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# Orbital Spacecraft Consumables Resupply System (OSCRS) Study

## Monopropellant Application to Space Station and OMV Automatic Refueling Impacts of ELV Launch

(NASA-CR-172029) ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM (OSCRS): MONOPROPELLANT APPLICATION TO SPACE STATION AND OMV AUTOMATIC REFUELING IMPACTS OF AN ELV LAUNCH, VOLUME 4 (Martin Marietta Corp.) N88-11741 Unclas G3/18 0103747

MARTIN MARIETTA

MCR-87-1339

Final Report
Volume IV

# ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM (OSCRS)

## MONOPROPELLANT APPLICATION TO SPACE STATION AND OMV AUTOMATIC REFUELING IMPACTS OF AN ELV LAUNCH (DRD-10)

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National Aeronautics and Space Administration
Johnson Space Center
Contract NAS9-17585

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## FOREWORD

This report documents work conducted by Martin Marietta Astronautics Group under contract NAS9-17585, Orbital Spacecraft Consumables Resupply System (OSCRS). The contract is administered by the National Aeronautics and Space Administration Johnson Space Center, Houston, Texas. The NASA Project Manager is Nancy Munoz, Propulsion and Power Division. This report provides the results of the contract changes to study the operation of the OSCRS at the Space Station and on the Orbital Manuevering Vehicle using automatic refueling, and launching OSCRS on an Expendable Launch Vehicle.

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R. Eric Traill - Avionics Systems Design
John A. VanderMeer - Structural/Mechanical Design

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GLOSSARY

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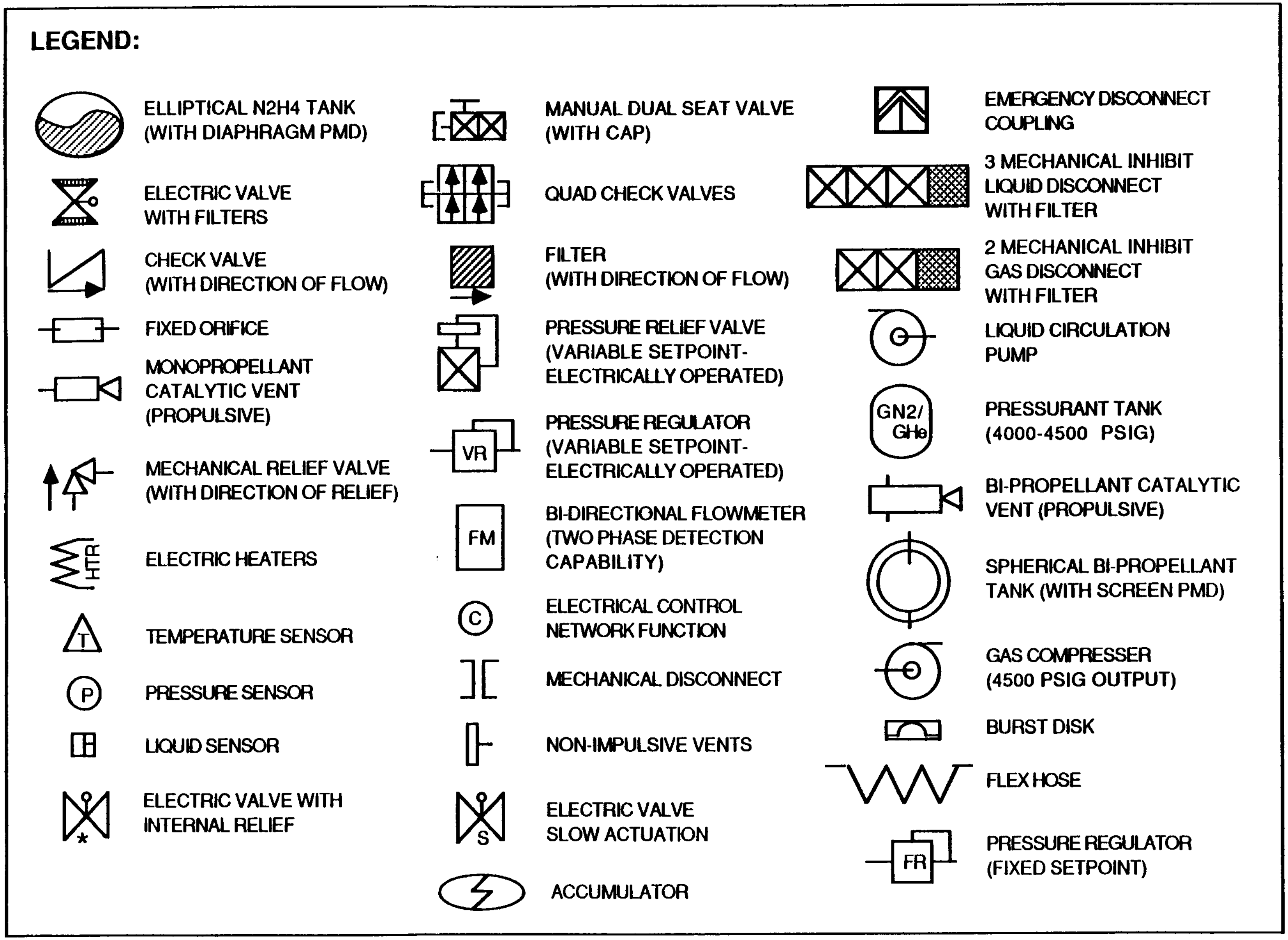
| | |
|---|---|
| ACD | Architectural Control Document |
| AFD | Aft Flight Deck |
| AUC | Automated Umbilical Connector |
| AUM | Automatic Umbilical Mechanism |
| CDU | Common Drive Unit |
| CT | Commercial Titan |
| ECLSS | Environmental Control and Life Support System |
| EDP | Embedded Data Processor |
| ELV | Expendable Launch Vehicle |
| EVA | Extravehicular Activity |
| FSS | Flight Support System |
| FTS | Flight Telerobotic Services |
| GSE | Ground Support Equipment |
| IOC | Initial Operating Capability |
| IVA | Intravehicular Activity |
| MDB | Multiplexed Data Bus |
| MDM | Multiplexer/Demultiplexer |
| MLI | Multilayer Insulation |
| MSC | Mobile Servicing Center |
| MWS | Mobile Work Station |
| NSTS | National Space Transportation System |
| OFS | Operational Flight Software |
| OMV | Orbital Maneuvering Vehicle |
| ORU | Orbital Replaceable Unit |
| OSCRS | Orbital Spacecraft Consumables Resupply System |
| PAE | Payload Attachment Equipment |
| PDRD | Program Design Requirements Document |
| PDU | Power Distribution Unit |
| PHF | Payload Holding Fixture |
| PLC | Pressurized Logistics Carrier |
| RGDM | RMS Grapple Docking Mechanism |
| RIU | Remote Interface Unit |
| RMS | Remote Manipulator System |
| RUM | Robotic Umbilical Mechanism |
| SBE | Service Bay Enclosure |
| SBM | Service Bay Manipulator |
| SFM | Service Facility Manipulator |
| SPDM | Special Purpose Dextrous Manipulator |
| SRD | System Requirements Document |
| SRV | Short Range Vehicle |
| STA | Service Track Assembly |

| | |
|---|---|
| TDRSS | Tracking and Data Relay Satellite |
| TPDM | Three Point Docking Mechanism |
| ULC | Unpressurized Logistics Carrier |
| UPA | Universal Payload Adapter |




FLUID LEGEND

# 1.0 INTRODUCTION

Martin Marietta completed a Phase B study of the Orbital Spacecraft Consumable Resupply System (OSCRS) in November 1986. That study included definition of requirements, conceptual and preliminary design of a monopropellant system, conceptual design of a bipropellant system, a commonality study, end item specifications, development plans, and cost estimates. The primary thrust of that study was for operation with the Shuttle using manual refueling. This report documents work of the contract extension which emphasized the operation of the monopropellant system at the Space Station and on the Orbital Maneuvering Vehicle (OMV) using automatic refueling and possible launch on an Expendable Launch Vehicle (ELV). The objective of this contract extension study is to define any impacts to the OSCRS design defined in the Phase B study as a result of this work.

The following groundrules and assumptions were established for the study.

1. OSCRS will not supply gas to Space Station.

2. Automatic mechanisms shall have an override that can be operated by extravehicular activity (EVA) or by a robot.

3. Fluid resupply shall not require the use of robots. However, nothing will preclude the use of robotics for use with OSCRS.

4. All OSCRS configured for Space Station use shall only provide safety monitors to the NSTS.

5. Space Station equipment will transport OSCRS between the National Space Transportation System (NSTS) and the Space Station service facility.

6. Space Station does not permit venting of liquids.

7. Gas venting is permitted only at 14-day intervals at Space Station.

Our approach to the study was to define the requirements for use of the OSCRS on the Space Station and OMV, define the minimum modifications required to the OSCRS to meet the requirements, and then consider other changes that could improve the efficiency of the OSCRS in these applications. The changes were primarily limited to those that could be accommodated by proper modularization of the OSCRS so that it could still be used for the many other applications for spacecraft refueling. We then assessed the impacts on the OSCRS program. In addition, we specifically defined potential simplifications to the OSCRS if it were used to supply water, define the impacts of launching on an ELV; and provided more depth in automatic refueling. Our approach to automatic refueling was first to define requirements for an automatic umbilical and combined automatic umbilical/docking mechanism, to study existing prototype mechanisms to determine their suitability to OSCRS, and to make recommendations for future work.

## 2.0 SUMMARY

A key objective of this study was to investigate the use of OSCRS at the Space Station, its use with the OMV, and launch of the OSCRS on an expendable launch vehicle. A system requirements evaluation was performed initially to identify any unique requirements that would impact the design of OSCRS when used at the Space Station. Space Station documents were reviewed to establish requirements and to identify interfaces between the OSCRS, Shuttle, and Space Station, especially the Servicing Facility. The interfaces between OSCRS and the Shuttle, shown in Figure 2.0-1, consist of an avionics interface for command and control and a structural interface for launch support and for grappling with the Shuttle Remote Manipulator System. Interfaces between OSCRS and the Space Station Servicing Facility are summarized in Figure 2.0-2. Fluid interfaces are required between the OSCRS and the Station for waste gas disposal and for nitrogen supply. The lone liquid interface would be between the OSCRS and the payload. Structural interfaces between the OSCRS and the Station can use many different types of mechanisms. A structural interface between the OSCRS and the Servicing Facility is required for berthing and for transporting. Avionics interfaces will be required to allow OSCRS to be powered, monitored, and controlled by the Station. Interfacing the basic OSCRS avionics subsystem to the Space Station should be a simple task because the Space Station will provide command and data and power interfaces that are two-fault tolerant and that exceed OSCRS requirements. The Space Station command and data interfaces are all computer controlled; therefore, the Shuttle hardwire switched functions will be accommodated by the Majority Vote Units (MVU) to allow majority voting of the computer-controlled Space Station commands. Figure 2.0-3 shows the command, data, and power interfaces to the Space Station.

For use of the OSCRS at the Space Station, three configurations were evaluated using the results of the interface definition to increase the efficiency of OSCRS and to decrease the launch weight by Station-basing specific OSCRS subsystems. The basic OSCRS, designed for use in the Shuttle, does not satisfy Space Station requirements without changes. A minimum modified OSCRS, essentially the basic version with the minimal design changes necessary to be compatible with the Station, was configured so that the pressurant tanks were removed and connections were added to receive nitrogen from the Station and to vent waste gas. A modular OSCRS was developed in which the major subsystems were Station-based where possible. The fluid subsystem was modularized with the pressurization system and the catalytic vent system hardware removed and left on the Station. From the avionics standpoint, the minimum modified and the modular OSCRS could be greatly simplified by basing the majority of the OSCRS avionics on Space Station. In order to Station-base the avionics, two changes were identified to allow monitoring of the OSCRS during NSTS transport: addition of a multiplexer unit to reduce the data interface to NSTS and splitting of the Power Distribution Unit (PDU) so that power switching to the

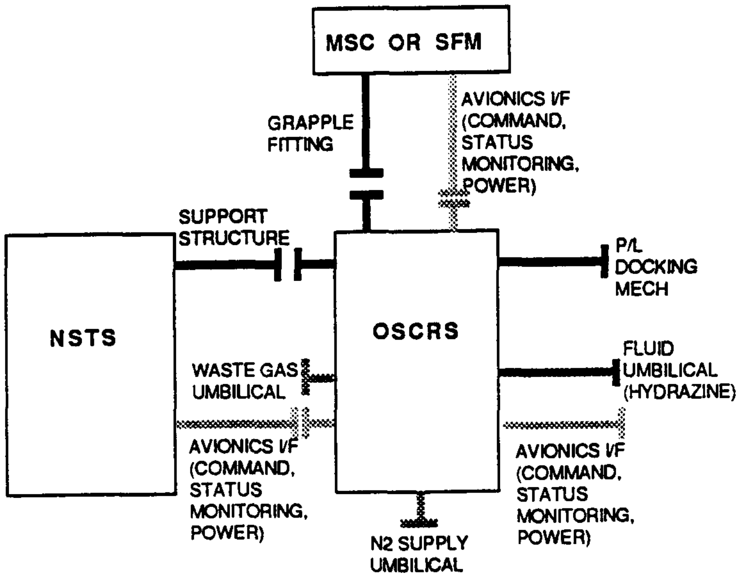



*Figure 2.0-1 OSCRS-to-NSTS Preliminary Interfaces*

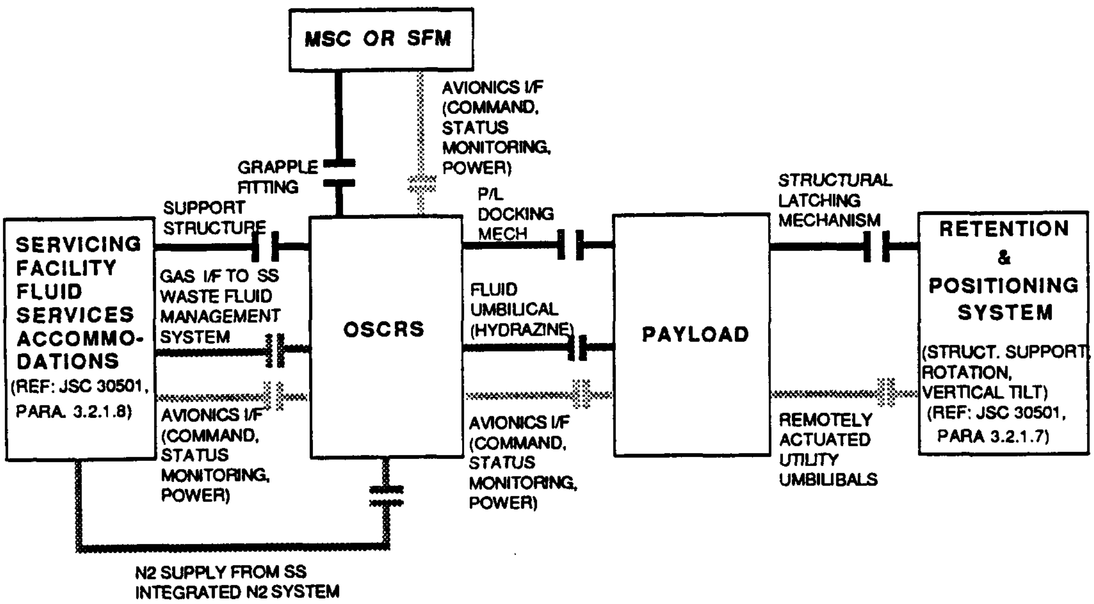



*Figure 2.0-2 OSCRS-to-Servicing Facility/Payload Preliminary Interfaces*

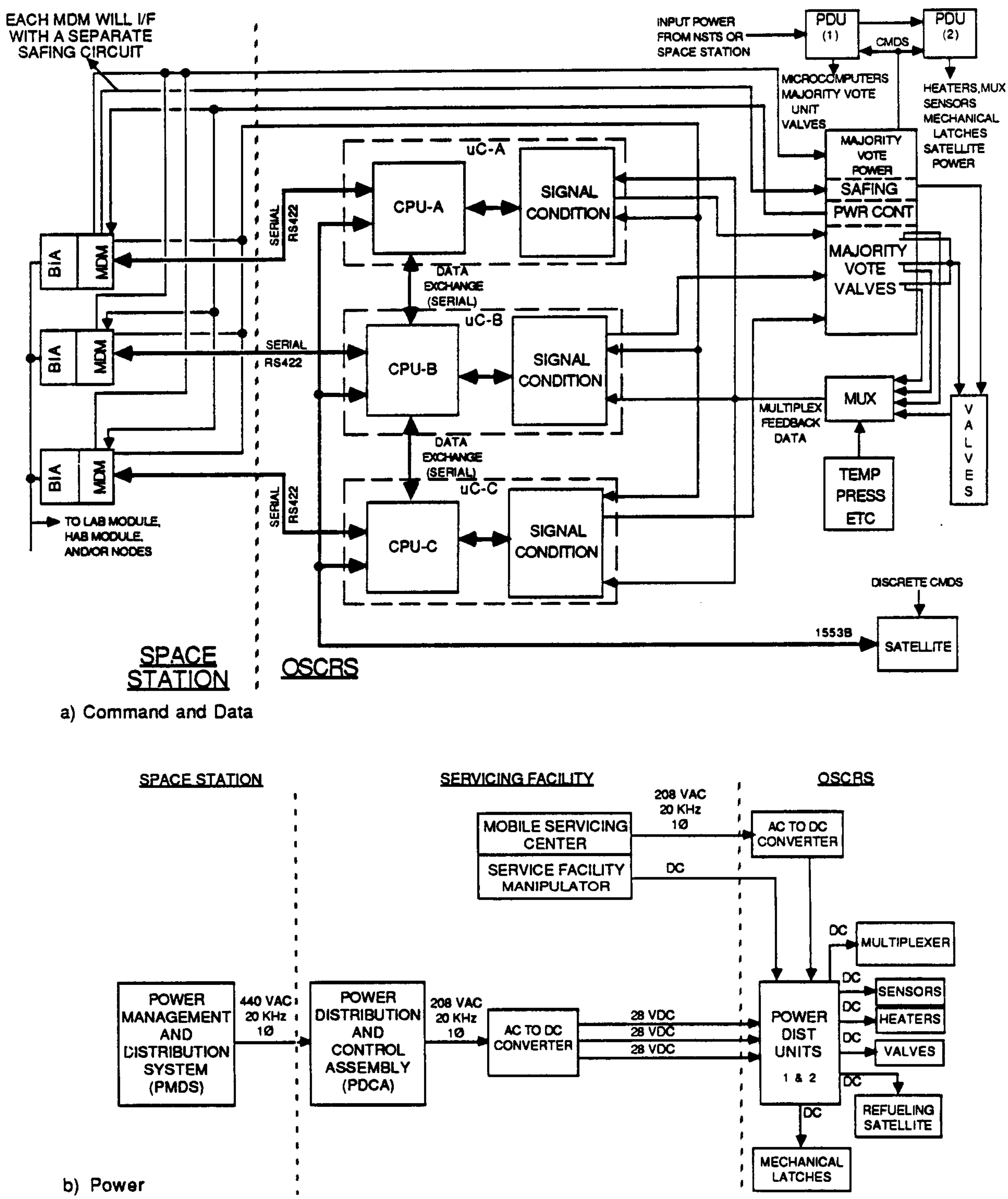



*Figure 2.0-3 Basic OSCRS-to-Space-Station Interface*

multiplexer, sensors, and heaters can be controlled by NSTS. All other power switching functions would be in a separate PDU that would be station based. Figure 2.0-4 shows a block diagram of the OSCRS avionics with station basing. The OSCRS computers have all been eliminated, and their functions are accomplished by the Space Station Embedded Data Processors (EDP).

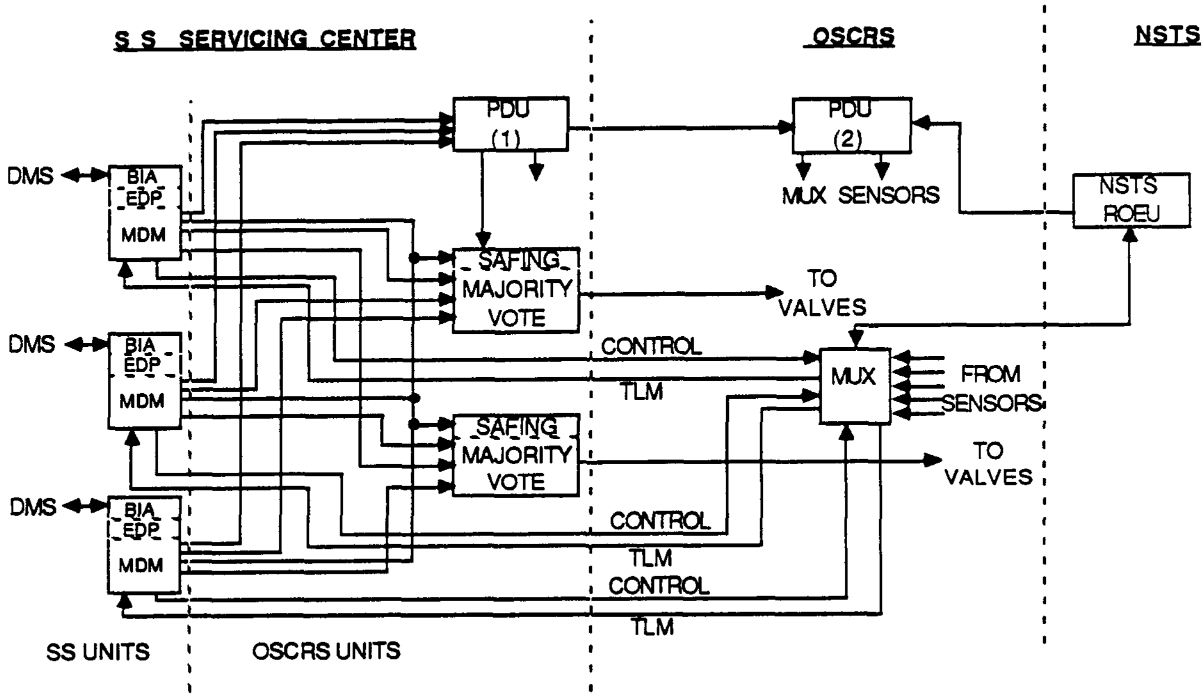
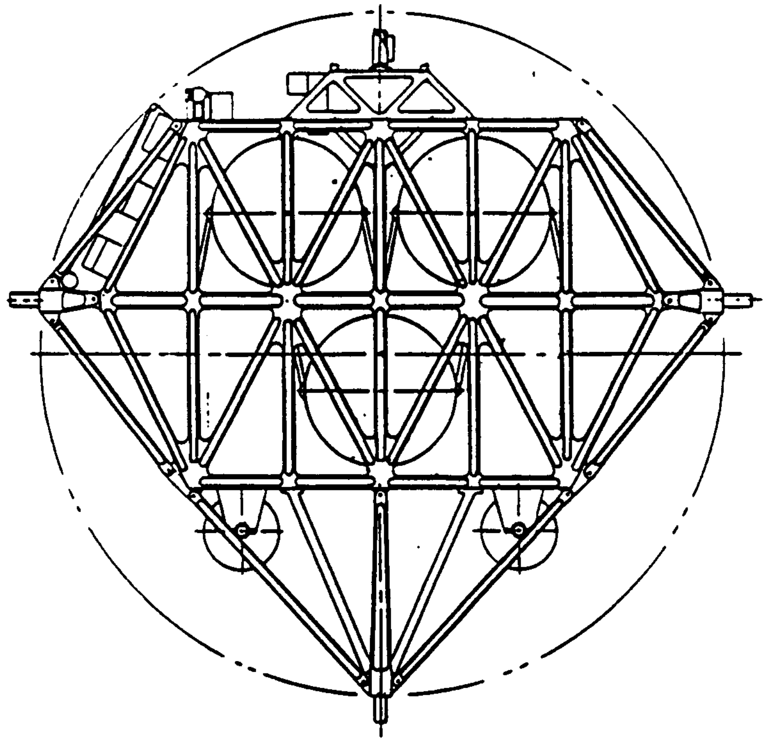


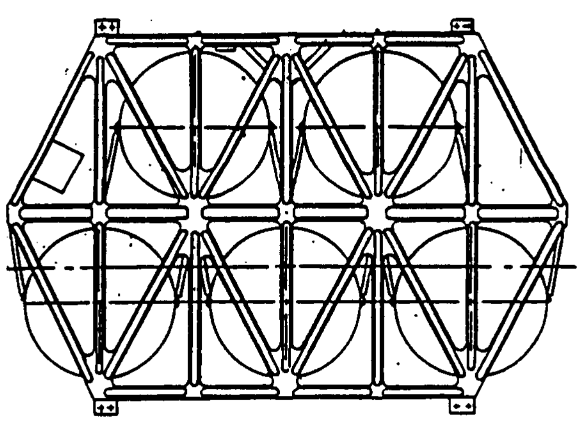

*Figure 2.0-4 Station-Based OSCRS Avionics Block Diagram*

The above changes allowed a simplified structural configuration, shown in Figure 2.0-5, resulting in a significant up/down weight savings. The weights for the three OSCRS configuration options are presented in Table 2.0-1 by subsystem. As shown, a significant increase in mass fraction can be achieved with the modular OSCRS compared to the basic OSCRS. With proper design, the modular OSCRS could be configured to permit assembly of the subsystems on a strongback structure to allow OSCRS to be used for refueling on the Shuttle and in-situ on the OMV. Because of this flexibility and the savings achieved in launch weight, the modular OSCRS configuration was recommended.

Another program objective was to define the configuration of an OSCRS for transport of water to the Space Station. Analysis of the Station water requirements for propulsion, laboratory, and life support identified an annual deficit of approximately 5000 lb. It was determined that the basic monopropellant OSCRS could be greatly simplified by using an augmented blowdown system for transfer of the water, as shown in Figure 2.0-6. The resulting simplification in the



**BASIC OSCRS**
**CONFIGURATION**



**MODULAR OSCRS**
**CONFIGURATION**

*Figure 2.0-5 Structural Changes--Modular OSCRS*

*Table 2.0-1 OSCRS Monopropellant Configuration Options Weight Summary*

| CONFIGURATION / SUBSYSTEM | BASIC OSCRS (3 TANK VERSION) | MINIMUM MODIFIED OSCRS (3 TANK VERSION) | MODULAR OSCRS (3 TANK VERSION) |
|---|---|---|---|
| FLUIDS<br>• PRESSURZATION<br>• VENT<br>• PROPELLANT STORAGE | 804 | 648 | 84<br>6<br>505 |
| THERMAL | 93 | 93 | 81 |
| TRUSS STRUCTURE | 504 | 504 | 237 |
| MECHANISMS | 213 | 192 | 20 |
| AVIONICS | 314 | 314 | 25 |
| MASS FRACTION | 0.60 | 0.63 | 0.76 |
| • ALL WEIGHTS IN LBS | | | |

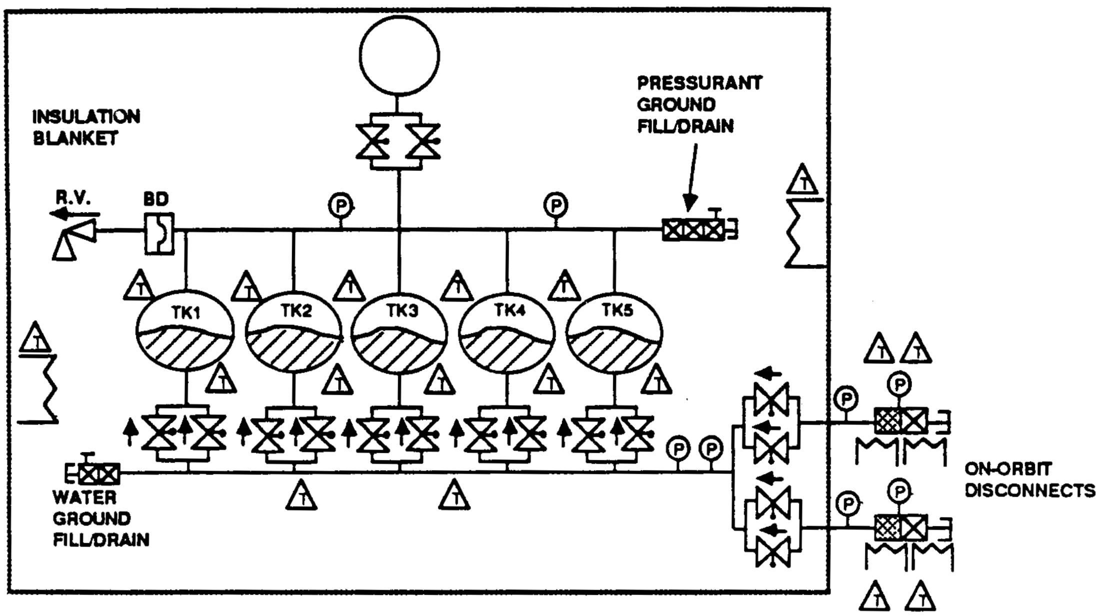


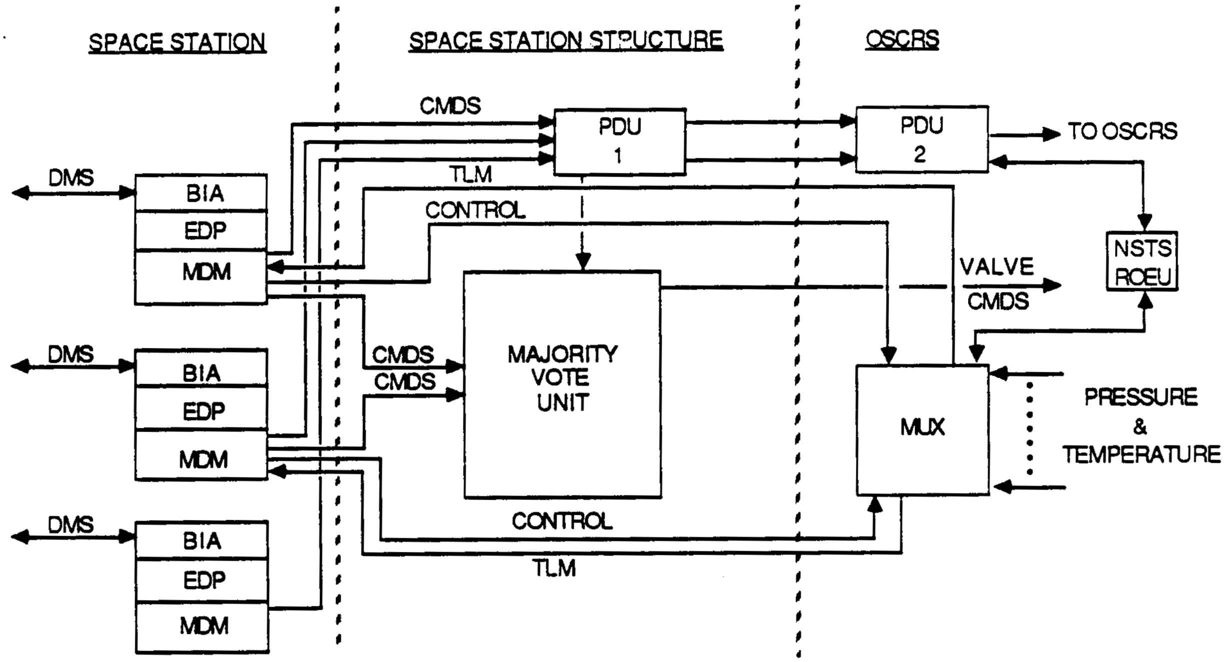

*Figure 2.0-6 OSCRS Water Version Fluid System Schematic*

plumbing allowed the avionics to be similarly reduced. To satisfy the 5000-lb yearly deficit, a water OSCRS configured with five tanks identical to the monopropellant OSCRS would be required. Smaller capacities could be used if the water OSCRS could be launched more frequently. The water OSCRS avionics is a simplification of the basic OSCRS avionics in that it is only two-fault tolerant for heater operations to prevent freezing. This allows the system to be reduced to one MVU, PDU1, PDU2, and the multiplexer unit. Figure 2.0-7 shows the command and data and power interfaces for the water OSCRS. Because the water OSCRS is used only for Space Station, the avionics is station based and uses the Space Station EDPs for processing.

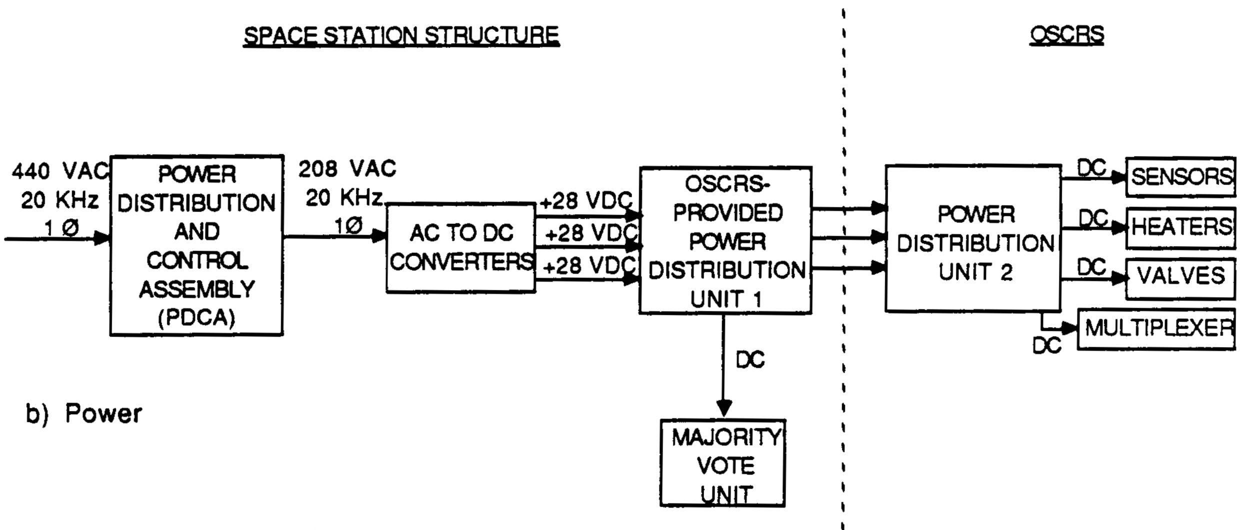
Systems trade studies were performed to examine operations of the OSCRS at Space Station, including transfer of the OSCRS to the Station, moving of the OSCRS to the refueling location versus the installation of propellant distribution lines on the Space Station, and the use of multiple OSCRSs. Transferring OSCRS from the Shuttle bay to the Station requires several umbilical mating/demating procedures. Unless the umbilical mechanisms and connectors are standardized, interfaces on the OSCRS will be complex. Transporting OSCRS via the Service Bay Manipulator and/or the Mobile Servicing Center will require two-fault-tolerant data and 28-Vdc power. Using OSCRS for fluid resupply while attached to the Service Bay Manipulator or Mobile Servicing Center will require two-fault-tolerant command and data and 28-Vdc power. These requirements are not presently part of the conceptual designs of the Service Bay Manipulator and Mobile Servicing Center.

If refueling is desired in a Station location other than the Servicing Facility, the OSCRS should be transported to that location rather than leaving it in a fixed location and running distribution lines out to the alternate refueling site. Maintenance, assembly, and heater power of external distribution lines would not be cost effective.

Use of multiple OSCRSs would be desirable to allow larger quantities of propellants to be stowed on-orbit and to allow an OSCRS to be offloaded into another to ensure that it was returned to the ground empty. The interconnection of two or more OSCRS, from the fluid subsystem design viewpoint, requires no design changes provided that the Station supply some additional plumbing with compatible connectors on each end. To avoid further complicating the avionics when using multiple OSCRS, the recommended method is to operate each OSCRS independently. This will avoid adding more input/output channel interfaces and software changes that would be required if the tankers would be interconnected in some fashion.




a) Command and Data




b) Power

*Figure 2.0-7 Water OSCRS-to-Space-Station Interfaces*

Another Space Station design impact on the OSCRS is the requirement to provide meteoroid and space debris protection to prevent catastrophic failure of the OSCRS tankage. The debris protection configuration, shown in Figure 2.0-8 would consist of an aluminum panel, 0.03-0.075 inches thick. The panels would be located toward the direction of flight and would be left on the Station. The amount of protection was reduced by orienting OSCRS such that its projected surface area facing the direction of flight was minimized.

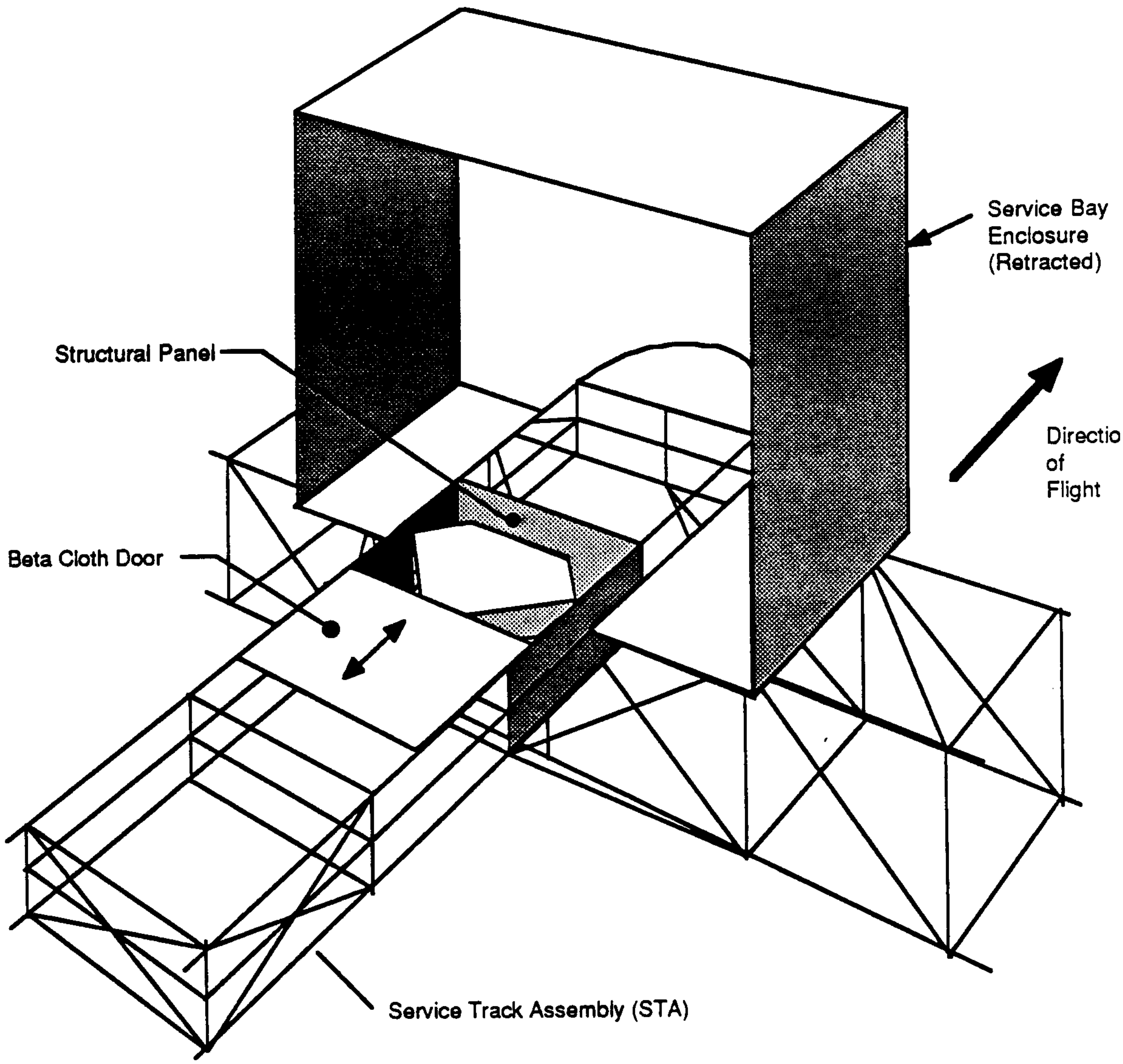



*Figure 2.0-8 Meteoroid Protection at the Space Station Customer Service Facility*

Operations of the OSCRS with the OMV were studied to determine interfaces and any design changes required by OSCRS. Refueling the OMV hydrazine and cold gas nitrogen propulsion systems can be accommodated by the OSCRS with no design changes. However, the baseline OMV has one hydrazine coupling and four separate nitrogen couplings, requiring at least four connector mating/demating sequences. Additionally, the connectors are not easily accessible as currently designed. To simplify OSCRS/OMV refueling interfaces, it was recommended that the OMV cold gas propulsion system be manifolded to allow recharging of the pressurant tanks with a single connector and that the hydrazine, nitrogen, and electrical connectors be physically located together to allow a single umbilical mechanism to perform the mate/demate operation. Structurally, the OSCPS can accommodate attachment to the OMV with minor design changes using either a circular bolted interface or the OMV Remote Manipulator System (RMS) Grapple Docking Mechanism, which interfaces with a standard grapple fitting on the OSCRS.

Interfacing OSCRS to OMV presented the most problems for the avionics subsystem. OMV does not presently provide payloads with two-fault-tolerant command, data, and power. In addition, OMV serial command/data interfaces are not of a standard format such as RS422 or 1553B. This requires OSCRS to provide an OMV-dedicated set of interfaces. All OMV payloads must provide their own Remote Interface Units (RIU) at a purchase price of $90-200K, depending on the setup charges involved. All commands and telemetry must be accomplished in real time because the OMV documentation does not show command/data storage devices such as tape recorders. Figure 2.0-9 shows the OSCRS-to-OMV interfaces.

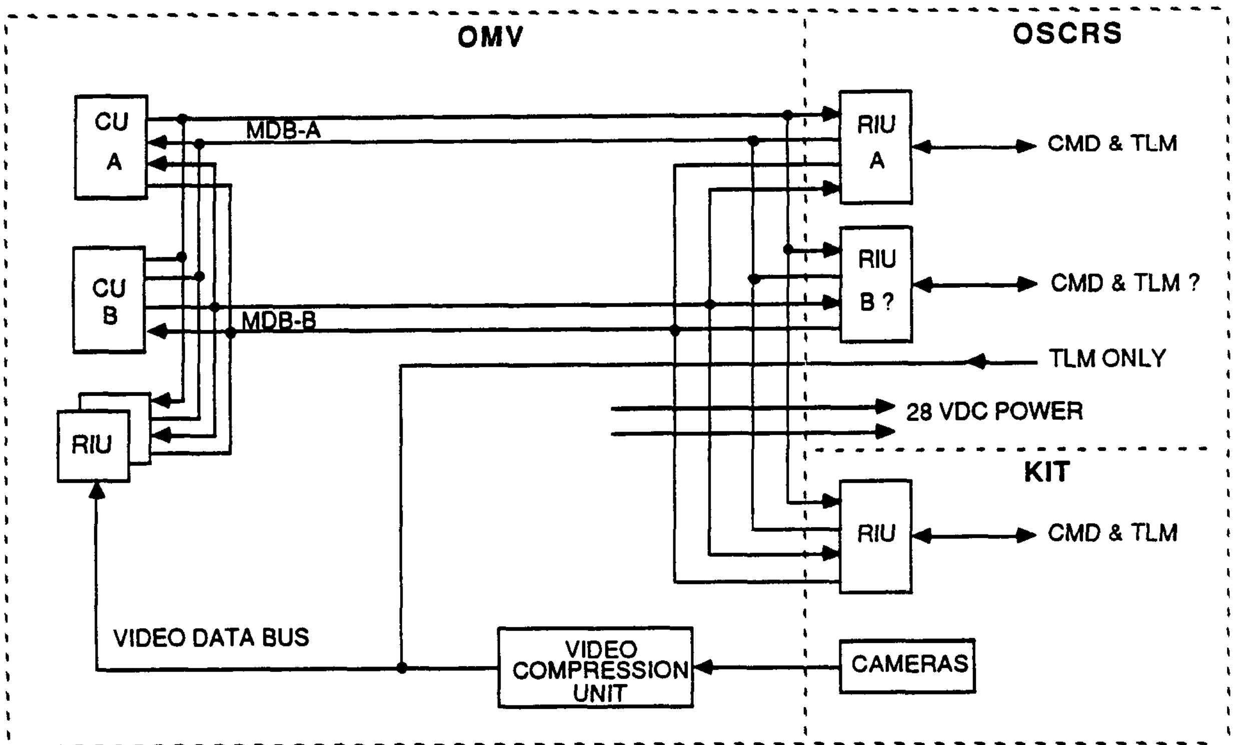



*Figure 2.0-9 OSCRS-to-OMV Avionics Interface*

Another major effort of this program was to define requirements for an automatic umbilical mechanism (AUM) to be used with OSCRS to perform automatic refueling. Automatic refueling of hazardous fluids will be required on Space Station and in-situ using the OMV/OSCRS combination. General requirements for the AUM were defined and tabulated based on a review of Space Station, Shuttle, and OMV requirements. Next, requirements for the AUM design that would be unique to the Shuttle, Space Station, and OMV were defined. Among the more significant requirements was the ability of the AUM to accommodate seven connectors; three electrical, two gaseous and two propellant. Also, the AUM drive motors must be one-fault tolerant for connector mating. For OMV and Shuttle use, the AUM must also have a two-fault-tolerant emergency satellite jettison capability. A requirement to provide contamination covers over the connectors on both halves of the AUM was also defined.

These requirements served as the basis for an evaluation of existing prototype AUMs to determine the adequacy of their designs. The Moog Automated Umbilical Connector (AUC) and the Martin Marietta Robotic Umbilical Mechanism (RUM) are both capable of automatically mating connectors. Each can satisfy the general requirements developed for the AUM with modifications. These modifications were defined for each of the two mechanisms and included such things as the accommodations of seven connectors. Changes to the OSCRS avionics subsystem to control an automatic umbilical would be minimal and would not result in significant cost, weight, power, or size impacts. Finally, the feasibility of designing an AUM to perform both the docking and connector mating functions was examined. It was concluded that designing such a mechanism would be possible and desirable since it would simplify both operations and interfaces.

The last item examined was the changes to OSCRS to be launched on an Expendable Launch Vehicle. The capabilities and costs of candidate vehicles were reviewed. Only the Titan IV vehicle has a payload fairing large enough to accommodate a basic OSCRS (assuming the trunnion pins and keel fittings are removed). Use with any other launch vehicle would necessitate a major redesign of the OSCRS structure. The Titan CT (Commercial Titan) has the capability to place the OSCRS in the same circular orbit as the Space Station and stabilize the OSCRS prior to release. The OSCRS could subsequently be retrieved by the OMV. The impacts to the OSCRS structure to fit within the Titan IV and Titan CT payload fairings is shown in Figure 2.0-10. Significant redesign of the OSCRS structure would be required to fit within the Titan CT envelope and would thus be a major impact. In addition to the Titan vehicle, the Delta and Atlas vehicles were examined. The Delta and Atlas vehicles have the payload capability to accommodate OSCRS but, unless an upper stage is flown, they have no ability to stabilize the OSCRS for deployment or to circularize the orbit. Therefore, emphasis was placed on the Titan IV because of its large payload fairing and on the Titan CT because of its ability to provide attitude control without an upper stage. The Titan ELVs, however, provide very limited command capability and no serial telemetry channels to the payloads. The command capability is sufficient to turn on necessary heaters to avoid freezing while awaiting pickup by an OMV for transport to the Space Station. Once OMV rendezvous with OSCRS, full command and telemetry capabilities would exist, and OSCRS status could be sent to Earth before reaching Space Station. Titan CT provides an attitude and control system that can maintain the stability of OSCRS for up to six hours. This estimate is based on OSCRS use of power for necessary heaters only and on its use of the standard complement of Titan batteries.

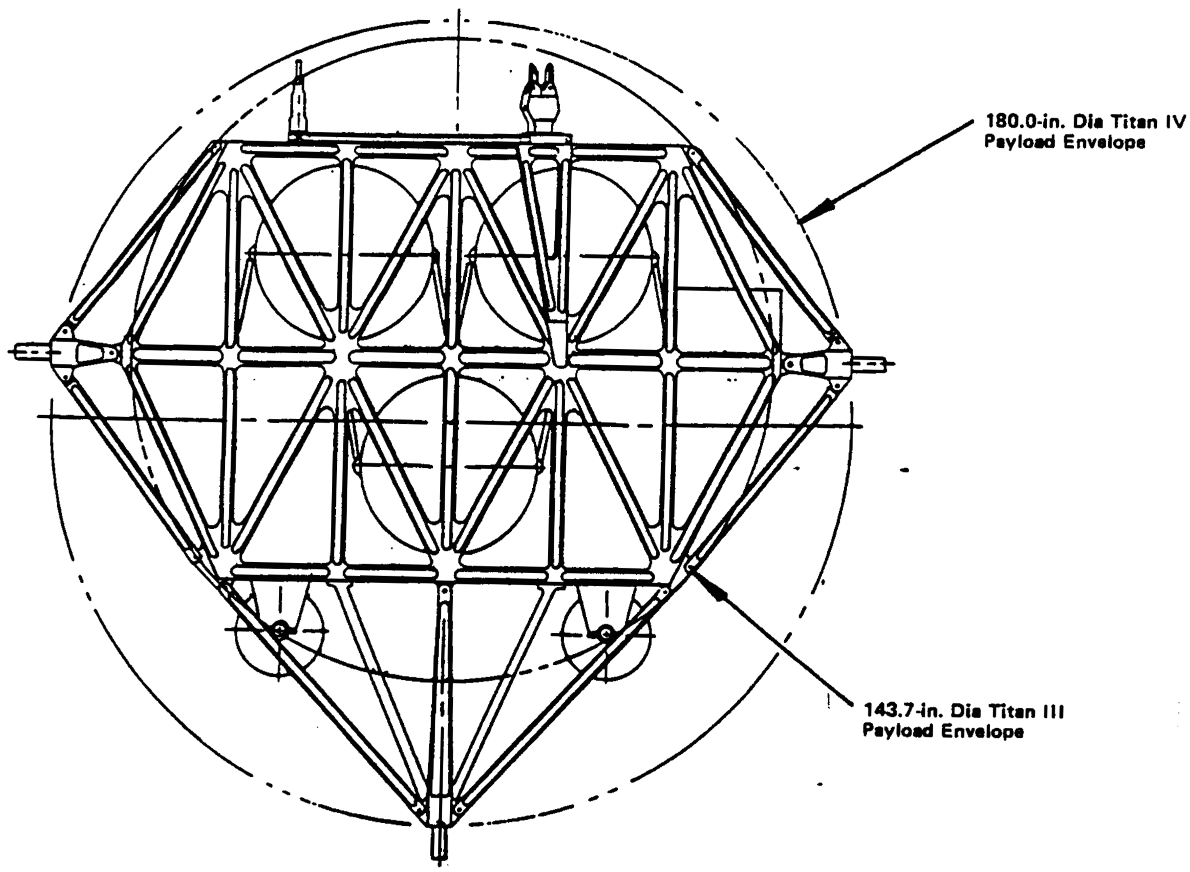



*Figure 2.0-10 OSCRS--Titan Payload Envelope*

# 3.0 SPACE STATION UNIQUE REQUIREMENTS

## 3.1 SPACE STATION DESCRIPTION

The Space Station is being designed as a permanently manned facility capable of performing various scientific investigations as well as spacecraft maintenance and resupply. The Station consists of both pressurized and unpressurized elements provided by both the United States and foreign partners. The Station is being designed for an orbit ranging from 150 nautical miles to 270 nautical miles at an inclination of 28.5°. The pressurized elements are attached to the truss assembly, which serves as the structural backbone of the Station. The major core elements are as follows:

- U.S. Laboratory Module
- Habitation Module
- Japanese Experiment Module
- Columbus Module
- U.S. Platforms
- Mobile Servicing Center
- Servicing Facility
- Nodes and Airlocks
- Logistics Elements

Two program options have been defined for the Station involving a phased approach to assembly. Program Option One consists of two phases. The first phase, shown in Figure 3.1-1, consists of only the transverse boom of the truss assembly with the four pressurized modules attached and a photovoltaic power system at Station Initial Operating Capability (IOC). The Servicing Facility and the upper and lower booms of the truss assembly are defined as phase two and would be added later. Program Option Two includes all of the elements listed above as being in place at Station IOC.

In evaluating the use of OSCRS at Space Station, the configurations of the Servicing Facility, Mobile Servicing Center, and Logistics Elements are especially important because OSCRS would directly interface with these elements. Therefore, these are discussed separately in the following paragraphs.

### 3.1.1 Servicing Facility

The Servicing Facility will be used for the servicing, assembly, and maintenance of attached payloads, OMV, and free-flyers, including specific operations such as refueling and repair and replacement of components. The Servicing Facility, shown in Figure 3.1.1-1, is an unpressurized structure attached to the transverse boom adjacent to the pressurized modules. The main elements of the Servicing Facility are:

Service Bay Enclosure (SBE) - Four telescoping thermal and contamination barriers.

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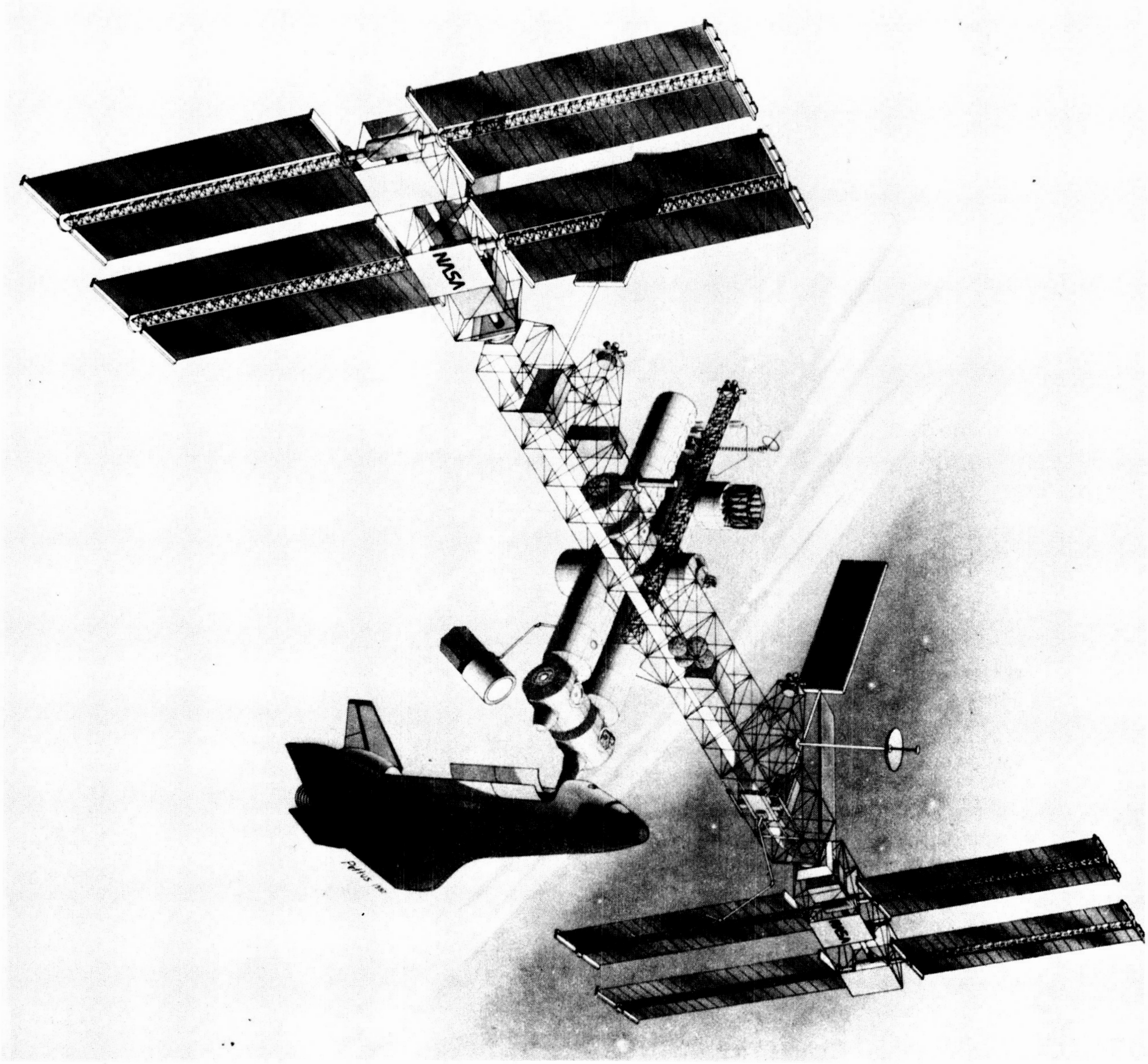

*Figure 3.1-1 Space Station Program Option/Configuration*

Service Track Assembly (STA) - Keel-mounted rail structure that supports the moving enclosure sections, the service bay manipulator, and the universal payload adapter. Equipment such as OSCRS is stored in separate bays of the STA as shown in Figure 3.1.1-2.

Service Bay Manipulator (SBM) - Track-mounted remote manipulator able to translate around the servicing facility and reach payloads mounted on the STA, backside of the keel, and Orbiter payload bay. It includes an EVA control station.

Mobile Work Station (MWS) - An SBM-mounted astronaut work station with Orbital Replaceable Unit (ORU)/instrument carrier.

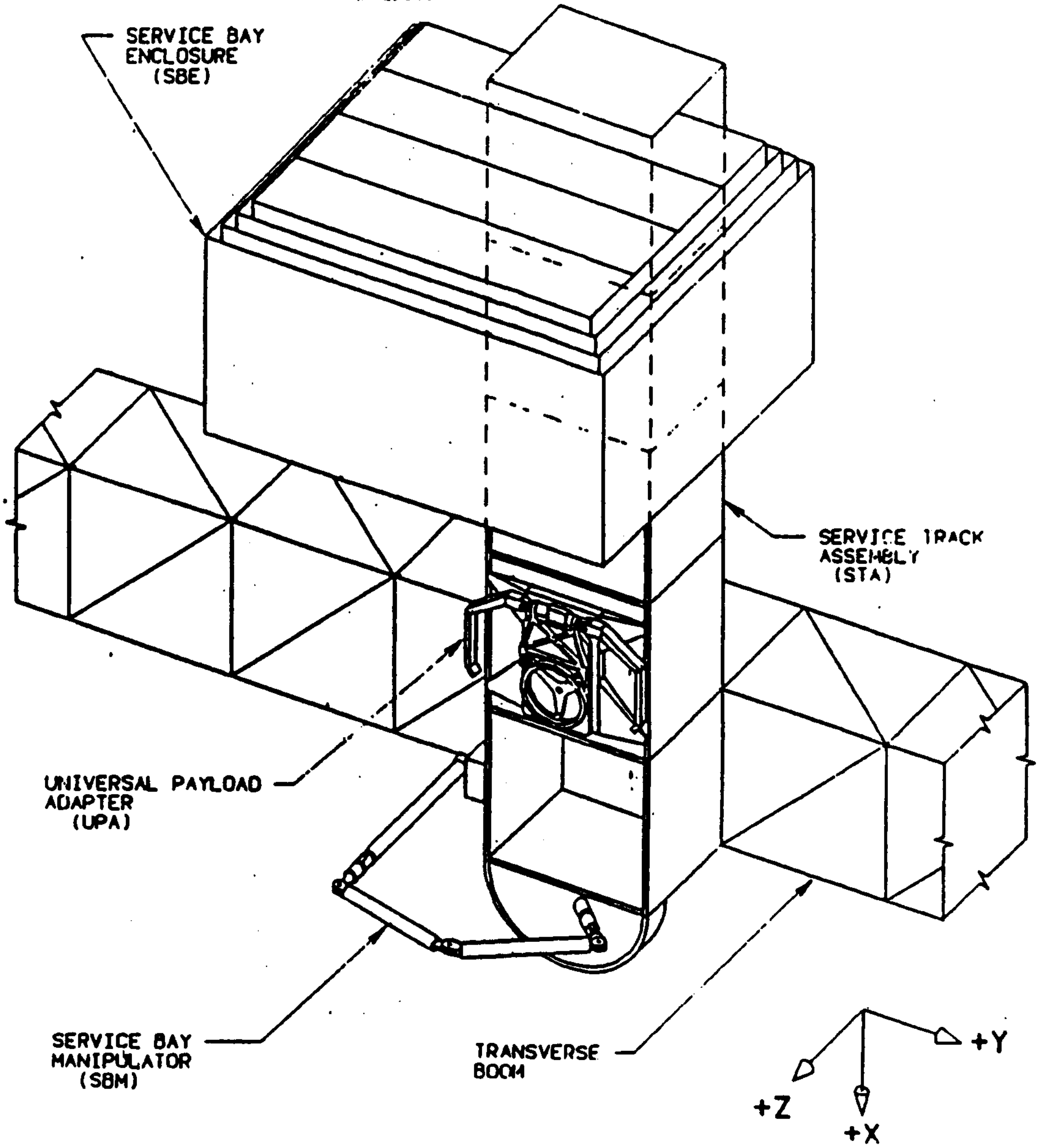


*Figure 3.1.1-1 Servicing Facility*

Payload Holding Fixture (PHF) - Passive trunnion adapter able to support a satellite and OMV inside and outside the Servicing Facility.

Universal Payload Adapter (UPA) - Articulating attachment device able to mate with grapple, flight support system (FSS), and trunnion fittings.

Fluid Servicing Module - Fluid storage and transfer system baselined as OSCRS.

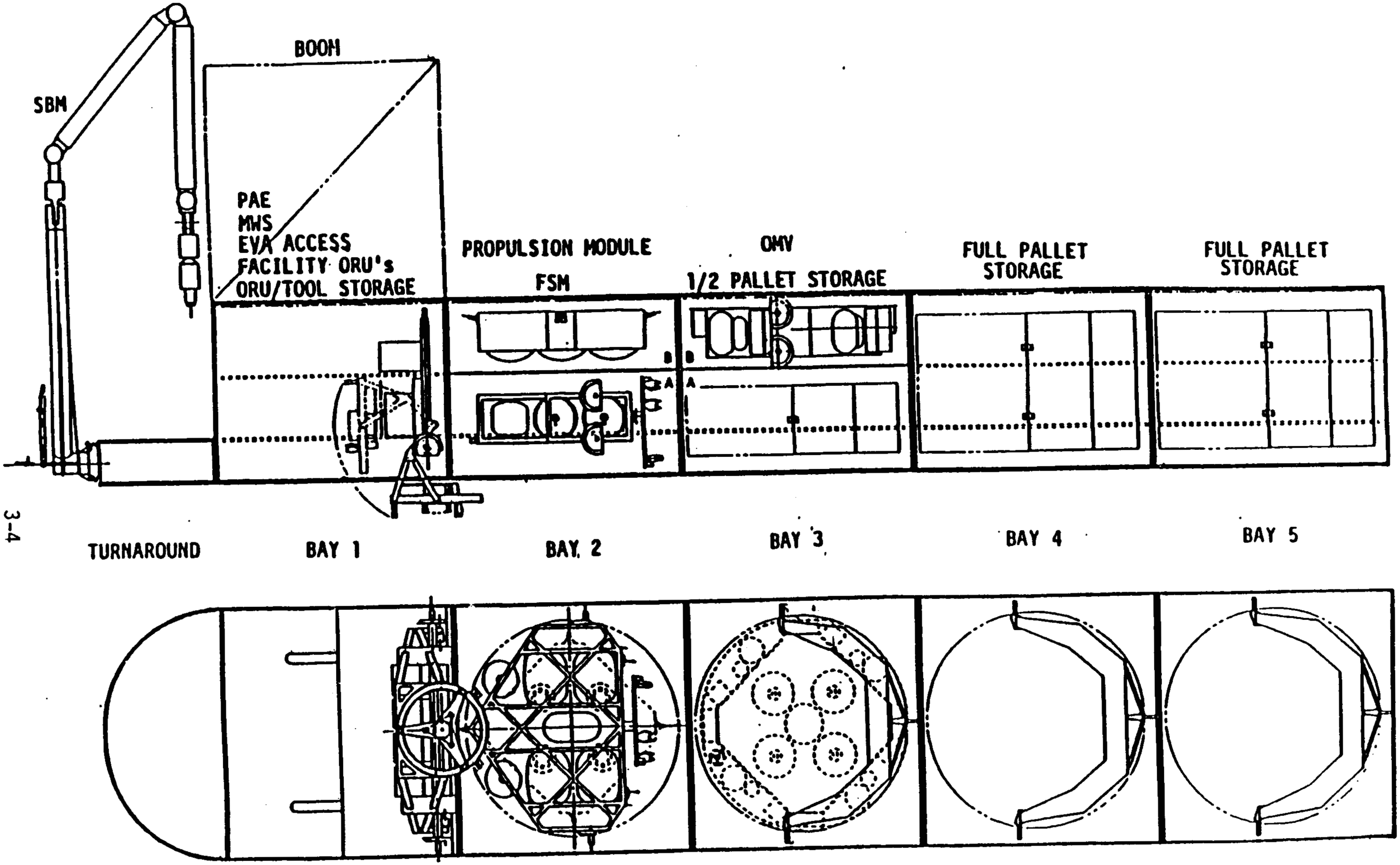


*Figure 3.1.1-2 Service Track Assembly Layout*

Payload Attachment Equipment (PAE) - Replication of payload attachment equipment on the Space Station to accommodate payloads serviced in the Servicing Facility.

Command/Control/Monitoring Station - Provides a central facility for support of all EVA servicing operations.

Intravehicular Activity (IVA) Work Bench - Provides a facility to test, diagnose, and repair equipment in a shirtsleeve environment.

The Servicing Facility must satisfy several requirements. It must provide for the physical attachment and retention of the vehicle being serviced. It must also receive power from the Space Station and convert and distribute that power for use throughout the facility. Both active and passive thermal conditioning for the facility and users must be provided as well as provisions for data handling for command, monitoring, measurement, and data processing through an interface with the Station data management system. The Servicing Facility must provide a contamination-free environment suitable for use by observatory-class payloads and provide facilities to permit easy EVA access to spacecraft for servicing operations. Manipulation and handling devices for removing and positioning spacecraft must be provided for handling within the Servicing Facility and for removal and replacement to or from the Orbiter payload bay. The Servicing Facility must provide the capability to resupply monopropellant hydrazine and other fluids and gases for which OSCRS has been baselined. It must also provide the handling and transfer to and from the Station of data for control and monitoring of all operations with the facility.

### 3.1.2 Mobile Servicing Center (MSC)

The MSC is being provided by Canada to manipulate and position major Station elements, assemblies, and utilities. It is also needed to support the integration of the major elements, such as the truss assembly and modules, during Station assembly. The MSC will transfer cargo from the Orbiter payload bay, transport the cargo to the required part of the Station, support EVA operations, and provide for post-assembly inspection of the Station elements. The MSC is shown in Figure 3.1.2-1 and consists of the Space Station Remote Servicer (MRS) base structure and the Special Purpose Dextrous Manipulator (SPDM). The MSC rests on the Mobile Transporter, which can translate along the truss assembly to provide mobility.

### 3.1.3 Logistics Elements

The Logistics Elements consist of the Unpressurized Logistics Carrier (ULC) and the Pressurized Logistics Carrier (PLC). The PLC is derived from a Station pressurized module and is used to transport and return equipment requiring a pressurized environment. The ULC transports equipment and fluids to the Station that do not require a pressurized

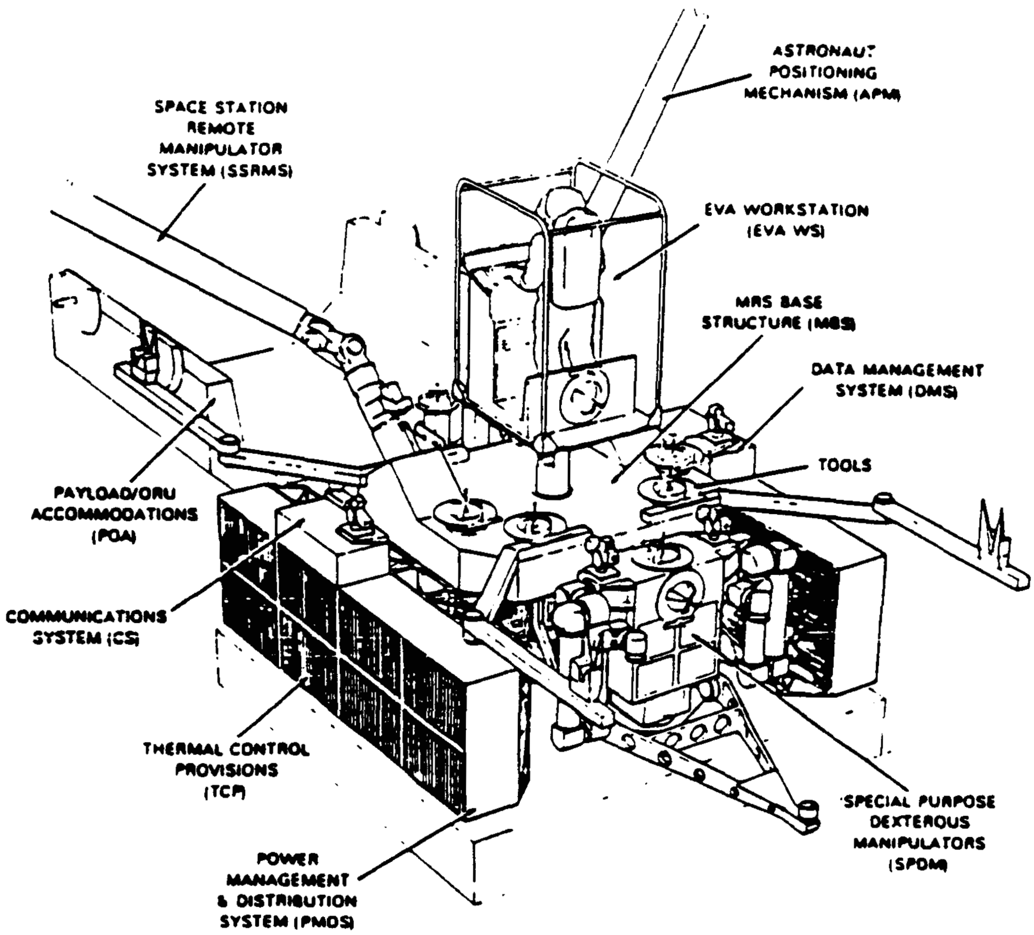


*Figure 3.1.2-1 Mobile Servicing Centre (MSC)*

environment and that are used external to the pressurized modules. Figure 3.1.3-1 presents the concept of the ULC capable of transporting both dry goods and fluids. The potential for interfacing the OSCRS with the ULC was examined for possible weight savings on the OSCRS.

## 3.2 GENERAL DESIGN REQUIREMENTS

The Space Station program has generated a set of unique system design requirements that reflect the philosophy associated with a long-life, permanently manned facility. These requirements are generally similar to those of the Space Shuttle, but, in some cases, they are more demanding. The Space Station program has developed system requirements documents (SRD), design criteria documents, and architectural control documents (ACD) containing all related requirements for each of the major subsystems.

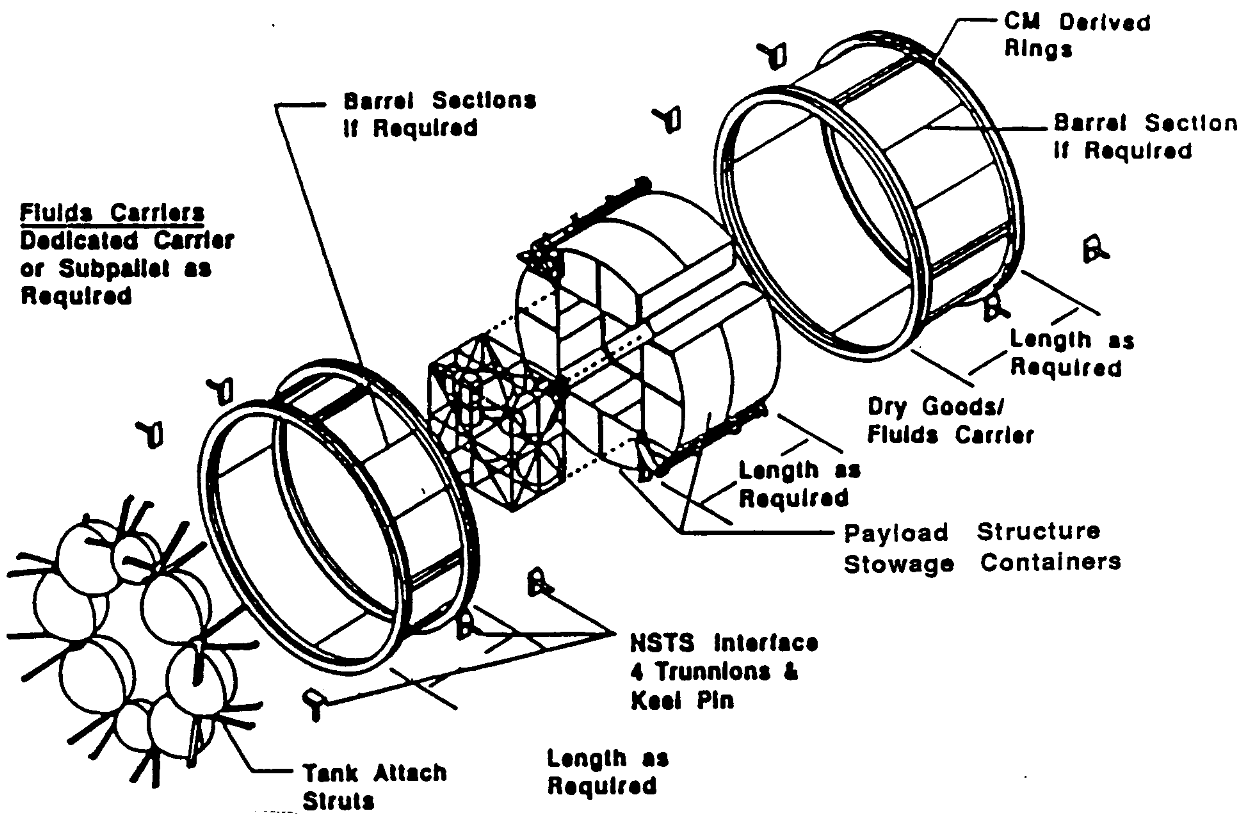


*Figure 3.1.3-1 Unpressurized Logistics Carriers (ULC)*

Table 3.2-1 lists the documents reviewed. The Space Station Program Design Requirements Document (PDRD) presents the requirements applicable to the entire Station, such as safety criteria and design guidelines for fluid, electrical, and mechanical elements. Requirements that are unique to Space Station and that would have an impact on the OSCRS design were identified and are listed in Table 3.2-2, showing the requirements, document reference, and subsystem applicability. The most important criterion is safety, and the Station program has identified three levels of redundancy for onboard systems as shown in Table 3.2-3. Those systems that are critical to crew safety and Space Station element survivability must be two-fault tolerant with three levels of functional redundancy. Those functions critical to mission support must be single-fault tolerant. Noncritical functions require no failure tolerance. Because OSCRS performs a critical mission support function, it was classified for this study as requiring one-fault tolerance to completing its refueling operation. This is the same as existing design requirements for the shuttle-based OSCRS. The requirement for two-fault tolerance to creating a hazard while in the shuttle bay, however, still must be met.

*Table 3.2-1 Reference Documents Used in Study*

| Document | Number | Title | Rev | Date |
|---|---|---|---|---|
| JSC 30000 | | SS PDRD, Sect 3: SS Systems Requirements | D | 1/15/87 |
| | | Sect 9: Product Assurance Reqmts | | 10/24/86 |
| JSC 30213 | | SSP Design Criteria | | 4/15/86 |
| JSC 30228 | | DMS Baseline, Vol 4, Sect 4, Item B, | | |
| JSC 30255 | SC0002422 | SS - BCD | | 1/15/87 |
| JSC 30258 | | Thermal - ACD | | 1/15/87 |
| JSC 30261 | | Data Management System - ACD | | 1/15/87 |
| JSC 30263 | | EPS - ACD | | 1/15/87 |
| JSC 30264 | SC0002457 | Fluid Management Systems - ACD | | 1/15/87 |
| JSC 30426 | | SS External Contamination Requirements | | 11/19/87 |
| JSC 30431 | SC0002706 | Servicing Facility/Truss Assy - IRD | | 1/15/87 |
| JSC 30501 | | Space Station Servicing Facility - ACD | | 1/15/87 |
| | SY 19-2 | OMV Flight Vehicle - CEI Specification | A | 10/15/86 |
| | SY 20-4 | OMV Payload Accommodations Equip. - CEI Spec | A | 10/15/86 |
| | 43267.000 | OMV Preliminary Design Document, Book 1 | | 8/30/85 |
| | " | " " " " Book 2 | | |
| | " " | " " " Book 3 | | |
| | - | OMV Executive Summary | | 8/30/85 |
| | - | | | |
| GE/TRW DR-02, V4 | | WP-03 Defin & Prelim Design, Cust Servicing | | 12/19/86 |
| NSTS 07700, Vol XIV | | Space Shuttle System Payload Accommodations, | I | 9/16/86 |
| ATT I (ICD 2-19001) | | Shuttle Orbiter/Cargo Standard Interfaces | I | 9/16/86 |

*Table 3.2-2 Space Station Unique Design Requirements Affecting OSCRS*

| REQUIREMENT | SUBSYSTEM APPLICABILITY | REFERENCE |
|---|---|---|
| FAILURE TOLERANCE LEVELS | ALL | JSC 30000, SEC 3; PARA 2.1.10.A |
| STORAGE CONTAINER LEAK BEFORE BURST | STRUCTURAL/MECHANICAL | JSC 30000, SEC 3; PARA 2.1.11.2.4.1 |
| CONTAMINATION CONTROL EXTERNAL VENTING (14 DAY HOLD) | FLUIDS | JSC 30426, PARA 3.1.1 |
| METEOROID/DEBRIS PROTECTION | STRUCTURAL/MECHANICAL | JSC 30000, SEC 3; PARA 2.1.3.1.1 |
| HAZARDOUS FLUID RESUPPLY SHALL USE REMOTELY OPERATED UMBILICALS WITH MANUAL OVERRIDE | FLUIDS; STRUCTURAL/ MECHANICAL | JSC 30000, SEC 3; PARA 2.1.2.4.3.4 |
| NON-HAZARDOUS DRAINS, VENTS, AND WXHAUST PORTS | FLUIDS | JSC 30000, SEC 3; PARA 2.1.11.2.6 |
| LEAK DETECTION, CONTROL, AND ISOLATION | FLUIDS | JSC 30000, SEC 3, PARA 2.2.12.2.2.2; PART 2, PARA 3.5.3.11 |

*Table 3.2-3 Space Station Redundancy Requirements*

| FUNCTIONAL CRITICALITY | FAILURE TOLERANCE | FUNCTIONAL REDUNDANCY |
|---|---|---|
| CREW SAFETY AND SSP SURVIVAL | 2 FAILURE | 3 MINIMUM |
| CRITICAL MISSION SUPPORT | 1 FAILURE | 2 MINIMUM |
| NONCRITICAL FUNCTIONS | 0 FAILURE | 1 MINIMUM |
| ALL SYSTEMS SHALL BE DESIGNED TO BE ON-ORBIT RESTORABLE | | |

Hardware changes to the basic OSCRS will be needed to satisfy the requirements in Table 3.2-2. All propellant and pressurant tanks on OSCRS must be qualified to satisfy the leak-before-burst criteria. The Space Station program has also established restrictions on overboard venting of fluids because of the presence of attached payloads for astronomical viewing. These requirements prohibit the venting of any solids or liquids with gas venting being permitted only at 14-day intervals and only in the -X direction of the Station. Changes in the venting approach on OSCRS must therefore be addressed. Hazardous fluid containers must be protected from impacts by meteoroids and space debris to prevent tankage failure and to contain any fragments from an exploded tank. Blast shields must be provided around each tank or the whole structure to satisfy this requirement, or it must be shown that the OSCRS can be protected by the Servicing Facility enclosure. The PDRD also has a requirement stating that all hazardous fluid resupply operations shall be accomplished remotely with manual backup requiring the addition of automatic umbilicals to the OSCRS. This is a major change from the Shuttle-based OSCRS where manual umbilicals were specified. These requirements were addressed throughout the study as design concepts for a Station-based OSCRS. They were evaluated and will be examined in more detail for each of the OSCRS subsystems throughout the remainder of the report.

## 3.3 FLUID REQUIREMENTS

The Space Station will require a wide variety of fluids for orbital resupply, ranging from nitrogen for life support to storable propellants for satellite resupply. Nitrogen will be the most widely used fluid on the Station; it is used for life support, experiment supply, and satellite servicing. Water will also be a major fluid for resupply because it is used as the propellant for the Station oxygen/hydrogen propulsion/reboost system. The OSCRS has already been baselined for hydrazine resupply, and an objective of this contract was to examine design changes to allow OSCRS to be used to transport water to the Space Station as well.

Fluid requirements generated by the Martin Marietta Space Station group were reviewed to determine capacities for a Station-based OSCRS for both hydrazine and water transport. Time-phased propellant requirements for satellite servicing and for OMV servicing were generated and are shown in Tables 3.3-1 and 3.3-2. Estimates for propellant quantities required by the OMV vary depending on the assumptions used; however, the numbers in Table 3.3-2 are representative of the usage rates expected of an OMV supporting Station operations. The OMV Short Range Vehicle contains the hydrazine and cold gas nitrogen propulsion systems that are designed for on-orbit refueling. The OSCRS/OMV interfaces for refueling will be discussed in detail in Section 5.2.1.

*Table 3.3-1 Servicing Facility Fluid Requirements*

| SPACECRAFT | FLUID | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|
| GRO | HYDRAZINE | 3000 | 3000 | | | | |
| SPARTAN | HYDRAZINE | 1650 | 3300 | 3300 | 3300 | 3300 | 3300 |

- ALL WEIGHTS IN LBS
- HYDRAZINE AT MIL-P-26536
- SUPPLY REQUIREMENTS: ≈500 PSI AT 100 LBS/MIN

*Table 3.3-2 OMV Propellant Requirements for Station Servicing Missions*

| OMV PROPELLANT REQUIRMENTS TO SUPPORT SPACE STATION SATELLITE SERVICING | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003(1/2 YEAR) |
| HST | BI-PROP | | 7662 | | | 7008 | | |
| | N2H4 | | 136 | | | 136 | | |
| | GN2 | | 167 | | | 171 | | |
| AXAF | BI-PROP | | | 6511 | | | 5428 | |
| | N2H4 | | | 150 | | | 154 | |
| | GN2 | | | 186 | | | 193 | |
| GRO | BI-PROP | 3286 | | 3344 | | | | 2624 |
| | N2H4 | 164 | | 164 | | | | 164 |
| | GN2 | 199 | | 199 | | | | 199 |
| SSPE CO-ORBITING PLATFORM #1 | BI-PROP | | 553 | 553 | 553 | 553 | | 553 |
| | N2H4 | | 171 | 171 | 171 | 171 | | 171 |
| | GN2 | | 208 | 208 | 208 | 208 | | 208 |
| SIRTF | BI-PROP | | | 7713 | | 7521 | | |
| | N2H4 | | | 95 | | 100 | | |
| | GN2 | | | 126 | | 127 | | |
| SPARTAN | BI-PROP | | | 0 | 0 | 0 | 0 | 0 |
| | N2H4 | | | 480 | 480 | 480 | 480 | 240 |
| | GN2 | | | 608 | 608 | 608 | 608 | 304 |
| SMM | BI-PROP | | | | 2686 | | | |
| | N2H4 | | | | 100 | | | |
| | GN2 | | | | 103 | | | |
| EXPLORER 2 | BI-PROP | | | | | 3470 | | |
| | N2H4 | | | | | 97 | | |
| | GN2 | | | | | 117 | | |
| EXPLORER 3 | BI-PROP | | | | | | 3288 | |
| | N2H4 | | | | | | 97 | |
| | GN2 | | | | | | 117 | |
| SSPE CO-ORBITING PLATFORM #2 | BI-PROP | | | | | 553 | 553 | |
| | N2H4 | | | | | 171 | 171 | |
| | GN2 | | | | | 208 | 208 | |
| TOTALS | BI-PROP | 3286 | 8215 | 18121 | 3239 | 19105 | 9269 | 3177 |
| | N2H4 | 164 | 307 | 1060 | 751 | 1155 | 902 | 575 |
| | GN2 | 199 | 375 | 1327 | 919 | 1439 | 1126 | 711 |

- ALL WEIGHTS IN LBS

Water is used by a number of Station systems, as shown in Table 3.3-3, and the resupply requirements depend on many factors. A supply of water is available to the Station from several sources. The Environmental Control and Life Support System (ECLSS) baseline design calls for a closed-loop water recovery system that, depending on the method of carbon dioxide reduction, can produce significant quantities of excess potable water. The Orbiter oxygen/hydrogen fuel cells produce highly pure water as a byproduct, and the current plan is to provide an interface between the Station and the Orbiter so that this water can be scavenged and integrated with the Station supply. Water is also transported in the form of food and subsequently becomes available through the ECLSS water recovery system. Water from the above sources and usage requirements must be balanced to determine how much extra water transported on an OSCRS would be required. Table 3.3-4 presents a typical 90-day water balance for the Station. This table reflects the complexity of the water balance, assuming Orbiter scavenging is available. On average, approximately 2000 lb of excess

*Table 3.3-3 Space Station Water Users*

| SYSTEM | USE |
|---|---|
| • PROPULSION/REBOOST SYSTEM | • GENERATION OF GH2/GO2 FOR PROPULSION/ATTITUDE CONTROL |
| • ENVIRONMENT CONTROL AND LIFE SUPPORT SYSTEM (ECLSS) | • CLOSED-LOOP SYSTEM; PRODUCES EXCESS POTABLE WATER |
| • U.S. LABORATORY | • EXPERIMENT SUPPORT |
| • JAPANESE EXPERIMENT MODULE (JEM) | • EXPERIMENT SUPPORT; LIFE SUPPORT |
| • COLUMBUS MODULE | • EXPERIMENT SUPPORT; LIFE SUPPORT |

*Table 3.3-4 Typical Space Station 90-Day Water Balance*

| SPACE STATION WATER BALANCE PER 90 DAYS | | | |
|---|---|---|---|
| INPUTS: | | WATER BALANCE,lbs | |
| Station Crew Size | 8 | ECLSS Potable | 762 |
| EVAs per 90 days | 39 | STS Potable Water | 2610 |
| EVA Duration,hrs | 6 | STS Waste Water* | 270 |
| EMU Loop Closure | Closed | Station Potable Water | 3372 |
| Food Water Content,lbm/man/day | 1.1 | Station EVA Water | 0 |
| Orbiter Crew Size | 8 | MTL Water Makeup | 1145 |
| Orbiter Crew on Station | 4 | Excess Water (Propulsion) | 2227 |
| Orbiter Power Level ,Kw | 12.6 | | |
| Orbiter Stay Duration,days | 5.625 | | |
| Orbiter Visits per 90 Days | 2 | *Not included in excess water | |
| Scavenged Orbiter Storage Tank H20,lbm | 0 | | |
| Scavenged Orbiter Waste Water,lbm | 0 | | |
| JEM Water Requirement | 0 | | |
| MTL Experiments Requirement ,lbm | 7633 | | |
| MTL Experiment Water Recovery,% | 85 | | |
| CFES Water Requirement,lbm | 0 | | |
| CFES Water Recovery,% | 95 | | |

water would be available to the Station propulsion system without any OSCRS resupply. However, water requirements for propulsion obtained from the Martin Marietta Space Station program indicate that this amount of water would be insufficient. Figure 3.3-1 presents the amount of water onboard the Station as a function of time, showing that a water deficit of approximately 5000 lb/year would result without augmentation by OSCRS resupply. Figure 3.3-2 shows the Station onboard water supply with OSCRS, assuming a 5000-lb-capacity OSCRS. The OSCRS would be flown an average of once per year. These results indicate that the water OSCRS should be sized larger than the basic OSCRS used for GRO hydrazine servicing. Hardware design changes to the basic OSCRS for water resupply are discussed in Section 4.5.

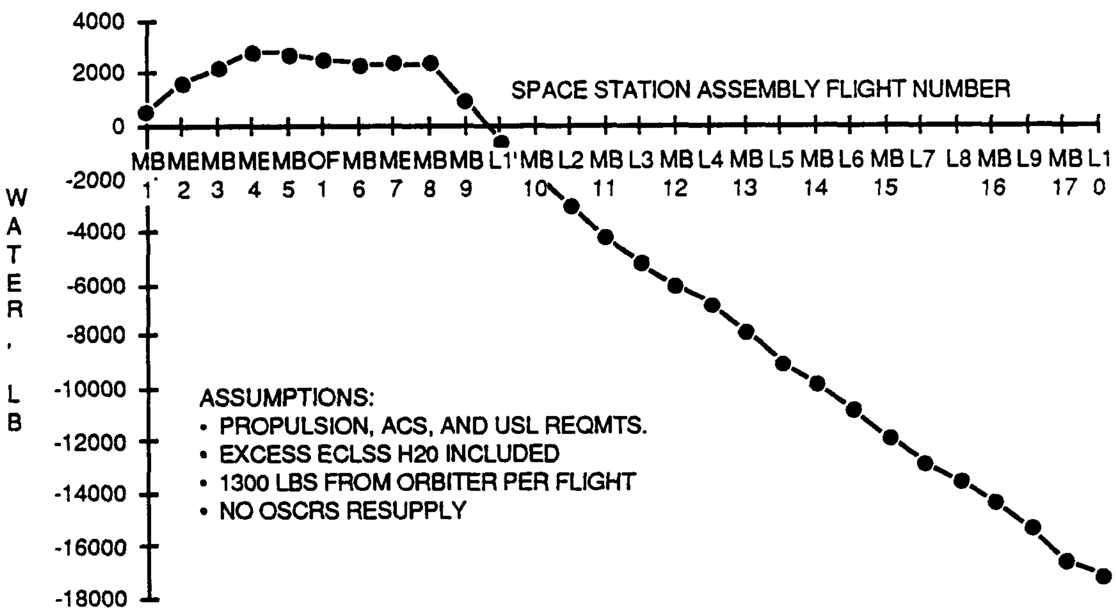


*Figure 3.3-1 Space Station On-Board Water -- No OSCRS Resupply*

## 3.4 INTERFACES

### 3.4.1 System Interfaces

The interfaces between OSCRS and the Space Station are more complex than those between the OSCRS and the Shuttle. The OSCRS interfaces with the Orbiter are structural and electrical; however, interfaces with the Station include fluid as well as structural and electrical interfaces. The OSCRS would physically be located in two areas on the Station as shown in Figure 3.4-1. The hydrazine OSCRS would be located in one of the Servicing Facility bays, while the water OSCRS would be attached to an interface on the transverse boom near the pressurized modules. The water OSCRS interface would allow transfer of water into the storage tanks located inside the pressurized nodes via external distribution lines in the truss structure, part of the Integrated Water System described in the Fluid Management System Architectural Control Document (Ref 1).

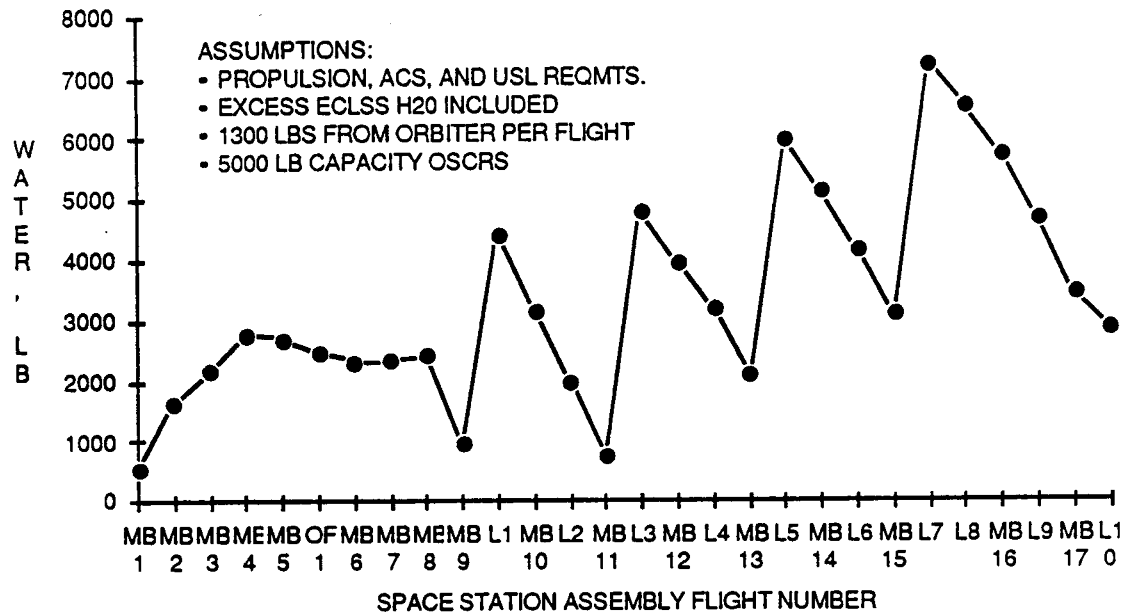


*Figure 3.3-2 Space Station On-Board Water with OSCRS Resupply*

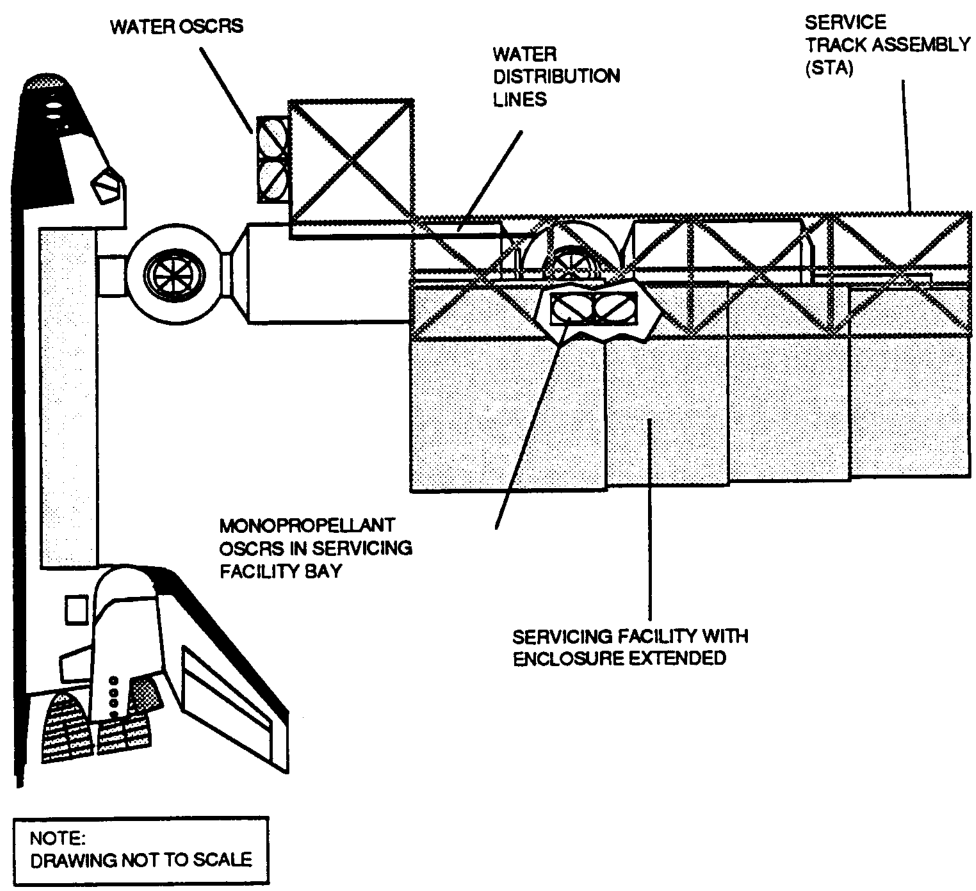


*Figure 3.4-1 OSCRS Locations at Space Station*

Preliminary system level interfaces between OSCRS and the Shuttle were established and are shown schematically in Figure 3.4-2. The interfaces are of three basic types: structural/mechanical, fluid, and avionics. The OSCRS-to-NSTS/Space-Station interfaces are a structural interface for launch and grappling and an avionics interface for command, power, and status monitoring. Required interfaces between the Station Mobile Servicing Center arm and the Servicing Facility Manipulator consist of a grapple fitting and an avionics interface used during the transfer of OSCRS from the Orbiter to the Station attachment location.

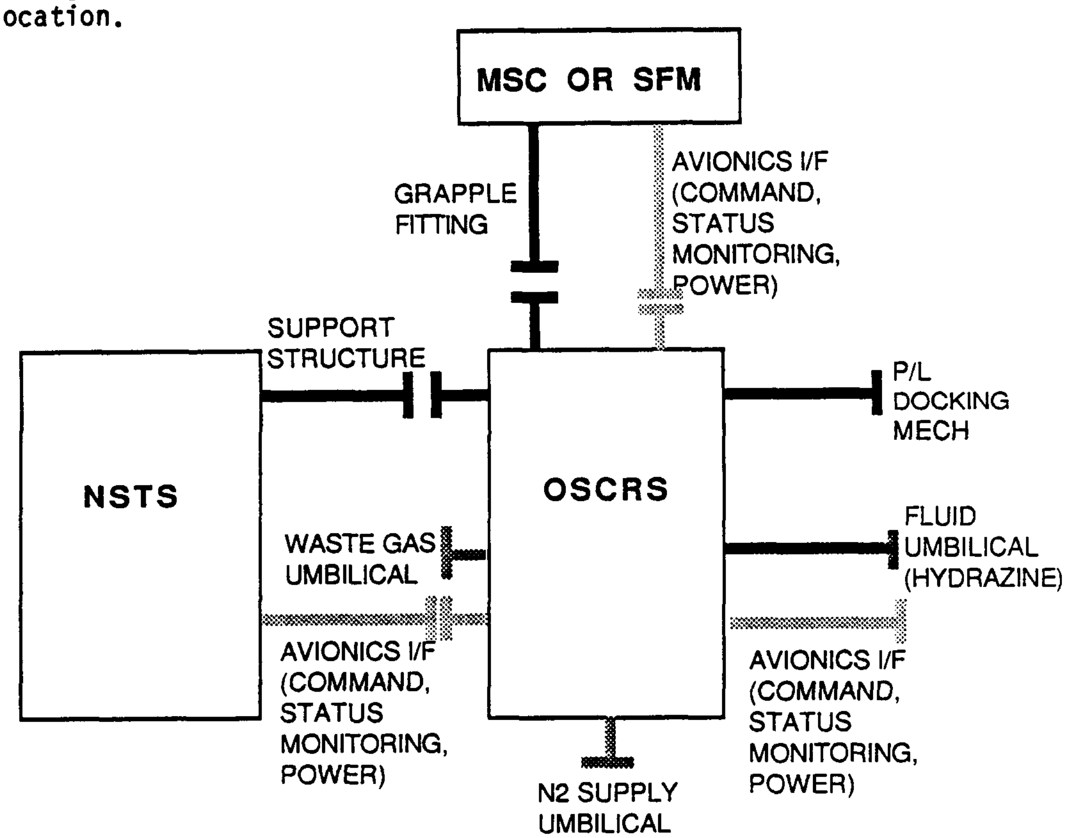


*Figure 3.4-2 OSCRS-to-NSTS Preliminary Interfaces*

Figure 3.4-3 shows the preliminary interfaces between OSCRS and the Space Station Servicing Facility and a payload. These interfaces include those utilities provided by the Space Station and the Servicing Facility. The Space Station Fluid Management System ACD describes three integrated fluid systems on the Station that provide fluid supply and handling hardware that can be utilized by the OSCRS. An integrated supply of high-pressure nitrogen is provided for all users, including the Servicing Facility. This supply would be available to the OSCRS as part of the Servicing Facility fluid services accommodations. In addition, an integrated waste fluid management system stores and disposes of all Station waste fluids per the contamination requirements. The Servicing Facility fluid services accommodations provide an interface between OSCRS and this system. A structural support interface between OSCRS and the Servicing Facility would be needed. The interfaces between OSCRS and a payload would be a structural docking mechanism, an automatic fluid umbilical (hydrazine), and an avionics interface. The satellite to be refueled is held in place by the Retention and Positioning System provided by the Servicing Facility. The specifics of each interface are discussed in detail in the following subsystem sections.

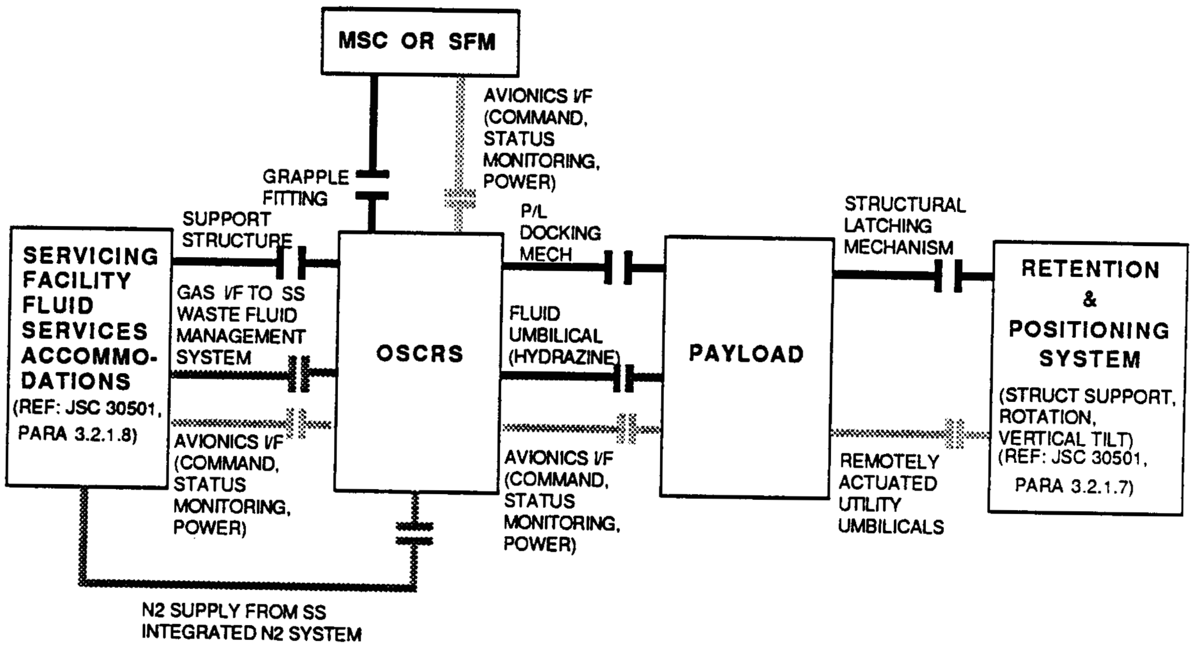


*Figure 3.4-3 OSCRS-to-Servicing-Facility/Payload Preliminary Interfaces*

## 3.4.2 Fluid Interfaces

The specific fluid interfaces between the OSCRS, Space Station, and the user payload consist of two gaseous interfaces and one liquid interface. The Station Integrated Nitrogen System supplies nitrogen at pressures of up to 3500 psi to the Servicing Facility. This nitrogen is available for use by OSCRS, provided a compatible interface is provided. The nitrogen could be used to resupply the OSCRS pressurant tanks, or the OSCRS pressurant tanks could be removed to save launch weight and the Station nitrogen supplied directly to the OSCRS pressure control subsystem. Because normal venting/purging operations, a standard OSCRS procedure for Shuttle-based refueling, will not be allowed on the Station except at controlled intervals and in controlled directions, the catalytic vent system on the OSCRS must be modified. The Station provides for onboard systems waste fluid storage tanks that the OSCRS could use to store pressurant gases expelled during leak check operations and the gaseous exhaust products from the catalytic vents.

Reference 1 describes the preliminary configuration of the Integration Waste Fluid Management System. This system segregates gaseous wastes by oxidizers and fuels. Primary sources of waste gases for this system will be the U.S. and international laboratory modules, where several types of gases will be used to purge experiments. All gases would discharge into common lines. Waste gases from OSCRS refueling operations will be contaminated with hydrazine, and, during line purging operations, hydrazine alone will be discharged. The catalytic vent system will react most of the propellant vapors, but, since the process is not 100% efficient, some propellant vapor would be added to the common Station waste vent line. Since the gases are compressed before storage, a safety hazard would exist in raising the temperature and pressure of the OSCRS waste gas. Based on the configuration of the waste system, it is recommended that the OSCRS waste gases be handled separately to avoid this potential problem or that additional catalytic reactors be added to the system to ensure complete reaction of the OSCRS vent products. In summary, to interface with the Station integrated fluid systems, the addition of two gas quick disconnects would allow the OSCRS fluid subsystem to receive Station nitrogen and remove waste gases in compliance with Station requirements. As with the Shuttle-based OSCRS, the lone liquid interface would be between the OSCRS and the user payload.

### 3.4.3 Thermal Interfaces

Thermal interfaces between the OSCRS and the Station Servicing Facility would be minimal. The OSCRS' own thermal control system would be adequate to handle the Station environment, and only power would be needed from the Station, Mobile Service Arm, or the Servicing Facility for heater control.

### 3.4.4 Structural/Mechanical Interfaces

OSCRS will need several structural and mechanical interfaces between the Shuttle, Space Station, and spacecraft. These interfaces will be made by using both existing mechanisms and mechanisms being designed for use on the Space Station. A structural support interface will be needed between OSCRS and the Shuttle during launch and on-orbit operations. This interface could be the standard trunnion pins and keel fittings of the basic OSCRS, or the OSCRS could interface structurally with the Unpressurized Logistics Carrier. A grapple interface compatible with the Station manipulator arms and the Shuttle Remote Manipulator System will be needed to remove the OSCRS from the payload bay. A payload docking interface to allow a spacecraft to be directly attached to the OSCRS would also be needed. Once at the Station, the OSCRS must structurally interface to either the Station truss assembly or the Servicing Facility for storage. If OSCRS is attached to the truss, it is anticipated that the same mechanism used to attach the Unpressurized Logistics Carriers would be employed.

Inside the Servicing Facility, OSCRS must provide the interface hardware necessary to permit attachment of manipulation and handling devices to move and position OSCRS for storage in the Service Track Assembly and for attachment and retention of OSCRS for servicing. The Servicing Facility will provide generic attachment fixtures for OSCRS, including primary and secondary structure for load transfer. The Servicing Facility Retention and Positioning subsystem provides a variety of means for securing spacecraft, payloads, and customer pallets for the purpose of servicing and storage. This subsystem will probably be used for the temporary storage and servicing of OSCRS and for positioning OSCRS for satellite refueling. It consists of a universal payload adapter, a payload holding fixture, and payload attachment equipment.

### 3.4.5 Avionics Interfaces

The following list of functional requirements provided a basis for assessing impacts to the basic OSCRS avionics conceptual design to allow basing OSCRS at the Space Station:

a) Operator control and monitor of fluid resupply via Space Station general purpose workstations;

b) Interface of OSCRS to Space Station with minimum modifications to OSCRS;

c) Control of fluid resupply using Space Station computers and Data Management System (DMS), using either OSCRS-provided software or Space Station software;

d) Provision of an interface with Space Station for control of OSCRS subsystem elements, collection of system data, and power;

e) Provision of an interface to the Space Station MSC and Service Facility Manipulator (SFM) for power and data monitoring;

f) Control of fluid resupply of spacecraft requiring multiple OSCRSs;

g) Control of offloading fluid from OSCRS for return via NSTS;

h) Maintenance of two-fault tolerance of data for safe control, caution and warning, power to OSCRS and satellite, and detection and control of out-of-limits conditions;

i) Provision of software to control fluid resupply, perform data acquisition, present graphic display of data, and provide an interactive operator interface;

j) Minimization of OSCRS on-board electronics by moving all or part to service facility and/or using Space Station electronics.

The details of the power interface requirement of the basic OSCRS are the same as those of the required interface for the NSTS. The following requirements are the present baseline:

a) +28 Vdc Power: 1000 watts maximum during normal operation
400 watts maximum during safing operation
500 watts average (without pump or compressor)

b) 115 Vac, 400 Hz, 3 phase: 325 watts maximum.

c) The dc power must be two-fault tolerant, and the ac power must be one-fault tolerant.

The physical way that the power, command, and data interface is made with Space Station has not been identified at this time; options could include NSTS ROEU, a manual mating scheme, or an automatic mating umbilical designed for Space Station. The approximate wire count for the various OSCRS configurations is presented later in this report (Table 4.4.4-1). The pyro circuits would not be required at Space Station because emergency separation will not be needed.

There are several options for the command and data interface requirements between Space Station and OSCRS. A more detailed description of these options is presented in Section 4.4. If the basic conceptual design is used, the command and data interface requirements at Space Station without any modifications are as follows:

a) Three serial interfaces, for normal operation command and data; can be RS422 or 1553 and must be two-fault tolerant;

b) Discrete channels for control and status of power and safing circuits;

c) Space Station must provide display, command input, and data storage capability.

The design documents currently available for Space Station show power, command and data, data storage, and processing interfaces that meet or exceed the requirements for basing OSCRS at Space Station. Figure 3.4.5-1 shows a block diagram of how OSCRS could interface to Space Station.

The only exceptions are the SBM and MSC, which presently are not defined as having the capability to be two-fault tolerant on power, telemetry, or commands. SPAR said they do not have any requirements to be two-fault tolerant and are planning to provide only 208-Vac, 20-Khz power. Goddard's baseline does not have OSCRS interfacing to the MSC, but uses the SBM to move OSCRS from NSTS to the Space Station and does not include electrical interfaces to OSCRS. If servicing or fluid transfer from OSCRS to OSCRS will involve the MSC or SBM, there must be a two-fault-tolerant interface for power, telemetry, and commands. If the MSC or SBM uses are limited to simply transporting OSCRS, then only a two-fault-tolerant power and telemetry interface is required.

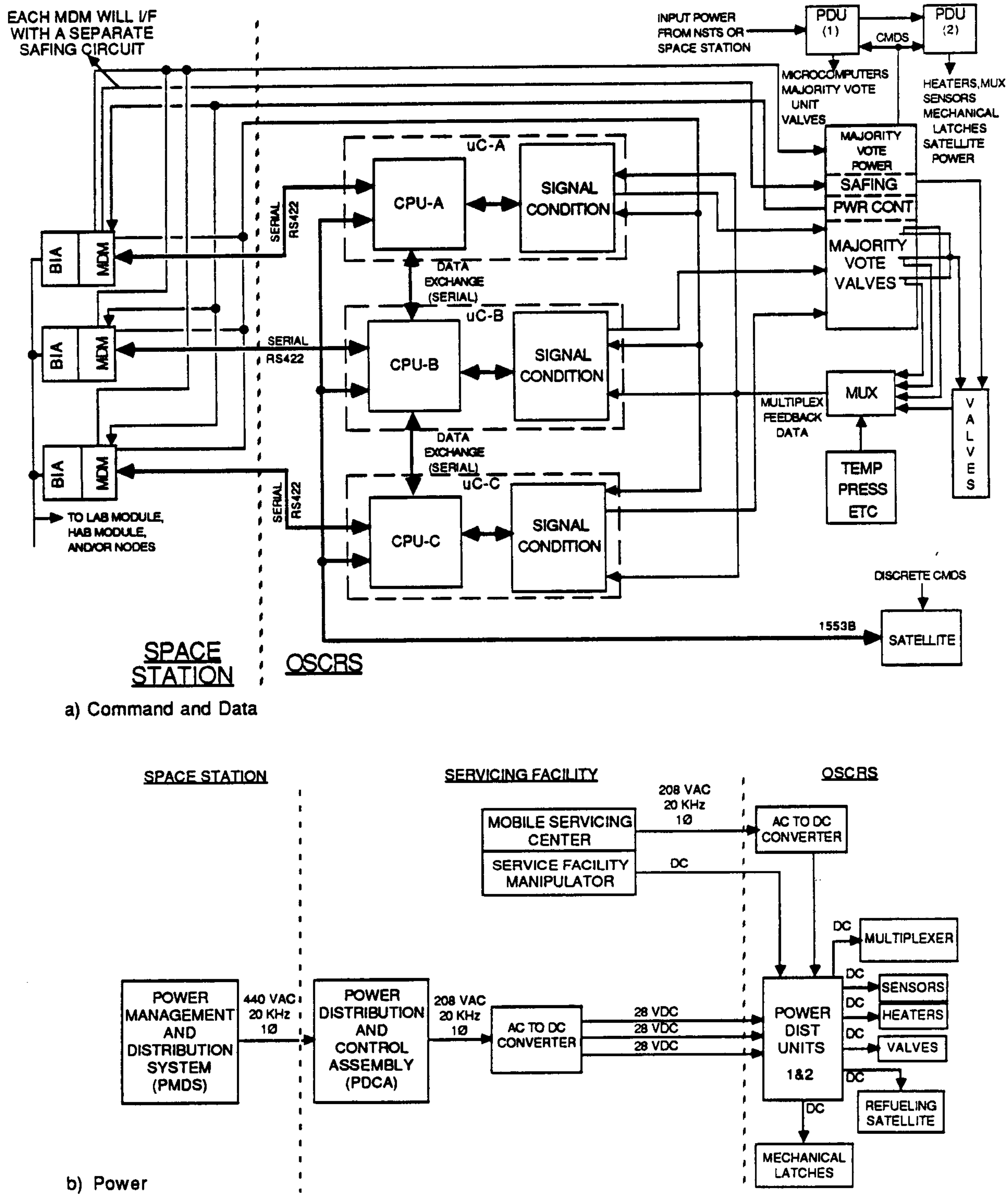


*Figure 3.4.5-1 Basic OSCRS-to-Space Station Interface*

## 4.0 OSCRS OPTIONS FOR SPACE STATION

### 4.1 OPTIONS

Three major configuration options were examined in this study to determine the benefits and drawbacks of each approach for a Station based OSCRS. Major problems encountered in the Phase B Space Station studies were caused by the resupply limitations of the Shuttle to the Station operating altitude of 250 nautical miles and the limitations in the Shuttle landing weight. The required dry weight of the Logistics Elements was estimated by evaluating the resupply requirements and the landing and launch weight limitations. Such studies, performed by the Martin Marietta Space Station program, indicated that all hardware involved with resupply of consumables to the Station, including OSCRS, must be weight optimized as much as possible. Therefore, the basic OSCRS was examined to determine which systems could be left on the Station to reduce the weight of the up/down portion.

The options defined for this study are summarized in Table 4.1-1. The first option was the Shuttle-based version, referred to as the basic OSCRS, with no modifications for use at Station. The other two options, a minimum modified and modular OSCRS, examined what changes could be made to optimize the OSCRS for use at the Station. The minimum modified OSCRS option was defined as the basic OSCRS with minimal changes to allow some optimization for Space Station use without major redesign. In the modular OSCRS, each subsystem was examined to identify portions that could be Station based or eliminated to achieve the lowest up/down weight. In all cases, however, the minimum modified OSCRS and the modular OSCRS were assumed to be functionally identical to the basic OSCRS.

*Table 4.1-1 OSCRS Configuration Options*

| Three Configurations Examined for Station Use: | |
|---|---|
| Basic OSCRS | Shuttle Baseline Version with No Changes |
| Minimum Modified OSCRS | Basic OSCRS with Minimum Changes To Enhance Space Station Compatibility and Operations<br>• Pressurant Tanks Removed<br>• QD's Added for Pressurant Supply and Waste Gas Venting |
| Modular OSCRS | OSCRS Uniquely Modified for Station Operations; Hardware Modularized for Station Basing<br>• Avionics Module -- Station Based<br>• Propellant Storage Module -- Up/Down Portion<br>• Pressurant Control Module -- Station Based<br>• Vent System Module -- Station Based<br>• OSCRS/Satellite Attach H/W -- Station Based |

## 4.2 BASIC OSCRS

The basic monopropellant OSCRS design, used as the starting point for this study, is shown in Figure 4.2-1 with the major subsystems identified. The basic flight configuration has been grouped by functional allocation into major subsystems and subsystem elements. The basic configuration uses three propellant tanks and two pressurant bottles as part of the fluids subsystem as shown in the schematic in Figure 4.2-2. The fluid couplings and electrical connectors are stowed on the port side of the structure. Primary components of the avionics subsystem are mounted on the structure covered with a motorized thermal shade. A representative valve and plumbing panel is shown in the second tier of the structure. Similar modular panels would be installed for options to the basic OSCRS for added propellant and pressurant load capability. The basic OSCRS weight statement is presented in Table 4.2-1 showing a mass fraction of the three-tank version of 0.60.

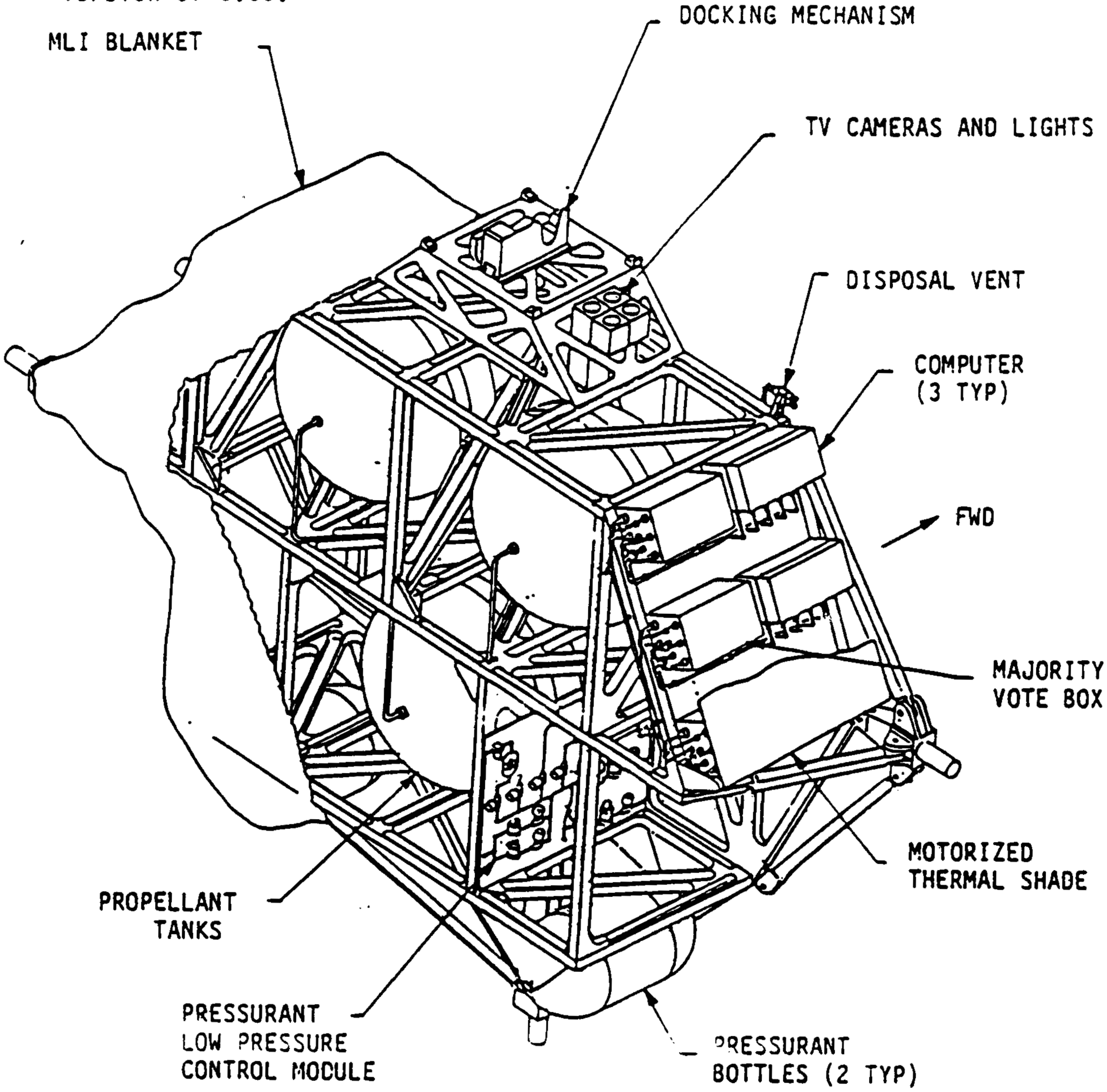


*Figure 4.2-1 Basic OSCRS Configuration*

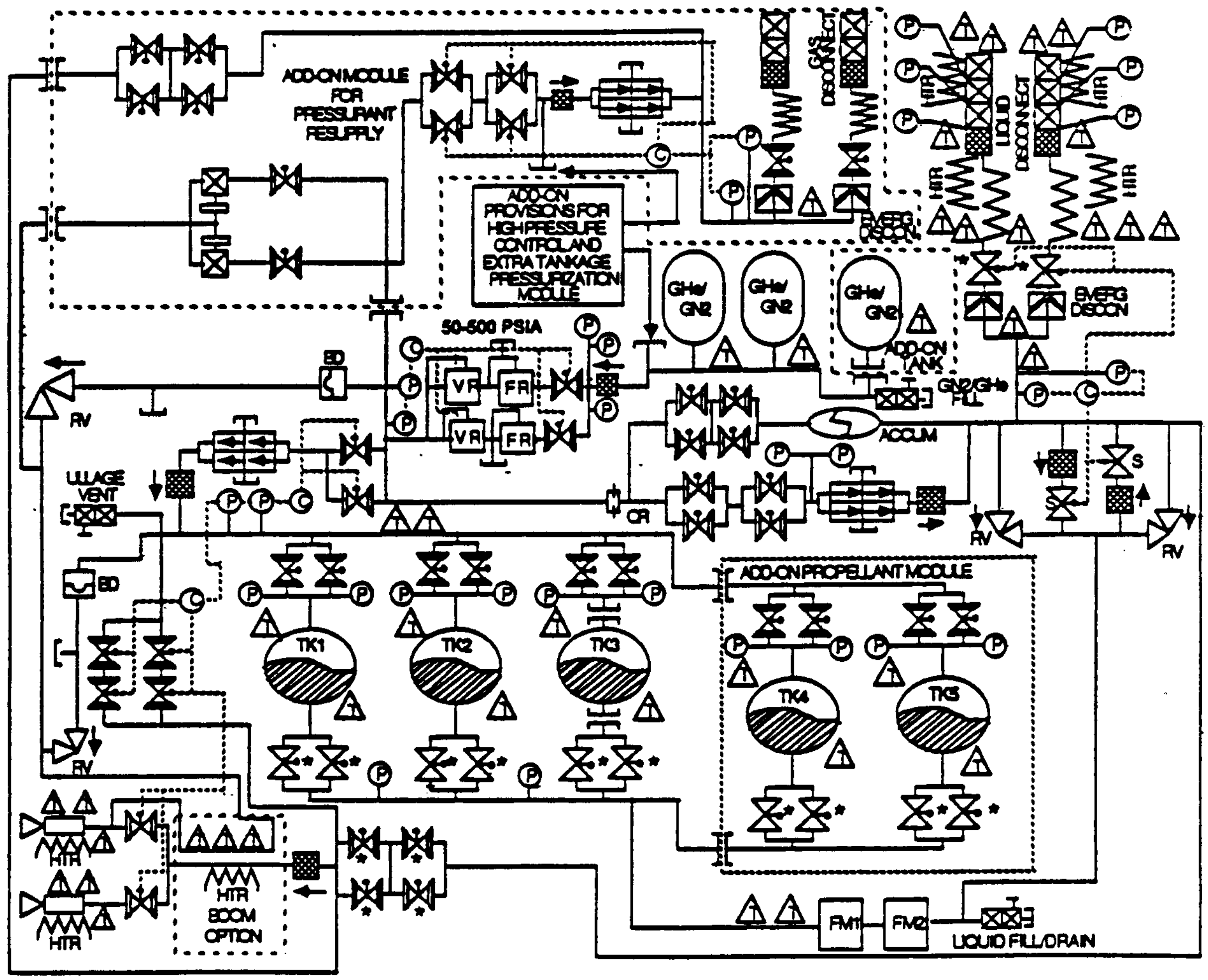


*Figure 4.2-2 Fluid Subsystem Schematic*

## 4.3 MINIMUM MODIFIED OSCRS

### 4.3.1 Minimum Modified OSCRS Fluid Subsystem

The minimum modified OSCRS fluid system was assumed to be functionally identical to the basic OSCRS but with modifications made to optimize it for station use. These modifications and their resulting interfaces, shown in a block diagram in Figure 4.3.1-1, included removing the pressurant tanks and replacing them with an interface to enable the OSCRS to receive nitrogen from the Station onboard supply. Additionally, an interface was added upstream of the catalytic vent system to interface with the Station Waste Fluid Management System to allow waste gases generated during the resupply operations to be stored for venting at the allowable time. The only liquid interface is between the OSCRS and the user payload. The plumbing schematic, modified with the above interfaces, is shown in Figure 4.3.1-2. The pressurant supply for the Station nitrogen system interfaces with the

*Table 4.2-1 Basic OSCRS Mass Properties*

| | Basic OSCRS Three TDRS Tanks | Primary GRO Configuration OSCRS Three TDRS Tanks | Basic OSCRS with Alternate Docking Mechanism Three TDRS Tanks | Future OSCRS with Growth Features Three TDRS Tanks |
|---|---|---|---|---|
| Truss Structure | 504 lb (229) kg | 504 lb (229) kg | 504 lb (229) kg | TBD |
| Mechanisms | | | | |
| PRLA & Hard Points | 130 (59) | N/A | N/A | |
| Goddard Latches | N/A | N/A | 430 (195) | TBD |
| Other | 83 (38) | 83 (38) | 83 (38) | |
| Avionics | 314 (143) | 314 (143) | 314 (143) | 415 (189) |
| Fluid Components & Tubing | 286 (130) | 286 (130) | 286 (130) | 316 (144) |
| Thermal System | 93 (42) | 93 (42) | 93 (42) | 93 (42) |
| TDRS Tanks | 360 (164) | 360 (164) | 360 (164) | 360 (164) |
| Pressurant Bottles | 158 (72) | 158 (72) | 158 (72) | 474 (215) |
| Pressurant Gas (GHe) | 26 (12) | 26 (12) | 26 (12) | 309 (140) |
| A' Cradle | N/A | 1329 (603) | N/A | N/A |
| Goddard Ring & Latches | N/A | 1171 (531) | N/A | N/A |
| Future Growth Features | N/A | N/A | N/A | TBD |
| Dry Mass, Total | 1954 (888) | 4324 (1965) | 2254 (1025) | TBD |
| Monopropellant (3% Tank Ullage) | 2973 (1351) | 2973 (1351) | 2973 (1351) | 2973 (1351) |
| Module Mass, Total | 4927 (2240) | 7297 (3317) | 5227 (2376) | TBD |
| Mass Fraction (2% residual fuel) | 0.60 | 0.40 | 0.56 | |
| Center of Gravity (Note: (1) OSCRS coordinate system) | X 18.2<br>Y 0.0<br>Z 414.6 | TBD | X 14.0<br>Y 4.1<br>Z 415.7 | TBD |
| Mass Moments of Inertia | Ixx 12810<br>Iyy 8520<br>Izz 4280 | TBD | TBD | TBD |

(1) OSCRS Coordinate System X - Origin at trunnion centerline, positive direction toward tanks
Y = Yo
Z = Zo

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OSCRS pressurant control hardware via a gaseous disconnect. The pressurant tanks are shown removed although they could be retained if desired. The pressurant, at 3500 psi, is regulated down by the fixed and variable pressure regulators before being sent to the storage tanks and the purge/leak check leg. An additional gaseous disconnect is provided downstream of the catalytic vents to interface with the Station Waste Fluid Management System for disposal of the vent products. The remainder of the schematic is identical to the basic OSCRS. These modifications result in a 158-lb savings in the fluid system weight if the pressurant bottles are removed.

## 4.3.2 Minimum Modified OSCRS Thermal Subsystem

An evaluation of the thermal control impacts of Station basing the OSCRS was performed. The first step was to identify the impacts to the thermal control system of the basic OSCRS. The thermal control system

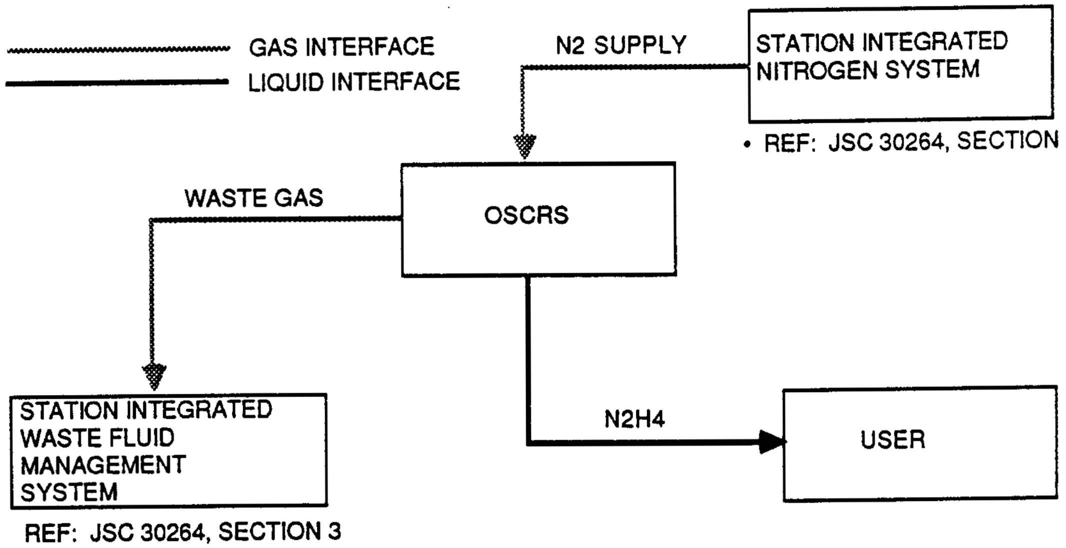


*Figure 4.3.1-1 Minimum Modified OSCRS/Space Station Fluid Interfaces*

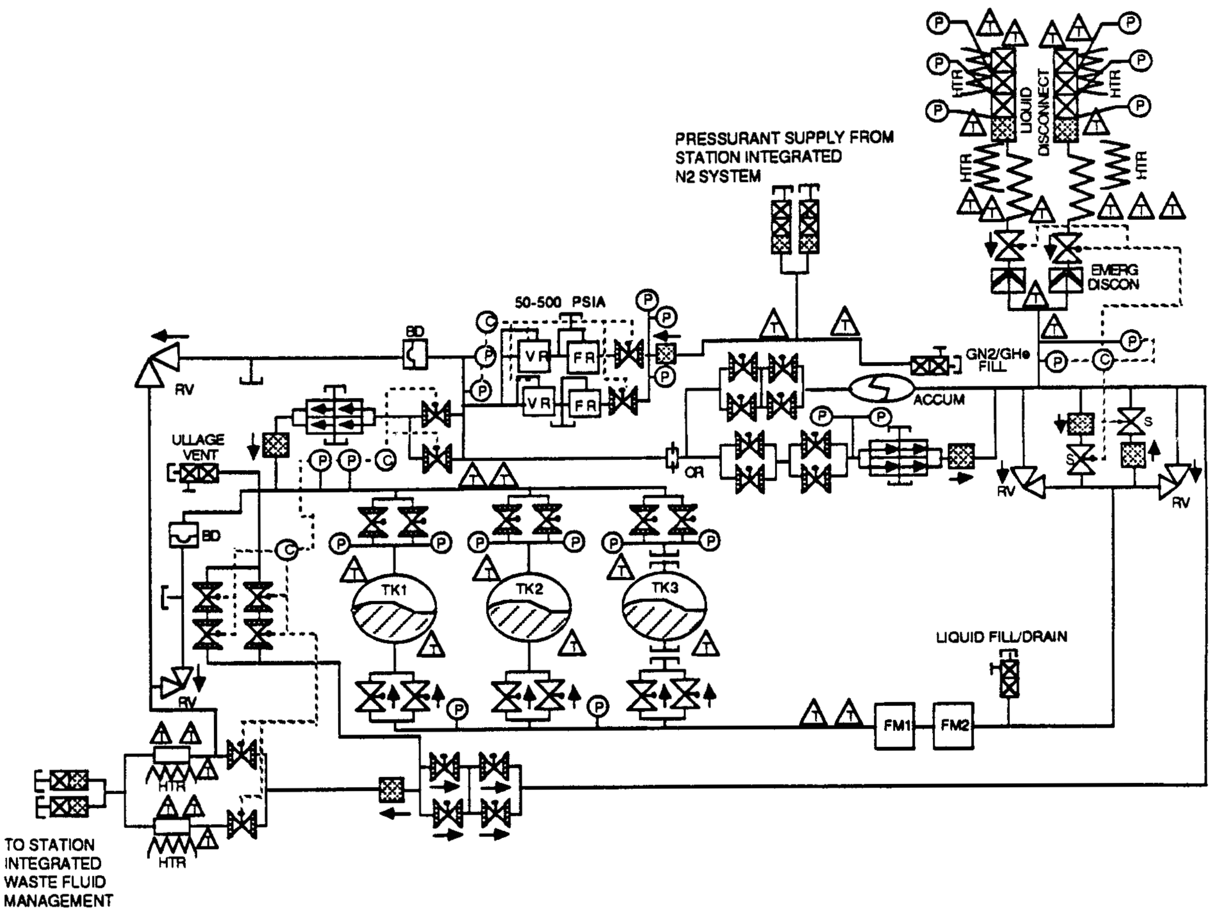


*Figure 4.3.1-2 Minimum Modified Monopropellant OSCRS Fluid Schematic*

of the basic OSCRS was designed for the hot and cold environments found in the Shuttle payload bay. The design is capable of deep space viewing, but the margin in the heater power is reduced from 50% to 10%. Attachment of the OSCRS to the Station can be accommodated with some restrictions. If the OSCRS is totally shaded from the sun and Earth, the heater power margin would be reduced to 10%. If the OSCRS were sun-oriented when placed in front of a large surface, overheating could occur if shading were not provided. The general conclusion, however, was that the basic OSCRS could tolerate the Station environment with no design modifications, but the design margins would be reduced.

Operations of a Station-based OSCRS that impact thermal control were identified and are summarized in Table 4.3.2-1. These operations include the transport of the OSCRS to the Station, transport to the Servicing Facility once at the Station, storage within the Servicing Facility, and the refueling operations themselves. Once the Shuttle reaches the Station, the stay time is expected to average five days, during which time cargo will be unloaded and transferred to the Station. Since it is possible that the OSCRS could spend a good portion of the stay time in the Shuttle Bay, heater power would be required. During the transport to the Servicing Facility, the Mobile Servicing Center manipulator arm or the Service Bay Manipulator could be used. This operation should normally be of a short duration; however, contingency situations (such as an arm failure) could mean that the OSCRS would be exposed directly to the space environment for an unknown period, and therefore heater power would be required. During storage at the Station, on the order of 90 days duration, the OSCRS will be located in Bay 2, which is protected by the Servicing Facility enclosure. The Servicing Facility bays will be covered with beta cloth and Multilayer Insulation (MLI) with doors located on the +Z and -Z faces. Power and Data Management System (DMS) interfaces will be provided for control of the OSCRS internal heaters. Additionally, the bay itself can be equipped with heaters if required. During the actual refueling operations, the OSCRS would be removed from Bay 2 and placed in the Servicing Facility enclosure. For these operations, heater power would be required for thermal control and also for conditioning of the catalytic vents.

### 4.3.3 Minimum Modified OSCRS Structural/Mechanical Subsystem

The minimum modified OSCRS structural/mechanical subsystem incorporates changes required to enhance the capabilities of the basic OSCRS at the Space Station. Since the Station Servicing Facility provides all of the equipment required to berth payloads, these types of mechanisms could be removed from the OSCRS to avoid duplication and save weight. A list of mechanisms and accessories that could be removed are listed in Table 4.3.3-1. Any or all of these mechanisms and accessories could be removed depending on the particular mission. This list also applies to the modular OSCRS to be discussed in the next section.

*Table 4.3.2-1 Thermal Control Impacts of Space Station Operations*

| OPERATION | OSCRS LOCATION | TIME PERIOD | THERMAL CONTROL REQUIREMENTS |
|---|---|---|---|
| TRANSPORT TO STATION | SHUTTLE BAY | TBD | HEATER POWER IF LEFT IN BAY FOR EXTENDED TIME |
| TRANSPORT TO SERVICING FACILITY | MSC/SBM | ~1 HR | HEATER POWER FOR CONTINGENCY |
| ON-ORBIT STORAGE | SERVICING FACILITY; BAY 2 | ~90 DAYS | POSSIBLE HEATER POWER; BAY 2 IS THERMALLY ENCLOSED |
| SPACECRAFT REFUELING | BAY 2 OR IN SERVICING FACILITY ENCLOSURE | ~ 8 HRS | HEATER POWER FOR CATALYTIC VENTS |

*Table 4.3.3-1 Mechanisms and Accesories Removed from the Basic OSCRS for use at Station*

| | | |
|---|---|---|
| Foot Restraints and Handholds | 14 lb | 6 kg |
| Toolbox and Tools | 15 lb | 7 kg |
| Emergency Demate - Coupling | 24 lb | 11 kg |
| Standard Propellant Coupling (2) | 35 lb | 16 kg |
| Umbilical Stowage | 20 lb | 9 kg |
| Flex Hose (20 ft x 0.45 lb/ft) | 9 lb | 4 kg |
| Payload Retention Latch Assy | 130 lb | 59 kg |
| Electrical Connector and Cable | 9 lb | 4 kg |
| Total Weight | 256 lb | 116 kg |

Three of the items listed in Table 4.3.3-1 (the standard propellant coupling, the umbilical stowage hardware, and the flex hose) are required for manual refueling operations of the basic OSCRS. Since the Space Station requirements mandate the use of automatic umbilicals for hazardous fluid resupply, the above items would have to be replaced with automatic umbilicals. The basic OSCRS umbilical system consists of two standardized EVA propellant couplings, each attached to 10 ft of flex hose, and an ITT Cannon wing nut electrical connector and 10 feet of electrical cable. Both propellant and electrical umbilicals are stowed on umbilical stowage mechanisms. An emergency umbilical separation system at the cable/hose interface meets the requirement for emergency jettison. The total weight of the umbilicals, stowage mechanisms, and the emergency separation system is 90 lb. These would be replaced by an automatic umbilical mechanism in order to satisfy the Station requirements. The configuration of such an automatic umbilical and its requirements will be addressed in detail in Section 6.0.

### 4.3.4 Minimum Modified OSCRS Avionics Subsystem

The modifications that can be made to the OSCRS avionics apply to both the minimum modified OSCRS and to the modular OSCRS. These modifications, which allow Station-basing of all the avionics, are discussed in Section 4.4.4.

## 4.4 MODULAR OSCRS

### 4.4.1 Modular OSCRS Fluid Subsystem

The basic OSCRS fluid subsystem was examined to determine what portions could be removed and Station based to save launch weight. The fluid subsystem performs two basic functions: storage of propellant and transfer of propellant. The hardware associated with the transfer process is required only when the OSCRS is at the Space Station because that is the location of all refueling. Therefore, this hardware could be Station-based. Additionally, the vent system hardware, including the catalytic vent, could also be based at the Station.

The modular OSCRS fluid subsystem was defined as three modules as shown in Figure 4.4.1-1. The propellant storage module consists of the tankage and associated plumbing components to store the hydrazine and safely transport it to the Station. The pressure control module consists of the hardware required to supply and regulate pressurant gas to the propellant storage module assuming the nitrogen is provided by the Station-integrated nitrogen system. The vent system module conditions the waste gases produced during the refueling operation and sends them to the Station-integrated waste fluid system for storage and disposal. With these modules defined, the basic fluid schematic was revised as shown in Figure 4.4.1-2. Also shown are the interfaces to the Station-provided nitrogen and waste gas system. As in the minimum modified OSCRS, the connections between the subsystem modules and the Station consist of gas quick disconnects with the only liquid interface being between OSCRS and the payload. The pressurant control module has three gaseous quick disconnect interfaces as shown in the schematic. One quick disconnect interfaces with the Station nitrogen supply to provide pressurant to the pressurant storage module via two quick disconnects for tank pressurization, line purging, and leak checking of the propellant couplings. The propellant storage module contains the tankage, transfer line hardware, and liquid interface with the spacecraft. It is also the portion that is transported back and forth from the ground to the Station. An interface with the vent system module is provided to catalyze the vent products produced during the purging operation. This modularization of the fluid subsystem results in a net savings in up/down weight of approximately 300 lb.

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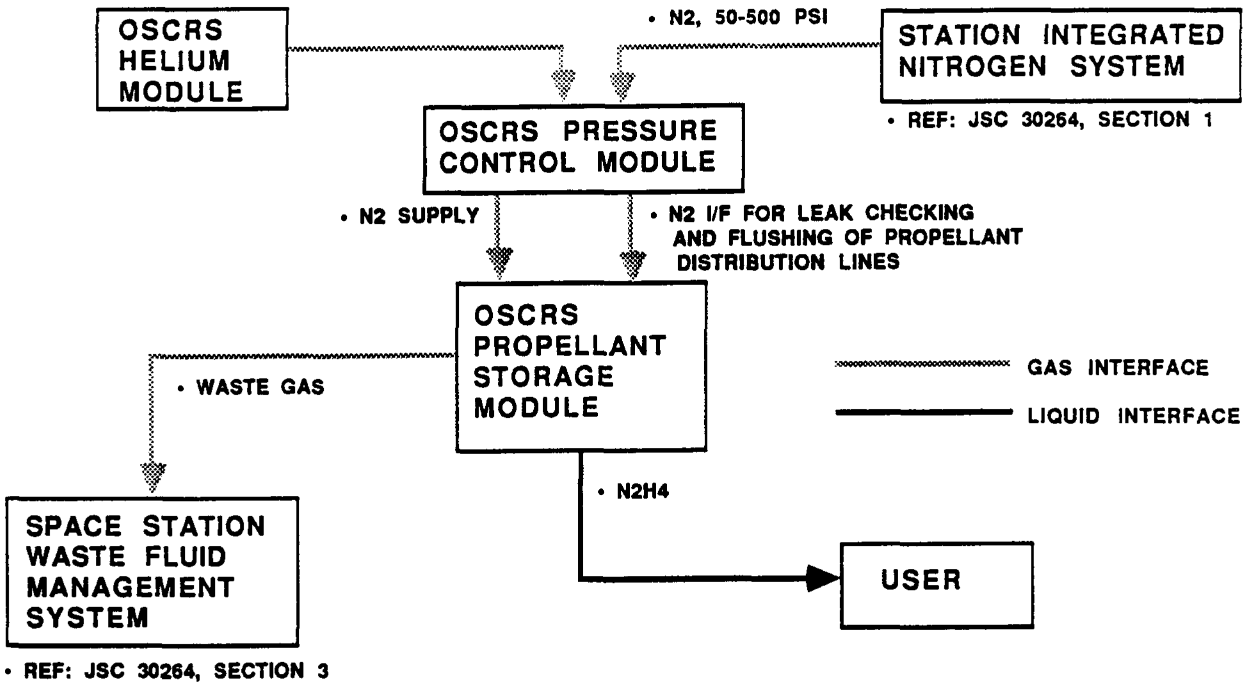


*Figure 4.4.1-1 Station-Based Monopropellant OSCRS Fluid Interfaces*

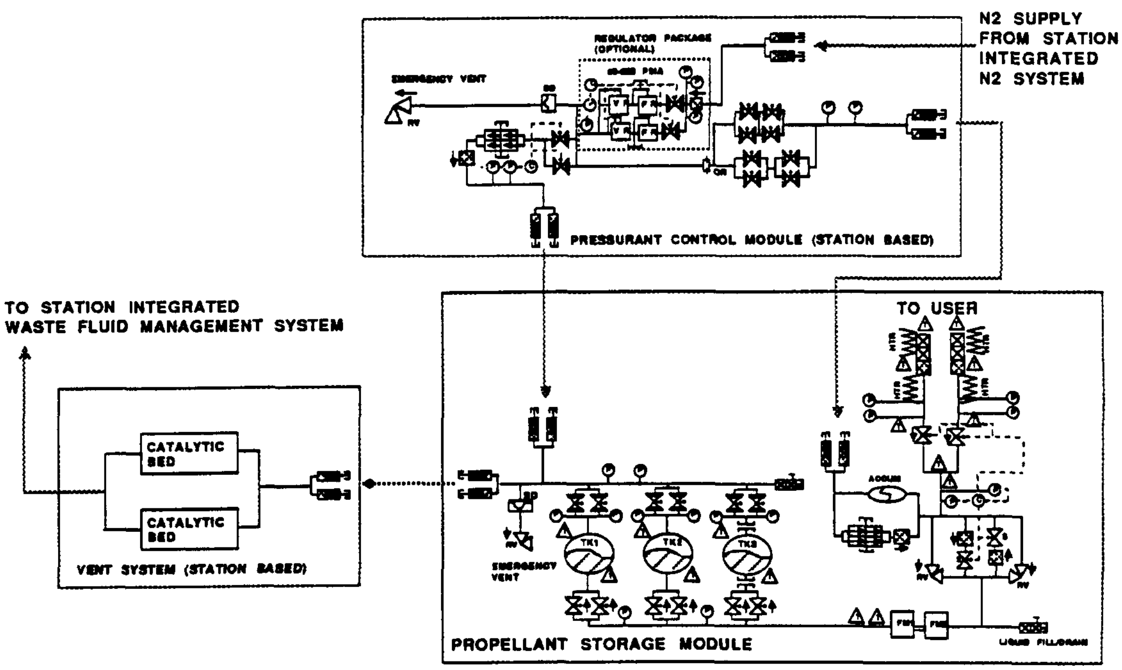


*Figure 4.4.1-2 Modular OSCRS Monopropellant Fluid System Schematic*

### 4.4.2 Modular OSCRS Thermal Control System

The modular OSCRS thermal control subsystem is similar to the basic OSCRS. Because of the modularization, the avionics on the propellant storage module can be greatly simplified. Therefore, the motorized thermal shade can be removed. The on-orbit operations at the Station and their impact on the OSCRS thermal control system design were discussed in Section 4.3.2.

### 4.4.3 Modular OSCRS Structural/Mechanical Subsystem

The goal of the modular OSCRS is to minimize the up/down orbiter weight while keeping the same functions as the basic OSCRS. Like the minimum modified OSCRS, the modular OSCRS will be used only at the Space Station and is subject to the same requirements; therefore, the mechanisms and accessories changes would be the same. A unique structural configuration was developed for the modular OSCRS that uses the Unpressurized Logistics Carrier (ULC) for structural support in the Orbiter bay. Both Martin Marietta and Boeing Aerospace have proposed a ULC that provides four stand-offs that simulate the inside of a module and provide a tie-down for pallets. The modular OSCRS attaches to these stand-offs and is cantilevered from the end of the ULC for orbiter transport. The trunnion and keel pins and their fittings and support structure, which transfer basic OSCRS loads to the orbiter, can be removed from the basic structure by unfastening 14 bolts. Four fittings are bolted to the OSCRS core structure or strongback, shown in Figure 4.4.3-1, and a mating fitting is bolted to each of the stand-offs at one end of the ULC to provide a tension bolt and shear pin interface between OSCRS and the ULC.

For remote operation, a universal servicing tool attached to the Shuttle RMS or the Service Bay Manipulator could be used with the appropriate socket wrench tool element to remove and tighten the tension bolts attaching the modular OSCRS to the ULC. An additional OSCRS camera to view the direction normal to the RMS axis may be necessary depending on the view available from the Orbiter Aft Flight Deck windows, four cameras in the orbiter bay, and the Space Station cameras.

The avionic boxes and mounting structure will be modularized to permit relocation to Space Station except for the multiplexer and one of the Power Distribution Units. This provides a weight savings on just the OSCRS structure of 237 lb. An additional weight savings is achieved by the elimination of the two payload retention latch assemblies (PRLAs) and the Active Keel Actuator, a total of about 600 lb depending on where OSCRS is located in the orbiter bay. (On mixed cargo flights

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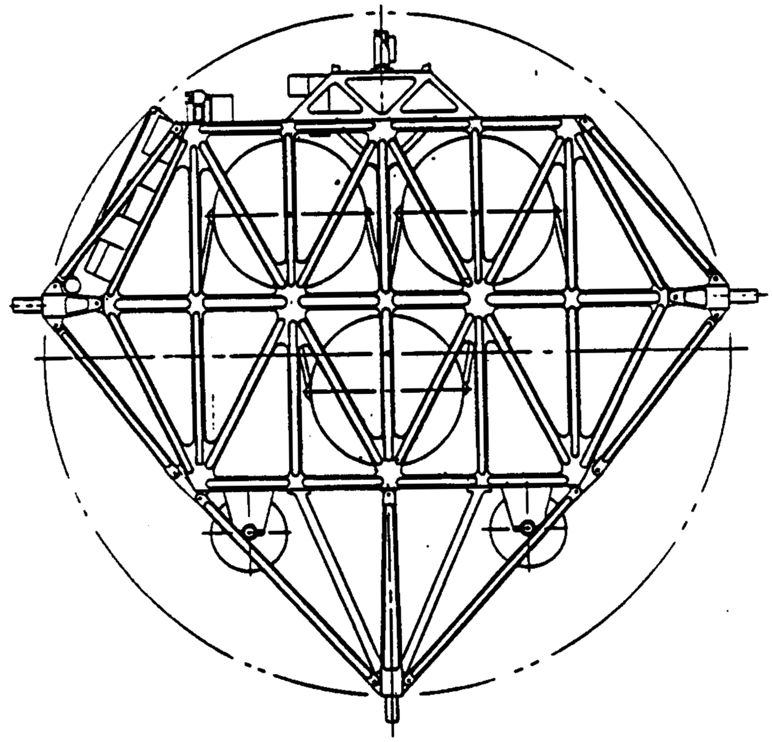
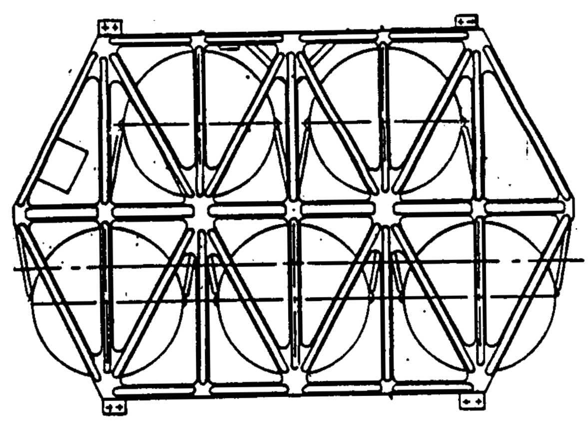


BASIC OSCRS
CONFIGURATION



MODULAR OSCRS
CONFIGURATION

*Figure 4.4.3-1 Structural Changes—Modular OSCRS* this weight is chargeable to the STS.) A comparison of the modular OSCRS and the basic OSCRS is presented in Figure 4.4.3-2. showing the installation of the tanks and the removal of the avionics. The weight penalty added to the ULC for carrying the modular OSCRS is difficult to determine. However, if the ULC is designed to support cantilevered fluids pallets, the weight impact could be negligible.

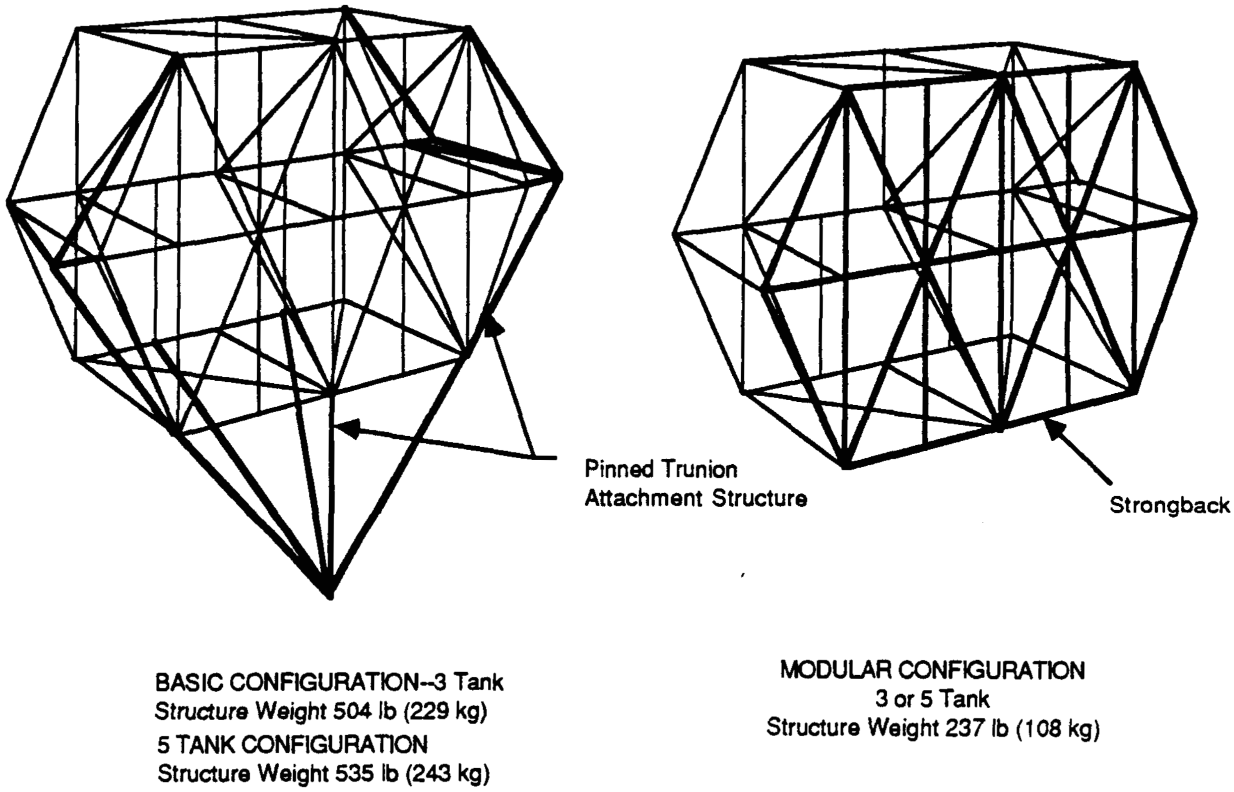



*Figure 4.4.3-2 Structural Changes for Modular OSCRS*

## 4.4.4 Modular OSCRS Avionics Subsystem

Several options for basing the avionics subsystem on Space Station were examined. The avionics block diagram of the basic OSCRS was used as a starting point with three variations considered as shown in Figure 4.4.4-1.

The line marked "baseline" is for OSCRS with all avionics on the OSCRS and Space Station providing the functions that were provided by Aft Flight Deck (AFD) equipment aboard NSTS. The only change required to OSCRS would be to majority vote the power switching commands from the Space Station Multiplexer-Demultiplexer (MDM) because Space Station will not provide any hardwire switch capability. This change could be made permanent and eliminate some hardwire switches from the AFD design.

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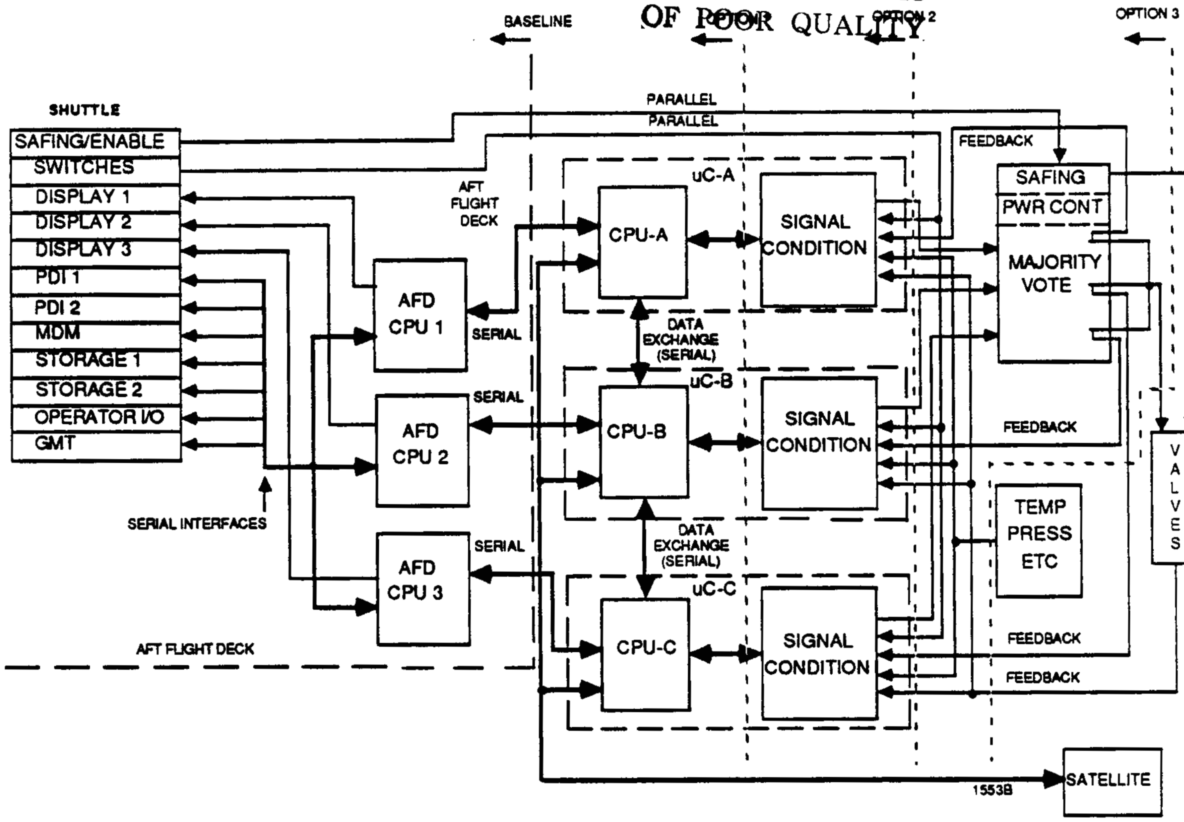



*Figure 4.4.4-1 Options Considered for Station Basing of Avionics*

The first option considered was to base the central processing unit (CPU) part of the Southwest Research Computer (SC-1) on the Space Station. This is not feasible since it would require adding line drivers and line receivers to the SC-1 and the Expander Unit.

The next option considered was to base both the SC-1 and the Expander Unit on Space Station. This option was rejected because it would require the two votes per computer per valve to cross the interface, making a large wire count interface.

The final option considered was to base the SC-1, Expander Unit, and Majority Vote Units all on Space Station. To make this option feasible, a multiplexer unit would be added to multiplex the temperature, pressure, and valve position signals to reduce the number of wires in the interface. The other problem with removing all the avionics from OSCRS is determining how to get health status and control heaters during the time OSCRS is in the NSTS. To solve this problem, the Power Distribution Unit would be split into two parts, with the part required to control functions needed for NSTS and the multiplexer staying on OSCRS. Thus, data can get to NSTS MDMs via the multiplexer, and the necessary power distribution to sensors, heaters, and the multiplexer can be controlled by the MDMs.

The Space Station basing of the avionics as part of the modular concept provides a weight savings by launching the avionics only once. The avionics can be launched the same as any ORU and then installed on the Space Station at a location that meets the thermal requirements.

The weight savings obtained by station basing the avionics will be 289 lb as shown in Table 4.6-1.

A very attractive feature of the Space Station interface will be the availability of an EDP that could be used to replace the OSCRS SC-1 computers for applications where the OSCRS avionics is station-based. Figure 4.4.4-2 shows a block diagram of this interface.

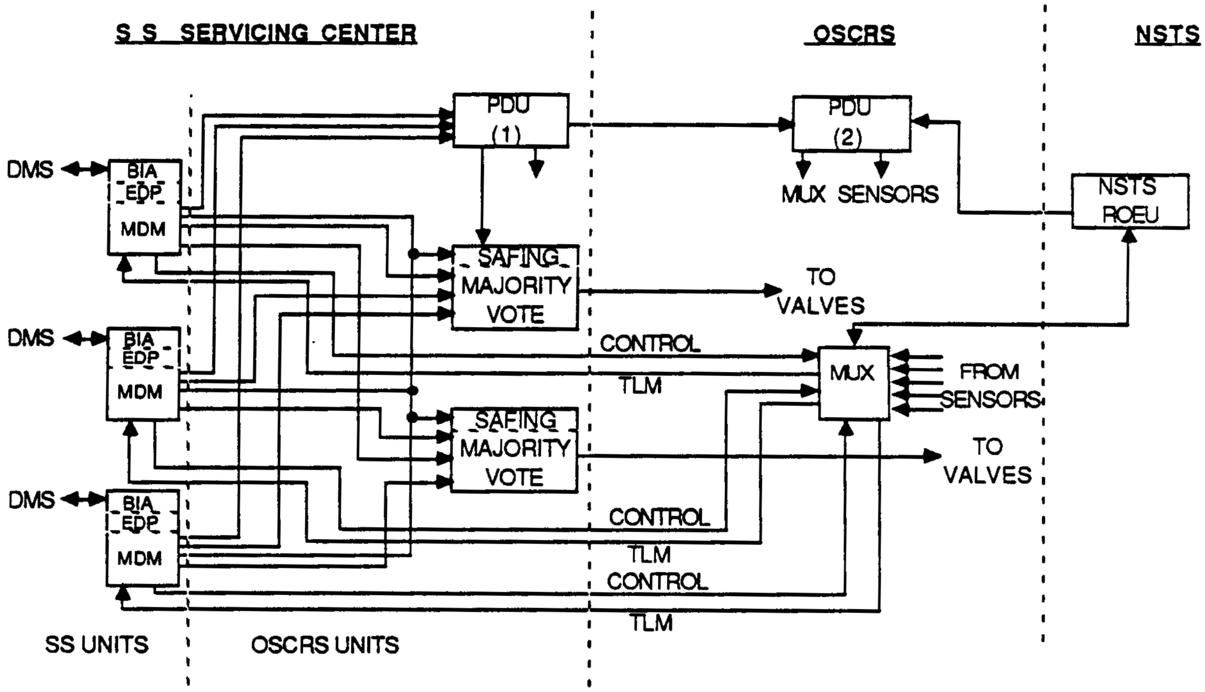



*Figure 4.4.4-2 OSCRS-to-Space-Station Interface with Avionics Station Based and Using Space Station EDPs*

An estimate of the number of wires needed in the umbilical to interface the various OSCRS options to Space Station is presented in Table 4.4.4-1.

*Table 4.4.4-1 Avionics Interface Wire Count for Various OSCRS Options*

| | |
|---|---|
| **BASIC MONOPROPELLANT** | |
| COMMAND/DATA-SERIAL | 6 WIRES |
| COMMAND/DATA-PARRALLEL | 36 WIRES |
| POWER | 6 WIRES |
| | 48 WIRES TOTAL * |
| **MONOPROPELLANT OSCRS-AVIONICS ON SPACE STATION** | |
| DATA | 50 WIRES |
| MUX CONTROL | 8 WIRES |
| POWER | 12 WIRES |
| VALVE COMMANDS | 156 WIRES |
| GROUND (VALVES) | 3 WIRES |
| | 229 WIRES TOTAL * |
| **MODULAR OSCRS-WITH MUX** | |
| DATA | 21 WIRES |
| MUX CONTROL | 4 WIRES |
| POWER | 6 WIRES |
| VALVE COMMANDS | 40 WIRES |
| GROUND (VALVES) | 3 WIRES |
| | 74 WIRES TOTAL |
| **WATER OSCRS-WITHOUT MUX** | |
| DATA | 30 WIRES |
| POWER | 6 WIRES |
| VALVE COMMANDS | 32 WIRES |
| GROUND (VALVES) | 3 WIRES |
| | 71 WIRES |

* A VALVE COUNT OF 78 WAS ASSUMED FOR THESE TOTALS.

## 4.5 SIMPLIFICATIONS FOR WATER

Simplifications to the monopropellant OSCRS for the transport of water to the Station were examined for each of the major subsystems. As discussed in Section 3.3.1, the water OSCRS would be attached to an interface on the Station transverse boom near the pressurized modules containing the necessary berthing hardware and utility umbilicals. The water would then be transferred to the internal water storage tanks contained in the Resource Nodes 1 and 2 which have a total capacity of 4000 lb. These tanks then interface with the internal water distribution system, which is at a relatively low pressure of approximately 30 psi.

Since the water system is at low pressure, a blowdown system could be used on the water OSCRS, simplifying the plumbing hardware. Additionally, the catalytic vents would not be required, and some instrumentation, such as flowmeters, could be removed and Station hardware used.

The plumbing schematic for the water OSCRS is shown in Figure 4.5-1. As discussed in Section 3.2, a 5000-lb/year water deficit exists on the Station using current requirements, which is approximately the capacity of an OSCRS using five tracking and data relay satellite (TDRSS) tanks. A simplified analysis was performed to model the blowdown process. Since the Station water distribution system will be at low pressure, the blowdown process is especially efficient in the water system. An initial tank pressure of 350 psi and a 20% ullage would allow 4070 lb of water to be transferred to the Station. However, if a single OSCRS pressurant bottle is added to augment the blowdown process, the tank ullage could be reduced to 5%, allowing 760 lb of additional water to be carried at the expense of approximately 120 lb in pressurant system wet weight. Therefore, an augmented blowdown system was selected as the baseline for the water OSCRS. The pressurant system could be eliminated by the addition of pumps to the

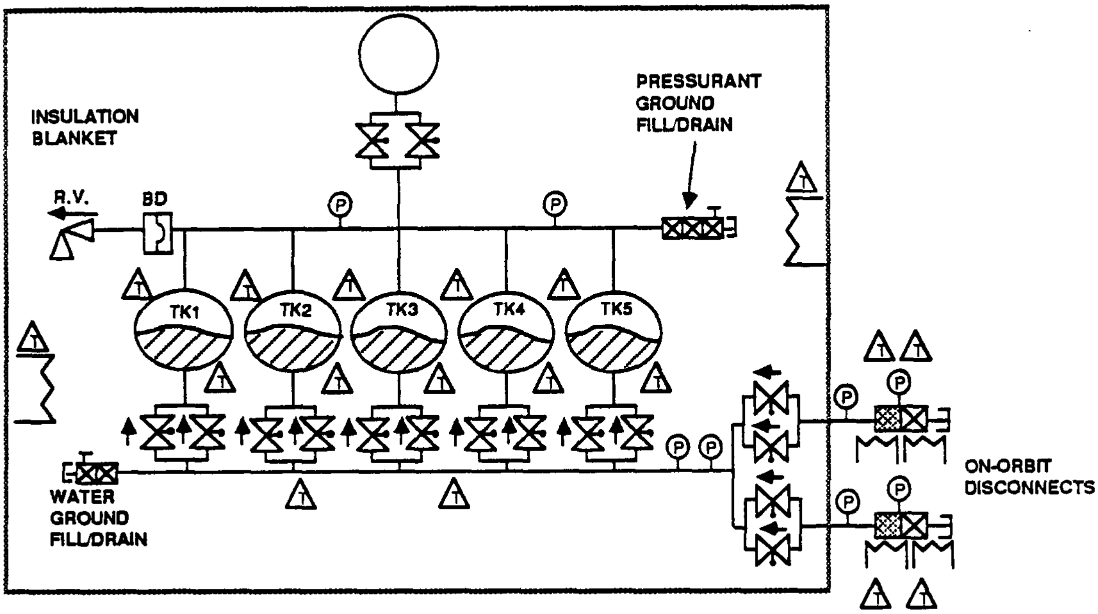



*Figure 4.5-1 OSCRS Water Version Fluid System Schematic*

water OSCRS. However, pumps are an integral part of the Station water distribution system, particularly in the ECLSS water system. If these pumps could be used to transfer the water from the OSCRS, a further savings in weight could be achieved. The entire plumbing system is much simpler than the monopropellant system, although two-fault tolerance against leaks has been retained.

The water OSCRS avionics was designed to be one-fault tolerant for mission success and two-fault tolerant for heater operations. One majority-vote unit would be required because one unit operates up to 20 valves and the preliminary water design uses 16 valves. Figure 4.5-2 is a block diagram of the water OSCRS-to-Space-Station command, data, and power interface using the Space Station EDPs.

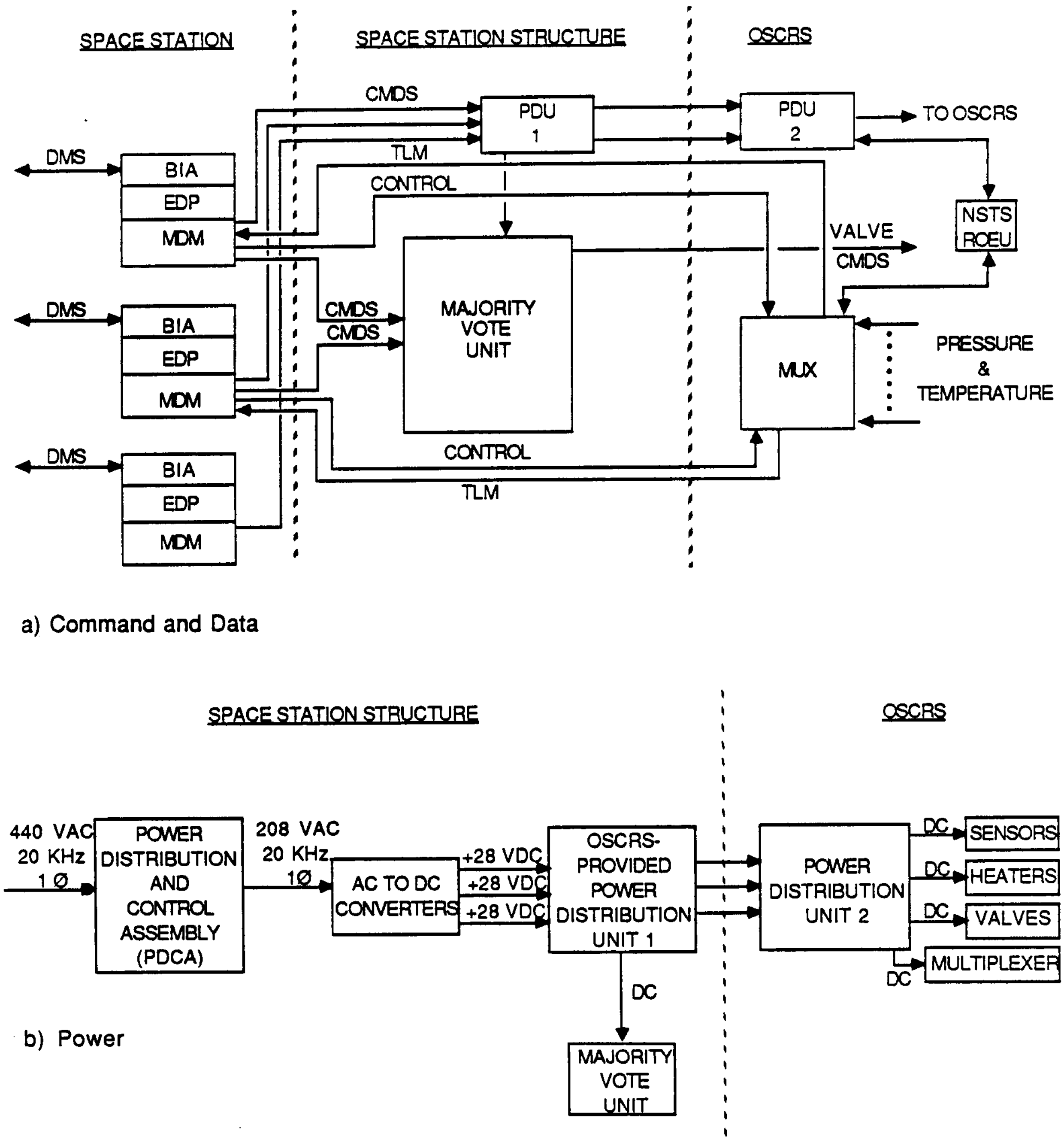



*Figure 4.5-2 Water OSCRS-to-Space-Station Interfaces*

## 4.6 COMPARISON OF OPTIONS AND RECOMMENDATIONS

A comparison of the three OSCRS configurations options was made to arrive at recommendations. A summary of the weights of the three options, broken down by subsystem, is given in Table 4.6-1. As shown, a significant increase in the mass fraction can be obtained by modularization of the OSCRS through station basing of the avionics,

*Table 4.6-1 OSCRS Monopropellant Configuration Options Weight Summary*

| CONFIGURATION / SUBSYSTEM | BASIC OSCRS (3 TANK VERSION) | MINIMUM MODIFIED OSCRS (3 TANK VERSION) | MODULAR OSCRS (3 TANK VERSION) |
|---|---|---|---|
| FLUIDS<br>• PRESSURZATION<br>• VENT<br>• PROPELLANT STORAGE | 804 | 648 | 84<br>6<br>505 |
| THERMAL | 93 | 93 | 81 |
| TRUSS STRUCTURE | 504 | 504 | 237 |
| MECHANISMS | 213 | 192 | 20 |
| AVIONICS | 314 | 314 | 25 |
| MASS FRACTION | 0.60 | 0.63 | 0.76 |
| • ALL WEIGHTS IN LBS | | | |

attachment mechanisms, fluid subsystem simplification, and truss structure modifications. Improvements in the mass fraction are especially important for Space Station since the Logistics Elements will be tasked to satisfy all of the resupply and return requirements.

Option 3, which bases the majority of the OSCRS avionics on Space Station, appears to be the best option. This is especially attractive if the EDPs can replace the OSCRS computers. In order to accommodate this option, it is recommended that the initial OSCRS design include the multiplexer and the two-part PDU. Additional design features should be the modularizing of the cable harness, if possible, to allow the easy removal of the avionics for station basing and adding the power switching to the majority vote unit. Splitting the PDU will create two boxes approximately 8x8x10 in., 13 lb, and 15 watts each versus one PDU, 18x12x7.5 in., 22 lb, and 6 watts; the multiplexer will be approximately 10x10x10 in., 12 lb, and 25 watts, for a net avionics weight increase of 16 lb to the basic OSCRS.

The ground support equipment (GSE) will require some additions for ground checkout and filling of the modular OSCRS because the avionics on the modular OSCRS will only consist of the multiplexer and a PDU. The approximate cost to modularize the avionics will be $250,000 for the PDU split, $750,000 for the multiplexer, and $150,000 for the GSE modifications.

In conclusion, we recommend that the modular approach be baselined for OSCRS because of the increased operating flexibility and launch weight reductions that can be gained when adapting the OSCRS for Space Station use.

## 4.7 OPERATIONS AT SPACE STATION

The use of OSCRS for refueling at Station can involve many scenarios that, because of the preliminary nature of the Space Station design, cannot be formalized at this time. However, general refueling scenarios were developed to make some preliminary assessment of the impacts to the OSCRS design. The scenarios are influenced by a number of factors, such as where OSCRS will be stored, where the refueling will take place, and whether more than one OSCRS is required. An additional impact is the configuration of the Space Station. Program Option 1, described in Section 3.1, does not include the Servicing Facility and therefore refueling operations will be different from the full-up Station. The purpose of this section is to review the basic operations and to develop general procedures involving the use of OSCRS at the Space Station.

### 4.7.1 Shuttle-to-Station Transfer

Transfer of the OSCRS from the Shuttle once it has docked to the Station will be necessary to place the OSCRS either in the Servicing Facility or on the truss. The water OSCRS would be attached to the truss near the pressurized modules. The monopropellant OSCRS could also be attached to the truss if it is used prior to the Servicing Facility's being operational (Option 1 Space Station). When the Servicing Facility is present, the monopropellant OSCRS would be stored in Bay 2 of the service track assembly.

The transfer from Shuttle to Station would require several mating and demating operations possibly involving several types of mechanisms. General Space Station requirements dictate that interfaces should be mated and verified before existing interfaces are demated. This is a specific requirement for the Logisitics Elements. This philosophy, while not specifically called for OSCRS, was used in evaluating impacts to OSCRS of the transfer operations. In general, the transfer would involve the following steps:

1. Mate and verify OSCRS to the Station RMS or Servicing Facility Manipulator interfaces (structural, power, DMS).

2. Demate OSCRS/Shuttle interfaces (structural, power, DMS).

3. Translate OSCRS to the Station docking location.

4. Mate and verify OSCRS/Station or Servicing Facility interfaces (structural, power, DMS, fluid).

5. Demate OSCRS/manipulator arm interfaces.

The above operations would be repeated in reverse order to return OSCRS to the Shuttle bay for transport to the ground. A derived requirement identified during the development of the transfer flow was the need for OSCRS to be monitored while attached to the Station RMS or Servicing Facility manipulator and to have power provided for heater supply. Since the actual transit time from the Orbiter bay to the Station interface location has not been identified and could vary, the provision for heater power was assumed to be a requirement. Additionally, failure of the arm or the MSC translation mechanism would mean that OSCRS could be attached for an extended period, making monitoring and heater power supply a safety requirement.

As mentioned previously, several types of mechanisms would be involved with the transfer operations. Table 4.7.1-1 lists each transfer step, with the mechanism options for each and the type of interface involved. The process of removing the OSCRS from the Shuttle would involve the demating of electrical and structural interfaces. The

*Table 4.7.1-1 Shuttle-to-Station Transfer Interfaces*

| | FUNCTION | MECHANISM USED | MECHANICAL INTERFACE |
|---|---|---|---|
| STS | Mate/Demate OSCRS/ Orbiter Electrical Interface | Remotely Operated Electrical Umbilical (ROEU) Orbiter Disconnect Assembly (ODA) | ROEU Payload Disconnect Assembly (PDA) |
| ULC | Attach/Release OSCRS | Universal Servicing Tool Attached to Service Facity Manipulator | Tension Bolts and Shear pins |
| SERVICING FACILITY | Attach/Detach, Retrieve, and Position OSCRS | Service Facility Manipulator (SFM) or | Electrical Flight Grapple Fixture or |
| | | Universal Servicing Tool (UST) Attached to SFM | UST Anchor Plate |
| | Mate/Demate Fluid Interfaces | EVA Astronaut or TBD Automated Umbilical Mechanism | Electrical, Fluid and Gas Connectors |
| | Mate/Demate Electrical Interfaces | Remotely Operated Electrical Umbilical (Orbiter Disconnect Assembly) | ROEU Payload Disconnect Assembly |

Rockwell Remote Connection Mechanism (formerly called the Remotely Operated Electrical Umbilical), shown in Figure 4.7.1-1, would be used for the automatic disconnection of the electrical interfaces. The Remote Connection Mechanism was developed by Rockwell International for making and breaking electrical connections between the Orbiter and a payload. The plug half of the connector would be mounted on the OSCRS, with the positioner mounted on the Orbiter. The drive assembly brings the positioner close to the OSCRS connector half. The positioner provides the adjusting movements necessary to align the connector halves and engage the pins. The structural connection could use the PRLA and active keel actuator to free the OSCRS trunnion and keel fittings. If the modular OSCRS is flown attached to the Logistics Elements ULC, then the Universal Servicing Tool, shown in Figure 4.7.1-2, could be used to disconnect the OSCRS from the ULC by unscrewing the captive tension bolts and shear pins.

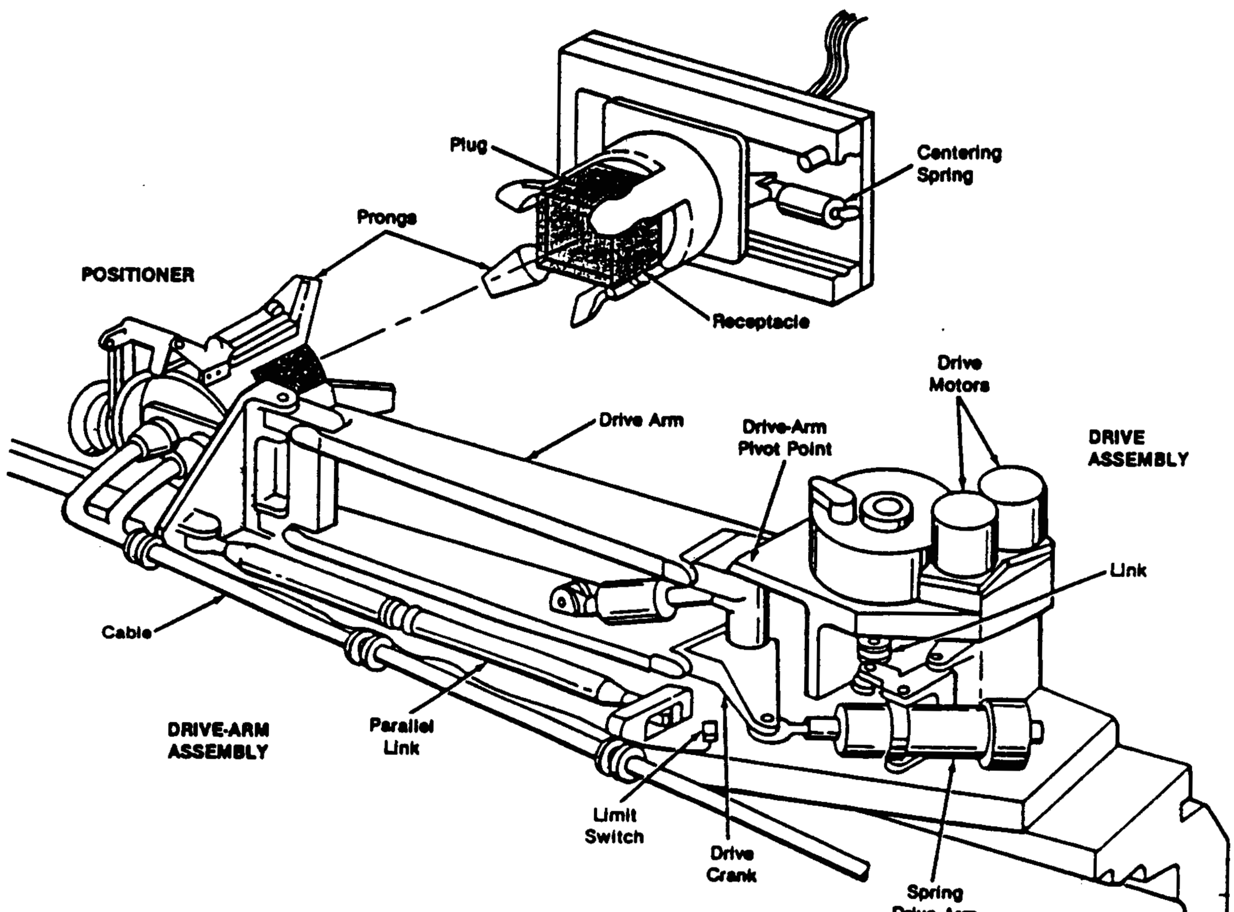



*Figure 4.7.1-1 Rockwell International Remote–Connection Mechanism*

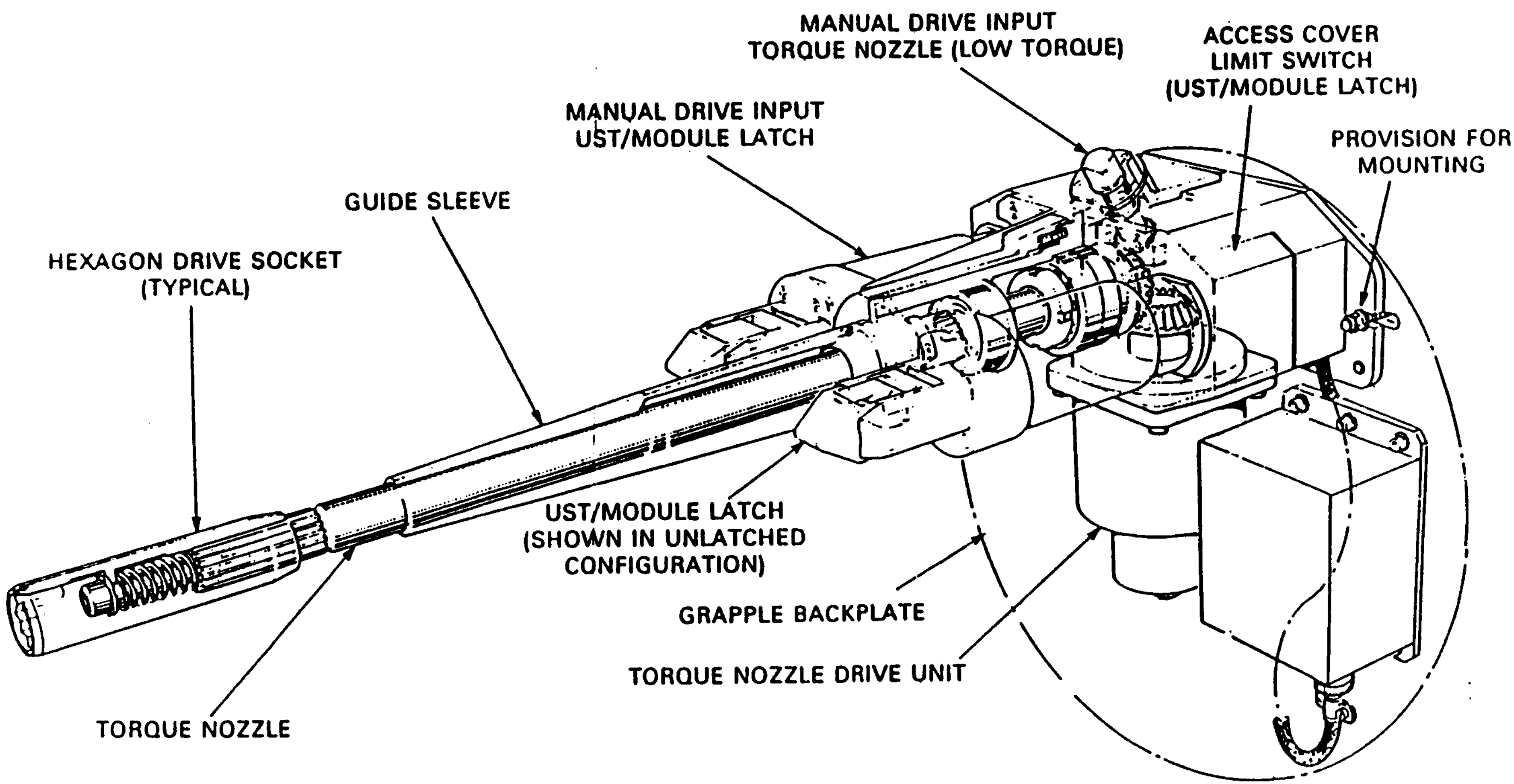



*Figure 4.7.1-2 Universal Service Tool*

Placing the OSCRS into the Servicing Facility sequences the mating of electrical, fluid, and structural interfaces. As summarized in Table 4.7.1-1, the OSCRS would be positioned using the Service Facility Manipulator, and then the connectors would be mated. The connections would be mated automatically using some type of umbilical connector. The number and type of connectors required varies, depending on whether a basic, minimum modified, or modular OSCRS is used. In general, however, two gaseous interfaces and one electrical would be required, not including redundancy.

Problem areas were identified on evaluating the OSCRS-to-Station transfer. The Station Remote Manipulator and the Servicing Bay Manipulator are currently only one-fault tolerant for supplying power. During a contingency, where OSCRS could remain attached to either arm for an extended time period, two-fault-tolerant power would be required to prevent the propellants from freezing. Additionally, there are a larger number of possible mechanisms used to mate and demate the interfaces. The number should be narrowed and standardized to prevent the OSCRS design from being burdened with accommodating them all.

### 4.7.2 Refueling at Space Station

Refueling operations at the Space Station involving OSCRS are not totally defined by the Space Station program as yet. However, refuelng will take place either in the Servicing Facility or out on the truss if OSCRS is used with the Option 1 Space Station. In general, however, the refueling operations will involve the following steps:

1. Remove any meteoroid, thermal, contamination shield(s) to gain access to the umbilicals and both OSCRS and the spacecraft. (This function could be incorporated into the umbilical mechanism).

2. Use a robotic arm or payload handling device to position the satellite near OSCRS or vice-versa.

3. Using the berthing mechanism on OSCRS, berth OSCRS with the spacecraft.

4. Use active side of the automatic umbilical mounted on OSCRS to mate umbilicals.

5. Refuel satellite.

6. Demate umbilicals.

7. Unberth satellite.

The variations in these steps can be numerous depending on the particular spacecraft involved. The following two sections discuss some operational trades that were examined in an attempt to determine how OSCRS could best be used at the Station.

4.7.2.1 Central Distribution versus Moveable OSCRS

One of the ways that OSCRS could be used at the Station would be to refuel, with either propellant or pressurant gas, attached payloads or other spacecraft not located in the Servicing Facility. Many attached payloads may be located some distance away from the Servicing Facility on the upper or lower truss booms. Resupplying these payloads would require that either OSCRS be moved to the payload location or plumbing be routed from the OSCRS storage location in the Servicing Facility to the payload. Use of the OSCRS as the central supply of a distribution system would simplify the OSCRS operations because its interfaces with the Station would not have to be mated and demated. However, the use of distribution lines located in the Station truss to route propellant to one or more refueling locations would involve complex assembly operations and thermal control on the lines to prevent freezing. Therefore, it is recommended that, if refueling is desired in a location other than the Servicing Facility, OSCRS be moved to that location.

4.7.2.2 Use of Multiple Tankers

Use of multiple OSCRSs at the Space Station was examined to determine feasibility and operational scenarios. Possible uses for multiple OSCRSs would be to increase the storage capacity of propellant at the Station, to allow differing configurations of OSCRS for specific servicing missions, and to offload one OSCRS into another to ensure that only an empty OSCRS returns to the ground.

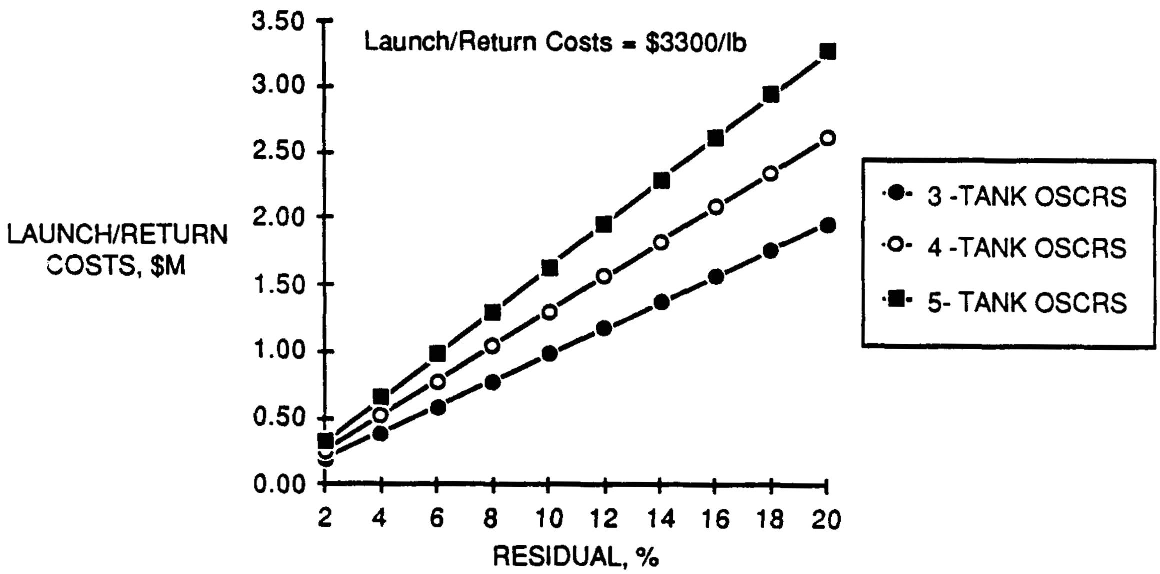



*Figure 4.7.2.2-1 Penalty for Returning Partly-Full OSCRS*

Return of the OSCRS to the ground in an empty condition is an important consideration. The penalties associated with returning unused propellant to the ground can be severe. Figure 4.7.2.2-1 shows the launch/return costs of three OSCRS configurations as a function of percent residual. The costs shown are for a single launch and are cumulative with time. A factor not shown in the graph is that the weight taken up by the propellant residual takes the place of useful cargo being returned to Earth from the Station. While these costs are difficult to quantify, they are important considerations in offloading the OSCRS.

Use of multiple OSCRSs for offloading or for resupply and storage of larger quantities of propellant requires the physical interconnection of two or more OSCRSs. Methods of this interconnection were examined to determine what hardware changes to the Station or the OSCRS, if any, would be required. Figure 4.7.2.2-2 shows one method of interconnection between two OSCRSs using one of the emergency quick disconnects on each tanker and a jumper connection. This type of

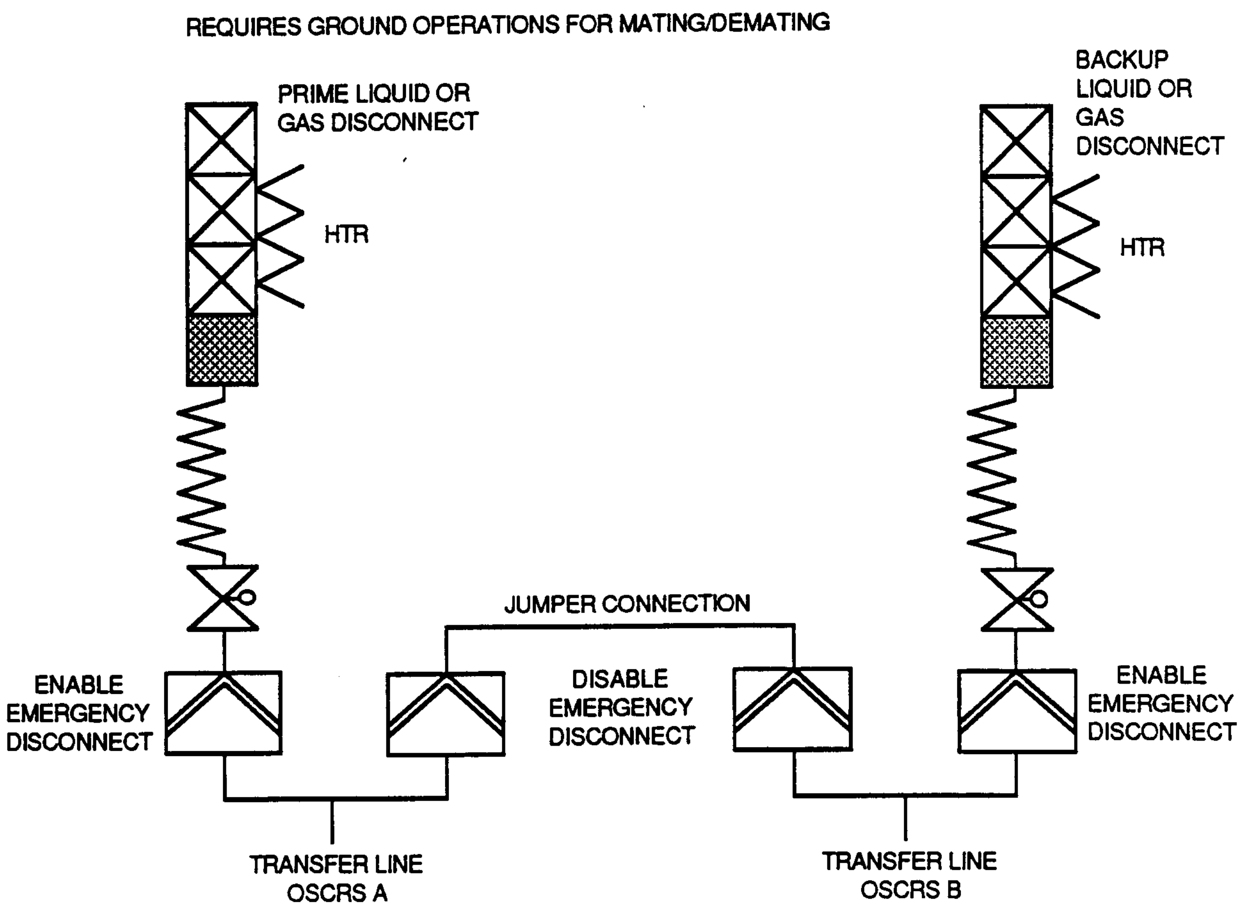



*Figure 4.7.2.2-2 OSCRS Interconnection Option 1*

connection does not lend itself well to Station operations because the OSCRS could not be moved once the connection has been made. Another interconnection option is shown in Figure 4.7.2.2-3. The spacecraft half of the quick disconnect is placed in the Servicing Facility, and the OSCRSs connect with each end. This method requires additional hardware in the Servicing Facility but would require no design changes to the OSCRS. This would allow the OSCRSs to be mated and demated from each other using the same procedure for spacecraft-to-OSCRS connections and would be applicable to both automated and manual umbilicals.

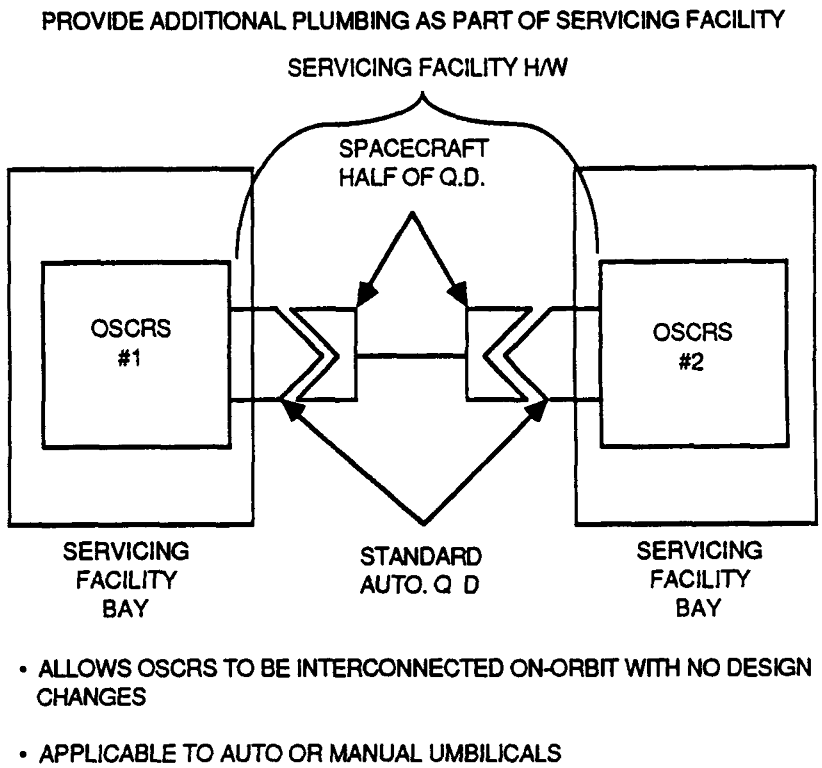



*Figure 4.7.2.2-3 OSCRS Interconnection--Option 2*

The use of multiple OSCRSs, if a firm requirement, could make pump transfer a more attractive system than pressure transfer. Interconnection of two or more OSCRSs using pressure transfer would require venting of the pressurant gases in one or more of the OSCRSs to facilitate transfer from one to the other. Pump transfer, however, would allow this operation to occur without the need to vent or use pressurant. Another concern with the use of multiple OSCRSs is the requirement for two-way flow to occur. In the basic OSCRS fluid subsystem, this would mean backflowing the filters in the propellant transfer line, which is not desirable. The addition of a bypass leg with check valves would be needed to avoid this problem.

Use of multiple tankers at Space Station requires that the avionics of one OSCRS have the capability to interface to the avionics of another OSCRS. There are several ways to configure two or more OSCRSs, listed below:

1) Master/Slave

2) OSCRSs working simultaneously

3) OSCRSs working independently.

In the Master/Slave configuration (1), one OSCRS will be configured as a master unit and the other(s) as slave unit(s), each assigned a unique address and controlled by the Space Station computers. The master OSCRS will be the link to Space Station. All commands (serial or discretes) will be sent to the master unit, then routed to the slaves. The handling of data will be performed by the master unit. Slave data will be interleaved with that of the master unit, then passed on to Space Station. Figure 4.7.2.2-4 shows a block diagram of the master/slave configuration.

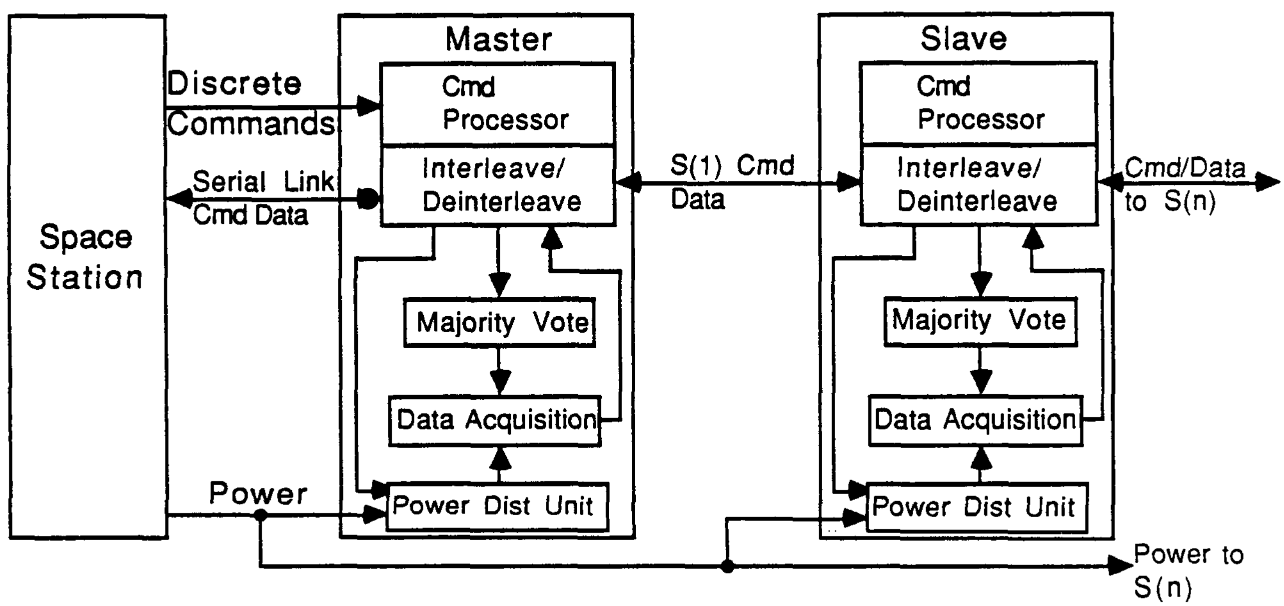



*Figure 4.7.2.2-4 Space Station Based--OSCRS Master/Slave Configuration*

The impacts on the avionics will effect both hardware and software. Below is a listing of the impacts:

- An extra serial channel will be required in each OSCRS for communication.
- Added capability to interface slave data
- Extra cabling and umbilicals for interconnection

- Extra auto-umbilical drivers
- More interfaces to test both on the ground and at Space Station
- Extra software to handle command recognition and routing
- Greater software requirement on Space Station to deinterleave and display data.

In the simultaneous configuration (2), each OSCRS will be up and operational as in the master/slave configuration. Each OSCRS will be electrically operating independently of the other, having its own unique electrical link to Space Station, receiving commands, and providing data. Figure 4.7.2.2-5 shows a block diagram of the simultaneous interfaces.

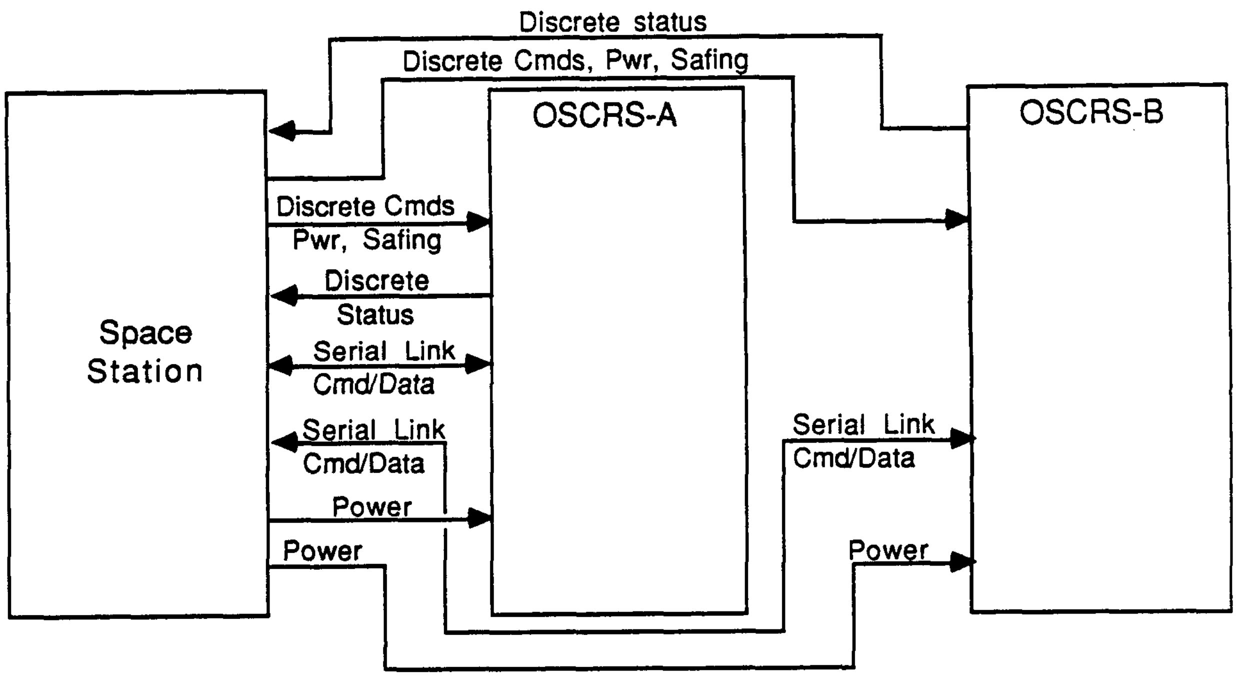



*Figure 4.7.2.2-5 Space Station Based--OSCRS Simultaneous Configuration*

The impacts on the avionics will affect both hardware and software. Below is a listing of the impacts:

- Extra umbilicals to interface OSCRS to Space Station
- Impact on Space Station to provide the extra interface capability of enough serial channels and discretes to handle all OSCRS units and redundancy requirements
- More interfaces to test at Space Station
- Each OSCRS will have different command address
- Greater software requirement on Space Station.

The last configuration (3) requires the least change to the overall system. Each OSCRS will be unique to itself as in Configuration 2. The only difference is that only one OSCRS will be operational at a time when refueling a satellite. Each OSCRS will be configured the same in hardware and software. This configuration avoids making the avionics more complex and more costly. Figure 4.7.2.2-6 shows an avionics block diagram.

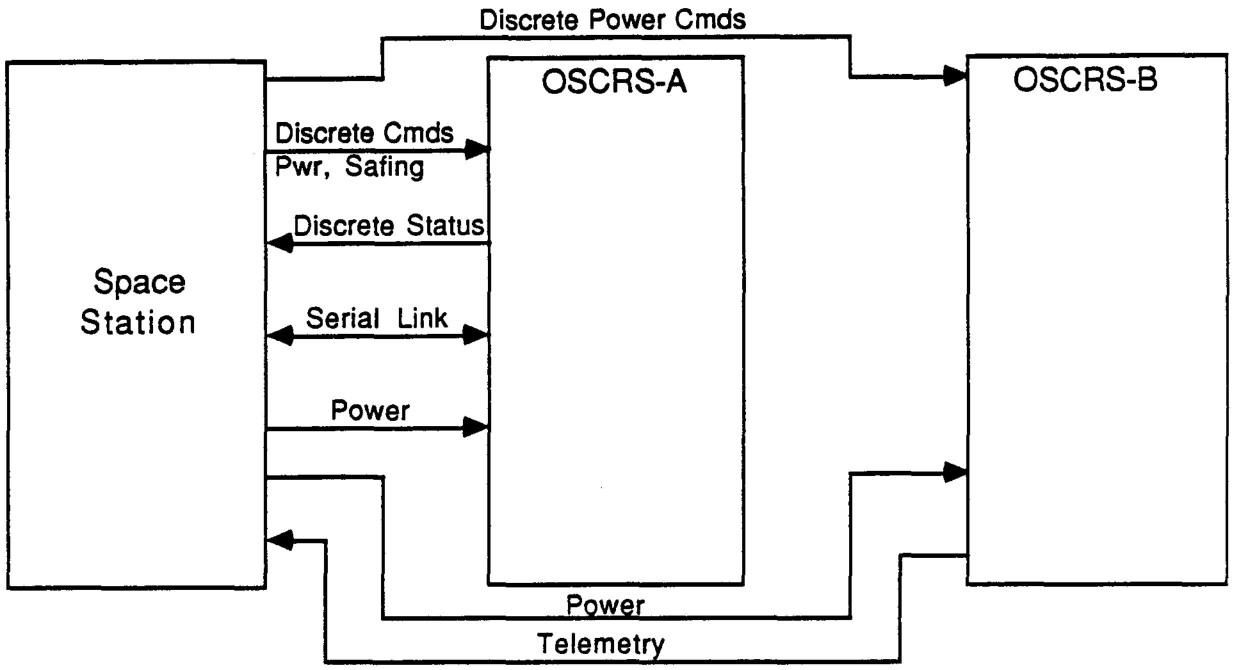



*Figure 4.7.2.2-6 Space Station Based--OSCRS Independent Configuration*

For offloading one OSCRS to another OSCRS, Configuration 3 would be the best choice. With each OSCRS being totally the same, one OSCRS could be based and controlled at the Service Facility while the other OSCRS was interfaced and controlled by one of the manipulating arms in or around the Service Facility. There is no hardware impact, and only minor software modifications will be necessary. Figure 4.7.2.2-7 shows an offloading block diagram.

Working with multiple OSCRSs within the shuttle cargo bay would best be performed with Configuration 3. The avionics is configured to interface to the shuttle in a stand-alone mode. As with Space Station, only one OSCRS would be used at a time, with the satellite being moved to another OSCRS to complete refueling.

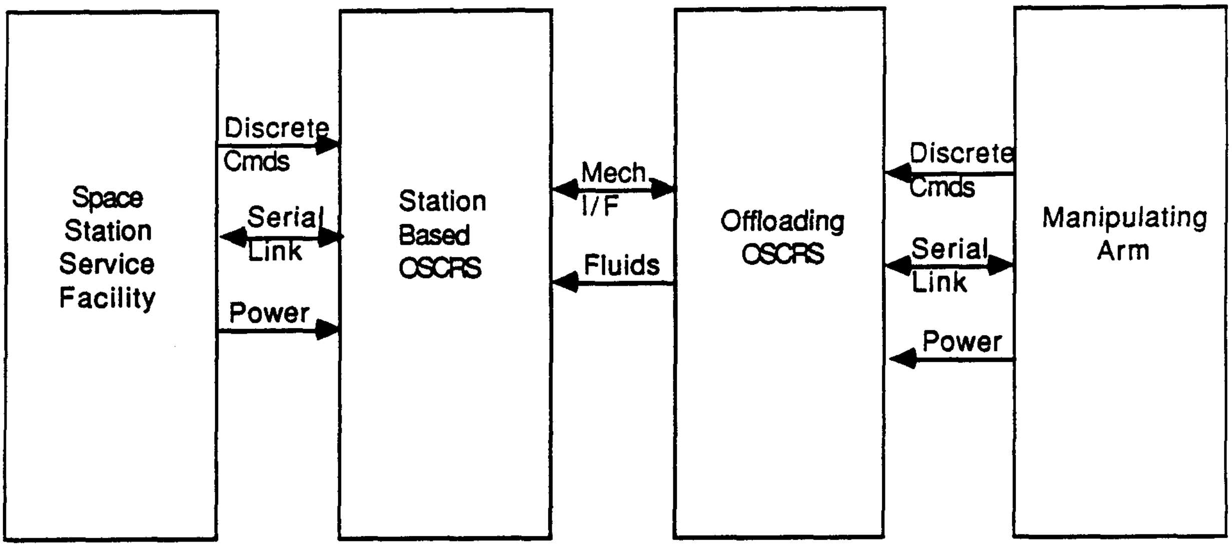


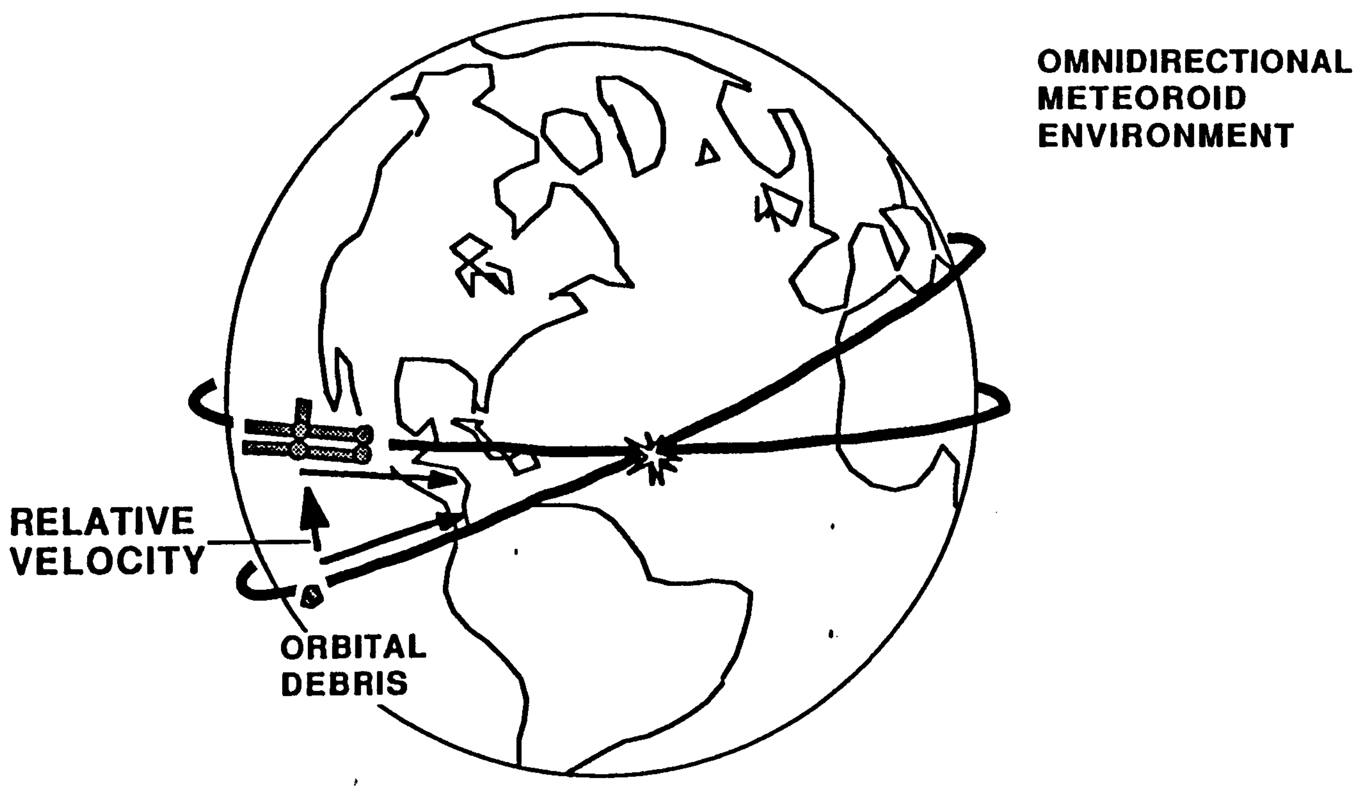

*Figure 4.7.2.2-7 Space Station Based--OSCRS Offloading Tankers*

## 4.8 METEOROID AND SPACE DEBRIS PROTECTION

### 4.8.1 Design Requirements

The Space Station is being designed to have a longer orbital life than any previous space hardware (30 years). Therefore, particular attention has been paid to the long-term hazards present on-orbit, especially that posed by meteoroid and space debris impact. Several Space Station elements and hardware based on the Station are particularly vulnerable to damage from meteoroids and debris. Propellant and pressurant tanks, such as those on OSCRS, could catastrophically fail if struck by a particle of sufficient size. The resulting fragments and propellant spill would pose a potentially life threatening situation if not contained. The Space Station PDRD has several requirements addressing the hazard posed by debris and meteoroids.

Specifically, Appendix A of the PDRD presents the detailed requirements for meteoroid and debris protection for the Space Station program elements, including information on the expected flux of meteoroids and debris and anticipated sizes at the Station orbital altitude, as shown in Figure 4.8.1-1. The average mass density for meteoroids is 0.5 $g/cm^3$, and the average particle velocity is 20 kilometers per second. The meteoroid environment is omnidirectional relative to the Earth, but for an orbiting spacecraft, most meteoroids come from the direction of motion. The average impact velocity for space debris is 10 kilometers per seconds with the debris particles having an average density similar to that of aluminum (2.89 gm/cm3). A summary of the meteoroid and debris data presented in Appendix A is given in Table 4.8.1-1.




| SPACE DEBRIS ENVIRONMENT | METEOROID ENVIRONMENT |
|---|---|
| ALUMINUM 2.8 $gm/cm^3$ | COMETARY 0.5 $gm/cm^3$ |
| IMPACT VELOCITY 0 - 16 km/s | IMPACT VELOCITY 16 - 72 km/s |

*Figure 4.8.1-1 Space Debris/Meteoroid Analysis*

*Table 4.8.1-1 Meteoroid and Space Debris Protection Requirements*

| | AVERAGE SPACE DEBRIS PARTICLE | AVERAGE METEOROID PARTICLE |
|---|---|---|
| IMPACT VELOCITY | 10 km/sec<br>Range 0 to 16 km/sec | 20 km/sec<br>Range 16 to 72 km/sec |
| DENSITY | 2.8 $g/cm^3$<br>for particles < 1.0 cm<br>(about the same as Al) | 0.5 $g/cm^3$<br>The more numerous cometary meteroids may be considered as loosely packed ice. |
| SIZE | From 1.0 mm to 1.0 cm in dia<br>Nominal particle 9.0 mm<br>(can range from microscopic to spacecraft size) | < 1.0 cm<br>Flux drops off rapidly with increasing mass. |
| ORIGIN | Man-made satellites, oxide pieces from rocket fuel, exploded boosters, antisatellite testing | Natural Origin<br>Comets or Asteroids |

Paragraph 2.1.3.1.1 in the PDRD gives the design criteria for dealing with meteoroids and debris. For attached payloads, satellites, and platform (a category which would include OSCRS) the design requirement is for a 0.99865% probability that exposure to the meteoroid and debris environment summarized in Table 4.8.1-1 will not endanger the crew or Space Station survivability whenever these hardware elements are within the vicinity of the Station.

## 4.8.2 Analysis

Based on the above criteria and requirements, an analysis was performed to determine the thickness of the debris protection for OSCRS. The determination of the required thickness for debris protection must depend on analysis. As shown in Figure 4.8.2-1, more than 70% of the impact velocity cases are beyond the capabilities of ground-based test equipment and must therefore depend on analysis.

- MORE THAN 70% OF IMPACTS ARE BEYOND TEST CAPABILITY
- TEST CASES ARE NEEDED TO VERIFY METHODOLOGY

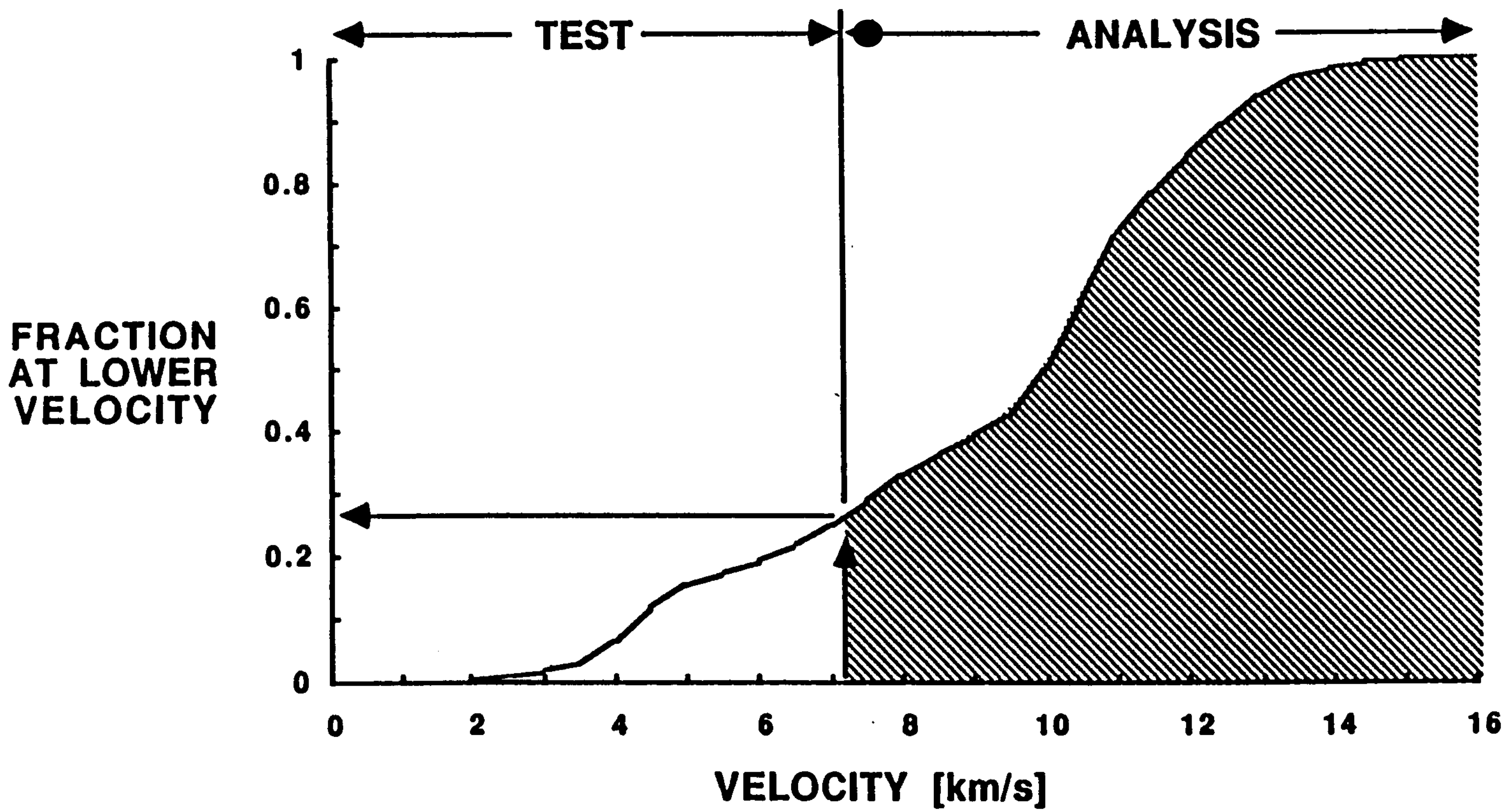



*Figure 4.8.2-1 Probability Depends on Analysis*

Given the probability requirement, the effective surface area of OSCRS, and the on-orbit lifetime, a critical flux can be calculated. For OSCRS, this flux corresponds to a particle diameter of 0.3 inches, meaning that the protection system will satisfy the requirements if it can stop a particle this diameter or smaller. Using aluminum for a bumper material, a thickness between 0.03 inches and 0.075 inches would be required.

### 4.8.3 Conceptual Design

Meteoroid and debris protection consists of a multilayered protection system designed to stop particles of a given size range from reaching critical hardware. A general schematic showing in impact process and how the protection system functions is shown in Figure 4.8.3-1. The bumper material, the outer wall of the layered protection system, fragments and/or vaporizes the particle upon impact. The intermediate shield further reduces the fragment velocity, allowing the rear wall to absorb fragments. In configuring meteoroid and debris shields for OSCRS, two cases were examined: OSCRS attached to the truss and OSCRS located inside the Servicing Facility. An assumption made in configuring the debris protection was that it would be left on the Station and not incorporated into the OSCRS structure to save weight. Figure 4.8.3-2 shows the concept for protection of OSCRS while

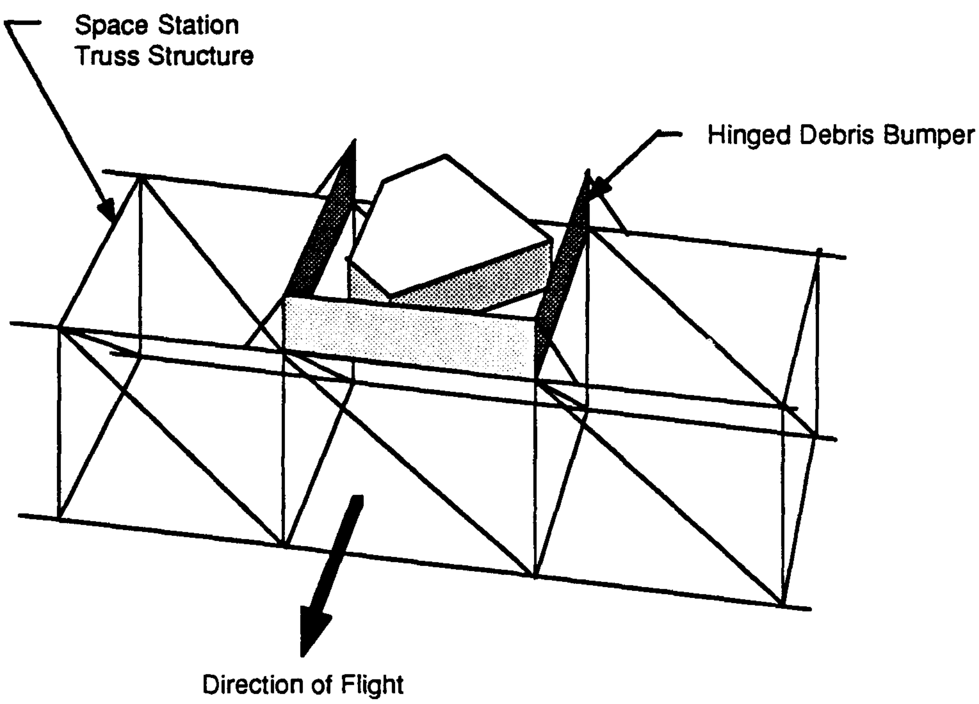



*Figure 4.8.3-2 Meteoroid/Debris Protection at Space Station*

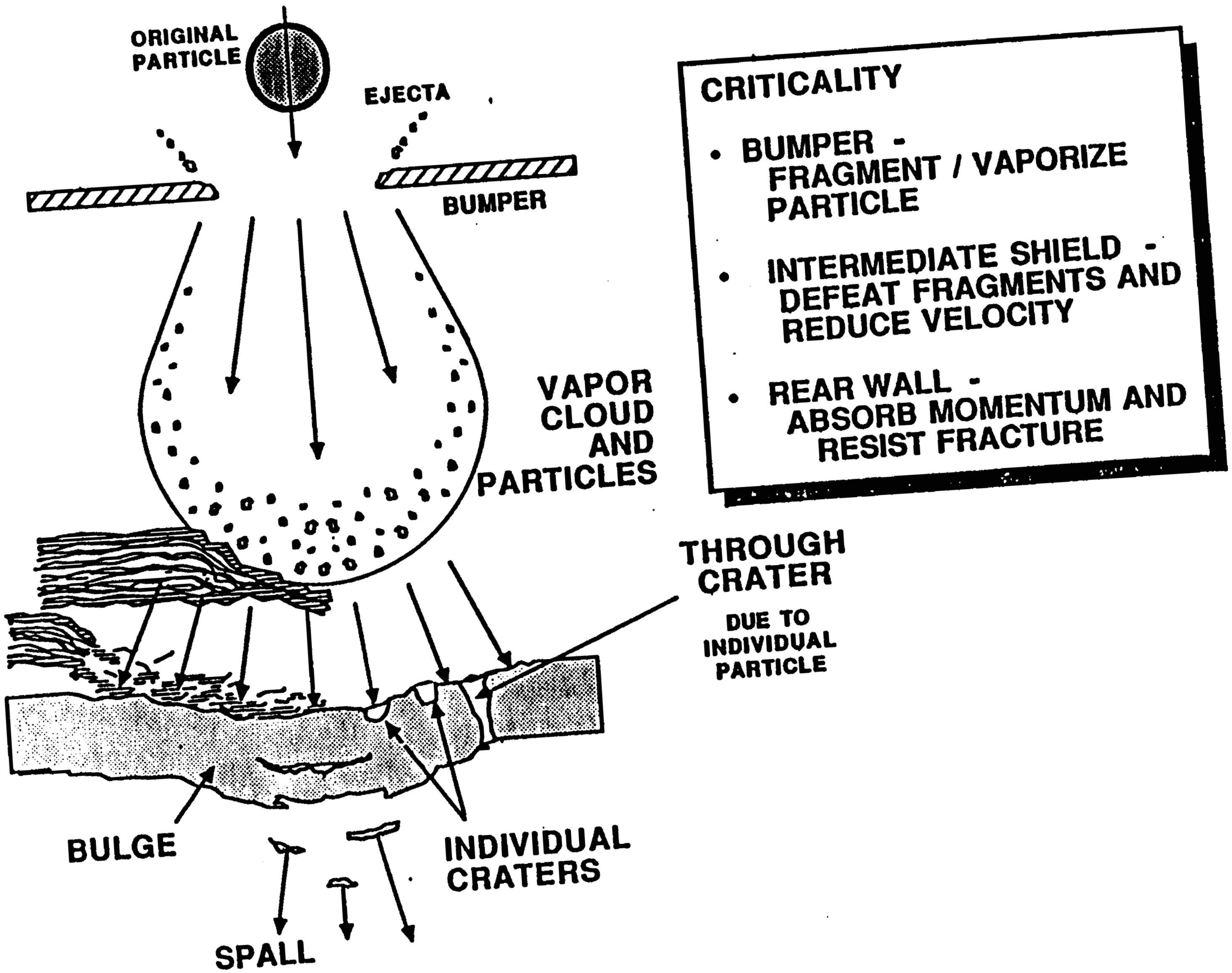



*Figure 4.8.3-1 Impact Process*

attached to the Station truss. The protection system is oriented toward the direction of flight with the OSCRS being protected on three sides. The OSCRS would be located on the truss such that its side would be facing the direction of flight to minimize the effective surface area. The bumper panels would be hinged to allow easy access to the OSCRS for removal and placement by the Station manipulator arm. A concept for protection of OSCRS while inside the Servicing Facility is shown in Figure 4.8.3-3. The protection would be configured similar to the truss-mounted concept with protection being provided on three sides of the OSCRS in relation to the direction of flight. Access to the OSCRS would still be provided by the retractable beta cloth-covered door that is part of the Servicing Facility bays.

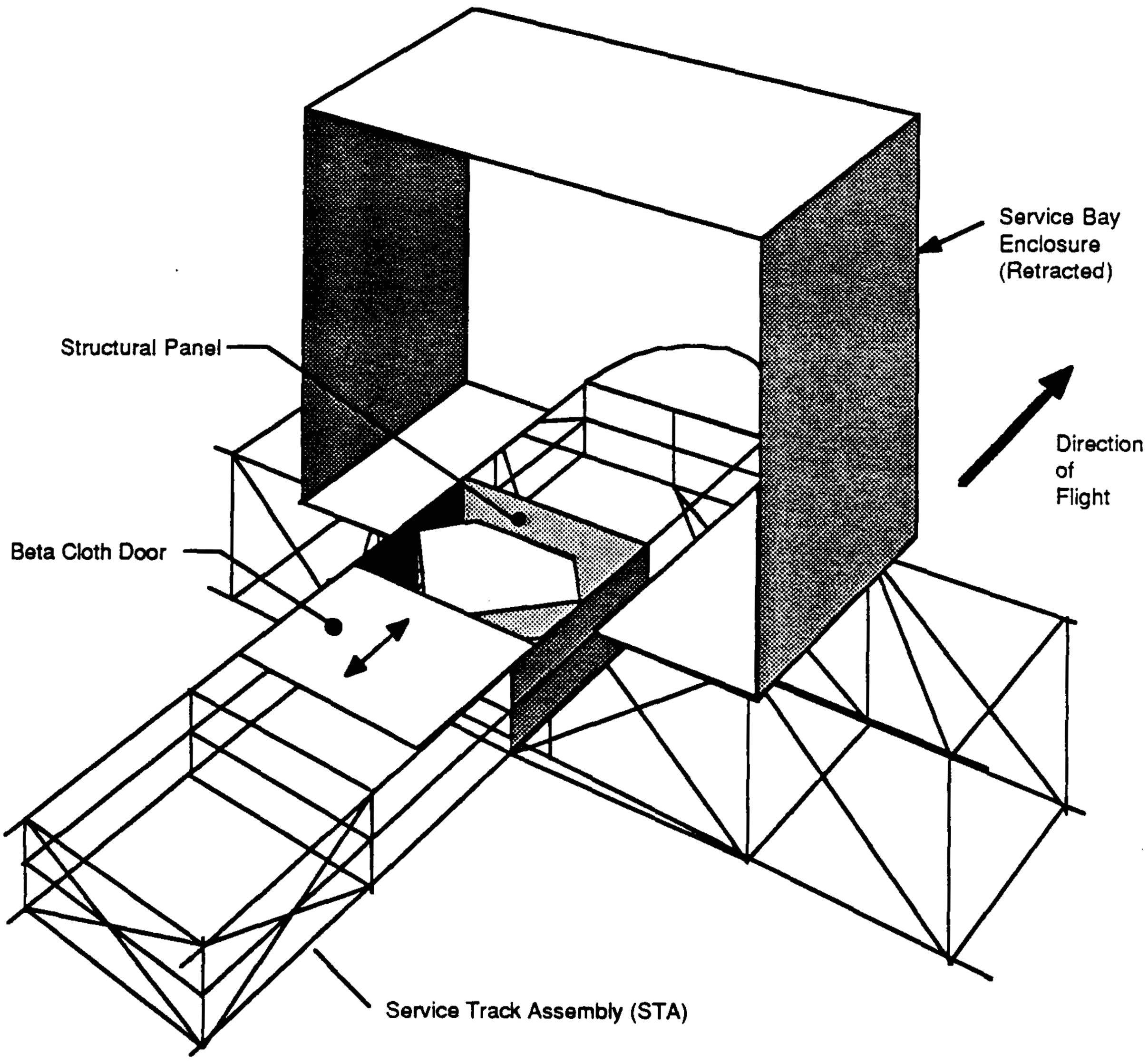



*Figure 4.8.3-3 Meteoroid Protection at the Space Station Customer Service Facility*

Another design requirement relating to debris protection is the requirement to shield potentially explosive containers such that their failure will not propagate to other nearby containers or endanger other Station elements such as the pressurized modules (JSC 3000, Sec 3, Rev D, Para 2.1.11.2.4.1). This requirement could imply that shielding must be provided around each tank to contain fragments caused by tank failure. However, this would, in the case of OSCRS or any other fluid carrier being transported from the ground to the Station on a regular basis, mean a substantial increase in the up/down weight of the system. In order to satisfy this requirement, the possible failure modes of such containers and the probability of each failure mode must be evaluated. Assuming that adequate debris protection is provided, then a pressurized vessel could explode if the internal pressure were to exceed the burst pressure or if a material flaw were undetected and caused the failure. The overpressure failure mode could be guarded against by providing two-fault-tolerant mechanical relief systems (such as burst disks and relief valves). Failure caused by material defect will be guarded against by designing all tanks for leak before burst criteria, meaning that the tank will rupture if overpressurized without catastrophically failing and producing fragments. Both of the above design solutions are requirements listed in the Station PDRD. Therefore, it is felt that the requirement to prevent failure propagation of tanks on the OSCRS could be satisfied by the above means without providing shielding around each propellant and pressurant tank, which would incur a large weight penalty.

## 4.9 INTERFACE ISSUES

Several issues relating to OSCRS interfaces with the Space Station were identified. In the fluid subsystem area, an area of concern is standardization of the fluid connectors between the OSCRS, Space Station, and the spacecraft to be refueled. Accommodation of a wide range of connectors makes the interfaces complicated and difficult to physically attach without several connector mating mechanisms. An additional fluid interface concern is the interface with the Station Waste Fluid Management System arising from the no-vent restriction with the Servicing Facility and the Station in general. As currently defined, the Station waste systems send various waste gases into a common line. Sending the OSCRS waste gas, which would contain some amount of hydrazine vapor, into a common waste gas line could create a safety hazard if not carefully controlled and monitored. Additionally, the waste gas will be compressed for storage for disposal at 14-day intervals. Compression and subsequent heating of the OSCRS waste gas would not be desirable because of the possibility of heating the propellant vapor excessively.

Interface concerns in the structural/mechanical area are associated with the large number of mechanisms that are called out for possible use at the Station. Again, accommodation of all the possible mechanisms would be difficult and would add cost. Standardization of mechanisms between the OSCRS, Shuttle, Space Station, OMV, and spacecraft should occur to narrow the range that OSCRS must accommodate.

The only interfaces to the Space Station that are of concern in the avionics area are the MSC and SFM. The MSC does not provide 28 Vdc power, only 208 Vac 400 Hz; and GSFC does not have OSCRS interfacing to the MSC. GSFC baseline has OSCRS being moved from NSTS to Space Station with the SFM but does not include any electrical interface. If OSCRS is ever required to interface to the MSC or SFM, there must be two-fault-tolerant power and telemetry for safety monitoring and two-fault-tolerant commands if fluid resupply is to take place from the MSC or SFM.

# 5.0 INTERFACES/OPERATIONS WITH OMV

## 5.1 OMV INTERFACES

The OMV is planned to play a major role in future operations involving both the Shuttle and the Space Station. It will be used primarily for the transport of spacecraft and equipment to and from the Shuttle and Station for deployment, resupply, and repair. The baseline TRW design is shown in Figure 5.1-1 and consists of two separable modules, the Propulsion Module and a Short Range Vehicle (SRV). The Propulsion Module has a self-contained bipropellant propulsion system that can be attached to the SRV when required and is designed to be resupplied by on-orbit changeout rather than by fluid transfer. The SRV contains two propulsion systems: a hydrazine system and a cold gas nitrogen system. The cold gas system is used where contamination from thruster exhaust plumes is a concern, such as around the Space Station. Both the propulsion systems on the SRV are designed for on-orbit refueling.

Possible uses of the OMV with OSCRS include transport to the Space Station of the OSCRS from the Shuttle or ELV parking orbit and transport to a spacecraft for in-situ refueling operations. Additionally, the OMV itself could be refueled with hydrazine and nitrogen from the OSCRS either in the Shuttle bay or at the Space Station. The interfaces between the OSCRS and the OMV were investigated to identify potential problem areas and to define requirements for these future operations. The OMV preliminary design documents, References 2 through 4, were the primary source of information for this review. Three major categories of interfaces were examined: fluid, for refueling of the OMV by the OSCRS; structural/mechanical, for attachment of the OSCRS to OMV for transport; and avionics, for monitoring and power purposes. Each of these interface categories is discussed in the following paragraphs.

### 5.1.1 Fluid Interfaces

Fluid interfaces between the OSCRS and the OMV would exist only when the OSCRS was being used to refuel the OMV SRV propulsion systems. For cases where the OMV is transporting the OSCRS, no fluid interfaces would be required or desired. The interfaces would consist of a hydrazine coupling at 400 psia and a cold gas nitrogen coupling at 3600 psia. These interfaces are compatible with the basic OSCRS design and would not have an impact provided a compatible refueling mechanism is used. The OMV design documents listed the hydrazine coupling as a Fairchild coupling used on the Voyager spacecraft and the nitrogen coupling as a Symmetrics MMU coupling.

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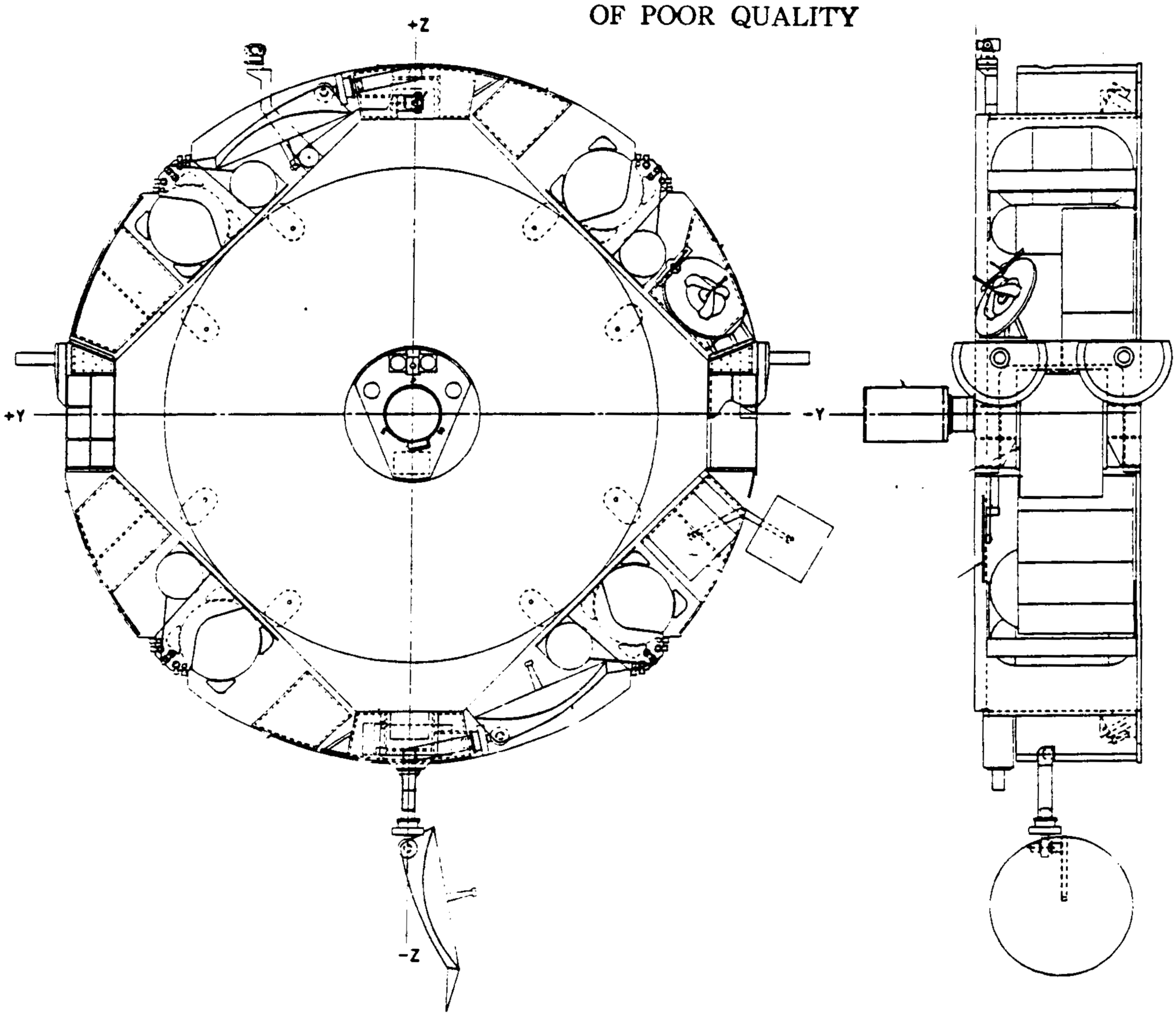


*Figure 5.1-1 OMV Configuration (TRW Drawing)*

### 5.1.2 Structural/Mechanical Interfaces

There are three types of OMV/payload structural/mechanical interfaces applicable to OSCRS that have been proposed by TRW as shown in Figure 5.1.2-1. For attachment of payload directly to the OMV, two rings of bolt holes in the front face of the SRV are provided. One ring is 135 inches in diameter and uses eight bolts to satisfy the load requirement of a 10,000-ft-lb cantilevered payload and a 13,000-ft-lb payload if the OMV propulsion module is attached to the SRV. The second ring is 65 inches in diameter and has four bolt holes but is not designed to support a cantilevered payload during launch. The second type of interface provided by the SRV would allow a payload to be carried in the location usually occupied by the propulsion module; however, this volume is geometrically constrained such that it would be

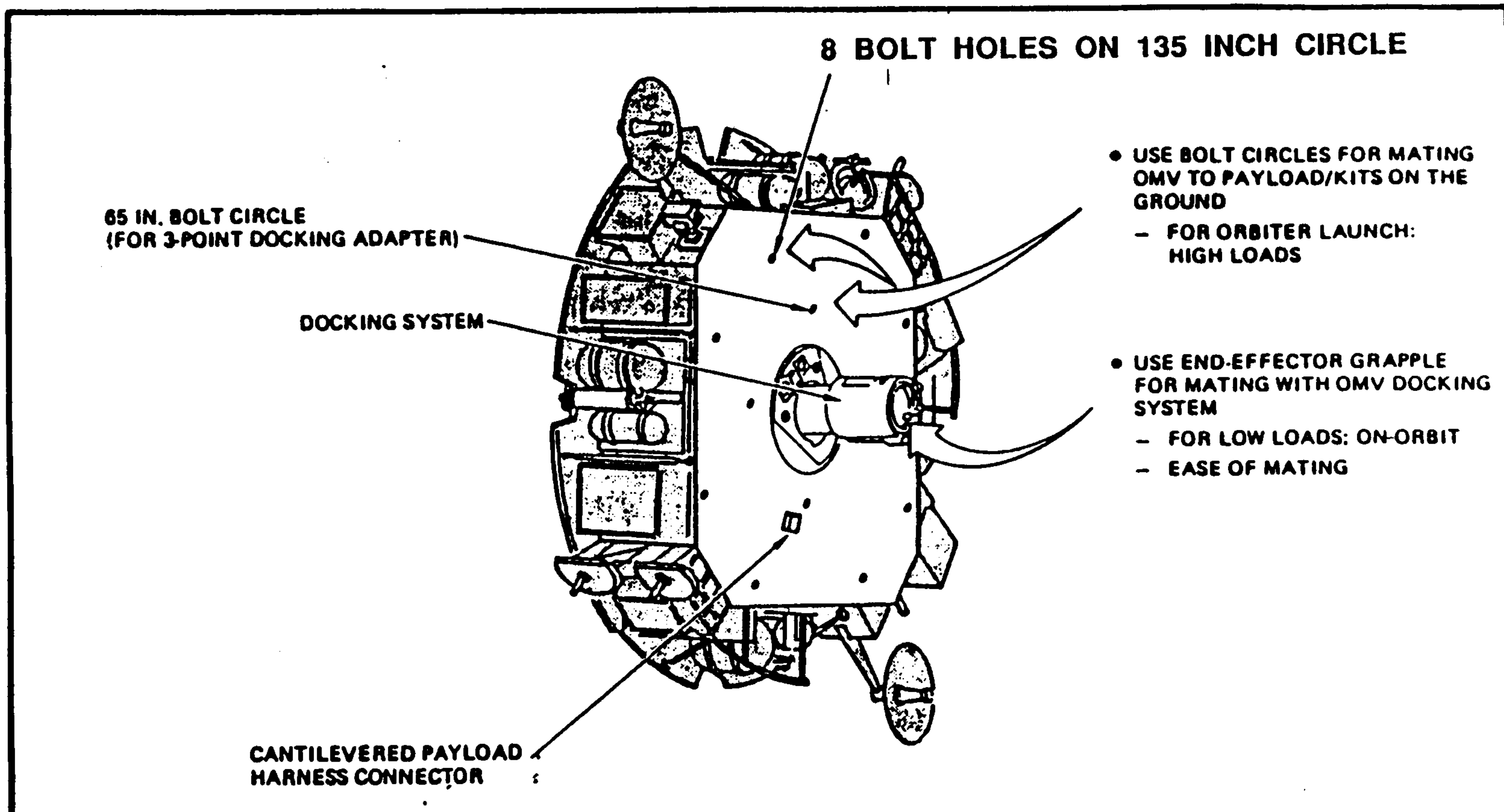


*Figure 5.1.2-1 OMV Structural/Mechanical Interfaces Payload Accommodations Equipment (PAE)*

impractical for OSCRS without significant reconfiguration. The third type of interface involves the use of several types of mechanical docking systems mounted on the centerline of the front face of the SRV. These include a modified SPAR RMS end effector called the RMS Grapple Docking Mechanism (RGDM), which interfaces with a standard grapple fixture, and the Three Point Docking Mechanism (TPDM).

The RGDM can be extended 27.5 inches and retracted into the face of the SRV by a three-screw mechanism. The TPDM, shown in Figure 5.1.2-2, consists of a structural ring interface with three FSS latches for docking equipped with FSS-compatible fittings on a 72-in.-diameter circle. Both docking mechanisms have television, lights, and a payload electrical umbilical. The impacts to OSCRS of interfacing with this set of mechanisms will be discussed in Section 5.2.2.1.

### 5.1.3 Avionics Interfaces

OMV will provide an interface to its data system for payloads to receive commands and send data to the ground control station. The payload interface to the Multiplexed Data Bus (MDB) is via an RIU, which the payload must provide on the payload side of the interface. The OMV provides one-fault-tolerant power to payloads with 5 kWh of 28-Vdc power as standard (1-kW peak) and has an optional battery pack kit that can provide 56.3 kWh at 1.8-kW peak.

## 5.2 OMV OPERATIONS

### 5.2.1 OMV Refueling using OSCRS

The current OMV design consists of two separate propulsion modules, a replaceable bipropellant module and an SRV containing a hydrazine and cold gas nitrogen propulsion system. The SRV is designed to have its hydrazine and cold gas nitrogen propulsion systems refueled on-orbit. There are four RCS modules located on the quadrants of the vehicle, and each contains a hydrazine storage tank using a diaphragm for propellant expulsion and a cold gas nitrogen storage tank. The hydrazine tanks are manifolded together to facilitate on-orbit refueling as shown in Figure 5.2.1-1. A single refueling coupling, a Fairchild Voyager quick disconnect, allows refilling of all four tanks via the RCS manifold. The cold gas nitrogen system, however, has a separate quick disconnect (made by Symmetrics and used on the Manned Maneuvering Unit) for each module, requiring four mate/demate operations to recharge all four N2 tanks. The layout of each RCS module is shown in Figure 5.2.1-2 taken from Reference 3. The total quantity of hydrazine is 1020 lb at 400-psia storage pressure at the start of blowdown. The N2 quantity is 130 lb with a 3600-psia operating pressure.

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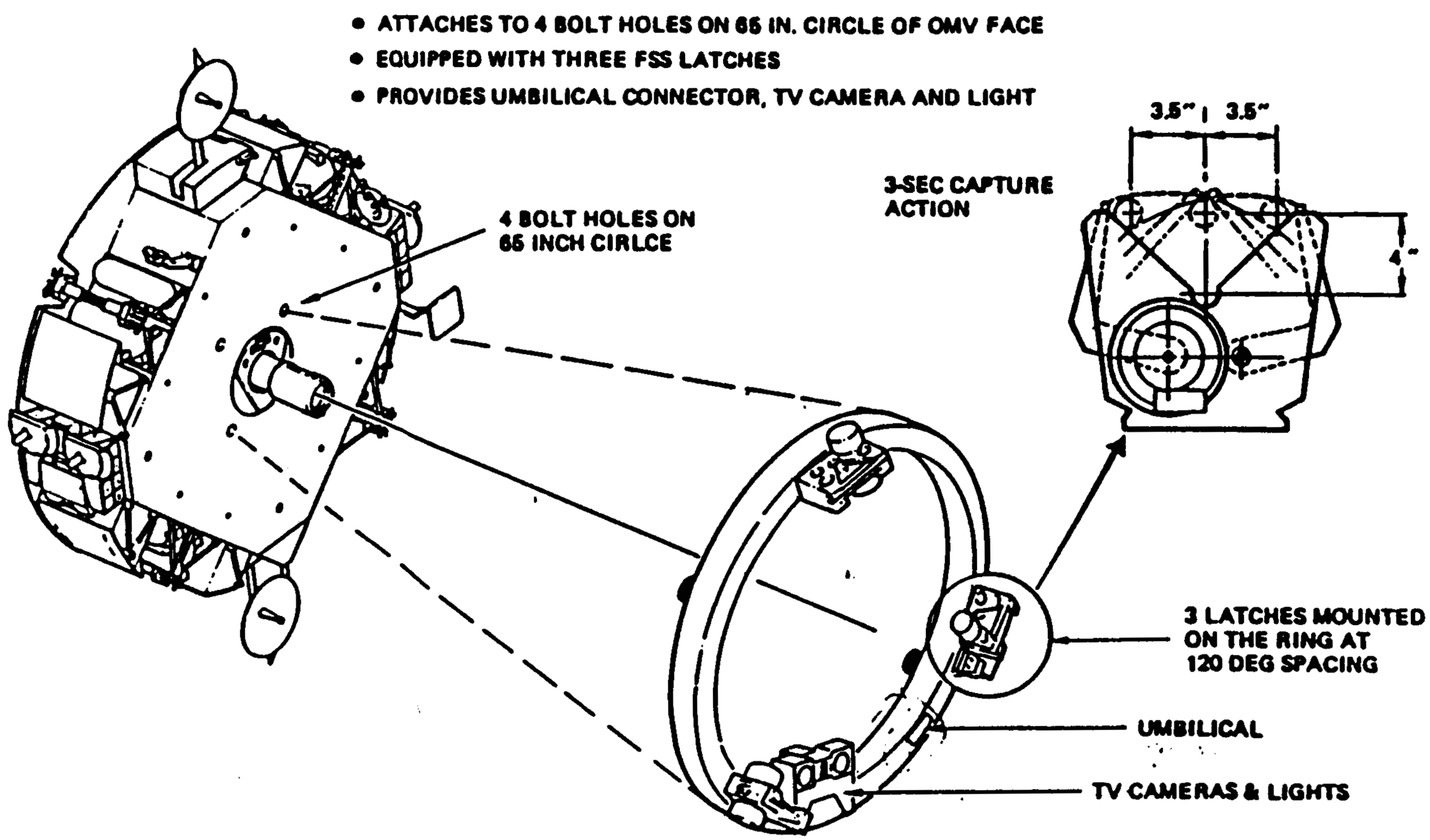
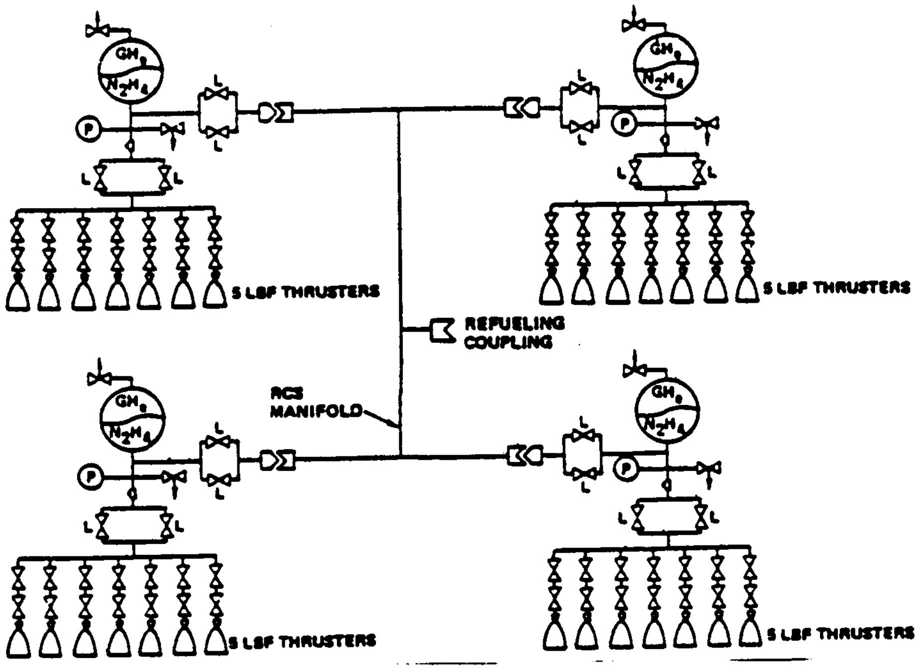


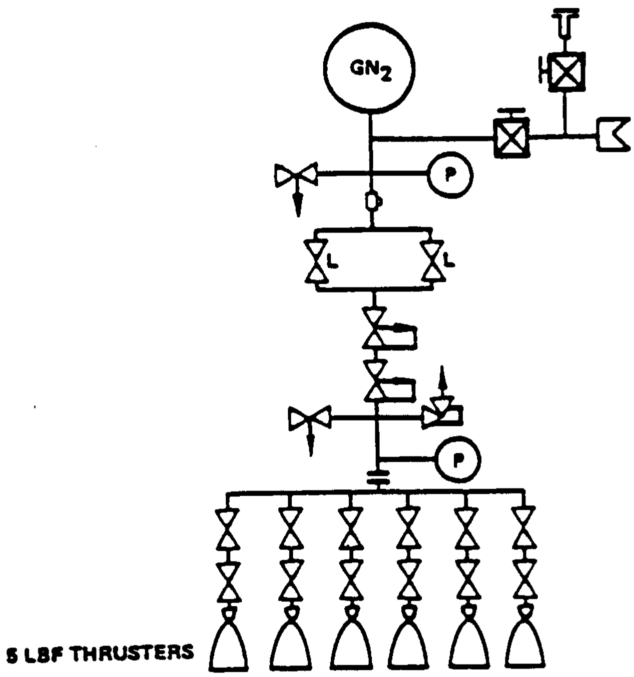

THREE POINT DOCKING MECHANISM (TPDM)

* FROM OMV PRELIMINARY DESIGN DOCUMENT, NAS8-36114 AUGUST 30, 1985

*Figure 5.1.2-2 OMV–Payload Accommodations Equipment (PAE)*




HYDRAZINE




RCS (TYPICAL 4 PLACES)

COLD GAS N2

*Figure 5.2.1-1 OMV RCS Schematics*

**REF: NAS8-36114: PRELIMINARY DESIGN DOCUMENT, BOOK 2; 8/30/85; TRW**

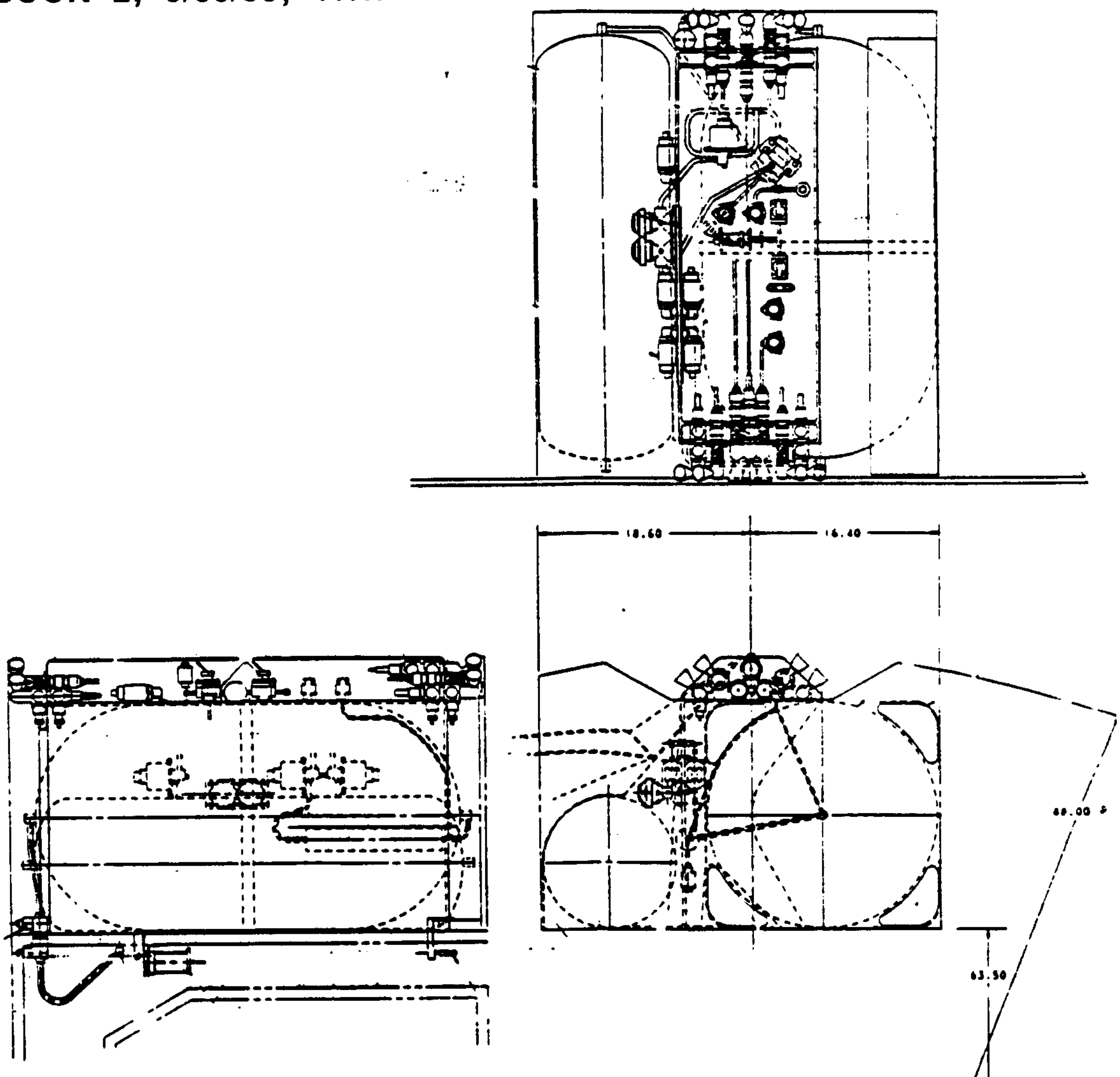


*Figure 5.2.1-2 OMV RCS Layout*

As currently designed, the OMV is not compatible with the basic OSCRS because it does not use the Fairchild EVA disconnect as does the Gamma Ray Observatory. The propellant and gas couplings on the SRV are not located together to allow a single mate/demate operation. Five such operations would be required, one propellant and four gas connections, which result in complicated operations. Neither the propellant coupling nor the gas couplings are located on the front of the SRV, which makes adaptation to automatic refueling difficult without redesign. To simplify the OSCRS/OMV interfaces and refueling operations, the following changes to the OMV Short Range Vehicle are recommended:

1. Manifold the nitrogen cold gas propulsion system to reduce the number of connectors from four to one.

2. Locate hydrazine, nitrogen, and electrical connectors in one location where they would be accessible by an umbilical mating mechanism.

3. Scar the SRV to provide umbilical mating on the front face to facilitate refueling using an automatic connector.

## 5.2.2 OMV/OSCRS Interface Impacts

### 5.2.2.1 Structural/Mechanical Interface Impacts

The structural and mechanical interfaces provided by the OMV will require design changes to the basic OSCRS. If it is desired to launch the OSCRS attached to the OMV, then the 135-in.-diameter bolt interface must be used. This interface is shown superimposed on the basic OSCRS in Figure 5.2.2.1-1 and on the modular OSCRS in Figure 5.2.2.1-2. For either a basic or modular monopropellant OSCRS, the cg would be located 1.5 feet from the OSCRS/OMV interface plane. The maximum load that could be accommodated by the OMV interface with this configuration is 6,667 lb, meaning that the OSCRS would be limited to a three- or four-tank configuration. For a heavier OSCRS, the OMV attachment would have to be made on-orbit either in the Shuttle

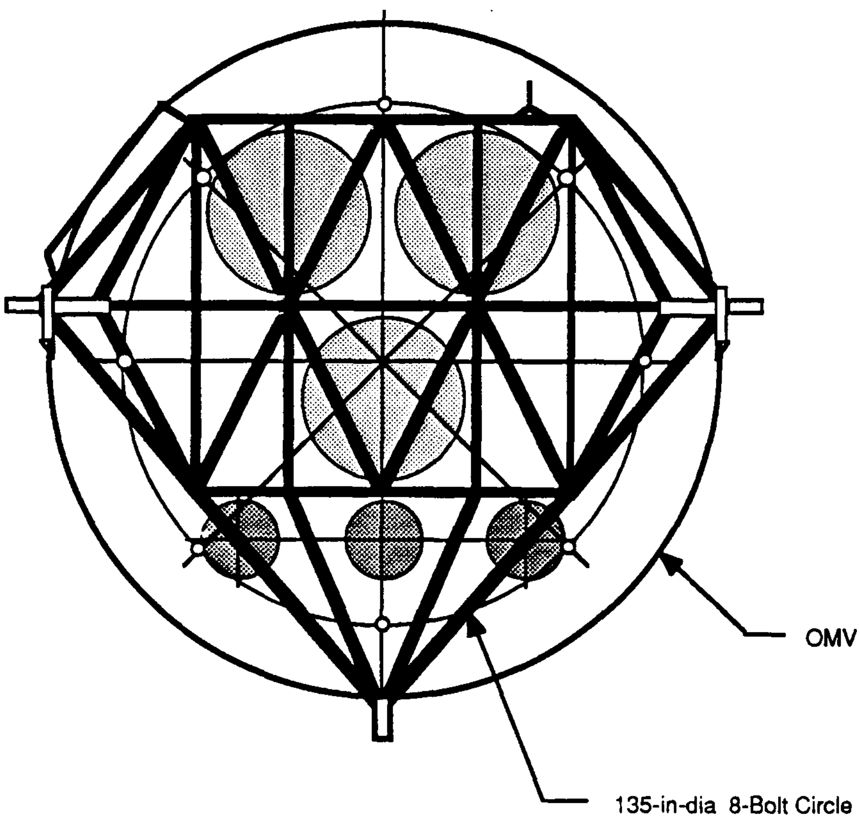



*Figure 5.2.2.1-1 Basic OSCRS-OMV Interface*

payload bay or at the Space Station with the payload accommodations equipment supplied by the OMV and mating hardware supplied by the OSCRS. Fittings for tension bolt and shear pin attachment would have to be bolted to or built to the OSCRS structure, and an interface adapter would be required to transfer the loads from the eight-bolt pattern to the node or tie-down points on the OSCRS.

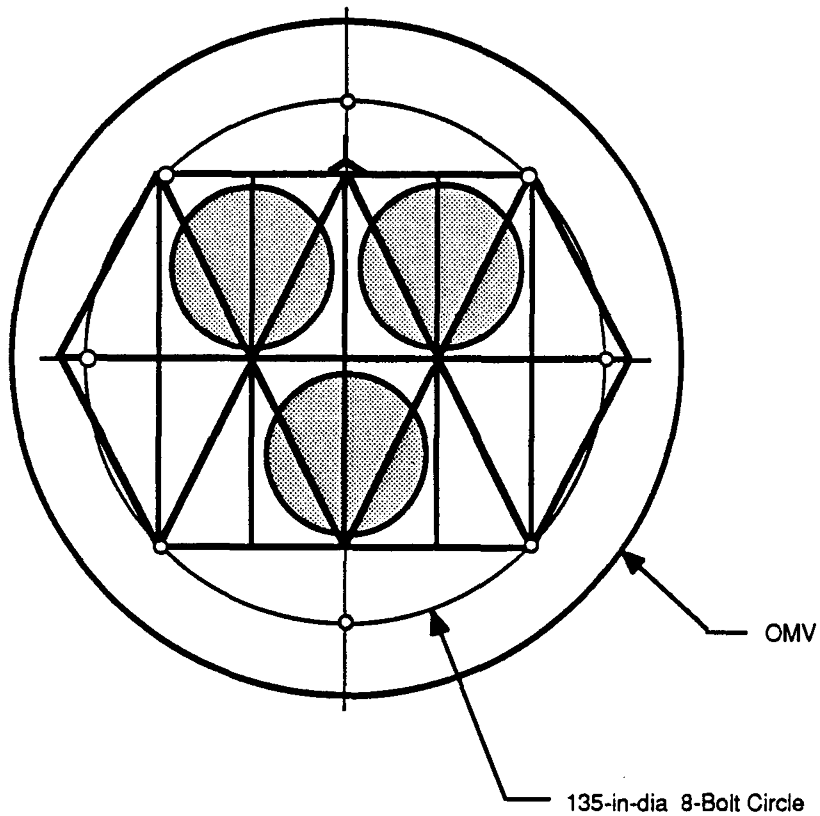



*Figure 5.2.2.1-2 Modular OSCRS-OMV Interface*

The RGDM can be used to mechanically attach the OSCRS to the OMV and has the advantage of being able to accommodate any of the OSCRS configuration options provided a standard grapple fixture is attached to the aft side of the OSCRS.

5.2.2.2 Avionics Interface Impacts

The latest cost estimates for each RIU is $90K-200K, depending on the set-up charges, because the RIUs are not currently in production. To avoid each OMV user's buying and placing RIUs on his own hardware, it would seem to be more efficient to put the payload RIUs on OMV even though the connector interface is more complex. The other option is to have the RIUs be government furnished equipment (GFE), but this still requires each payload to accommodate the RIUs on its hardware. The OMV data system contains only two MDBs; therefore it is only one-fault tolerant, which does not meet OSCRS needs. This assumes OSCRS can put an RIU on each of the MDBs; if OSCRS can use only one RIU, then the interface is zero-fault tolerant. The serial digital command and data streams into and out of the RIU are not a standard format such as RS422 or 1553 and will require OSCRS to provide serial channels that meet the required format. This could be accomplished by adding a card to each Southwest Research Computer on OSCRS.

The OMV documentation does not show any command or data storage device, such as a tape recorder; therefore all commands and telemetry must be accomplished in real time.

There is a problem with the amount of power redundancy provided by CMV to the payload. Figure 5.2.2.2-1 shows a block diagram of the OMV/OSCRS data system and power interface.

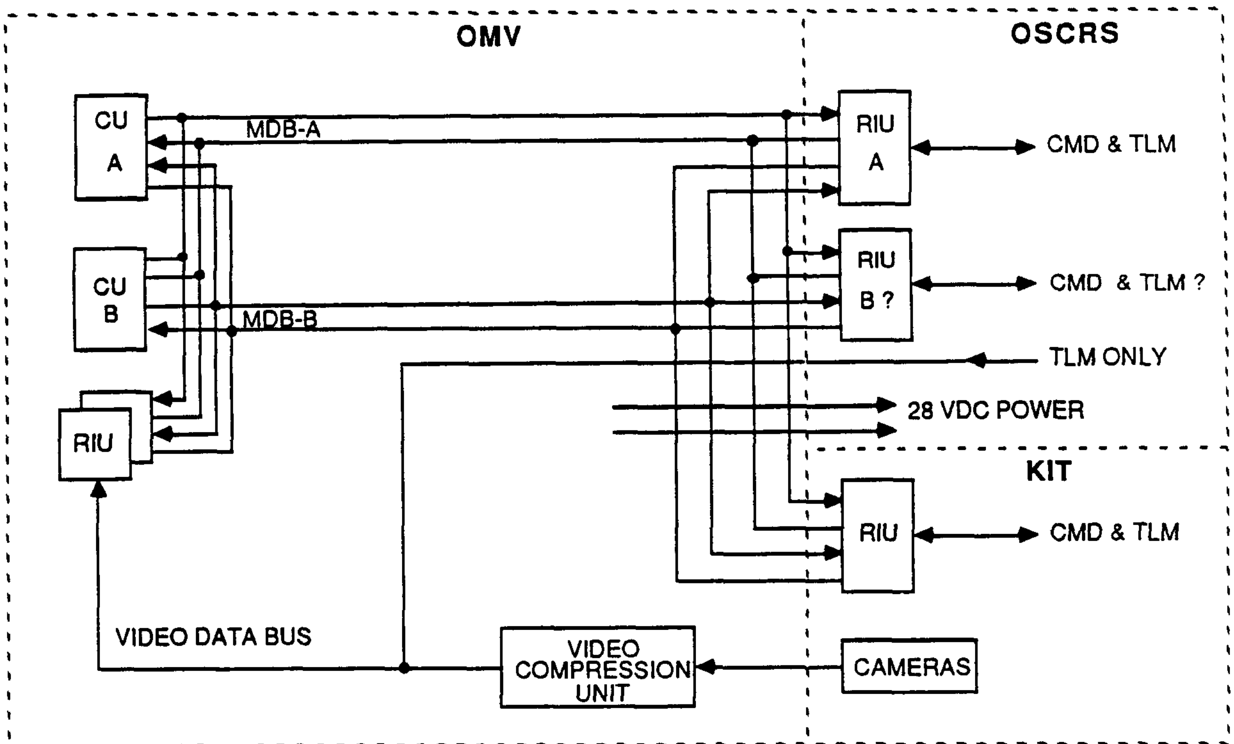



*Figure 5.2.2.2-1 OSCRS-to-OMV Avionics Interfaces*

The OMV should not be required to provide the capability of running any special software for OSCRS, because the OMV should be only a relay station for commands and telemetry. OMV will be putting commands into OSCRS and receiving data from OSCRS essentially the same as NSTS, except that the OSCRS AFD equipment is needed to provide an operator interface and will not be required for OMV missions.

# 6.0 AUTOMATIC REFUELING

The objective of this part of the study was to develop a more in-depth understanding of automatic refueling at the Space Station, from the STS, and remote operations from the OMV and to provide recommendations for future work.

Automatic refueling of a spacecraft from OSCRS involves a sequence of complex functions involving docking, berthing, umbilical mating, propellant transfer, and release. Docking at the STS orbiter is accomplished by the orbiter RMS. Docking at the Space Station will most likely be performed by the Space Station RMS or the SBM. For in-situ refueling, either from the OMV or the OTV, a docking device must be attached to the OSCRS structure. At all locations, a mechanism on OSCRS will be required to attach the satellite to OSCRS and hold it in place so that umbilicals can be mated. This can be accomplished with a standard berthing mechanism, such as the FSS latches, with a modified end effector design or with a device which incorporates berthing with umbilical mating. For in-situ refueling it could be the same mechanism used for docking. Once the satellite is attached, an automated mechanism is required to mate umbilicals to enable refueling and to demate these umbilicals to release the satellite after refueling and safing. For this report, this device, which mates and demates umbilicals, will be generically refered to as an automated umbilical mechanism (AUM). Two existing AUMs will be examined in Section 6.2.

In future spacecraft, it may be desirable to have a single combined mechanism for docking and umbilical mating because both mechanisms have common functions. However, there may be spacecraft that have hardware to enable attachment of separate docking mechanisms, such as the FSS latches, the PRLA, or modified RMS end effectors, which may also require automatic refueling. Therefore, we must consider separate AUMs for these applications. Automatic refueling will require specific definition and standardization of interfaces in order to keep the mechanisms as simple as possible.

This report will define requirements for automated OSCRS-to-satellite refueling from the Orbiter bay, at the Space Station, and in-situ; study mechanisms now available and compare them to these requirements; and make recommendations about how to proceed with mechanism development. The development of requirements is an iterative process, particularly in preliminary design. As the preliminary design is developed, requirement allocations should be challenged.

Our approach to this study is as follows:

1) Define requirements, desired features, and assumptions;

2) Define design drivers;

3) Study existing prototype mechanisms and define the changes necessary to meet the requirements;

4) Recommend an approach for the development of automatic refueling which will meet all the requirements.

## 6.1 REQUIREMENTS

### 6.1.1 General Design Requirements

The first step in the evaluation of AUMs for use with OSCRS was a definition of the requirements. This definition is dependent on where the refueling operation will take place; however, there are general requirements that will apply to the AUM regardless of where the device will be used with OSCRS. These requirements were identified and are described in this section. Requirements specific to the location where OSCRS is being used (i.e. Shuttle, Space Station, or OMV) will be described in subsequent sections.

The intent of the requirements development was to establish a baseline set that could be used to determine general design features of an AUM. This definition effort is iterative, and the requirements put forth here are preliminary in nature. These requirements were also developed considering the overall system operation, not just those of the AUM. Many of the requirements, particularly safety, can be more efficiently addressed at a system level rather than a component level. Additionally, the requirements were defined considering only a refueling operation, not considering a mission where refueling and servicing are combined. Missions where it is desirable to combine refueling with servicing could result in different requirements being placed on the design of the AUM, particularly if both the docking and refueling functions are combined into a single mechanism.

Groundrules were established to aid in the derivation of the requirements. It was assumed that, regardless of the location, an EVA astronaut would not be required for any phase of a normal OSCRS mission involving automatic refueling. The AUM design would be designed to be as simple as possible, and only in a contingency situation would any astronaut involvement be required. Similarly, it was assumed that the use of a Flight Telerobotic Servicer (FTS) would not be required during normal operations but could be used in a contingency to take the place of an EVA astronaut.

General requirements were developed by reviewing Shuttle, OSCRS, Space Station, and OMV design documents. The results are presented in Table 6.1.1-1 along with the source of the requirement. A requirement identified was the need for the AUM to accommodate up to seven connectors for a typical refueling mission on OSCRS. Two gaseous and two liquid connectors would be required for single-fault tolerance, and three electrical connectors would be required to provide two-fault tolerance for safing the spacecraft system. The connectors' capabilities were derived based on previous OSCRS experience and

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 1. | No two credible failures shall result in personal injury, loss of life, STS, OMV, or Space Station. | 12<br>11 | 3.2.3(2)<br>2.1.10.A.1 |
| 2. | Thermal control shall be a minimum of two-failure tolerant to protect safety-critical hardware from critical temperature limits. Hydrazine temperature shall be maintained at +40-+120°F (+4-+49°C). | 9 | 3.3.3.1.a |
| 3. | The AUM shall accommodate up to seven connectors, three electrical, two gas, and two propellant, with the following capabilities: hydrazine at 500 psi and 2 gallons-per-minute flow rate; gaseous nitrogen at 500-5000 psi and 100 lbs-per-hour flowrate; gaseous helium at 500-5000 psi and 8 lbs per hour. | Derived<br><br>9 | <br><br>3.3.4.2.i&h |
| 4. | The AUM shall, as a design goal, meet the following envelope to permit mounting on either the front face or top face of OSCRS: 24.0-in. diameter and 30.0-in. length. | Derived | |
| 5. | The AUM shall provide the following connector alignment tolerances during operation:<br>Axial (in.) 0.1<br>Lateral (in.) 0.1<br>Angular (deg) $\pm$ 1.5°<br>Rotary (deg) $\pm$ 0.4° | Derived | |
| 6. | The AUM flight configuration shall not exceed 30 lb (excluding connectors). | Derived | |
| 7. | The AUM shall be two-fault tolerant for providing power, command, and telemetry interfaces to the spacecraft. As a minimum, a single string electrical interface connector shall provide 9-10 gauge, 40-16 gauge, and 27-20 gauge wires or equivalent. | 9<br><br>Derived | 3.3.5.1.k |

Table 6.1.1-1 General Requirements for an OSCRS Automated Umbilical Mechanism

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 8. | Propellant connectors shall be two-fault tolerant to fluid leakage when mated. They may be zero-fault tolerant to fluid leakage when demated if the fluid system provides two inhibits upstream to shut off fluid flow. | 9 | 3.3.4.1.a |
| 9. | No single failure shall produce loss of OSCRS, or OSCRS mission, OSCRS payload, STS mission, OMV, OMV mission, or Space Station mission. | 12 | 3.2.3(1) |
| 10. | Provisions shall be made to accommodate sticking connectors during both mating and demating. | Derived | |
| 11. | The AUM shall accommodate OSCRS fluid resupply of a satellite from the orbiter payload bay, at Space Station, or attached to the OMV or the OTV for remote servicing and shall meet the specific requirements at each of these locations. | Derived | |
| 12. | Interfaces shall be standardized for compatability with the STS, Space Station, OMV, and satellites to be refueled. | Derived | |
| 13. | The AUM shall place minimum weight volume and complexity requirements on the spacecraft connector receptacle assembly. The active side of the AUM shall be located on the OSCRS with the passive half on the spacecraft. | 9 | 3.3.2.3.b |
| 14. | The AUM shall provide EVA override capability by both an astronaut and a robotic servicer. | 11 | 2.1.2.4.3.4 |
| 15. | The system shall be designed to preclude inadvertant or improper connector mating. | 9 | 3.3.4.1.p<br>3.3.5.1.m |
| 16. | Contamination protection shall be provided for all umbilicals on both sides of the AUM. This protection shall be replaceable for multi-mission flights. | Derived | |
| 17. | Sufficient diagnostic instrumentation shall be provided on the OSCRS half of the AUM to determine the mode of failure should an on-orbit failure occur. | 10 | 3.4.14 |

Table 6.1.1-1 (cont) General Requirements for an OSCRS Automated Umbilical Mechanism

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 18. | The AUM shall use previously flight-certified hardware where practical. If flight-certified hardware is not available, flight certification of commercial hardware with extensive service history shall be considered. | 9 | 3.3.4.2.g |
| 19. | The number of pyrotechnic events shall be minimized and, if possible, eliminated. Pyrotechnic devices shall be removable or made inoperable when mission requirements allow. | 10<br>11 | 3.4.2.3<br>2.1.11.2.9 |
| 20. | The AUM shall be designed so that forces between it and the mating spacecraft are minimized or eliminated. | Derived | |
| 21. | The AUM shall be designed for a life of 10 years (approximately 80 mission cycles), with maintenance. The AUM shall be maintainable on the ground. | 12 | 3.2.1.1(3) |
| 22. | The AUM shall be designed to accommodate repeated operations during a single mission. | Derived | |
| 23. | The AUM shall be capable of being mounted on either the top or front face of OSCRS and be easily removable/relocatable to optimize OSCRS weight and envelope. | 9 | 3.3.2.3.b |
| 24. | The location of the AUM on the OSCRS structure shall be compatible with all ground handling, processing, and transport operation constraints. | Derived | |
| 25. | The AUM shall be modifiable for use in a bipropellant system. | 9 | 3.3.4.2.a |
| 26. | All moving metal parts of the mechanism assembly shall be grounded to OSCRS structure to minimize charge buildup in space and shock hazards on the ground. | 10 | 3.4.6 |
| 27 | The AUM shall provide for electrical connector mating prior to fluid connector mating. | Derived | |
| 28 | The AUM shall accommodate connectors that mate/demate by translation only. | Derived | |

Table 6.1.1-1 (cont) General Requirements for an OSCRS Automated Umbilical Mechanism

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 29. | The AUM shall be activated/deactivated by a 28±6 Vdc, TBD Ampere power source. | Derived | |
| 30. | The power supplied to the AUM shall be fused at the source. | Derived | |
| 31. | The AUM shall be designed for the following environments:<br>a. Ferry Flight (atmospheric)<br>1. Temperature: With no hydrazine loaded: Maximum (compartment): 190°F (88°C) for one hour; 150°F (65°C) for 6 hours. Minimum: -65°F (-54°F) With hydrazine: Maximum: 122°F (50°F) Minimum: 40°F (4°C)<br>2. Pressure: Maximum: 15.23 psia (105.1 kN/m²) Minimum: 8.0 psia (55.2 kN/m² (Rate of depressurization 0.5 psi/min (3.5 kN/m²/min); rate of repressurization 2.0 psi/min (13.8 kN/m²/min))<br>3. Acceleration: ± 2.4 g in any direction (maneuvering)<br>4. Random Vibration: Acceleration spectral density: + 6.0 dB/Oct, from 20 to 90 Hz Constant 0.002 g²/Hz, from 90 to 300 Hz 6.0 dB/Oct, from 300 to 2000 Hz (10 hours duration in each of the three orthogonal axes)<br>b. Ascent/On-orbit:<br>1. Thermal: Per JSC 07700 (Vol XIV), Attachment 1<br>2. Pressure: Maximum: 15.23 psia (105.1 (kN/m²) Minimum: 1x10¹⁰ torr. (1.3x10⁻¹¹ kN/m²) (Rate of depressurization 15.4 psi/min. (106.3 kN/m³); rate or repressurization 10.0 psi/min (69 kN/m³)<br>3. Solar Radiation: As specified in JSC 07700 (Vol XIV) | 12 | 3.2.7.1 |

Table 6.1.1-1 (cont) General Requirements for an OSCRS Automated Umbilical Mechanism

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| | 4. Shock Transient Vibration: Swept sinusoidal vibration environment imposed in the frequency range from 5-50 Hz at an acceleration amplitude of plus and minus 0.25g peak in each axis.<br>5. Acceleration: Per JSC 07700, Vol XIV, Attachment 1<br>6. Random: Per JSC 07700, Vol XIV, Attch. 1<br>7. Acoustic Vibration: Per JSC 07700, Vol XIV, Attachment 1<br>c. Entry and Landing<br>1. Thermal: Per JSC 07700, Vol XIV, Attch. 1<br>2. Pressure: Maximum: 15.23 psia (105 $kN/m^2$)<br>Minimum: $1x10^{-10}$ torr ($1.3x10^{-11}$ $kN/m^2$)<br>3. Acceleration: Per JSC 07700, Vol XIV, Attachment 1<br>4. Vibration: Per JSC 07700, Vol XIV, Attachment 1<br>5. Crash Safety: Per JSC 07700, Vol XIV, Attachment 1 | | |
| 32. | The emergency jettison capability shall be designed to maximize the probability that the satellite will be jettisoned in a flyable condition/configuration and will be able to complete its mission. | 9 | 3.3.2.3.d |
| 33. | The TCS heater system will be controlled by thermostats rather than through the instrumentation system. | 9 | 3.3.3.2.a |
| 34. | Specific propellant compatibility data shall be required on all materials used in the fluid subsystem unless the materials are isolated from the propellant by weld seals or they are external to the fluid. | 9 | 3.3.4.1.c |
| 35. | The AUM design shall exhibit no external leakage of liquid propellant during any normal operational use or as the result of exposure to ground, storage or flight environments, whether operating or static for the life of the system. Gas leakage shall not exceed 1.4 x $10^{-4}$ SCCS of helium for mechanical connections. | 9 | 3.4.2.5 |

Table 6.1.1-1 General Requirements for an OSCRS Automated Umbilical Mechanism (concl)

represent a range of flowrates that would be required. Requirement 4 defines a preliminary envelope for the AUM which would allow mounting on either the top face or front face of the OSCRS. This envelope was arrived at by examining the dimensions of prototype umbilical mechanisms that have been designed. Requirement 5 defines tolerances for the AUM for connector mating operations. As with the envelope definition, the capabilities of existing prototype automatic umbilical mechanisms were used as a guideline. The requirements for the electrical connector used in the AUM are defined in requirement seven. The number and gauge of the wires that must be accommodated were arrived at by estimating the number of valves and other components that must be controlled in both the OSCRS and a spacecraft to allow reconfiguration and safing. Requirement 8 deals with leakage during mating and demating of fluid connectors. Implicit in this requirement is the capability to leak-check disconnects to ensure that a good connection exists and that the seals are intact. Additionally, purging of the liquid connector to ensure zero spillage upon disconnection is also implied. This requirement, in general, could be eased in the case of an AUM where crew involvement is not desired or planned or where the system leakage could be limited by an overall system approach. Valving placed close to the disconnect would limit the amount of propellant spilled if a seal were to be damaged. The AUM could be designed such that the spilled volume resulting from a seal failure would be such that it would not constitute a hazard to the spacecraft, OSCRS, or an EVA crew member.

Requirement 13 states that the spacecraft half of the AUM should be the passive half to minimize impacts to the spacecraft. The active side of the AUM, which would contain the drive mechanisms, etc, would be located on the OSCRS. The capability to provide override capability by an EVA astronaut or a robotic servicer would be for contingency operations only. For refueling on the Shuttle, Space Station, or in-situ using the OMV, either an astronaut or a robotic servicer would likely be present. Requirement 20 states that the forces between the AUM and the spacecraft are minimized during mating. This would require that connector mating/demating loads be reacted through a latch or latches, either at the connectors or at a separate latch interface. These loads, especially for high-pressure gas connectors, should not be reacted at the berthing or docking mechanism interfaces. Self latching, high pressure gas disconnects should be designed to minimize axial forces which result from internal pressures to help reduce the load at a common latch. If each high-pressure gas connector is required to latch upon mating, a remotely operated latching/unlatching mechanism, which will add complexity to the AUM, will be required. This mechanism would most likely have to provide a translation motion to a single part of the connector independent of the connector assembly to perform the latching or unlatching task. It would be preferable to react the loads from the high-pressure gas connectors at a latch interface that provides alignment and, in the case of a combined docking and umbilical mating mechanism, a hard dock between OSCRS and the satellite. The allowable misalignment between connector mating

C-2

assemblies and individual connectors, the required connector mating and uncoupling force, and the required inches of travel for connector mating are all dependent on the specific connector used. However, in order to simplify the design of the AUM, Requirement 28 was added to limit the connectors to those types that are mated and demated by translation, not rotation.

### 6.1.2 AUM Requirements Unique to Shuttle

An evaluation of the unique requirements for the operation of an AUM in the Shuttle payload bay was performed to determine if there were any unique requirements that could drive the design. The results, listed in Table 6.1.2-1, indicated that there are no real Shuttle design drivers that would significantly impact the AUM design that are not accounted for in the general requirements table. The only unique requirement that could be identified was the requirement to satisfy the Orbiter payload bay envelope during refueling operations in the payload bay and the requirement that the design be capable of accommodating different satellite docking mechanisms in the physical constraints of the payload bay. An additional requirement is the capability to provide two-fault tolerance for emergency jettison of the spacecraft in the payload bay. This was not listed in the general requirements because it would not be feasible to perform this operation inside the Station Servicing Facility.

### 6.1.3 AUM Requirements Unique to Space Station

Requirements for an AUM that are unique to Space Station were compiled by reviewing several Space Station documents, in particular the Space Station Program Data Requirements Document (PDRD). The results are shown in Table 6.1.3-1. Although OSCRS is not part of the Space Station program and hence not a program element, it will operate and be stored at the Station for extended periods of time, therefore, the Station requirements must be satisfied. The most significant difference is that, unlike the previous requirement for an OSCRS used on the Shuttle, use of an AUM is a requirement for Space Station.

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 1. | OSCRS and associated ASE shall conform to the orbiter payload bay envelope as defined in JSC 07700, Volume XIV. The OSCRS shall be compatible with all ground handling, processing and transportation operation constraints. | Systems Require-ments Docu-ment for OSCRS Rev. A, Oct. 85 | 3.2.2 |
| 2. | In the event a customer elects to provide docking facilities separate from OSCRS, unnecessary docking hardware shall be easily removeable to optimize OSCRS weight and envelope. | | 3.3.2.3.a |
| 3. | The OSCRS docking structure and mechanism shall be modifiable to provide optimum accommodations for a reasonable range of satellite envelopes and masses. | | 3.3.2.3.a |
| 4. | Provide emergency two-failure operational jettison of spacecraft when refueling from the orbiter bay. The satellite shall be able to complete its mission after jettison. | | 3.3.2.3.d |

Table 6.1.2-1 Requirements for OSCRS AUM on the STS Orbiter

| No. | Requirement | Reference Document | Paragraph Number |
|---|---|---|---|
| 1. | Hazardous fluids shall be replenished using remotely operated equipment with manual over-rides. | NSTS 07700 Vol. XIV Revision 1 | 2.1.2.4.3.4 |
| 2. | The AUM shall be designed to meet all performance requirements for operation in the natural environment conditions, e.g., orbital density and composition, plasma. Charged particle and electromagnetic radiation, meteoroids and space debris, magnetic and gravitational fields, thermal, pressure and physical constants, etc., as prescribed in JSC 30000, Section 3, Appendix A, natural environment definition for design. | | 2.1.3.1 |
| 3. | No equipment, material, or consumable transported to an orbiting SSPE shall be reconfigured erected, or otherwise operated upon in a manner that prevents it from being returned to a condition (size, packaging, steady-state, nonvolatile, etc.) suitable for safe return to Earth or for controlled and safe jettison from the Space Station. | | 2.1.4.3.2 |
| 4. | SSPE's shall employ common hardware, software, and standard interface to the maximum beneficial extent. Modification of the SSPE or its subsystems shall maintain hardware and software commonality. | | 2.1.5 |
| 5. | SSPE design shall minimize the need for ground control and support of operational functions in favor of onboard autonomy. | | 2.1.7 |
| 6. | Robotic devices shall be designed to accept contingency hold and emergency stop commands issued by the EVA and IVA crewmembers. | | 2.1.8.1.5 |
| 7. | Safety and reliability programmatic requirements shall be as specified in JSC 30000, Section 9, product assurance requirements. | | 2.1.10 & 11 |
| 8. | The AUM shall meet the requirements for hazardous materials, flammability and outgassing as specified in JSC 20149. | | 2.1.11.3 |

Table 6.1.3-1 Requirements for OSCRS AUM at the Space Station

### 6.1.4 AUM Requirements Unique to OMV

The use of OSCRS with an OMV for in-situ satellite refueling would necessitate the use of an AUM. The TRW OMV Preliminary Design Documents and Payload Accommodations Equipment documents (References 2, 3, and 6) were reviewed to develop specific requirements for this application. It was assumed that OSCRS interface to a spacecraft would have to be compatible with the OMV payload accommodations equipment (PAE) requirements.

One of the requirements for the OMV PAE is that at a minimum it shall provide electrical and mechanical interfaces to dock with a payload grapple fixture as defined in ICD-2-1-19001 and a system compatible with the FSS berthing and positioning system as defined in MMS Flight Support System Users Guide, GSFC 408-2112-0004. If this is a requirement which must be extended to OSCRS, then the AUM would have to be compatible with both grapple fixture and FSS latch interfaces. For compatibility with a spacecraft which provides a grapple fixture for docking, it is likely that either a modified end effector would be mounted on OSCRS front face with the AUM alongside, or the AUM would be incorporated into the end effector. To be compatible with an FSS latch interface, the AUM could be located anywhere on OSCRS front face, preferably within the 72-in. diameter of the latches.

Another requirement for the AUM is to provide for the transmission of a continuous power level of 1.8 KW to a docked spacecraft.

### 6.1.5 Additional Requirements for a Combined Docking/Refueling AUM

A mechanism combining the docking and refueling function would be desirable because it would simplify the interfaces between OSCRS and another system and simplifying procedures. Such a device would have to satisfy all of the requirements given in the preceeding sections, plus satisfy the minimum docking requirements developed for the OMV Payload Accommodations Equipment (PAE). The OMV Payload Accommodations Equipment consists of the RMS Grapple Docking Mechanism (RGDM) and the Three Point Docking Mechanism (TPDM) and are subject to the requirements listed in the Table 6.1.5-1. It is likely that the capture envelopes in this table reflect the mechanism capabilities more than their requirements. The capture envelope requirement for angular misalignment specified for the RGDM in the OMV Preliminary Design Document, Book 2, August 30, 1985, was $\pm 5°$, and it was necessary for the RGDM to be extended 15 inches (with a 176.0-inch-diameter OMV) to meet this requirement. In Table 6.1.5-1 it is $\pm 15°$.

It would be desirable to use an existing docking interface with the combined docking/AUM. The two standards are the FSS latches and the RMS standard end effector. The FSS latches are too large and heavy to be considered, but it would be possible to modify the RMS standard end effector design, proposed as the grapple docking mechanism for OMV, for use as a combined docking/AUM. Upon rigidization, the grapple fixture

*Table 6.1.5-1 OMV Payload Accommodations Equipment*

| REQUIREMENT \ MECHANISM | | RGDM | TPDM |
|---|---|---|---|
| MAX PAYLOAD WEIGHT, lb | | 75K | 75K |
| LOAD TRANSFER CAPABILITY | | | |
| BENDING MOMENT, ft-lb | | 1200 QUAL<br>1642 LIMIT | 4500 |
| TORSION, ft-lb | | | - |
| AXIAL, lb | | - | 1000 |
| SHEAR, lb | | - | - |
| IMPACT LOADS, lbf | | 2215 | |
| CAPTURE ENVELOPE | AXIAL, in. | ±2.0 | ±4 |
| | LATERAL, in. | ±4.0 | ±3.5 EA LATCH |
| | ANGULAR | ±15° | |
| | ROTARY | ±10° | |
| CAPTURE TIME, SECONDS | | 3 | 3.5 |
| RELATIVE DOCKING VELOCITY | | | |
| LATERAL, ft/s | | .01 | .01 |
| AXIAL, ft/s | | .01 | .01 |
| ROTATIONAL, deg/s | | .5 | .5 |
| ANGULAR, deg/s | | .5 | .5 |
| CONNECTOR ALIGNMENT | | | |
| AXIAL, in.<br>LATERAL, in.<br>ANGULAR<br>ROTARY | | NOT GIVEN, BUT SHOULD BE SAME AS STANDARD END EFFECTOR IN TABLE 6.4.1-2 | NOT AVAILABLE |
| MECHANISM WEIGHT | | 112 | 150 |
| ENVELOPE | ACTIVE SIDE<br>SPACECRAFT | 34.0 X 32 | 37-82 DIA X 29.5 |

on the spacecraft is captured by snare wires inside the end effector, which are then retracted, pulling the spacecraft into rigid contact with the end effector face. The standard end effector motor develops 45-oz-in. torque, which produces 1,200-lb grapple pin load. If rigidization were used to mate connectors, this 1,200-lb axial force would be available for connector mating. Also, some additional means for alignment prior to connector engagement may be necessary. An alternative to mating connectors during rigidization would be to drive the connectors together after rigidization using a separate carriage assembly and drive motors. To react axial forces generated by the fluid and high-pressure gas disconnects, the docking mechanism can accommodate up to 2215-lbf axial force, but it is unlikely that it would be enough to react these loads. A separate latch mechanism at the end effector interface that engages after rigidication would probably be required.

The docking velocity requirement for the OMV PAE, 0.01 feet per second, is quite small compared to those during the Apollo program. When larger relative docking velocities must be accommodated, the combined docking/AUM design becomes significantly more complex because it must absorb impact loads and transfer them to some other form of energy.

### 6.1.6 Requirements for a Common Docking/Refueling AUM

A common docking/refueling AUM is defined as one that could be used in conjunction with some other docking mechanism. This means that if an AUM were designed with both a docking and umbilical mating capability, it should be capable of independent umbilical mating to allow the AUM to be used in those cases where a separate docking mechanism is already in place. The docking part of the RUM would have to be designed to avoid interference during spacecraft-to-CSCRS docking. This would provide a great deal of flexibility for umbilical mating and/or docking for satellites with a variety of docking/berthing interface hardware.

## 6.2 DESCRIPTION OF EXISTING MECHANISMS

This section will review existing designs of automated umbilicals and docking mechanisms that have been either flown or ground tested. Two automated umbilical mechanisms have been built, one by Martin Marietta and one by Moog. Both are designed to mate fluid and electrical connectors and would be used in conjunction with some type of docking mechanism. A summary of the design features and capabilities of each is presented in Table 6.2-1. The two umbilicals are prototypes and have not been designed for flight. Both are planned for ground testing by NASA Marshall Space Flight Center. In comparing the capabilities of the two AUMs in Table 6.2-1, the Martin Marietta RUM has better capability for handling misalignment of the mating halves and can accommmodate six connectors. Additionally, it can sequentially mate the connectors allowing the electrical connectors to be mated before the fluid connectors. Existing designs of connectors which could be used with either umbilical mechanism were also reviewed, and the capabilities of each are presented in this section.

*Table 6.2-1 Automated Umbilical Mechanisms*

| | Remote Umbilical Mechanism (RUM) MMC | Automated Umbilical Connector (AUC) Moog* |
|---|---|---|
| Est Flt Weight (lb) without Connectors | 34 | 36 |
| Alignment Capabilities: Axial<br>Lateral<br>Angular<br>Rotary | 625 in.<br>875 in.<br>5.0°<br>15.0° | 125 in.<br>125 in.<br>5.0°<br>1.0° |
| Number of Connectors | 6 | 4 |
| Contamination Covers on Connectors | Yes on P/L Side Only | Yes |
| EVA-or Robot-Operated Override | Yes | yes |
| Individual Connector Alignment Capability | Yes | Yes |
| Motor Type | 28-V dc Gear Motor | 115/200- vac Motor |
| Power Requirements | 14.4 watts Nominal | 100 watts Nominal |
| Time of Operation | 15-sec Latch Up<br>15-sec Translation | 3- min Total |
| Ability to Mate Electrical Connectors for System Check-out Prior to Mating Fluid Connectors | Yes | Not in Present Design |

* Moog Model 50E559 Report No. MR E-4866 Rev A Jan 26 1987

### 6.2.1 Moog Automatic Umbilical Connector (AUC)

The AUC was developed by Moog for Boeing Aerospace as part of their Space Station advanced development effort. Performance testing on the prototype has been completed, and the unit was delivered to NASA MSFC in January 1987 for further testing. The following is a summary of the design taken from Reference 7. The Moog AUC, shown in Figures 6.2.1-1 and 6.2.1-2, is a fully automated system requiring only electrical power and input control commands. The unit is fully automated and uses

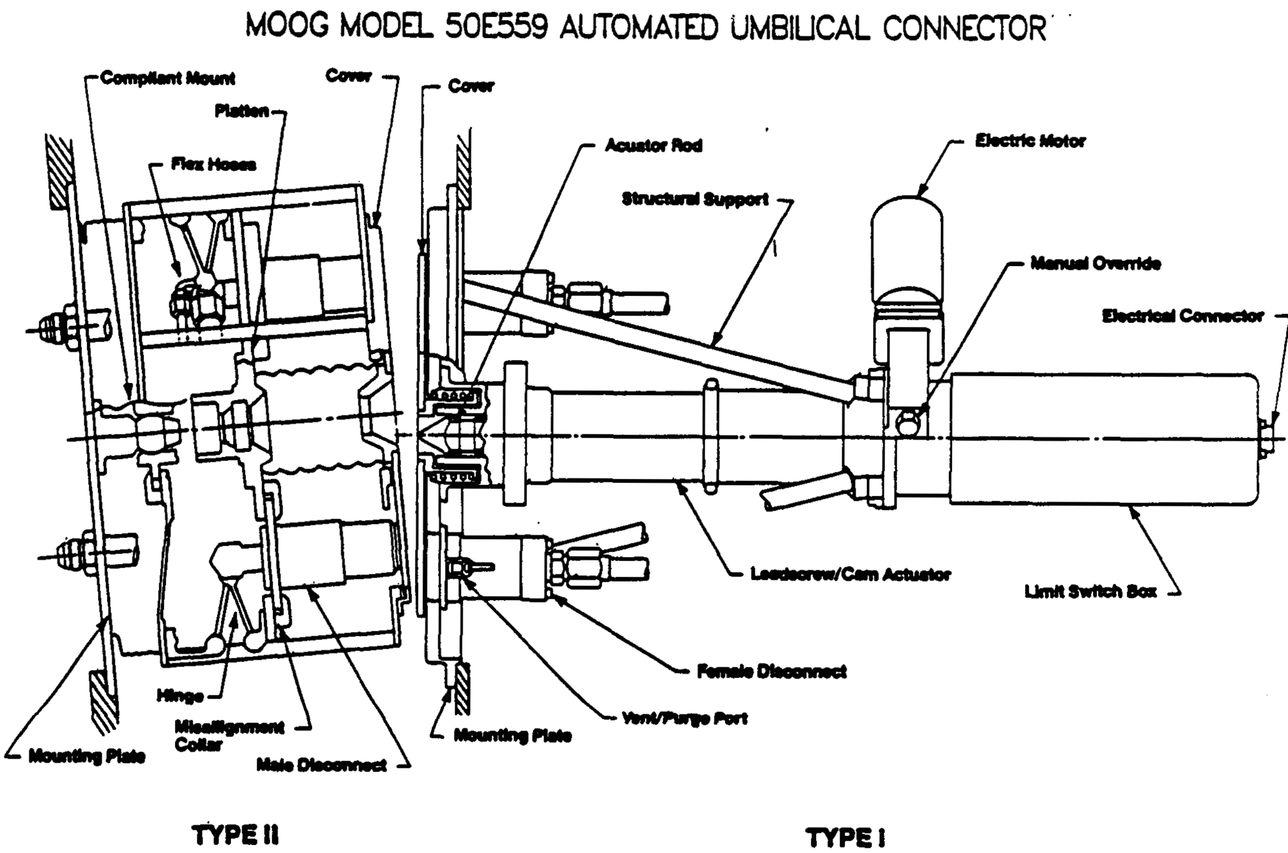



*Figure 6.2.1-1 Automated Umbilical Connector (AUC)*

an electromechanical actuator powered by a single 3-phase, 400-Hz gear motor. Manual override in case of motor failure is provided. The unit is divided into two halves, a Type 1 half, containing the drive mechanism, and a Type II half, which is electrically passive and requires no power or control. The Type 1 structure is cantilevered from a circular mounting plate. This mounting plate is bolted to a face of OSCRS so that all but a small portion of the unit is suspended inside the OSCRS structure. The Type II half has a circular mounting plate which is attached to the spacecraft. The balance of the Type II half houses connectors and is cantilevered from the mounting plate through a compliant mount which is composed of a spherical bearing. Four return springs cause the assembly to tend toward a normal position. The engagement sequence, shown in Figure 6.2.1-3, begins with the input command to the control which initially drives the electric gearmoter in the electromechanical actuator clockwise (viewed from the motor shaft end), driving the actuator rod toward a square hole in the Type II cover. This provides initial alignment of the two halves. The square cross-section actuator rod continues through the cover toward the actuator rod receptacle on the platten. The tapered actuator rod will contact the conical lead-on to the receptical, causing the Type II half to pivot into full alignment as the rod engages the receptacle. The actuator rod continues to advance to push

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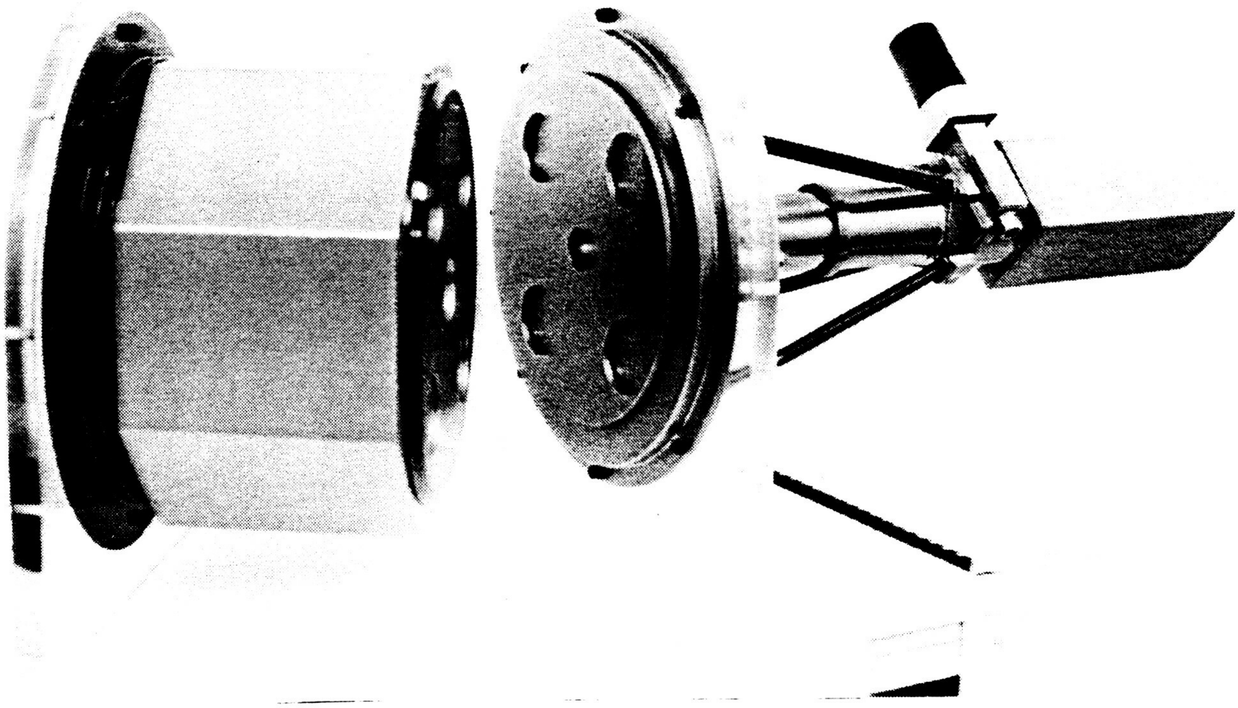
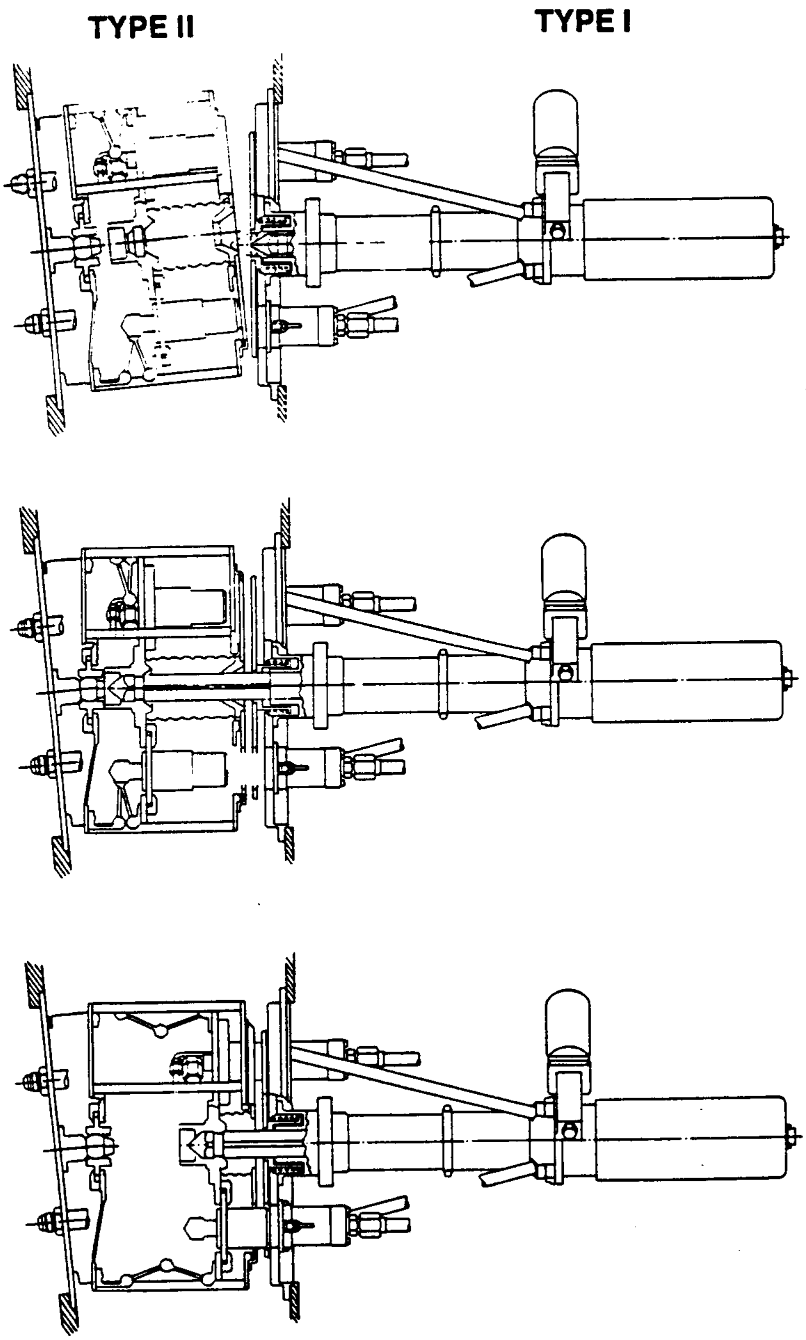


*Figure 6.2.1-2 Moog Model 50E559 Automatic Umbilical Connector*

the covers off the disconnects and then rotates 45 degrees, causing both covers to rotate, positioning holes in these covers over the disconnects. The control automatically reverses the gear motor, and the actuator and platten, moving as a unit, then retract, driving the connectors together. Any remaining misalignment is compensated for by compliant disconnect mounts. Upon full engagement, the motor shuts off and signals the end of the engagement sequence. Fluid and data transmission can then take place. The disengagement sequence is essentially the reverse of the engagement sequence. The AUC prototype was configured to accommodate the Moog Rotary Shut-off (RSC) connector, described in the next section, but other connector types could also be used.

### 6.2.2 Martin Marietta Remote Umbilical Mechanism (RUM)

Martin Marietta has built a prototype Remote Umbilical Mechanism designed to mate fluid and electrical connectors in conjunction with FSS latches for structural mating. The unit, shown in Figure 6.2.2-1 and 6.2.2-2, is currently undergoing modification to support vacuum chamber testing at NASA MSFC.




- Initial alignment
- Actuator rod retracted

- Full alignment
- Actuator rod at full stroke, rotates 45° cw
- Platten captured by actuator rod
- Covers rotate open

- Actuator rod retracts
- Platten moves through stroke
- Connectors drive across interface and engage
- Fluid/Power/Data transfer

*Figure 6.2.1-3 Engagement Sequence*

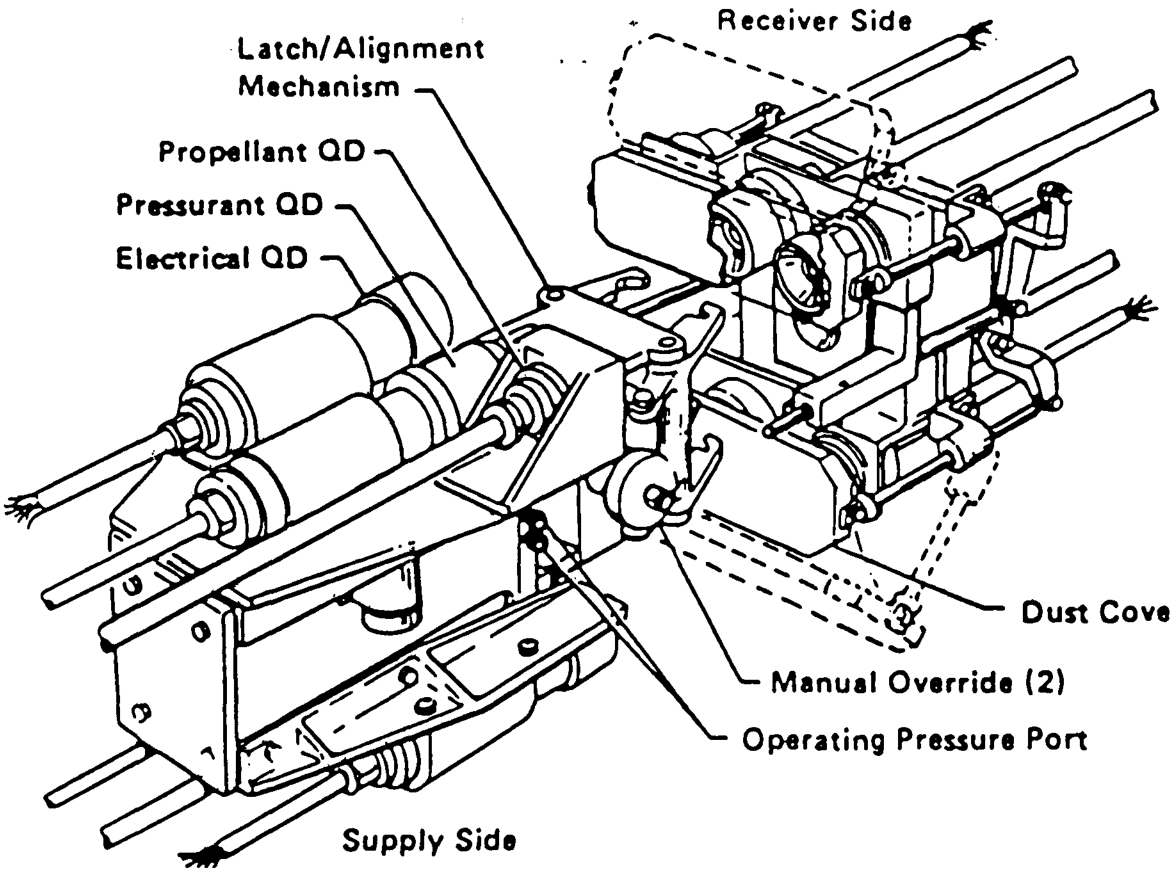



*Figure 6.2.2-1 Robotic Umbilical Mechanism*

The RUM consists of an active side called a translation assembly, which houses a motor-and-ball screw assembly to power an over-center latch and a motor-and-ball screw assembly which drives a connector carriage assembly. Nominally, the connector carriage assembly mounts connectors in two parallel rows around the centrally located latch. Each row contains a fluid, a gas, and an electrical connector. Attached to the carriage assembly are two dust cover actuation pads.

The alignment receptacle is the receiver side of the RUM. It has two dust covers to cover each row of connectors. Internal slide assemblies and pinned joints provide six degrees of freedom alignment capabilities. It is electrically passive and requires no power or control. Connectors on both sides are attached to flexible lines to permit connector motion.

The operating sequence of the RUM begins after the spacecraft has been secured with the FSS latches. A cone on the translation assembly engages a conical depression on the receptacle assembly. The receptacle assembly, with its six-degrees-of-freedom alignment capability, moves to provide the initial alignment of the connectors. Four latches on the translation assembly are then driven through the

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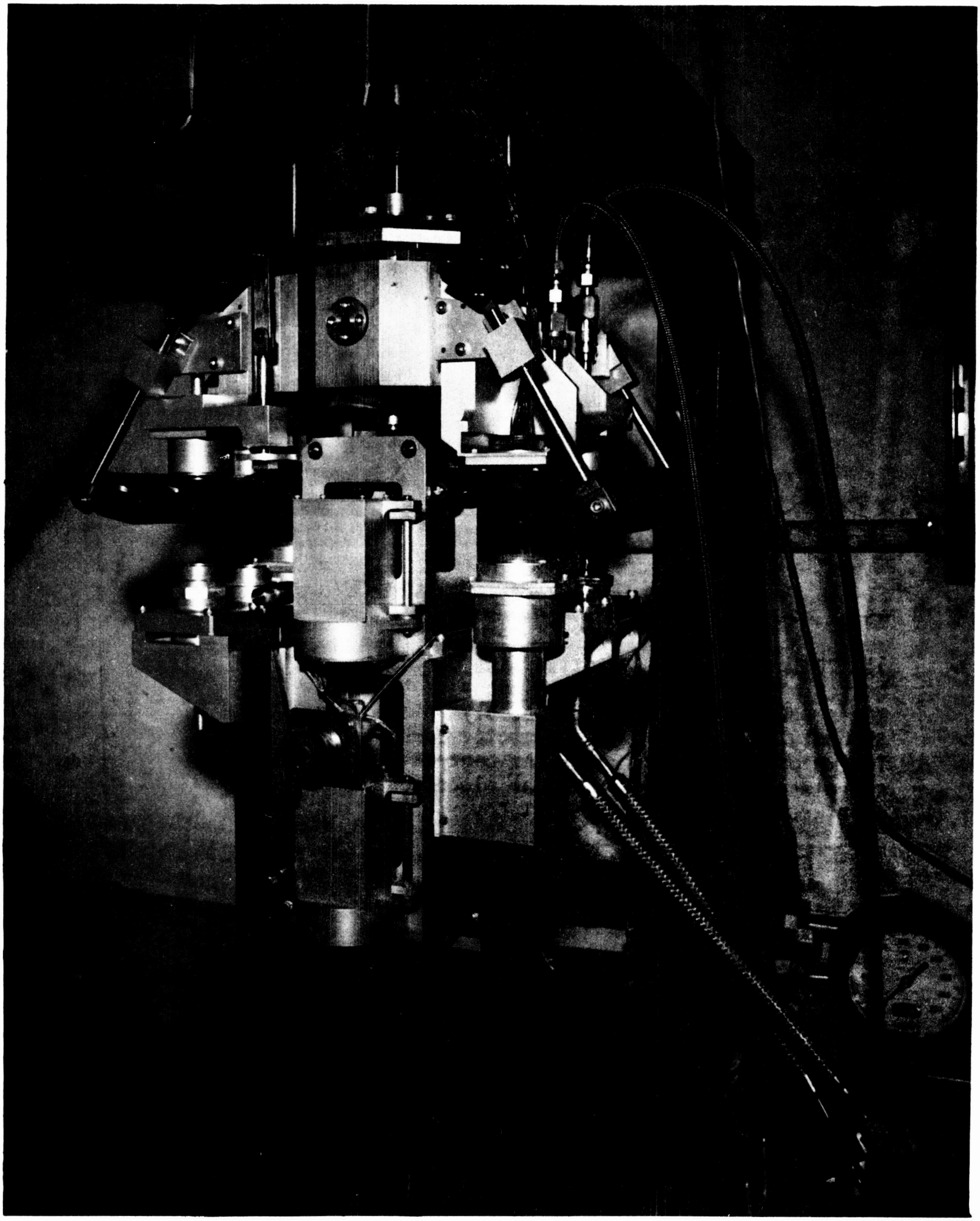


*Figure 6.2.2-2 Robotic Umbilical Mechanism Photograph*

ball nut/lead screw mechanism by a 28-Vdc gear motor. As the latches close, they engage a rectangular plate on the alignment receptacle to provide final alignment. During latching, the dust cover actuation pads extend and engage rods attached to a bell crank mechanism that translates the covers axially and then along a radial path exposing the face of the connectors. A second 28-Vdc gear motor then drives the translation assembly connectors into their mating halves on the alignment receptacle.

The RUM was designed to accommodate up to six connectors, fluid or electrical. Each connector is mounted in a keeper assembly that allows lateral misalignments. The two electrical connectors on the prototype are mounted on a spring assembly so that they can be mated prior to mating the fluid connectors to allow reconfiguring and checkout of the spacecraft system prior to fluid transfer operations.

### 6.2.3 Description of Existing Connectors

There are several types of existing connectors that could be used in either the existing automatic umbilicals or a new design, and they are summarized in this section. Depending on where the OSCRS is used, the number and type of connectors it requires varies because interfaces with the Station, Shuttle, and OMV are different. The connector requirements for the basic OSCRS and the modular OSCRS designs are presented in Table 6.2.3-1 giving the type and number of connectors required for each application. The number of connectors was developed based on the interface requirements discussed in Section 3.4. The maximum number of connectors, considering redundancy requirements, is seven: two propellant, two gas, and three electrical.

*Table 6.2.3-1 Connector Requirements*

| OSCRS I/F WITH / CONNECTOR | SATELLITE TO BE REFUELED | | SPACE STATION | | OMV FOR TRANSPORT | | ORBITER BAY | |
|---|---|---|---|---|---|---|---|---|
| | BASIC | MOD | BASIC | MOD | BASIC | MOD | BASIC | MOD |
| PROPELLANT | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| ELECTRICAL | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 1 to ULC |
| GAS (IF SUPPLIED) | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| TOTAL | 7 | 7 | 1 | 3 | 1 | 1 | 1 | 1 |

Potential connectors were reviewed from vendor-supplied data. A requirement derived for AUMs was that the connectors should be limited to those that can be mated by axial motions only. A connector made by Fairchild, shown in Figure 6.2.3-1, is capable of push/pull mating and is compatible with hydrazine. The self-aligning swivel joints provide +3° of angular misalignment, +0.062° of lateral misalignment, and 0.062° of axial misalignment. This connector is currently being considered for use in the OMV Reaction Control System in a 3/8-inch size.

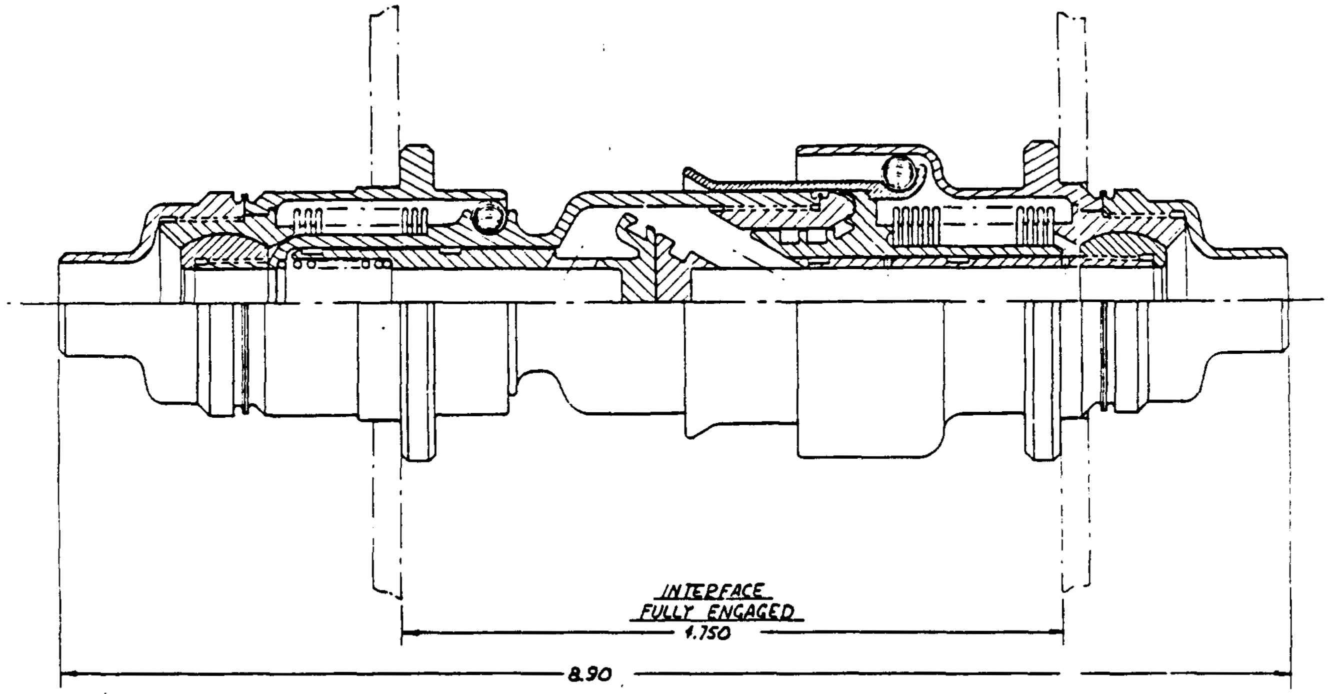



*Figure 6.2.3-1 Fairchild Hydrazine Coupling*

The Moog Rotary Shut-Off (RSO) disconnect, described in Reference 8 and shown in Figure 6.2.3-2, uses spherical cocks to close and seal the flow path instead of poppets. The disconnect provides three seals against propellant leakage when connected, three seals against propellant leakage during mating and demating, and one seal against propellant leakage when disconnected. An optional sensing port could be used to leak-check the seals if required. This connector is currently undergoing testing for a variety of space applications.

G & H Technology, Inc is investigating connectors that would combine both fluid and electrical connections in a single housing. Such a connector could be used in the Remotely Operated Electrical Umbilical (ROEU) for the OSCRS interface to the Station.

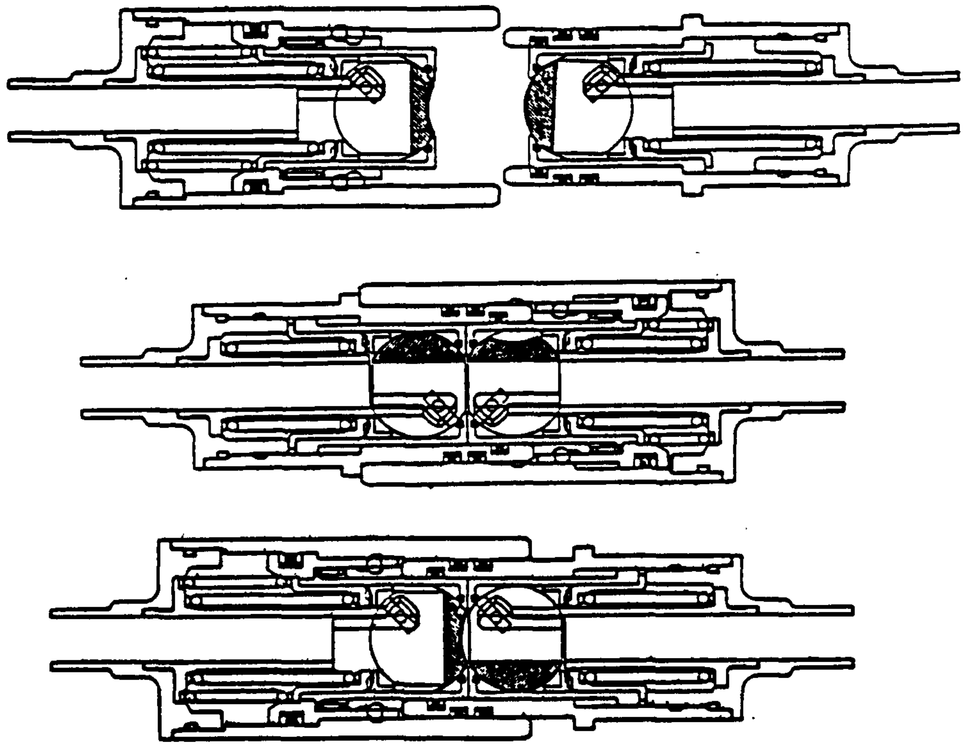


*Figure 6.2.3-2 Moog Rotary Shut-Off (RSO) Disconnect*

## 6.3 RECOMMENDED CHANGES TO EXISTING AUMs

Both the Martin Marietta RUM and the Moog AUC designs can meet the requirements of Section 6.1 with modifications. The requirements developed for an AUM and presented in Section 6.1.1 that are not satisfied by the current designs of the Moog AUC and Martin Marietta RUM are summarized in Table 6.3-1. This table addresses requirements that appear to have significant impact on the AUM designs. Requirements at the component level, such as connector requirements or requirements that the AUMs could meet by a simple design change, are not addressed here. Both units would have to be reconfigured to accommodate the number and type of connectors listed in Table 6.2.3-1. Three electrical connectors are required to accommodate the number of wires required for data, power, and commands and to provide two-fault tolerance. Two hydrazine and two pressurant connectors would be required to provide one-fault tolerance for mission success. Both units would also require redundancy to meet requirements in latching and connector mating operations. This could be achieved by replacing the gear motors with a Common Drive Unit (CDU) that consists of two motor-brake assemblies driving a single output shaft through a common differential. During normal operation of the CDU, both motors would be powered. If one motor locks its shaft, the remaining motor can provide

*Table 6.3-1*
*Requirements Not Satisfied by Existing AUMs*

| Requirement Number from Table 6.1.1-1 | Does Not Meet Requirement | |
|---|---|---|
| | RUM Martin Marietta | AUC MOOG |
| 1 | ✓ | ✓ |
| 2 | ✓ | ✓ |
| 3 | ✓ | ✓ |
| 7 | ✓ | ✓ |
| 9 | ✓ | ✓ |
| 10 | ✓ | ✓ |
| 11 | ✓ | ✓ |
| 12 | * | • |
| 15 | * | • |
| 16 | ✓ | ✓ |
| 19 | • | * |
| 25 | | |
| 27 | | ✓ |
| 29 | | ✓ |
| 31 | • | * |
| 32 | ✓ | ✓ |
| 33 | ✓ | ✓ |

• Requirement Compliance is Dependent on Connector Selection

output through the differential and not backdrive the failed motor. If the differential fails, output can still be provided by powering both motors. Operation of both motors, as compared to one, yields the same output torque with twice the output speed. The Moog AUC would require one CDU, and the Martin RUM would require two. To eliminate a 28-Vdc to 3-phase-400-Hz-AC converter, when used on OMV, the Moog AUC motor should be replaced with a 28V brushless DC motor.

To meet the emergency two-failure operational satellite jettison requirement when refueling from the Orbiter Bay, the CDU provides one fault tolerant latch release and connector demating. A second fault tolerance level for the latch could be provided on the AUC by making the tip of the probe a separate piece attached with a pyrotechnic bolt. The second level of fault tolerance could be added to the Martin RUM by installing a non-explosive initiator pin puller at the over-center toggle link of the latch.

Compliant mounting of the individual connectors is important to prevent connector binding due to tolerance buildups and differential thermal expansion. The Moog AUC provides connector mounts on the spacecraft side that permits some lateral connector movement. Springs inside these mounts cause the connectors to tend toward the normal position. Flexible hoses and cables routed in a spiral fashion can accommodate lateral motion for individual connector alignment and axial motion for connector mating. Connectors on the OSCRS side would be hard mounted. The Martin RUM has compliant connector mounts on the translation assembly (active) side. Flexible hoses and cables are required on both sides to permit lateral and axial motion on the active side and to permit movement of the receptacle assembly on the spacecraft side.

If connector binding is determined to be a credible failure mode, it could have a major impact on the automatic umbilical design. In the present configuration of the Moog AUC and the Martin RUM, if one fluid connector sticks, it is possible that none of the fluid connectors could be mated. On the Martin RUM, if an electrical connector (mounted on a spring assembly) sticks, its axial motion would stop, but the remaining connectors would continue to be mated as the spring behind the jammed connector compressed. Mounting all of the connectors on spring assemblies would be one way to meet the mission success requirement. Another way would be to have two separate connector assemblies driven by separate Common Drive Units. For a connector sticking on demating, the requirement for two-fault-tolerant release could be met by using electrically released in-flight disconnects, similar to G&H Technology Inc Model Number 676. This connector has redundant non-pyrotechnic hot wires that hold back a predesigned spring load. Current is passed through these wires until hoop stress rupture can occur and the inside of the connector comes apart. Two-fault-tolerance release could also be achieved by using a device for fluid lines similar to the one used on the basic OSCRS, as shown in Figure 6.3-2. This disconnect contains a pyrotechnic ring that ruptures the thin cylindrical wall holding the disconnect halves together. Each half contains a valve that shuts off flow when separation occurs.

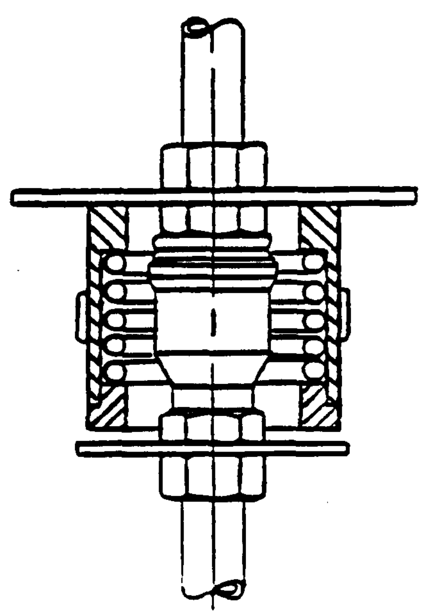


*Figure 6.3-2 Fluid Emergency Separation*

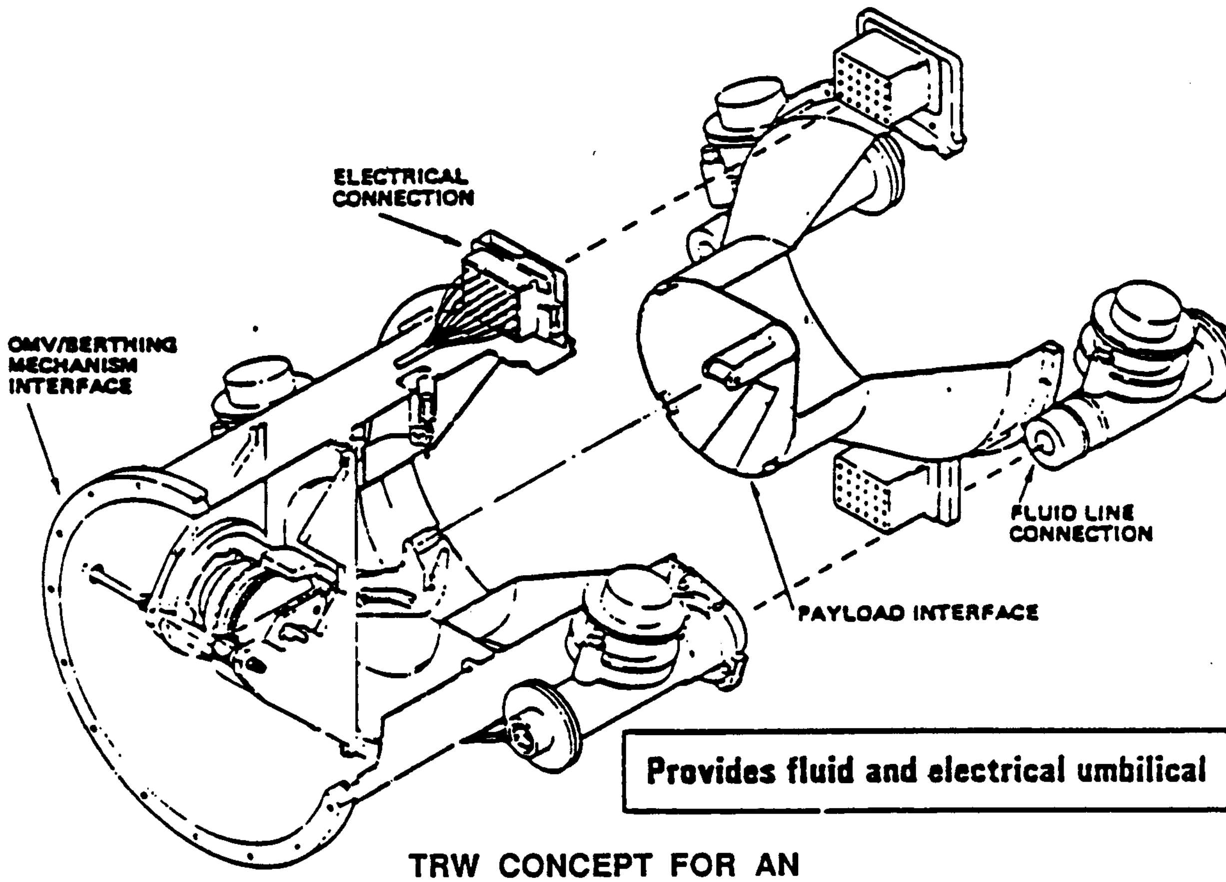
Another design modification concerns thermal control. Both the propellant connectors and hoses for both the Moog AUC and the Martin RUM protrude beyond the thermal blanket of OSCRS and/or the spacecraft and therefore will require thermal protection to prevent freezing of the propellant. Thermal protection might consist of a layer of multilayer insulation (MLI) as on the OSCRS structure. The MLI blanket consists of a Gortex Ortho cloth exterior and a black kapton inner layer that maintains a radiation environment in the heated areas which helps to maintain the temperature of the fluid lines. If heaters are required, each component requiring heat would have three heaters and three thermostats in series for redundancy. Power for the three circuits would be supplied from three electrical buses. Each circuit would be able to maintain the minimum component temperature. Heaters would be active only during the fluid transfer operation.

## 6.4 COMBINED DOCKING/REFUELING AUTOMATIC UMBILICAL

The combining of the docking and refueling functions into one mechanism has potential advantages. The interfaces between the OSCRS and other systems such as the Space Station and a spacecraft would be simplified. Only one mate/demate operation would have to be performed, simplifying operations. One set of motors on the AUM could perform drive of both the docking and utility connectors. Misalignments during connector mating would also be minimized because fluid and electrical connectors would be in close proximity to the docking point. Designs of such a mechanism have been studied previously. This section reviews the status of such a mechanism and discusses recommedations for further work.

### 6.4.1 Description of TRW Alternate Berthing Mechanism

The TRW Alternate Berthing Mechanism (ABM), shown in Figure 6.4.1-1, was designed as an alternate to the RGDM for mating the OMV to another vehicle. The mechanism provides two fluid lines connections for fluid transfer and two electrical connectors for power and telemetry. The ABM consists of two parts: the probe, which is the spacecraft side of the mechanism; and receptacle cylinder, the active half of the mechanism. Four keys on the probe mate with four grooves in the receptacle that are oriented in a radial direction to allow thermal expansion clearance between the probe and the receptacle. The keys/grooves carry shear loads and moments in the mechanism. A single hook mounted in the receptacle, driven by one of two geared, redundant wound stepper motors with redundant drive electronics, engages a roller on the probe to pull it into the receptacle. A switch mounted on the receptacle indicates when the probe is within the capture range of the hook. The motion of the hook is controlled by a slot and a roller on the support. The probe travels a total distance of 5.5 inches, the outer keys engage the receptacle grooves, and the probe is constrained to linear motion to control the mating of the fluid and electrical connectors. The ABM is installed in the same location on the OMV as the RGDM, as shown in Figure 6.4.1-2, extends 15 inches in from of the SRV, and is nonretractable. The ABM is electrically redundant and provides EVA backup by separating the roller and the hook to ensure separation.




TRW CONCEPT FOR AN ALTERNATE BERTHING MECHANISM

* FROM OMV PRELIMINARY DESIGN DOCUMENT, NAS8-36114 AUGUST 30, 1985

*Figure 6.4.1-1 TRW Alternate Berthing Mechanism*

The ABM was designed to meet the requirements shown in Table 6.4.1-1. An engineering model of the ABM was tested in the NASA MSFC six-degree-of-freedom simulation facility in 1981. Eleven separate docking test runs were performed. The output of the tests is included in Table 6.4.1-2. The Shuttle RMS docking capabilities are also shown in this table for comparison.

### 6.4.2 Recommended Changes to the TRW ABM

In order to meet the requirements for use as a combined docking/AUM on OSCRS, the alternate berthing could be changed as follows:

1) Add 1 electrical connector.

2) Add 2 high pressure gas connectors.

3) Provide replacable dust covers for both sides of all connectors.

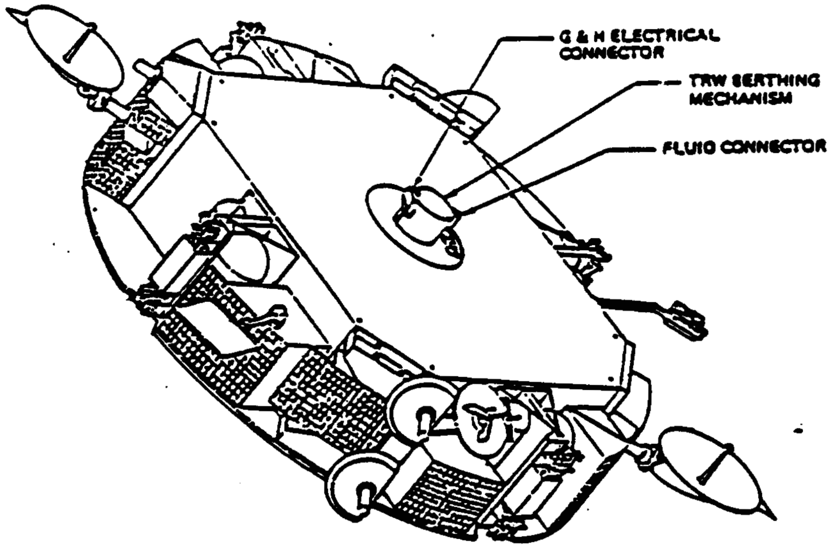



*Figure 6.4.1-2 TRW Alternate Berthing Mechanism on OMV*

*Table 6.4.1-1 OMV Alternate Berthing Mechanism Requirements*

| | | | | |
|---|---|---|---|---|
| 1. | PROVIDE STRUCTURAL ATTACHMENT OF PAYLOADS TO OMV | | | |
| 2. | PROVIDE MECHANICAL MATING FOR TWO BODIES | | | |
| 3. | PROVIDE CONNECT FLUID LINES | | | |
| 4. | PROVIDE ELECTRICAL CONNECTIONS | | | |
| 5. | ACCOMMODATE IMPACT LOAD DUE TO VELOCITY OF 0.11 ft/s = 25 POUNDS | | | |
| 6. | MAXIMUM DESIGN MOMENT = 7814 in-lb | | | |
| 7. | MATING REQUIREMENTS ARE AS FOLLOWS: | | | |
| | | | NOMINAL | MAXIMUM |
| | | TRANSLATIONAL | 0.03 ft/s | .11 ft/s |
| | | ROTATIONAL | 0.083 deg/s | 0.24 deg/s |
| 8. | THE LATCH SHALL BE OPERATED WITH REDUNDANT POWER SOURCES | | | |

4) Provide for two-fault tolerant release of connectors in the event of connector sticking by replacing electrical connectors with redundant nonpyrotechnic, electrically released in-flight disconnects, and using a pryo-type emergency fluid separation device as shown in Figure 6.3-2 for all fluid and gas lines.

5) Mount the electrical connectors on the probe side further forward, and on longer springs than the fluid connectors, to permit their mating prior to the fluid connectors.

6) Permit two-fault-tolerant release of probe to receptacle either at the hook-to-roller interface or, if sticking at the probe-to-receptacle-payload interface could be a problem, at the probe-to-satellite interface.

The most difficult change listed above would probably be the addition of contamination protection for the connectors. The hook-to-roller interface might have to be strengthened to react loads from the two high-pressure gas disconnects.

## 6.5 AUM IMPACTS TO OSCRS

Addition of an AUM to the OSCRS would require modifications to the OSCRS subsystems. There will be negligible impact to the OSCRS fluid subsystem by using an AUM. Structurally, the AUM will have to be capable of being mounted on the front and back side of OSCRS to accommodate simultaneous attachment to a spacecraft and an OMV. An opening in the middle of the OSCRS structure would be desirable to allow retraction of the AUM when not in use.

The addition of an AUM to the basic OSCRS will also require modifications to the avionics. The changes are small, and the cost and weight impacts are negligible. Provided below is a list of the electrical characteristics of the AUM and the provisions that will be provided by the OSCRS avionics to accommodate these functions.

1) Redundant motor drive circuitry will be added to the Power Distribution Unit for the protection, control, and telemetry of each motor.

2) AUM status signal, such as latch position, end of travel, umbilical proximity, connector mating complete, will be handled by existing equipment.

3) Discrete output commands (emergency mode) are required to handle the control of pin pullers to release latch mechanisms (emergency mode), and pin pullers or hot wires to release electrical connectors (emergency mode). When operating from the Shuttle, the commands are switch actuated from the AUM; operating from Space Station the commands will be software controlled.

4) Fluid lines will have pyros to separate lines in the case of an emergency. Control hardware is already present.

5) Additional software required to control, monitor, and test each motor. Commands could be ON/OFF and/or timed feedback.

*Table 6.4.1-2 Docking Mechanism Capabilities*

| MECHANISM / REQUIREMENT | | SHUTTLE RMS[1] | ALTERNATE BERTHING MECHANISM (TRW) [2] |
|---|---|---|---|
| MAX PAYLOAD WEIGHT, lb | | 65K (VRCS)<br>8K (PRCS) | |
| LOAD TRANSFER CAPABILITY | | | |
| BENDING MOMENT, ft/lb | | 1200 | 7800 |
| TORSION, ft/lb | | 700 | - |
| AXIAL, lb | | - | 600 |
| SHEAR, lb | | 50 | 600 |
| IMPACT LOADS, lbf | | | |
| CAPTURE ENVELOPE | AXIAL, in. | 3.9 | 1.5 |
| | LATERAL, in. | ±4.0 | ±4.0 |
| | ANGULAR | | ±4° |
| | ROTARY | - | ±4° |
| CAPTURE TIME, s | | 3 + 20 RGD | 135 TO 320 |
| RELATIVE DOCKING VELOCITY | | | |
| LATERAL, ft/s | | .1 | .13 |
| AXIAL, ft/s | | .1 | .13 |
| ROTATIONAL, deg/s | | .3 | .3 |
| ANGULAR, deg/s | | .3 | .3 |
| CONNECTOR ALIGNMENT | | | |
| AXIAL, in. | | .1 | |
| LATERAL, in. | | .1 | |
| ANGULAR | | ±15° | |
| ROTARY | | ±.4° | |

1 NSTS O77OO VOLUME XIV, REVISION 1, SEPETEMBER 16, 1986

2 OMV PRELIMINARY DESIGN DOCUMENT, BOOK 2, AUGUST 30, 1985, NAS8-36114

## 7.0 ELV LAUNCH OF OSCRS

### 7.1 CANDIDATE LAUNCH VEHICLES, INTERFACES, AND CAPABILITIES

An evaluation of design changes to OSCRS to accommodate launch by an ELV was performed. ELVs are becoming an increasingly important part in the planning of future launches, and they are being considered for use in resupply to the Space Station because Shuttle availability will be limited, particularly during the assembly phase of the Station. The current types of ELVs were examined for capabilities and interfaces. Several variables were considered in the evaluation. These included payload delivery weight to final orbit, payload fairing restrictions, availability, and cost. A list of the candidate vehicles and their performance is given in Table 7.1-1. For comparison, a specific circular orbit of 218 nmi and 28.5° due east from KSC is listed (similar to the Space Station orbit) with the performance capability of each vehicle. The Commercial Titan (CT) and the Delta can place a payload in this orbit without an upper stage, while the Titan II and Atlas must use an upper stage, which is a weight and cost penalty for these vehicles.

*Table 7.1-1 Candidate Launch Vehicle Capabilities*

| LAUNCH VEHICLE | PERFORMANCE (LEO-DUE EAST) | PAYLOAD ENVELOPE, ft DIA X MAX LENGTH | LAUNCH COST, $M |
|---|---|---|---|
| TITAN IV | 39300 | 15 X 66 | 90 |
| TITAN III | 33600 | 10 X 51 | 75 |
| TITAN II | 5200 | 9.3 X 25 | 35 |
| DELTA 3920A | 8600 | 7 X 14 | 35 |
| DELTA 3920A STRETCH | 9300 | 8.3 X 14 | 50 |
| ATLAS G CENTAUR | 13500 | 9 X 28 | 60 |
| ATLAS K CENTAUR | 14500 | 12 X 28 | 65 |

As shown in Table 7.1-1, only the Titan IV, with its Shuttle-sized payload fairing, could accept an unmodified OSCRS. However, the large launch capability of the Titan IV is not practical unless other payloads are launched with the OSCRS. The Titan CT, described in Reference 5, has the capability to stabilize a payload without the use of an upper stage and could place the OSCRS in the Space Station orbit for retrieval by the OMV. The Titan CT second stage has a complete attitude control system in the forward skirt to provide three-axis stabilization in a parking orbit. Payload accommodations include a launch environment compatible with Shuttle or Ariane, payload unique adapters, acoustic blankets if required, and radio frequency windows and access doors where needed. The Titan CT can provide a payload with thermal control maneuvers to reduce thermal loads, collision/contamination avoidance maneuvers to mitigate payload contamination by the Titan's attitude control system, and payload separation to allow ample distance between deployed payloads. Because the OSCRS could be left in a relatively stable attitude by the Titan CT second stage, retrieval by the OMV for subsequent transfer to the Space Station should be feasible and well within the capabilities of the OMV. The Atlas and Delta launch vehicles have the payload capability to launch OSCRS to orbits near those of the Space Station. However, unless an upper stage is flown with these vehicles, none can provide stabilization of a payload that does not have its own propulsion system. The upper stages designed for use on the Atlas and Delta are primarily intended to place payloads into geosynchronous transfer orbits and are not ideally suited for low-orbit payload maneuvering. Therefore, because of the Titan CT's ability to place the OSCRS in a circular orbit in a relatively stable attitude and the Titan IV's Shuttle-sized payload fairing, these vehicles were focused on in assessing OSCRS impacts.

The interfaces between an ELV and the OSCRS would be primarily structural and electrical. An attachment interface on the OSCRS would be required that matches the standard interfaces of the launch vehicle. Currently, the Titan IV is not designed to accommodate multiple shuttle payloads using trunnion and keel fittings attached to its payload fairing.

The electrical interfaces provided by a Titan consist of power, command, and telemetry. Both the Commercial Titan and Titan IV provide these interfaces, but the characteristics of each are different.

Power is provided by silver-zinc batteries with characteristics being identical for both Titan CT and Titan IV. Voltage level is +28 Vdc with limits of +24V to +34V. Peak power is 1800 watts with a total energy level of 6000 watts-hours. Total battery power of 6000 watts-hours is used for both payload requirements as well as Titan 2A skirt requirements. It may be possible to extend the total energy level available to OSCRS by adding a dedicated battery.

The command interface consists of discrete commands only. No serial interface is provided by either Titan. The Titan CT provides four high-level discretes (+28 Vdc) with an option for up to 40 more. The optional discretes are worked on an individual basis. The Titan IV provides 16 high-level discretes. Discrete commands can be issued in any sequence with any command being repeatable. The discrete circuitry precludes inadvertent issuance of a command prior to or later than its scheduled time.

Telemetry sent back to Earth is by S-band transmitter. Each Titan provides the capability to acquire data from a payload and interleave the data with its own data before transmitting. The Titan CT provides two bilevel channels and three analog channels as standard service with an option for an extra bilevel channel and two analog channels if required. Titan IV provides 14 channels as standard service. Optional channels can be provided if required; the number of channels is worked on an individual basis.

Software is provided to handle the control of Titan operations from launch to payload insertion and stabilization. The Operational Flight Software (OFS) controls the Titan in placing a spacecraft into a desired orbit. Software functions provide calculation and control capabilities for mission sequencing, guidance, navigation, attitude control, vehicle stabilization, and tracking and communication.

The interfaces will exist in the 2A skirt within a Titan. This area is at the top of Section 2 and below the payload fairing.

## 7.2 POTENTIAL IMPACTS TO OSCRS

The design impacts on the basic OSCRS to accommodate launch on an ELV were identified. The impacts are primarily structural and avionic.

Structural impacts are due to the restricted size of the payload fairings. The Titan CT payload fairing, shown in Figure 7.2-1, can accommodate a 143.7-in.-diameter payload. The basic OSCRS is shown in Figure 7.2-2 with the Titan CT and IV fairing envelopes shown. For the Titan CT, Delta, and Atlas fairings, significant redesign of the structure would be required, including the removal of the trunnion and keel fittings and modification of the structure to allow repositioning of the tanks to stay within the payload envelope, particularly if five tanks are required, as in a water OSCRS. While the Titan IV payload faring is large enough to contain an OSCRS without redesign with the trunnion and keel fittings removed, the attachment interface does not accommodate trunnion and keel fittings but consists of eight hard points on an 11.7-in. diameter as shown in Figure 7.2-2. In either case, the trunnion and keel fittings must be either deployable or able to be attached on-orbit to allow the OSCRS to be transported back down in the Shuttle payload bay. The Titan IV payload capacity is much larger than that required for OSCRS and is not cost effective unless other payloads are launched with OSCRS. Launch of a stack of multiple payloads, including OSCRS, with an OMV attached, would be a workable solution. Such missions could take place if Titan IV were to be used for Station resupply.

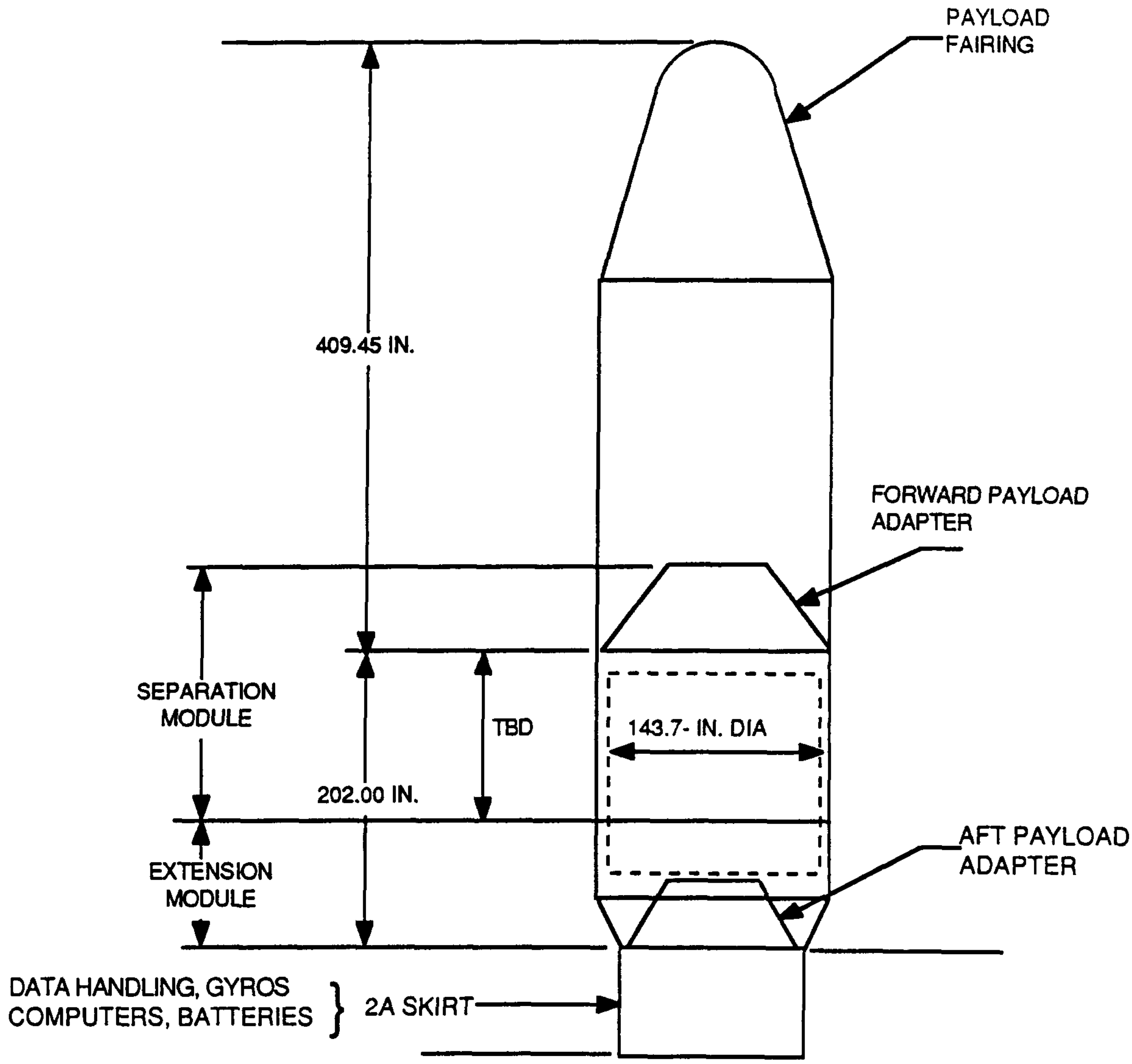



*Figure 7.2-1 Titan Payload Envelope and Supporting Avionics*

Launch of the OSCRS on the Titan II, Delta, or Atlas vehicle would require the addition to these vehicles of all subsystems necessary to stabilize the OSCRS attitude until it could be retrieved by the OMV. A solution not considered practical is the addition of these systems to OSCRS itself. Therefore, based on the current design of ELVs, the Titan CT and Titan IV appear to be the most practical for launch OSCRS.

In order to minimize the impacts on OSCRS it is recommended that the mission be designed so that the OMV can rendezvous with the OSCRS attached to the Titan 2A skirt within 6 hours. Titan command systems would configure OSCRS to have only vehicle heaters on. This will save power and maintain temperature. Titan's telemetry system would monitor temperature sensors and transmit to monitoring ground crews until either OMV arrives or six hours have ended. The impacts on OSCRS and the mission if the rendezvous does not occur within the six hours are major and include:

1) No attitude control system is available on OSCRS to stabilize it for OMV pick-up.

2) A command/telemetry system, transmitter, receiver, and antennas for data and control must be added.

3) Addition of batteries for the avionics.

These additions would add substantial cost and weight to the OSCRS.

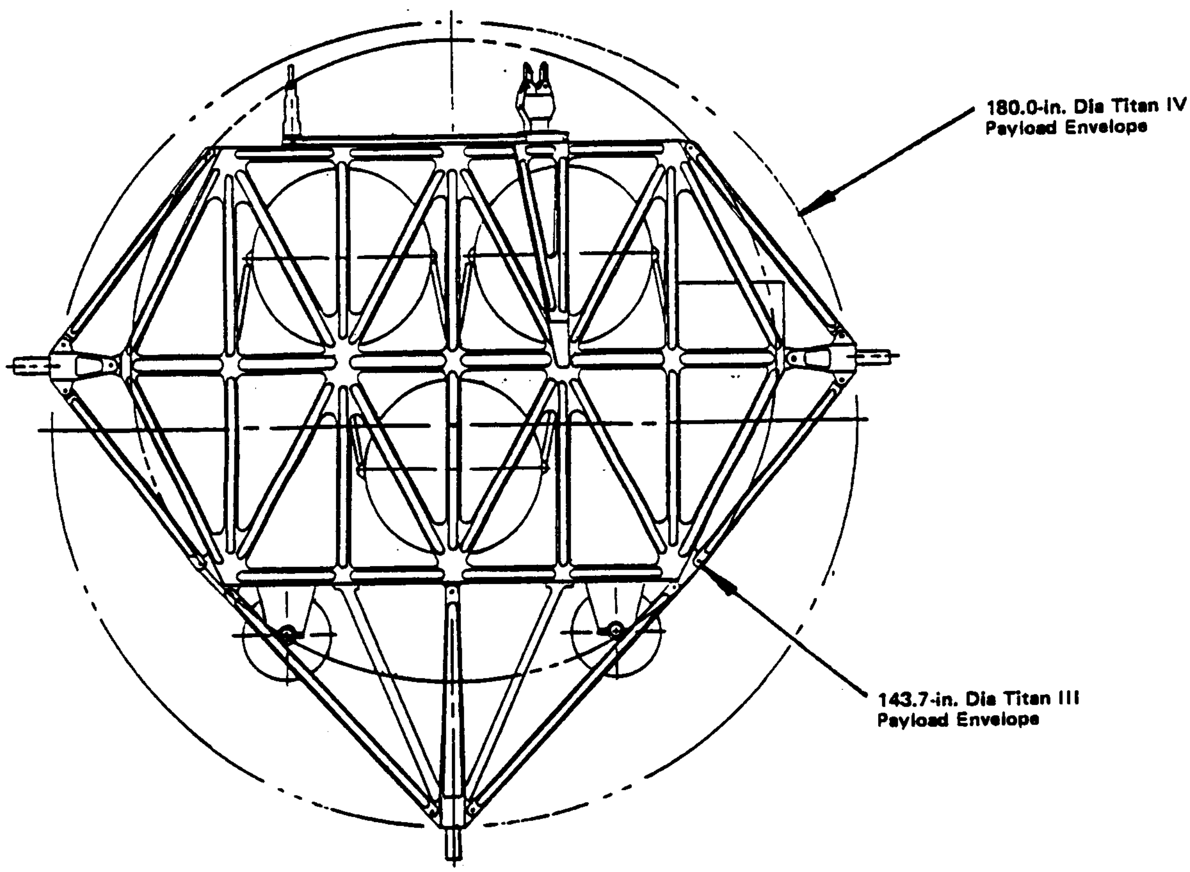



*Figure 7.2-2 OSCRS—Titan Payload Envelope*

# 8.0 CONCLUSIONS AND RECOMMENDATIONS

The overall conclusions and recommendations from this contract extension effort are summarized in this section. The basic OSCRS designed for manual refueling in the Shuttle payload bay must be modified to satisfy several Space Station requirements. The modular OSCRS design, where major subsystems are station-based, was found to be the most versatile and most efficient approach for Space Station. The modular OSCRS station-bases portions of the fluids subsystem and the avionics resulting in a significant decrease in structural up/down weight. Preliminary evaluations indicate that this modularization can be implemented with modest cost impacts compared to the basic OSCRS. The OSCRS design should also be made compatible with automatic refueling since it is a Space Station requirement. The OSCRS should be designed for and used at the Station as a mobile tanker that is transportable to various refueling locations other than the Servicing Facility. Meteoroid and space debris protection must be provided for the OSCRS while it is at the Station. An aluminum bumper panel between 0.03 and 0.075 inches thick would provide adequate protection for the OSCRS where it is not already protected by the service facility. The meteoroid and debris protection should not be a part of OSCRS but should be Station-based to avoid a launch weight penalty. To allow OSCRS to refuel OMV, it is recommended that changes to the basic OMV SRV propulsion system design be implemented. Reducing the number of gas connectors from four to one and locating it next to the propellant connector would simplify the refueling operations, particularly if an automatic umbilical mechanism is used. Launch of OSCRS on an Expendable Launch Vehicle is feasible with design changes. The need for OSCRS to be stabilized by the launch vehicle was identified to allow the OMV to retrieve OSCRS. Currently, only the Titan CT can provide this stabilization without an upper stage. The subsystems required to provide this capability would have to be added to the Titan II, Delta, and Atlas vehicles. Titan IV could provide this capability because its payload capacity would allow the simultaneous launch of an OSCRS and OMV. The Titan IV vehicle, with its Shuttle-sized payload fairing, is also the only vehicle capable of launching the basic OSCRS as presently configured for Shuttle. Use of any other vehicle requires significant structural redesign of the OSCRS because of the restricted diameters of the payload fairings. If ELV launch compatibility is a firm requirement for OSCRS, it must be considered early in the hardware design phase.

The conclusions and recommendations specifically relating to avionics are as follows. The MSC and SFM interface capability need further definition to include two fault tolerant command, data and 28 VDC power. Adopting a standard serial interface such as RS422 or 1553B would greatly simplify the interface capability problem. The other Space Station avionics interfaces are very adequate as defined in the current ACD and BCD.

Station basing of the avionics makes sense if there is a standard location where OSCRS will be used for resupply. If OSCRS is to be moved to various locations on the Space Station, then providing multiple sets of station based avionics seems inefficient and keeping the avionics on OSCRS would be more appropriate. In order to allow station basing of the avionics, it is recommended that a multiplexer unit be added and the existing PDU be split into two units as part of the basic OSCRS design. When station basing the avionics it is further recommended that the Space Station EDPs be used to replace the existing OSCRS computers to reduce the amount of hardware that has to be station based.

In doing the OMV avionics interface research, several recommendations for improving the OMV to payload interface were surfaced. One is to provide two fault tolerant command, data and power to the payloads that require it. This could be provided either though the main OMV or by providing a kit to the OMV to supplement the basic OMV provisions.

Another recommendation is to move the payload RIUs to the OMV side of the interface to save cost, space and weight on each payload. Along with moving the RIU(s), it would be easier to accommodate payloads if there was a standard serial interface available such as RS422 or 1553B to the RIU(s). A final recommendation is to provide command and data storage for the payload since operating the OMV realtime has priority over payload commands and data, this would prevent loss of critical payload data while OMV is being controlled via the ground.

In order to avoid complication of the avionics subsystem, it is recommended that for resupply missions that require multiple OSCRS that each OSCRS be used independently (one at a time) to do the resupply. To use OSCRS in some sort of interconnected scheme would require significant hardware and software modifications. It would also require multiple sets of station based OSCRS avionics if using tankers that do not have full complements of avionics.

The requirements defined in this report are for an automatic refueling system and not just a refueling mechanism. These requirements need to be expanded and refined. In order to keep the refueling process as simple as possible (i.e., avoid a complex robotic-type system), it is imperative that standard interfaces be defined as soon as possible. There are significant common functions in the docking and automatic umbilical mechanisms. For future systems, we recommend that an interface be developed that will allow combining these functions. However, it is likely that some spacecraft will use another type of docking interface such as the FSS latches which would not be compatible with the combined docking/umbilical mechanism approach. For these applications, a separate automatic umbilical would be needed. We believe it may be cost effective to develop a single mechanism for docking and refueling which could be modified for use as an automatic umbilical when some other docking device is used. We recommend that the OSCRS design be modified to provide space in the center for the docking and automatic umbilical mechanisms. This feature would be particularly valuable when the OSCRS is used with the OMV.

Existing engineering prototype AUMs, both Moog and Martin Marietta, and the TRW combined mechanism provide a good starting point for development. However, they must be modified to meet many of the requirements defined for OSCRS.

Fluid couplings and electrical connectors that meet the requirements need to be integrated into the mechanisms. It would be desirable to be able to design the mechanism to accept different couplings and connectors. However, we should not pay a large penalty for this feature. For example, we should design the mechanism for translation only for mating the couplings (no rotation).

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12) Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Final Report, Vol II, Appendix II, Study Results Monopropellant End Item Specification, November 1986.

## APPENDIX A - ADDENDA TO OSCRS END ITEM SPECIFICATIONS

The following is a list of addenda to the OSCRS System End Item Specification (EIS) and the Flight Vehicle End Item Specification (DRD-7) to accommodate the modular OSCRS configuration.

| Paragraph | Change |
|---|---|
| **System EIS** | |
| 1.0 Scope | Add to Item 2: "The OSCRS shall be designed modularly to accommodate basing of subsystem elements at the Space Station." |
| 3.1 System Definition | Add the following to Item 1: "The OSCRS structural, fluid, and avionics subsystems shall be modularized to allow removal for Station-basing." |
| 3.1.1 General Description | Add the following to Item 1: "The OSCRS shall consist of the following modules: propellant storage module, pressurant storage/control module, vent system module, and avionics module." |
| 3.3.6 | Change Item 5 to the following: "Electronic equipment that is electrostatic discharge sensitive shall be handled according to Martin Marietta Procedure 75025." |
| 3.6.1.2.3.1 | Change Item 2 as follows: "Power available to the receiver spacecraft shall be 250 watts maximum." |
| **Flight Vehicle EIS** | |
| 1.0 Scope | Add to Item 2: "The OSCRS shall be designed modularly to accommodate basing of subsystems elements at the Space Station." |
| 3.1.1 General Description | Add to Item 1: The OSCRS shall consist of the following modules: propellant storage module, pressurant storage/control module, vent system module, and avionics module." |
| 3.2.1.5 | Delete Item 19. |
| 3.3.5.3 | Change Item 6 to read: "Electronics equipment that is electrostatic discharge sensitive shall be handled according to Martin Marietta Procedure 75025." |

## APPENDIX B - PROGRAM PLAN

We have not identified any items that would have a significant impact on the basic program plan submitted with our basic OSCRS study. However, we do recommend that R&D work continue on automatic refueling including system integration, interface definition, mechanism requirements refinement and the design and test of a prototype mechanism.

# APPENDIX C - COST ESTIMATES

All of the recommended design changes to the OSCRS are expected to be within the error band of the estimate provided with the basic OSCRS study except in the avionics subsystem.

We estimate that the avionics cost will increase by $1.2M. The basis is as follows:

| | |
|---|---|
| Added multiplexer | $ 750K |
| Split PDU into two boxes | $ 250K |
| Added GSE | $ 150K |
| | $1,150K |