 12 manned missions (all of Mercury and through Gemini VI) seven would have been failures without intervention of the man. The special advantages and capabilities of man in space, and his contribution to total mission sources, were extended to several orders of magnitude when he achieved the capability of providing support to the mission outside of the spacecraft. The Skylab program would have resulted in an object failure without the special repair support provided by the crewmen performing EVA. The significant contributions provided by man in EVA are the same as those accruing to man in space: his adaptability, versatility, problem solving, visual abilities, and dexterity.

While EVA is an established operational resource which has repeatedly demonstrated its significant contribution to total space system capability, space remote manipulator systems are still in the development stage. The RMS emerged as a strong contender for shuttle and payload mission support in in 1970 with the formulation of the NASA teleoperator/robot task team. That team, chaired by Dr. Stanley Deutsch, Director of the Bioengineering Division, NASA Office of Life Sciences, developed the research and technology development program for applications of remote manipulators to space mission support. In 1971 the team was dissolved and its functions were incorporated into the NASA EVA/RMS Committee, also chaired by Dr. Deutsch.

The essential components of a remote manipulator system include: manipulators and sensors at the remote site, a human operator located at a control station, and a control and feedback link between these two locations. The primary advantages of the use of RMS combine the adaptability of the man, located at a safe control site, and the strength, durability, and expendable nature of the machine, the manipulator system.

Given that two radically different techniques (EVA and RMS) for shuttle mission support are under consideration, the question becomes one of identifying the strengths and weaknesses of each, and of developing guidelines for selecting either EVA or RMS for specific types of support missions. It was toward this end that the present study was conducted. The objectives of the study were:

- to identify candidate shuttle and payload mission support tasks for RMS and EVA
- to determine the relative effectiveness of EVA and RMS to complete the candidate tasks, and to satisfy requirements associated with each task
- to recommend use of EVA and RMS for specific tasks
- to develop guidelines for selection of EVA and RMS for mission support activities
- to identify problem areas and requirements associated with EVA and RMS performance of support tasks

The scope of the study limited the RMS configuration investigated to the shuttle attached manipulator. The free flying teleoperator being developed by NASA MSFC was not included in the study.

The study guidelines included the following:

- use of the baseline EVA system concept (4 psi suit with back pack astronaut life support assembly)
- initial reliance on information developed in Space Shuttle Payload Descriptions, updated by personal communications with payload planning personnel at NASA HQ and field centers, and NASA contractors
- provision for defining support tasks in terms of a range of alternate variations or task conditions, in order to accommodate a wide range of payload requirements
- Primary attention given to payloads furthermost along in development (LST, Advanced Technology Laboratory, Shuttle IR Telescope Facility)
- Task selection criteria to ensure a balance of tasks initially identified as more appropriate for EVA or RMS
- Shuttle support tasks derived based on consultation with shuttle systems development personnel at JSC
- Initially it was planned to investigate two RMS configurations, the 50 ft. baseline arm, and a proposed 42 foot arm; midway through the study the baseline achieved final acceptance and was then the only configuration studied.

The outputs of the study are intended to benefit shuttle and payload systems planners, in selection of appropriate systems for mission support tasks, and EVA and RMS system developers, in identifying problems and requirements.

The specific EVA and RMS support systems (hereafter referred to as EVA or RMS modes) studied include the following:

- Unaided EVA (EVA with handrails as in Skylab and Gemini)
- EVA/MMU (Manned Maneuvering Unit)
- EVA/RMS combination
- EVA on RMS - the Cherry Picker mode with the EVA crewman controlling the RMS from an end effector station
- RMS - the shuttle attached manipulator system

These modes are described in Section 2.0. The study methodology and mission analysis results are contained in Section 3.0. The study results are presented in Section 4.0 in terms of modes selected for tasks, guidelines for mode selection, problems with EVA and RMS modes, and requirements for completing support tasks using the EVA and RMS modes.

The appendix to this volume is a bibliography of sources used in the study.

2.0 DESCRIPTION OF EVA AND RMS MODES

2.1 BACKGROUND

Intensive review of level II documents related to the payloads and shuttle systems yielded a number of classes or categories of potential exterior tasks to be performed on-orbit. (Exterior tasks are defined, for purposes of this report, as those activities performed outside the pressurized confines of the Shuttle and/or Spacelab. The term does not necessarily specify that these activities are performed by a pressure-suited crewman.)

Following the review and classification or categorization of tasks, a feasibility analysis was performed to determine all possible means of accomplishing the work necessary to meet mission/payload requirements. Considerations which entered and influenced this analysis included reach envelope, mass handling capability, time constraints, and support equipment required. Five modes enabling completion of support tasks were identified: These are:

I. Unaided EVA

II. EVA with Manned Maneuvering Unit (MMU)

III. EVA/RMS Combination

IV. EVA on Remote Manipulator System (RMS)- Cherry Picker

V. Shuttle Remote Manipulator System (RMS)

It must be pointed out that these descriptions or titles refer to the translation technique employed under a given mode. For example, Unaided EVA is a mode where the crewman translates to the worksite using permanent or portable handrails. It is not intended to imply that the crewman does not fully utilize tools and task aids to perform the required tasks.

2.2 DESCRIPTION OF MODES

2.2.1 Unaided EVA

Under this mode, a suited EVA crewman translates to the worksite using handrails, handholds and footholds. These handrails may be single or dual, permanent or portable and continuous or interrupted (because of structured interference or integrity). This technique was used successfully on previous missions after extensive testing in Water Immersion Facilities (WIF). The crewman transports tools and spares tethered to his Extravehicular Mobility Unit (EMU). As is evident, a variety of systems and hardware are required to support the mode. Following is a list of those items required along with a brief description of each. A detailed definition of the capabilities of these systems will be included in Table 2-3 in the summary of this section.

Space Suit

The suit currently being investigated will be at least an advanced version of the A7LB suit used during the Apollo program. It will be a 4.0 psi system which will require the user to pre-breathe prior to EVA. Pre-breathing is started 3.5 hours prior to the start of EVA; however, other non-EVA related tasks may be performed for the first 1.5 hours of this pre-breathe time.

The suit is anticipated to provide better mobility than previous suits through the use of rotary bearing joints in the scye (shoulder area), upper arm and body seal closure. In addition, the convoluted joints will be replaced by gathered material joints which still allows the bending, twisting, rotating motions required at these points. Improvements are anticipated in the glove design as well to allow better dexterity and manipulation of the fingers/hands.

Improvements in the visual field-of-view will be accomplished through the use of hemispherical helmet as opposed to the bubble helmet previously used. The quality of improvement is not known at this time; however, preliminary investigations indicate that visibility in all planes is greater than that in the A7LB helmet.

Two suits are provided on each Shuttle flight.

Astronaut Life Support Assembly (ALSA)

The ALSA is comprised of several subsystems which provide life support, emergency oxygen (when necessary) and recharging capability in the Orbiter.

First, there is a Portable Life Support System (PLSS) which provides breathing and pressurization gas for the spare suit as well as cooling for the crewman. This is a closed loop system which affords a 6 hour EVA capability with respect to the oxygen supply. Cooling water is circulated through the tubes of the liquid cooled garment (LCG) worn by the crewman. The system is rechargeable on orbit. Two ALSA's are provided for each flight and each is launched charged except for water. Water from fuel cells is used to charge the ALSA prior to EVA.

There is also a Secondary Oxygen Pack (SOP) provided with each ALSA. This unit provides 30 minutes of emergency oxygen for the crewman in the event of a malfunction in the PLSS or if an extremely high leak rate is encountered. The SOP is not rechargeable on orbit.

Finally, there is the Service and Cooling Umbilical (SCU). This system provides the capability to service the PLSS on orbit. It provides a total of 4 recharges or 2 per PLSS twice each, allowing a total of 3 EVA's per PLSS. Two of these are programmed for nominal EVA and one for a contingency operation which could be rescue or shuttle support. The SCU also provides cooling to the crewman in the airlock prior to suit donning.

It can be seen that there is a time constraint imposed on the EVA capability as a direct function of expendables supply. However, it must be remembered that there is some finite period of time after initiating EVA preparation activities before the use of expendables in the PLSS is begun.

Translation Aids

It is outside the purview of this report to investigate the design requirements of the translation aids to be provided for unaided EVA. As is mentioned earlier, handrails and handholds will be used by the suited pressurized crewman to translate to and from the worksite. One concept being investigated by Rockwell International provides full-bay access through the use of single handrails. These handrails would be integral to the Payload bay doors and placed to not interfere with payloads when the doors are either open or closed. In addition, single handrails would be built onto the fore and aft bulkheads to provide a translation path across the bulkheads to the payload bay rails on the opposite side of the Orbiter (Figure 2-1).

These rails will be sized and shaped to be compatible with the forces expected to be imported by a suited crewman handling nominal cargo with a gloved hand. For purposes of this study, it was assumed that the design met all required crew interfaces.

Handholds could be permanent or portable. A variety of techniques are being investigated in other studies (i.e., URS-Matrix) for attachment of portable handholds. These include the use of pre-drilled holes where structured integrity can be maintained. The portable handhold would be plugged into or installed by some means into the provided hold pattern to support the crewman during operations or for translation. Other methods being investigated include electro and chemo-adhesive devices. Major problem areas reported seem to focus on depth of non-conducting (electrical) materials in some areas for

HANDRAIL/LIFELINE PLAN - PAYLOAD BAY

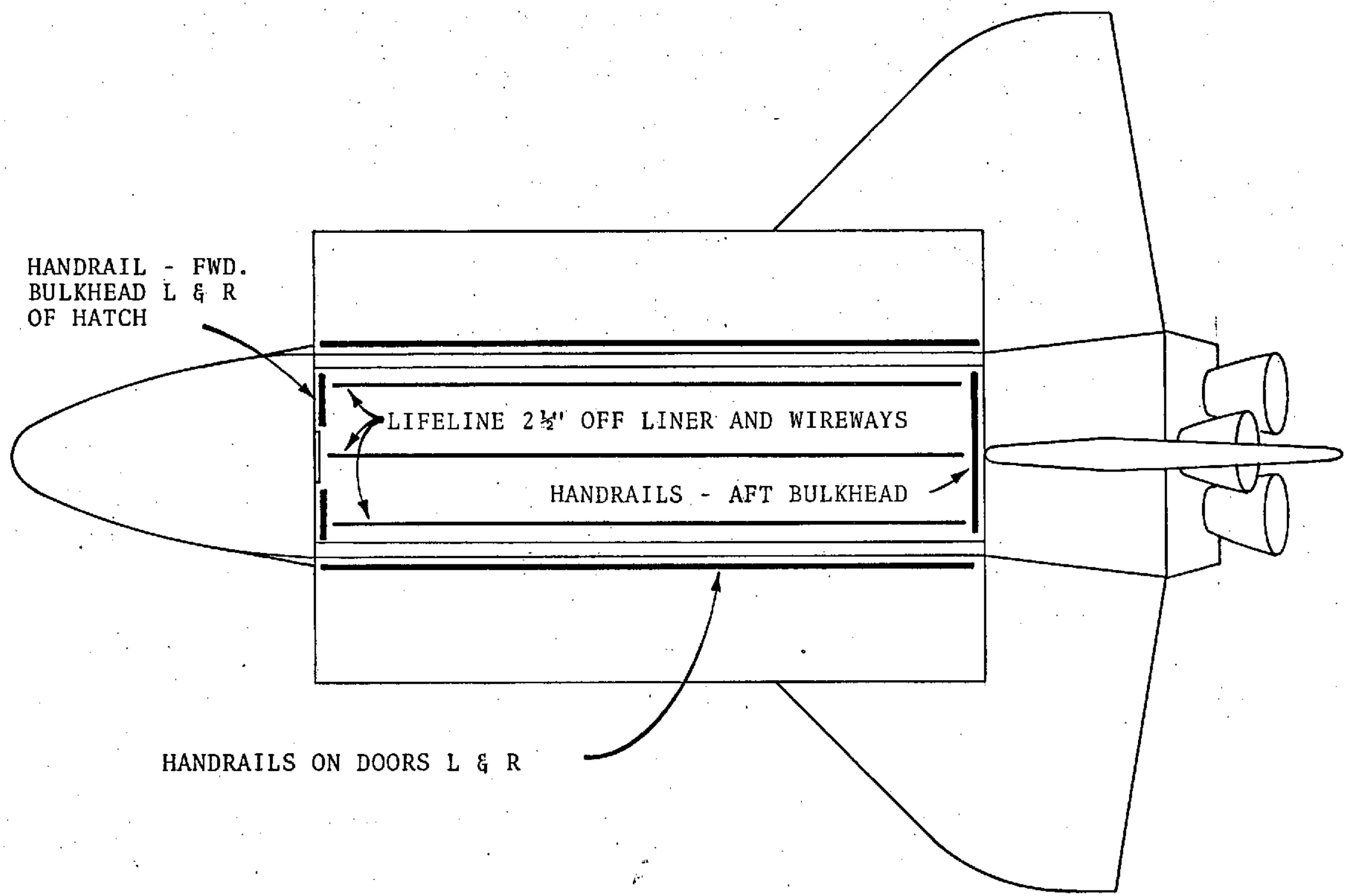


FIGURE 2-1. ROCKWELL PROPOSED HANDRAILS

the electro-adhesive device surface cleanliness/damage potential for chemo-adhesives. Penetration of thermally protective surfaces, compression of materials (providing thermal leaks) and structured integrity problems are those encountered for mechanically installable portable devices.

Finally, in addition to handrails and handholds, the unaided crewman requires some means of restraint in order to achieve a force-emission capability. Restraints used in previous missions include waist tethers used in conjunction with foot restraints. Again, the foot restraints could be built in (permanent) or portable. One of the types being investigated in studies concerned with work aids is the Skylab type foot restraint wherein the toe of the boot is engaged under a cross-bar and the heel is friction fit over a raised bar. These restraints (along with the appropriate tether) allow a suited crewman to exert forces almost equal to those he can exert under 1 g, shirtsleeve conditions.

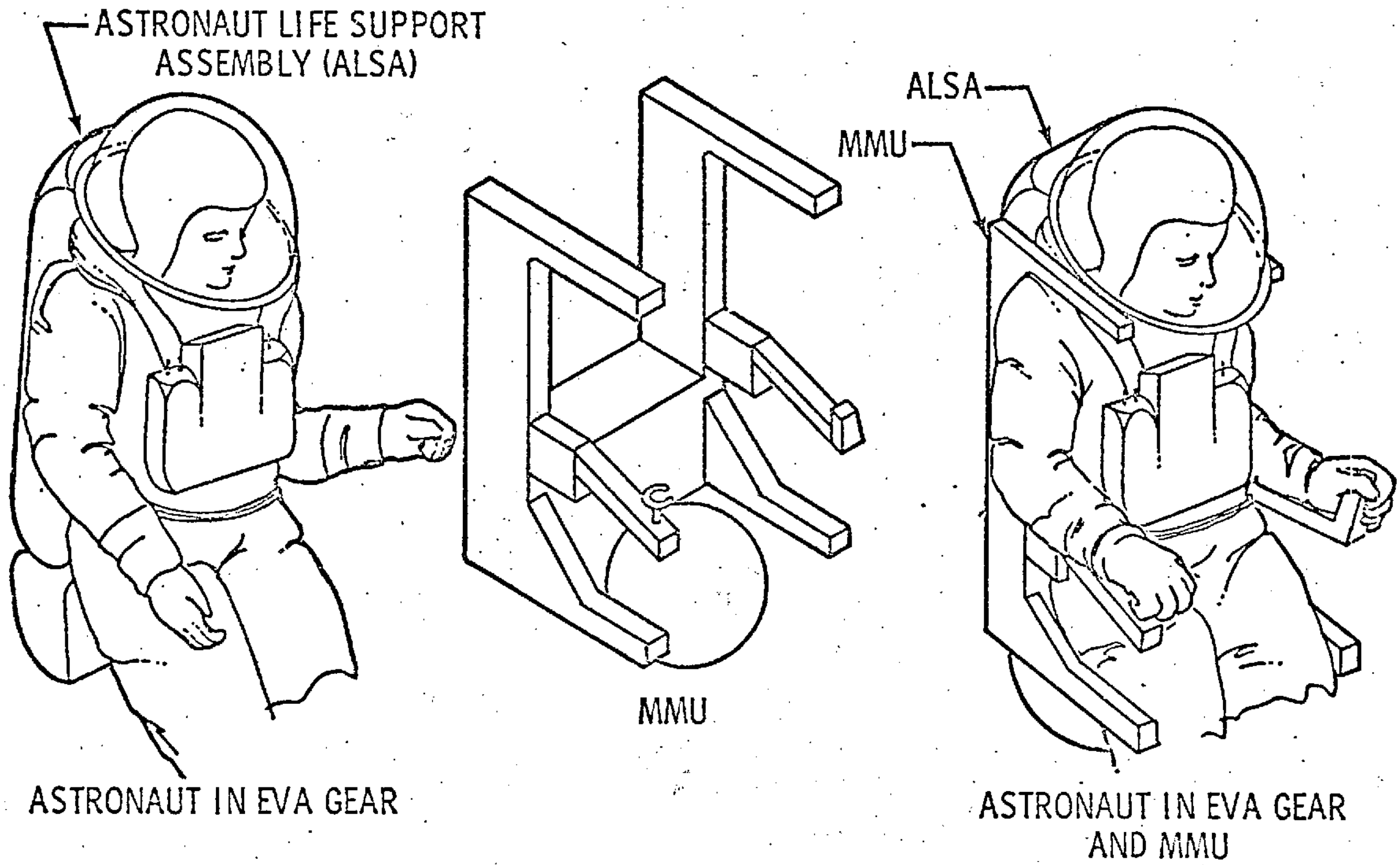
2.2.2 Manned Maneuvering Unit (MMU)

The MMU will provide the suited, pressurized crewman a means for translating to and from worksites under external power. Conceptually, the MMU will be an advanced, improved version of the M509 experimented tested on various Skylab missions (Skylab 2, 3, and 4). Studies are underway to determine feasibility of incorporating the MMU integrally with the ALSA/Suit to save donning time. (Figure 2-2).

Some of the preliminary system and operational requirements for the MMU have been identified. These are:

- Control System
  - 6 DF control authority
  - spacecraft piloting logic

ARTIST CONCEPT OF MANNED MANEUVERING UNIT (MMU)



- automatic attitude hold: rate gyro (prime)
  - rate deadband: $\pm$ 2°/sec.
  - displacement deadband: $\pm$ 2°
  - drift: 0.05°/sec.
- attitude rate command: acceleration command
- manual attitude hold (backup)

- Propulsion
  - gaseous nitrogen
  - acceleration
    - translational: 0.1 $\pm$ 0.01 m/sec.^{2} (0.3 $\pm$ .05 ft./sec.^{2})
    - rotational: 10 $\pm$ 3°/sec.^{2}
  - hot gas module provisions
- Weight
  - MMU: 75 Kg. (165 lbs.)
  - Total: TBD

The preliminary operational requirements which have thus far been identified are:

- EVA qualified
- Fail Operational/Fail Safe
- Mission Duration: 6 hours
- Range: 100 m (330 ft.) Nominal
- Total: Δ V available for translation and rotation: 16 m/sec. (52 ft./sec.)
- One man service, don/doff MMU
- Worksite attachment provisions
- Cargo/crew transfer capability
- Self contained system
- Safety tether (optional)

Table 2-1 presents a comparison of the M509 and MMU (preliminary) system.

Table 2-1. System Comparison M509 and MMU

	M509	MMU
Overall height (inches)	42	48
Thickness (inches) (Arms up)	48	30
Thickness (in) (Arms down)	22	30
Width (inches)	27	26
Wt (lbs - wet)	245	165
ΔV (ft/sec)	36 (per tank)	52 (per tank)
Propellant	Gaseous N_2	Gaseous H_2 or O_2
Auto Altitude control modes	2	1
Manual Altitude/translation control	Yes	Yes
EVA Rated	No	Yes

Current usage concepts of the MMU are that the MMU would be most useful for performing out-of-bay EV tasks. Use of the MMU allows the crewman to translate to worksites where handrails and/or handholds (permanent or portable) are not feasible (e.g., TPS on underside of the Orbiter) and to areas which exceed the reach envelope of the Remote Manipulator System (RMS). However, upon arrival at the worksite, the crewman must tether/restrain himself in some manner if application of forces is required. His force emission capability will be only slightly greater than zero when operating in the unrestrained mode. The only compensating factor would be the reactive force of the automatic attitude control system. Therefore, use of the MMU to perform tasks where forces (horizontal/vertical/rotational) must be applied requires use of restraints which the crewman may be required to carry. This improves the penalty in terms of reducing the quantity and volume of functional cargo.

Another penalty imposed by the use of the MMU is time. Even if the MMU becomes integrated with the ALSA, there will be a finite time period required to recharge the system (propellant and batteries). Preliminary estimates of the time requirements are approximately 15 minutes for propellant recharge and 18 hours for battery recharge.

Some of the types of tasks which could be performed while using the MMU consist of photography for documentation, inspection of surfaces, servicing/receiving of small, stable payloads, adjusting of experiment/payloads systems and performing repairs. The MMU provides the only feasible means of inspecting the TPS on the Orbiter underside and performing repairs on the system. Also, it is the only means for inspecting and repairing all of the active vent doors on the orbiter (safety of flight control).

2.2.3 EVA on RMS

This mode utilizes the Cherry Picker to translate cargo and personnel to the worksite. The Cherry Picker is a platform attached to the front end of the RMS in place of a standard end effector. It is not currently baseline but has been considered as an RMS application. This platform combines a control station so that the crewman riding the Cherry Picker can assume control over the system. In addition, the platform will contain built-in tool/cargo storage, auxiliary lighting and a video system.

A physical description of the RMS is presented later in this report under the "RMS Only" sub-section (Item 2.4)(Figure 2-3).

When one crewman is using the Cherry Picker to translate to and from the worksite, it is assumed that the second EVA crewman utilizes the most economical method available to him for translation. If the worksite is of the in-bay" type, the second crewman would use the unaided EVA translation mode. For "out-of-bay" worksites, the MMU translation mode is used by the second crewman to access the area.

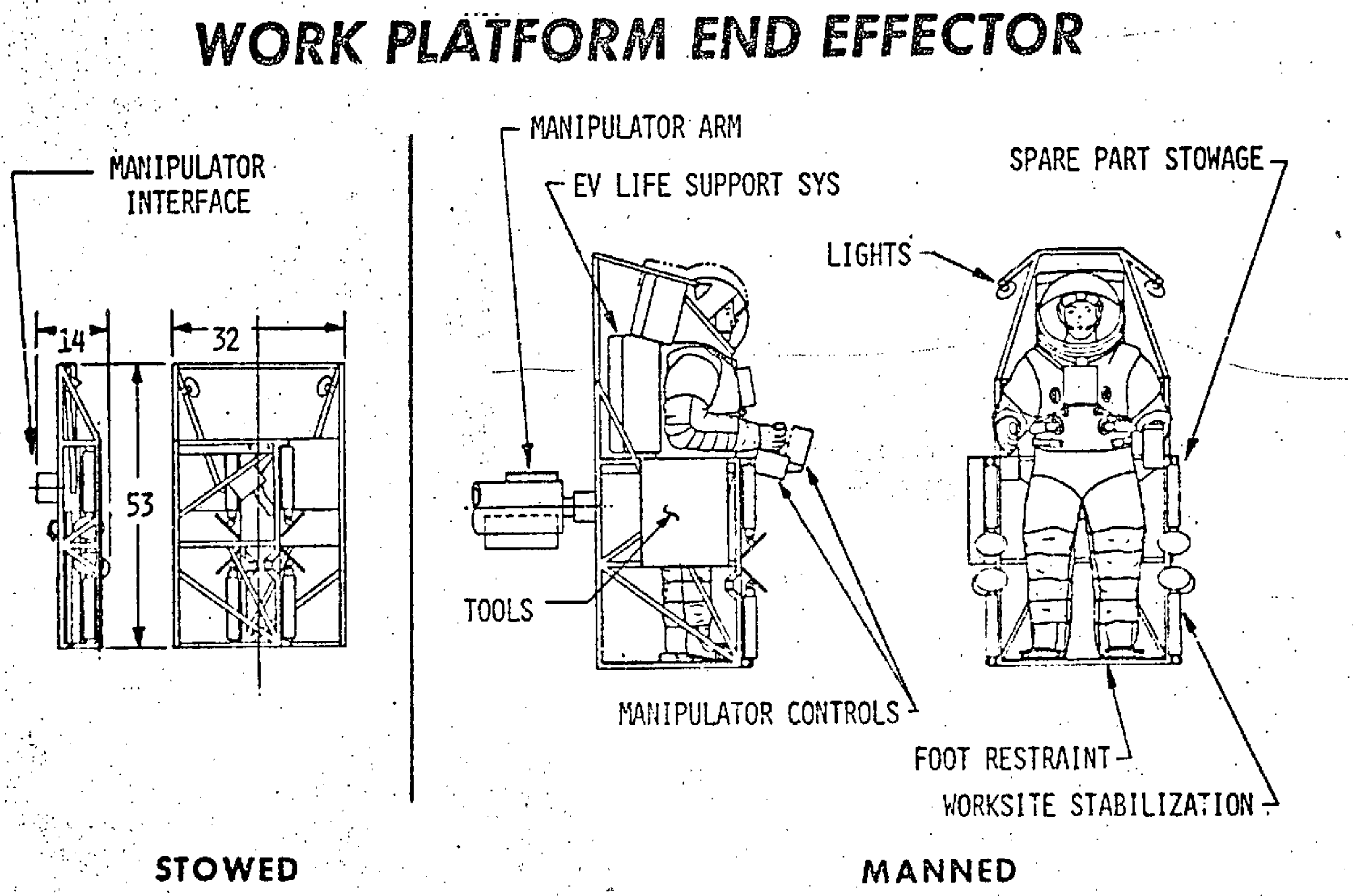


FIGURE 2-3. CHERRY PICKER CONCEPT (VAUGHT SYSTEMS, 1972)

Since there are EVA crewmen directly tied to the Cherry Picker mode, there is still a requirement for pre-breathing and post-EVA time expenditure; hence there is no time savings using this mode. In fact, the time required to change out the end effector, substitute the Cherry Picker, check out the system and translate it to the forward bulkhead for ingress may increase the time requirements. Some of this is gained back in faster translation rates achievable with the RMS over those in the unaided mode.

A distinct advantage of the Cherry Picker is that it serves as the work-station as well as the translation aid. The crewman is provided tether and foot restraints which allow him to exert the forces required to perform the tasks without having to retrieve, stow, transport, and install this type of aid at an unprepared worksite.

2.2.4 EVA/RMS Combination

This mode utilizes the RMS to transport cargo (tools/spares, etc.) to and from a worksite where an EVA crewman is performing the fine manipulation tasks; thereby freeing the man from having to transport stores with a large mass. In some cases (e.g., rescue operations or vertically oriented payloads in the bay), the RMS may be used to string a handline for the EVA crewman to be used for translation. Depending on the location of the handline at the termination of the RMS (i.e., attached at wrist or to the end effector), the RMS could transport the tools/spares at the same time it strings the handline. If this is not possible, the EVA crewman would not be required to translate to the worksite and tether himself. The RMS would then retract and disassemble the handline, translate to the tool/space stowage area, retrieve and translate them back to the worksite. While these operations are being performed, the crewmen would be inspecting the worksite, reviewing repair/servicing procedures, or resting. The procedure would then be reversed to terminate operations with the RMS translating tools/parts to stowage, restringing the handline to the worksite for the crewmen to use as a translation device. It is apparent that the latter is considerably more time consuming than the case where the handline and cargo are handled simultaneously.

This mode appears to utilize the best of both systems; however, in view of the ground rule that two crewmen will be suited for any EVA activity, a third crewman will be required in the Orbiter cabin to operate the RMS. Other than this, the capabilities of this mode are the same as for each mode operating individually.

2.2.5 RMS Only

The Remote Manipulator System (RMS) is, in essence, a subsystem of the Payload Deployment and Retrieval Mechanism (PDRM). The other subsystems which comprise the PDRM are: (1) Manipulator Retention Latches (MRL), (2) Manipulator Deployment Mechanism (MDM), and (3) the Manipulator Jettison Subsystem. This system (PDRM) is located in the payload bay and provides capability to deploy, retrieve, handle/service payloads, support EVA and to lock payloads in the bay. The MRL locks the manipulator boom in the stowed position and the MDM deploys/stows the boom.

For purposes of this report, the RMS is the only subsystem that will be defined in detail to the extent possible. There are many details which have not been thoroughly defined at this moment.

The RMS (Figure 2-4) provides six degrees-of-freedom with pitch and yaw at the shoulder, pitch at the elbow and pitch, yaw and roll at the wrist. It is 50 feet (15.1 m) in length and is mounted on the left side of the Orbiter payload bay at station X_o = 680 (see Figure 2-5). The RMS will be capable of deploying and retrieving a 15 foot (4.5 m) diameter, 60 foot long (18.2 m) payload weighing up to 65,000 lbs. (29,500 Kg). It will deploy a

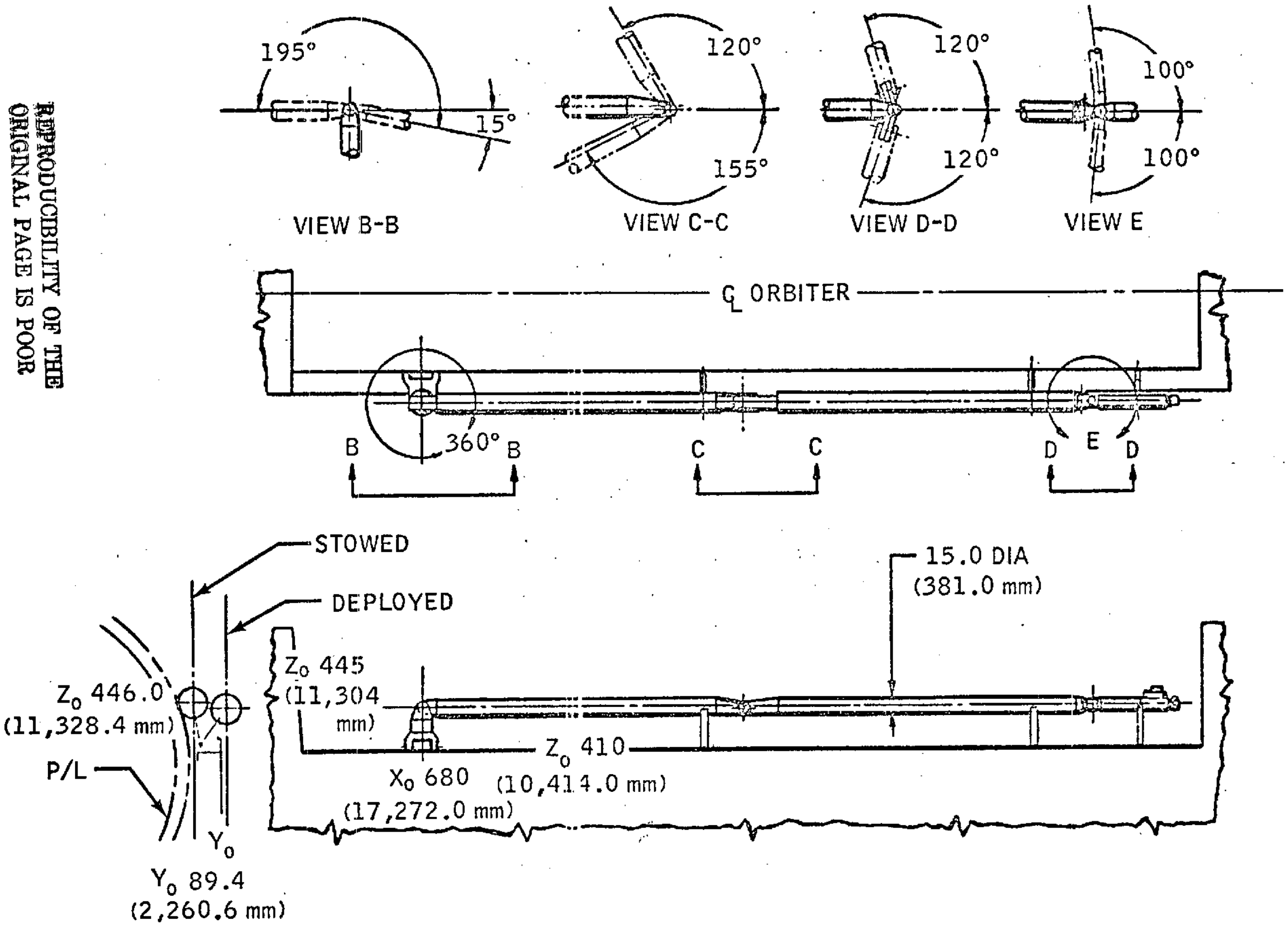


FIGURE 2-4. RMS DEGREES OF FREEDOM

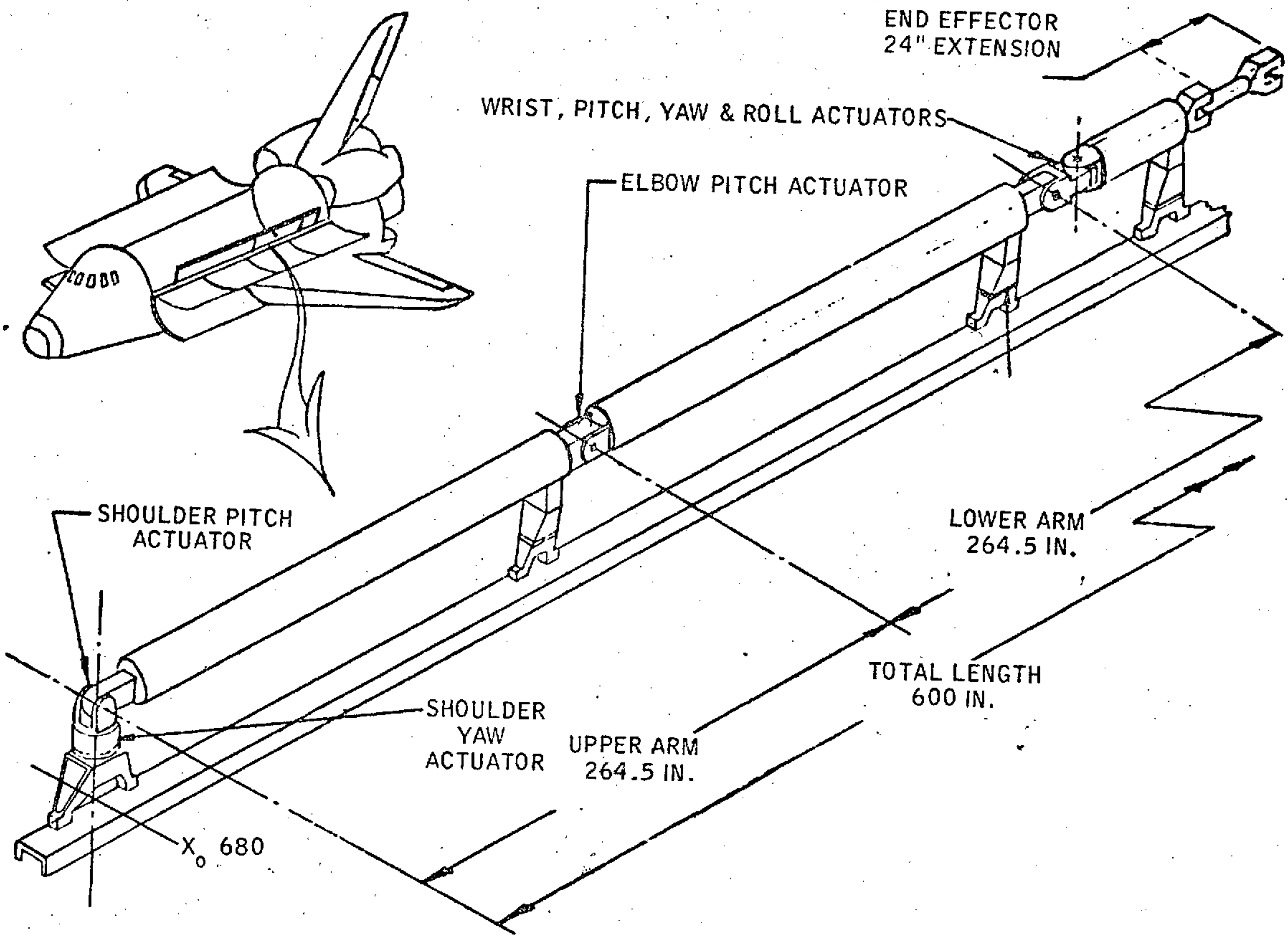


FIGURE 2-5. RMS CONCEPT

32,000 lb. (14,500 Kg) payload to a position 25 feet (7.6 m) above the Orbiter horizontal centerline (Z_o = 400) and the Orbiter vertical centerline (X_o = 710) in no more than seven minutes. The capability also exists of retracting a 32,000 lb. (14,500 Kg) payload in seven minutes or less from the start of retraction to initiation of the payload tie-down latches.

The type of RMS being investigated is electro-mechanical with bilateral force feedback.

The RMS will provide a lighting and viewing capability for the operator in the Orbiter cabin. Specifics on type and location of these items are to be determined (TBD).

Following is a description of the RMS:

- Physical Parameters
  - longeron attachment locations
    - . stowed: X_o = 680, Y_o = -89.4, Z_o = 446
    - . deployed: X_o = 680, Y_o = -100, Z_o = 445
  - total length (arm and end effector) = 50 ft. (15 m)
  - manipulator arm diameter = 15.0 inches (37.5 cm)
  - weight - no more than 810 lbs.
  - reach: Station X_o = 580 to X_o - 1180
  - manipulator station end effector viewing limits: TBD
- Maximum Payload Release Errors (Inertial)
  - linear tip-off motion: 0.2 ft./sec.
  - angular tip-off rates: 0.04°/sec.
- Allowable Manipulator Arm Rates at Payload Contract
  - maximum closing rate at contact: TBD
  - maximum angular rate of contact: TBD
- Allowable Orbiter Dynamics with Payload Attached to Arm

- Orbiter limit cycle/rates:

  roll ±.1°

  pitch ±.1°

  yaw ±.1°

  roll rate ± .01°/sec.

  pitch rate ± .01°/sec.

  yaw rate ± .01°/sec.

- Orbiter maximum allowable accelerations

  . roll, pitch, yaw - TBD

• Allowable Payload Dynamics Prior to Retrieval

  - maximum limit cycle (inertial): ± 3 inch or less attach point motion

  - maximum limit cycle rates: ± 0.1°/sec. about any axis

  - allowable attach point or docking ring motion

    . relative: ± 3.0 inches (± 7.5 cm)

• End effector linear and angular position capability: TBD

Table 2-2 presents the RMS Performance Characteristics/Limitations.

TABLE 2-2. RMS Performance Characteristics

Payload Attached to Manipulator		Performance Characteristics
Maximum Torques		
• Shoulder	Pitch	6,000 in-lbs (677.9 N.m.)
	Yaw	6,000 in-lbs (677.9 N.m.)
• Elbow	Pitch	3,600 in-lbs (406.7 N.m.)
• Wrist	Roll	2,400 in-lbs (271.2 N.m.)
	Pitch	2,400 in-lbs (271.2 N.m.)
	Yaw	2,400 in-lbs (271.2 N.m.)
Wrist		
• Extension/Retraction Force		10 lbs @ 24 inch stroke (4.5 Kg @ .6M)
• Holding Force		200 lbs. (brakes locked) (91 Kg)

2.3 ADDITIONAL REQUIREMENTS/CAPABILITIES

Thus far in this report, the various modes which can be used for support tasks have been defined and discussed. Some of the support system requirements (e.g., space suit, ALSA, and translation aids) have also been discussed as they relate to certain operational modes. In addition to these, there are other requirements which must be met as the crewman translates to the worksite, performs his tasks and returns to the airlock. These include:

- Worksite
  - restraints
  - clearances
  - lighting
  - viewing
  - glare
  - tools
- Translation Path
  - clearances
  - lighting

Worksite

Worksites can be classified as prepared or unprepared. The prepared worksite is one which has restraints built in or has provisions for attaching a portable workstation. This is a site where on-orbit task requirements were identified and taken into account during the design phase.

The unprepared worksite is one where special restraints are not provided in the design. It is an undefined location and may require special types of restraints (e.g., electro-adhesive or chemo-adhesive devices) since there is no provision for attachment of portable restraints (i.e., no pre-drilled holes, etc.).

Clearance of the worksite will be dependent upon the suit/ALSA/MMU design anthropometrics and the types of tasks to be performed. A minimum body clearance of 1 m (40 inches) will be required and will increase if binding, twisting, turning, kneeling, etc., is required. Preliminary data indicates that the maximum reach of a 5% crewman is 0.53 m (21.2 inches). Maximum reach is defined as the distance from the palm to the nearest interference point (RCS or helmet) with a fully extended arm of a standing crewman. Minimum size of an access opening (where the arm must be inserted to reach the worksite) has not yet been determined.

Preliminary analyses indicate that 20-40 ft. candles will be required at the worksite. Lighting fixtures are to be installed prior to launch at locations compatible with the particular payload. Shadow effects will be considered and compensated for during lighting fixture installation. Some of these fixtures are expected to be remotely controllable in azimuth and elevation to direct lighting into required areas. For tasks where no special lighting is provided (e.g., TPS inspection with the MMU), portable lights will be required.

Viewing of the worksite and performance of task activities at the worksite will be provided by TV cameras mounted in the payload bay and by the RMS mounted cameras in EVA/RMS modes. These cameras will incorporate pan and tilt along with zoom capability.

Glare at the worksite will be minimized by the use of diffuse coatings (e.g., Z - 13, magnesium oxide paints) which are shown to maintain thermal compatibility. There may be some glare problems where tasks are performed near the payload bay door radiators. These radiators are lined with aluminized mylar with a 98% specular surface. When viewed from normal to the surface, there is high reflectivity and glare.

Tools of a special nature may be stowed near the worksite or be carried. Those which must be transported to the worksite must be tethered and must not interfere with translation (i.e., snagging, etc.). It is not in the scope of this study to identify specific tools; however, it is safe to say (from experience in previous missions) that a tool kit should include some cutting type tools, impact tools, torquing type tools and any other special/general purpose tools which might be identified. Appropriate restraints must be provided to allow use of each type of tool which might be required.

Translation Path

Preliminary analyses indicate that a free space 1 meter (40 inches) diameter is required for translation to and from a worksite. This is based on the dimensions of the A7LB suit where the 95% suited crewman measures 0.73 m (29.5 inches) breadth (elbow to elbow) with arms relaxed. An open diameter of 1 m (40 inches) allows sufficient room for arm motions required for translation.

Lighting requirements for an EVA translation corridor have been established to be not less than 1 ft. candles. It has been determined that is is sufficient lighting to allow the EVA crewman to make his way along the translation path while keeping power drain for lights at an acceptable minimum.

Capabilities

The capabilities of RMS are stated in the previous section of this report. This section will concern itself primarily with the capabilities of a suited crewman and include translation rates, force/torque application and time constraints.

Results of ground based simulations using the water immersion facility (WIF) indicated that velocities of 0.3 m/sec. (1 ft./sec.) were attained by unencumbered crewmen. Crewmen transporting a 146 Kg (320 lb.) mass achieved a realistic translation rate of 0.23 m/sec. (0.75 ft./sec.). Other studies were performed to examine the differences between translation rates achieved when using a single vs. dual handrail system. Crewmen translated a given distance transporting a 744 Kg (1,650 lbs.) mass using both single and dual handrails as translation aids. On the single handrail test, the results were that an average velocity of 0.06 m/sec. (0.2 ft./sec.) was attained whereas, an average velocity of 0.09 m/sec. (0.3 ft./sec.) was possible when using the dual handrail.

It is anticipated that a translation rate of 0.3 m/sec. (1 ft./sec.) or greater would be realistic for an unencumbered crewman translation along the payload bay using the single handrail system (unaided EVA). The mass of cargo being transported would directly affect the translation rates on-orbit. The timelines for study tasks used .5 fps. (see Appendix).

At the worksite, the crewman will have to exert forces and/or torques to perform his tasks. Ground based simulations using Skylab foot restraints (in the WIF) were conducted to determine what level of forces or torques could be exacted. The results indicated that suited crewmen could exert 27.2 Kg (60 lbs.) pushing force against a lever at heights between 0.7 m (28 inches) and 1.3 m (52 inches) above the restraints. Pulling forces (unmeasured but known to be) greater than 27.2 Kg (60 lbs.) were applied to a lever 0.3 m (1 foot) above the restraints. The forces applied were greater than the capability of the measuring devices. It can be seen that greater horizontal pulling forces can be exerted than can pushing forces. These factors must be taken into account during design of the shuttle and payload systems in order to enhance crew capability during EVA.

Comments from crewmen on previous missions (Skylab, Apollo) indicate that a properly restrained crewman could exert, in a zero g environment, torquing forces almost equal to those that the shirtsleeve crewman could exert on Earth. The critical element of this statement is that the crewman must be properly restrained. Suit constraints primarily impact the arc through which the torque is applied; not the amount.

Time Constraints

It was mentioned earlier that a three hour pre-breathing period is required of each EVA crewman. This pre-breathing period begins 3.5 hours prior to the start of EVA. Of this time, approximately 1.0 hours are required for EVA preparation (including cabin preparation, airlock configuration, donning, communications checks, etc.). This means that during approximately 1.5 hours of the pre-breathing time the crewman can perform useful, non-EVA related functions if a portable oxygen system is used. The final .5 hour of the time is required for final EVA preparation including buttoning up, performing airlock operations, hatch opening and egress to begin EVA operations.

At closeout of EVA, 1.5 hours per man are required for post EVA activities including ingress to airlock, hatch closing, airlock operations, doffing of EMU's, recharge of ALSA (and possibly MMU), initiation of suit drying operations and stowage of loose equipment.

Assuming that the use of breathing gas in the ALSA begins at the start of the last .5 hour EVA prep and terminates at the end of the first .5 hours of post EVA activites, this leaves about 5 hours of the 6 hour EVA capacity of the ALSA to perform EV tasks. System design (whether EVA is scheduled or unscheduled) should be compatible with these requirements/constraints.

Needless to say, there is no pre-breathing or post EVA activities time requirement when the RMS only mode is utilized. The only time requirement will be for the operator to access the control systems, unlatch the arm, energize the system (including lights and video), perform arm and joint checkout, and begin operations. These tasks will require far shorter time than that needed for pre/post EVA activities.

2.4 SUMMARY

The various translation modes which can be utilized to satisfy mission/payload task requirements were discussed. These are:

- Unaided EVA - handrails, handholds, restraints, handline/lifeline (RMS installed)
- EVA with MMU - powered, free-flying mode
- EVA on RMS - Cherry Picker, built-in workstation, video, lights
- EVA/RMS Combination - RMS transports cargo (tools, spares, etc.)
  - EVA crewman performs five manipulative tasks
- RMS only - deploys/retrieves payloads, built-in video system and lights

This was followed by a discussion of systems required to support task performance and system capabilities/limitations.

EVA Systems Requirements

- EVA space suit - improved A7LB, improved material assembly, 4.0 psi, better helmet
- PLSS - rechargeable closed loop system, breathing/pressurization gas, 4.0 psi, 30 minutes emergency oxygen supply for 6 hour EVA
- Translation aids - permanent/portable handrails, handholds and restraints, RMS installed handlines, MMU, RMS
- Worksite - restraints, accessibility, video feedback, lighting
- Lighting - 5 ft. candles along translation paths, 20-40 ft. candles at worksite, adjustable, portable
- Cargo transfer - stowage, mass/volume, ground based simulations, previous flights, RMS/EVA combination
- Tool requirements - standard tool kit, variety of types of tools (cutting, torquing, etc.), location, built-in special tools/aids

Capabilities/Limitations

- Translation rates - results of previous missions, ground based simulations, time required to translate along payload bay for encumbered crewman

- Clearance - need translation path of 1 m (40 inches) diameter, functional reach (5% crewman) = 0.53 (21.2 inches)

- Force/torque application - ground based simulations using Skylab restraints - horizontal pulling forces greater than pushing forces

  - torque application (properly restrained crewman) approximately equal to that achievable under earth 1 g shirt-sleeve environment

- Time - EVA - approximately 1.5 hours/man required for EVA preparation

  - pre-breathe
  - don suit/PLSS
  - airlock operations
  - open hatch
  - egress to start EVA

- Approximately 1.5 hours/man needed for closeout/post EVA

  - ingress
  - close hatch
  - airlock operations
  - doff suit/PLSS
  - recharge PLSS (and MMU if used)
  - initiate suit drying operations
  - stow hardware

- RMS - no pre-breathe, no pre/post EVA preparation

  - access operator's station
  - energize system (including lights and video)
  - unlatch arm
  - perform arm and joint checkout
  - initiate operations
  - terminate operations/return to stowage
  - de-energize system

- latch arm
- egress operator's station

Table 2-3 presents a summary of the EV system capabilities for the Unaided EVA, EVA with MMU, and RMS modes. Since the EVA on RMS and EVA/RMS Combination are variations of the Unaided EVA and RMS modes, it is not necessary to enumerate these in this table.

TABLE 2-3.

SYSTEM CAPABILITIES - SUMMARY

SYSTEM	MASS HANDLING	TIME	TRANSLATION RATE	CLEARANCE ENVELOPE	FORCE/ TORQUE	DEXTERITY	VISUAL ENVELOPE	VISUAL PERFORMANCE	REACH/ RANGE
Unaided EVA with ALSA	3,856 Kg (8,500 lbs) (Hand rails)	1.5 hrs./ man - Prep EVA 1.5 hrs/ man - closeout EVA	.15 m/sec (.5 ft/sec) unencumbered	1.2 m (40 inches)	Horizontal: Push - 27.2 Kg (60 lbs) Roll - Greater than 27.2 Kg (60 lbs) Torque - Approach 1g (restrained)	Handle small objects: Connectors Tools Captive bolts	Up - 90° Down-105° Lateral - ±120°	12 arc sec. ideal 0.5 arc min. stero acuity w/helmet 1 arc min size acuity 1 arc-sec motion acuity	Outstretched Arm = 0.53 m (21.2 inches) minimum panel opening - T.B.D.
MMU	Estimated 228 Kg (500 lbs).	Donning/ Doffing Time T.B.D.	.5 fps close in higher rates further out	1.2 m(40 inches) Translation path Greater than 0.8m (32 inches) For Twisting, Turning, Kneeling etc.	0Kg unrestrained Restrained-same as above	Handle small objects: Connectors Tools Captive bolts	Up - 90° Down-105° Lateral - ±120°	12 arc sec. ideal 0.5 arc min. stero acuity 1 arc min size acuity 1 arc min sec. sec. motion acuity	Tether length Propulsion capacity 100m nominal 1600m maximum
RMS	up to 29,500 Kg (65,000 lbs.)	7 min. to deploy/ retrieve payload-only time to move P/L into and out of bay	unloaded- 0.6 m/sec (2FPS) 0.06 m/sec (0.2 FPS) Loaded	Minimum 0.3m (15 inches) Payload deployment/ retrieval ± 3.5 cm side and end	Tip Force = 6.4 Kg fully extended arm Torque-TBD	7.6 cm maximum deflection (unloaded) Tip placement accuracy - T.B.D.	T.B.D.	stero acuity 10 arc min. size acuity 5 arc min. motion acuity 5 arc min/sec	Base at Xo 680 15.25 m (42 ft) far reach Near reach - T.B.D. 0.6 m (2 ft) extraction perpendicular to surface

3.0 STUDY METHODOLOGY

The study was conducted along four basic worksteps:

Step 1 - Mission Analysis - leading to support tasks and task conditions for study

Step 2 - Comparison of modes for each task

Step 3 - Identification of problems and requirements for each task

3.1 STEP 1.- MISSION ANALYSIS

This step was directed toward establishing the set of tasks and task variations to be considered in the study. The essential factor in selecting tasks was to assure that the requirements associated with the selected tasks are representative of a wide range of shuttle and payload support missions. The results of the investigation should therefore be directly applicable to a wide variety of mission support tasks, beyond the specific tasks selected for study.

3.1.1 Mission Analysis Activities

The activities in this step involved:

1) Identification of shuttle and payload support operations required to be performed outside of a pressurized enclosure (shuttle cabin or spacelab). These activities were initially identified from the Space Shuttle Payload Descriptions and Volumes X and XIV of Space Shuttle Program documentation. The list of payload outside activities was updated through contacts with payload working group personnel for all payload areas. These personnel included cognizant payload planners and developers both within NASA (HQ, Langley, MSFC, JSC, Ames, and JPL) and NASA contractors.

For the payload support activities, it was determined that 51 automated spacecraft and 34 spacelabs have outside support operations required. The distribution of payloads by discipline is presented in Table 3-1. Specific automated payloads are described in Table 3-2, and spacelab payloads are described in Table 3-3. The specific outside operations considered in identifying outside support tasks are indicated in Table 3-4 for payload support, and in Table 3-5 for shuttle support. Table 3-6 indicates identified requirements for support tasks by payload with indications of the currently planned method of accomplishing the tasks.

2) Task Selection - The selection factors for task inclusion in the study are listed in Table 3-7. Based on these criteria a set of 11 payload support tasks and 6 shuttle support tasks were identified. The next step was to identify potential variations in the tasks which could impact the mode selection, and which would broaden the requirements associated with a task. Variations include:

- Payload location/orientation
- Worksite location
- Location of spares
- Number of modules
- Number of activations
- Operational requirements

The provision of alternate task conditions extended the list of tasks and conditions to a total of 35 (which are essentially different tasks since they have different requirements). The final list of tasks and conditions is presented in Table 3-8.

3) Determination of Task Requirements - For each task and task condition requirements to complete the task were identified. These requirements included functional sequences, and information, performance, and interface requirements. An example of the requirements for one task condition (P-11 - Module Removal/Replacement) is presented in Table 3-9.

4) Determination of Task Timelines and Procedures by Modes - When the applicability of each mode for each task condition was determined, a procedural sequence and timeline for the sequence was developed. This timeline provided the basis for estimating time required to perform a task by each mode.

3.1.2 Task Descriptions

A description of each task selected for inclusion in this study is presented below.

3.1.2.1 Task P-1 Payload Deploy/Retrieve

This task was concerned with the retrieval and retraction of payloads into the bay. Two conditions were investigated: capture and retrieval of a free flying payload; and retraction of an attached and deployed payload (e.g., telescope) into the bay.

Condition 1 - Free Flying Payload Capture and Retrieval

Task Justification: Required for 38 of the 51 automated satellites on the NASA mission model.

Task Description: The task involves actual capture of a stable payload and retrieval of the payload into the bay. The task sequence begins with deployment of the retrieval system and ends with retrieval system deactivation with the payload secured in the bay. The baseline payload for the task was the Large Space Telescope (LST) located initially 25 feet above the orbiter bay. Figure 1 depicts the RMS used to capture the LST in this position.

Task Requirements: The task places stringent demands on the stability limits of payloads (± .1°/sec. limit cycle rate) and of the orbiter. The actual retrieval of payloads requires emplacement into the bay with a 3 inch clearance in all directions.

Condition 2 - Attached Payload Retraction

Task Justification: General Dynamics Convair report on Space Tug Systems (January 1974) indicates a requirement for emergency manual retraction of the tug into the bay in the event of swing table failure. Personnel at Ames Research involved in development of the Shuttle IR Telescope Facility (SIRTF) also cite a requirement for a backup means of retracting the telescope into the bay.

Task Description: A payload attached and deployed from the bay is retracted in a backup mode of operation.

Task Requirements: A hand crank or rotatable mechanism is assumed for the task which retracts the payload at the rate of .1 foot/sec.

3.1.2.2 Task P-2 - Pallet Apparatus Deploy

This task involves activities associated with deployment of spacelab pallet apparatus. The baseline payload was the Advanced Technology Laboratory under definition at Langley Research Center. The ATL (Figure 2) incorporates a 20 foot pressurized module and a 20 foot pallet. The pallet for the conceptual Payload I includes four booms to be deployed, a large antenna to be extended and unfolded, and a film camera to be loaded.

Three conditions were investigated which comprise progressively greater degrees of complexity. These conditions were: (1) antenna deploy; (2) antenna deploy and film loading; and (3) full pallet deploy.

Condition 1 - Search and Rescue and Imaging Radar Antenna Deploy

Task Justification: The current ATL Pallet concept uses motors to raise and unfold the antenna. The deployment of the antenna was included in this study to investigate the feasibility of alternate methods, as well as to provide a credible task with requirements representative of those projected for shuttle spacelab pallet deployment activities.

Task Description: The task entails raising a 30 foot long 6.5 foot wide antenna up over the tug of the pressurized module, and unfolding the antenna over the module (Figure 3).

Task Requirements: Two steps are involved in the task, raising the antenna (when folded) up approximately 6 feet, and unfolding it to the fully deployed position. The end of the antenna is moved over a 180° arc which, for the 15 foot segment, entails motion of the end over a 47 foot arc. The rate of unfolding ranged from .1 fps (RMS to .25 fps (EVA modes). A hand crank was assured for the unaided EVA mode while for the RMS, Cherry Picker, and EVA/MMU modes the antenna segment was directly unfolded.

Condition 2 - Antenna Deploy and Film Loading

Task Justification: Representative of tasks requiring both manual activation and module handling.

Task Description: Same as Condition 1 with the added task of loading a 30 lb. .5 cubic foot film magazine at the meteor spectroscopy camera located at the aft pallet.

Task Requirements: Boom deploy rates - 1 foot/sec.

3.1.2.3 Task P-3 Payload Door Open

This task involves opening payload doors in a backup mode after the primary method of door opening has failed. The payload investigated was the

Shuttle IR Telescope Facility (SIRTF) which has two doors, one at the end of the telescope which is opened when the telescope is deployed, and a window, also at the end of the telescope, which is removable when contamination levels permit.

Two conditions were investigated for this task. The first assumes a failure of the door at the base of the telescope from unlatching, therefore presenting the telescope from being deployed. Condition 2 assumes a failure of the window removal mechanism and requies a manual removal and stowage of the window.

The task is applicable to 19 spacelab payloads which have deployable telescopes.

Condition 1 - Door in the Bay

Task Justification: Personnel involved in the development of SIRTF concepts at Ames indicate that they are considering EVA and RMS as alternate feasible backups to the automatic door removal system.

Task Description: The preliminary SIRTF Concept Description published by the Space Science Division and Flight Project Development Division of Ames Research Center (January 1974) states that an insulated cover will mate with the front of the telescope. This cover, through its structural mounting to the pallet, will provide additional support for the telescope during powered flight phases. The cover is removed by deploying the telescope, on a swing table, out and away from the door structure. The task investigated here assumes a failure of the door unlatching mechanism requiring unlatching of the door in a backup mode of operation.

Task Requirements: The task requires unlatching and retracting the door and then automatically deploying the telescope free of the door structure. Two worksites are therefore required, one at the door latch and one at the swing table.

Condition 2 - Out of Bay

Task Justification: The window is required to control contamination levels at telescope apertures and mirrors. If the window cannot be removed no data can be acquired by the telescope, resulting in failure of the mission. The backup mode of window removal can also be considered as the primary technique in the interest of simplifying telescope design.

Task Description: This task involves the contingency removal of a thin plastic window placed over the end of the telescope. The window is to be removable in flight, with the telescope deployed outside of the bay, when contamination levels permit. The task assumes a failure of the primary window removal mechanism and requires backup removal and stowage of the window. Figure 4 depicts the window removal in the EVA/MMU mode.

Task Requirements: The window is assumed to comprise a rigid plastic covering mounted to the end of the telescope which, at least in a backup mode, must be totally removed and stowed. The window is 2.4 m. (7.9 feet) in diameter and weighs an estimated 20 lbs.

Performance requirements - same as Condition 1 with the addition of the mass handling requirement of 20 lbs.

3.1.2.4 Task P-4 - Contamination Control Shroud Deployment

This nominal task was selected to investigate the capabilities and limitations inherent in the EVA and RMS modes for contamination cover deployment over a payload. The payload investigated was the LST. The LST Phase A Final Report (December 1972) describes a clean bag proposed as a method of controlling contamination while at the same time reducing purge leakage. The bag is folded at the aft end of the bay when the shuttle is retrieved. Two conditions of the task were investigated, one in which the bag is deployed over the LST with the payload in the bay, and the other in which the bag is deployed over the LST which is attached to the bay at its base but is still deployed out of the bay. As described in the LST Phase A report, it is assumed that three guide cables are mounted on the exterior of the telescope and that the end of the bag is attached to a rigid ring which travels along the cables during deployment.

In personal communications with LST development personnel at NASA MSFC it was determined that the nominal approach to contamination control would involve integrating the shield into the LST structures. However, the personnel indicated that use of the deployable shroud is still viable and merits consideration in an EVA-RMS comparison study.

Condition 1 - In Bay

Task Justification: A total of 14 automated spacecraft (including the LST) require contamination covers (27% of payloads investigated). Most of the payload developers are more or less uncertain as to how the cover will be activated or integrated into the payload design. According to LST personnel at MSFC, manual deployment of a clean bay warrants consideration as an alternative to the more complex integrated shielding approach presently planned for the LST.

Task Description: This task involves deployment of the shroud over the LST while the payload is in the bay but not fully tied down. The task involves covering the LST with the shroud, estimated at 200 Kg (441 lbs.) (Level II Payload Description), and then emplacing a boot cover over the end of the telescope and shroud.

Task Requirements: For this study it was assumed that the shroud deployment operation requires minimal preparation and setup of the shroud or the payload. It is assumed that the shroud is stowed in a lap folded configuration at the base of the payload and that it is pulled over the payload from that position.

Condition 2 - P/L Deployed

Task Justification: Same as Condition 1.

Task Description: In this condition the contamination control shroud is deployed over the LST as described in Condition 1; however, the LST is deployed out of the bay at an angle of 60°, while attached to the aft bay at the base.

Task Requirements: Same as Condition 1 except that the payload is attached and extended out of the bay.

3.1.2.5 Task P-5 Payload Sunshade Retraction

This task assumes that a failure has occurred in the sunshade retraction mechanism while a payload is erect in the bay, resulting in inability to retract the payload into the bay. Mission options given this failure mode would be to repair the mechanism or to jettison the shade. In this case it is assumed that the decision is to repair.

The specific failure is a break of the sunshade retraction tape which requires mending prior to retraction. The tape break failure was selected as the most demanding failure feasible for the sunshade retraction system.

Two task conditions were investigated. In Condition 1, the LST is fully erect (90°) in the bay. In Condition 2, the SIRTF (Shuttle IR Telescope Facility) is erect at a 45° angle in the bay.

Condition 1 - Payload 90° in Bay

Task Justification: Given a failure of the sunshade retraction mechanism the alternate options are to jettison the shade or to repair, since the payload cannot be retrieved into the bay with the shade extended. Since there will always be a major risk to the orbiter and to on-orbit personnel of jettisoning debris in the close vicinity of the shuttle, the requirements for sunshade repair need to be identified and examined.

Task Description: In this task it is assumed that a retraction tape in the sunshade activation system has broken requiring tape mending as the repair operation. The tape is a .005 inch thick by .5 inch wide stainless steel bank which runs the distance of the sunshade (10.76 m. or 35.5 feet). Two activation systems are provided 180° apart which are synchronized for sunshade retraction. It is assumed that when the break in the tape is located, it is repaired by means of a crimping tool.

Figure 5 depicts the sunshade retraction task with the MMU mode.

Task Requirements: The primary operational requirement associated with this task is the repair of the sunshade mechanism. The specific repair mode postulated for the task involves mending of a severed retraction tape. The significant requirements associated with this repair include identification of the failure, location of the break in the tape, and the actual mending.

Condition 2 - Payload 45° Deployed From the Bay

Task Justification: The rationale for this condition is basically the same as for Condition 1 with a different location of the payload in the bay.

Task Description: The EVA/MMU mode was the only applicable technique for sunshade repair with an LST class payload erect at 90° in the bay. It was apparent that other conditions could prevail which would make other modes as applicable, such as payload position in the bay. In this condition it is assumed that the Shuttle IR Telescope Facility (SIRTF) while erect at 45° in the bay with the sunshade extended suffers the failure of the sunshade retraction tape.

Task Requirements: The same as Condition 1. It is assumed that the sunshade retraction mechanism in the SIRTF is identical to that in the LST.

3.1.2.6 Task P-6 Solar Panel Retraction

Task Justification: The task is representative of manual activation activities applicable to a wide range of payload missions. It is also representative of backup solar array retraction which is feasible for 24 of the 51 automated payloads.

Task Description: This task involves backup retraction of the solar array when the primary retraction mechanism has failed with the payload attached to the shuttle. The payload investigated was the LST. The LST Reference solar array consists of two deployable wings mounted on two booms 180° apart at the base of the LST SSM (Support Systems Module). Each wing consists of six hinged rigid panels which become erect when the booms are deployed. Each panel consists of two modules on which solar cells and cover slides are mounted.

The retraction sequence begins with boom deployment motor activation in a reverse mode. When the boom reaches the stops on the SSM, limit switches de-energize the boom motors and energize the retraction motors. The retraction motor and cable linkages unlatch the wing panels and draw them back around the SSM mounting. Limit switches then deactivate the retraction motors. (LST Phase A Final Report, Volume V-SSM).

The failure mode postulated for this task is the situation in which one of the latch assemblies is hung up on the cable and fails to unlatch, preventing closure of the wing. The unlatching operation takes place when the boom has been retracted and panels are stowed. The latch locations are therefore at three foot intervals along the 19 foot span formed by the retracted panels. The maximum distance between the boom location and a latch is about six feet.

The solar panel retraction operation is depicted for the unaided EVA mode in Figure 6.

Task Requirements: The basic requirement for this task is to manually activate (close) a latch which has hung up. The failed latch may be at a location at the retraction boom, or three or six feet out from the boom on either side of the boom on a level with the retraction motor on the exterior of the SSM, in a plane parallel with the orbiter X-axis. The failed latch can be located on either the right side or the left side array.

3.1.2.7 Task P-7 Film Replacement

This task comprises operations associated with loading of film on a spacelab payload. The payload selected for investigation is the Atmospheric Science Facility (ASF). The task has two conditions:

1. loading of one camera on the ASF
2. loading of five cameras on the ASF

Condition 1 - One Camera

Task Justification: Representative of 13 spacelab payloads which require film data.

Task Description: The task involves loading film into a camera on the pallet of a spacelab mission. The payload selected for study was the Atmospheric Science facility (ASF). As indicated in the space shuttle payload description for the ASF, a requirement has been identified to load film at the outset of orbital operations. It is assumed that a film magazine 30 lbs. in weight and .5 cubic feet in size will be installed into the solar monitor at the mid-pallet.

A simplified view of the film loading operation using the RMS is depicted in Figure 7.

Task Requirements: The task requires transfer of one film package into an instrument on the monitor.

Condition 2 - Five Cameras

Task Justification: Five instruments on the ASF require film data.

Task Description: Same as Condition 1 except that five cameras are loaded.

Task Requirements: Successive film loading for five instruments on the ASL pallet.

3.1.2.8 Task P-8 Antenna Retract and Feed Change

This task requires the retraction of a deployable antenna and also the completion of a feed change on the antenna. Personnel involved in the erectable antenna development program at the Communications and Navigation Spacelab at the Jet Propulsion Laboratory indicate that the antenna would be deployed in an automatic manner and retracted manually. They further indicated that a capability to change antenna feeds on orbit would be a desirable feature of the antenna system.

The task conditions include retraction and stowage of the antenna prior to return to earth, and on-orbit change of an antenna feed.

Condition 1 - Antenna

Task Justification: Personnel at JPL involved in the erectable antenna program state that a manned means will be required to retract the antenna. The Level II payload requirements indicate that for the Comm-NAV Spacelab, EVA will be required to retract the antenna. The task is comparable to the retraction of the Shuttle Imaging System Antenna (SIMS) on the earth observations spacelab, which also identifies EVA as the method of antenna retraction.

Task Description: The payload selected for this task is the communications-navigation spacelab. The antenna concept investigated was an erectable umbrella type antenna four meters in diameter on a boom 11 meters long. The antenna is located on the pallet aft of the spacelab pressurized module. The retraction operation is depicted for the EVA/MMU mode in Figure 8.

Task Requirements: In this task the essential requirements involve retraction of the 11 m. boom and folding the 4 m. dish, and then tying down and stowing the retracted antenna.

Condition 2 - Feed Change

Task Justification: Statements of JPL personnel involved in COMM-NAV erectable antenna development that an on-orbit feed change capability will be desirable.

Task Description: The task involves changing an antenna feed during a communications-navigation spacelab mission. No information is currently available concerning the physical parameters of the feed. For purposes of this study it is assumed to comprise a small black box (6 cubic inches and 10 lbs.) to be replaced at the outboard center of the dish. The antenna is the same system described in Condition 1.

Task Requirements: The primary requirement is to transfer a new feed to the antenna, remove the old feed, and replace it with a new feed.

3.1.2.9 Task P-9 Contamination Monitoring

Task Justification: The monitoring of contamination is cited as a candidate experiment for the Advanced Technology Laboratory but will probably be required for all contamination sensitive payloads. The current approach is to monitor with the IRTCM mounted in the bay. This task investigated localized monitoring which would provide more information on contamination levels and sources over the entire bay.

Task Description: This task involves monitoring of contamination in and out of the bay with a spacelab payload. The payload selected was the Advanced Technology Lab described in 3.1.2.2. In the task it is assumed that contamination monitoring would be performed in conjunction with one or more other tasks (for example P-2, Pallet Apparatus Deploy). Therefore, no prep and post times were determined in the development of task timelines.

The task assumes that two integrated real time contamination monitors (IRTCM) are mounted in the vicinity of the bay doors on each side of the bay. The IRTCM's are retrieved from the mountings and are placed at 10 different locations for a two minute period each to measure contamination. The ten locations include six in the bay and four outside.

In the bay the locations are:

- At the front bay, right and left sides
- At the front pallet, right and left
- At the aft pallet, right and left

Outside the bay the locations are 10 feet up and out from:

- The front pallet right and left
- The aft pallet right and left

The entire package of sensors, less the pallet, is 1.42 cubic feet and weighs 78 lbs.

Task Requirements: The basic requirement is to transfer the IRTCM to each monitoring location and hold it in position for a two minute period.

3.1.2.10 Task P-10 Payload Umbilical Connect/Disconnect

This task comprises the requirements representative of those associated with payload umbilical connection or disconnection. Two conditions were investigated. In the first case the activity is to connect nine umbilicals from the payload service panel at the aft bulkhead to the tug. In Condition 2 an electrical lead is disconnected from the LST prior to LST deployment.

Condition 1 - Tug Umbilical Connection

Task Justification: Investigation of alternate methods for umbilical connection.

Task Description: The task involves connection of nine umbilicals to a payload (tug) in the bay. The current concept for umbilical connection for the tug is to integrate the connections into a tug-orbiter support adapter which also serves as a docking hatch, swing table, and support structure for six helium tanks. In this task it is assumed that umbilical connections are made manually with no support adapter present.

Task Requirements: In this task each of nine umbilicals must be acquired at the orbiter panel, moved 80 inches to the tug panel, and connected to the appropriate connector.

Condition 2 - Electrical Lead Disconnect

Task Justification: Connection and disconnection of the electrical link between LST and the orbiter in an automated manner was cited by MSFC LST personnel as a problem. These personnel requested that electrical disconnection using EVA or RMS be investigated in this study.

Task Description: The task involves disconnection and stowage of an electrical lead initially attached to the LST erect in the bay.

Task Requirements: Functional requirements for this task include disconnection of an electrical lead and stowage of the lead.

3.1.2.11 P-11 Module Removal-Replacement

This task was selected to be representative of module removal and replacement activities over a wide range of spacelabs and automated payloads (31 in all have module replacement requirements). The payload selected for investigation was the LST and the baseline mission is the LST servicing mission. Variables in the task which were identified as having potential effects on the performance of the modes included payload location, spares location, module location, and number of modules to be removed/replaced.

The specific conditions investigated include the following:

Condition 1 - LST forward in the bay, CMG located inside the LST, spares in the orbiter

Condition 2 - LST forward, CMG in, spares in bay

Condition 3 - LST forward, CMG out, spares in bay

Condition 4 - LST aft, CMG in, spares in bay

Condition 5 - LST aft, CMG out, spares in bay

Condition 6 - LST aft, five modules out, spares in bay

Condition 7 - LST aft, five modules in, spares in bay

The CMG was selected as the module to be replaced in single module conditions. The reference CMG is 1,019 by 775 by 548 mm. (40.1 x 50.5 x 23 inches) and weighs 80.9 kg. (178 lbs.).

Figure 11 depicts the removal/replacement task with the EVA/RMS mode.

Conditions 1, 2, 4, and 7 - Module Inside, LST Forward on Aft

Task Justification: Inside servicing is the approach currently being considered by MSFC - for the LST.

Task Description: The four conditions treated here are the cases where modules are to be removed and replaced inside the LST.

Task Requirements: The essential requirements include removal of one or more modules, transferring them to storage, acquisition of fresh modules, and replacement of these modules.

Condition 3 - LST Forward, CMG Outside

Task Justification: This task offers a viable option to interior servicing.

Task Description: Removal and replacement of the CMG located anywhere on the exterior of the LST SSM with the LST erect in the forward bay.

Task Requirements: Same as Condition 1, 2, 4, and 7.

Condition 5 - LST Aft, CMG Outside

Task Justification: A viable option to interior servicing.

Task Description: Removal and replacement of the CMG located anywhere on the exterior of the SSM with the LST erect in the aft bay.

Task Requirements: Same as Conditions 1, 2, 4, and 7.

Condition 6 - Five Modules Outside

Task Justification: Multi-module replacement probably imposes different requirements than single module replacement.

Task Description: This task requires successive replacement of five modules located outside the LST which is erect in the aft bay, with spares located in the bay. The modules were assumed to be of the same size and mass as the CMG.

Task Requirements: Same as Conditions 1, 2, 4, and 7.

3.1.2.12 Shuttle Thermal Protection System Inspect and Repair

Task Justification: A required shuttle support operation.

Task Description: This task involves two conditions: inspection of the thermal protection system (TSP); and repair of the TPS if failures are detected. The TPS is essentially the outer skin of the orbiter, composed of a surface made up of six inch square silica tiles. These tiles cover 95% of the orbiter exterior.

The task is initially to inspect the undersurface of the orbiter for gaps in the TPS. On detection of a gap the repair is made by filling the gap with an ablative foam. The repair procedure is to be constrained such that it does not disrupt other tiles.

A representation of the task in the EVA/MMU mode is presented in Figure 12, and in the RMS mode in Figure 13.

Task Requirements: The requirement for this task is first of all to inspect the entire undersurface of the orbiter (approximately 4,000 square feet) nose to tail (122 feet) and wing (78 feet span). Once a gap in the TPS is detected, a repair is required wherein the gap is filled.

3.1.2.13 Task S-13 Rendezvous Sensor Deploy

Task Justification: If the rendezvous sensor deploy motor fails to operate rendezvous with a payload cannot be accomplished. Loss of the sensor could also lead to abort of a payload deploy mission if initial position data on the payload are provided by the orbiter.

Task Description: The rendezvous sensor is a deployable antenna located on the right side of the bay 83 inches aft of the forward bulkhead. Deployment of the sensor involves rotating it over about 135° or over a distance of 43 inches in the Y_o (lateral) direction, and 130 inches in X_o. The antenna is 68 inches long and has a dish 17 inches in diameter (preliminary concepts, JSC, May 1974).

Task Requirements: The task involves deploying the sensor out from its stowed position to its fully deployed position. The mass of the sensor has not yet been determined, but is estimated at 50 lbs. minimum.

The task requires retraction of a lock pin, deploy of the sensor, and reinsertion of the pin.

3.1.2.14 Task S-14 Payload Retention Lock Repair

The baseline payload attachment concept provides for 13 primary payload structural attachments along the bay. With the exception of the aft-most attachment (X_o = 1,303), each attachment consists of three attach points, one at each of two longerons ($\pm Y_o = 94$) and one at the keel ($Z_o = 305$, $Y_o = 0$). The aft attachment has no keel attach point. The points are spaced 59 inches apart. A tug in the bay would be attached to 11 points along the longeron and 10 points at the keel. Thus, there are 22 longeron attachments for a tug in the payload bay.

In this task the basic assumption is that one or more longeron attachment mechanisms have failed to operate, due to debris or to a mechanical failure, with a tug in the payload bay. The task has three conditions:

Condition 1 - lock at station X_o 951 fails due to debris

Condition 2 - same lock fails to activate due to mechanical failure

Condition 3 - all 22 locks must be manually activated

The task is depicted in Figure 14 for the unaided EVA mode.

<u>Condition 1 - Lock Repair</u>

Task Justification: Credible failure mode with no identified solution.

Task Description: In this task it is assumed that a lock at X_o 951 fails to activate due to debris in the mechanism. The repair mode is to remove the debris.

Task Requirements: The task involves cleaning a lock with general and special purpose tools.

<u>Condition 2 - Manual Lock Activation</u>

This task is similar in most respects to the Condition 1, Lock Repair, except that here the operation is to manually activate the lock.

<u>Condition 3 - Manual Activation of all Locks</u>

Task Justification: Investigation of alternate methods of payload retention lock activation.

Task Description: In this task all 22 of the longeron retention points are activated manually.

Task Requirements: Access each of 22 locks, 11 on each side 59 inches apart, and manually activate each lock.

3.1.2.15 Task S-15 Payload Bay Door Repair

Task Justification: This contingency operation is a candidate task for RMS or EVA.

Task Description: The payload bay door mechanism consists of door hinges, radiator hinges, door action, door latches, and door-to-radiator latches. Components include latches, hinges, gear boxes, torque tubes, motors, differentials, actuators, etc. In the Orbiter redundancy status report of early 1974, it has been stated that failure modes involving jamming of hinges, gear boxes, linkages, etc. which prevent closing of the doors currently have no correction action and therefore require crew rescue. The report does indicate that EVA methods of opening and closing the door are under consideration (Space Shuttle and Spacelab Discussions, JSC, Marsh 21-22, 1974, p. 417).

Task Requirements: The primary dexterity requirement involves handling of the 2 inch linkage pin.

3.1.2.16 Task S-16 Star Tracker Door Repair

Task Justification: A single point failure requiring on-orbit repair or rescue.

Task Description: The star tracker door is located at the forward left side of the orbiter. The doorway is 18 by 24 inches. The failure mode assumed for this task is a jam in the linkage of the door assembly which prevents closing of the door and therefore prevents return of the orbiter. The repair action is to remove the linkage, realign or replace it, and reinstall the linkage.

Task Requirements: As in the cargo bay door repair task, the requirement here is to remove a pin, remove the door linkage, replace or realign the linkage, and to reinstall it into the door assembly.

3.1.2.17 S-17 Rescue Mission Support

Task Justification: In a letter to Rockwell International concerning redirection of the EVA rescue baseline (February 1974) NASA JSC established the following baseline:

- All shuttle flights will carry EVA provisions for two crewmen and personal rescue systems for other crewmembers
- If the spacecraft requiring aid has a docking module, the primary rescue mode will be by docking, with crew transfer through the tunnel; otherwise, emergency rescue will be with pressure suits or personal rescue systems outside the spacecraft

Task Description: In this task two techniques of rescue were examined. Both involved the EVA/RMS mode, with the techniques differing in terms of what holds the personal rescue system during transfer, the RMS or the EVA crewman using a line set up by the RMS.

Task Requirements: The primary requirement is the 25 foot transfer of a personal rescue system or pressurized enclosure for non-EVA crewmen. The personal rescue system components, including cooling/pressure umbilical, communications umbilical, cooling vest, and pressure enclosure, weigh an estimated 24.5 lbs. with crewman weights ranging from 100 to 200 lbs. The range of masses to be handled in the rescue mode is from 124.5 to 224.5 lbs for each enclosure.

3.2 STEP 2 - COMPARISON OF MODES FOR EACH TASK CONDITION

The initial activity in this step was to develop mode comparison criteria. The criteria selected are presented in Table 3-10. Each applicable mode was ranked on each of the factors under the criterion groups in terms of the degree to which problems can be expected, and the magnitude of expected problems, in performing the task in the mode. The selected mode for the task is the mode with the lowest sum of all rankings (ranking of 1 indicates best mode, ranking of 5 indicates worst on each criterion measure). In essence, this approach represents a comparison of modes rather than a formal tradeoff. No weighting factors were used to emphasize the rankings on more important criteria. The mode selected for a task is simply the mode judged to have minimum problems on the criteria for the task. Other modes not selected for a task but which are judged close to the score of the selected task (generally a difference of 5 or less on the sum of ranks) were judged feasible for the task. Thus, while one mode (or two for some tasks) was judged most effective for a task in terms of minimal problems, other candidate modes for the task are identified as feasible. Problems were then summarized for all applicable modes for a task, and task completion requirements were identified for feasible tasks. The results of mode comparisons, problems, and requirement identifications for each mode are contained in the Appendix.

3.3 STEP 3 - PROBLEM AND REQUIREMENT IDENTIFICATION

To facilitate decisions that modes were applicable for specific tasks, and to assist in the identification of problems and requirements, a 50th scale model of the orbiter, the RMS, and selected payloads were constructed. The orbiter model was a wood model built to requirements specified in Volume XIV, Shuttle Program Requirements. Photographs of selected task conditions depicting the modes used are presented in Figures 1 through 17.

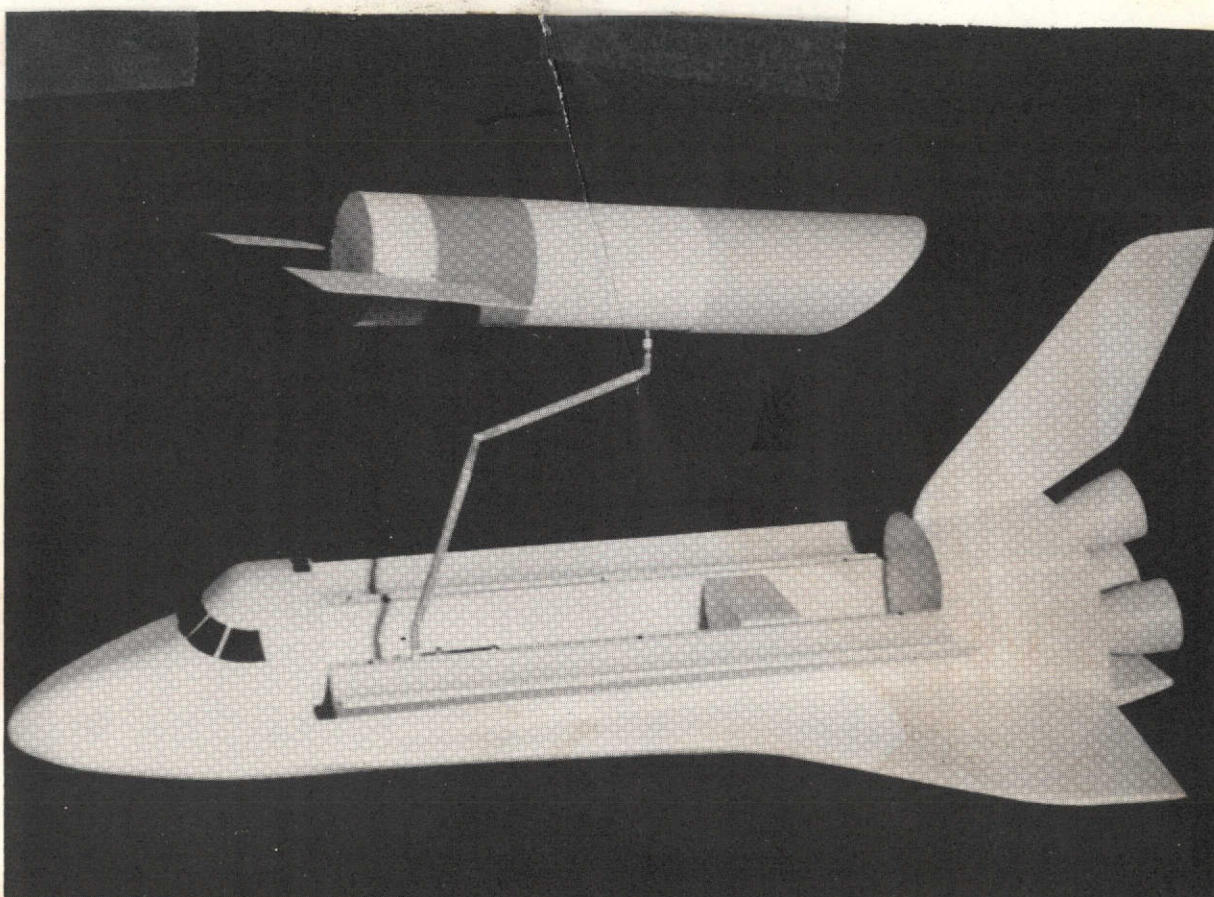


Figure 1 TASK P-1 , Payload Retrieval, Condition 1 LST Retrieval, Mode - RMS

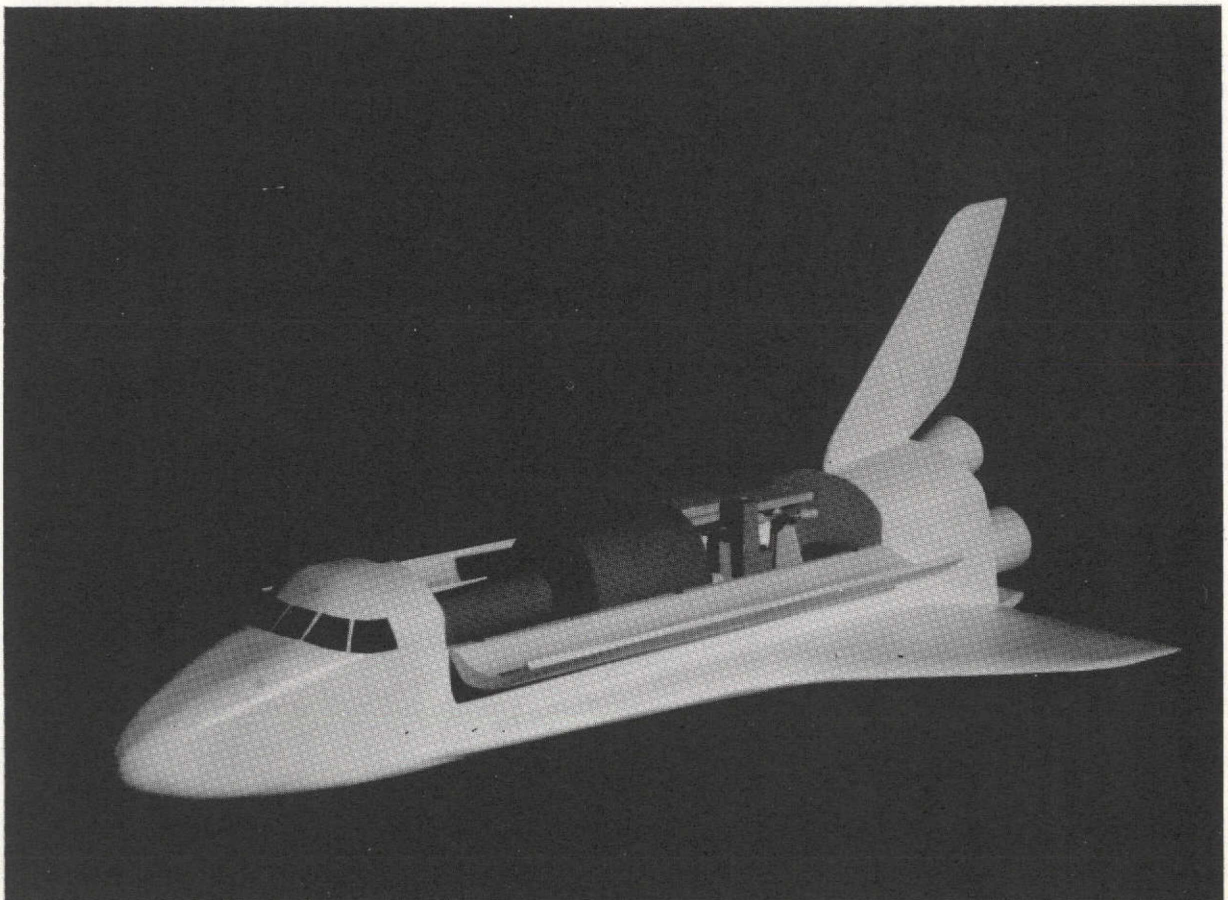


Figure 2 TASK P-2 Pallet Apparatus Deploy, Advanced Technology Laboratory before Deployment

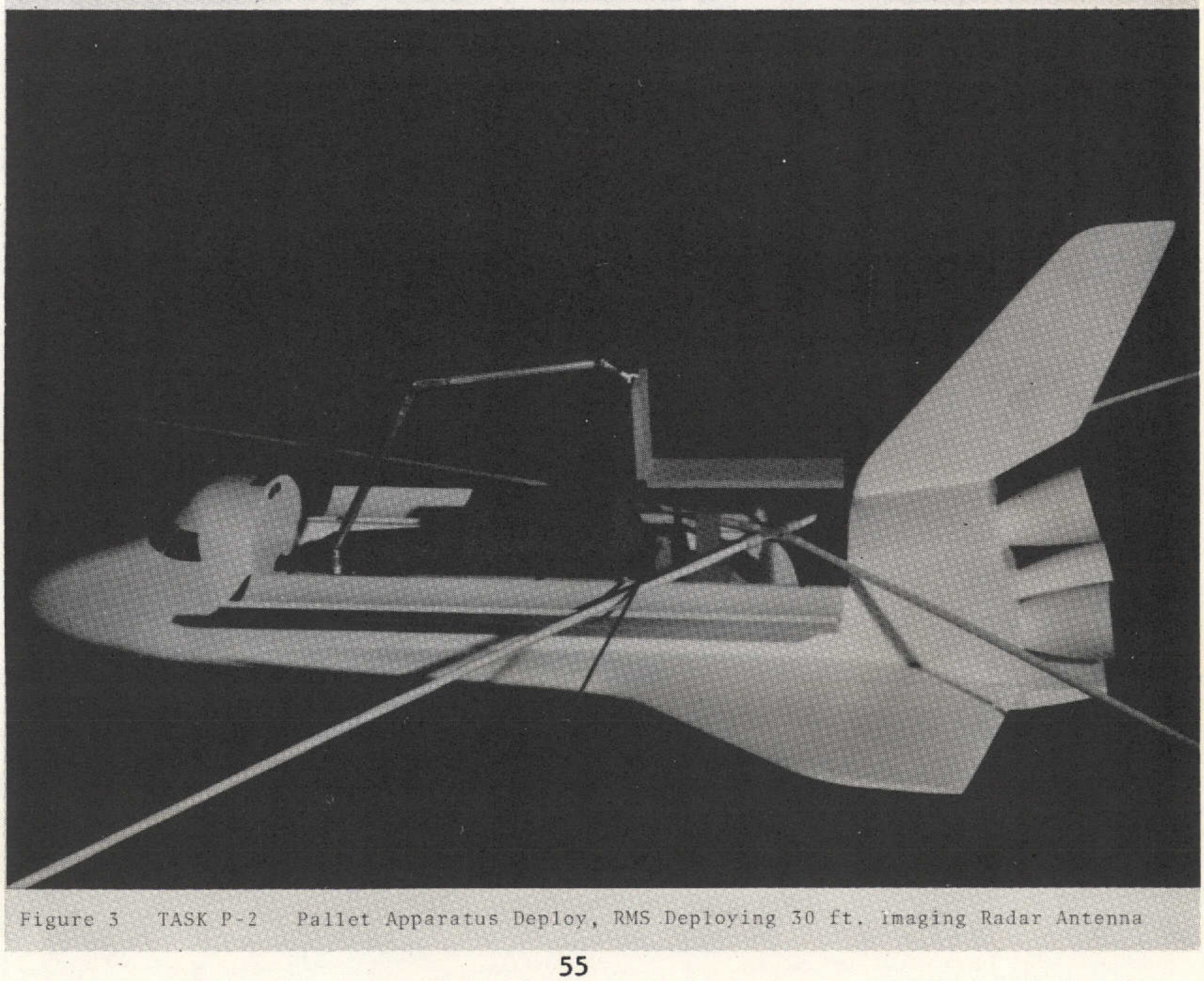


Figure 3 TASK P-2 Pallet Apparatus Deploy, RMS Deploying 30 ft. imaging Radar Antenna

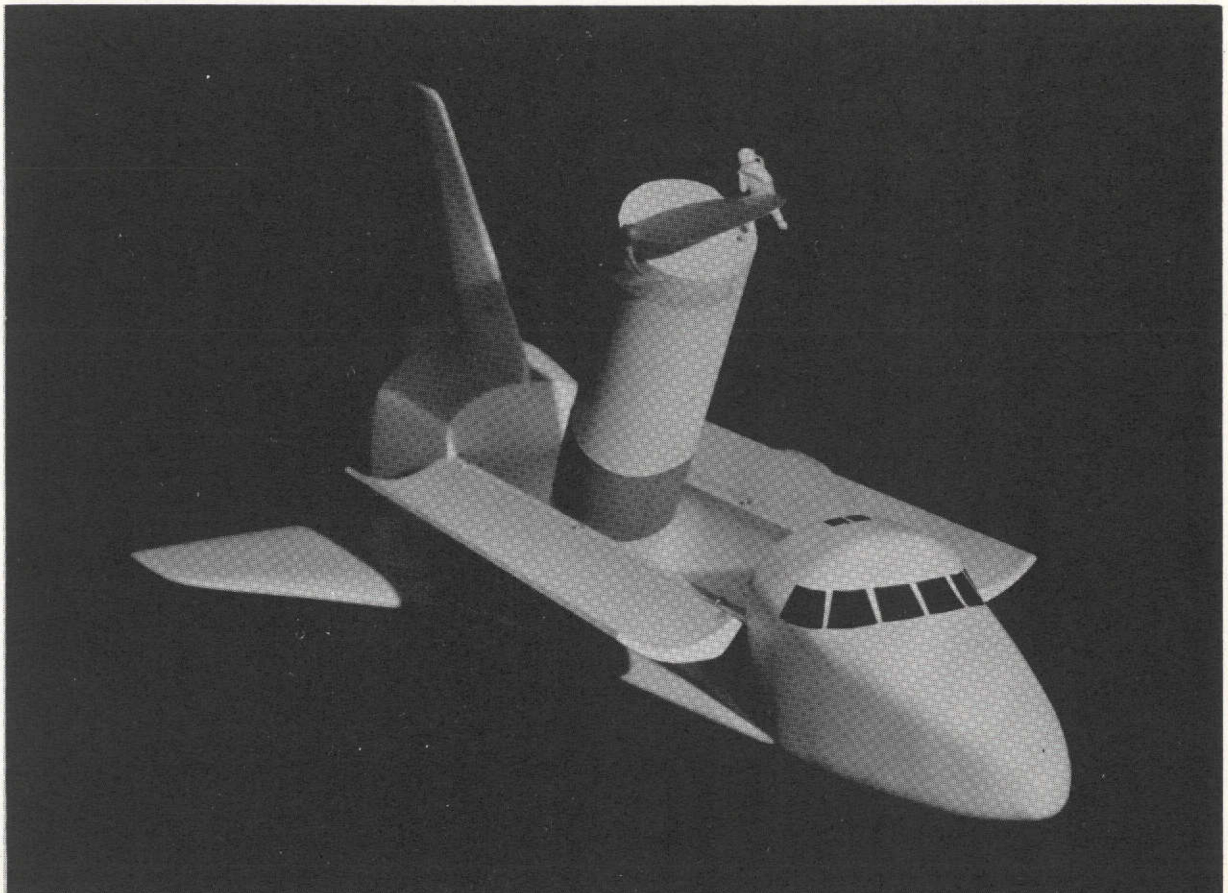


Figure 4 TASK P-3 Payload Door open - Condition 2, Window at End of Telescope (Shuttle IR Telescope Facilities) with MMU

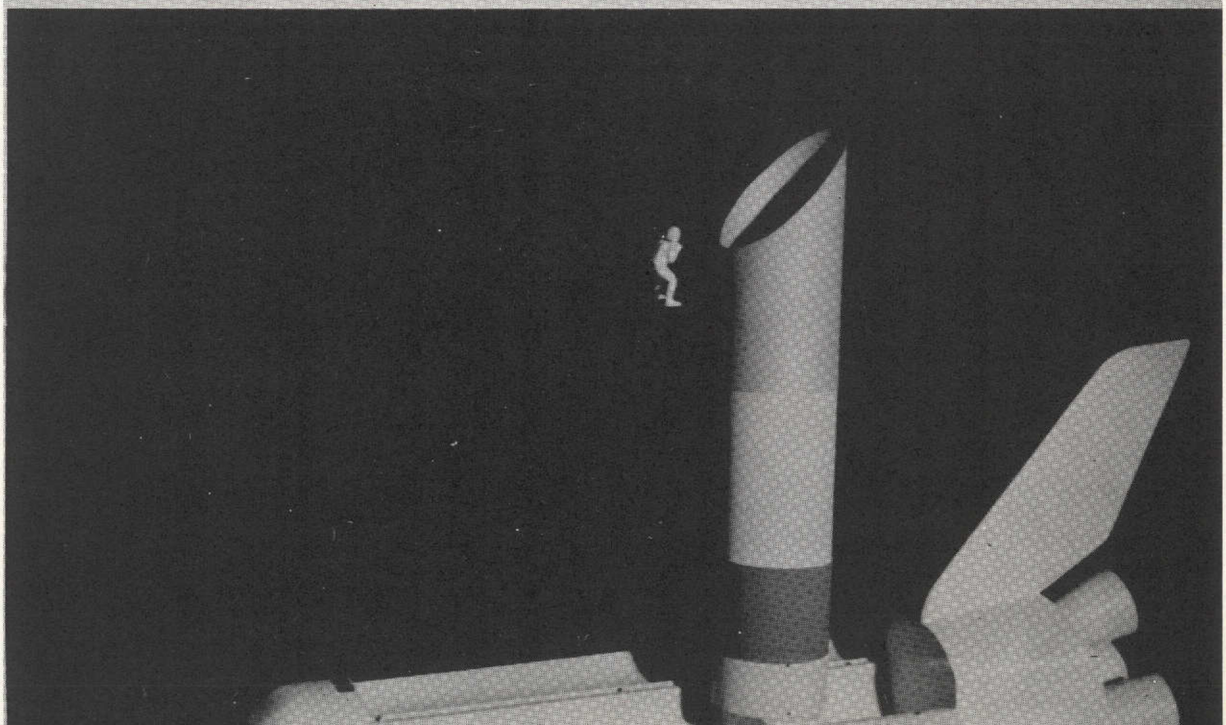


Figure 5 TASK P-5 Sunshade Retraction - LST - MMU

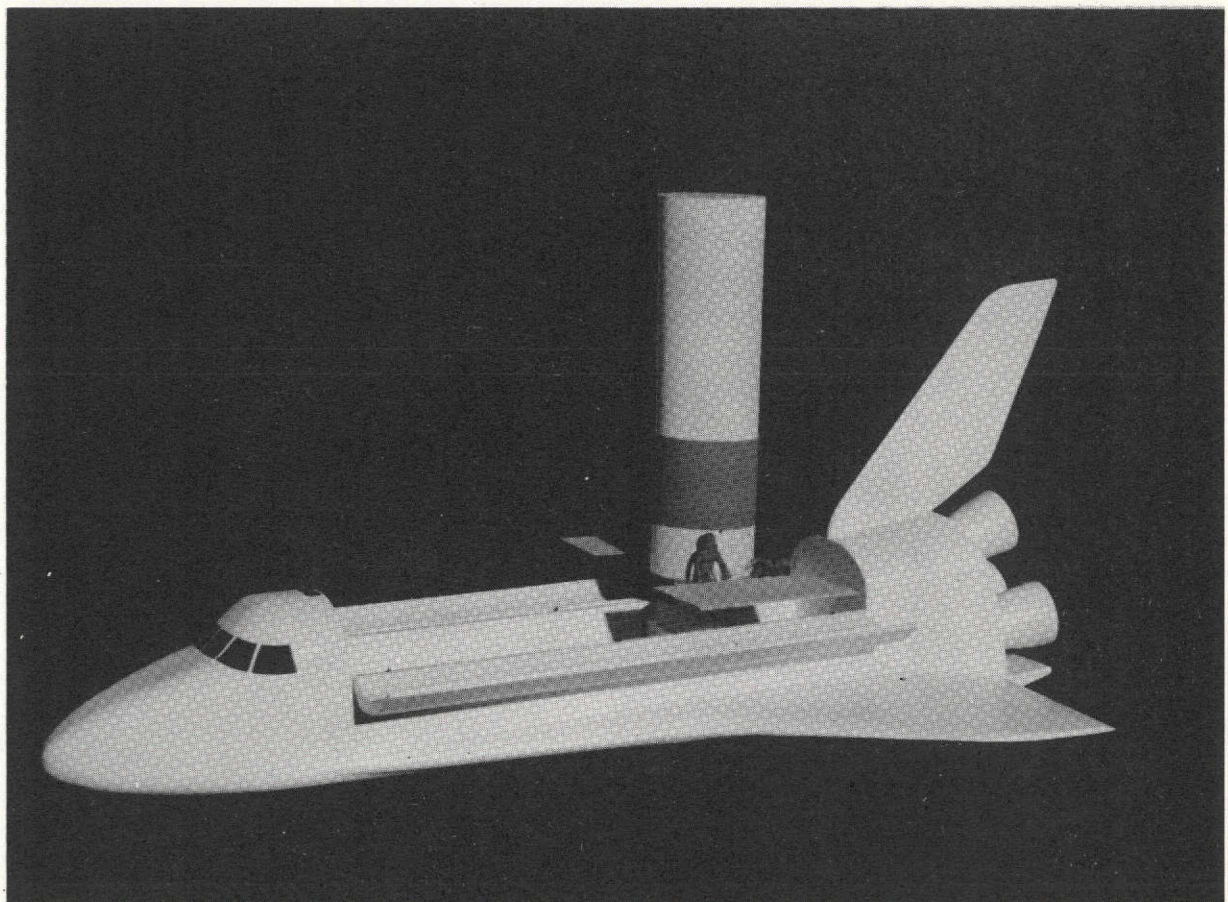


Figure 6 TASK P-6 Solar Panel Retraction - LST - Unaided EVA

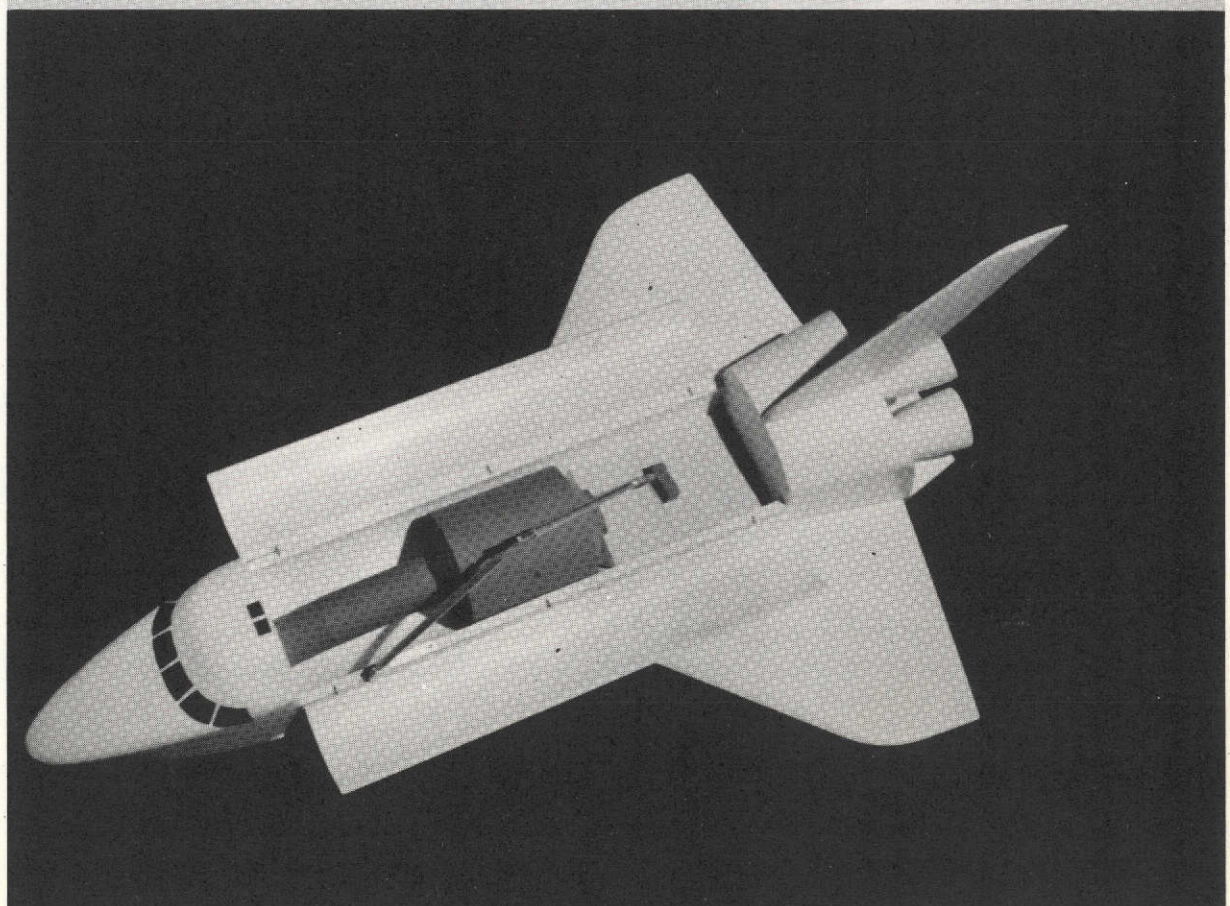


Figure 7 TASK P-7 Film Loading on Pallet - Atmospheric Science Facilities - RMS

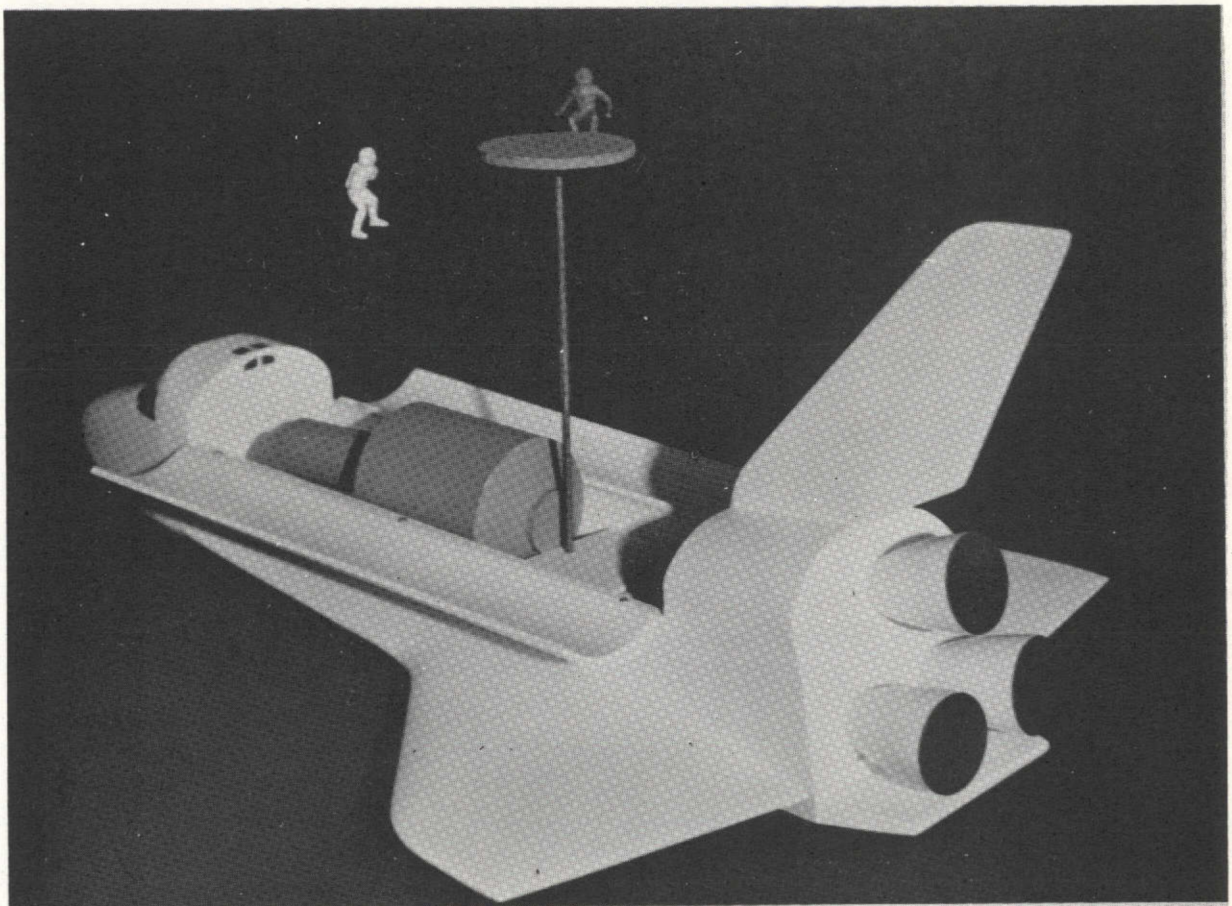


Figure 8 TASK P-8 Antenna Retract and Feed Change - Comm/Nav Erectable Antenna - MMU

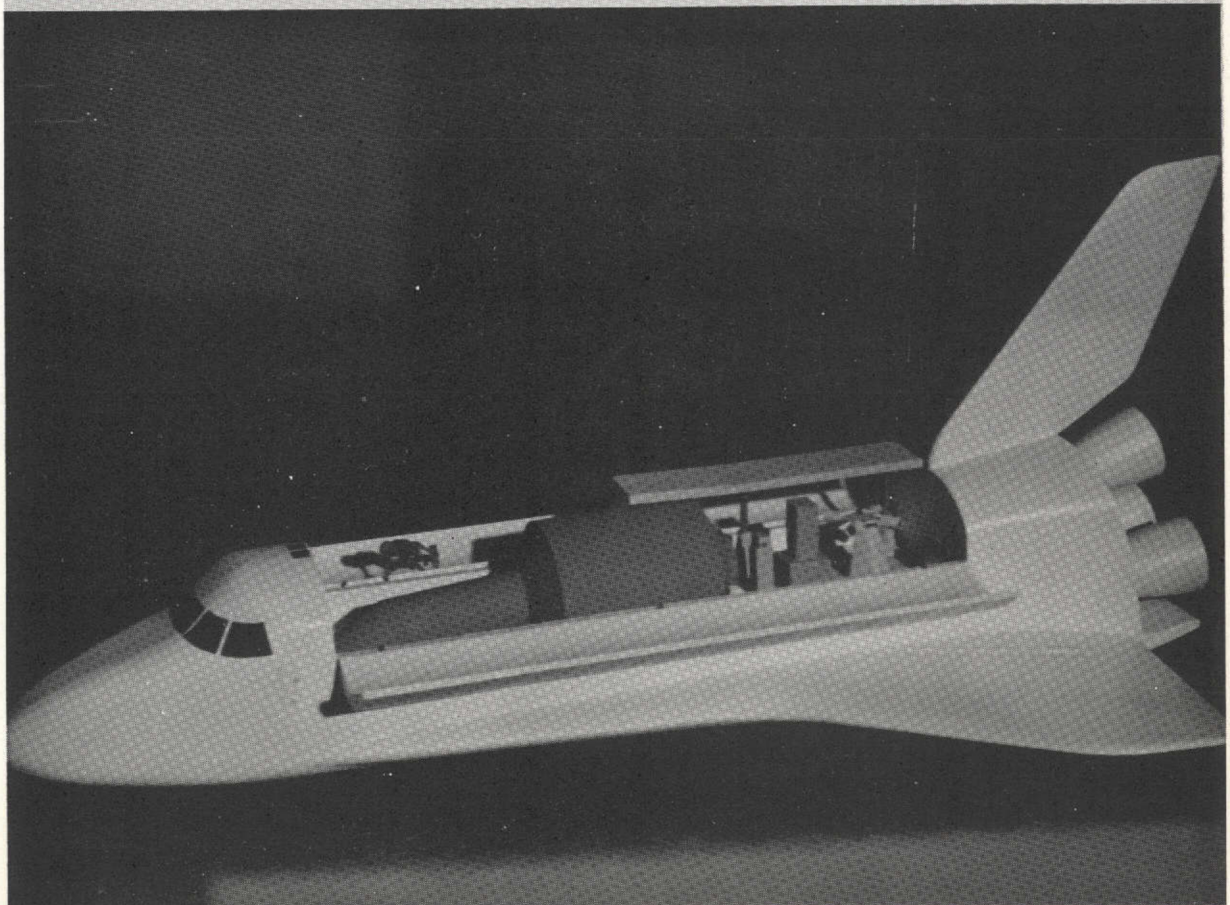


Figure 9 TASK P-9 Contamination Monitoring - Unaided EVA

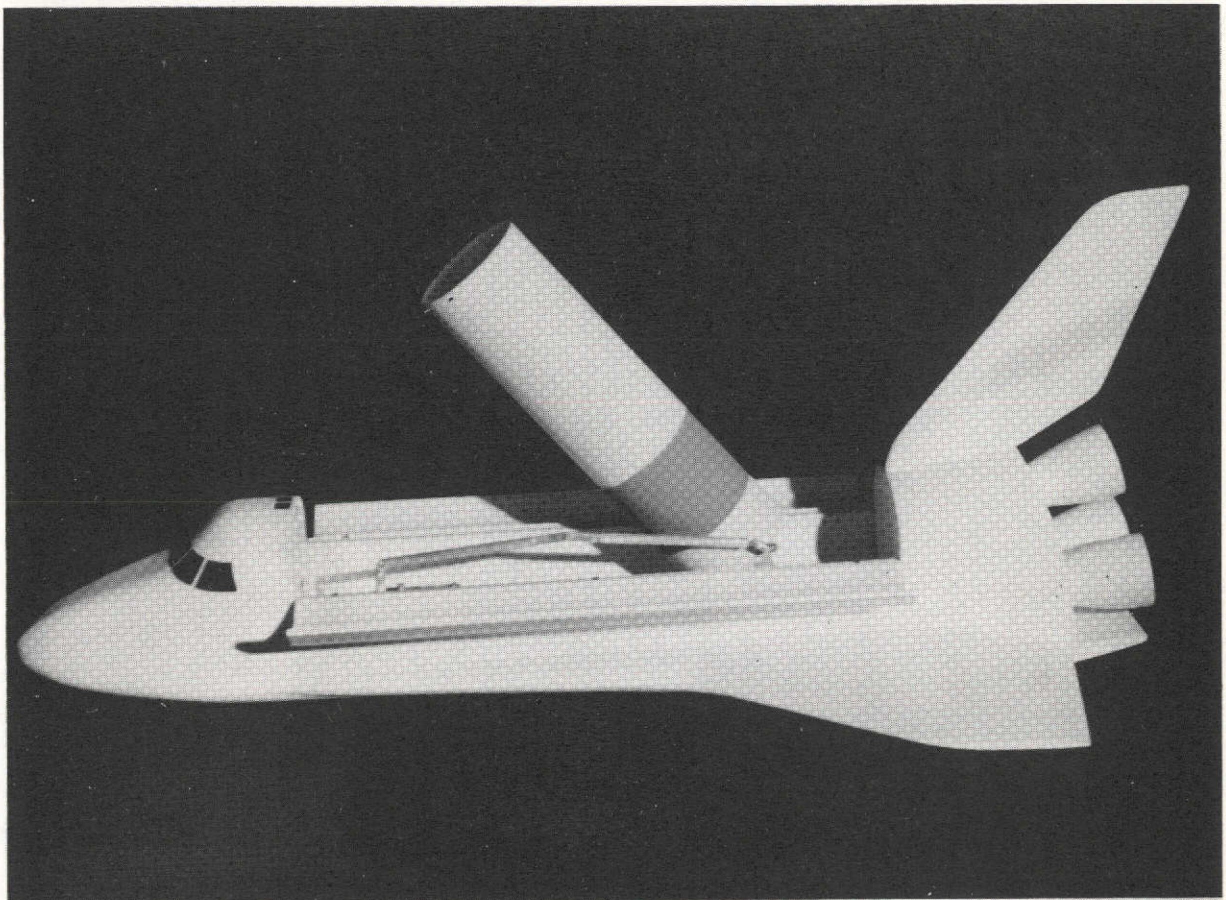


Figure 10 TASK P-10 Electrical Lead Disconnect - LST - RMS

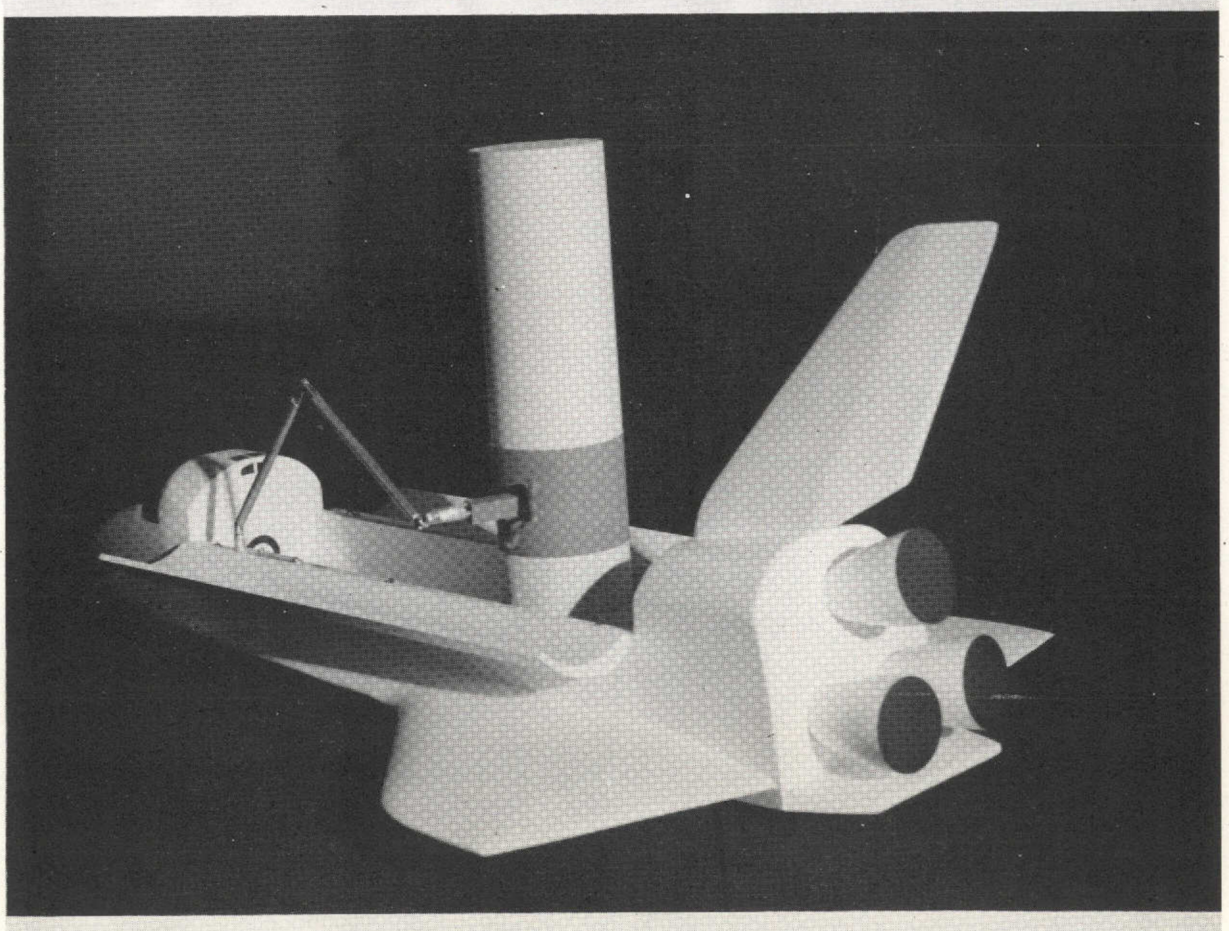


Figure 11 TASK P-11 Module Replacement, LST - CMG EVA and RMS

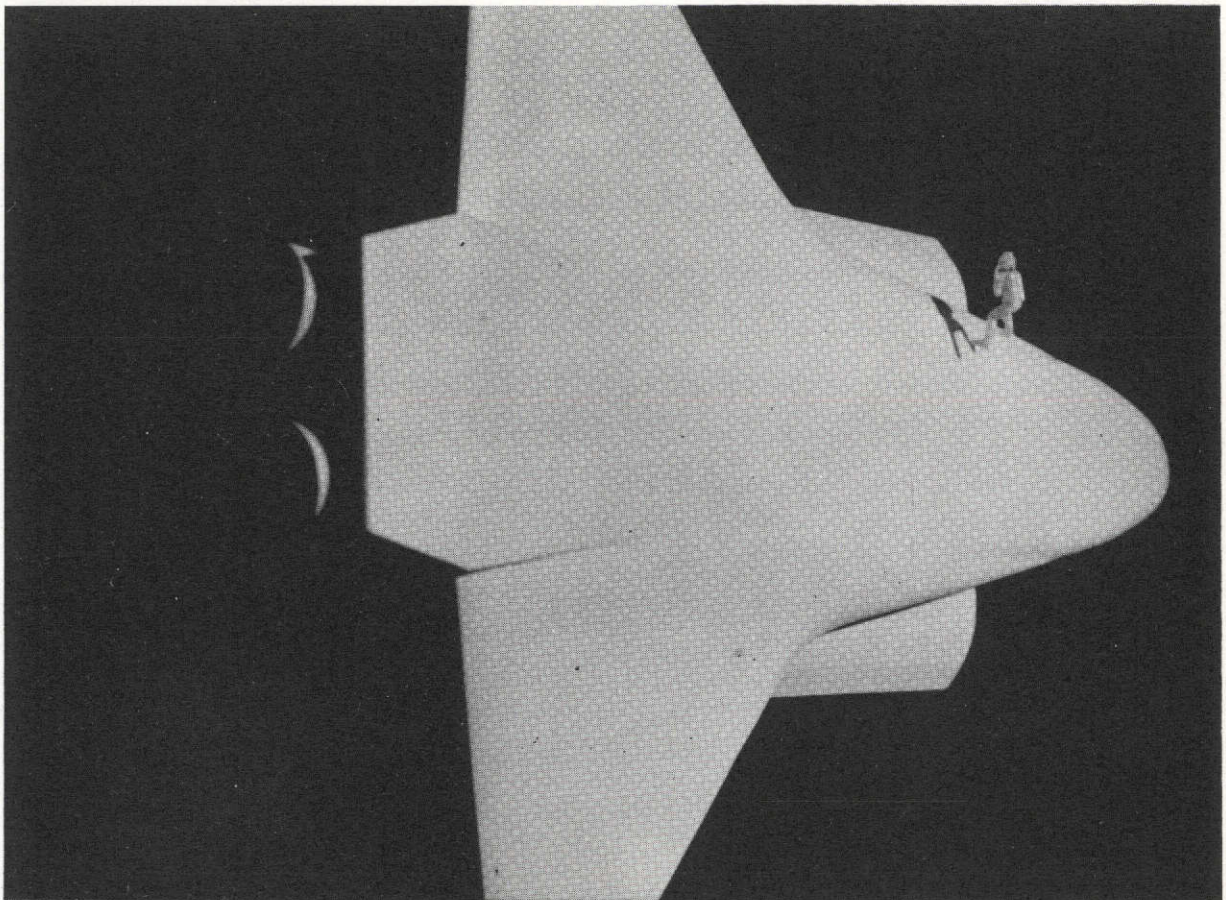


Figure 12 TASK S-12 Thermal Protection System Inspection and Repair - MMU

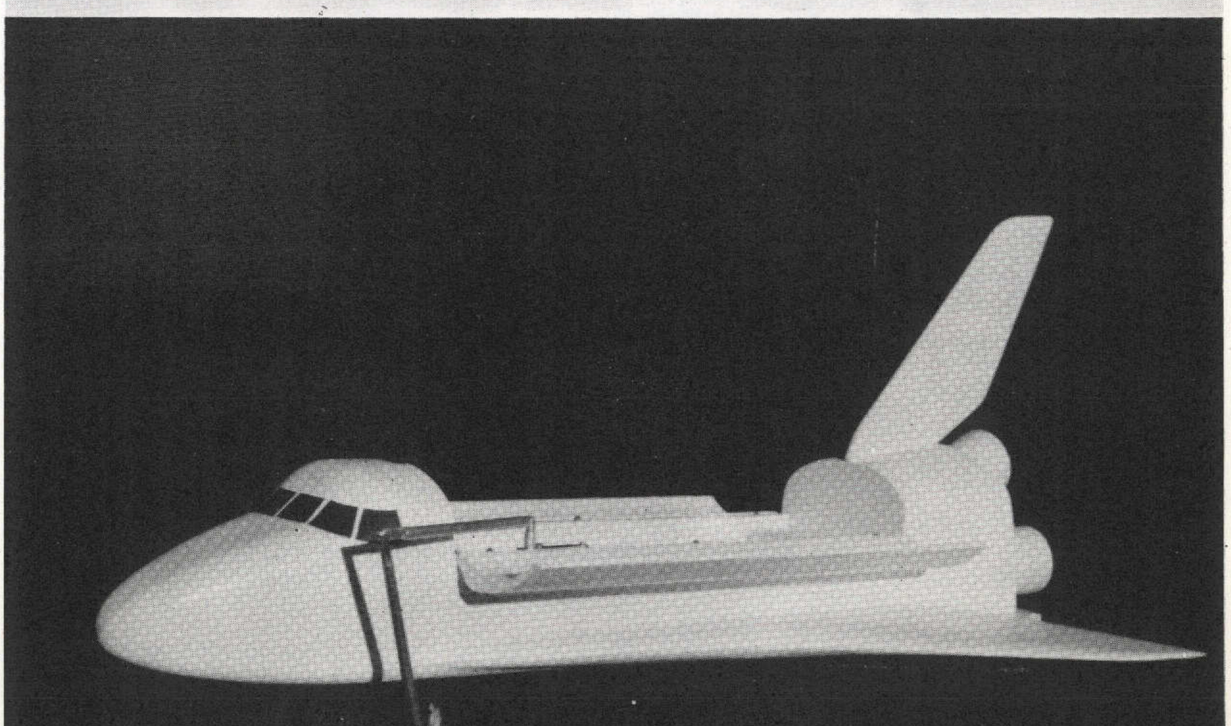


Figure 13 TASK S-12 Thermal Protection System Inspection - RMS

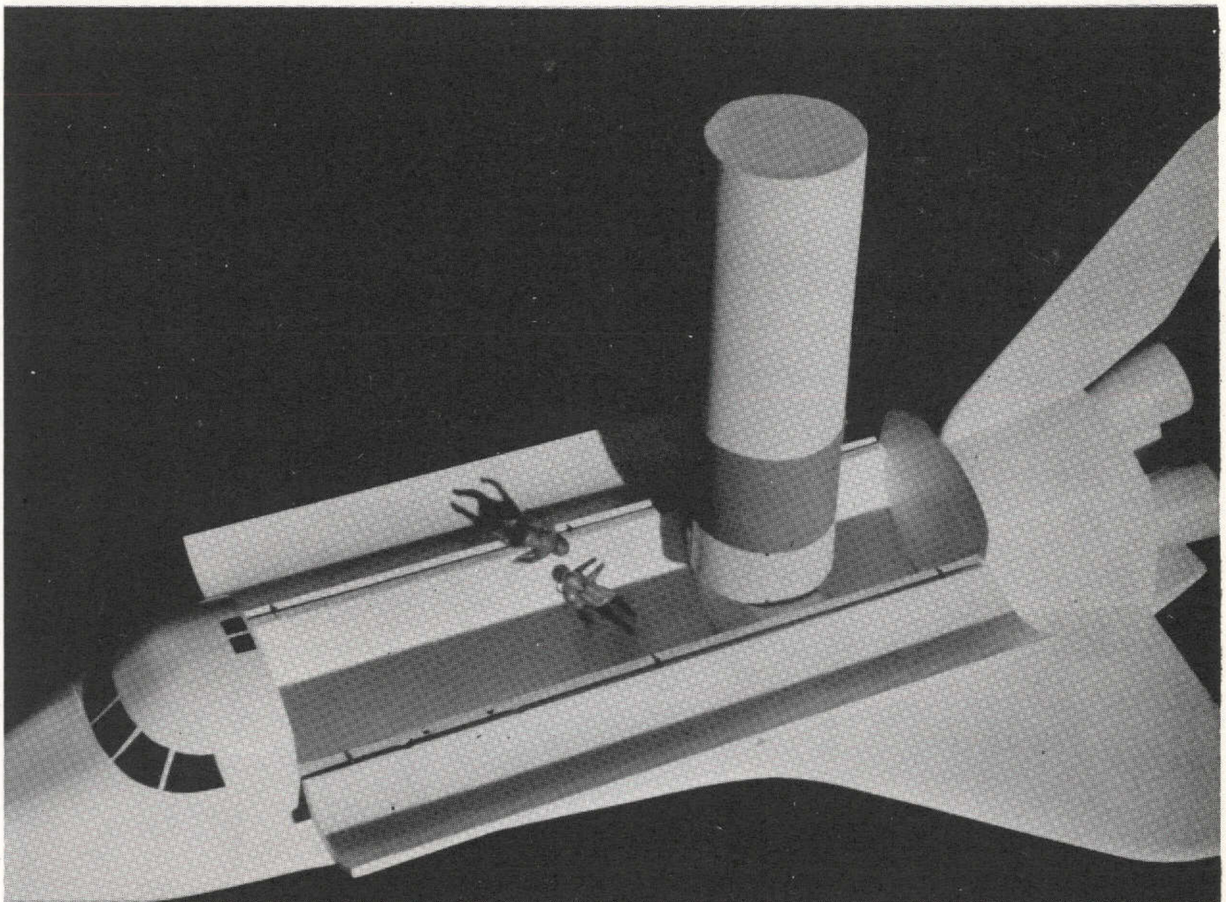


Figure 14 TASK S-14 Payload Retention Lock Activation - Unaided EVA

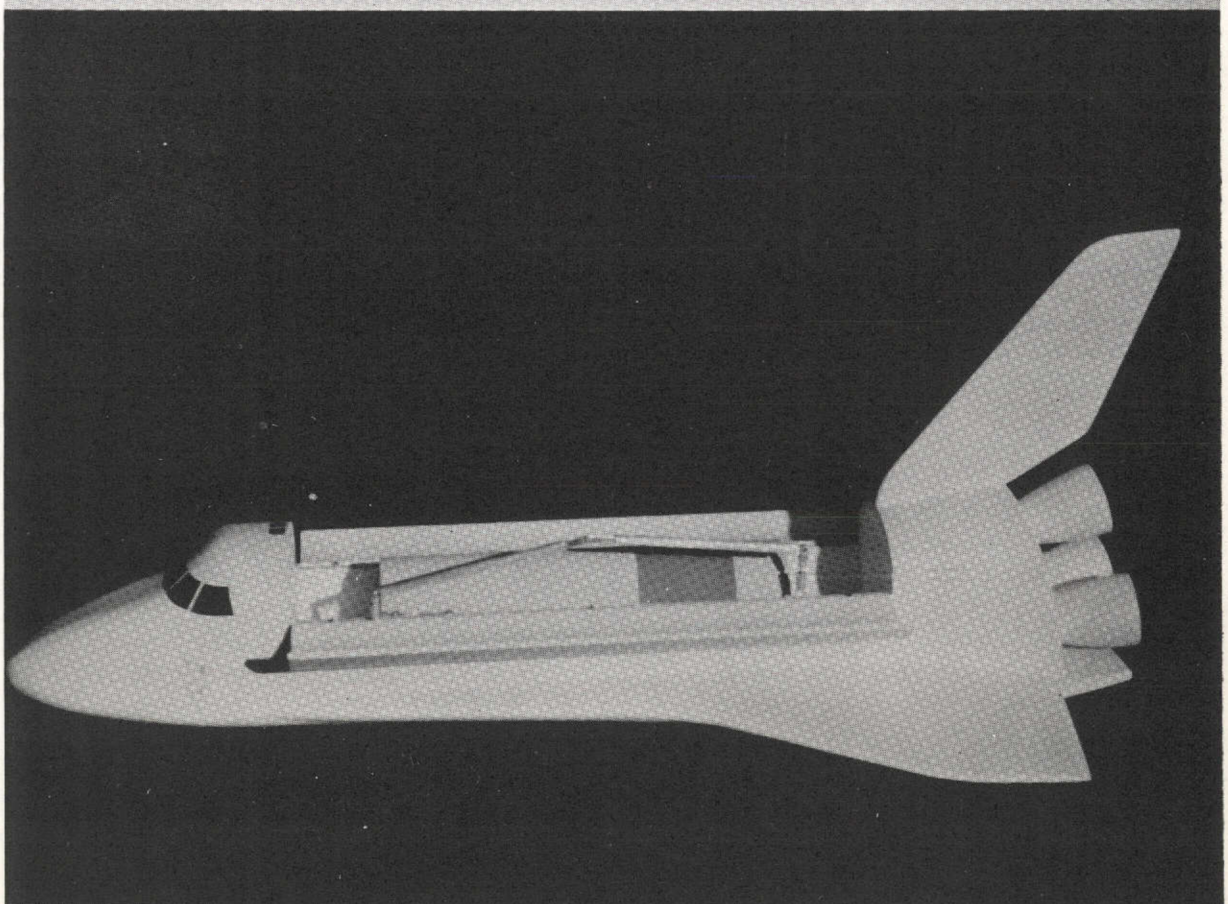


Figure 15 TASK S-15 Cargo Bay Door Activation - RMS

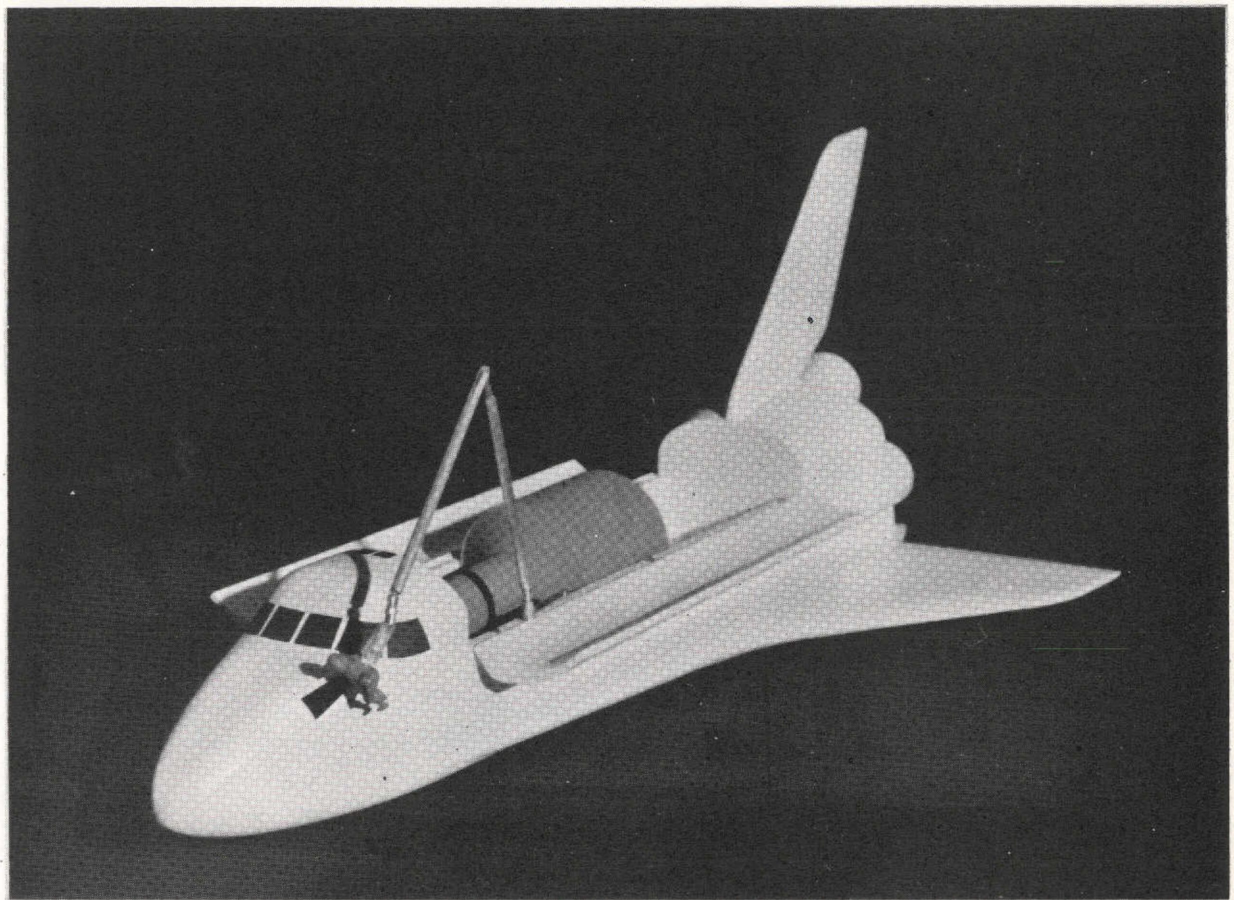


Figure 16 TASK S-16 Star Tracker Door Close - Cherry Picker

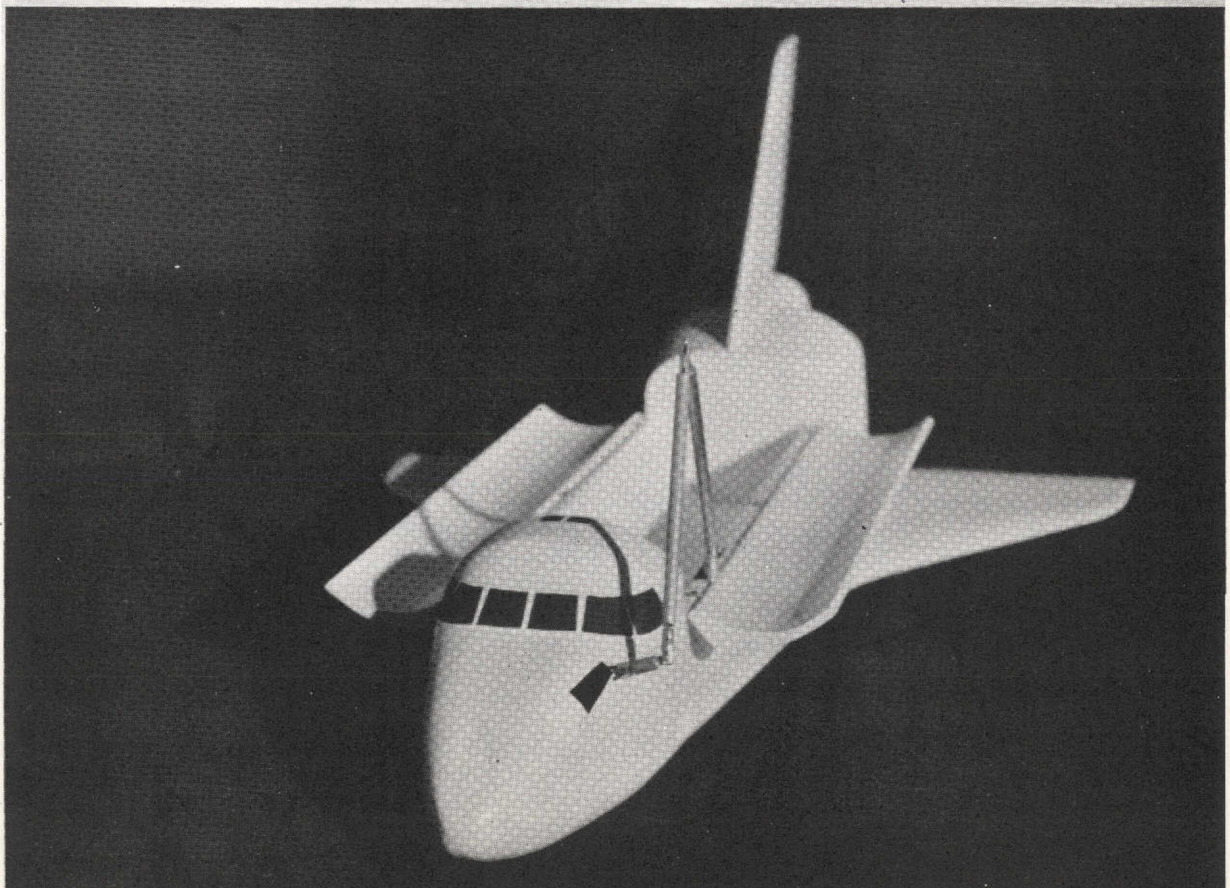


Figure 17 TASK S-16 Star Tracker Door Close - RMS

TABLE 3-1. PAYLOADS HAVING OUTSIDE SUPPORT REQUIREMENTS

DISCIPLINE	AUTOMATED	SPACELAB
ASTRONOMY	4	10
HIGH ENERGY ASTRO.	6	5
SOLAR PHYSICS	1	4
ATMOS. AND SPACE PHYSICS	5	3
COMM-NAV	7	2
EARTH OBSERVATION	9	3
EARTH AND OCEAN PHYSICS	7	1
LIFE SCIENCES	1	0
SPACE TECHNOLOGY	1	6
PLANETARY & LUNAR	10	0
	51	34

TABLE 3-2.
AUTOMATED P/L DESCRIPTIONS

P/L	First Launch	Prog. Life	Service	Nom. Retr.	Refurb. Interval	Orbit	Louvers	Contam. Cover	Solar Arrays	Sun Shield	Conting. Retrieval	Sim./Nom. EVA	Emerg. EVA	RMS	Tug
AS01A LST-01	80	15	X	X	3	LEO	X	X	X	X	X		X	X	
AS-02A LAE	80	14				1AU	X	X	X	X	X		X	X	X
AS03A	79	14				LEO	X	X	X	X	X		X	X	
AS05A	80	10				Synch	X	X	X		X		X	X	X
HE01A	86	10	X	X	5	LEO	X	X	X	X	X		X	X	
HE03A	82	7	X	X	4	LEO	X	X	X	X	X		X	X	
HE07A	83	8			2	LEO	X	X	X		X		X	X	
HE08A	87	10	X	X	4	LEO	X	X	X		X		X	X	
HE09A	80	5	X	X	3	LEO	X	X	X		X		X	X	
HE11A	83	12	X	X	4	LEO	X	X	X	X	X		X	X	
S003A	80	13		X	2	LEO	X		X		X	X			
AP01A	79	13				LEO									
AP02A	79	13				HEO									X
AP03A	80	8				1AU									X
AP04A	80	5				LEO			X	X	X				
AP05A	81	6				HEO					X				
E007A	87	5	X	X	5	Synch			X		X				X
E008A	80	13				LEO			X	X				X	X
E009A	81	12				Synch			X	X	X			X	X
E010A	79	13				Synch	X		X					X	X
E012A	82	2				HEO			X		X			X	X
E056A	80	13				HEO			X		X			X	X
E057A	81	14				Synch								X	X
E058A	79	16				Synch								X	X
E061A	79	14				LEO	X		X					X	X
OP1A	79	5				Synch									X
OP02A	80	1				LEO									
OP03A	80	10				LEO									

TABLE 3-2, Continued:

P/L	# S/C	# Launches	# Retrievals	# Service	Weight in Kg Min P/L Service	Weight in Kg Max P/L Service	Deployed Dimens. (in M) Weight or Diameter	Height	Length	Weight (Kg)	Stability	Deploy. Booms	Docking Provisions
AS01A	1	3	2	9	3.2K	5.6K	4.27		19.5	5600	CMG		X
AS02A	6	6					1.83	4.06		104	Cold Gas		
AS03A	7	7					1.83	3.13		104	Cold Gas		
AS05A	8	4/2 ea.					1.83	2.46		104	Cold Gas		
HE01A	1	1	1	2	500	1000	4.27		21	8910	CMG		X
HE03A	1	1	1	2	1000	2000	4.27		7.55	7472	CMG		X
HE07A	4	6					1.83	2.63		594	Cold Gas		
HE08A	1	1	1	2	500	1000	4.27	4.27	5.22	8170	CMG		X
HE09A	1	1		1	1200	1820	4.57		5.5	5309	CMG		X
HE11A	1	2	1	2	500	1000	4.57		14.3	7604	CMG		X
S003A	2	6	6				1.22	2.44		1381	Cold Gas		X
AP01A	4	4					1.37		1.83	895	Spin	6	
AP02A	4	4					1.37		1.83	278	Spin	4	
AP03A	6	6					1.22		1.83	426	Spin	4	
AP04A	2	2					1.88		3.58	787	Cold Gas		X
AP05A	2	2					2.10		3.70	1488	Cold Gas		X
E007A	1	1					1.88	2.14	6.65	1300	Hydrazine		X
E008A	13	13					2.8		11.0	2950	Hydrazine		X
E009A	9	9					2.18	3.26	6.92	1232	Hydrazine		X
E010A	16	16					1.92		2.77	394	Hydrazine		
E012A	1	1					2.7		4.06	2214	Hydrazine		X
E056A	9	9					2.7		3.72	2186	Hydrazine		X
E057A	6	6					1.91		3.14	257	Spin		
E058A	9	9					1.91		3.14	257	Spin		
E061A	13	13					1.52		3.05	660	Hydrazine		
OP01A	2	2					2.0		2.50	1169	Cold Gas		
OP02A	1	1					4.0		4.6	3244	Spin		
OP03A	12	2/6 ea.					0.5			102	None		

TABLE 3-2, Continued:

P/L	First Launch	Prog Life	Service	Nom. Retr.	Refurb. Interval	Orbit	Louvers	Contam. Cover	Solar Array	Sun Shield	Conting. Retrieval	Nom. EVA	Emerg. EVA	RMS	Tug
OP04A	79	2				LEO									
OP05A	81	10				LEO									
OP06A	81	10				HEO									
OP07A	82	5				LEO									
LS02A	80	12		X	.5	LEO	X							X	
ST01A	80	11		X	2	LEO							X	X	
PL01A	84	4		X		Mars	X		X				X	X	
PL03A	80	1				Venus	X		X				X	X	
PL07A	83	1				Venus	X						X	X	
PL11A	81	2				Planet.	X						X	X	
PL12A	81	2				Planet.	X		X				X	X	
PL13A	84	1				Planet.	X						X	X	
PL18A	81	1				Planet.			X				X	X	
PL21A	79	2				Planet.			X				X	X	
PL22A	80	2				Planet.	X						X	X	
CN51A	79	22				Synch			X					X	X
CN52A	79	11				Synch								X	X
CN53A	84	17				Synch			X					X	X
CN54A	81	14				Synch			X					X	X
CN55A	79	16				Synch			X					X	X
CN56A	81	17				Synch			X					X	X
CN58A	83	10				Synch	X		X					X	X
LU01A	84	4				Lunar	X		X					X	

TABLE 3-2, Continued:

P/L	# S/C	# Launch	# Retrieval	# Service	Weight in Kg		Deployed Dimens. (in M)			Weight (Kg)	Stability	Deploy. Booms	Docking Provisions
					Min P/L Service	Max P/L Service	Weight or Diameter	Height	Length				
OP04A	2	1/2 ea.					2.0		2.7	2397	Cold Gas		
OP05A	9	9					1.22		1.37	150	Cold Gas	1	
OP06A	3	3					1.22		1.37	200	Cold Gas	1	
OP07A	1	1					3.96		4.57	1012	Grav.Grad.	1	
LS02A	3	24	24				1.52		2.43	682	Cold Gas		
ST01A	1	6	6				1.22		1.83	3860	Grav.Grad.		X
PL01A	2	2					3.81		6.86	3283	Cold Gas		X
PL03A	5	5					2.59		5.25	684	Cold Gas	2	
PL07A	3	2					4.26		6.90	3958	Hydrazine	2	
PL11A	2	1					2.74		2.9	508	Hydrazine	1	
PL12A	3	2					4.26		7.56	2670	Hydrazine	2	
PL13A	2	2					2.74		2.9	508	Hydrazine	1	
PL18A	3	2					3.63		3.75	2154	SEP	2	
PL21A	1	1					3.63		3.75	1838	SEP	2	
PL22A	2	1					2.74		2.9	508	Spin-Hydrazine	1	
CN51A	21	21					1.83	2.5	2.7	1774	Hydrazine		
CN52A	7	7					1.7		2.2	261	Spin-Hydrazine		
CN53A	14	14					1.83	2.5	2.7	1774	Hydrazine		
CN54A	4	4					1.4		5.12	583	Ion		
CN55A	11	11					1.17	1.58	3.22	315	Hydrazine		
CN56A	11	11					1.6	1.5	2.36	308	Hydrazine		
CN58A	6	6					1.92	4.18	7.92	311	Hydrazine		
LU01A	2	2					2.03	2.03	4.77	757	Cold Gas		

TABLE 3-3.

SPACELAB PAYLOADS (LEVEL II)

P/L		1st LAUNCH (1971-91)	Number SPACECRAFT (1971-91)	Number FLIGHTS (1971-91)	TYPE
Astronomy					
AS 01S	1.5m IR	1980	1	15	Module & Pallet
AS 02S	very large IR	1983	1	12	Module & Pallet
AS 03S	deep sky UV	1984	1	7	Module & Pallet
AS 04S	1m UV diff. limited	1984	1	23	Module & Pallet
AS 05S	very wide field galactic	1982	1	2	Module & Pallet
AS 07S	cometary simul.	1985	2	2	Pallet
AS 09S	30m IR interfer.	1985	1	1	Pallet
AS 15S	3m amb. temp. IR	1983	1	11	Pallet
AS 18S	1.5 Km IR interfer.	1984	1	4	Pallet
AS 20S	2.5m cryo cooled IR	1983	1	8	Pallet
HE Astrophysics					
HE 02S	x-ray imaging	1984	1	4	Pallet
HE 05S	cosmic ray	1982	1	10	Pallet
HE 06S	x-ray/gamma ray	1981	1	18	Pallet
HE 11S	x-ray anq. structure	1982	1	8	Pallet
HE 15S	magnetic spectrum.	1980	1	9	Pallet
Solar Physics					
SO 01S	dedicated solar sortie	1980	2	40	Pallet
SO 07S	dedicated solar sortie II	1979	3	19	Module & Pallet
SO 08S	large fine pointing	1980	2	25	Module & Pallet
SO 10S	hi energy solar physics	1980	2	25	Module & Pallet
Atmosphere & Space Physics					
AP 01S	plasma physics	1980	1	19	Module & Pallet
AP 03S	atmos. sci. facility	1980	1	14	Module & Pallet
AP 04S	manned auroral	1983	1	5	Module & Pallet

TABLE 3-3.
SPACELAB PAYLOADS (LEVEL II) CONTINUED)

P/L		1st LAUNCH	Number SPACECRAFT	Number FLIGHTS	TYPE
Earth Observation					
EO 02S	EO sensor lab	1980	2	12	Module & Pallet
EO 05S	SIMS	1980	TBD	5	Either
EO 06S	scan spectru.	1980	1	2	Either
Comm/Nav					
CN 01S	Comm/Nav sortie	1981	3	11	Module & Pallet
CN 02S	Comm/Nav Sortie	1980	3	12	Module & Pallet
Earth-Ocean Physics					
OP 01S	solid earth test bed	1980	3	12	Module & Pallet
Life Science					
LS 04S	free flying teleop.	1981	2	12	Pallet
Space Technology					
ST 01S	adv. tech lab 1	1980	1	9	Module & Pallet
ST 02S	adv tech lab 2	1981	1	7	Module & Pallet
ST 03S	adv tech lab 3	1982	1	7	Module & Pallet
ST 04S	physics & chem 1	1980	1	23	Module & Pallet
ST 05S	physics & chem 2	1980	1	23	Module & Pallet
ST 06S	physics & chem 3	1980	1	23	Module & Pallet
ST 07S	physics & chem 4	1980	1	23	Module & Pallet
ST 08S	IRTCM	1980	10	162	Pallet
ST 09S	contam release	1969	1	3	Pallet
ST 11S	laser data	1984	1	3	Pallet

TABLE 3-4. MISSION ANALYSIS RESULTS -

CLASSES OF EV TASKS IDENTIFIED FOR SHUTTLE PAYLOADS AND P/L EXPERIMENTS

- PAYLOAD SUPPORT

  NOMINAL

  - FILM RETRIEVAL/REPLACEMENT
  - ANTENNA DEPLOY/RETRACT
  - SUBSATELLITE EJECT/RETRIEVE
  - PAYLOAD DEPLOY
  - PAYLOAD RETRIEVAL
  - RETRIEVAL SUPPORT
  - ANTENNA FEED CHANGE
  - PURGE - VENT P/L

  CONTINGENCY

  - COVER REMOVAL
  - DOOR OPEN/CLOSE
  - TELESCOPE DEPLOY/RETRACT
  - SUNSHIELD DEPLOY/RETRACT
  - CAMERA DEPLOY/RETRACT
  - BOOM ERECT/RETRACT
  - FLUID REPLENISHMENT
  - GIMBAL PLATFORM DEPLOY
  - CMG SERVICING
  - MODULE REPLACEMENT
  - STARS SERVICING
  - SPACELAB SERVICING-SETUP
  - LIGHTING SERVICING
  - SOLAR ARRAY DEPLOY/RETRACT
  - LOUVER SERVICING

- EXPERIMENT SUPPORT

  WAKE SAMPLING, RADIATION ENVIRONMENT, CAMERA POINTING

TABLE 3-5. MISSION ANALYSIS RESULTS - POTENTIAL OPERATIONS FOR SHUTTLE SUPPORT

IDENTIFIED EV OPERATIONS INCLUDE:

NOMINAL

- THERMAL PROTECTION SYSTEM INSPECTION
- CONTAMINATION MONITORING
- SURVEILLANCE OF ON-ORBIT OPERATIONS

CONTINGENCY - MECHANICAL SYSTEMS

- RETENTION LOCK ACTIVATION
- RENDEZVOUS SENSOR DEPLOYMENT/RETRACTION
- CARGO BAY DOOR ACTIVATION & LATCH
- RCS DOOR OPEN/CLOSE
- STAR TRACKER DOOR OPEN/CLOSE
- DOCKING MODULE DEPLOYMENT

CONTINGENCY - SERVICING

- THERMAL PROTECTION SYSTEM REPAIR
- STAR TRACKER REPAIR
- RENDEZVOUS SENSOR REPAIR

EMERGENCY

- EVA ASTRONAUT RESCUE
- RESCUE MISSION SUPPORT

TABLE 3-6.

P/L SUPPORT REQUIREMENTS

ayloads	P/L Deploy	P/L Retrieve	Safeing-Purge	Film Retrieval	Antenna depl/retr.	Telescope depl/retr.	Sunshield depl/retr.	Solar Array depl/ret	Camera depl/retr.	Retention lock/unloc	Cover remove/repl.	Door open/close	Fluid Replenish	Module Replace	Mech-Sys-Service	Boom exect/retr.	Inspection/check	Subsat-depl/retr.	Expmt Support	
stronomy																				
S-01S	X	X	X	X	X	AM	RO	X	X	AM	RO	RO	PO	?	?	X	X	X	X	
S-02S	X	X	X	X	X	AM	X	X	X	AM	AM	AM	RO	?	?	X	X	X	X	
S-03S	X	X	X	RO	X	AM	AM	X	X	AM	X	AM	PO	?	?	X	X	X	X	
S-04S	X	X	X	PO	X	AM	AM	X	X	AM	X	AM	X	?	?	X	X	X	X	
S-05S	X	X	X	AL	X	X	X	X	AM	PO	X	AM	X	?	?	X	X	X	X	
S-07S	X	X	X	PO	X	AM	X	X	AM	PO	X	PO	RO	?	?	X	X	X	X	
S-09S	X	X	X	X	X	AM	X	X	X	PO	X	PO	X	?	?	AM	X	X	X	
S-15S	X	X	X	X	X	AM	RO	X	X	AM	X	AM	PO	?	?	X	X	X	X	
S-18S	X	X	X	X	X	AM	X	X	X	PO	X	PO	PO	?	?	X	X	RO	X	
S-20S	X	X	X	X	X	AM	RO	X	X	AM	X	RO	RO	?	?	X	X	X	X	
S-01A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	RO	RO/ EVA	RO/ EVA	X	X	X	X	
S-02A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	RO	RO/ EVA	RO/ EVA	X	X	X	X	
S-03A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	RO	RO/ EVA	RO/ EVA	X	X	X	X	
S-05A	RMS	RMS	?	X	X	X	X	AM	X	AM	RO	AM	RO	RO/ EVA	RO/ EVA	X	X	X	X	
igh Energy Ast.																				
HE 02S	X	X	X	X	X	AM	X	X	X	PO	X	PO	RO	RO	PO	X	X	X	X	
HE 05S	X	X	X	X	X	X	X	X	X	PO	X	PO	PO	?	?	X	X	X	X	
HE 06S	X	X	X	X	X	X	X	X	RO	PO	X	PO	RO	RO	?	X	X	X	X	
HE 11S	X	X	X	X	X	AM	X	X	X	PO	X	PO	RO	RO	PO	X	X	X	X	
HE 15S	X	X	X	X	X	X	X	X	AM	AM	X	PO	RO	?	?	X	X	X	X	
HE 01A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X	
HE 03A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X	
HE 07A	RMS	RMS	?	X	X	X	X	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X	

EY

X - identified as not applicable
PO - probably required - no method identified
RO - required - no method identified

AM - Automated system identified
EVA - EVA identified
RMS - RMS identified
AL - Airlock

TABLE 3-6, CONTINUED:

Payloads	P/L Deploy	P/L Retrieve	Safeing-Purge	Film Retrieval	Antenna depl/retr.	Telescope depl/retr.	Sunshield depl/retr.	Solar Array depl/retr	Instum/ Camera depl/retr.	Retention lock/unloc	Cover remove/repl.	Door open/close	Fluid Replenish	Module Replace	Mech-Sys-Service	Boom excet/retr.	Inspection/check	Subsat-depl/retr.	Expmt Support
HE 08A	RMS	RMS	?	X	X	X	X	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X
HE 09A	RMS	RMS	?	X	X	X	X	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X
HE 11A	RMS	RMS	?	X	X	X	AM	AM	X	AM	RO	AM	PO	RO/ EVA	RO/ EVA	X	X	X	X
Solar Physics																			
SO-01S	X	X	X	PO	X	AM	?	X	AM	AM	X	PO	X	?	?	X	X	X	X
SO-07S	X	X	X	?	X	AM	?	X	AM	AM	X	PO	X	?	?	X	X	X	X
SO-08S	X	X	X	?	X	AM	?	X	AM	AM	X	PO	X	RO/ EVA	RO/ EVA	X	X	X	X
SO-10S	X	X	X	X	X	X	X	X	AM	AM	X	PO	X	RO/ EVA	RO/ EVA	X	X	X	X
SO-03A	RO	RO	EVA	X	X	X	X	AM	X	AM	X	AM	EVA	EVA	EVA	X	EVA	X	X
Atmos & Space ph																			
AP 01S	AM	AM	X	?	AM	X	X	X	AM	AM	?	PO	RO	?	?	RO	X	AM	PO
AP 03S	X	X	X	RO	AM	AM	AM	X	AM	AM	?	PO	X	?	?	X	X	X	X
AP 04S	X	X	X	?	AM	X	?	X	AM	AM	?	PO	X	?	?	RO	X	AM	PO
AP 01A	RO	RO	?	X	X	X	X	X	X	AM	AM	X	X	?	?	RO	X	X	X
AP 02A	RO	RO	?	X	X	X	X	X	X	AM	AM	X	X	?	?	RO	X	X	X
AP 03A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	RO	X	X	X
AP 04A	RO	RO	?	X	X	X	AM	AM	X	AM	X	X	X	?	?	X	X	RO	X
AP 05A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
Comm/Nav																			
CN 01S	X	X	X	RO	EVA	X	X	X	X	AM	?	?	X	EVA	RO	AM	X	X	X
CN 02S	X	X	X	RO	RO	X	X	X	X	AM	?	?	X	EVA	RO	X	X	X	X
CN 51A	RMS	RMS	RO	X	X	X	X	AM	X	AM	X	?	X	?	?	X	X	X	X
CN 52A	RMS	RMS	RO	X	X	X	X	X	X	AM	X	?	X	?	?	X	X	X	X
CN 53A	RMS	RMS	RO	X	X	X	X	AM	X	AM	X	?	X	?	?	X	X	X	X

KEY

NA - identified as not applicable
PO - probably required - no method identified
RO - required - no method identified

AM - automated system identified
EVA - EVA identified
RMS - RMS identified

TABLE 3-6, CONTINUED:

Payloads	P/L Deploy	P/L Retrieve	Safeing-Purge	Film Retrieval	Antenna depl/retr.	Telescope depl/ret.	Sunshield depl/ret	Solar Array depl/r	Camera depl/retr.	Retention lock/unl	Cover remove/repl	Door open/close	Fluid Replenish	Module Replace	Mech-Sys-Servic	Boom exect/retr.	Inspection/chec	Subsat-depl/retr.	Expmt Support
CN 54A	RMS	RMS	?	X	X	X	X	AM	X	AM	X	?	X	?	?	X	X	X	X
CN 55A	RMS	RMS	RO	X	X	X	X	AM	X	AM	X	?	X	?	?	X	X	X	X
CN 56A	RMS	RMS	RO	X	X	X	X	AM	X	AM	X	?	X	?	?	X	X	X	X
CN 58A	RMS	RMS	RO	X	X	X	X	AM	X	AM	X	AM	X	?	?	X	X	X	X
LS 02A	RMS	RMS	?	X	X	X	X	X	X	AM	X	AM	X	X	X	AM	X	X	X
EO-04S	X	X	X	PO	X	X	X	X	AM	AM	?	?	X	?	?	X	X	X	X
EO-05S	X	X	X	X	EVA	X	X	X	EVA	AM	?	?	X	?	?	X	X	X	X
EO-06S	X	X	X	X	X	X	X	X	X	AM	?	?	X	EVA	EVA	X	X	X	X
Earth Ocean ph.																			
OP-01S	X	X	X	PO	AM/ EVA	X	X	X	AM	AM	?	?	?	EVA	EVA	X	X	X	X
OP-01A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-02A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-03A	RO	RO	X	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-04A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-05A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-06A	RO	RO	?	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
OP-07A	RO	RO	X	X	X	X	X	X	X	AM	X	X	X	?	?	X	X	X	X
Space Technology																			
ST-01S	X	X	X	PO	AM	AM	X	X	AL/ AM	AM	?	?	PO	PO	PO	AM	PO	X	PO
ST-02S	X	X	X	PO	AM	AM	X	X	AL/ AM	AM	?	?	PO	PO	PO	AM	PO	X	PO
ST-03S	X	X	X	PO	AM	AM	X	X	AL/ AM	AM	?	?	PO	PO	PO	AM	PO	X	PO
ST-04S	X	X	X	PO	AM	AM	X	X	AL/ AM	AM	?	?	PO	PO	PO	AM	PO	X	PO
ST-07S	X	X	X	X	X	X	X	X	AM	AM	?	?	X	?	?	AM	X	X	X
ST-11S	X	X	X	X	AM	X	X	X	X	AM	?	AM	X	?	?	X	X	X	X

KEY

NA - identified as not applicable
PO - probably required - no method identified
RO - required - no method identified
AM - automated system identified
EVA - EVA identified
RMS - RMS identified
AL - Air lock

TABLE 3-6, CONTINUED:

Payloads	P/L Deploy	P/L Retrieve	Safeing-Purge	Film Retrieval	Antenna depl/ret	Telescope depl/r	Sunshield depl/r	Solar Array depl,	Camera depl/retr	Retention lock/u	Cover remove/re	Door open/close	Fluid Repleni	Module Replace	Mech-Sys-Serv.	Boom excet/retr.	Inspection/che	Subsat-depl/ret	Expmt Support
ST 01A	RMS	RMS	X	X	X	X	X	X	X	AM	X	X	X	EVA	EVA	X	X	X	PO
PL 01A	RMS	RMS	X	X	X	X	X	RM	X	AM	X	X	AM	EVA	EVA	X	X	X	X
PL 03A	RMS	X	X	X	X	X	X	X	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 07A	RMS	X	X	X	X	X	X	X	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 11A	RMS	X	X	X	X	X	X	X	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 12A	RMS	X	X	X	X	X	X	AM	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 13A	RMS	X	X	X	X	X	X	X	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 18A	RMS	X	X	X	X	X	X	AM	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 21A	RMS	X	X	X	X	X	X	AM	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
PL 22A	RMS	X	X	X	X	X	X	X	X	AM	X	X	AM	EVA	EVA	AM	X	X	X
LU 01A	RMS	X	X	X	X	X	X	AM	X	AM	X	X	PO	EVA	EVA	AM	X	AM	X
EO 07A	RMS	RMS	AM	X	X	X	X	AM	X	AM	X	X	X	RO	RO	X	X	X	X
EO 08A	RMS	RMS	AM	X	X	X	X	AM	X	AM	X	X	X	RO	RO	X	X	X	X
EO 09A	RMS	RMS	AM	X	X	X	X	AM	X	AM	X	AM	X	RO	RO	X	X	X	X
EO 10A	RMS	X	X	X	X	X	X	AM	X	AM	X	PO	X	PO	PO	X	X	X	X
EO 12A	RMS	RMS	AM	X	X	X	X	AM	X	AM	X	X	X	PO	PO	X	X	X	X
EO 56A	RMS	RMS	AM	X	X	X	X	AM	X	AM	X	X	X	PO	PO	X	X	X	X
EO 57A	RMS	X	X	X	X	X	X	X	X	AM	X	X	X	PO	PO	X	X	X	X
EO 58A	RMS	X	X	X	X	X	X	X	X	AM	X	X	X	PO	PO	X	X	X	X
EO 61A	RMS	X	X	X	X	X	X	AM	X	AM	X	X	X	PO	PO	X	X	X	X

KEY

NA - identified as not applicable
PO - probably required - no method identified
RO - required - no method identified

AM - automated system identified
EVA - EVA identified
RMS - RMS identified

TABLE 3-7.

SELECTION FACTORS FOR TASK SELECTION

1. TASK HAS REQUIREMENTS WHICH ARE SENSITIVE TO EVA/RMS COMPARISON
2. INCLUDE NOMINAL AND CONTINGENCY TASKS.
3. INCLUDE TASKS IN BAY AND OUT.
4. EACH TASK HAS UNIQUE REQUIREMENTS ASSOCIATED WITH IT.
5. SET OF TASKS HAVE REQUIREMENTS REPRESENTATIVE OF THE RANGE OF TASK REQUIREMENTS.
6. TASK SELECTION BASED ON AVAILABILITY OF DATA.
7. USE OF RMS OR EVA IS FEASIBLE FOR EACH TASK

8. TASK SELECTED WHERE USE OF RMS OR EVA IS A POTENTIAL APPROACH FOR SINGLE POINT FAILURE SITUATIONS.
9. TASK SELECTED WHERE REPLACEMENT OR REPAIR BY RMS OR EVA IS IMPORTANT FOR DATA RETURN OR FOR SYSTEM RETURN.

TABLE 3.8. SELECTED TASKS/CONDITIONS

PAYLOAD SUPPORT TASKS/CONDITIONS	TYPE*	LOCATION	PAYLOAD**	APPLICABLE P/L'S
P-1 PAYLOAD DEPLOY/RETRIEVAL				
CONDITION 1 - LST RETRIEVAL	N	OUT-IN	LST	38
CONDITION 2 - TUG RETRACTION	C	IN	TUG	19
P-2 PALLET APPARATUS DEPLOY				
CONDITION 1 - ANTENNA DEPLOY	N	IN	ATL	30
CONDITION 2 - ANTENNA DEPLOY & FILM LOAD	N	IN	ATL	30
CONDITION 3 - FULL PALLET DEPLOY	N	IN	ATL	30
P-3 PAYLOAD DOOR OPEN				
CONDITION 1 - IN BAY	C	IN	SIRTF	19
CONDITION 2 - OUT-END OF TELESCOPE	C	OUT	SIRTF	19
P-4 SHROUD DEPLOY				
CONDITION 1 - IN BAY	N	IN	LST	14
CONDITION 2 - OUT	N	OUT	LST	14

* N = NOMINAL, C = CONTINGENCY

** ATL - Advanced Technology Laboratory (Langley Research Center)
SIRTF - Shuttle IR Telescope Facility (Ames Research Center)
LST - Large Space Telescope (Marshall Space Flight Center)

TABLE 3-8, CONTINUED:

PAYLOAD SUPPORT TASKS/CONDITIONS	TYPE*	LOCATION	PAYLOAD**	APPLICABLE P/L'S
P-5 SUNSHADE RETRACTION				
CONDITION 1 - P/L ERECT IN BAY	C	OUT	LST	9
CONDITION 2 - P/L 45° IN BAY	C	OUT	SIRTF	9
P-6 SOLAR PANEL RETRACTION	C	IN	LST	24
P-7 FILM RETRIEVAL				
CONDITION 1 - ONE CAMERA	N	IN	ASL	13
CONDITION 2 - FIVE CAMERAS	N	IN	ASL	13
P-8 ANTENNA RETRACT - FEED CHANGE				
CONDITION 1 - ANTENNA RETRACT	N	IN-OUT	C/N SPACELAB	11
CONDITION 2 - FEED CHANGE	N	IN-OUT	C/N SPACELAB	11
P-9 CONTAMINATION MONITORING	N	IN-OUT	ATL	ALL
P-10 UMBILICAL CONNECT/DISCONNECT				
CONDITION 1 - P/L IN BAY	N	IN	TUG	3
CONDITION 2 - P/L ERECT IN BAY	N	IN	LST	3
P-11 MODULE REPLACEMENT				
CONDITION 1 - P/L FORWARD, CMG IN, SPARES-ORBITER	N	IN	LST	31
CONDITION 2 - P/L FORWARD, CMG IN, SPARES-BAY	N	IN	↓	↓
CONDITION 3 - P/L FORWARD, CMG OUT, SPARES-BAY	N	OUT	↓	↓
CONDITION 4 - P/L AFT, CMG IN	N	IN	↓	↓
CONDITION 5 - P/L AFT, CMG OUT	N	OUT	↓	↓
CONDITION 6 - 5 MODULES OUT	N	OUT	↓	↓
CONDITION 7 - 5 MODULES IN	N	IN		

TABLE 3-8, CONTINUED:

SHUTTLE SUPPORT TASK/CONDITION	TYPE*	ION**
S-12 TPS INSPECT - REPAIR		
CONDITION 1 - INSPECT	N	
CONDITION 2 - REPAIR	C	
S-13 RENDEZVOUS SENSOR DEPLOY	C	
S-14 PAYLOAD RETENTION LOCK ACTIVATION		
CONDITION 1 - LOCK REPAIR	C	
CONDITION 2 - MANUAL LOCK ACTIVATION - 1 LOCK	C	
CONDITION 3 - MANUAL LOCK ACTIVATION - 22 LOCKS	C	
S-15 CARGO BAY DOOR CLOSE	C	
S-16 STAR TRACKER DOOR REPAIR	C	[illegible]
S-17 RESCUE MISSION SUPPORT	C	[illegible]

TABLE 3-9.
LST CMG REMOVAL REQUIREMENTS

Subtask	Information Rqmts	Performance Reqmts	Interface Reqmts
Decision to replace CMG	Criteria	Evaluate options	Flight plan
Prepare EV systems	Configuration reqmts Verification feedback systems status	Configure EV systems for CMG replacement	Shuttle - EV sys. interfaces - personnel - equipment - data - procedures
Prepare P/L systems	Configuration reqmts feedback - CMG run down systems status	Deactivate CMG monitor run down (≈4 hours)	Power
Prepare Shuttle systems	Configuration reqmts systems status	Configure Life Support Configure power Configure structures	Shuttle systems
Plan CMG replacement	Time constraints associated EV tasks Translation route constraints	Schedule CMG replacement Assign responsibilities Select procedures Identify equipment	Flight Plan
Identify location of Spare Module	Module location	Consult spares locations documentation	Spares Provisions

TABLE 3-9, CONTINUED:

Subtask	Information Reqmts	Performance Reqmts	Interface Reqmts
Translate to CMG replace site	Site location Translation route Obstacles enroute View of surroundings enroute	LST located at aft bay erected on swing table Translation distance to top of SSM (16 ft from LST end) from: - EVA hatch = 76 - RMS tip stow = 16 Translation - loaded with tools and test equip. Translation FOV 45° Time to perform - TBD	Lighting of route Reflectivity of - reflectors - bay liner - LST skin - Shuttle skin
Configure EV system at worksite	Configuration reqmts. feedback	Access worksite Position EV system at site Orient EV system at site Visual for 45° Configure - stow tools Configure - stow test equip.	
Configure worksite	Configuration reqmts feedback	Remove obstructions Configure for thermal control Configure for contam. control Configure LST mech. systems	LST thermal system LST contam. control sys LST mech. systems LST structures
Configure support systems	Configuration reqmts feedback	Emplace - configure lighting Configure stabilization aids Min. of 2 lights - 45° apart Light field - 45° Install camera - if req'd. Configure cargo transfer systems	LST structures

TABLE 3-9, CONTINUED:

Subtask	Information Rqmts	Performance Rqmts	Interface Rqmts
Identify/locate CMG module	Indication of failed CMG	Inspect CMG's (4) Identify failed CMG Inspect removal clearance	LST CMG coding LST CMG location
Remove CMG	Procedures Visual feedback Force feedback	• unplug 4 elec. connectors on gimbal control electronics	
		Acuity - See .5 in. lead at 60 in. max. viewing distance = 27 arc. min.	Connector location, clearance, orientation WRT EV system
		Depth - Detect .25 in. offset at 60 in. = .5 arc min. stereo acuity	
		• stow connector leads	
		• unstow wrench/tool	
		• remove constraint bolts (1in.) mounting brackets - and stow alignment (visual) = .1 in. at 60 in. = 5 arc min. alignment (motor) = ± .1 in. stability (4 sec. bolt removal) = ± .025 in/sec. torque = 100-200 in. lbs	Bolt orientation WRT EV system
		• remove and stow mount bracket	
		• remove CMG - up or out ± 3 inch clearance CMG mass 178 lbs CMG size 40 x 30.5 x 23 inch	CMG handle

TABLE 3-9, CONTINUED:

Subtask	Information Reqmts	Performance Rqmts	Interface Rqmts
Transfer used CMG to storage	Storage location Transfer route Obstacles en route Visual feedback	Load and secure CMG on EV system or cargo transfer aid Transfer CMG to spare location (assume location) at midpoint of bay - max distance 16+30 = 46 ft) Field of view during transfer = 45° View of CMG and route	Storage location
Prepare stow worksite	Configuration Requirements	Stabilize at worksite Configure EV system Configure lighting Configure structures/ thermal system	Shuttle structures thermal system
Temporarily stow used CMG	Stow location Visual feedback	Emplace used CMG in temp. stow location Tie down used CMG	Tie down at stowage location
Access and free new CMG	Procedures Visual feedback	Identify new CMG Release launch restraints Free new CMG	
Temporarily stow new CMG	Procedures Location Visual feedback	Move new CMG to stowage Tie down new CMG	
Permanently stow used CMG	Procedures Visual feedback	Free used CMG Move to stowage location Stow used CMG	Stowage tie downs

TABLE 3-9, CONTINUED:

Subtask	Information Rqmts	Performance Rqmts	Interface Rqmts
Unstow new CMG	Procedures	Release tie down	Tie down
Transfer new CMG to Replacement site	Visual feedback Obstacles enroute	Load and secure CMG on EV or cargo transfer system Transfer CMG to replacement site Max distance = 46 ft. fov = 45°	Shuttle equipment enroute
Access worksite with new CMG	Access location	Enter worksite Orient CMG for replace. Stabalize at worksite	LST structure
Install new CMG	Install procedures Visual feedback Force feedback	Reach envelope at worksite 6 feet Visual field of view 45° Reverse steps of removal	
Perform static checks	Visual feedback	Check connectors Check bolts Check CMG orientation	

TABLE 3-10. MODE COMPARISON CRITERIA

CAPABILITY TO COMPLETE

TIME TO PERFORM

- TOTAL
- TASK

PERFORMANCE CRITERIA

MANIPULATIVE:

- FORCE APPLICATION
- ALIGNMENT
- DEXTERITY
- MASS HANDLING
- TOOL ORIENTATION
- REACH
- CONFINED OPERATION
- STABILITY

SENSORY:

- ACUITY
- DEPTH
- FIELD OF VIEW
- ALIGNMENT
- FORCE FEEDBACK

MOBILITY:

- TRANSLATION
- CARGO TRANSFER

OPERATIONAL CRITERIA

- NUMBER OF OPERATIONS
- NUMBER OF CREWMEN
- NUMBER OF WORKSITES
- DEGREE OF P/L PREPARATION
- CREW WORKLOAD
- CREW SKILLS
- DAMAGE POTENTIAL
- INTEGRATION WITH OTHER OPS.

FLEXIBILITY - EFFECT OF:

- P/L LOCATION
- MODULE LOCATION
- MODULE SIZE
- FORCE/TORQUE RANGE
- CONNECTOR DESIGN
- OPERATIONAL TECHNIQUE
- DEGRADED TRANSLATION
- STOWAGE LOCATION

SAFETY CRITERIA

EFFECT OF SYSTEM FAILURE:

- ON OPERATOR
- ON ORBITER

REQUIREMENTS FOR MAN-RATING

HAZARD POTENTIAL:

- TRANSLATING
- WORKSITE

SUPPORT CRITERIA

- CARGO TRANSFER
- LIGHTING
- WORKSITE AIDS
- LIFE SUPPORT
- ADDITIONAL EXPENDABLES
- CONTAMINATION
- P/L DESIGN INTERFACE
- SHUTTLE DESIGN INTERFACE
- SPECIAL TOOLS
- P/L HANDLING

CONFIGURATION CRITERIA

- SYSTEM WEIGHT
- SYSTEM VOLUME
- EFFECT ON P/L CONFIGURATION
- DEVELOPED TECHNOLOGY

4.0 RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

4.1 RESULTS

The results of this investigation include a selection of an EVA or RMS mode for each task, guidelines for deciding on the use of specific modes for specific tasks and identified problems with the modes.

4.1.1 Mode Comparison Results

In the comparison of modes, three decisions were involved:

- the applicability of each mode for the task
- the feasibility of each mode for the task
- the selection of a mode for the task

In the decision of mode applicability for each task, a mode was judged not applicable if it clearly does not possess the requisit capabilities to perform a task, or if it is not inherently different than other modes for the specific task. The decision of mode feasibility for a task is based on the results of the mode comparisons over the criteria. A mode which was selected for a task was automatically classified as feasible for the task. A mode which was not selected, but which scored close enough to the selected mode (generally a difference of 5 or less in total ranking) was also classified as feasible. The decision of mode selection was based solely on the sum of the rankings of the modes across all criteria.

Table 4-1 presents, for each task and task condition, the selected modes, other feasible modes, and other applicable but not feasible modes. Table 4-2 presents the summary data of mode applicability, feasibility, and selection, over all tasks. As indicated in the latter table, the unaided EVA mode was selected as the best mode on 15 or 43% of the tasks. The order of the other modes (and percentage of tasks) is: EVA/MMU - 10 tasks (29%); RMS - 9 tasks (26%); EVA/RMS - 7 tasks (20%); and Cherry Picker - 2 tasks (6%).

Table 4-2 also indicates that while unaided EVA is most applicable and feasible for payload support tasks, the RMS mode is most applicable and feasible for shuttle support tasks. However, the EVA/RMS mode was selected most for shuttle tasks, while unaided EVA was the selected mode by a 2 to 1 majority over any other mode for payload support tasks.

A comparison of EVA and RMS modes was conducted where the number of tasks selected for at least one RMS mode (RMS, EVA/RMS, and Cherry Picker). The results of this analysis indicated that for 89% of all tasks (31 of 35) at least one EVA mode was the selected mode. For the RMS modes the figure was 49% (17 of 35 tasks). Comparing EVA only modes (unaided EVA and EVA/MMU) with the three modes which incorporate the RMS (two of which also incorporate EVA), it was found that either of the two EVA modes were selected for 71% of the tasks (25 tasks) against the 49% for RMS modes. From these data it can be concluded that EVA in some form is the most effective technique for completing the greater majority (89%) of support tasks.

In terms of the feasibility of modes for the tasks (cases where a mode is either the selected mode for a task or where the overall rating of a mode on a task is close enough to that of the selected mode) the following results were obtained:

- Both unaided EVA and RMS were feasible for 43% of tasks (15)
- Both unaided EVA and EVA/MMU were feasible for 26% (9 tasks)
- Both EVA/MMU and RMS were feasible for 26% (9 tasks)

These data indicate that if either unaided EVA or RMS are not available for a specific flight, that almost half of the support tasks could still be performed effectively by the other mode. It is also interesting to note that there is a good deal more commonality of effectiveness between unaided EVA and RMS than for EVA/MMU paired with either unaided EVA or RMS. This would lead to the conclusion that the EVA/MMU mode is more effective for specific types

C.2

of tasks and for specific task requirements while unaided EVA and RMS have more general effectiveness across a wider array of tasks.

While the EVA/MMU mode has capability for specific task requirements, the EVA/RMS mode is even more task specific. The EVA/RMS mode and the unaided EVA mode are both feasible for 20% of the tasks (7 tasks), and the EVA/RMS and RMS modes are feasible for only 14% (5 tasks).

The Cherry Picker, while being applicable to a little more than half of the tasks (54%), was judged feasible for only 4 tasks, and was selected for only 2 tasks.

TABLE 4-1. SUMMARY OF MODE COMPARISONS

Task/Condition	Selected Mode	Other Feasible Modes	Other Applicable Modes
P-1 Payload Deploy/Retrieve			
1. Payload retrieval	RMS	None	None
2. Payload retraction	RMS Unaided EVA	None	EVA/RMS
P-2 Pallet Apparatus Deploy			
1. Antenna deploy	Unaided EVA	EVA/MMU RMS	EVA/RMS Cherry Picker
2. Antenna and film	Unaided EVA	RMS	EVA/RMS EVA/MMU Cherry Picker
3. Entire pallet	Unaided EVA	RMS	EVA/RMS EVA/MMU Cherry Picker
P-3 Payload Door Open			
1. In bay	Unaided EVA	RMS	EVA/MMU Cherry Picker
2. Out of bay	RMS	EVA/MMU Cherry Picker	Unaided EVA
P-4 Contamination Shroud Deploy			
1. In bay	RMS	EVA/MMU Unaided EVA	EVA/RMS Cherry Picker
2. Out of bay	EVA/MMU RMS	None	Unaided EVA EVA/MMU EVA/RMS
P-5 Sunshade Retraction			
1. P/L 90° in bay	EVA/MMU	None	None
2. P/L 45° in bay	EVA/MMU	Cherry Picker	None

TABLE 4-1. SUMMARY OF MODE COMPARISONS, Continued:

Task/Condition	Selected Mode	Other Feasible Modes	Other Applicable Modes
P-6 Solar Panel Retract	Unaided EVA Cherry Picker	EVA/MMU RMS	None
P-7 Film Replacement			
1. One camera	Unaided EVA RMS	None	EVA/RMS
2. Five cameras	EVA/RMS	Unaided EVA RMS	None
P-8 Antenna Retract - Feed Change			
1. Antenna retract	Unaided EVA	EVA/MMU	RMS Cherry Picker
2. Feed change	EVA/MMU	RMS	Unaided EVA Cherry Picker
P-9 Contamination Monitoring	EVA/MMU	RMS Unaided EVA	EVA/RMS Cherry Picker
P-10 Payload Umbilical			
1. Connect	Unaided EVA	None	EVA/MMU
2. Disconnect	Unaided EVA RMS	None	None
P-11 Module Removal/Replacement			
1. Module in - forward	Unaided EVA	None	None
2. Module in - forward	Unaided EVA	None	None
3. Module out - forward	EVA/MMU	EVA/RMS Unaided EVA	None
4. Module in - aft	Unaided EVA	None	None
5. Module out - aft	EVA/RMS EVA/MMU		Unaided EVA RMS Cherry Picker

TABLE 4-1. SUMMARY OF MODE COMPARISONS

Continued:

Task/Condition	Selected Mode	Other Feasible Modes	Other Applicable Modes
6. 5 modules out - aft	EVA/RMS	EVA/MMU Unaided EVA	RMS Cherry Picker
7. 5 modules in - aft	Unaided EVA	None	None
S-12 TPS Inspect/Repair			
1. TPS inspect	EVA/MMU	None	None
2. TPS repair	EVA/MMU	None	None
S-13 Rendezvous Sensor Display	RMS	Unaided EVA	None
S-14 Payload Retention Lock Repair			
1. Lock repair	EVA/RMS	RMS Unaided EVA	Cherry Picker RMS
2. Lock activation	EVA/RMS	RMS Unaided EVA	Cherry Picker RMS
3. Activation of 22 locks	EVA/RMS EVA/MMU	Unaided EVA	RMS Cherry Picker
S-15 Cargo Bay Door Repair	Unaided EVA	RMS EVA/RMS EVA/MMU	Cherry Picker
S-16 Star Tracker Door Activation	Cherry Picker	EVA/MMU RMS	EVA/RMS
S-17 Rescue Mission Support	EVA/RMS	None	None

TABLE 4-2

TASKS FOR WHICH EACH MODE IS APPLICABLE, FEASIBLE, AND SELECTED

	MODES				
	Unaided EVA	EVA/MMU	EVA/RMS	Cherry Picker	RMS
TASKS Where Mode is Applicable:					
Payload Support	23	17	11	14	18
Shuttle Support	5	5	6	5	7
Total	28	22	17	19	25
% of all Tasks	80%	63%	49%	54%	71%
TASKS Where Mode is Feasible:					
Payload Support	19	12	4	3	14
Shuttle Support	5	5	5	1	6
Total	24	17	9	4	20
% of all Tasks	69%	49%	26%	11%	57%
% of Applicable Modes	86%	77%	53%	21%	80%
TASKS Where Mode is Selected:					
Payload Support	14	7	3	1	7
Shuttle Support	1	3	4	1	2
Total	15	10	7	2	9
% of All Tasks	43%	29%	20%	6%	26%
% of Applicable Tasks	54%	46%	41%	11%	36%
% of Feasible Tasks	62%	59%	77%	50%	45%

4.1.2 Implications of Results for Mode Selection Guidelines

In order to enable the selection of an EVA or RMS mode for any shuttle or payload support task, the distinguishing characteristics of the study tasks were identified and correlated with selected modes for the tasks. The characteristics of interest included:

- Type of task - nominal or contingency
- Module handling
  - number of modules - one or multiple
  - module mass - small (< 100 lbs.), moderate (100-300 lbs.), large (300+ lbs.)
- Activation force requirements - small (< 25 lbs.) or large
- Precision or dexterity-alignment requirements - low or high
- Degree of worksite or route confinement - low or high
- Worksite location - in bay, out, or in and out
- Time constraints - none or tight
- Flexibility requirements or degree of versatility required - low or high

The number of tasks at each level of each characteristic, and the percentages of tasks for which each mode was selected, are presented in Table 4-3. This table indicates that of the 25 tasks requiring module handling, unaided EVA was the selected mode for 32%, EVA/MMU for 28%, etc. The percentages are greater than 100% since for 8 of the 35 tasks two modes were selected.

Based on the data in Table 4-3, a set of mode selection guidelines were developed which are presented in Table 4-4. In choosing a mode for a specific shuttle or payload support activity, a series of questions can be answered based on the task characteristics in Table 4-4. The initial question is, where is the worksite? Subsequent questions include: what are masses to be handled, and how many? What are force application requirements? What are worksite confinement, precision, and flexibility levels required to perform the task? A list of answer requirements would follow the form of:

- Worksite location
  - in bay only - choose unaided EVA, EVA/RMS, Cherry Picker
  - out of bay only - choose EVA/MMU, EVA/RMS, Cherry Picker, and RMS
  - in bay <u>and</u> out - choose EVA/MMU and RMS
- Mass handling
  - small to moderate (up to 300 lbs.) - unaided EVA, EVA/MMU
  - large (over 300 lbs.) - EVA/RMS, RMS
- Number of modules
  - one - unaided EVA, EVA/MMU, EVA/RMS
  - several - unaided EVA, EVA/RMS
- Force/torque Applications Required
  - small (less than 25 lbs., 25 ft.-lbs.) - unaided EVA, EVA/MMU, EVA/RMS, RMS
  - large - EVA/RMS, RMS
- Manual Activation Required - Unaided EVA, EVA/MMU, RMS
- Precision (dexterity + alignment) or flexibility
  - low level - any mode
  - high - any mode involving EVA
- Level of Confinement
  - low - any mode
  - high - unaided EVA

TABLE 4-3. PERCENTAGE OF TASK REQUIREMENTS ASSOCIATED WITH TASKS ASSIGNED TO MODES

	No. of Tasks	Unaided EVA	EVA/MMU	EVA/RMS	Cherry Picker	RMS
Module handling:	25	32%	28%	28%	0%	28%
single module	22	31%	31%	23%	0%	31%
multiple modules	3	33%	0%	67%	0%	0%
mass < 100 lbs.	15	26%	26%	26%	0%	33%
mass 100-300 lbs.	9	44%	33%	33%	0%	11%
mass > 300 lbs.	1	0%	0%	0%	0%	100%
Activation:	33	42%	28%	21%	6%	24%
low force (< 25 lbs.)	31	45%	30%	22%	6%	20%
high force (25 lbs. +)	2	0%	0%	0%	0%	100%
Dexterity-Alignment:	35					
low level	19	42%	26%	10%	0%	47%
high level	16	44%	31%	31%	13%	0%
Confined Workspace:						
not confined	20	10%	45%	35%	5%	35%
confined	15	86%	6%	0%	6%	12%
Worksite Location:						
in bay	20	75%	0%	20%	0%	20%
out of bay	13	0%	70%	23%	15%	30%
in and out	2	0%	50%	0%	0%	50%
Time Constraints:						
none	33	45%	30%	30%	7%	21%
tight	2	0%	0%	0%	0%	100%
Flexibility Requirements:						
low level	8	12%	12%	12%	0%	87%
high level	25	56%	32%	24%	8%	8%
Type of Task:						
nominal	21	53%	30%	14%	0%	24%
contingency	14	29%	29%	29%	14%	29%

TABLE 4-4. TASK CHARACTERISTICS BY EVA AND RMS MODES

Modes	Worksite Location	Module Handling	No. of Modules	Module Mass	Manual Activ.	Force Level	Degree Dexterity	Degree Confine.	Degree Flex. Required	Type of Task
UNAIDED EVA	In bay	Yes	Any	Small to moderate	Yes	Low	High	High	High	Nominal
EVA/MMU	Out and in and out	Yes	One	Small to moderate	Yes	Low	High	Low	High	Nominal or Contingency
EVA/RMS	In bay or out	Yes	Any	Small to large	No	Low or high	High	Low	High	Conting. or Nom.
CHERRY PICKER	Out of bay, in bay, or out	Yes	N/A	Probably small only	No	N/A	High	Low	High	Conting.
RMS	In, out, in and out	Yes	One	Small to large	Yes	High	Low	Low	Low	Nominal or Contingency

4.1.3 Problems Identified for EVA and RMS Modes

In the analysis of specific tasks to this report, problems were identified for all modes applicable for each task. A summary of the problems, and the proportion of tasks which exhibited the problems, is presented in Table 4-5. As indicated in this table, the proportion of tasks for which time was a problem for unaided EVA was 25% of the tasks for which unaided EVA was applicable, 41% for EVA/MMU, 24% for EVA/RMS, etc.

Problems identified for 10% or more tasks for each mode were arbitrarily judged to be serious problems for that mode. For each mode the serious problems, in descending order of magnitude, are as follows:

Unaided EVA

- mass handling/transfer (61% of unaided EVA applicable tasks)
- crew workload (50%)
- impact of EVA on shuttle or payload design (39%)
- time (25%)
- force/torque applications (25%)
- workstation location - orientation (25%)
- crewman safety - translation and at the worksite (21%)
- degree of worksite confinement (21%)
- contamination potential (14%)
- translation around obstacles (11%)

EVA/MMU

- crewman safety - translating or at the worksite (64%)
- force/torque application capability - unrestrained (50%)
- time (41%)

TABLE 4-5

PROPORTION OF TASKS FOR WHICH MODES ARE APPLICABLE WHICH HAVE SPECIFIC PROBLEMS IDENTIFIED WITH EACH MODE

Problems	Unaided EVA (28)	EVA/MMU (22)	EVA/RMS (17)	Cherry Picker (19)	RMS (25)
Time	25%	41%	24%	11%	4%
Force/Torque Application	25%	50%	0%	5%	8%
Workload	50%	5%	12%	5%	0%
Station Location/Orientation	25%	0%	0%	0%	0%
Translation	11%	0%	0%	0%	0%
Mass Handling/Transfer	61%	41%	12%	0%	25%
Confined Operations	21%	32%	0%	11%	4%
Tether Management	4%	41%	0%	0%	0%
Safety	21%	64%	83%	26%	0%
Design Impact	39%	0%	24%	5%	8%
Contamination	14%	27%	12%	5%	0%
Damage Potential	7%	5%	35%	11%	28%
Reach Limitations	7%	5%	47%	53%	50%
Mobility Limitations	7%	0%	0%	0%	0%
Backup Requirements	0%	14%	0%	0%	0%
Stability	0%	32%	12%	16%	40%
Visual Capabilities	0%	0%	0%	11%	60%
Dexterity/Alignment	0%	0%	0%	0%	28%
Communications	0%	9%	0%	0%	4%
Control Problems	0%	0%	0%	32%	
Flexibility/Versatility	0%	0%	6%	11%	4%
No Advantage of Mode	0%	14%	6%	16%	0%

- mass handling/transfer (41%)
- tether management/dynamics (41%)
- stability at the worksite (32%)
- operations in confined worksites (32%)
- contamination potential (27%)
- requirements for back-up systems in the event of MMU failure (14%)
- no advantages of EVA/MMU over other modes (14%)

<u>EVA/RMS</u>

- crewman safety in proximity to the RMS (82%)
- reach limitations of the RMS (47%)
- damage potential (35%)
- impact on shuttle or payload design (24%)
- time (24%)
- crew workload (12%)
- mass handling/transfer - hand-off between EVA and RMS (12%)
- contamination potential (12%)
- RMS stability at the worksite (12%)

<u>Cherry Picker</u>

- reach limitations of the RMS (53%)
- Cherry Picker end effector positional control (32%)
- crewman safety in proximity to structures (26%)
- RMS stability with the crewman in the station (16%)
- no advantages of the mode over other modes (16%)
- limited flexibility-versatility (11%)
- visual capabilities from the end effector station (11%)
- damage potential (11%)

- operations in confined workspace (11%)
- time (11%)

RMS

- reach limitations of the manipulator (60%)
- visual capabilities of the RMS operator (60%)
- RMS tip stability at the worksite (40%)
- RMS dexterity - alignment capabilities
- damage potential (28%)
- mass handling /transfer (25%)

A second method used to identify problems and problem magnitude for the EVA and RMS modes consisted of analyzing mode performance against each of the mode comparison criteria (Table 3-10). As indicated in the discussion of mode comparisons in Section 3.0, the modes were ranked for each criterion for each task in terms of the magnitude of problems identified for the mode for the criterion. The mean ranking of each mode on each criterion, over all tasks, is a measure of the relative effectiveness of the mode for the factors associated with the criterion. The results of the analyses over all criteria are presented below:

Criterion of Basic Capability

Table 4-6 presents the mean rating of each mode on the capability criterion, across all tasks. As indicated in this table the unaided EVA, EVA/MMU, and RMS modes were most effective (i.e., had fewest problems) in terms of having full capability to perform all aspects of each task. The table also indicates times that a mode was applicable to a task the proportion where it was judged most effective in terms of basic capability. In this respect the EVA/MMU mode was most effective, having been judged fully capable of 87% of the tasks for which it was applicable. Finally, Table 4-6 indicates the significant problem areas for each mode for the basic capability criterion.

Criterion of Time to Complete

The estimated times to complete all tasks for each mode are presented in Table 4-7. The times are expressed in terms of total time, and in terms of task time which is total time less preparation and closeout times.

The mean total times for each mode and the range of times (minimum-maximum) are presented in Table 4-8. In this table it is seen that the mean time for the RMS is almost half of the total times for the EVA modes.

The mean task times are presented in Table 4-9. Again the RMS mode had the smallest time but the differences between RMS task time and task times for EVA modes are much closer than was true of total time (Table 4-8).

Table 4-10 presents the mean ratings of modes for the performance criterion. The most effective mode was EVA/MMU. The mode having greatest degree of performance problems was RMS.

The operations criterion mean ratings are listed in Table 4-11. The most effective modes were EVA/MMU and RMS. The most effective mode in terms of proportion of time being rated best was RMS.

Flexibility mean ratings are contained in Table 4-12. The most effective modes were EVA/MMU, EVA/RMS, and Unaided EVA. The mode rated best most often on this criterion was Unaided EVA.

The mean safety ratings are presented in Table 4-13. The RMS was the most effective mode in terms of safety, and was rated best on every task for which it was applicable.

Support criteria mean ratings are contained in Table 4-14. The most effective modes were unaided EVA, RMS, and EVA/RMS. The spread of mean ratings on this criterion is much closer than for other criteria, indicating that modes

TABLE 4-6

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - BASIC CAPABILITY

CRITERION DEFINITION - CAPABILITY OF PERFORMING ALL ASPECTS OF THE TASKS UNDER ALL FEASIBLE VARIATIONS

	MODES	MEAN CAPABILITY RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RATED FULL CAPABILITY	% OF APPLICANTS	SIGNIFICANT PROBLEMS
I.	UNAIDED EVA	1.8	27	21	78%	limited to in-bay
II.	EVA WITH MMU	1.8	22	19	87%	limited in bay
V.	RMS	2.0	24	7	29%	limited reach-access
III.	EVA AND RMS	2.7	16	11	70%	limited to cargo transfer tasks
IV.	CHERRY PICKER	3.7	19	5	26%	limited reach-access

do not differ as widely on the support factors as they do for other criteria.

The configuration criteria mean ratings are listed in Table 4-15. The most effective mode is unaided EVA. The mode with greatest problems is the Cherry Picker.

In order to provide an overview of model effectivness, in terms of degree of problems associated with each, a scale of problem magnitude was established. If a mode had a mean rating of 1.0 to 1.9 on a given criterion, it was judged to have only minor problems for that criterion. If the mean rating was 2.0 to 2.9 the mode was judged to have moderate problems on the criterion. Finally, if the mean rating was 3.0 to 5.0, the mode was judged to have serious problems on the criterion factors. Table 4-16 presents the results of the scaling of problems for the modes. Based on the numbers of criteria in each problem category for each mode, an order of mode effectiveness can be structured as follows:

1) (most effective mode in terms of problems) EVA/MMU
2) Unaided EVA
3) RMS
4) EVA/RMS
5) Cherry Picker

TABLE 4-7. TIME (IN MINUTES) TO COMPLETE EACH TASK

TASK/CONDITION		MODES I Unaid. EVA	II MMU	III EVA/ RMS	IV Cherry Picker	V RMS
P-1 P/L DEPLOY/RETRIEVAL						
1. LST DEPLOY	TOTAL TIME					78.5
	TASK TIME					11
2. TUG RETRACT	TOTAL TIME	229		226		85
	TASK TIME	49		46		17
P-2 PALLET APPARATUS DEPLOY						
1. ANTENNA DEPLOY	TOTAL TIME	228	257	236	237	83.5
	TASK TIME	41	50	43	44	16
2. ANTENNA DEPLOY-FILM LOAD	TOTAL TIME	240	270	248	248	112
	TASK TIME	52	63	55	55	45
3. PALLET DEPLOY	TOTAL TIME	259	292	264	262	128
	TASK TIME	71	84	71	71	61
P-3 PAYLOAD DOOR OPEN						
1. COVER REMOVAL-IN BAY	TOTAL TIME	223	222		222	75
	TASK TIME	37	37		36	8
2. WINDOW REMOVAL - OUT OF BAY	TOTAL TIME	231	235		225	85
	TASK TIME	45	40		40	18
P-4 CONTAMINATION CONTROL SHROUD DEPLOY						
1. IN BAY	TOTAL TIME	226	239	218	228	87
	TASK TIME	30	24	38	47	20
2. OUT OF BAY	TOTAL TIME	243	239	218	228	87
	TASK TIME	48	24	38	47	20

TABLE 4-7, CONTINUED:

		MODES				
		I Unaided EVA	II MMU	III EVA/ RMS	IV Cherry Picker	V RMS
P-5 SUNSHADE RETRACTION						
1. LST ERECT (90°)	TOTAL TIME		257			
	TASK TIME		38			
2. SIRTF 45°	TOTAL TIME		257		219	
	TASK TIME		38		35	
P-6 SOLAR PANEL RETRACTION	TOTAL TIME	229	267		227	93
	TASK TIME	49	48		46	25
P-7 FILM REPLACEMENT						
1. One Camera	TOTAL TIME	213				85
	TASK TIME	32				17
2. Five Cameras	TOTAL TIME	230		227		104
	TASK TIME	48		44		36
P-8 ANTENNA RETRACT AND FEED CHARGE						
1. ANTENNA RETRACT	TOTAL TIME	231	264		234	83
	TASK TIME	49	55		53	16
2. FEED CHANGE	TOTAL TIME	252	257		226	90
	TASK TIME	1	38		35	23
P-9 CONTAMINATION MONITORING	TASK TIME	75	52	69	61	74
P-10 UMBILICAL CONNECT						
1. TUG IN BAY	TOTAL TIME	225	280			
	TASK TIME	45	80			
2. LST 60° ERECT	TASK TIME	5.5				6.8

TABLE 4-7, CONTINUED:

		I Unaided EVA	II MMU	III EVA/RMS	IV Cherry Picker	V RMS
P-11 MODULE REPLACEMENT						
1. LST FORWARD, CMG IN, SPARES-ORBITER	TOTAL TIME	232				
	TASK TIME	59				
2. LST FORWARD, CMB IN, SPARES BAY	TOTAL TIME	236				
	TASK TIME	62				
3. LST FORWARD, CMG OUT	TOTAL TIME	240	295	259		
	TASK TIME	67	76	77		
4. LST AFT, CMG IN	TOTAL TIME	239				
	TASK TIME	65				
5. LST AFT, CMG OUT	TOTAL TIME	240	298	259	260	219
	TASK TIME	67	79	79	80	151
6. LST AFT, 5 MODULES OUT	TOTAL TIME	364	499	427	399	560
	TASK TIME	190	279	247	219	492
7. LST AFT, 5 MODULES IN	TOTAL TIME	360				
	TASK TIME	186				
S-12 TPS INSPECT-REPAIR						
1. INSPECT ONLY	TOTAL TIME		257			
	TASK TIME		38			
2. INSPECT AND 1 REPAIR	TOTAL TIME		268			
	TASK TIME		49			

TABLE 4-7, CONTINUED:

TIME (IN MINUTES)		I Unaided EVA	II MMU	III EVA/ RMS	IV Cherry Picker	V RM
S-13 RENDEZVOUS SENSOR DEPLOY	TOTAL TIME	210				87
	TASK TIME	29				20
S-14 PAYLOAD RETENTION LOCK FAILURE						
1. LOCK REPAIR - NO P/L IN BAY	TOTAL TIME	230		225	220	95
	TASK TIME	50		45	40	27
2. MANUAL LATCHING - 1 LOCK	TOTAL TIME	221		215	219	80
	TASK TIME	41		35	39	12
3. MANUAL LATCHING - 22 LOCKS	TOTAL TIME	308	312	284	303	332
	TASK TIME	128	122	104	123	264
S-15 REPAIR FAILED OPEN CARGO BAY DOOR	TOTAL TIME	237	267	233	224	98
	TASK TIME	57	57	53	55	30
S-16 STAR TRACKER DOOR LINKAGE REPAIR	TOTAL TIME		263	228	226	89
	TASK TIME		83	48	46	21
S-17 RESCUE MISSION SUPPORT	TOTAL TIME			208		79
	TASK TIME			28		11

TABLE 4-8

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - TOTAL TIME

CRITERION DEFINITION - TOTAL TIME TO COMPLETE THE TASK, INCLUDING PREPARATION, SETUP, CONDUCT, AND TERMINATION

MODES	MEAN TOTAL TIME (MINUTES)	RANGE - MINIMUM/ MAXIMUM (MINUTES)	SIGNIFICANT PROBLEMS
V. RMS	128	75-560	Time to perform high precision activities, e.g. alignment
IV. CHERRY PICKER	245	219-399	Time to attach station to end of RMS
I. UNAIDED EVA	246	210-364	EVA prep- Post Time
III. EVA AND RMS	250	208-427	EVA prep- Post Time
II. EVA WITH MMU	276	222-499	EVA prep- Post Time

TABLE 4-9

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION-TASK TIME

CRITERIA DEFINITION - TIME TO PERFORM LESS PREP AND POST TIME - FOR EVA MODES FROM AIRLOCK DEPRESS TO REPRESS

	MODES	MEAN TASK TIME (MINUTES)	% OF TOTAL TIME	RANGE - MINIMUM/ MAXIMUM (MINUTES)	SIGNIFICANT PROBLEMS
V.	RMS	59	46%	7-492	high precision activities
IV.	CHERRY PICKER	62	25%	35-219	align-orientation at worksite
I.	UNAIDED EVA	63	26%	6-190	mass handling at worksite
II.	MMU	66	24%	24-279	mass handling at worksite
III.	EVA AND RMS	67	27%	28-247	coordination of RMS and EVA

TABLE 4-10

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - PERFORMANCE

CRITERION DEFINITION - PERFORMANCE CAPABILITY IN TERMS OF MANIPULATION, SENSOR FACTORS, AND MOBILITY

MANIPULATION FACTORS	SENSORY FACTORS	MOBILITY FACTORS
force application	visual acuity	translation ability
alignment	depth acuity	cargo transfer
dexterity	field of view	
mass handling	alignment	
tool orientation	force sensing	
reach		
confined operations		
stability		

	MODES	MEAN PERFORMANCE RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATIONS	SIGNIFICANT PROBLEMS
II.	MMU	1.5	22	12	55%	confined ops., cargo transfer
III.	EVA AND RMS	1.9	16	11	69%	translation
IV.	CHERRY PICKER	2.2	19	3	16%	confined ops.
I.	UNAIDED EVA	2.3	27	9	33%	translation, cargo transfer
V.	RMS	3.8	24	2	8%	manipulation and sensing

TABLE 4-11

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - OPERATIONS

CRITERION DEFINITION - FACTORS RELATED TO NUMBER AND COMPLEXITY OF TASK OPERATIONS BY MODE

FACTORS:

- number of operations
- number of crewmen
- number of prepared worksites
- degree of site preparation
- crew workload
- crew skills
- collateral damage potential
- integration with other operations

	MODES	MEAN OPERATIONS RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATIONS	SIGNIFICANT PROBLEMS
II.	MMU	1.5	22	12	55%	degree of site preparation
V.	RMS	1.5	24	15	63%	crew skills
I.	UNAIDED EVA	2.0	27	8	30%	degree of site preparation crew workload collateral damage
IV.	CHERRY PICKER	3.8	19	0	0%	number crewmen crew skills
III.	EVA AND RMS	4.0	16	0	0%	number crewmen number operations crew workload damage potential

TABLE 4-12

MODE COMPARISON RESULTS - BY CRITERIA
CRITERIA - FLEXIBILITY

CRITERION DEFINITION - FACTORS RELATING TO THE DEGREE OF ADAPTABILITY AND VERSATILIBY OF THE MODE FOR THE TASK

FACTORS: EFFECTS OF CHANGES IN:

- payload location
- module location
- module size/mass
- force-torque range
- stowage location
- operational techniques
- connector design

EFFECTS OF DEGRADED TRANSLATION SYSTEM

	MODES	MEAN FLEXIBILITY RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATIONS	SIGNIFICANT PROBLEMS
II.	MMU	1.5	22	11	50%	module size-mass force-torque range
III.	EVA AND RMS	1.8	16	8	50%	P/L location
I.	UNAIDED EVA	1.8	27	15	56%	module size-mass force-torque range
IV.	CHERRY PICKER	3.4	19	1	5%	degraded transl.system locations
V.	RMS	3.7	24	2	8%	locations of P/L, site, module, stowage different connectors

TABLE 4-13

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - SAFETY

CRITERION DEFINITION - CREW SAFETY FACTORS FOR TASK ACTIVITIES

FACTORS:
- effects of system failure on operator
- effects of system failure on orbiter
- requirements for man-rating
- hazard potential - worksite
- hazard potential - translation

MODES	MEAN SAFETY RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATIONS	SIGNIFICANT PROBLEMS
V. RMS	1.0	24	24	100%	effect of failure on orbiter
II. MMU	2.1	22	5	23%	hazard - worksite
I. UNAIDED EVA	2.4	27	5	19%	hazard - translation
IV. CHERRY PICKER	3.4	19	0	0%	effect of failure on operator
III. EVA AND RMS	4.0	16	0	0%	effect of failure on orbiter & operator hazard - worksite

TABLE 4-14

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - SUPPORT

CRITERION DEFINITION - DEGREE TO WHICH ADDITIONAL REQUIREMENTS ARE IMPOSED ON OTHER SYSTEMS TO SUPPORT THE TASK

FACTORS:
- cargo transfer requirements
- special lighting
- special tools-attachments
- worksite aids
- payload handling
- life support requirements
- additional expendables
- contamination control requirements
- payload interfaces
- shuttle interfaces

	MODES	MEAN SUPPORT RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATIONS	SIGNIFICANT PROBLEMS
I.	UNAIDED EVA	2.0	27	11	41%	cargo transfer worksite aids
V.	RMS	2.2	24	9	38%	special lighting P/L handling P/L interfaces
III.	EVA AND RMS	2.3	16	7	44%	worksite aids P/L interfaces
II.	MMU	2.7	22	5	23%	contamination addtl. expendables
IV.	CHERRY PICKER	2.8	19	5	26%	special attachments shuttle interfaces

TABLE 4-15

MODE COMPARISON RESULTS - BY CRITERIA
CRITERION - CONFIGURATION

CRITERION DEFINITION - FACTORS ASSOCIATED WITH THE PHYSICAL ASPECTS OF THE MODE

FACTORS:
- overall system weight
- overall system volume
- effect on payload configuration
- use of developed technology

	MODES	MEAN CONFIGURATION RATING	NO. OF TASKS APPLICABLE	NO. OF TIMES RANKED FIRST	% OF APPLICATION	SIGNIFICANT PROBLEMS
I.	UNAIDED EVA	1.0	27	27	100%	None
II.	MMU	1.8	22	5	23%	None
V.	RMS	2.5	24	2	8%	effect on P/L configuration
III.	EVA/RMS	3.6	16	0	0%	weight and volume
IV.	CHERRY PICKER	4.0	19	0	0%	developed technology weight and volume

TABLE 4-16

DEGREE OF PROBLEMS BY MODES - EACH CRITERION

	MINOR PROBLEMS (1.0-1.9)	MODERATE PROBLEMS (2.0-2.9)	MAJOR PROBLEMS (3.0 - 5.0)
I. UNAIDED EVA	BASIC CAPABILITY FLEXIBILITY CONFIGURATION	PERFORMANCE OPERATIONS SAFETY SUPPORT	
II. MMU	BASIC CAPABILITY PERFORMANCE OPERATIONS FLEXIBILITY CONFIGURATION	SAFETY SUPPORT	
III. EVA/RMS	PERFORMANCE FLEXIBILITY	BASIC CAPABILITY SUPPORT	OPERATIONS SAFETY CONFIGURATION
IV. CHERRY PICKER		PERFORMANCE SUPPORT	BASIC CAPABILITY OPERATIONS FLEXIBILITY SAFETY CONFIGURATION
V. RMS	OPERATIONS SAFETY	BASIC CAPABILITY SUPPORT CONFIGURATION	PERFORMANCE FLEXIBILITY

4.2 MODE REQUIREMENTS

The task descriptions presented in Volume II include a description of requirements to complete the task for modes judged feasible for the task. A summary of the requirements for each mode is presented in Tables 4-17 through 4-21.

4.3 CONCLUSIONS AND RECOMMENDATIONS

The conclusions to be drawn from this study are as follows:

- Unaided EVA is required for shuttle mission support - in the cargo bay
  - selected mode for 43% of all tasks
  - selected mode for 67% of in-bay tasks
  - applicable for 89% of tasks
  - feasible for 86% of tasks
  - only applicable mode for 11% of tasks
- EVA with MMU is required for shuttle mission support - outside the bay
  - selected mode for 29% of all tasks
  - selected mode for 70% of out-of-bay tasks
  - applicable for 63% of tasks
  - feasible for 77% of tasks
  - only applicable mode for 9% of tasks
- RMS is requied for shuttle mission support - in and outside the bay
  - selected mode for 26% of all tasks
  - applicable for 71% of tasks
  - feasible for 80% of tasks
  - only applicable mode for 3% of tasks

- EVA and RMS desirable for shuttle mission support
    - selected mode for 20% of all tasks
    - applicable for 49% of tasks
    - feasible for 53% of tasks
    - applicable where precise operations are required and where cargo weighing over 100 lbs. must be transferred or where several modules are to be transferred
    - feasible for 53% of tasks
- Cherry Picker mode not required for shuttle mission support
    - selected for 6% of tasks (2 of 35)
    - in each case where it was selected - the task can be performed as well by at least one other mode

Recommendations formulated on the basis of this investigation include the following:

- Unaided EVA, MMU, and RMS recommended for shuttle mission support
    - unaided EVA for P/L servicing, mechanical systems activation, film replacement in bay
        - key issues - cargo transfer, contamination, design interfaces
    - MMU for P/L servicing, mechanical systems activation, inspection and monitoring outside of the bay
        - key issues - contamination, tether dynamics, design interfaces
    - RMS for P/L deploy and retrieve, film replacement, contamination monitoring umbilical disconnect, and shroud removal - in and out of bay
        - key issues - reach limits, performance capability, design interfaces
- EVA and RMS combination desired for some mission where high precision tasks are required and where multiple mass transfers for cargo in excess of 100 lbs. are required
    - key issues - EVA and RMS cooperation, EVA safety

- Cherry Picker - not recommended for shuttle mission support
    - least applicable mode with greatest magnitude problems
    - selected tasks equally applicable to other modes

Recommendations for each mode include:

- <u>Unaided EVA</u>:
    - incorporate as an operational capability to be available for payload and shuttle mission support - both planned and unplanned
    - develop guidelines for cargo handling and transfer by an EVA crewman, and develop cargo
    - develop methods to measure and monitor EVA crewman workload, and establish workload criteria for EVA
    - develop standard measures of EVA crewman performance capability (visual, manipulative, mobility)
    - establish design criteria for shuttle and spacelab component interfaces with EVA crewmen, based on identified crewman performance capabilities
    - establish techniques for generating validated EVA timelines based on statistical analysis of empirically derived data
    - develop standard EVA workstation and translation aid designs, and interfaces between stations and aids (rails, handholds, etc.)
    - assess requirements and constraints for EVA as applied to in-flight maintenance
    - develop standard manual activation techniques (hand crank, portable motor, etc.)
- <u>EVA/MMU</u>:
    - incorporate as an operational capability to be available for payload and shuttle mission support - planned and unplanned
    - develop design criteria for the MMU man-machine interface
    - establish timelines for EVA/MMU operations
    - investigate methods and problems for EVA/MMU crewman activation and deactivation of the MMU, and of quick secure and release at the worksite
    - investigate problems and techniques for flying into and out

of the bay, encumbered and unencumbered

- EVA/RMS:

  - establish techniques of EVA and RMS cooperation and coordination

  - EVA recommendations as for unaided EVA

  - RMS recommendations as for RMS

- Cherry Picker:

  - discontinue investigation of the Cherry Picker mode, due to:

    - number and magnitude of problems associated with the mode

    - requirements for end-effector change, and stowage of the end-effector station

    - complexity of the station - RMS interface (Hamilton Standard 1972 estimated 150 electrical interfaces between the station and the manipulator)

    - the mode limits EVA capability (RMS reach envelope) handholds required on RMS for EVA crewman escape from the station with an RMS failure)

    - the mode was selected for only 2 of 35 tasks, and was feasible for only 4 tasks

    - limited development resources for shuttle and payload support more effectively allocated to other EVA and RMS modes

- RMS:

  - incorporate as an operational capability to be available for payload and shuttle support, beyond payload deployment and retrieval

  - investigate RMS stability and dynamics in terms of task requirements

  - develop computer assisted control techniques

  - develop design criteria for the RMS man-machine interface

  - incorporate force gradient sensing into the RMS control system

- investigate techniques of proximity sensing for RMS operation in confined areas

- develop shuttle and payload component design criteria for interface (visual and manipulative) with RMS

TABLE 4-17

REQUIREMENTS FOR UNAIDED EVA

- PREPARED AND UNPREPARED WORKSITES ARE REQUIRED (EACH CITED FOR 9 DIFFERENT TASKS)
- CARGO HANDLING AND TRANSFER AIDS REQUIRED FOR 15 TASKS
- PAYLOAD AND SHUTTLE COMPONENTS DESIGNED FOR EVA INTERFACE - 11 TASKS
- ASSURE 40 INCH CLEAR BODY ENVELOPE AT WORKSITE (7 TASKS)
- UP TO 10 WORKSTATIONS ARE REQUIRED FOR A SINGLE TASK (P2-3)
- SPECIAL HANDRAILS REQUIRED (FOR 11 TASKS)
- FEEDBACK OF SYSTEMS STATUS REQUIRED AT THE WORKSTATION (4 TASKS)
- DESIGN FASTENERS FOR QUICK ONE-HNAD CONNECT/DISCONNECT) (2 TASKS)
- SPECIAL TOOLS REQUIRED (2 TASKS)
- PLAN THE MISSION TO INCORPORATE OTHER (NON-EVA) MISSION TASKS DURING PRE-BREATHE

TABLE 4-18

REQUIREMENTS FOR EVA/MMU

- DEADBAND LIMITS AND RATES: LIMITS FROM $\pm$ 1° TO 5°
  RATES FROM $\pm$ .5°/SEC. TO 2°/SEC.
- DEADBAND LIMITS AND RATES CAN BE RELAXED IF ATTACH POINTS ARE PROVIDED
- HANDHOLDS REQUIRED AT A WORKSITE (9 TASKS)
- CONTAMINATION SHIELDING OR CONTROL (4 TASKS)
- TWO MMU UNITS REQUIRED (6 TASKS)
- PROVISIONS FOR FLYING INTO THE BAY (3 TASKS)
- MODULE INTEGRATION INTO MMU OR MODULE HANDLING AIDS (7 TASKS)
- STATIONKEEPING AT ONE LOCATION (TPS REPAIR) FOR 9 MINUTES
- DESIGN SHUTTLE AND PAYLOAD COMPONENTS FOR EVA ACCESS-INTERFACE (6 TASKS)
- TETHER MANAGEMENT TECHNIQUES (3 TASKS)
- PROVIDE RATE COMMAND WITH ATTITUDE HOLD WHILE TRANSLATING

TABLE 4-19

REQUIREMENTS FOR EVA/RMS

- ESTABLISH TECHNIQUES OF EVA AND RMS COOPERATION - COORDINATION (8 TASKS)
- DESIGN COMPONENTS FOR EVA AND RMS INTERFACE (7 TASKS)
- SPECIAL TOOL REQUIREMENTS (2 TASKS)
- SPECIAL RAILS (3 TASKS)

TABLE 4-20

REQUIREMENTS FOR CHERRY PICKER

- PROVIDE RMS STABILITY OF FROM ± .5 IN./SEC. TO ± 2 IN./SEC. (3 TASKS)
- ESTABLISH TECHNIQUES FOR COOPERATION BETWEEN CHERRY PICKER AND EVA
- PROVIDE QUICK REACTION CAPABILITY FOR RAPID EGRESS FROM A WORKSITE

TABLE 4-21

REQUIREMENTS FOR RMS

- DESIGN SHUTTLE AND PAYLOAD COMPONENTS FOR RMS INTERFACE (13 TASKS)
- TIP PLACEMENT ACCURACY 1 INCH (12 TASKS) TO 2 INCH (4 TASKS)
- TIP STABILITY $\pm$ 25 IN./SEC. (1 TASK) TO $\pm$ .5 IN./SEC. (9 TASKS)
- STEREO ACUITY FROM 5 ARC MINUTES (2 TASKS) TO 7 ARC MINUTES (12 TASKS)
- LIGHTING VARIABLE FROM 5 TO 50 FT. LAMBERTS AT THE OPERATOR'S EYE
- PROVIDE PROXIMITY SENSING FOR CONFINED OPERATIONS
- PROVIDE FORCE FEEDBACK (7 TASKS)
- PROVIDE COMPUTER ASSISTED CONTROL TO SUPPORT PAYLOAD DEPLOY AND RETRIEVAL

BIBLIOGRAPHY

Payload Descriptions: Volume 1 - Automated Payloads (Space Shuttle Payload Descriptions - SSPD), NASA Marshall Space Flight Center, October 1973.

Test Report: EVA Suited Crewman Handling 8,500 Lb. Shuttle Payload Mockup, NASA Johnson Space Center, March 1973.

Remote Manipulator System Design Requirements, Performance and Interface Specification, JSC-08977, Spacecraft Design Division, August 22, 1974.

Space Shuttle System Payload Accommodations: Level II Program Definition and Requirements, Volume XIV, Revision C, NASA JSC, July 1974.

Teleoperator System Man-Machine Interface Requirements for Satellite Retrieval and Satellite Servicing; Volume I Requirements, Volume II Design Criteria. T. B. Malone, Essex Corporation, Contract NASW-2220, June 1972.

Large Space Telescope Phase A Final Report, NASA TMX 64726, NASA MSFC, December 1972.

Space Tug Systems Study (Cryogenic), General Dynamics for NASA MSFC, Contract NAS8-29676, January 1974.

Personal Communications with personnel on the LST task team at MSFC, Shuttle IR Telescope Facility personnel at Ames Research Center, and space tug personnel at MSFC.

Study of Shuttle-Compatible Advanced Technology Laboratory (ATL), Staff of Shuttle Experiments Office, Langley Research Center, NASA TM X-2813, September 1973.

Meeting with ATL development personnel at Langley Research Center, June 1974.

Personal Communications, ATL Data Package, from Karen D. Brender, NASA Langley, to T. B. Malone, Essex Corporation, July 21, 1974.

Sortie Payload Definition and Requirements Data, Level II, Advanced Technology Laboratory Payload 1, General Dynamics for NASA MSFC, July 1973.

Preliminary SIRTF Concept Description, Space Science and Flight Project Development Divisions, Ames Research Center, January 1974.

Personal Communications, Mr. B. C. Look, SIRTF Development Program, Ames Research Center.

Sortie Payload Definition and Requirements, Level II, Atmospheric Science Facility AP03S, General Dynamics for NASA MSFC, July 1973.

Martin Marietta Preliminary Concepts from Woodshole Atmospheric and Space Physics Meeting, October 1973.

Personal contacts with Atmospheric and Space Physics personnel at NASA HQ, MSFC, and Martin Marietta.

BIBLIOGRAPHY, Continued:

Dr. Woo, Jet Propulsion Lab Erectable Antenna Program - telephone conversation.

Communications/Navigation personnel at NASA HQ and MSFC - personal communications.

Shuttle Imaging Microwave System personnel at NASA HQ and JSC - personal communications.

LST SSM Manned Maintenance Study LMSC Briefing for NASA, January 1974.

Personal contacts, LST personnel at Lockheed and MSFC.

Personal communications, Mr. George Strouhal, Manager of the Thermal Protection Section, Structures and Mechanics Division, NASA JSC.

Rockwell International, Space Division, Thermal Protection System Description.

Personal communication - Spacecraft Design personnel at JSC, especially Mr. Robert Langley.

Space Shuttle and Spacelab discussions, JSC, March 21-22, 1974.