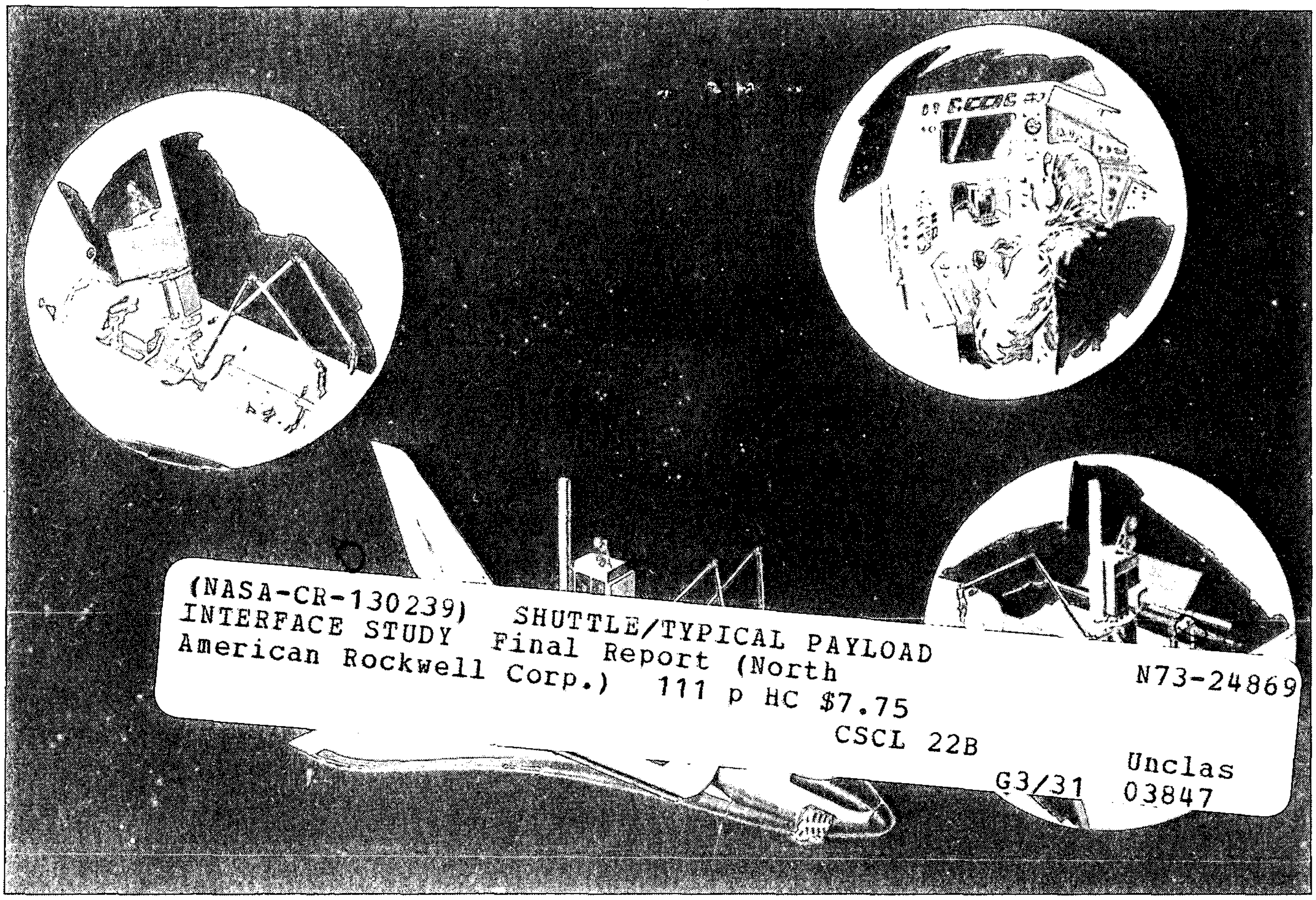
OCTOBER 30, 1972 NASA CR-130239 SD 72-SA-0194



FINAL REPORT

SHUTTLE/TYPICAL PAYLOAD INTERFACE STUDY

Prepared For

GODDARD SPACE FLIGHT CENTER

NAS5-23093

Space Division
Rockwell International

SD 72-SA-0194

FINAL REPORT

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30 October 1972

Space Division
North American Rockwell

TECHNICAL REPORT INDEX/ABSTRACT

ACCESSION NUMBER	
DOCUMENT SECURITY CLASSIFICATION	UNCLASSIFIED
TITLE OF DOCUMENT	SHUTTLE/TYPICAL PAYLOAD INTERFACE STUDY - FINAL REPORT
LIBRARY USE ONLY	
AUTHOR(S)	MANSFIELD, J. M.
CODE	QN085282
ORIGINATING AGENCY AND OTHER SOURCES	SPACE DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION, DOWNEY, CALIFORNIA
DOCUMENT NUMBER	SD 72-SA-0194
PUBLICATION DATE	30 OCTOBER 1972
CONTRACT NUMBER	NAS5-23093

DESCRIPTIVE TERMS

SHUTTLE PAYLOADS; ON-ORBIT MAINTENANCE; LOW-COST PAYLOADS; PAYLOAD MODULE EXCHANGE EARTH OBSERVATION SATELLITE; LARGE SPACE TELESCOPE

ABSTRACT

CONCEPT SYNTHESIS AND PRELIMINARY DESIGN STUDIES ARE SUMMARIZED OF SUPPORT SYSTEMS TO IMPLEMENT THE LAUNCH/REFURBISHMENT/RETRIEVAL WITH SHUTTLE OF A FAMILY OF LOW-COST EARTH OBSERVATION SATELLITES IN LOW EARTH ORBIT. SHUTTLE CONSTRAINTS AND ISSUES ARE DESCRIBED.

FORM M 131-V REV. 1-68

FOREWORD

The Shuttle/Typical Payload Interface Study was conducted by the Space Division of North American Rockwell under Contract NAS5-23093 for the Goddard Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Projects Directorate of the Goddard Space Flight Center. This document is the final report on the study.

The requirement for the use of the International System of Units (SI) in this report has been waived under the authority of Goddard Management Instruction 2220.4, Paragraph 5.d.

ACKNOWLEDGEMENTS

The Shuttle/Typical Payload Interface Study was conducted by the Space Division of North American Rockwell under Contract NAS5-23093 for the Goddard Space Flight Center.

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STUDY SUMMARY

INTRODUCTION

A significant issue in the design and implementation of a space system is the method for assuring its continued effective operation for the desired mission lifetime. This report describes the conceptual design of a Flight Support System which, in conjunction with the Space Shuttle, will provide the required functional support for the launch, refurbishment, and retrieval of a class of low earth orbit satellites.

The design synthesis and analysis effort described herein was done as a contracted study for the Goddard Space Flight Center as a part of their overall effort to develop a low cost approach to space systems utilizing the unique capabilities of the Space Shuttle. These capabilities for man-attended on-orbit operations and spacecraft retrieval have broadened the potential spacecraft design approaches to include options for on-orbit maintenance and updating, with the backup of retrieval for ground maintenance. Maintenance is cost effective from its influence on design simplification (redundancy) and reduction of reliability testing requirements. Updating permits extension of effective mission life as the mission objectives and sensor state of the art change.

The NASA at Goddard Space Flight Center have been conducting in-house studies of several space missions to define spacecraft designs which can implement these maintenance and updating options. These missions have included both the Earth Observatory Satellite (EOS) and the Large Space Telescope (LST) as examples of early Shuttle-supported spacecraft. Accordingly, this effort involved support of both of these missions although primary emphasis was given to the EOS Flight Support System.

The overall objective of this study was to develop a system concept for shuttle support to orbital operations of low cost unmanned satellites in low earth orbit. The operations considered include the launch and retrieval, but it was found that the major driver was the on-orbit refurbishment of the satellite.

Implementation of this objective involves the Space Shuttle Orbiter which provides the supporting functions and utilities, and a Flight Support System (FSS) (Figure 1) which executes the required operations and procedures to assure the operational success.

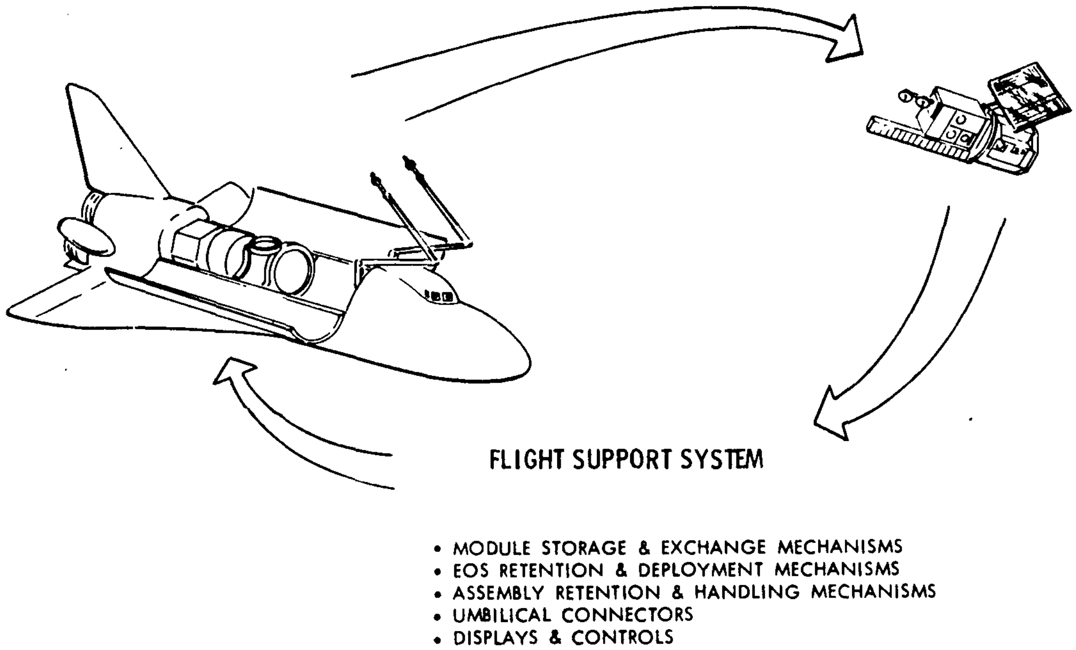

Figure 1. Shuttle Based EOS

INTERFACING SYSTEM ELEMENTS BASELINE

In order to define the support system elements, baseline descriptions of the interfacing system elements were adopted. These systems included the Space Shuttle with its attached manipulator system and the GSFC satellite designs.

Space Shuttle Orbiter (References 1 through 4)

The shuttle payload bay is essentially cylindrical with forward and aft flat bulkheads, and two pairs of upper, outward opending doors/radiators hinged and actuated at the bay upper longerons. Each door set is provided with a half-compartment for stowing the shuttle manipulators.

The baseline adopted for the shuttle payload deployment/retrieval system was the Shuttle Attached Manipulator System (SAMS) (described in References 5 and 6) which consists of two manipulators, 50 feet long when extended, each attached to a swing-out shoulder arm secured to the payload bay forward bulkhead. The shoulder arms deploy SAMS to the operating position and do not intrude on the payload envelope. The EOS/FSS/SAMS control center is located in the crew compartment. Operations taking place in the payload bay are partially observable from the control center via a window located in the forward bulkhead of the bay in addition to various TV cameras.

Rendezvous at the EOS orbit establishes a requirement for Shuttle Orbit Maneuvering Systems (OMS) propellant above the basic design capacity. To satisfy this requirement, an OMS kit containing the necessary tankage and equipment is installed at the aft end of the payload bay. The payload envelope aft limit is three inches forward of the OMS kit.

The key driver on the structural approach for installing payloads in the cargo bay is the requirement to withstand an approximately 8-g forward acting "crash" load.

Earth Observatory Satellite

The EOS No. 6B - Terrestrial Configuration (Figure 2) consists of a forward instrument section mounting five instrument modules (including the K-band antenna assembly) and an aft instrument section mounting one instrument module and three subsystem modules. Structural connection between the two instrument sections is accomplished by a payload retention interfacing assembly called the transition ring, which also provides a mounting base for the EOS capture and solar array couplings.

In addition to the instrument/subsystem modules a set of devices, termed mission peculiar or unique assemblies, are attached to the EOS structure. These are a side-looking radar antenna mounted on the forward instrument section, a solar array mounted on the adapter, and an orbit adjust engine assembly with attitude control thrusters located in the center cavity of the aft instrument section and pointing aft. A docking ring and a power/signal umbilical connector are located on the base of the aft instrument section to implement the interfacing functions with the FSS.

The modules are secured in their respective locations by latches located at each corner of the modules [K-band antenna (2), others (4)] which mate with components located on the EOS structure. All module latch mechanisms are of identical configuration and operation and are compatible with installation and removal.

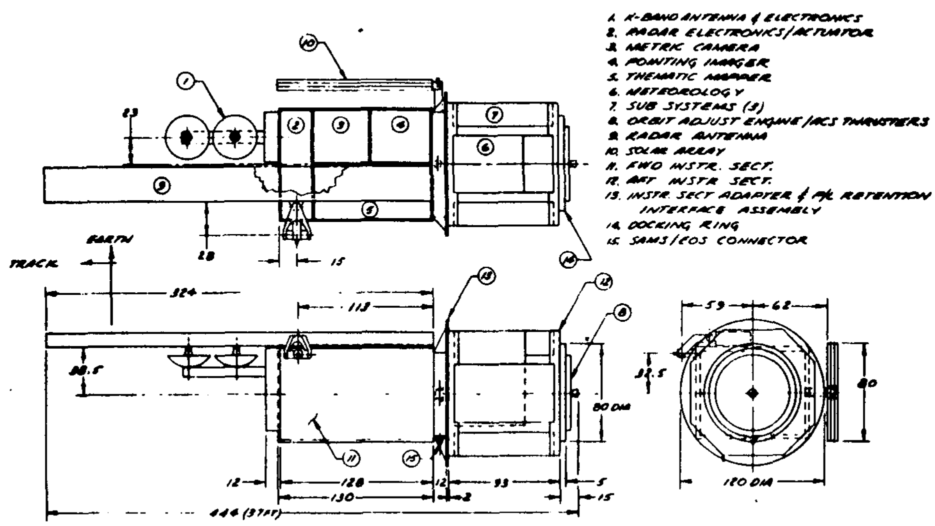

Figure 2. Terrestrial Earth Observatory Satellite No. 6B

Each unique assembly is secured to the EOS by means of a single point latching/coupling system. The latch portion supports the unique assembly and provides the engaging system to the coupling on the EOS. Unique assembly actuation devices for the solar array and the radar antenna are secured to their respective latch bodies.

The EOS No. 6C - Oceanographic Configuration (Figure 3) is different from EOS No. 6B in that the microwave radiometer replaces the forward instrument section and the K-band and radar antennas. In all other respects the satellites are identical and compatible in regard to handling modes and procedures.

MISSION REQUIREMENTS AND FUNCTIONS

The missions considered were those shuttle-supported operations associated with the launch, refurbishment and/or retrieval of the EOS. The EOS utilizes a retrograde sun-synchronous (98 degrees), 400-n mi circular orbit. The most recent performance data for the shuttle indicates a limited payload capability for orbits of this energy level if nominal mission rules are followed. This is a problem area and will require continuing investigation into achieving adequate margins for accomplishing the EOS missions. For the purpose of this study it was assumed that a solution would be found as the shuttle and EOS programs evolved. Primary emphasis was, therefore, placed on the accomplishment of the refurbish mission since it was the most significant driver

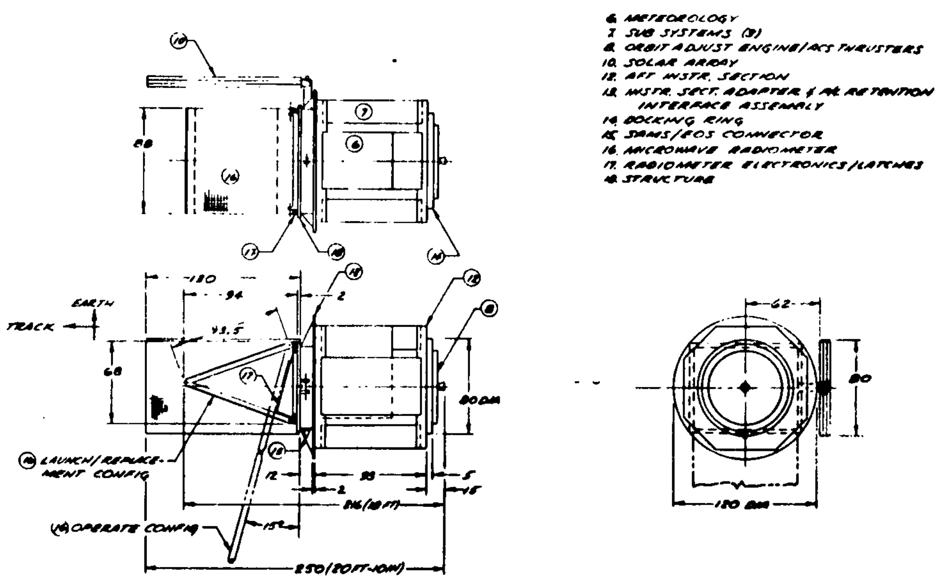

Figure 3. Oceanographic Earth Observatory Satellite No. 6C

from the standpoint of complexity of operations and interfaces with the shuttle. The functions to be accomplished on the refurbishment mission included the exchange of up to three subsystem modules, five sensor modules, and three of the unique assemblies (e.g., solar array). In addition, contingency provisions were required to retrieve the EOS, without jettison of any equipment in the event the refurbishment was not successful in restoring the EOS to full operational status.

SYSTEM CONSTRAINTS AND ISSUES

Assuming solution of the performance problem mentioned earlier, the most significant issues in the overall interface with the shuttle are considered to be those associated with the shuttle-induced environment (particularly contamination), the constraints due to the installation of the tank kits for the Orbital Maneuvering System (OMS) in the aft part of the cargo bay, and the performance of the SAMS.

Contamination

While the precise requirements for contamination limits in the vicinity of the EOS have not been determined at this time, it is anticipated that at least some sensors will require protection to a level consistent with a Class 10,000 clean room. At the present stage of shuttle definition, no specific criteria have been established for contamination control in the cargo bay.

Environmental shrouds can be utilized as shown in Figure 4 to provide protection from the ambient environment during installation in the cargo bay. At this time, the characteristics of the liner shown in the lower cargo bay and its capabilities to protect the payload from contamination are not known. After closing the bay doors, the combination of a clean bay liner and a Class 100000, dry nitrogen purge around the satellite will provide some inherent control up to lift-off. A study is currently in progress within the Shuttle Program to identify and quantify the various contamination agents which could affect orbiter payloads. As a corollary to this study, recommendations will be made for the reduction or elimination of contaminants by system design changes or operational procedures.

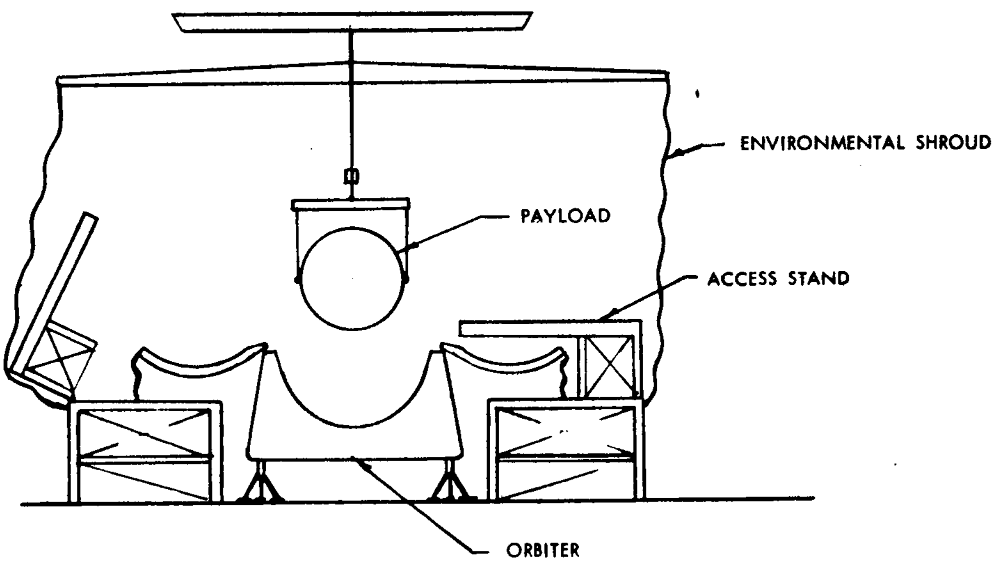

Figure 4. Shuttle Payload Handling

Supplementary covers may be required for sensitive elements of the satellite because of the contaminating effects of the shuttle reaction control subsystem and other shuttle effluents while in the vicinity of the orbiting satellite. The shuttle provides storage for all human waste products for the total mission duration but surplus fuel cell water can currently be stored for only a limited time (nominally less than 24 hours) and there will be additional outgassing, leakage, and minor effluent dumps. The discharge ports for the scheduled dumps are shielded from the payload but some temporary protection may be required for sensitive elements until the residual atmosphere at the orbital altitude sweeps away contaminating elements.

There is a potential for some contamination from the RCS plumes, particularly during the capture and release operations when tight attitude control requirements will necessitate utilizing the RCS. The desired orientation of the significant RCS jets is shown in Figure 5. Note that this orientation would require tilting the upward firing jets in the forward RCS module, 45 degrees outboard to assure the avoidance of a satellite impingement within the 95 percent plume envelope. This is a design complication of the shuttle and other alternatives including the selective inhibiting of the contaminating jets are currently under study by the Shuttle Program.

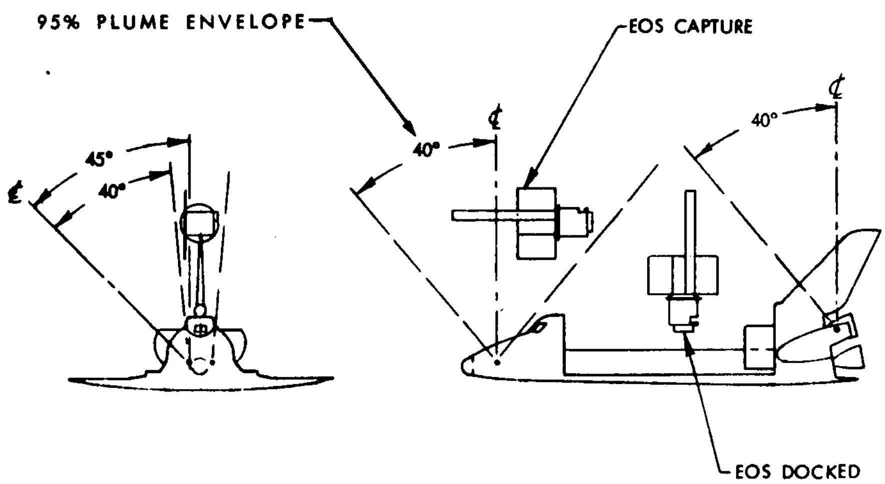

Figure 5. Desired Orbiter RCS Plume Profiles

OMS Tank Kits

As mentioned earlier the orbit required for the EOS missions will require additional propellant for the shuttle OMS. The design approach presently adopted by the shuttle is to install the added tankage as kits in the aft end of the cargo bay. This location, together with the center of gravity (c.g.) limits established for control of the shuttle, constrain the EOS and FSS allowable c.g. envelope and available cargo bay volume. For the refurbish missions when there is a relatively light up-payload, the net c.g. at launch falls outside of the allowable aft c.g. for landing. This condition will require either shuttle provisions for propellant dump prior to a landing from an early abort, relocation of the OMS tank kits, forward ballasting, or some alternate trajectory to reduce the OMS propellant requirements.

The OMS tank kit installation reduces the free length of cargo bay to 51 feet although some volume is available above the tank installation. For the case of contingency retrieval of the EOS in the No. 6B configuration with the long radar antenna, packaging became very constraining for the remaining elements. This along with other considerations, led to the adoption of pivot mechanisms to assure meeting the tight clearances when deploying the satellite from the cargo bay or stowing it for retrieval.

Shuttle Attached Manipulator Subsystem (SAMS)

The inclusion of a manipulator on the shuttle provides a versatile capability for accomplishing operations while on orbit. The shuttle manipulator arms are long and articulated in order to reach multiple payloads at various points in the payload bay and to deploy them and maneuver them in a variety of motions for deployment, capture, and stowage. They are constrained in diameter due to critical weight allocation requirements. Since they are long and slender and limited in weight of materials, they must of necessity be designed to optimize the strength to weight characteristic.

In order to accomplish maneuvering of large masses within reasonable times, a maximum stiffness to weight design is required. Since the tip loads are limited by the torque capabilities at the joints, this factor allows increasing the tip loads within reasonable limits without substantial increase in manipulator arm weight. For example, the extended arm tip load capability can be increased from 10 pounds to 50 pounds with an arm weight increase from 525 pounds to 550 pounds and was baselined for this study. However, the system weight rapidly increases with further tip load increases to an extent that substantial force requirements will generate a substantial impact on shuttle weight. A modifying factor is that the tip loading criteria does not define the useful tip load in a typical working configuration of an articulated manipulator arm. For instance, the 50-pounds tip load criteria will generate tip loads on the order of 80 to 100 pounds in nominal working configurations. Nevertheless, this order of magnitude of forces will not provide directly the requirements for the engagement of the EOS modules which involve four attachment points requiring 2,000 pounds of thrust force each for latch preload. Forces of this magnitude can be generated, however, by specialized fixtures which can trade time for force by utilizing suitable gear reductions to gain the mechanical advantage. This type of fixture can be incorporated into the SAMS as an end effector in order to perform the latching function. Also, this end effector could conceptually incorporate the necessary devices and drives to provide the breakaway forces associated with module removal. It was found, however, that this highly specialized end effector was not compatible with the baselined SAMS, which did not incorporate the mechanical or electrical capabilities to exchange end effectors while on orbit.

In summary, the constraints imposed by SAMS at the baselined stage of definition result from the lack of on-orbit end effector exchange, the relatively low tip forces generated, and an uncertainty in the dynamic positioning accuracy achievable. For these reasons and other programmatic considerations, The SAMS is not the preferred concept for performing module exchange. However, as shown in Figure 6, because of its versatility, SAMS is preferred to perform the manipulation and exchange of those unique assemblies which, as a result of the geometry or location of the satellite, were not found to be compatible with the basic module exchange concept. In addition, SAMS is utilized in its normal role to perform the capture and maneuvering of the satellite to its docked position for refurbishment and the subsequent return of the satellite to its normal flight attitude.

Additional Environmental Issues

Although contamination is considered to be one of the major unresolved shuttle impact issues, there are other aspects of the shuttle environment which may be problem areas. The EOS desires to be maintained at a temperature of 70 $\pm$ 20 F. The shutle is being designed to an assumed set of allowable temperature limits which allows the cargo bay walls to reach 150 F during the launch mission and 200 F during entry and landing not considering any effects of the payload temperature. The actual temperatures which the EOS elements might attain are, of course, a function of the thermal interchange with time and a more detailed analysis is required to define the potential problem.

The acoustic level in the cargo bay is required to be limited to 145 dB overall. It is not anticipated that this overall level will be a problem to the EOS but there may be peak levels at discrete frequencies which may require corrective measures.

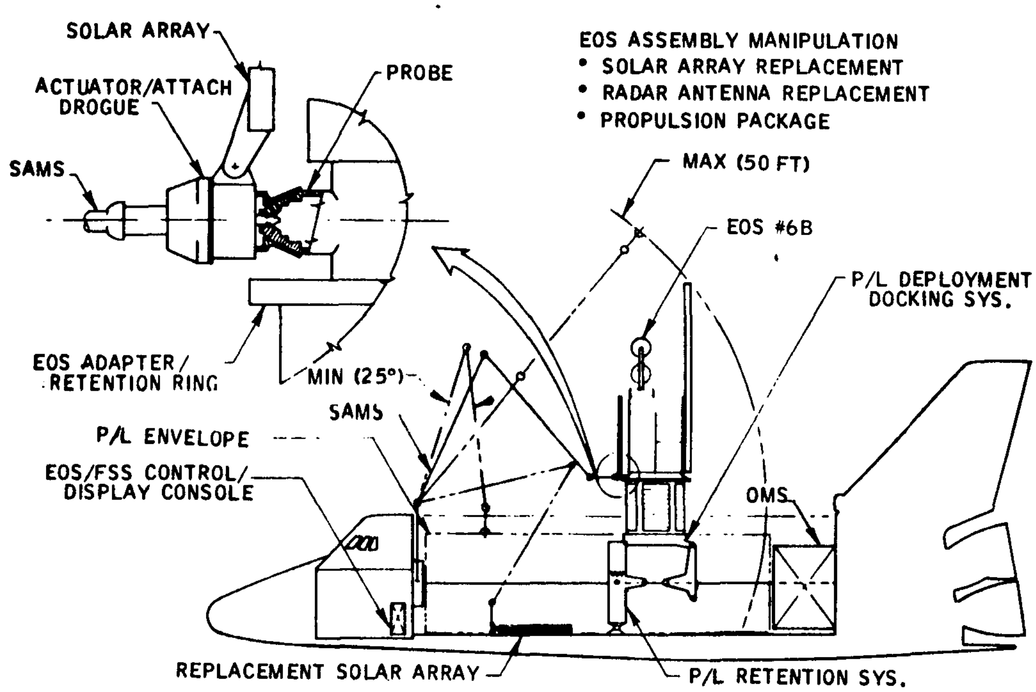

Figure 6. Shuttle-Attached Manipulator System (SAMS) Utilization

SYSTEM CONCEPT SYNTHESIS

A number of conceptual arrangements for the support system elements were synthesized utilizing the results of separate analyses which defined certain standard operations and the associated system components which were common to all concepts. The elements which were varied between concepts involved the fore and aft location relative to the satellite of the magazine holding the replacement modules, whether the magazine remained in the bay during the module exchange or was tilted up to a more convenient orientation, and, finally, whether the module exchange was accomplished utilizing SAMS only or by a separate mechanism with SAMS providing only the services previously discussed. The selected standarized elements are summarized in Table 1 and the combinations of the variables which formed the candidate concepts are shown in matrix form in Figure 7. Additional combinations were examined briefly but were rejected early for such reasons as blocked access.

Table 1. Standardized Operations for All Concepts

Resupply Activity	Approach Selected
• Capture, berthing and release to free flight	• SAMS with payload handling end effector
• Docking, umbilical connection, indexing, deploy and stow in payload bay	• Mechanized pivoted platform
• Subsystem and sensor module storage	• Mechanized rotating magazine
• Unique assembly actuation/ exchange (solar array, radar antenna, and propulsion package)	• SAMS with appropriate end effectors
• Unique assembly storage	• Palletized structure
• EOS launch/reentry retention	• Split ring structure (pivot de-coupled)
• Displays and controls	• Payload specialist station, orbiter cabin

FSS CONCEPT	MAGAZINE LOCATION		MAGAZINE SERVICE POSITION		MODULE EXCHANGE MECHANIZATION	
	AFT	FORWARD	IN BAY	TILT UP	AUTO + SAMS	SAMS ONLY
I	X		X		X	
II	X			X		X
III		X	X			X
IV		X		X	X	

Figure 7. Candidate EOS FSS Concepts

These alternate concepts were compared and evaluated in a qualitative sense considering such factors as hardware complexity and operational issues. It was found that all mission requirements and constraints can be met by all concepts although with varying degrees of complexity and confidence. In particular, the concepts involving tilting of the module magazine out of the bay offered only marginal benefits at the price of significant increases in complexity. As indicated earlier, while the actuation and replacement of the unique assemblies on the satellite with SAMS is considered feasible and desirable at this time, it was concluded that further development and testing is needed to verify that SAMS can perform the module exchange function. Accordingly, the concept involving an aft fixed magazine with a separate module exchange mechanism was selected as the preferred approach for further development.

The basic concept for the selected approach is illustrated in Figure 8, which shows the sequence for exchanging a typical subsystem module. The satellite aft end is shown docked to a ring platform which holds the satellite erect out of the cargo bay and provides the capability to rotate the satellite

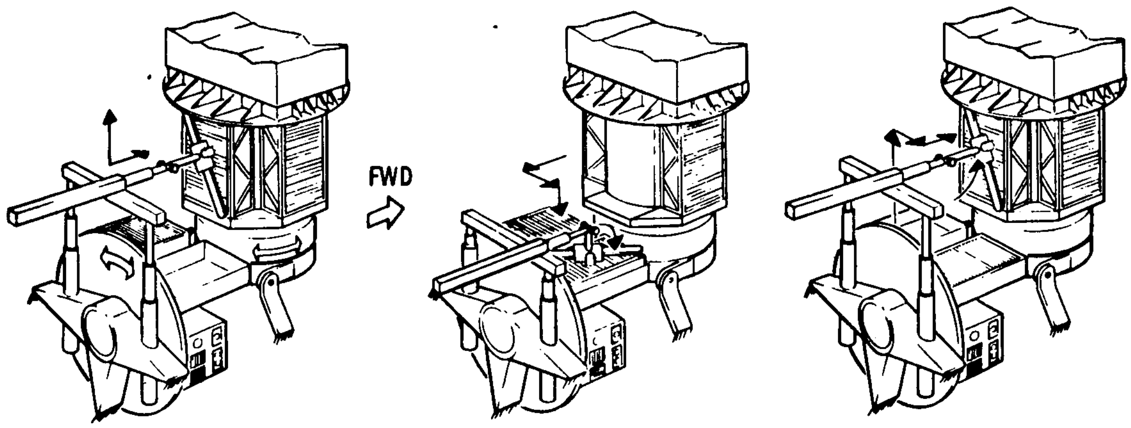

Figure 8. EOS Module Exchange and Retention

about its longitudinal centerline. This rotation allows access to all sides of the satellite by the module exchange mechanism (MEM). The replacement modules are held in a magazine which can be rotated to bring the module(s) being manipulated to the upper side for access by the MEM. For the case illustrated in Figure 8, the replacement subsystem module has been rotated into position and it was assumed that the adjoining slot was empty and could be utilized for stowing of the replaced module. For the general case, a temporary holding fixture is utilized to restrain the replaced module while the new module is inserted in the satellite. The replaced module is then stowed in the slot vacated.

The MEM concept adopted utilizes an orthogonal drive mechanization to provide the basically straight line motions involved. Two right angle rotations are also required; one to swing the modules off to the side to reach the temporary holding fixture, and the other to rotate the modules from their orientation in the magazine to the satellite orientation. Additional rotary motion is required in the module handling fixture which interfaces first with one diagonal set of corner latches and then the other to release (or re-latch) each module. This fixture also contains the drives and mechanisms to provide the pre-loads required for each latch.

Figure 9 illustrates the utilization and sequential functions of the selected Flight Support System (FSS) for the refurbish missions including, as an option, the contingency retrieval of the satellite in the event the refurbishment does not restore the satellite to full operational status. Also illustrated in Figure 9 is the utilization of SAMS for satellite capture and docking and for exchange of the unique assemblies. Note that the docking ring platform is tilted back during exchange of the propulsion package to allow better visibility and access for the SAMS operator. The unique assemblies are stowed on a framework pallet in the forward part of the cargo bay where they are accessible to the SAMS and do not interfere with stowage of the EOS during contingency retrieval. A temporary holding position on the side of the pallet framework mount is utilized to hold the replaced assembly in the same way as the modules are handled. Figure 10 illustrates the use of some of the same FSS elements to accomplish the launch (or retrieval) missions.

NEW TECHNOLOGY

No new technology requirements have been identified at this time in order to implement the selected concept for the EOS Flight Support System. All elements appear to be well within the present state of the art.

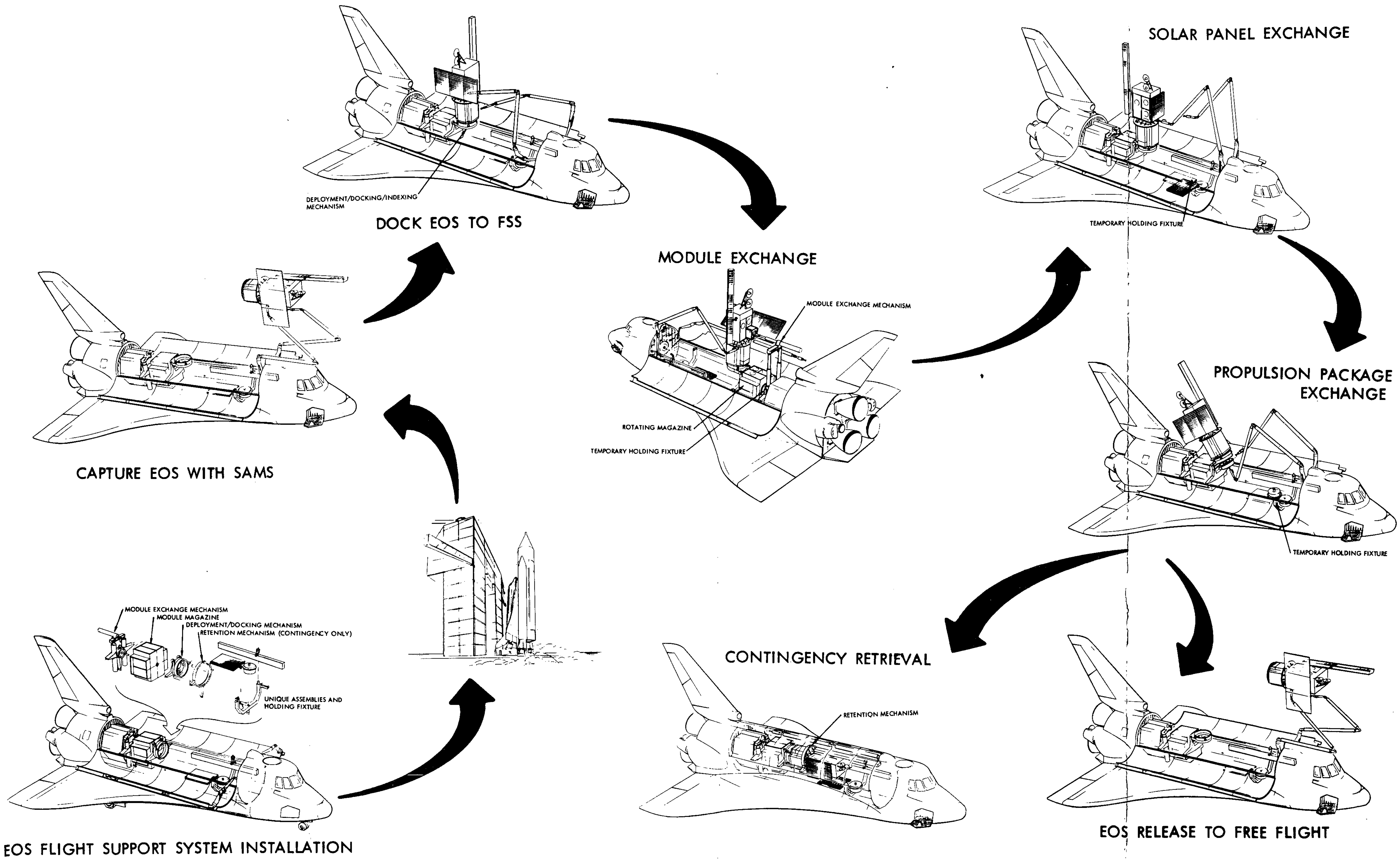

Figure 9. EOS Refurbish Mission Sequence

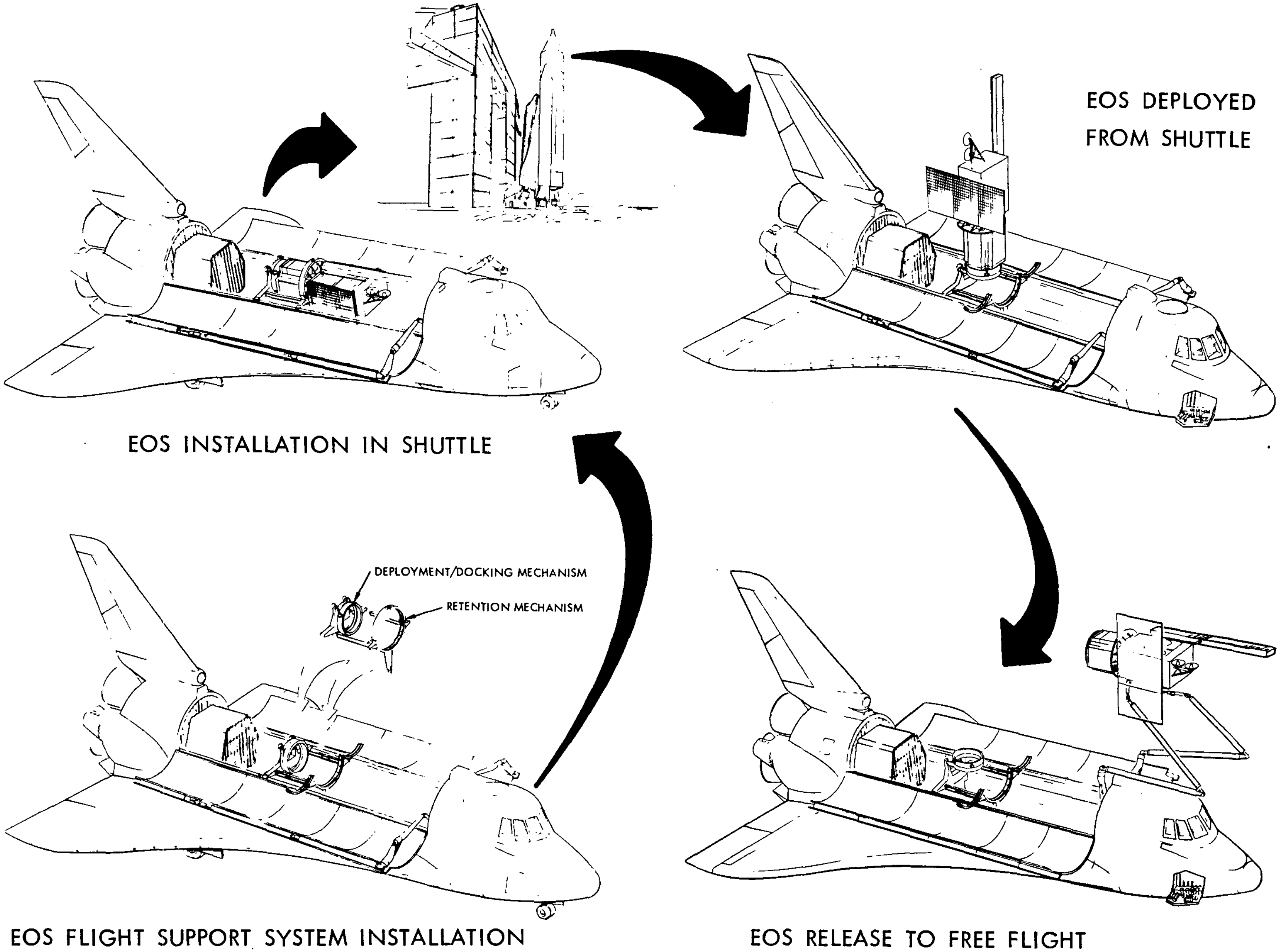

Figure 10. EOS Launch Mission Sequence

CONCLUSIONS

It is felt that this study has been of particular benefit to the eventual implementation of on-orbit servicing of future low-cost satellites since the spacecraft selected for study exemplify the key issues associated with the refurbishment mission. In particular, the following shuttle constraints and issues have been identified on which further action needs to be taken:

- Payload capability to sun-synchronous orbits
- Limits on payload center-of-gravity
- Lower bearing restraint loading direction
- SAMS tip force limits
- Payload bay thermal environment
- Payload bay contamination environment
- Thruster impingement

Each of these is described more fully in the paragraphs which follow.

The performance required of the shuttle has been specified in terms of three reference missions (Reference 4) and extrapolated to other missions. Recently the requirements of the reference missions were revised and the capability to perform the EOS mission appears marginal. Continued analysis of the performance of the shuttle for the EOS is required to assure that these significant mission requirements are not overlooked.

The location of the OMS tank kits in the aft section of the cargo bay introduces a significant bias in the location of the center-of-gravity and, for the refurbish mission when the ascent payload is small, creates an out of tolerance condition for a landing from an abort during the launch phase. The most desirable solution from the payload standpoint, would relocate the supplementary OMS propellant to some other location than the cargo bay near the desired center-of-gravity. Failing that, the most straightforward approach would appear to be to design the shuttle to ensure expending or dumping of the propellant prior to landing from a launch abort.

Lacking any definitive requirements from payloads, the shuttle design of the structural approach to retain payloads in the cargo bay has been oriented toward a generalized model in which the payload contains discrete hardpoints which can interface directly with corresponding points in the cargo bay structure. The retention system desired by the EOS can be made to utilize the resultant shuttle configuration, but only by introducing additional structural complexity and weight into the FSS. In particular, the shuttle approach of not taking any fore and aft loads on the lower bearing restraint has led to a heavier design for the EOS retention mechanism. It is believed that further analysis of alternate load paths will lead to design simplification and lower weight.

The constraints resulting from the limits on tip forces producible by SAMS contributed to selection of a separate mechanism for effecting module exchange. This selection has other programmatic benefits also. The EOS family will include satellites for deployment by the tug into geosynchronous orbits which will utilize some subsystems packages in common with the lower altitude satellites. In order to service these geosynchronous satellites on-orbit, a mechanism similar to that selected in this study will be required to be mounted on the tug. There is, therefore, a commonality of technology and interfaces which would not be present if SAMS were used for module exchange.

The temperature limits in the cargo bay to which the satellite is being designed are much broader than the desired range of temperatures for the EOS. Temperatures are a result of thermal interchange with time however, and much detailed analysis is required to evaluate the extent and solutions to the apparent EOS thermal problems in the shuttle.

The contamination levels and constitutents in the cargo bay are under study at this time, but it is not expected that they will meet the requirements of all EOS sensor equipments. The inclusion in the shuttle of a clean liner in the lower cargo bay and a clean purge flow during ground operations are considered essential steps towards assuring a suitable environment but considerable additional analysis is needed to completely resolve the issue.

The desired thruster plume arrangement which involves rotation of the forward RCS pod is associated with the capture and release phases of the mission. If the suggested rotation proves to be infeasible, an operational approach will have to be found which avoids direct impingement on the EOS during these operations.

In addition to the shuttle constraints and issues described, the study has resulted in the definition of a Flight Support System which has potential for wide application by virtue of its versatility and straightforward control. By defining only a relatively few, simple interface provisions on a spacecraft, the EOS Flight Support System can be adapted to refurbish a whole family of satellites. These interfaces include the latches, module sizes and locations, the docking structure, retention requirements, umbilicals, and displays/controls.

Finally, it should be noted that the adequacy of the cargo bay cannot be judged from the size of the satellite alone. In order to accomplish the total mission, additional system elements are required which can test the designer's skill to include within the fixed limits of what would otherwise be a generously sized volume.

RECOMMENDATIONS

It is considered necessary to continue the parallel definition of the Flight Support System with the EOS and shuttle definition because of the interactions between the systems. In particular, it is felt to be essential to develop the capability to provide, in the near future, the feasibility of on-orbit module exchange in view of the potential impact on the satellite and shuttle designs. This proof might logically take the form of a working engineering model of the system. Further, it is important to the shuttle program to continue investigations of payload interfaces and requirements such as those described above to provide realism to the evolving designs. Finally, a continuing cognizance should be maintained of the development and demonstration of the capabilities of the shuttle manipulators.

FLIGHT SUPPORT SYSTEM CONCEPTUAL DESIGN

FLIGHT SUPPORT SYSTEM - SUMMARY

The function of the FSS is to perform and support all operational procedures established by mission requirements for the proper handling and monitoring of the EOS through the phases of ground handling, launch to orbit acquisition, on-orbit operations, i.e., deployment and launch, retrieval and docking, module and unique assembly exchange, stowage of EOS, modules and assemblies and earth return. Jettison provisions for all or part of the payload are also incorporated for crew and orbiter safety.

The FSS consists of several subsystems secured in the payload bay each configured to perform the required functions in support of the EOS.

These functions are:

1. EOS retention in the payload bay to meet launch and retrieval requirements.
   Subsystems - payload retention ring
2. EOS deployment from the payload bay to a position 90 degrees (120 degrees for engine exchange) to the SSO longitudinal axis in preparations for on-orbit launch and/or assemblies and modules exchange.
   Subsystems - deployment platform/docking system
3. Rotation of the EOS about its longitudinal axis when in the deployed position to face toward the refurbishment systems.
   Subsystems - rotating docking ring incorporated in the deployment platform
4. Stowage of exchange assemblies and modules in the payload bay.
   Subsystems - module magazine and unique assemblies stowage frame
5. Assemblies and module exchange from the EOS to the payload bay stowage and reverse.
   Subsystems - module exchange mechanisms with module handling fixture and SAMS with end effector

6. EOS docking to the SSO for refurbishment/retrieval
   Subsystems - deployment platform/docking ring and SAMS
   with end effector

GENERAL ARRANGEMENT (Drawing 3061-51)

The EOS when stowed in the payload bay occupies the forward 36 feet of the payload envelope with the longitudinal centerline 15 inches above the SSO centerline. The payload retention ring located at the approximate midpoint of the payload envelope encircles and clamps to the EOS payload retention interfacing assembly approximately at the EOS center of gravity. Aft of the stowed EOS base and in order are the deployment platform/docking system supported by a 15-foot transverse beam which also supports the magazine forward bearing, the module stowage magazine, and the module exchange mechanism (MEM). A second 15-foot transverse beam supports the MEM and magazine aft bearing. The stowed unique assemblies frame is located forward of the EOS about 9.5 feet aft of the payload envelope forward face.

Two temporary hold devices are provided to accommodate assemblies/modules removed from the EOS prior to moving to the permanent stowage positions. The module hold position is located on the left-hand vertical extend housing and the unique assemblies hold position is located on the right-hand top edge of the stowage frame.

The longitudinal axis of the deployed EOS is approximately 34 feet aft of the payload envelope forward face and the earth viewing side nominally faces the magazine and the MEM. In this position six modules are in the correct attitude for transfer by the Module Exchange Mechanism.

Exchange of the engine assembly utilizing SAMS with its end effector is also accomplished in this orientation by tilting the EOS an additional 30 degrees further back.

The EOS capture/launch coupling is installed on the side opposite the earth viewing face. This enables SAMS to dock the EOS with the same face presentation as described for the deployed EOS.

Exchange of the three subsystem modules, the radar antenna, and the solar array requires a docking ring rotation to present the engaging mechanisms of the units to their respective exchange systems.

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The described payload arrangement with the unique assemblies stowed forward, the EOS centered, and the MEM and magazine aft was selected to give direct access to the various unique assembly positions throughout the exchange cycle and insures that the control of SAMS is in the field of view of the operator. The arrangement also made the most stowage length available for the replacement radar antenna (27 feet long) and the EOS radar antenna without overlapping structural components of the FSS which would increase the constraints on the SAMS and FSS operational modes. The module exchange operation is not considered to require the same operator visibility because of the motion precision that can be incorporated into mechanisms of this type. TV cameras on the SAMS can provide the necessary monitoring function.

FLIGHT SUPPORT SYSTEM VARIATIONS WITH MISSION MODES

Differing EOS mission objectives identify various FSS arrangements for compatibility with mission requirements. FSS subsystems arrangements required for different missions are summarized as follows:

1. EOS launch and/or retrieval mission
   a. Payload retention ring, complete
   b. Deployment platform/docking ring assembly with the support beam
   c. Connecting beams from the retention ring to the deployment/docking system beam
   d. SAMS terminal device
2. EOS refurbishment only
   a. Unique assemblies stowage frame with replacement assemblies
   b. Bottom half of the payload retention ring to provide radar antenna and solar array stabilizers. (The upper sector clamps and actuators can be omitted for this mission.)
   c. Deployment platform/docking ring assembly with the support beam
   d. Module magazine with the replacement modules and the MEM
   e. SAMS terminal device
3. EOS refurbishment/contingency retrieval
   a. All of the FSS subsystems listed in Item 2
   b. Payload retention ring complete with the pitch link

STRUCTURAL INTERFACES WITH SHUTTLE

As presently configured, the shuttle will incorporate a series of hard points along th hinge-line longeron and the lower centerline of the cargo bay to provide attachment points for the payload retention system. No single, standard way of utilizing these points, i.e., number of attach points and direction of loading at each, has been designated at this time. However, Reference 3 identifies four acceptable options which have the desirable characteristics of being deterministic and, therefore, decoupling the shuttle and payload flexures under dynamic loading. The structural approach which was selected by GSFC for the EOS utilizes a single ring bulkhead structure, approximately at the satellite center of gravity called the transition ring, from which the fore and aft compartments are cantilevered. This configuration is held during launch and reentry by a split-ring structure, described in more detail in a later section, which clamps around the transition ring. Figure 11 illustrates the approach selected from among the four options in Reference 3 for mounting this retention ring and the other elements of the FSS in the cargo bay. This particular approach avoids side loads on the cargo bay longerons which might require shuttle structural modifications and does prevent any loading of the EOS or FSS structure from flexure of the shuttle. However, it should be noted that the requirement to react pitch loads on the EOS retention ring into the longerons will create a more complex design problem than would exist if these loads could be reacted at the bottom fitting. This is a shuttle impact area requiring further investigation before a final structural interface approach is adopted. (See Conclusions - Lower Bearing Restraint.)

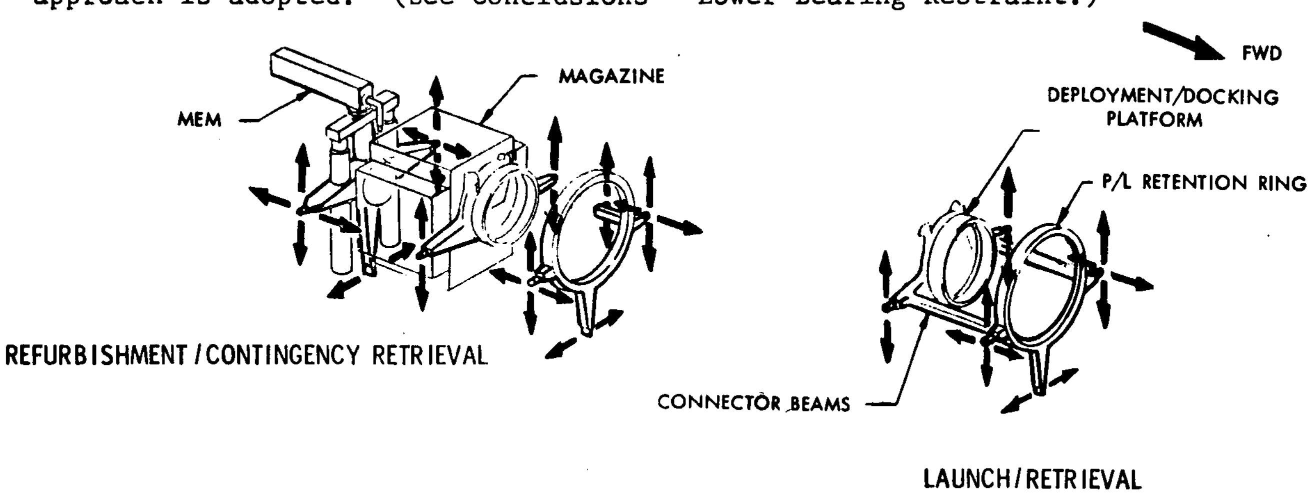


Figure 11. FSS-to-Orbiter Load Paths

FLIGHT SUPPORT SYSTEM DESCRIPTION

SAMS END EFFECTOR AND UNIQUE ASSEMBLY LATCH

As a result of the trades discussed in the earlier sections of this report, the shuttle manipulators (SAMS) were selected to perform a number of different tasks. These include capture of the EOS, solar panel folding and positioning prior to replacement, and replacement of other unique assemblies such as the radar and the pneumatics/orbit adjust module. A common SAMS end effector was felt to be desirable to avoid the problem of changing end effectors for each task. In order to define a conceptual mechanical design for the end effector, it was necessary to assemble requirements for a unique assembly latch and solar panel folding and positioning, and prepare conceptual designs for these mechanisms.

Functional Requirements

The SAMS and its end effector must be able to grasp the unique assembly securely, move it from place to place, orient it correctly and accurately, and then release it. Grasping and release of the assembly is a function of the end effector while orientation and placement of the assembly is a function of the SAMS.

In addition to the requirement for solar panel exchange as a unique assembly, the SAMS and its end effector must have the capability of folding the outboard solar panels prior to removal from the spacecraft and of positioning the solar panel for the particular orbit being flown.

SAMS and its end effector must have the prime responsibility of capturing and docking the passive spacecraft to the deployment platform. Spacecraft capture should be positively accomplished without applying force to the spacecraft until after capture is complete.

The SAMS as defined in Martin Marietta Corp. Report MSC 05218, "Preliminary Design of a Shuttle Docking and Cargo Handling System" was used. The SAMS incorporates a wrist rotation in all three axes at its extremity.

During these functions SAMS is controlled manually aboard the shuttle where the primary method of determining SAMS position and movement is both by visual observation and via a television link.

End Effector and Latch Design Approach

The functional requirements and design constraints were used to develop an approach to the design of an end effector and unique assembly latch. The design approach is illustrated on Drawing 3061-55. The mechanism may be broken down into assemblies; the end effector and the latch which attaches the unique assembly to the EOS. In essence the latch consists of a spring-loaded rod with ball lock. The spring load provides the necessary compressive preload between the EOS structure and the unique assembly. The unique assembly is released from the EOS by pushing the center rod which allows the balls to retract. The latch is provided with a female docking cone which mates with a conical attachment fitting on the EOS. This provides axial alignment with radial alignment provided by a pin riding along a tapered slot in the female cone.

The end effector consists of four claws which are used to grasp the capture disk of the latch and draw it into contact with the end effector structure. The preload rod and center rod may then be actuated. Torques produced by SAMS can be transmitted across the interface by means of flats on the rim of the capture disk. The claws may be opened sufficiently wide to take care of misalignments between the end effector and capture disk.

The method for attachment of a unique assembly to the EOS is as follows:

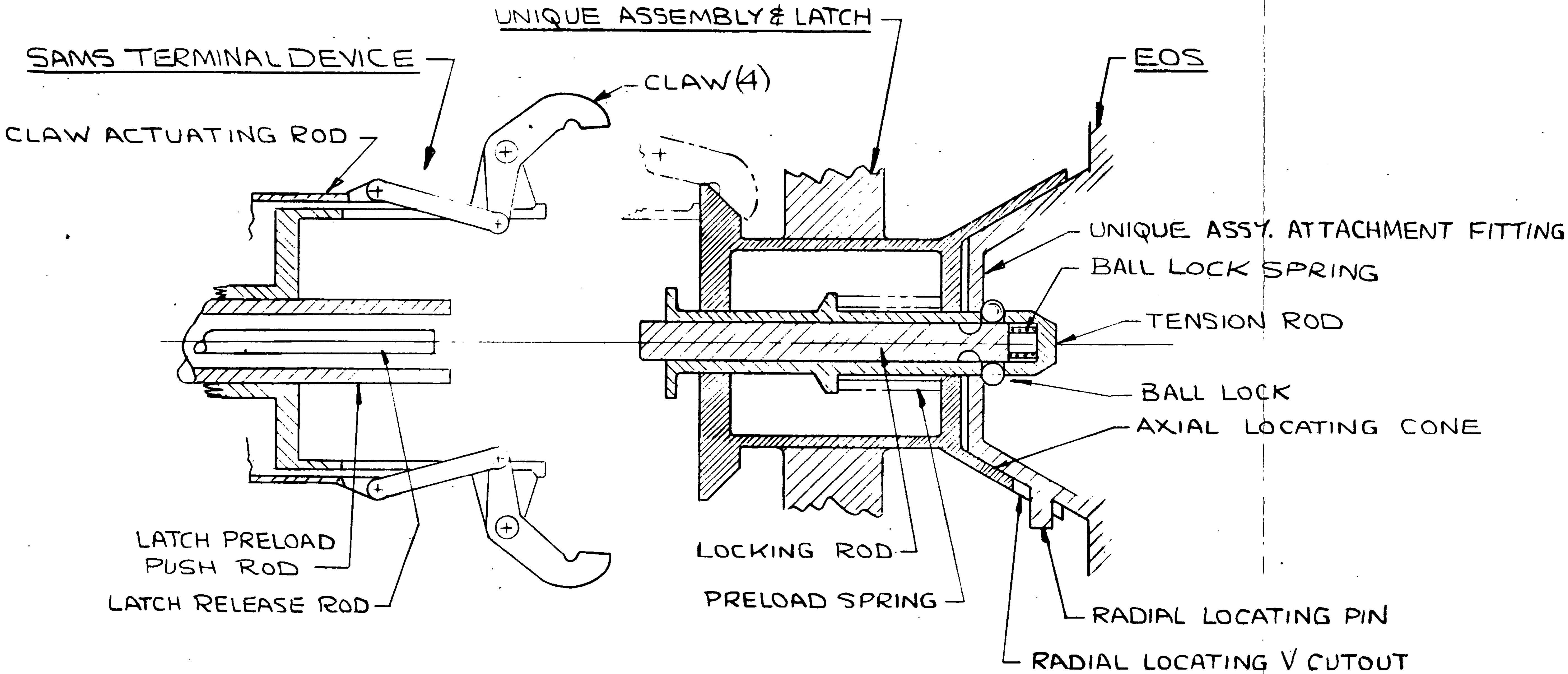
1. Grasp unique assembly latch with end effector
2. Locate unique assembly on EOS conical attachment fitting
3. Push center locking rod by extending center rod of terminal device to relase ball lock
4. Push preload rod
5. Extend ball lock by retracting center rod
6. Retract preload rod
7. Open claws and remove end effector

Solar Panel Latch Concept

Drawing 3061-58 shows the latch required to attach the solar panel unique assembly to the EOS using the mechanical concept described above. The latch also incorporates electrical power and signal connections and the panel drive mechanism. It was found necessary to define a latch conceptual design to derive a SAMS end effector design.

FOLDOUT FRAME 1

FOLDOUT FRAME 2



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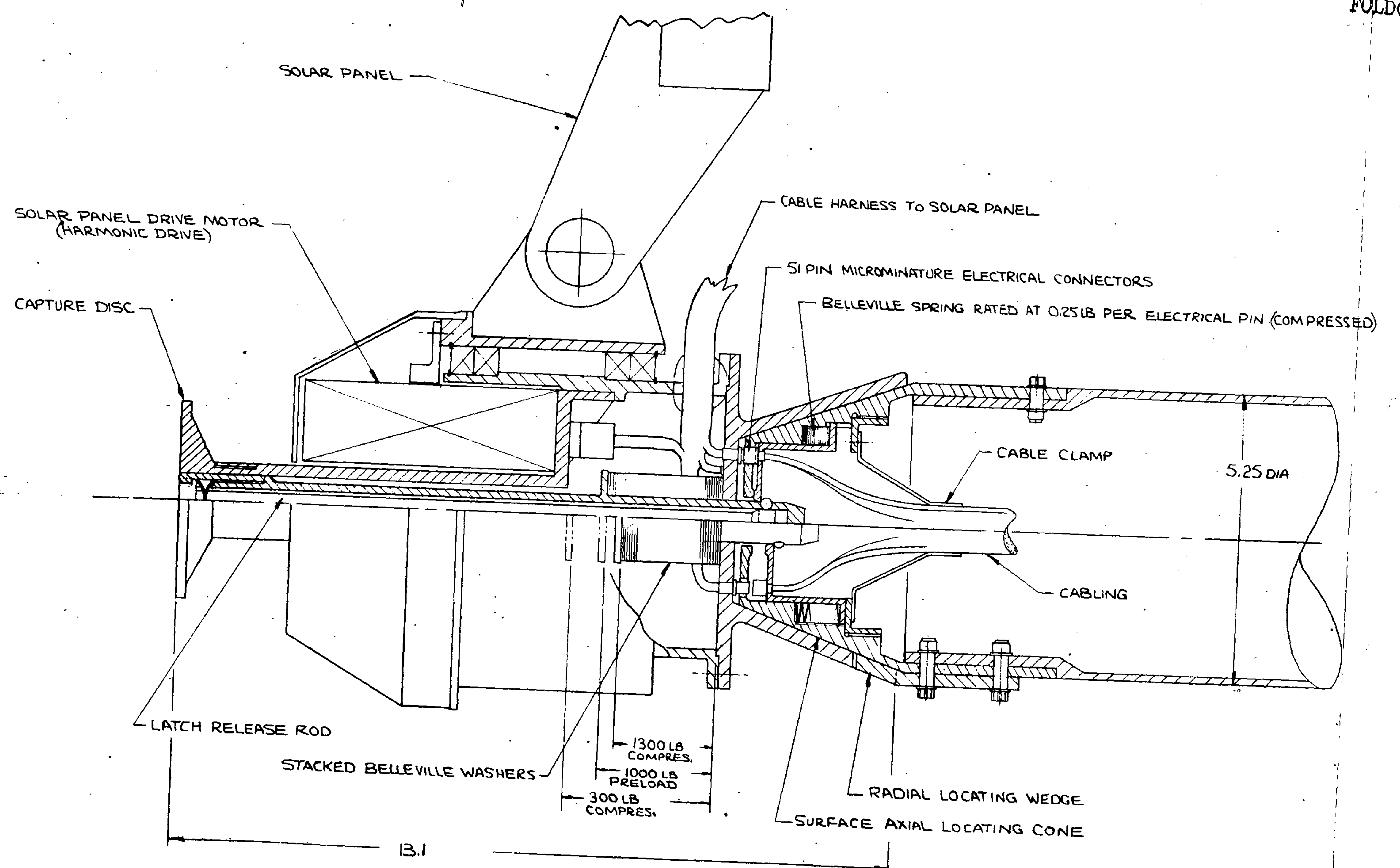
SPACE DIV NR	FUNCTIONAL AND MECHANICAL DIAGRAM. UNIQUE ASSEMBLIES LATCH AND EOS CAPTURE DEVICE	3061-55

FOLDOUT FRAME 1

FOLDOUT FRAME 2



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NORTH AMERICAN ROCKWELL CORPORATION

LATCH CONCEPT - SOLAR PANEL ASSY.

3061-58

SD 72-SA-0194

The latch consists of an octagonal capture disk and axially located preload rod and release rod. Preload of 1000 pounds is provided by a series of Belleville washers. The design incorporates electrical connectors of the microminiature kind typified by Microdot D series. Approximately 300 pins are available if necessary. Attachment of the electrical connectors halves to their rings features a small amount of float to ensure that the tapered metal cases can align satisfactory. Each pin in the connector requires between 0.25 to 0.5 pound force to provide a good electrical contact. The force to mate the connector is available out of the preload force with the disconnecting force provided by a separate spring.

SAMS End Effector

A conceptual SAMS end effector is shown on Drawing 3061-56. The concept consists of four claws having the capability of opening wide enough to take care of lateral and angular misalignments of the latch capture disk relative to the SAMS. The claws are positioned over the capture disk, so that the fingers are behind the disk, then slowly closed. The first claw to contact the disk will apply a small force to the disk while the remaining three continue to close until all four claws grasp the disk. Further claw retraction aligns the disk axially and radially and in contact with the central tube of the end effector. It should be noted that a force feedback system in the SAMS will limit the force applied to the capture disk which would occur due to deflection of the manipulator arms if the end effector is initially misaligned with the latch. Actuation of the central rods operate the unique assembly latch mechanisms. Force requirements for these rods are estimated as 50 pounds for the latch disconnect rod and 1300 pounds for the preload rod. Motors for device operation are contained in the rear housing.

Candidate instrumentation for the end effector will consist of:

1. Motor and structure temperature transducers
2. Structural load transducers
3. Preload rod force transducers and position indicator
4. Lock rod force transducers and position indicator
5. Capture disk position indicator

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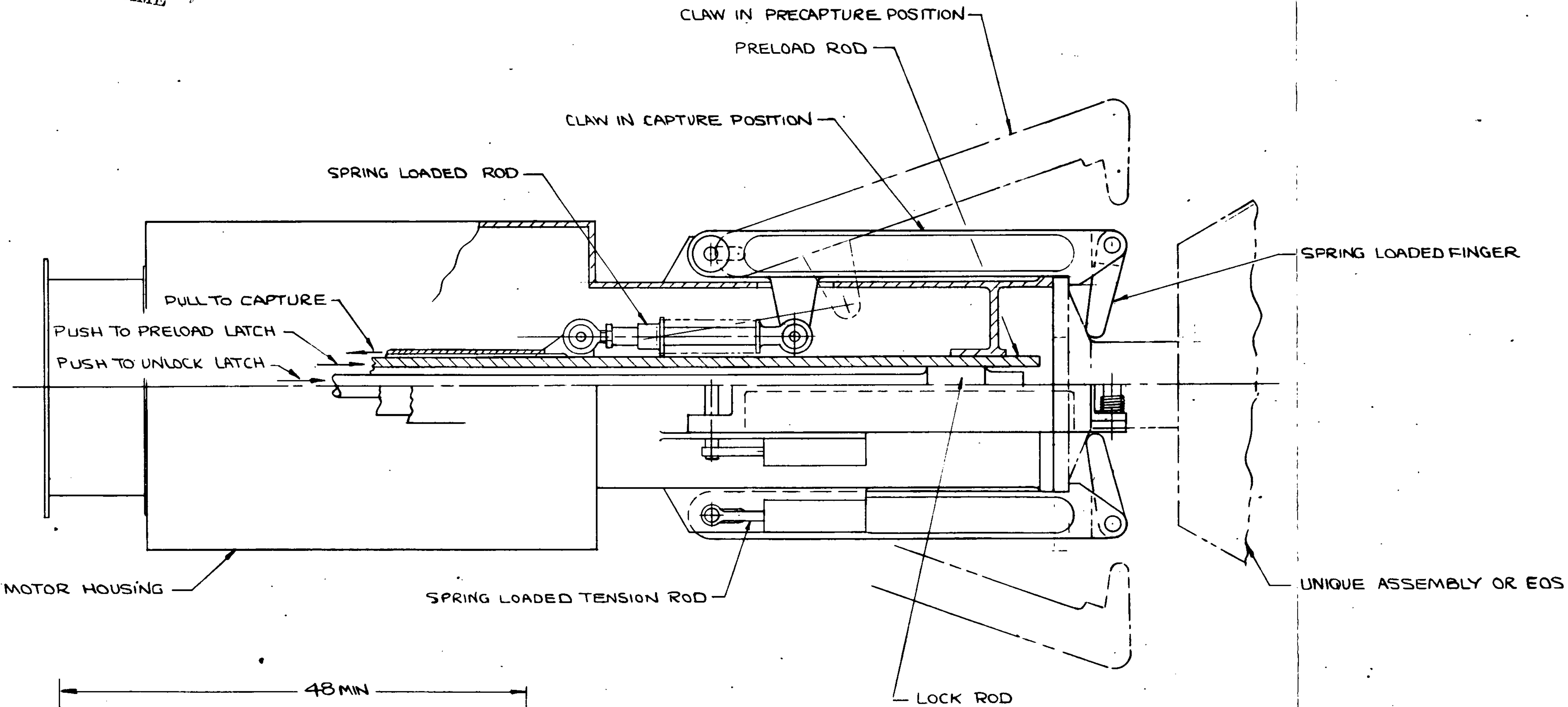
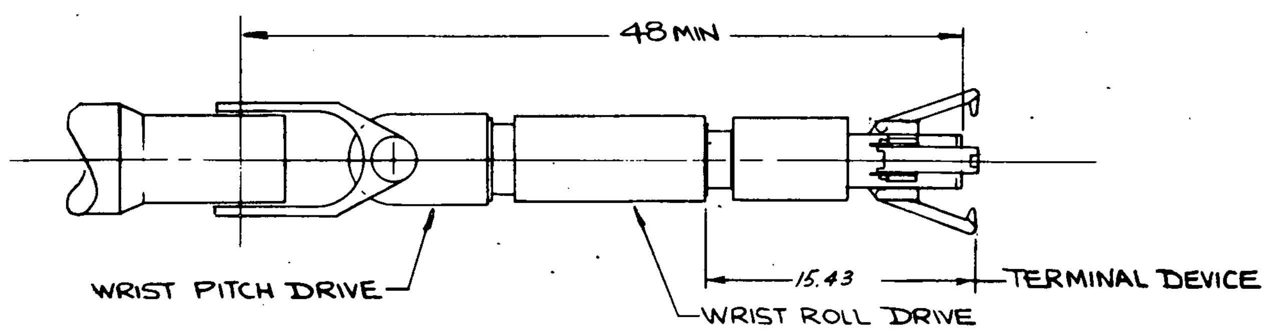
FOLDOUT FRAME 1

FOLDOUT FRAME 2





DETAIL OF SAMS TERMINATION
SCALE 1/6

SD 72-SA-0194

SPACE DIVISION
NORTH AMERICAN ROCKWELL CORPORATION
12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA

SAMS TERMINAL DEVICE MECHANISM CONCEPT

3061-56

Solar Panel Folding and Positioning Device

As shown on Drawing 3061-57 the SAMS end effector is used for positioning and folding the EOS solar panels. Folding or unfolding of the panels is required in order to stow the EOS in the shuttle bay while positioning is required to orient the panel to the proper attitude for the orbit being flown. The mechanical concept to operate the panels is used for both folding and positioning. In essence, the mechanism consists of a capture disk and spring-loaded central locking device, which will lock the panels in an unfolded and folded position and into the orientations required for various orbits. The mechanism capture disk is grasped by SAMS end effector and unlocked by pushing the central rod using the preload rod. This has the effect of moving a key from a keyway. Torque applied by SAMS wrist roll motor is used to fold or position the panel.

UNIQUE ASSEMBLIES STOWAGE AND REPLACEMENT

Three unique assemblies are stowed on the assemblies stowage frame; the orbit adjust engine assembly, solar array, and the radar antenna. Attachment of the assemblies to the frame is accomplished by passive couplings secured to the frame at the appropriate positions which are compatible with the unique assemblies latching mechanisms.

Drawing 3061-52 depicts the unique assemblies interface conditions and operational modes during removal of these unique assemblies from the spacecraft and their replacement by new components as stored in the Shuttle vehicle. There are no electrical connections made between SAMS and the unique assemblies. The only electrical connection is between the unique assembly and the EOS.

The drawing illustrates the spacecraft (EOS 6B) mounted to the docking ring and tilted aft 30 degrees to allow SAMS to be positioned as shown to accommodate engine exchange. The SAMS terminal device as shown incorporating the end effector is 48 inches in length. This length is necessary to allow SAMS to clear the docking ring shown in section on the drawing.

For radar and solar array exchange the spacecraft is erected to a 90-degree position and is rotated as required to allow SAMS access to the appropriate handling capture disk on the solar array or radar antenna.

A temporary hold coupling is located on the top right-hand side of the frame and takes part in the transfer sequence of an unique assembly exchange.

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The following describes the transfer sequence for the solar array assembly exchange.

1. The SAMS end effector actuates the array positioning mechanism to place the array parallel to the longitudinal axis of the EOS.
2. The SAMS end effector actuates the array panel folding mechanism to stack the panels.
3. The SAMS end effector grasps the array latching assembly and unlocks it from the EOS coupling.
4. The SAMS transfers the array to the temporary hold coupling and locks it in place in an aft facing position.
5. The SAMS transfers to the replacement array latching assembly, grasps the latch, unloads it, and with a translating, rotating motion disengages the array stabilizing/attenuation attachment on the payload retention ring.
6. The SAMS transfers the array to the EOS coupling and locks it in place.
7. The steps described in 1 and 2 are reversed to unfold and position the array.
8. The SAMS returns to the array on temporary hold, grasps the latch, unlocks it, and transfers the array to the stowage position.
9. The SAMS engages the array in the stabilizing/attenuation attachment and the coupling and completes the locking process.
10. The SAMS proceeds to the next operation.

The unique assemblies stowage frame has a hollow box cross-section and is shown in Drawing 3061-52 to be "C" shaped with the left and right arms terminating in bases at their ends for attachment of the load transfer trunions. Brackets are provided for the couplings for the stowed radar antenna and solar array and a center side load transfer member is secured to the bottom of the frame and extends down to a blade type load reaction fitting on the payload bay lower centerline. The aft pair of trunions mate with saddle type fittings secured to the payload bay upper longerons and react forward and aft and up and down loads. The forward pair of trunions mate with longeron fittings that react up and down loads only.

In order to meet crew safety requirements, all longeron fittings which support FSS elements which could malfunction and prevent closure of the cargo bay doors (and, therefore, prevent reentry) are provided with contingency jettisoning devices to break the load path connection between the FSS element and the shuttle. The SAMS is utilized to perform the separation maneuver.

All unique assemblies stowage couplings on the frame are provided with lock/unlock signal devices to assure the FSS operator that the assemblies are secured or ready for transfer.

PAYLOAD RETENTION RING AND DEPLOYMENT PLATFORM ASSEMBLY

The payload retention ring is used to structurally support the spacecraft during launch, entry from orbit, and landing. Since the spacecraft is not attached to the deployment platform during this time, the platform is only subjected to loads associated with on-orbit operations only such as EOS docking, positioning, and module or subsystem exchange.

The spacecraft thus has two retention alternatives; supported by the retention ring or docked to the deployment platform. Spacecraft transfer between these two alternatives is accomplished by either retracting the docking latches on the deployment platform or releasing these latches and actuating the retention ring mechanisms so that the spacecraft is supported by the retention ring only. The purpose of this transfer is to eliminate loading the docking ring during flight conditions.

Two connector bars are incorporated between the retention ring and the deployment platform to integrate the two elements into a single unit for ground handling. As a secondary benefit, the connector bars provide accurate spacing between the two elements to facilitate docking the spacecraft to the platform prior to deployment. When the FSS includes the magazine the connector bars are replaced by a pitch link attached to the retention ring. The purpose of this change is to simplify structural load paths. A conceptual design of these elements is shown on Drawing 3061-54 and discussed in the following paragraphs.

Retention Ring

The retention ring is an all aluminum box section structure spanning the payload bay where it is attached to the Shuttle bay longerons by saddle fittings and attached to the bay keel structure through a fitting having capability of resisting side loads only. The upper portion of the ring features two hinged sector clamp halves which are opened to allow installation or deployment of

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the spacecraft. Hinging is accomplished by two linear motion electric actuators. After the clamp halves are closed with spacecraft in place, an upper motorized latch is activated which applies a hoop tension to the ring thus clamping the spacecraft in place.

The interior ring of the box structure which interfaces with the spacecraft will be a close tolerance machined section made in three pieces to accommodate the clamps. Forward movement of the spacecraft is restrained by a one inch high lip or flange on the section. The spacecraft transition ring is held against this lip by a series of eight mechanisms on the rear surface of the ring when the spacecraft is to be retained by the ring.

Two fittings installed on the forward side of the lower ring structure are used to support unique assemblies when they are stowed in the payload bay.

When the spacecraft is docked to the deployment platform there is a nominal gap of 1.5 inches between the lip of the retention ring and the spacecraft frame. This gap is used to minimize the amount of lip required to be removed to clear the arcing motion of the spacecraft as it is deployed. Lip removal amounts to 20 degrees below the centerline to eliminate this problem.

Deployment Platform

The deployment platform consists of two basic elements; a docking ring support frame and docking ring.

Support Frame

The support frame spans the payload bay and is attached to the Shuttle structure with two pillow blocks. By using a sliding block arrangement, fore and aft loads will not be transmitted into the Shuttle structure by this frame. The frame has provisions for attachment to the module magazine when necessary. A vertical extension from the basic frame to the hinge line supports the docking ring structure.

Docking Ring

The docking ring consists of an inner and outer ring structure. The inner ring structure is sized to allow withdrawal of the EOS propulsion system through the center. A gear quadrant attached to the inner ring is driven by a rotary actuator attached to the frame structure. The ring is locked in any of three positions by an electrically operated lock pin. The outer ring, supported by ball bearings, is rotated on the inner ring by a gear drive and rotary actuator.

Attachment of the spacecraft to the docking ring is accomplished by four latches. The worst case under which the latches must function is that of a docking operation using SAMS. For this case, axial misalignments up to 2 inches and angular misalignments up to 1 degree have been specified as the baseline SAMS accuracy in positioning a payload. After latch operation bringing the spacecraft to a fully docked condition, correct relationship between the spacecraft and docking ring is necessary for MEM operations. This requirement is accomplished by the latch mechanism which incorporates a double angle wedge feature for alignment of the spacecraft as it seats on the docking ring. Seating of the spacecraft is performed simultaneously by four motorized latch hooks engaged to the spacecraft lower frame. Last motion of the spacecraft connects a floating electrical umbilical which is provided on the docking ring so that spacecraft functions can be monitored during support operations when the spacecraft is fully docked. At other times, such as during launch, the connector is open.

Deployment platform cabling must be designed to flex during docking ring rotation. A design incorporating rolled ribbon cable is considered suitable.

Connector Beams and Pitch Bars

The connector beams are defined conceptually as aluminum rectangular beams, 8 inches by 16 inches in section, and 101 inches long. Flanged end fittings provide bolted joints to the frames at each end. The beams are replaced by a pitch bar bolted to the retention ring for certain operational modes when the connector bearms are not required.

MODULE MAGAZINE AND EXCHANGE MECHANISM

The module magazine and exchange mechanism is an integrated assembly with provisions for stowage of the replacement modules and a mechanism for performing module exchange between the EOS and the magazine. The mechanism consists of a number of major elements described in the following paragraphs and illustrated in Drawing 3061-53.

Module Magazine

The magazine is a boxlike structure mounted and rotatable on a center shaft and supported at the forward end by the deployment platform load transfer beam, and at the aft end by a transverse beam which also supports the MEM and the magazine rotation system.

The aft beam transfers the loads into the payload bay upper longeron and to the bay lower centerline in the same manner as described in the section headed "Payload Retention Ring" which also includes a description of the jettison and separation method.

The magazine is compartmented to match the replacement modules, 8 for EOS No. 6B and 5 for EOS No. 6C, and includes module latching components and signal devices identical to those on the EOS. The replacement modules that are included in the magazine for EOS No. 6B follow: radar electronics, metric camera, pointing imager, thematic mapper (alternate is the K-band antenna assembly), instruments and three subsystem modules. The magazine also provides a stowage position aft of the subsystem modules compartments for the module handling fixture.

For missions involving EOS No. 6C, the magazine is configured to receive the microwave radiometer in the compartments formerly occupied by the radar electronics, metric camera, pointing imager and the thematic mapper. The remaining modules are the same as described for EOS No. 6B.

As shown, the magazine has the capability of rotating in 90-degree increments to expose the modules to the module handling fixture for extraction. The magazine structure features a central tubular structure on which the magazine rotates, driven by a rotary actuator and gear wheel. Primary structure of the magazine is of aluminum honeycomb construction although machined aluminum frames may be considered as an alternate. The module or subsystems are held in the magazine by two latches similar to those used on the spacecraft (four are used on the spacecraft).

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A two-point attachment is provided to support the module handling fixture during launch. The arm-tip actuator of the fixture is used to grasp dummy latch fittings.

The modules and subsystems are not connected electrically to the umbilical when they are installed in the magazine. Therefore, no checkout of the subsystems is possible until installation in the spacecraft. The thermal and launch dynamic environment of subsystems installed in the magazine will be different from those seen by subsystems installed and launched in the spacecraft. Any additional requirements placed on the FSS design by the subsystem must be defined by future analysis.

Module Exchange Mechanism

The module exchange mechanism (MEM) provides the capability of exchanging experiment modules and spacecraft subsystems. Exchange operations take place outside the view of the system operator, and remote TV viewing may be used to monitor the operations.

Module Handling Fixture

The module handling fixture is the portion of the MEM which attaches to the spacecraft modules or subsystems and unlocks the latches preparatory to removal. The attachment feature is used to hold the module during the motions associated with module exchange. The concept consists of a central box structure through which two parallel arms extend. The arms are retracted fully for stowage but are extended to match different modules. The end of each arm contains the module-latch actuator used to grasp and unlock the module latch. The actuator concept is expected to be similar in concept to the SAMS terminal device design described earlier. Only two latches are actuated at one time, requiring that the handling fixture be rotated across the other diagonal to complete actuation of all four latches on a module. During module stowage a further degree of freedom is required, that of a wrist action which translates the module through 90 degrees to stow the module in the magazine. The fixture structure is constructed of aluminum.

Arm extension and retraction is performed by a single rotary actuator through a precision rack on the arm and pinion on the actuator. Limit switches on the arm may be used to accurately position the outboard tip of the arm. Rotary motion and wrist motion of the fixture is accomplished by two similar rotary actuators using a harmonic drive for the final speed reduction.

X-X Traverse Arm

The arm consists of two telescoping tubes having an extension capability of approximately 10 feet. Arm extension and retraction is used for installing and removing modules from the spacecraft. The arm drive motor is powerful enough to overcome any friction forces in the module guides.

The arm is constructed of square-section aluminum using low friction bearings at the sliding corners to minimize binding and maintain precision. The telescoping sections are extended by two similar rotary actuators driving precision rack and pinion. Position lock is achieved by incorporating a harmonic drive as the last gear reduction together with a motor brake. (A stepper motor with permanent magnet field would be suitable.)

X-X Traverse Turntable

The turntable is used to orient the traverse arm for placing a spacecraft module on the temporary hold fixture. The mechanism consists of inner and outer sleeves using ball bearings for accuracy and low friction forces. The turntable is rotated by a pair of actuators similar to those on the X-X traverse.

Y-Y Traverse and Carriage

This mechanism consists of a carriage moving in two aluminum I-section beams. The requirement for this construction, rather than a more efficient box structure, is dictated by clearance for the center extender. The carriage features an aluminum structure with eight rollers guiding the carriage on flanges of the I-beams. The carriage is driven by a rotary actuator using a precision rack and pinion. A second actuator attached to the carriage drives the center extender.

Z-Z Telescoping Mechanism

In order to reach the K-band antenna module, the module handling fixture must have an extension capability of about 20 feet from its stowed position in the Shuttle bay. This has been achieved by utilizing a pair of telescoping structures with two elements each and a center extender. The telescoping tubes are constructed of aluminum tubing featuring low friction bearing material attached to exterior ribs. The two telescoping structures are driven simultaneously by pairs of rotary actuators using precision rack and pinion drives. The diameter of the telescope housing is 16 inches, based on stiffness requirements.

Thermal distortions due to temperature gradients across and between the two telescoping tubes could introduce binding and unacceptable misalignments in this mechanism. While no detailed analysis has been performed, preliminary estimates indicate that these distortions can be kept to tolerable levels by suitable surface treatment and shuttle attitudes. Additional countermeasures which could be effective include heaters and enclosing insulation. Thermal control will be a key issue in future studies of this system.

MEM Support Structure and Cabling

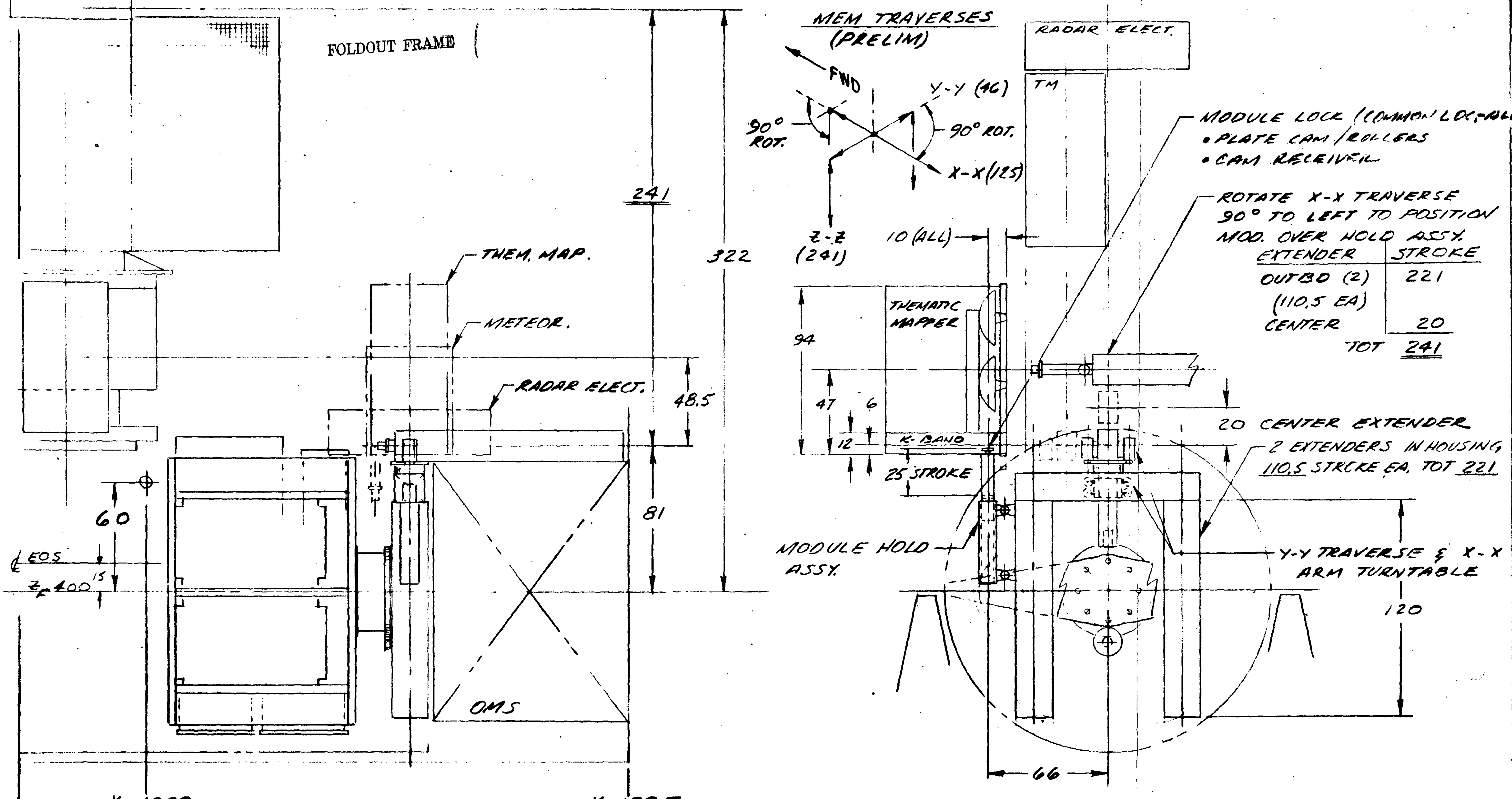
The structure consists of a box-section aluminum beam which spans the Shuttle payload bay with an extension to the Shuttle keel. This beam also supports the aft end of the magazine structure through a bolted flange joint.

An extensive cabling system will be required to electrically connect various components to a central data handling system. These components have been identified as: load transducers, position indicators, temperature transducers, and motors. The cabling will be required to move with the various extension and traverses of the components. A cabling system design utilizing either flat conductor or round wire ribbon cable has been tentatively selected. The ribbon is rolled using a center roll technique having the capability to return to its original configuration after extension.

Temporary Hold Assembly (Drawing 3061-45)

This device is used as a temporary hold for modules or subsystems being transferred to or from the magazine. The device extends beyond the payload bay envelope after the Shuttle doors open to provide adequate clearances for the modules. The end of the extending part of the assembly is equipped with a motorized latch. The lower surface of each module or subassembly must be equipped with a circular recess and cam surface. In operation the module is placed upon the latch; the cam follower is turned to lock the module in place. Switches in the latch indicate positive lock.

During the time that the module or subassembly is in temporary hold position, it will be exposed to a different thermal environment that it would see when installed in the spacecraft. Requirements for thermal control of the subsystem by the FSS should be examined in the light of this requirement. If found necessary, electrical powers for heaters could be transferred across the module latch interface.



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SPACE DIV NR	MODULE TEMPORARY HOLD SYS. EOS NO. 6B	3061-45

CONTROL AND DISPLAY

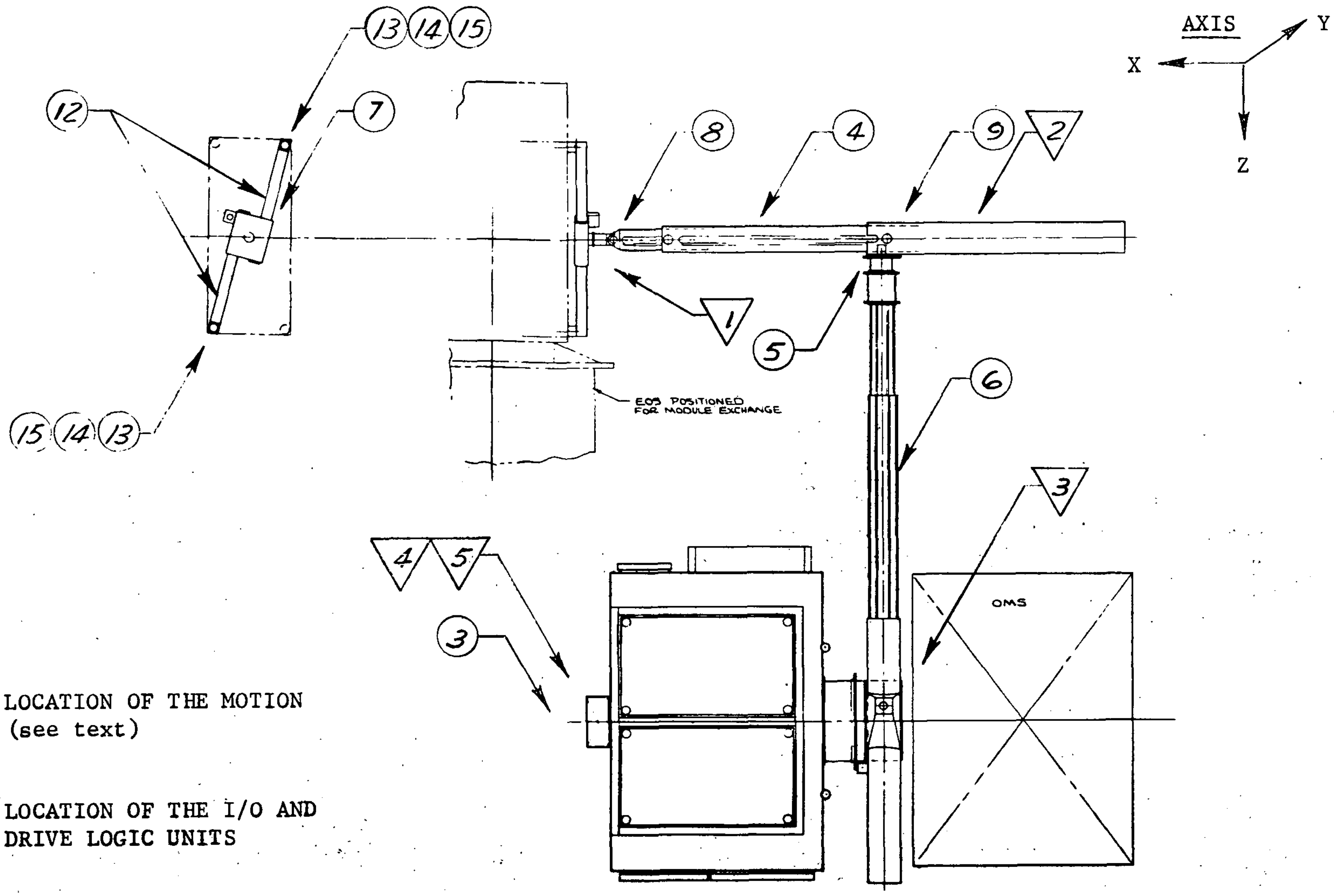
Objective

The objective of the analyses on the control and displays for the EOS Flight Support System was to establish the performance characteristics to a sufficient depth to allow estimating their physical properties; i.e., the size, mass properties, and power requirements. The control and display subsystem includes:

1. The motors, gear boxes, instrumentation, etc., necessary to control or position loads
2. The motors, gear boxes, instrumentation, etc., necessary to perform the module latching function
3. The acquisition and analyses of the data necessary to perform the control function
4. The display of the operations of the module magazine and exchange mechanism (MMEM)
5. The command of the operation of the module magazine and exchange mechanism by a operator alone or supplemented by automatic sequences
6. The providing of data for external monitoring

Baseline Flight Support System

The baseline MMEM used for this analysis is shown in Figure 12. Not shown in the figure and included within the scope of the baseline are: (1) the retention ring used to hold the spacecraft, (2) the electrical connector between the satellite and the FSS, (3) the latching/actuation mechanism located on the SAMS end effector (similar to the ones on the module handling fixture at the end of the MEM X-X traverse arm), (4) the temporary holding fixture, (5) the deployment/docking/indexing mechanism, and (6) the unique assemblies. The axes used for the analysis are shown for reference purposes.



LOCATION OF THE MOTION (see text)

LOCATION OF THE I/O AND DRIVE LOGIC UNITS

Figure 12. Baseline Module Magazine and Exchange Mechanism

The motions identified for the Baseline Flight Support System are:

1. Deployment/docking/indexing: Rotation Z axis
2. Rotation Y axis
3.* Magazine rotation, X axis
4.* Exchange mechanism: Traverse X-X
5.* Traverse Y-Y
6.* Traverse Z-Z
7.* Rotation X axis
8.* Rotation Y axis
9.* Rotation Z axis
10. Temporary hold mechanism: Extension
11. Rotation lock
12.* Module handling fixture: Traverse arm extender
13.* Locking rod
14.* Push rod
15.* Claws
16. Terminal device: Locking rod
17. Push rod
18. Claws
19. Retention ring: Upper ring actuation
20. EOS clamp mechanism
21. Ring latch
22. Electrical connector umbilical

*The approximate location or axis of these motions are identified on Figure 12.

Functional Analysis

A functional analysis was performed to establish a baseline procedure for replacing a module in the satellite using the MMEM. The mission operation was broken into seven functions with the module replacement part of the maintenance function. The maintenance function was in turn broken down into seven steps, one of which is module replacement. The functional analysis is shown in concept form in Figure 13 with the functions of particular interest to this study listed below.

5.0 MAINTENANCE
- 5.4 Replace
  - 5.4.1 Position TV for surveillance
  - 5.4.2 Verify position of satellite for module removal
    - 5.4.2.1 Inspect position of satellite with TV
    - 5.4.2.2 Apply power to position drive (if required)
    - 5.4.2.3 Inspect position of satellite
  - 5.4.3 Position module magazine for removal
    - 5.4.3.1 Inspect position of module magazine with TV
    - 5.4.3.2 Release securing mechanism
    - 5.4.3.3 Drive magazine to correct position
    - 5.4.3.4 Inspect position of module magazine with TV
    - 5.4.3.5 Lock securing mechanism

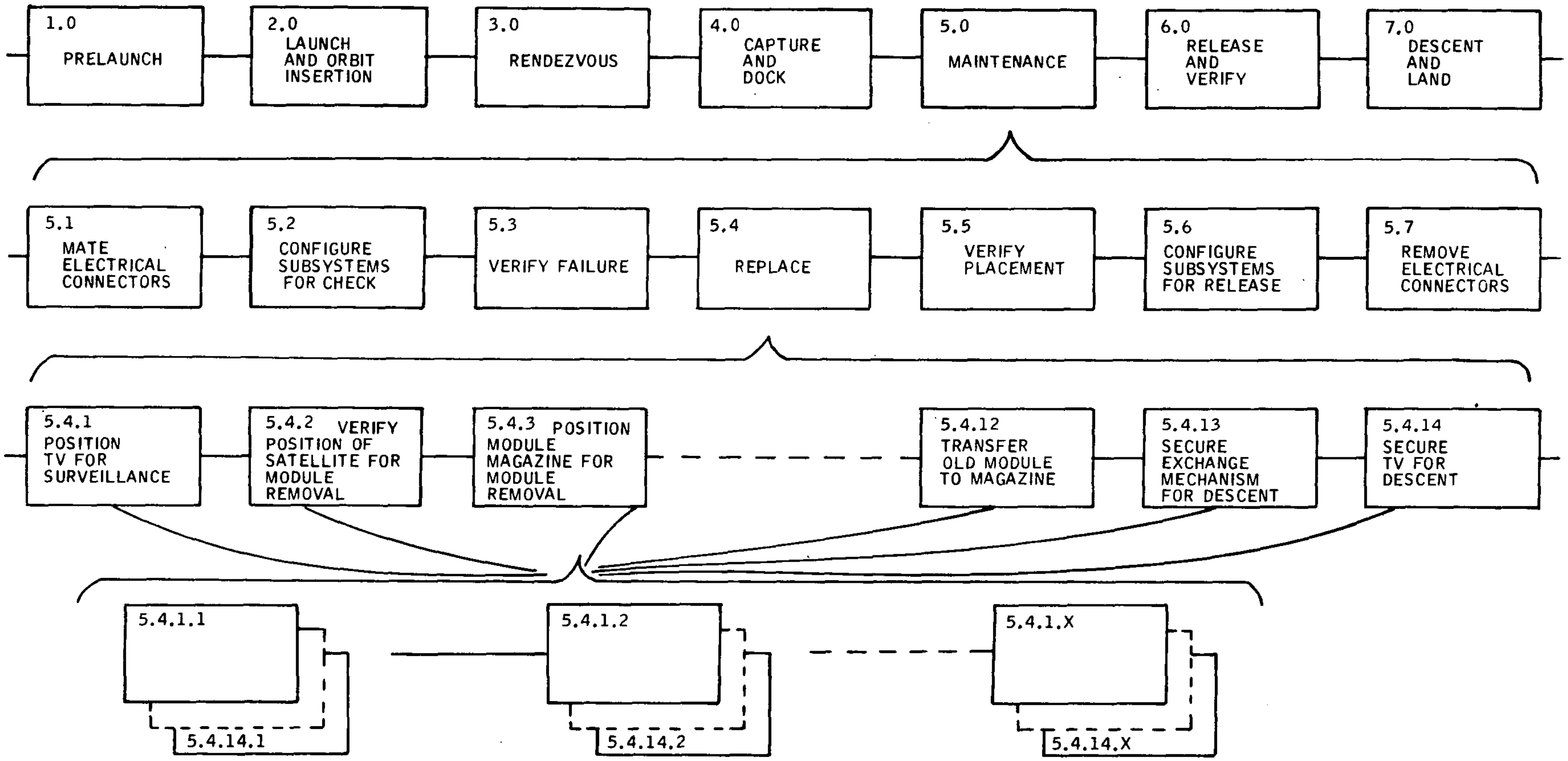


Figure 13. Functional Analysis - Mission Operations

5.4.4 Verify operation of exchange mechanism
- 5.4.4.1 Replace launch security mechanism
- 5.4.4.2 Apply power to control station and check its operation
- 5.4.4.3 Position TV to watch exchange mechanism
- 5.4.4.4 Apply power to drive mechanism
- 5.4.4.5 Test operation of each motion of mechanism
- 5.4.4.6 Perform calibration positioning of mechanism

5.4.5 Engage mechanism in old module
- 5.4.5.1 Position TV to watch mechanism engagement
- 5.4.5.2 Position Z-Z traverse through engagement sequence
- 5.4.5.3 Position Y-Y traverse through engagement sequence
- 5.4.5.4 Position X-X traverse through engagement sequence
- 5.4.5.5 Latch module handling fixture to old module

5.4.6 Remove old module
- 5.4.6.1 Disengage latches between module and satellite
- 5.4.6.2 Traverse in X-X direction to free module from satellite

5.4.7 Secure module in temporary holding
- 5.4.7.1 Position X-X traverse through the sequence for temporary hold
- 5.4.7.2 Position Y-Y traverse through the sequence for temporary hold
- 5.4.7.3 Position Z rotation through the sequence for temporary hold
- 5.4.7.4 Position Y rotation through the sequence for temporary hold
- 5.4.7.5 Position TV
- 5.4.7.6 Position Z-Z traverse through the sequence for temporary hold
- 5.4.7.7 Lock old module in the temporary hold
- 5.4.7.8 Release handling fixture from old module

5.4.8 Engage mechanism in new module
- 5.4.8.1 Position TV to observe engagement in new module
- 5.4.8.2 Position Z-Z traverse through sequence
- 5.4.8.3 Position Z rotation through sequence
- 5.4.8.4 Position Y-Y traverse through sequence
- 5.4.8.5 Position Z-Z traverse through sequence towards new module
- 5.4.8.6 Latch handling fixture to new module
- 5.4.8.7 Release new module from magazine
- 5.4.8.8 Position Z-Z traverse to remove new module

5.4.9 Transfer new module to satellite
- 5.4.9.1 Position TV to observe motion of new module
- 5.4.9.2 Position Z-Z/X-X traverse and Y rotation through sequence
- 5.4.9.3 Position Y-Y/Z-Z traverse through sequence

- 5.4.9.4 Position TV to observe motion of new module towards satellite
- 5.4.9.5 Position X-X traverse through sequence towards satellite

5.4.10 Latch new module in satellite
- 5.4.10.1 Position X-X traverse, engage new module in satellite
- 5.4.10.2 Secure new module in satellite
- 5.4.10.3 Release handling fixture from new module
- 5.4.10.4 Position X-X traverse free from satellite

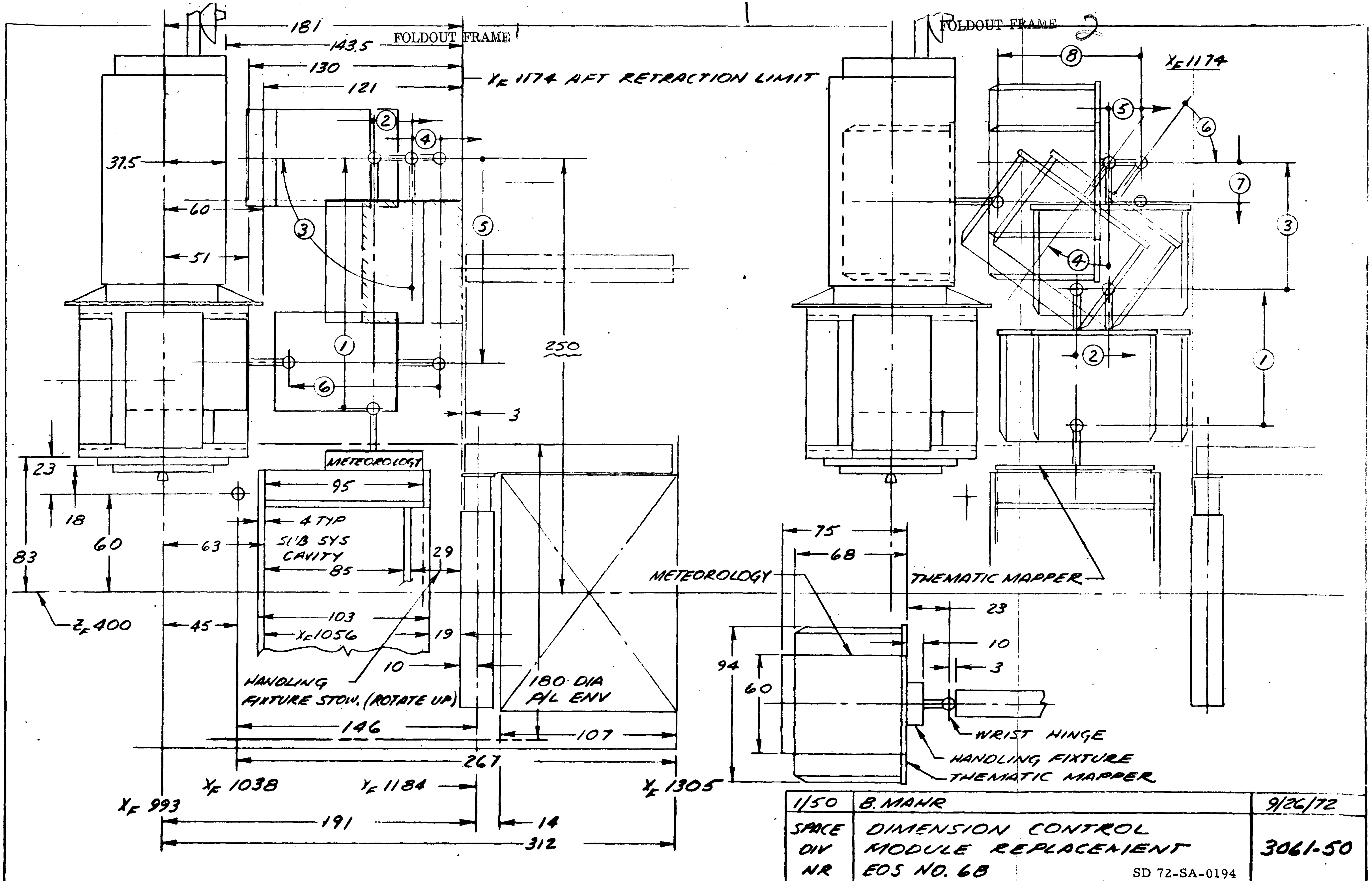
5.4.11 Engage mechanism in old module
- 5.4.11.1 Position TV to observe engagement
- 5.4.11.2 Position X-X traverse through sequence
- 5.4.11.3 Position Y-Y traverse through sequence
- 5.4.11.4 Position Z rotation through sequence
- 5.4.11.5 Position Z-Z traverse through sequence towards old module
- 5.4.11.6 Engage handling fixture in faulty module

5.4.12 Transfer old module to magazine
- 5.4.12.1 Release security mechanism at temporary hold
- 5.4.12.2 Position TV to observe transfer
- 5.4.12.3 Position Z-Z traverse through sequence
- 5.4.12.4 Position Z rotation through sequence
- 5.4.12.5 Position Y-Y traverse through sequence
- 5.4.12.6 Position X-X traverse through sequence
- 5.4.12.7 Position Z-Z traverse through sequence towards magazine
- 5.4.12.8 Engage old module in magazine
- 5.4.12.9 Secure old module in magazine

5.4.13 Secure exchange mechanism for descent or prepare to replace another old module

5.4.14 Secure TV for descent or prepare to replace another old module

A count of the number of motions required by the exchange mechanism showed 80 separate motions were necessary to accomplish the replacement cycle. This does not include the latching, clamping, and securing functions or those associated with the TV motion, nor does it count the individual stops and starts which may be required to provide clearance for movements of the large modules within the restricted volume between the MEM and the EOS. Drawing 3061-50 illustrates some of the sequential steps involved in transferring two of the larger modules from the magazine to their location in the EOS.


FOLDOUT FRAME 1
FOLDOUT FRAME 2
X_F 1174 AFT RETRACTION LIMIT
X_F 1174
METEOROLOGY
4 TYP
SUB SYS CAVITY
X_F 1056
HANDLING FIXTURE STOW. (ROTATE UP)
180 DIA P/L ENV
Z_F 400
X_F 1038
Y_F 1184
Y_F 1305
X_F 993
METEOROLOGY
THEMATIC MAPPER
WRIST HINGE
HANDLING FIXTURE
THEMATIC MAPPER
1/50
B. MAHR
9/26/72
SPACE DIV NR
DIMENSION CONTROL
MODULE REPLACEMENT
EOS NO. 68
3061-50

Control Analysis

An analysis was performed to establish the parameters for controlling the positioning of the various motions of the exchange mechanism. Two motions were examined in sufficient detail to allow the estimation of the physical properties of the command and display equipment. These two motions were the Y rotation and the X-X traverse, numbers 8 and 4 on Figure 12. The Y rotation involves a high inertia load encountered during the motion to/from the magazine and the satellite. The X-X traverse encounters the high friction loads associated with the entry/exit of the module to/from the satellite.

To perform the analyses it was necessary to estimate the time required to accomplish the motion. With the 80 motions identified, one minute was selected to accomplish each motion, which would then require at least 1.3 hours to accomplish the replacement of one module. Figures 14 and 15 show the results of this analysis and the selection of the control loop concept. The sketches of Figures 14 and 15 show a gear box; however, by using the RESPONSYN motor/gear system built by USM Corporation these components can be combined into one assembly. The velocity was found to be the influencing factor which sized the motor and gear trains. The motor torques then became adequate to drive the inertia loads. The frictional loads (X-X traverse) required the selection of a large torque motor. Once the large torque motor was selected the maximum speed of the motor and the required velocity established the gear ratio. Reflecting the stall torque of the motor through the gear ratio established the maximum forces that can be handled. The acceleration is then a function of the difference between the friction forces and the maximum forces available.

The control could be performed entirely manually utilizing the payload specialist crewmen to directly command the actions of the MMEM utilizing a force feedback control and monitoring the movements by the various TV presentations and position readouts. This approach provides the inherent flexibility and adaptability of the human operator and the Canadian study team of SPAR Aerospace Products and Dilworth, Secord, Meagher and Associates were directed by GSFC to evaluate it in more depth.

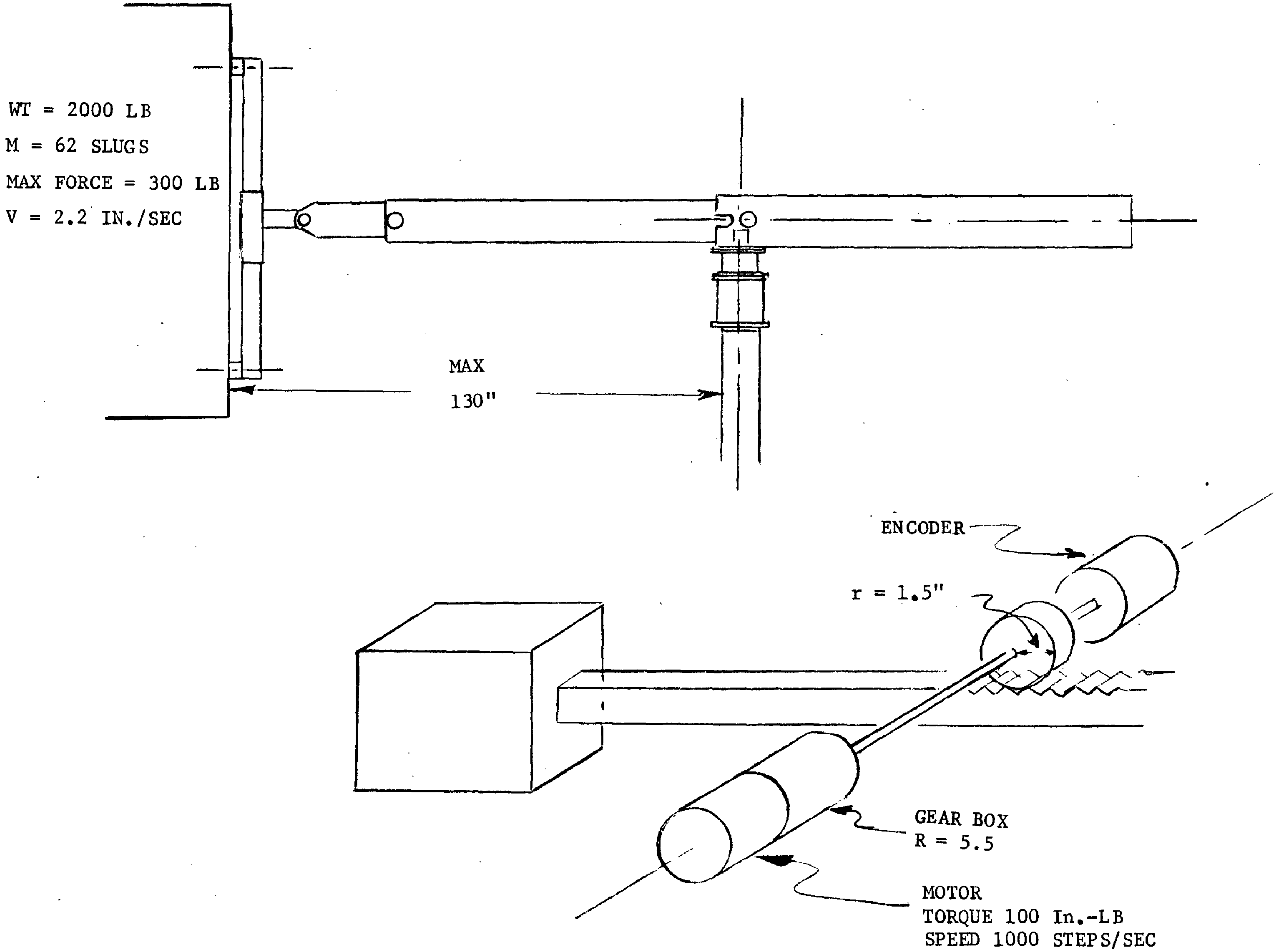


Figure 14. X-X Traverse

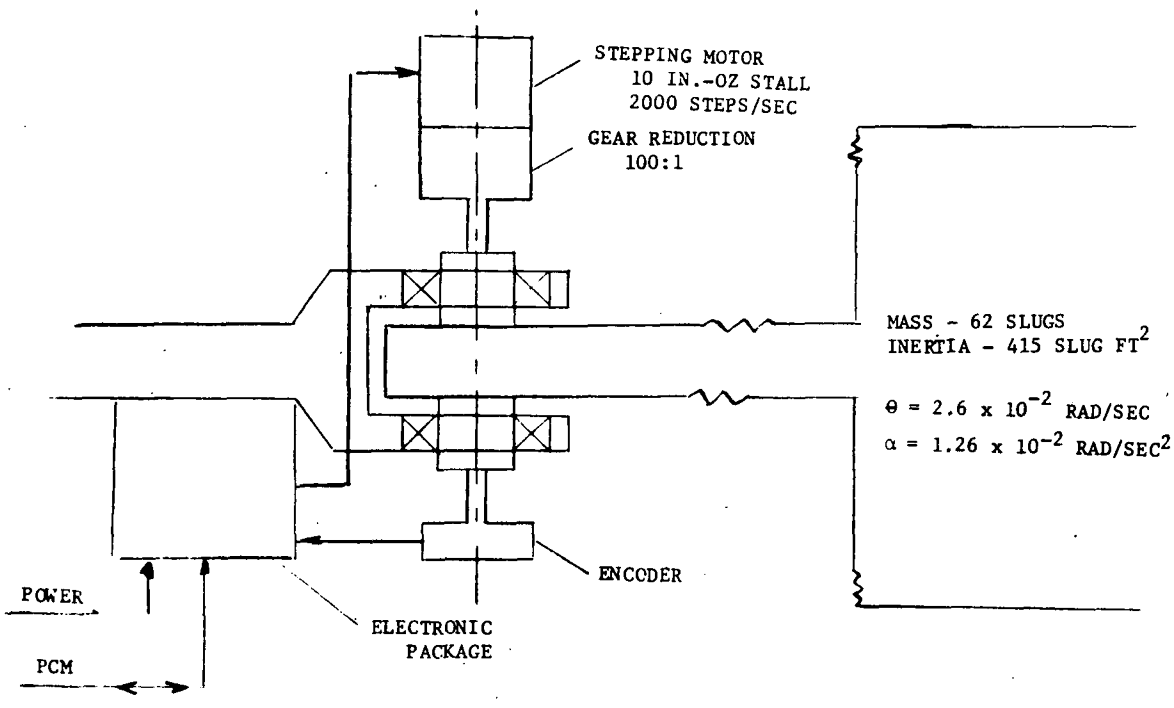


Figure 15. Y Rotation Closed Loop, Digital

The manual control can also be supplemented by automated sequences utilizing any of several basic concepts: (1) stepping motor drive with a shaft position encoder feedback, (2) analog motor with synchros for feedback, or (3) a steeping motor without feedback. Although no decision has been made at this time regarding manual control versus manual plus automation, the first of the concepts as shown in Figures 14 and 15 was selected for further examination in this study in order to gain some insight into the potential weight and volume impacts.

Command and Display Configuration .

The number of motions which are needed to operate the MMEM were defined in the baseline system, Figure 12. For the purposes of estimating the physical properties a mechanization was established in terms of components for each controlled motion and the instrumentation required. The results of this mechanization are shown in Table 2. The numbers in the columns represent the components needed and were used to define the physical properties. Included in Table 2 are 21 instrumentation points used to indicate position of the modules and unique assemblies in the stowed and temporary holding fixtures. Not included in this listing are instrumentation points associated with the locks on the SAMS (Shuttle Attached Manipulator) and the locks between the module and satellite itself, these being part of other systems.

The configuration of the command and displays is shown in schematic form in Figures 16, 17, and 18. Figure 16 shows the concept in its entirety, Figure 17 shows the concept for the closure of control loops, and Figure 18, the I/O and the drive logic. The concept involves the sharing of I/O and drive logic units with several position control loops.

The control and display concept consists of a processor addressing I/O and drive logic units in a time-shared manner. Data would be transferred over a "one wire bus".

The utilization of bits in a given word would be as follows:

- Identification of I/O and drive logic unit
- Identify the specific control motions
  (set up the switches in the I/O unit)
- Command information
- Status mechanical motion

Other options would run a two bus system, keeping the command and status bus separate.

The operations require the processor to send a command to a specific position control to move to a new point. The data word would address the I/O and drive logic unit thereby allowing the switch selection and motor position data to pass to the storage registers. The switch storage register would set and hold the proper switches open. The encoder output would be compared against the required position and the error fed into the drive generator. The error would also be fed into an error rate generator to obtain rate correction

Table 2. Command and Display Mechanization

Motions and Instrumentation	Stepping Motors	Continuous Motion Motors	Actuator	Encoder	Position or End-of-Travel Transducer
Deployment/docking/indexing					
Rotation Z-Z	1			1	
Rotation Y-Y	1			1	
Magazine rotation					
X-X axis		1			1
Exchange mechanism					
Traverse X-X	2			2	
Traverse Y-Y	1			1	
Traverse Z-Z	5			5	*
Rotation X-X	1			1	
Rotation Y-Y	1			1	
Rotation Z-Z	1			1	
Temporary hold mechanism					
Extension		1			1
Rotation lock		1			1
Module handling fixture					
Traverse arm extender	1			1	
Locking rod			2		4
Push rod		2			4
Claws		2			4
Terminal device					
Locking rod			2		4
Push rod		2			4
Claws		2			4
Retention ring					
Upper ring actuator		2			4
EOS clamp mechanism		8			16
Ring latch		1			1
Electrical connector umbilical		1			1
Module stowed/temporary position indicator					21
Total	14	23	4	14	70

*4 on primary, 1 on center post

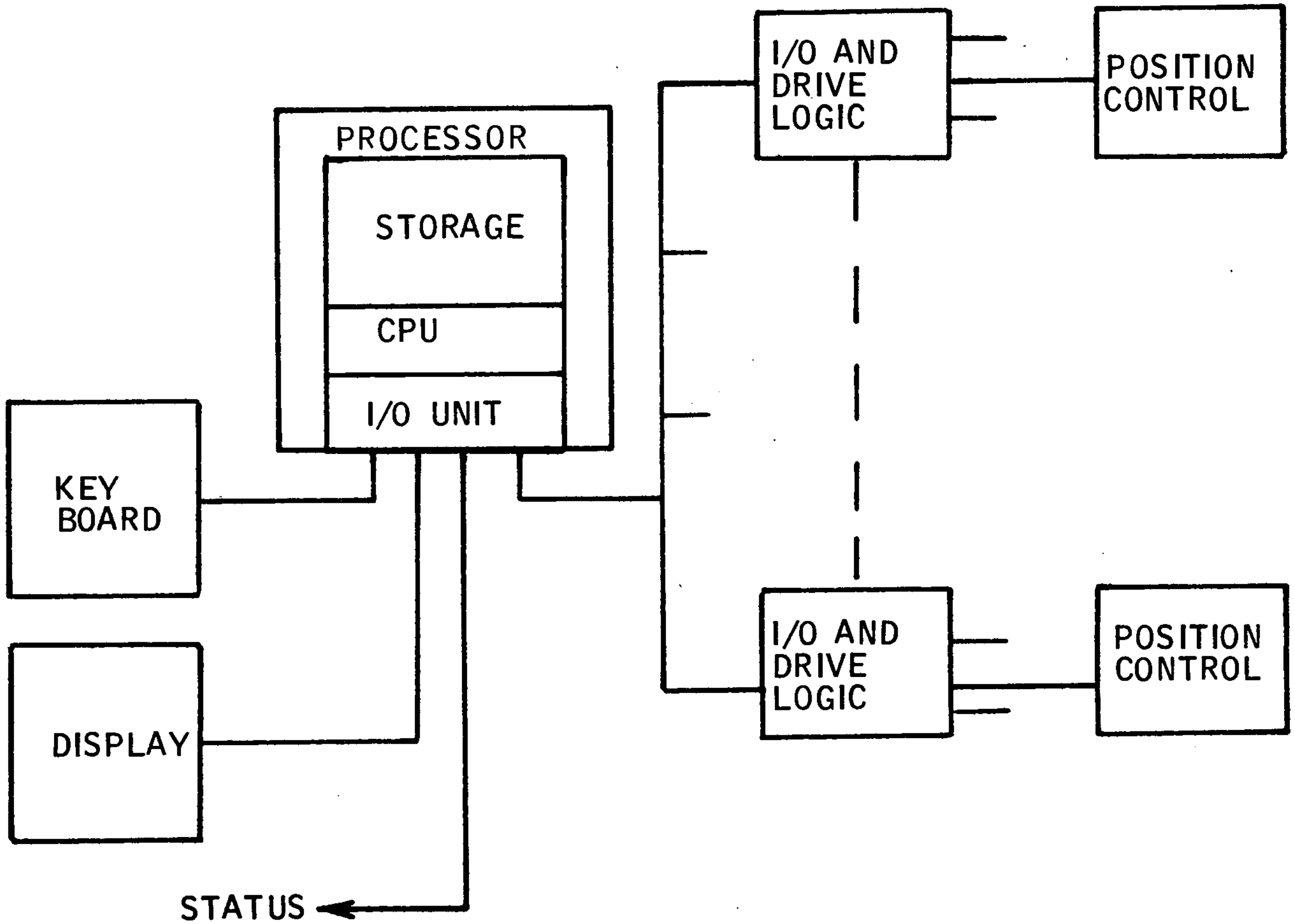


Figure 16. Control and Display

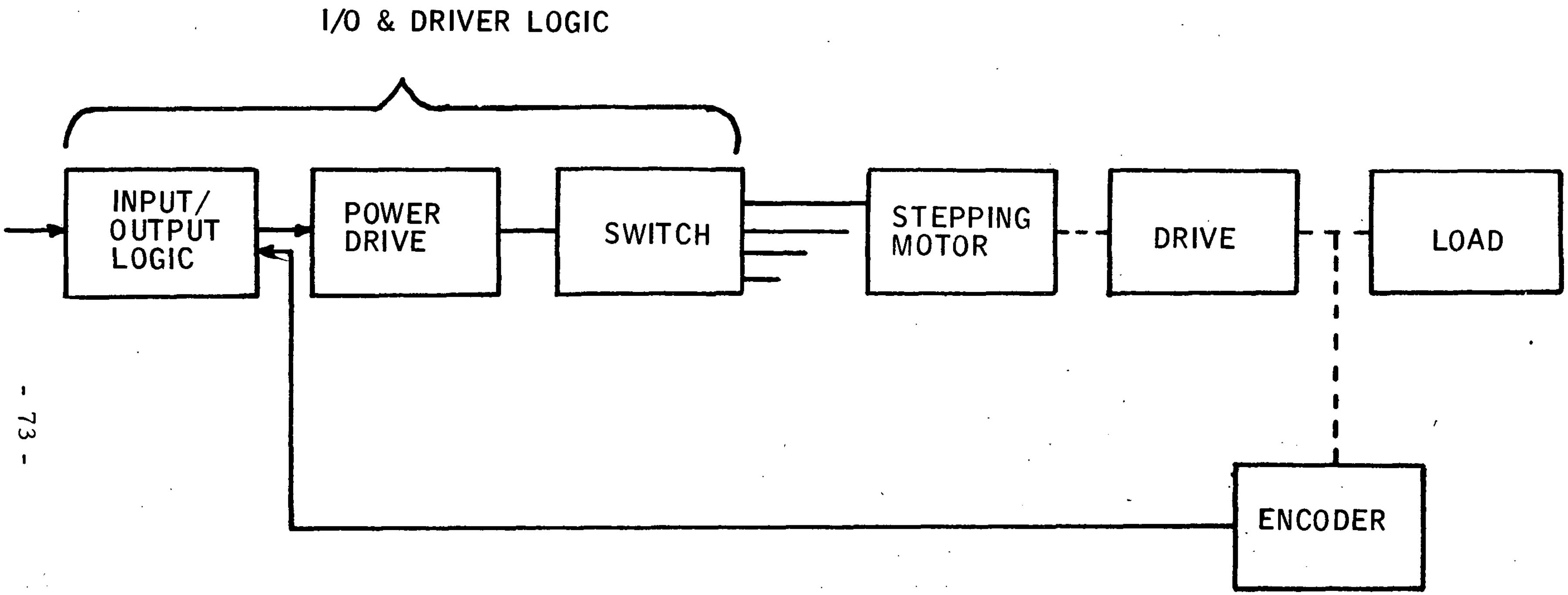


Figure 17. Position Control Loop

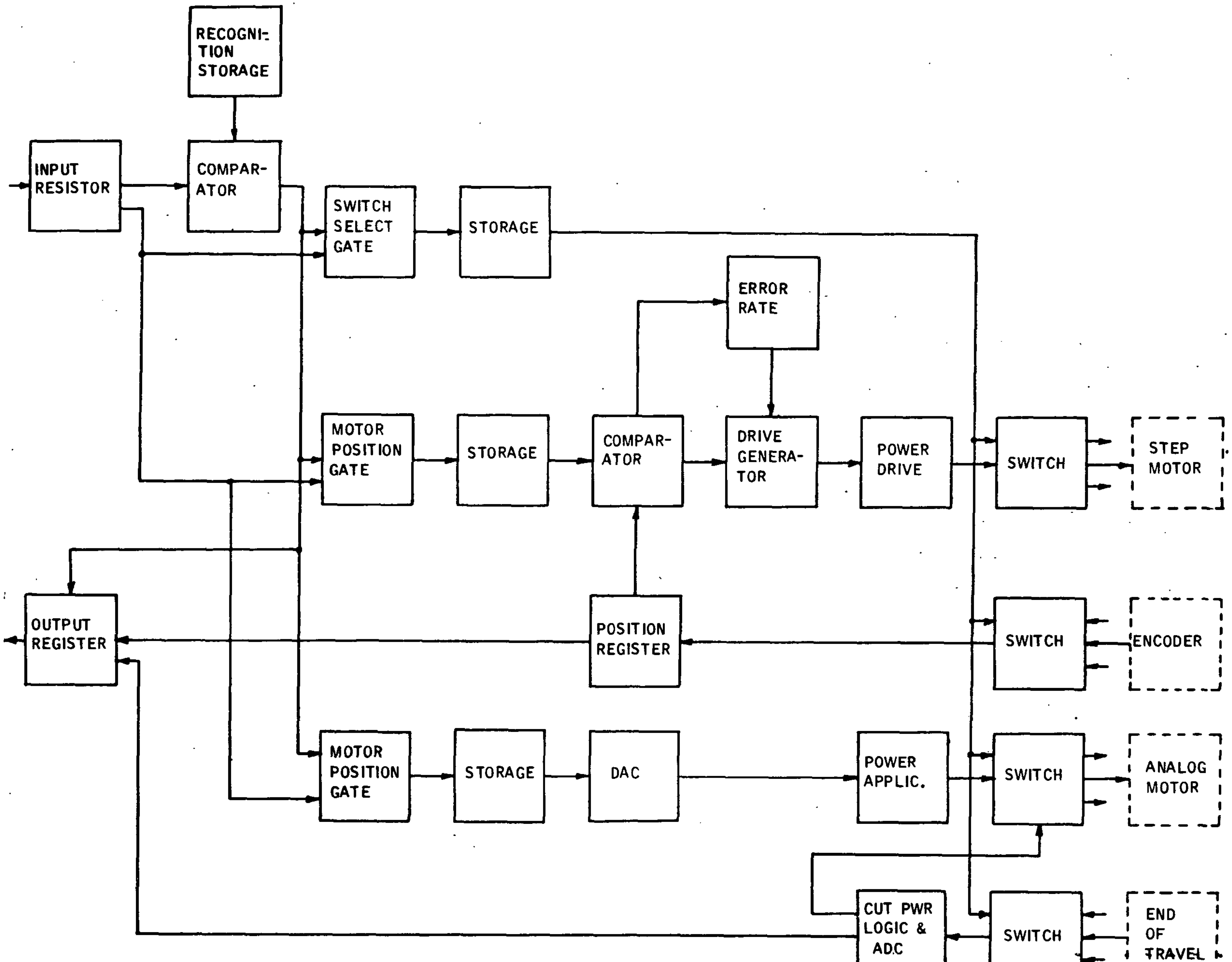


Figure 18. Input/Output and Drive Logic

if necessary. The output of the encoder would also be fed to the output register to be transmitted to the processor and then to the display for manual monitoring.

The I/O and drive logic unit is capable of servicing several position control devices and as such is placed at appropriate locations within the MMEM. The units should be placed to minimize the length of wire between the unit and the MMEM. It was estimated that six units would be sufficient. The approximate location of these units are shown on Figure 12. Input/output and drive logic units numbers 4 and 5 are located on each side of the magazine and used for the retention ring latching. Additional study may show these locations can be serviced by unit number 3. Unit number 6 is located on the terminal device arm.

It is expected that the processor, displays and keyboard units described herein could be used for other tasks in the maintenance function. An example is the checkout associated with certifying the satellite after a replacement has been accomplished (see functions 5.2 through 5.6 of Figure 13).

Physical Properties

The physical properties estimates for the command and display are listed in Table 3. These estimates are based on the mechanization described in previous paragraphs and do not include redundancies that may be required.

The physical properties are based on components having the following characteristics.

Processor

The processor is a typical airborne unit, presently available from several manufacturers; North American Rockwell (Autonetics), Control Data Corporation, etc. The processing unit has an add execution time of 2.4μ seconds, 16 bit instruction/data word, direct execute interrupts, fixed point. The memory was sized for 32 K - 16 bit words, 1.6μ seconds cycle time, 1.0μ second access time and random access using MOS technology. The memory size required "add-on" capability above the memory normally available. If additional memory is required, different techniques could be used, i.e., bubble memory.

Table 3. Part List and Physical Properties

I.D. NO.	PART	NUMBER REQUIRED	UNIT POWER (WATTS)	UNIT SIZE (INCHES)	UNIT WEIGHT (LB)	MAXIMUM POWER (WATTS)	TOTAL WEIGHT (LB)
1.0	PROCESSOR	1	20	4 x 3 x 8	6.0	20	6.0
2.0	COMMAND/DISPLAY						
2.1	KEYBOARD	1	5	18 x 8 x 4	15.0	5	15.0
2.2	DISPLAY	1	20	10 x 10 x 6	25.0	20	25.0
3.0	POSITION CONTROL						
3.1	INPUT/OUTPUT & DRIVE LOGIC	6	10	4 x 4 x 3	15.0	60	90.0 ①
3.2	STEPPING MOTOR	13	75 ②	2.25d x 3	1.2		16.0
3.3	STEPPING MOTOR	1 ③	290 ②	8.5d x 9	18.0	290	18.0
3.4	CONTINUOUS MOTION MOTOR	23	35 ④	3.4d x 5	1.8		41.0
3.5	ACTUATOR	4	60	3 x 2 x 2	1.5		6.0
3.6	GEAR TRAIN	37 ⑤					
3.7	ENCODER	14 ⑥	0.5	1.5d x 1.2	0.2	7	3.0
3.8	POSITION OR END-OF-TRAVEL TRANSDUCERS	70	--		0.1		7.0
	ASSUME 20% FOR WIRE & FIXTURES						45.0
	TOTAL				40.2		272.0

NOTES
① THE MOTOR POWER DRIVE ELECTRONICS ARE ASSESSED TO MOTORS
② PER STEP
③ ON X-X TRAVERSE
④ FOR STALL CONDITION
⑤ WEIGHT INCLUDED WITH MOTORS
⑥ MAY REQUIRE GEAR TRAIN

Display

The displays estimated are alphanumeric indicator, seven segments, gallium arsenide phosphide monochromatic red, light emitting diodes. They have a luminance of 500 foot-lamberts at 10 ma. In the area allocated, approximately 10 lines of 20 characters are available. The power allocation was based on 75 percent of the lights being lit at one time and 8 watts for the supporting electronics.

Keyboard

The keyboard was estimated as a "typewriter type" with fixed command capability.

I/O and Drive Logic

The I/O and drive logic is shown conceptually by the schematic in **Figure 18.** The units use LSI/MOS technology. To conserve units they are universal in nature, i.e., all built the same and switched to the motors/encoders being commanded. A preliminary count showed that the maximum number of position controls being commanded from one unit is 11. To be universal each unit must be mechanized with the capability to accomplish 7 stepping and 11 continuous position motions; however to allow for growth, 10 stepping and 15 continuous position motions should be mechanized.

Stepping Motors/Gear Trains

The drive system consists of a stepping motor and gear train built into one housing. The unit is a "harmonic drive" as built by USM Corporation. All motors except the one on the X-X traverse were sized with a stall torque of 10 in.-oz and a maximum speed of 2000 steps per second. The remaining motor (high-friction load motion "X-X travers") has a 100 in.-lb torque and a maximum speed of 1000 steps per second.

Continuous Motion Motors

The continuous motion motors are reversible units which drive latches and locks and are not used in feedback control applications.

Actuators

The actuators are solenoid units used to drive locks and latches in applications where short strokes are needed.

Encoders

The encoders proposed for this application are optical shaft position units.

Position or End-of-Travel Transducers

These transducers are two types depending on the application. The end-of-travel are switch closures that monitor the point in travel where a motion has been completed. The position transducers are of the LVDT (Linear Variable Differential Transformers) type which detect relative motion between two masses.

Additional Considerations

The analysis herein was performed to a depth necessary to allow estimating the physical properties of the command and display equipment. The analysis was directed toward a minimum cost system for this concept and, therefore, reflected the minimum equipment necessary to accomplish the assigned tasks without redundancy. Questions relative to reliability and methods necessary to achieve required reliability (redundancy) were deferred to later studies

Two loops which were judged to be the most critical were analyzed in sufficient depth to allow the determination of the loop major characteristics. Questions concerning loop damping, friction levels, and spring constants were left for further studies. Additional studies would examine each loop to determine its characteristics and components necessary for mechanization.

Of major concern during the analysis was (1) the accuracy necessary to align a module for engagement into the satellite, and (2) the stability of the module magazine and exchange mechanism within the various thermal environments (light side versus dark side of the earth). If high accuracy is required and thermal stability became a problem, a calibration scheme would be required that could allow absolute postion relative to the module and the satellite. This is an example of the type of problem where a manually controlled system can utilize the adaptability of the crewman to compensate for in-flight difficulties. Concepts for performing this calibration automatically could consist of a linear motion pickoff close to the point of engagement to detect the relative position between the two masses. Figure 19 shows a concept where a C-type pickoff is used. The Y and Z positions are detected by the position of the core relative to the magnetic material plate used to close the magnetic pitch. The X position is detected by the magnitude of the pickoff signal.

The processor, keyboard and display units identified herein are universal and as such can be used for other functions in the maintenance activity. The final configuration, therefore, will depend on the integrated tasks assignment and the input/output requirements.

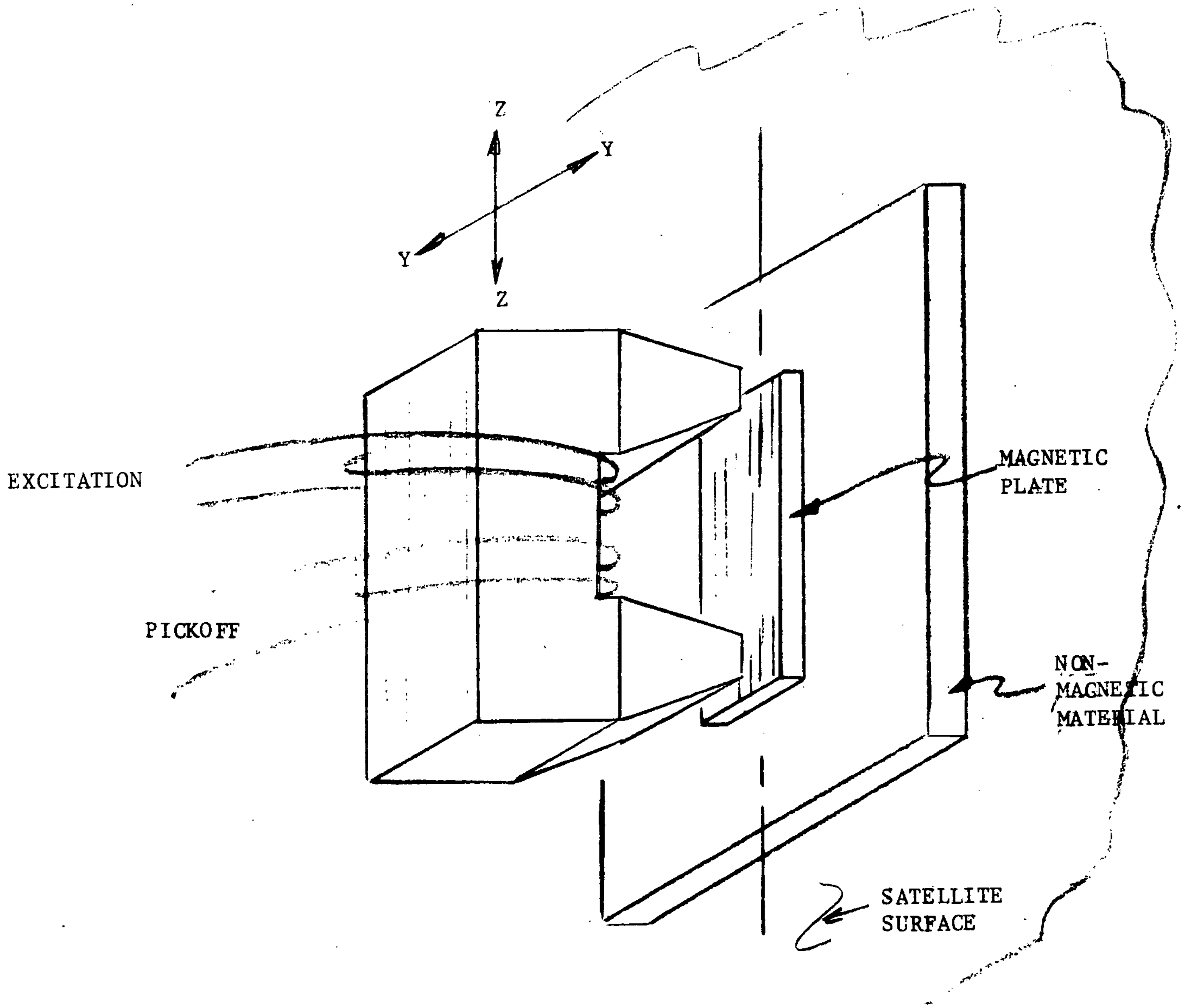


Figure 19. X, Y, Z Calibration Pickoff Concept

SYSTEM WEIGHT ESTIMATES

An initial weight estimate was prepared assuming that all components would be constructed of welded aluminum plates and/or low-density aluminum honeycomb with minimum gauge facing sheets. This type construction is most cost effective when lightweight structure is not the driving design factor. The estimated weight of the FSS configured for a launch mission was 1740 pounds, and for a refurbish mission, 5880 pounds. Total mission weights and center-of-gravity locations within the shuttle payload bay are shown in Figure 20 for seven mission conditions using estimated weights for the EOS and for the replacement modules and assemblies. The OMS kit weights have been adjusted for the specific mission requirements; i.e., delivery only to 400 nautical miles polar orbit or rendezvous with an EOS in that orbit. Note that for a launch abort landing, dumping of the OMS kit propellant moves the center-of-gravity well within the allowable boundary for a safe landing.

LAUNCH MISSIONS	ASCENT ■	ABORT LANDING ▼	DESCENT ●
EOS	10,000	10,000	-
FLIGHT SUPPORT SYSTEM	1,740	1,740	1,740
OMS KIT	15,560	2,400	2,400
	27,300	14,140	4,140

REFURBISH MISSIONS	ASCENT □	ABORT/DESCENT	CONTINGENCY RETRIEVAL ◇
FLIGHT SUPPORT SYSTEM	5,880	5,880	5,880
MODULES & ASSEMBLY	2,400	2,400	2,400
OMS KIT	16,970	2,400	2,400
EOS	-	-	10,000
	25,250	10,680	20,680

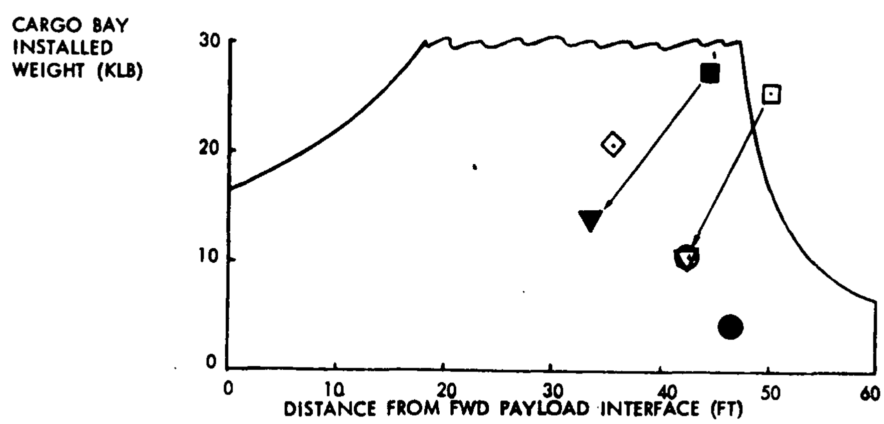


Figure 20. Mission Weights and Center-of-Gravity

The maximum payload-to-orbit weight for the conditions assumed is 11,740 pounds which is very marginal for the shuttle capabilities to the desired orbit. For this reason a preliminary assessment of weight saving design changes was made which indicated that the FSS weight could readily be reduced to 1490 pounds for the launch mission, and to 4340 pounds for the refurbish mission. The estimated contribution of the various FSS elements to this total is shown in Table 4. The principal source of this weight reduction came from the elimination of the box structure for the module magazine and its reduction to a simpler space frame to retain the replacement modules. It is felt that additional weight reduction can still be achieved by a more extensive analysis of the structural requirements. A reasonable goal for the refurbishment mode would appear to be 3600 pounds and for the launch mission, 1200 pounds.

Table 4. Flight Support System Weight Estimates

FSS Element	Launch Mission (lb)	Refurbish Mission (lb)
Module exchange mechanism		2000
Module magazine		800
Deployment/docking mechanism	400	400
Retention mechanism	500	500
Unique assembly fixture		370
Side rails	320	
Controls and displays	270	270
Total	1490	4340

SUPPLEMENTARY STUDIES

LARGE SPACE TELESCOPE SUPPORT CONCEPTS

In addition to the primary effort described in the preceding sections, support concepts for the Goddard-designed Large Space Telescope (LST) (Figure 21) were also examined. The effort included:

1. The shuttle constraints due to orbit maneuvering system, configuration and envelope.
2. Two system concepts; one concept utilized the SAMS for capture, berthing and solar array folding and exchange; a pivoted platform for LST deploy/stow, indexing and umbilical hook-up; and a semi-mechanized module exchange system used in conjunction with the SAMS and special end effectors. The other concept was similar but provided a fully mechanized module exchange capability.
3. Comparison and evaluation of the two concepts.

The highlights of this effort are summarized in the following.

MISSION REQUIREMENTS

The missions examined were those shuttle-supported operations of the LST including launch, retrieval, and resupply/refurbish with contingency retrieval. Two potential orbits were identified; 400 nautical miles at a nominal 35-degree inclination was baselined, and 500 nautical miles polar was examined as potentially desirable. As indicated for the EOS, the refurbish mission with contingency retrieval was the main driver on the design because of the complexisty of the operations and interfaces. The launch mission to the desired 500 nautical miles polar orbit was found to exceed the shuttle orbital injection capability.

For the refurbish mission the functions to be provided by the support system included exchange of any combination of the modular elements of the LST including the radial-axis instrument modules, the on-axis instrument module, and the subsystem modules with a goal of 100 percent exchange considered

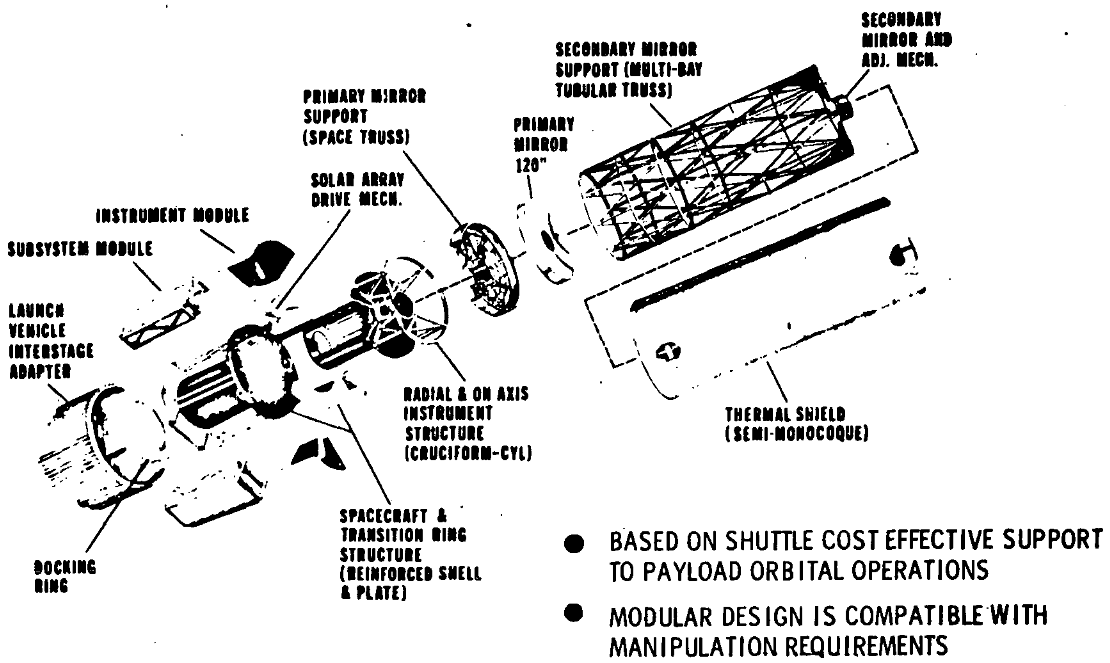


Figure 21. Large Space Telescope

desirable. Actuation and/or replacement of the solar arrays was also considered a required function. Jettisoning of mechanisms and replacement modules to provide for LST contingency retrieval was not considered an acceptable concept although jettisoning provisions were included where required to assure a safe return of the shuttle and crew.

SHUTTLE CONSTRAINTS AND ISSUES

The same basic constraints, issues, and potential resolutions identified in the discussion of the EOS support, i.e., contamination, OMS tank kit installation, and SAMS capabilities are applicable to the LST mission also and with increased emphasis in some respects. The contamination control of the environment to protect diffraction-limited optics and sensors is a key issue. The installation of the OMS tank kits in the aft end of the cargo bay introduces the same constraints on c.g. as shown in Figure 22, and is even more of a volume constraint for the LST because of the larger overall length of the satellite (Figure 23).

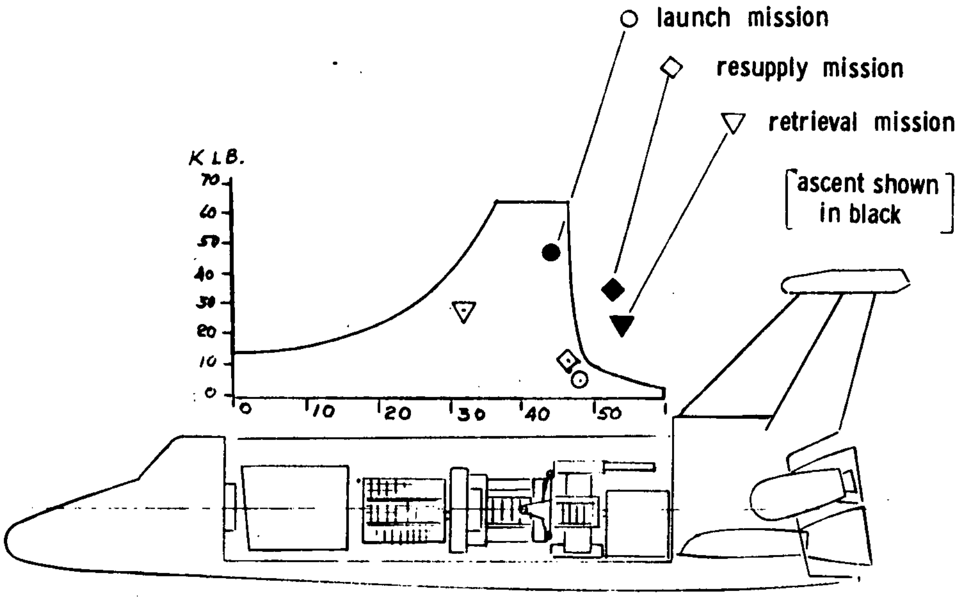


Figure 22. Payload Bay c.g. Constraints

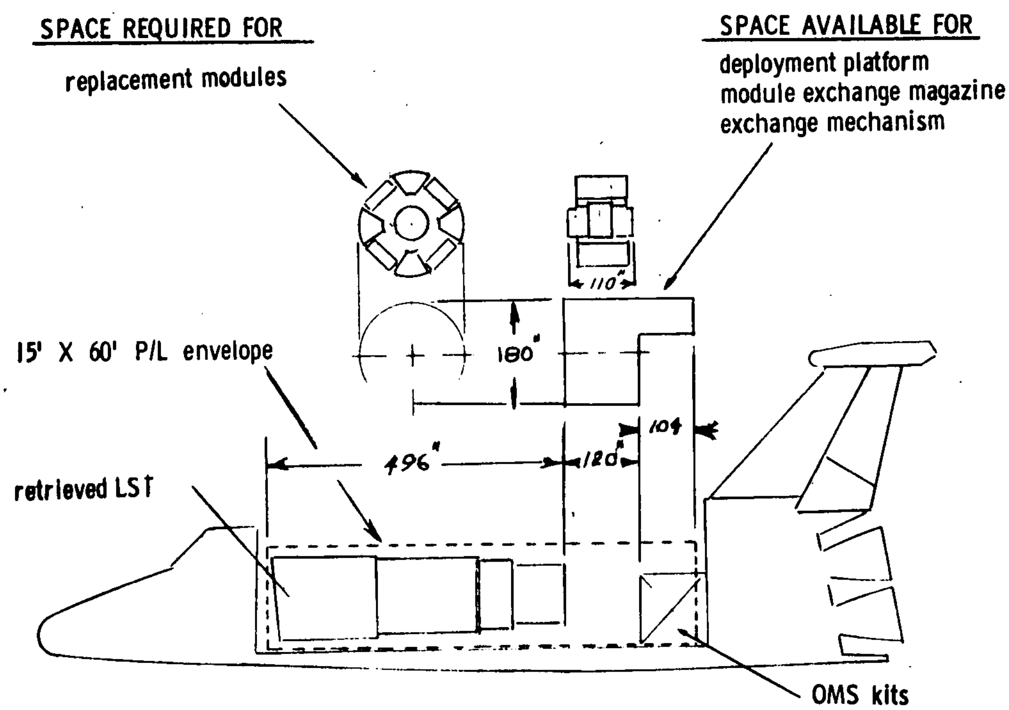


Figure 23. Envelope and Configuration Constraints

LST SUPPORT SYSTEM CONCEPT SYNTHESIS

Alternative concepts for support of the LST missions were synthesized within the constraints defined. As with the EOS, sub-analyses resulted in selection of certain operations and approaches as standard for both concepts examined.

Capture of a free-flying LST and berthing to a docking ring was assigned to SAMS as a baseline payload handling capability. Docking to a pivoting deployment/stow fixture which incorporates a mechanized umbilical connection mechanism was selected as a building block for system synthesis. Such a pivoting deployment platform can be mechanized to provide the required indexing of the LST with respect to orbiter stations so as to provide for access by the SAMS or by other mechanized equipment.

Module storage was provided by rotary turrets. These are mechanized to index under remote control from the crew cabin of the orbiter.

Solar array actuation and exchange will be accomplished by the concept described previously for the EOS using SAMS. Provisions must be made in the payload bay for latching and retention devices for replacement solar arrays.

Modular Magazine Arrangements

Two configurations of module magazine arrangements were developed as building blocks for synthesis of the total LST support system. As shown in the sketch (Figure 24), one is a rotary turret with an axis vertical with respect to the shuttle payload bay. The other is a rotary turret magazine with replacement modules and the axis of rotation parallel to the axis of the orbiter payload bay.

The concepts are based on utilizing a mechanized rotary indexing turret to which are attached a variety of module holding fixtures each suitable for the type of module which it must retain and position for module exchange operations. These adapters can be assembled into the turret magazine as required and in such a manner that the number of replacement modules of a given type can be varied. The general shape of each module is shown in the left-hand column of the chart for the on-axis module, the radial instrument module, and the subsystem module. In order for the vertical axis module magazine to be within the 15-foot diameter maximum payload envelope, the vertical axis magazine must be smaller in diameter than the horizontal axis magazine. As indicated in the column to the right of each magazine sketch, the number of modules available for replacement can be predetermined to provide replacement of modules of one type to a greater or lesser degree than those of another type as required. For instance, with the vertical axis magazine the assembly can be made to provide the exchange of one on-axis instrument package,

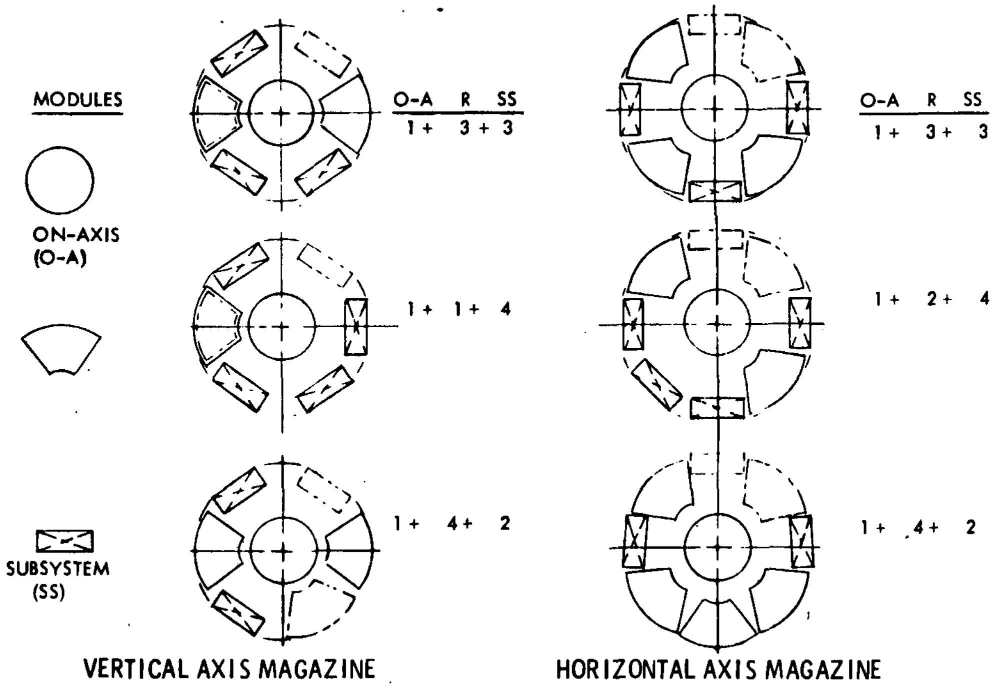


Figure 24. Module Magazine Arrangements

one radial instrument package, and four subsystem packages. However, under the same conditions the horizontal axis magazine could provide for the exchange of one on-axis instrument package, two radial instrument packages, and four instrument packages.

These two concepts for module magazines were adopted as building blocks for the synthesis of the complete system.

Semi-Automated Concept

Module exchange is provided by this system concept by use of the SAMS equipped with special end effectors which are capable of attaching to any of the modules, engaging their attachment mechanisms, to latch or unlatch them from the module magazine or the LST, and transporting the modules between the magazine and the LST as required. Loading guides at a loading station are required in this concept to guide the module into engagement with the module cavities in the LST in order to reduce the position stability requirements and the operator control precision to reasonable limits while engaging the modules with their guide rails in the spacecraft. The end effectors will provide the mechanical advantages required by the SAMS end effector drive shaft to produce the torques required to compress and release the module attachment devices (2,000 pounds per device).

Launch/Reentry Configuration

The configuration of the orbiter for the launch and reentry configuration (Figure 25) shows that the OMS kit, the pivot deployment and indexing platform with the module replacement magazine attached below, the transition ring retention clamp, the replacement on-axis module, and two replacement solar arrays can be accommodated. The deployment and indexing platform provides the docking latches with umbilical hook-up functions and also drives the module replacement magazine so as to provide indexing to both the spacecraft and replacement modules as required.

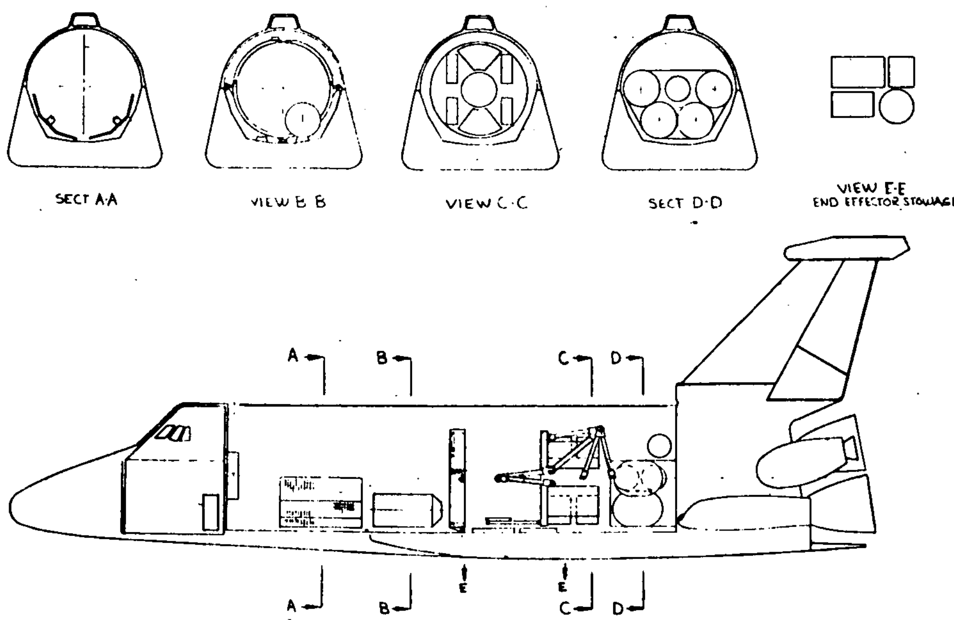


Figure 25. Launch/Reentry Configuration

Capture and Berthing Configuration

The LST is shown in Figure 26 in a position for capture and motion arrest by the SAMS in a position along the Z-axis above the line of sight of the manipulator operator. After capture and motion arrest the LST is transported and berthed to the docking ring which has been pivoted up out of the payload bay and has the capability to draw the LST down to a docked and properly

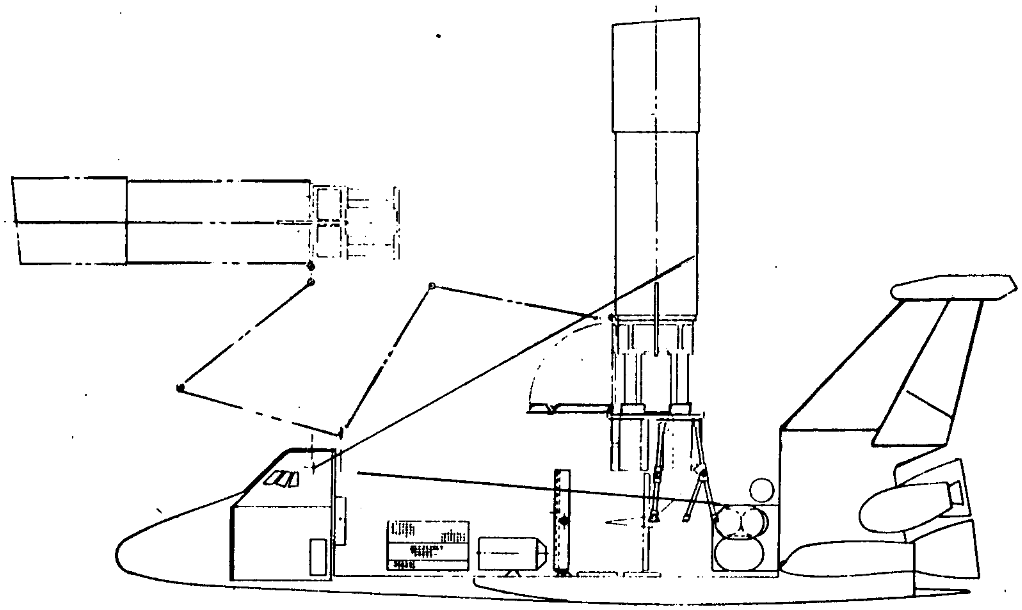


Figure 26. Capture and Berthing Configuration

aligned orientation. These mechanisms are controlled remotely from the crew cabin as is the umbilical connection which is made at this time to provide the required control and communications linkages to the orbiter.

Module and Solar Array Exchange Configuration

With the LST docked and aligned on the pivoting deployment/indexing platform and with umbilical connections made, the SAMS is shown in Figure 27 to have adequate access to the hub of the solar array actuator mechanism so as to provide the required solar array actuation and/or replacement functions without the use of any special end effector.

With the loading station module exchange guides deployed up into alignment with the LST by remote control the SAMS engages module exchange end effectors which have been retained on the floor of the shuttle as shown and moves them through the loading station guides so as to engage the required module for replacement. The removed module is stowed in the empty cavity in the magazine attached to the indexing platform which provides the required remote controlled indexing of both the LST and the magazine. Access to the on-axis module is achieved by a special end effector with vertical guides which both guides the on-axis instrument module and stabilizes the terminal end of the manipulator

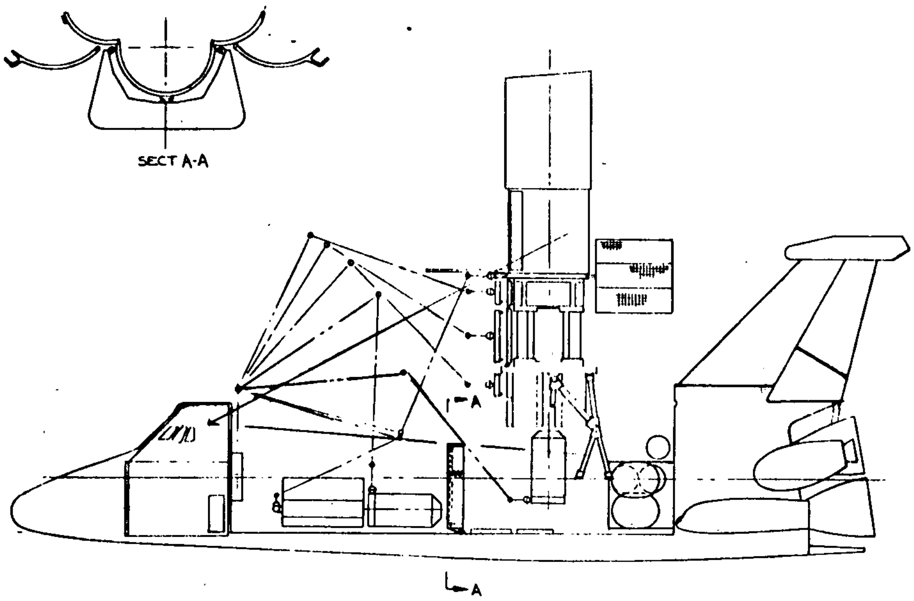


Figure 27. Module and Solar Array Exchange Configuration

as it goes up through the slots in the magazine turret to reach the on-axis module in the LST base. The force to elevate and engage the on-axis end effector will be provided by a mechanized drive. The spare on-axis module and the temporary storage position are shown forward of the transition ring retention clamp.

Contingency Retrieval Configuration

Figure 28 shows on the inboard profile that after the module replacement and solar array replacement operations have been accomplished and the replacement solar arrays stowed for reentry, the docking and indexing platform can pivot the LST down into the transition ring retention clamp which then is closed to retain the LST for the reentry flight phase. It is shown that the payload bay is completely used by the OMS kits, the replacement module magazine, the pivoted docking indexing platform, and the Large Space Telescope. This shows clearly the importance of studying shuttle payload handling requirements in detail in order to judge the adequacy of the payload accommodation. In no case is it reasonable to judge the adequacy of the availability of the payload bay volume by the size of the satellite itself. The cross-section views in the upper part of the figure show that all of the equipment of the installation

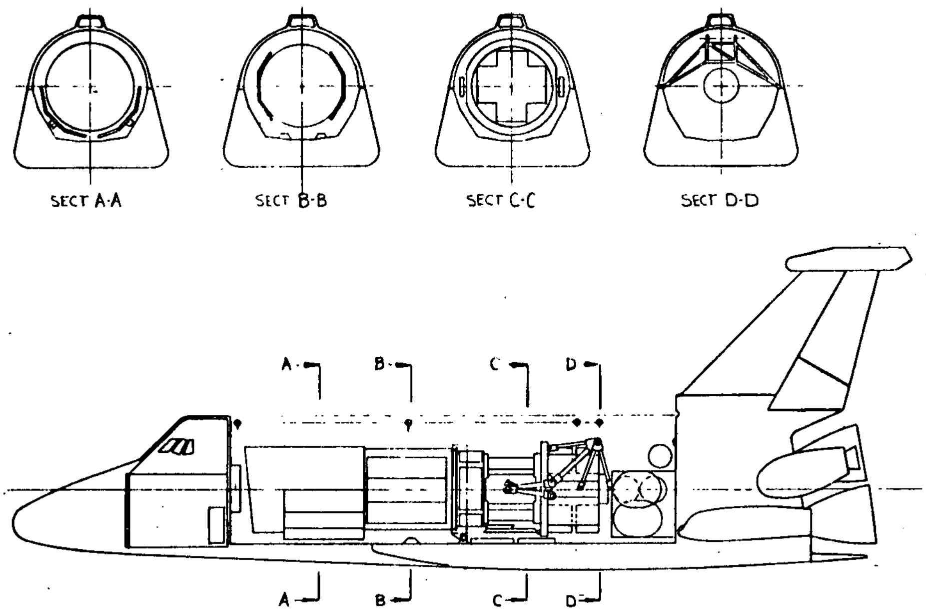


Figure 28. Contingency Retrieval Configuration

can be within the envelope of the 15-foot diameter allocation for payloads in the payload bay of the orbiter.

Automated System

Module exchange is provided by this system concept by use of a separate module exchange mechanism which performs all of the functions of attaching to the modules, engaging their attachment mechanisms, latching or unlatching them from the module magazine or the LST, and transporting them between the magazine and the LST as required. The remaining mission functions are handled in essentially the same way as the previously described semi-automated concept.

Launch and Reentry Configuration

The inboard profile in Figure 29 shows the OMS kit and forward of that the deployment indexing platform, automated module exchange mechanism, and the horizontal axis replacement module magazine. Further forward is the transition ring retention clamp and near the front of the payload bay are shown two replacement solar arrays as in the case of the semi-automated system concept.

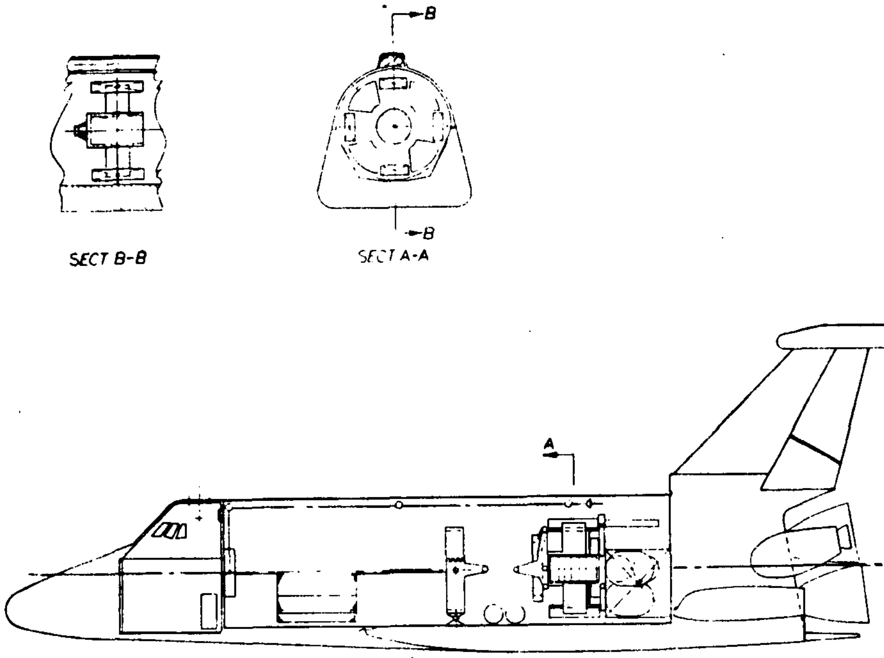


Figure 29. Launch and Reentry Configuration

Capture and Berthing Configuration

As in the case of the semi-automated system, the operational sequence depicted in Figure 30 is capture of the LST along the line-of-sight on the Z-axis above the operator and transportation of the captured LST to place or berth it on the docking indexing platform which has been pivoted upward to receive the LST. As before, all of these operations are remotely controlled from the crew compartment. With the LST latched to the docking indexing platform the umbilical connection is made by remote control as before.

Module Exchange Configuration

In this concept the manipulators are not used for module exchange and are, therefore, shown in Figure 31 in a standby position where either could provide TV viewing of the work in process. The loading and module transfer arm is shown in two positions opposite a radial instrument package and at a lower level opposite a subsystem package of the LST. Since the LST indexing axis is at right angles to the module magazine rotational axis, this concept involves an additional indexing feature compared to the semi-automated approach. The solar arrays are shown in the folded up position to be out of

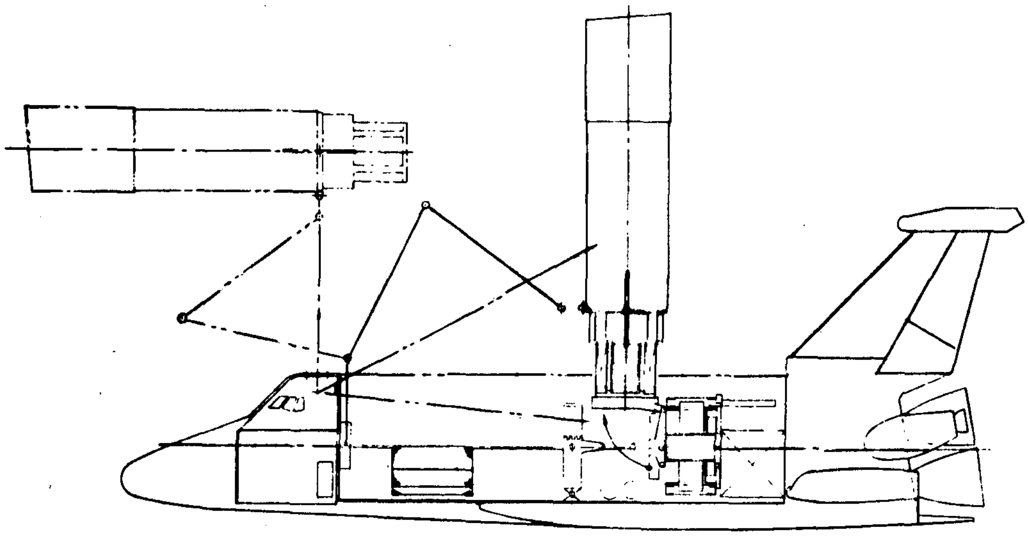


Figure 30. Capture and Berthing Configuration

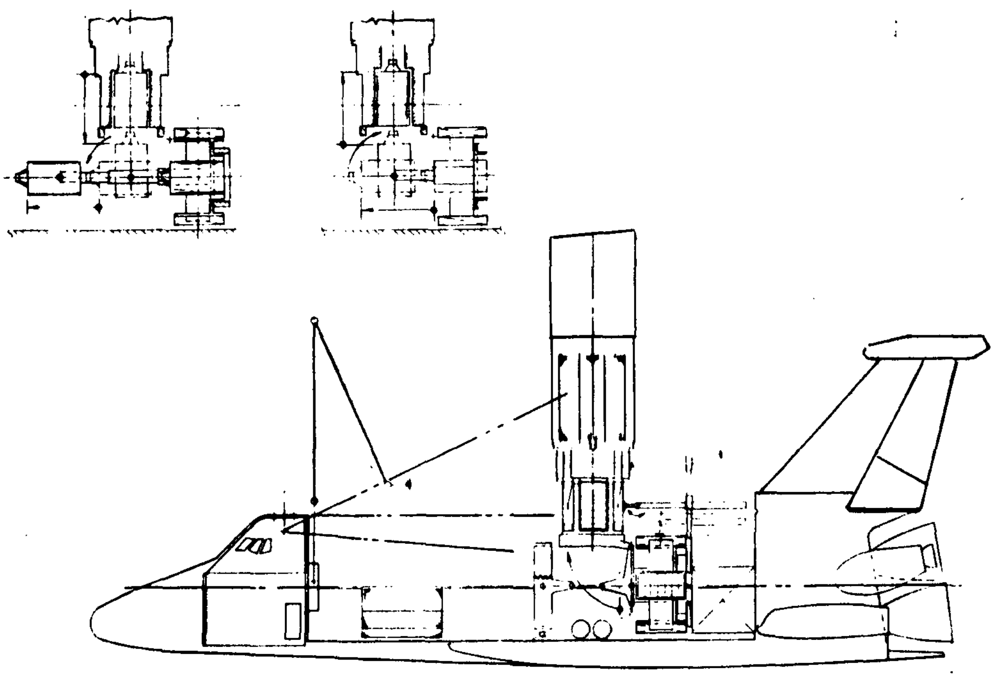


Figure 31. Module Exchange Configuration

the way of the module exchange process, particularly at the radial instrument module operation. Since the ground rules for the study are that the solar arrays cannot be stowed and folded by their own power, this function is accomplished by use of the SAMS to actuate the arrays as in the case of the semi-automated concept. The automated module exchange and transfer operations are shown in the upper left-hand corner of the figure but are better explained in Figure 32 which is discussed below.

On-Axis Instrument Module Exchange

The on-axis instrument module exchange is the most difficult of the LST tasks and was, therefore, chosen for more detailed description of the design concept for automated module exchange. In the left-hand portion of Figure 32 the LST is shown in the docked position on the deployment/indexing platform and the replacement module magazine is shown to its right with the on-axis replacement module located at the center of the horizontal axis magainze. In the first step of the exchange sequence the on-axis module carrier advances forward until directly below the center of the docked LST. At this point, the carrier revolves 90 degrees to aim upward at the on-axis instrument module where it is latched in the cavity of the LST. The carrier elevates upward until it engages the latching mechanisms of the module and is remotely controlled to release them. It then lowers the module until it is below the

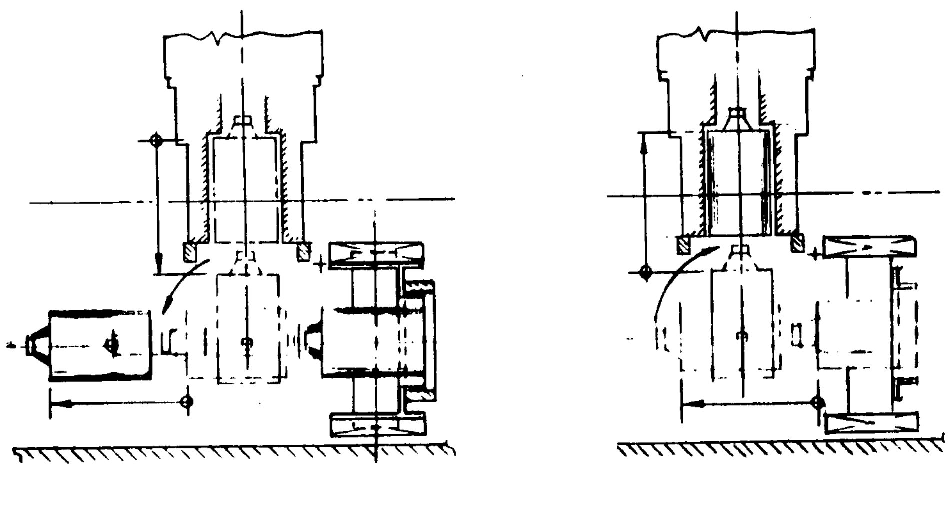


Figure 32. On-Axis Instrument Module Exchange

docking ring of the deployment/indexing platform and is clear to swing it 90 degrees to the left as shown in the sketch. The carrier then advances the removed module to the left and engages it into a temporary holding fixture for temporary storage.

The carrier is then retracted into the module magazine where it surrounds the replacement module and engages with it for further steps of the sequence. The sketch at the right of the figure shows that the engaged replacement module is then advanced forward to the horizontal pivoting position and then pivoted upward to aim at the cavity in the LST. In the next steps the on-axis replacement module is elevated into the cavity of the LST and the latching mechanisms are actuated to engage and align the module for operational checkout. The carrier then retracts, pivots again to the left, advances to the removed module, disengages it from its holding point and retrieves it into the center cavity of the module magazine.

This task is the same as was required in the case of the semi-automated module exchange design and both concepts required guided, remotely controlled mechanisms for the translational and latching operations. However, considering the very limited access to the operation for the visual feedback required by SAMS operations and the very high degree of positioning accuracy that is required, it is concluded that the automated concept of on-axis instrument module exchange is more feasible than is the concept for the SAMS/semi-automated on-axis instrument module exchange.

By a similar line of reasoning the radial and subsystem modules shown in Figure 31 can be translated and rotated between the LST and the module exchange turret without the requirement for direct viewing by the operator and with a degree of positioning accuracy that is more easily controlled by a machine approach than it is by the SAMS manipulator booms. On the other hand, the module pickup and actuation devices on the transfer and loading mechanism are similar in design requirements to the special end effectors required for the SAMS for the semi-automated module exchange concept. However, it appears that the automated module exchange concept for the radial and subsystem modules is more feasible overall than is the concept requiring the utilization of the SAMS and special end effectors.

Contingency Retrieval Configuration

Figure 33 shows on the inboard profile that the flight support system and the retrieved LST can be accommodated within the payload bay to meet this mission mode requirement with about the same latitude as was observed in the case of the semi-automated module exchange concept.

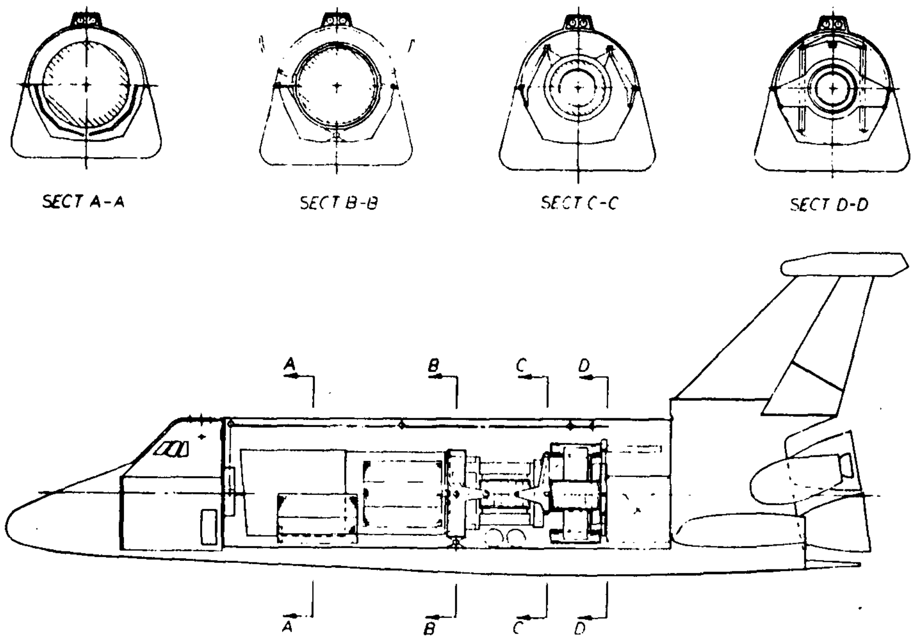


Figure 33. Contingency Retrieval Configuration

It should be added at this time that in the case of both concepts when the deployment/indexing platform is erected it extends beyond the mold lines of the orbiter. It is, therefore, necessary that this platform be provided with jettisoning capability such that if the operator is not able to retract it within the design maximum payload envelope for reentry, the platform can be released and ejected to permit the closing of the payload bay doors.

Concept Comparisons - Module Exchange Operations

Since the two candidate design concepts utilize the SAMS for its baseline capabilities of capture, berthing, and other manipulative tasks, they differ only in the mode for accomplishing the exchange of the LST instrument and subsystem modules. Consequently, the final trade is carried out on the basis of comparing the module exchange concept advantages and disadvantages. As shown on Table 5, the technology base is considered to be adequate for both the semi-automated and the automated system. Comparing hardware complexities, the module magazine requires no indexing in the case of the semi-automated system since it is indexed by the LST docking and indexing platform while in the case of the automated system a separate indexing mechanism is required. The module exchange end effectors are complex in the case of the semi-automated system but the requirement is not applicable for the automated system which does not use the SAMS. The automated module exchange is evaluated as a complex system by comparison since it requires the transport and loading mechanism as well as the equivalent of end effectors for handling and latching the modules. The factor of cost was not quantitatively evaluated in this study at this stage. However, the extent to which the SAMS reduces the cost of the semi-automated system for the module exchange function is in favor of that system. The software complexity for the semi-automated system with SAMS is higher than is the case for the automated machinery operating on limit controls, status indicator lights, and so forth. This factor is reflected in both cost and reliability considerations. Comparing the operational considerations, damage risks due to collisions, jams, and so forth might be established as moderate for the semi-automated system, but it would be lower for the automated system. On the other hand, the task time rates are very slow for the manipulator which requires supervisory control and override authority by the operator as compared to the relatively fast machine sequences that are achievable with the automated approach. The operator skill is shown as being very high for the manipulator operator under space operational conditions and, of course, very low for the machine approach of the automated system. The demands for observation by direct viewing, TV, and lighting is critical as the means of feedback control to the SAMS operator and is relatively non-critical in the case of the automated machine approaches and as always the chance of error is higher for a manual system than it is for a machine system.

For the purpose of concept selection the above factors were reviewed without the benefit of a pre-determined weighting system and traded off as simply plus or minus factors. Under this simplifying constraint the semi-automated module exchange system showed one plus factor compared to the

Table 5. .Concept Comparisons
Module Exchange Operations

Factors	Semi-Automated System	Automated System
Technology base	Adequate	Adequate
Hardware complexity		
. Docking/indexing platform	Required	Required
. Module magazine	No indexing	Indexing
. Module - exchange end effectors	Complex	N/A
. Automated module - exchange	N/A	Complex
. Cost		
Software complexity	High	Low
Operational considerations		
. Damage risk	Moderate	Low
. Task time rates	Slow	Fast
Human requirements		
. Operator skill	High	Low
. Observation	Critical	Non-critical
. Chance of error	More	Less
Net number of plus factors	One	Six
Factor weight	TBD	TBD

automated system in that it eliminated one indexing mechanism. However, the automated module exchange system showed six plus factors compared to the semi automated system and these six were in areas that substantially influence technical feasibility, reliability, and mission success.

SUMMARY

The conclusions and recommendations for this portion of the study effort are as follows.

1. The replacement mission with contingency LST retrieval is the driver on the system design in several areas. The replacement mission with retrieval (considering the OMS kit requirement) requires all of the 60-foot payload bay length with such small clearances between the system elements that the pivoting docking/indexing platform is required for deployment and stowage of the LST. In addition this mission mode is a driver

due to the payload c.g. limits with particular reference to the launch-abort limitations and the propellant dump capability of the orbiter.

2. OMS capabilities constrains the 500-nautical mile polar orbit. This constraint is in conjunction with the orbit injection capability of the shuttle. While this orbit is not baseline for the LST, the indication is that earth observations satellites with mass properties equivalent to the LST would be constrained from achieving the 500-nautical mile altitude.

3. The configuration and envelope constraints were found to be acceptable considering the system elements selected for this concept synthesis.

4. The SAMS can meet the capture and arrest and berthing requirements for these mission modes and is cost effective as a baseline element of the conceptual system.

5. A pivoted deployment and indexing platform also provides the proper base for a remotely controlled umbilical connection and it provides for the release of the LST to free flight.

6. The automated module exchange system is the most feasible concept considering all of the factors evaluated.

7. Solar array actuation and replacement is feasible with the SAMS.

It is, therefore, recommended that:

NASA avoid over-taxing the first-generation SAMS with requirements to accomplish module exchange. This requires complex end effectors, substantial forces, and high position accuracy together with visual feedback limitations due to the large area end effectors blocking visual access to the modules and the module cavities in the LST and in the module magazine. Studies of remote LST maintenance should be carried out on the basis of the automated system concept and its ancillary equipment.

REFERENCES

1. NR Phase B Shuttle Design Studies
2. NR Phase C Shuttle Technical Proposal, Volume III
3. NR Briefing SV 72-17, Payload Impact Analysis on Orbiter Subsystems
4. MSC Internal Note No. 71-FM-350, Rev. 1, Space Shuttle Performance Capabilities
5. MSC Internal Note No. 72-EW-3, Shuttle Attached Manipulator Requirements
6. Martin Marietta Report MSC 05218, Preliminary Design of a Shuttle Docking and Cargo Handling System