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Final
Technical
Report

December 1987

Fluid Resupply and
Module Exchange
Integration Analysis

Servicer System Demonstration Plan and Capability Development

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SERVICER SYSTEM DEMONSTRATION PLAN AND CAPABILITY DEVELOPMENT

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FOREWORD

This document was prepared by Martin Marietta Corporation under Change Order 10, Fluid Resupply and Module Exchange Integration Analysis, of Contract NAS8-35625, Servicer System Demonstration Plan and Capability Development, Data Procurement Document 650, Data Requirement DR-5, Final Technical Report. This effort was accomplished for the George C. Marshall Space Flight Center of the National Astronautics and Space Administration under the technical direction of Mr. James R. Turner, the Contract Technical Manager.

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ACRONYMS

AIAA	American Institute of Aeronautics and Astronautics
cg	Center of Gravity
cm	Center of Mass
DAACD	Data Acquisition, Analysis, Control and Display
DoD	Department of Defense
ELV	Expendable Launch Vehicle
ETU	Engineering Test Unit
EVA	Extra-Vehicular Activity
FRIU	Fluid Resupply Interface Unit
FSS	Flight Support System
FWD	Forward
g	Unit of Gravity
GCS	Ground Control Station
GEO	Geosynchronous Earth Orbit
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
GRO	Gamma Ray Observatory
GSFC	Goddard Space Flight Center
H&CMS	Hose and Cable Management System
IOSS	Integrated Orbital Servicing System
IR&D	Independent Research and Development
IUS	Inertial Upper Stage
IVFTD	Intervehicle Fluid Transfer Device
JSC	Johnson Space Center
LEM	Lunar Excursion Module
LEO	Low Earth Orbit
MACS	Modular Attitude Control Subsystem
MLI	Multilayer Insulation
MMAG	Martin Marietta Astronautics Group
MMH	Monomethylhydrazine
MMS	Multimission Modular Spacecraft
MSFC	Marshall Space Flight Center
N_2H_4	Hydrazine
NASA	National Aeronautics and Space Administration

NTO	Nitrogen Tetroxide
OBC	Onboard Computer
OMS	Orbital Maneuvering System
OMSS	Orbital Maintenance and Servicing System
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replacement Unit
OSC	Operations Support Center
OSCRS	Orbital Spacecraft Consumables Resupply System
P/L	Payload
PM	Propulsion Module
PMD	Propellant Management Device
P/N	Part Number
PRLA	Payload Retention Latch Assembly
Q/D	Quick Disconnect
RCS	Reaction Control System
RF	Radio Frequency
RGDM	Remote Grapple Docking Mechanism
RM	Remote Supply Module
RMS	Remote Manipulator System
RSO	Rotary Shut-Off
RUM	Remote Umbilical Mechanism
S/C	Spacecraft
SDI	Space Defense Initiative
SPERC	Space Platform Expendables Resupply Concept
S/R	Stowage Rack
SRV	Short Range Vehicle
SSDP	Spacecraft Servicing Demonstration Plan
STAS	Space Transportation Architecture Study
STS	Space Transportation System
TDRSS	Tracking and Data Relay Satellite System
TMS	Teleoperator Maneuvering System
TPD	Three Point Docking
TV	Television
TYP	Typical
WGT	Relative Weight
W/O	Without

1.0 SUMMARY

The effort addressed in this report is an analysis to define an orbital maneuvering vehicle (OMV) front end kit capable of performing in-situ fluid resupply and modular maintenance of free flying spacecraft based on the integrated orbital servicing system (IOSS) concept. This integration analysis, with respect to missions that combine module exchange and fluid resupply, involved analyses and tradeoff studies to identify equipment configurations, interfaces between major elements, mission scenarios, and operational considerations. The exchange of tanks and the transfer of fluids through umbilical connectors were considered as options. The analysis also addressed the compatibility of the IOSS to perform gas and fluid umbilical connect and disconnect functions utilizing connector systems currently available or in development. A conceptual approach to the demonstration of fluid transfer in 1-g using the engineering test unit in the MSFC Robotics Laboratory was identified and recommended to NASA.

It was found during the study that fluid resupply integrates very well with orbital replacement unit (ORU) exchange and the combination is better than the sum of the parts. The resulting orbital maintenance and servicing system (OMSS) evolved into a set of building blocks that could be readily assembled to cover a wide range of fluid resupply capacities while retaining the ORU exchange function and with a very acceptable loss in ORU carrying capacity. The word "servicing" has taken on a variety of meanings in recent years. However, for this report, "maintenance" is used for ORU exchange, and "servicing" is used for fluid resupply.

The first of the two major study results is the variety of configurations of the OMSS. The Type A OMSS configuration, shown in Figure 1.0-1, combines the fluid resupply version of the IOSS with the OMV. Fluid is transferred to the serviced spacecraft via an umbilical connection where the fluid resupply interface unit (FRIU) is positioned by the IOSS servicer mechanism. The umbilical is constrained and guided by a hose and cable management system (H&CMS) on the IOSS.

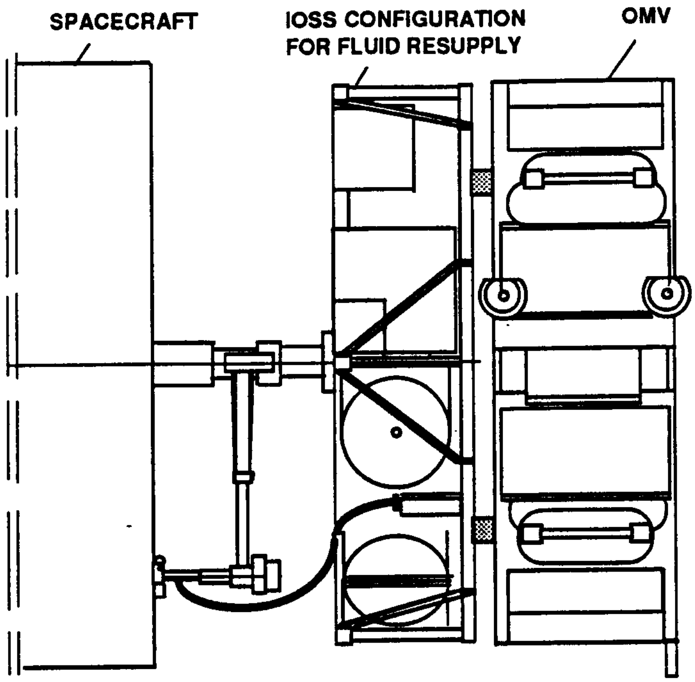

Figure 1.0-1 Type A OMSS Configuration

The hose and cable management system with its fluid resupply interface unit is stowed in the IOSS stowage rack during launch and reentry. Also, a set of three monopropellant tanks and two pressurant bottles for driving the propellants, two pressurant bottles for pressurant resupply, and an ORU tank set, are stored in two opposing quadrants of the IOSS stowage rack. This fluid resupply form of the IOSS stowage rack is used in the other three OMSS configurations.

The most complex of the OMSS configurations resulting from this analysis combines the fluid resupply form of the IOSS stowage rack with a five tank orbital spacecraft consumables resupply system (OSCRS) monopropellant tanker, a six tank OSCRS bipropellant tanker, and the OMV.

Fluids can be transferred between any of the resupply elements so that any extra capacity of the OMV can be used for propellant resupply and so that missions requiring more propellant than the OMV capacity can be accomplished using fluid from the OSCRS. The large hydrazine capacity of the OMV may make this feature attractive. Two hose and cable management systems with fluid resupply interface units could be used for redundancy or for fuel/oxidizer separation. Fluid management is controlled by an electronics system that is part of the OSCRS on OSCRS missions or is carried in the IOSS for non-OSCRS missions. The flexibility to carry a variety of fluid quantities and types enhances the system's capability for multiple spacecraft fluid resupply on a single mission.

An advantage of the OMSS being made up of a number of elements that can be combined in various ways is that the elements can be developed separately starting with the IOSS and its fluid resupply form of stowage rack. Other elements could then be developed as the need arises and funding becomes available.

The Figure 1.0-1 fluid resupply configuration of the IOSS stowage rack can hold up to 2910 lb of monopropellants and 135 lb of gaseous nitrogen. However, the most complex OMSS configuration, including the OMV, can hold up to 8940 lb of monopropellant, 240 lb of gaseous nitrogen, and 20,175 lb of bipropellants. This capability should handle most fluid resupply requirements in low Earth orbits and provide the OMV with a significant increase in maneuvering energy.

The second major study result involves the recommended concept for the ground demonstration of fluid resupply using the servicer system engineering test unit (ETU), which was built by Martin Marietta Corporation on a prior contract and is now in operation in the MSFC Robotics Laboratory. The recommended concept is shown in Figure 1.0-2. The existing capability for ORU exchange demonstrations is retained. The H&CMS shown has the same minimum radius of curvature as the flight unit. The cable carrier part of the H&CMS guides the single hose and cable and keeps them in a single plane. Because the cable carrier can bend on each end, as well as connect two points that are close or far apart, it greatly simplified the overall design. Additional degrees of freedom are provided to the H&CMS at each end so

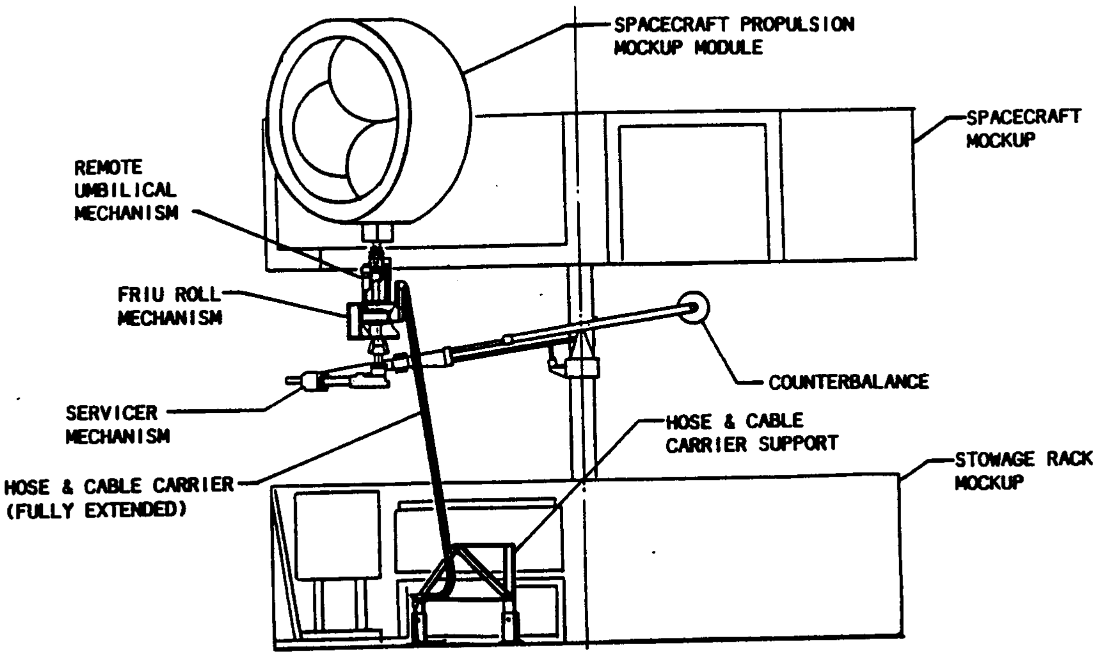

Figure 1.0-2 General Arrangement for Fluid Resupply Demonstrations

that the ETU servicer mechanism can align the FRIU to a wide range of positions on the spacecraft mockup.

The remote umbilical mechanism (RUM) is a design that has been built and tested at Martin Marietta. It is unique in that it was designed to do precisely what is required for this application. The flight unit version of the RUM can handle up to a total of six electrical or fluid connections, although one of each type is recommended for the demonstrations to reduce the weight that must be handled by the ETU. A propulsion module mockup is shown on the spacecraft to increase the fidelity of the demonstration. The need for fluid handling equipment, such as tanks, pipes, and valves, was recognized and no difficultly with this aspect of the concept is expected.

The weights of the various parts have been estimated and it appears that the ETU has a good chance of handling the H&CMS if the joint capacity is increased by modifying the electronics and if additional counterbalances are added for the fluid resupply demonstrations. The additional counterbalances would be made easy to add or remove and would bias the servo drives so that they could pull up more than they could push down. This simple approach would obviate the need for complex additional mechanisms and would retain the general appearance of the ETU.

1.1 INTRODUCTION

The fluid resupply form of onorbit servicing has been addressed in a number of studies in recent years. These studies have shown how fluid resupply might be accomplished, the quantities and types of fluids of interest and examples of specific spacecraft that might desire fluid resupply. The economic advantages of fluid resupply, by itself, have not been very clear. However, the advantages of fluid resupply when combined with onorbit maintenance in the form of orbital replacement unit exchange, are numerous and the process is economic. Prior to this study there has been little done to investigate the combination of fluid resupply and ORU exchange. Fluid resupply via ORU exchange, where the fluid is contained in a tank that is exchanged, was suggested as part of the IOSS studies. Also, the transport of fluid in tanks in the IOSS stowage rack and then transfer of the fluid to the serviced spacecraft via an umbilical that would be positioned by the IOSS servicer mechanism (Figure 1.1-1) has been suggested. However, neither of these concepts had been addressed in much detail or as part of a more inclusive consideration of integrating fluid resupply with ORU exchange. The purpose of this study is to examine the effects of adding fluid resupply to the capabilities of the IOSS.

This study is part of a series of tasks involving onorbit servicing and the engineering test unit of the onorbit servicer. The ETU is a full-scale operational version of the IOSS including a control system and the necessary software. The objective of the broader activity is the advancement of orbital servicing by expanding the Spacecraft Servicing Demonstration Plan (SSDP) to include detail demonstration planning utilizing the Multimission Modular Spacecraft (MMS) and upgrading the ETU control system.

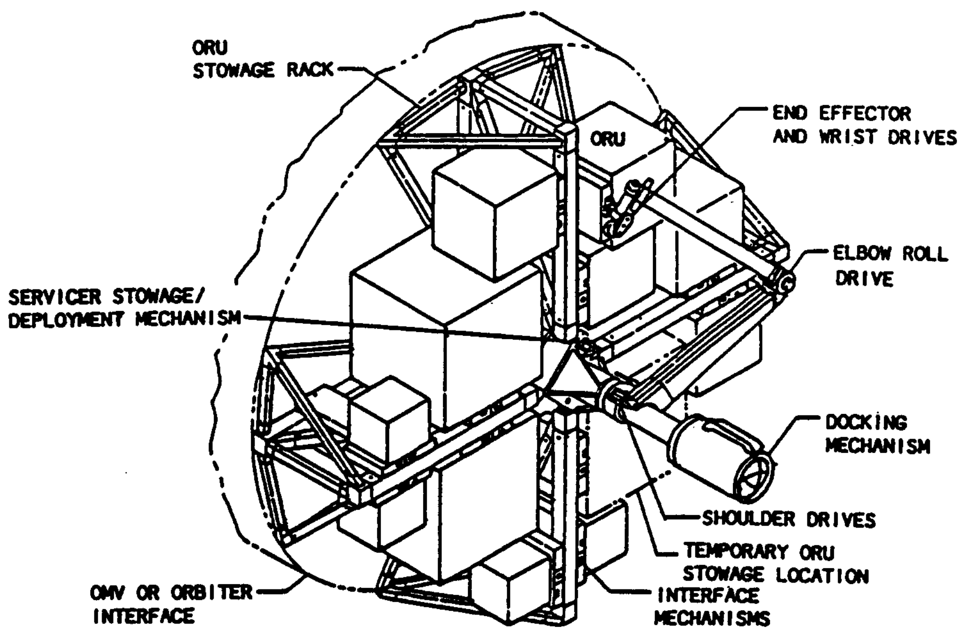

Figure 1.1-1 IOSS Onorbit Servicer Configuration

1.2 STUDY OBJECTIVES

The broad objectives of this Servicer System Demonstration Plan and Capability Development study are to identify all major elements and characteristics of an onorbit servicing development program and to integrate them into a coherent set of demonstrations, to upgrade the ETU control system for single fastener ORU exchange demonstrations, to upgrade the MSFC servicing demonstration facility mockups to permit the exchange of MMS modules, to prepare a Servicer System User's Guide, to upgrade the ETU control system for easier operator interaction, and to perform an analysis of the integration of fluid resupply and module exchange.

The last study objective is the focus of this report. More explicitly, the objective of this phase of the contract, as shown in Table 1.2-1, is to define an orbital maneuvering vehicle front end kit that is capable of performing both fluid resupply and ORU exchange at a spacecraft in its operational orbit. The objective also includes the determination of the compatibility of the IOSS to perform gas and

Table 1.2-1 Objective and Guidelines

Study Objective
Define an orbital maneuvering vehicle front end kit capable of performing, in-situ, both fluid resupply and modular maintenance
Guidelines
Base on Integrated Orbital Servicing System concept
Includes gases, hydrazine and bipropellants
Consider for tanks and tankers - Orbital Maneuvering Vehicle - Mark II Propulsion System - Space Platform Expendables Resupply Concept - Orbital Spacecraft Consumables Resupply System
Evaluate both exchange of tanks and fluid transfer through umbilicals

liquid umbilical connect and disconnect functions. The third part of the analysis objective is to address methods of demonstrating fluid transfer in 1-g using the engineering test unit. The guidelines for the integration analysis are also given in the table.

1.3 RELATIONSHIP TO OTHER NASA EFFORTS

Servicing development activities were initiated in the early 1970's and continue through the present time. Studies and development work have been performed by NASA, other government agencies, and contractors. Early study results concluded that onorbit servicing was a more cost effective approach than ground refurbishment of satellites.

Recommendations included that spacecraft be designed for servicing and that module exchange was the most cost-effective method of servicing. During the IOSS study, an ETU was designed and built, and has been in use at MSFC since 1978 for ground demonstrations of remote satellite servicing and other development activities. A wealth of experimental data was accumulated during that servicer demonstration and development program and constitutes the basis for further development of an onorbit satellite servicing capability.

Many studies during the past decade indicated the cost benefits of onorbit fluid resupply. The areas of fluid management requiring new technology have been identified. Cargo-bay experiments completed by NASA-JSC demonstrated fluid transfer in 0-g and tested new quick-disconnects and sensors. For these first experiments, extra-vehicular activity (EVA) operations were used. Standardization of the fluid resupply interface is an important issue affecting the economics and ultimately the success of the spacecraft fluid resupply activities. An interface standardization project is being pursued by NASA-MSFC through a fluid coupling effort and they are supported by NASA-JSC in terms of fluid disconnects and requirements. The objective is to develop a standard propellant servicing interface for all satellites.

The Orbital Spacecraft Consumables Resupply System study was performed by three contractors, including Martin Marietta Corporation. The primary mission was to resupply the Gamma Ray Observatory (GRO) with monopropellant from the orbiter cargo bay using astronauts on EVA to connect the fluid umbilicals. A significant concern was system safety. The OSCRS monopropellant capability (Figure 1.3-1) was extended to bipropellants and pressurants. Future propellant transfers were to be accomplished remotely using tankers in conjunction with the OMV and space station. The major study emphasis was on requirements and design. These initial studies were continued with an analysis of the application of the OSCRS configuration to space station.

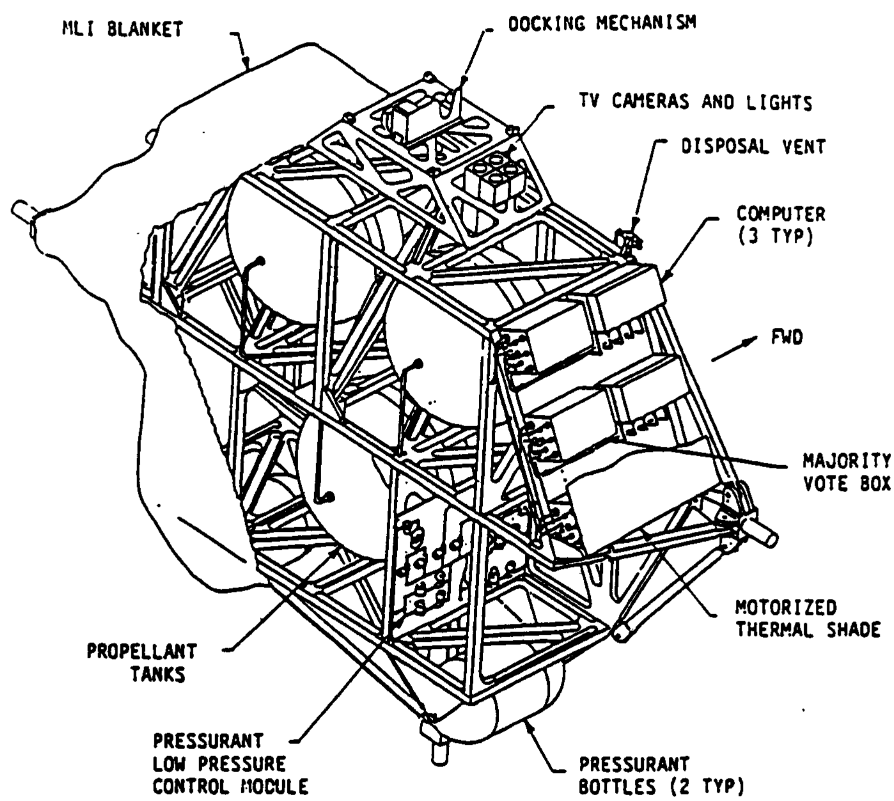

Figure 1.3-1 OSCRS Monopropellant Tanker

1.4 STUDY APPROACH

Our approach to the fluid resupply integration analysis was organized into the six subtasks shown in Figure 1.4-1. In the Data Collection and Requirements Identification subtask, data were collected for each of the major elements involved in fluid resupply and module exchange. These included: IOSS, OMV, the four tankers listed in Table 1.2-1, candidate tanks, candidate fluid transfer umbilicals, and hoses. Concurrently with the data collection, sets of requirements for each of the major equipments and functions involved were prepared.

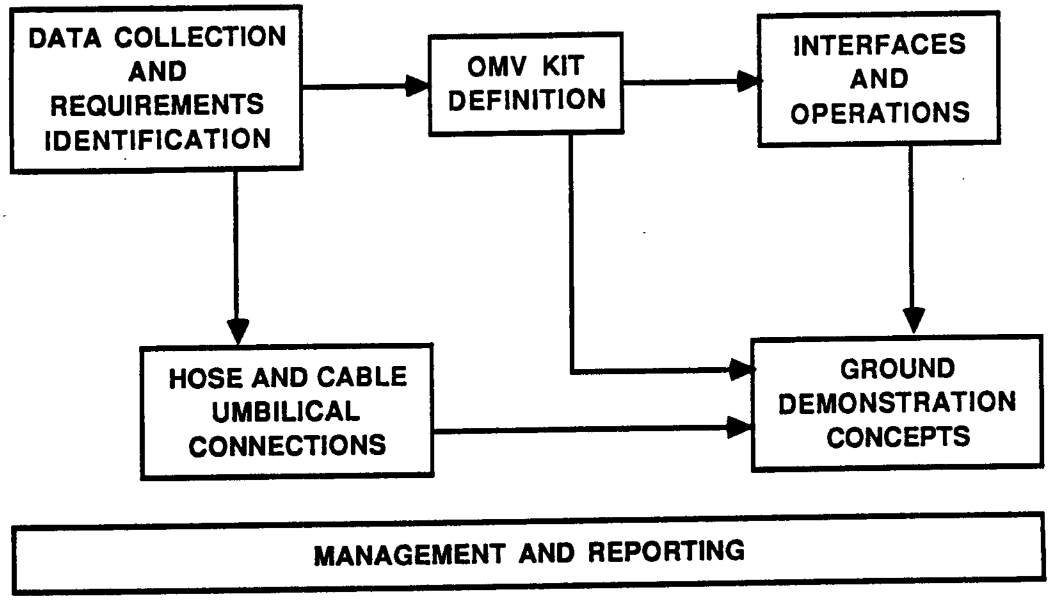

Figure 1.4-1 Task Flow Chart

The OMV kit definition activity started with the identification of candidate systems. These systems were combinations of the IOSS, OMV, tankage, and fluid transfer systems. Candidates were identified and defined sufficiently to conduct trade studies. A set of three interrelated trade studies were conducted on the candidate OMV kits to identify significant characteristics of the candidate systems and to obtain a better understanding of the candidates. A recommended concept was selected based on the results of an evaluation, and was further defined including conceptual drawings and lists of characteristics.

The interfaces and operations activity started with identification and definition of interfaces between the major elements of the selected concept. The next part was the preparation of mission scenarios that resulted in the identification of additional system and subsystem requirements, which were added to those prepared initially. The last part was the identification and definition of operational considerations for the selected concept.

The hose and cable umbilical connection work started with identification of requirements and their documentation. A gas and fluid umbilical connector concept was selected and recommended to MSFC for use in the candidate fluid resupply and module exchange concept. The umbilical connector also involves electrical connections as well, as it is necessary to control valves and monitor pressures and temperatures during fluid transfer.

Concepts for the ground demonstration of gas and liquid resupply using the engineering test unit of the onorbit servicer in the MSFC Robotics Laboratory were identified and described. From this basis, a new concept was evolved and recommended to MSFC.

1.5 STUDY RESULTS

The study found that the integration of fluid resupply with ORU exchange using an IOSS type of servicer mechanism is straightforward and the resulting OMSS should be relatively easy to develop. The use of the IOSS servicer arm to position the fluid resupply interface unit results in the spacecraft designer having a great deal of freedom as to where the fluid interface may be located with respect to the docking interface on his spacecraft. The space allocated to the fluid resupply equipment in the spare ORU stowage rack does not materially affect the space required for ORUs, as the ORU requirements did not use all of the ORU stowage rack space.

The concept of transferring fluids between tankers and the IOSS can be extended to where fluids can be transferred between the OMV, multiple OSCRS tankers, tanks in the IOSS stowage rack, and the serviceable spacecraft. The capability for transfer of fluids to the OMV can increase the impulse available to the OMV and thereby increase its orbit transfer capabilities. It is also possible to use the concept to transfer hydrazine from the OMV to a serviceable spacecraft.

Each of the equipments necessary to build a successful OMSS either exists, is under development, or does not appear to present a serious development risk.

A concept for the demonstration of fluid transfer using the ETU in the MSFC Robotics Laboratory has been prepared. The approach incorporates many of the requirements and constraints of the recommended flight hose and cable management system. The concepts that were sketched out appear to be amenable to extension to a detailed design. The recommended counterbalance system is to extend the inherent characteristics of the ETU and to add removable counterbalances during fluid resupply demonstrations. The extra counterbalance weights added for fluid resupply demonstrations would be removed for ORU exchange demonstrations. The effect of the added shoulder counterbalance weight is to bias the shoulder pitch drive so it can lift more than it can push down. A similar approach is recommended for the wrist pitch drive.

The following sections summarize the next level of detail results and conclusions.

1.5.1 Data Collection and Requirements

The major data sources used in the analysis are listed in Table 1.5-1. All of this information was directly available to us. The Servicer System User's Guide was complemented by our extensive IOSS data base. The OMV data was a mixture of TRW data and older Martin Marietta Astronautics Group (MMAG) data. In particular, MMAG data was used for the tanks considered in the tank trade study.

Table 1.5-1 Data Sources

Integrated Orbital Servicing System - Servicer System User's Guide
Orbital Maneuvering Vehicle - User's guide and other capabilities data
Space Platform Expendables Resupply Concept - 1984 concept definition study - 1985 study addendum
Mark II Propulsion Module - 1982 AIAA paper by J. F. Haley, Jr.
Orbital Spacecraft Consumables Resupply System - MMAG final report in eight books

The Space Platform Expendables Resupply Concept (SPERC) study data available was a complete set of the study reports including presentation handouts. The Mark II Propulsion Module information in the noted paper was adequate for the level of analysis conducted. While Martin Marietta builds the Mark II Propulsion Module, specific data is difficult to obtain because of the application of the module. The major source of information on tanks and candidate tankers was contained in the eight book final report of the Martin Marietta Astronautics Group Orbital Spacecraft Consumables Resupply System team. This data is extensive and thorough, covering both monopropellants and bipropellants. As would be expected from the timing and size of the study, the OSCRS data includes the results and approaches developed in prior studies and gives answers that fit current mission model requirements.

The requirements for a fluid resupply system that would be integrated with the IOSS have been collected from a variety of sources over a period of time. The OSCRS requirements were also included, as were some requirements from our space station activity. Table 1.5-2 provides a summary of the requirements, while a full compilation of all of the requirements is given in Appendix B.

Table 1.5-2 Fluid Resupply Requirements Summary

System requirements for operational servicer (21 items)
Non-propellant cryogenic fluid transfer (5 items)
Contamination related (3 items)
Thermal control (6 items)
Standardized spacecraft interfaces (3 items)
Safety (12 items)
Reliability and maintainability (2 items)
Cost (2 items)
Hose and cable management subsystem (19 items)
Connector requirements (32 items)
Command and control and software (4 items)
Ground demonstrations (21 items)

1.5.2 Tank/Tanker Trade Study

The tank/tanker trade study was the major analysis effort and it had the objective of developing a recommended approach for the definition of an OMV kit that would integrate the fluid resupply function into the IOSS form of onorbit maintenance that emphasizes ORU, or module, exchange. Three alternative, or complementary, approaches were considered. These are:

1) Tanks in the IOSS stowage rack;
2) Tanker concepts prepared by others;
3) Tanks as orbital replacement units.

The trade study lead to a recommended fluid resupply approach and identified significant aspects involved in the integration of fluid resupply with ORU exchange. No concerns that might inhibit the integration of the fluid resupply function into the IOSS form of onorbit maintenance were identified. All three candidate approaches should be integrable into a versatile system.

A flow chart showing the activities involved is shown in Figure 1.5-1. Three parallel, and complementary, paths were used to develop a recommended approach for the integration of fluid resupply with module exchange. The three paths are alternative, or complementary, approaches and all three paths start with the same set of requirements and data. The conclusions from the three paths were combined into an overall recommended approach. The implications of the recommended approach were extended to further recommendations as to how the concept might be used to extend its capability.

The conclusions from the tank/tanker trade study are listed in Table 1.5-3. All three approaches to the integration of fluid resupply into ORU servicing that were addressed in the trade study have specific areas of utility, and no one approach could efficiently handle all applications. Tanks that are installed in the IOSS stowage rack are more useful for monopropellant resupply and can handle all but the most demanding monopropellant resupply requirements. As there is insufficient room on the IOSS stowage rack for the catch tanks that are likely to be needed, it is recommended that bipropellants not be resupplied from tanks in the IOSS stowage rack.

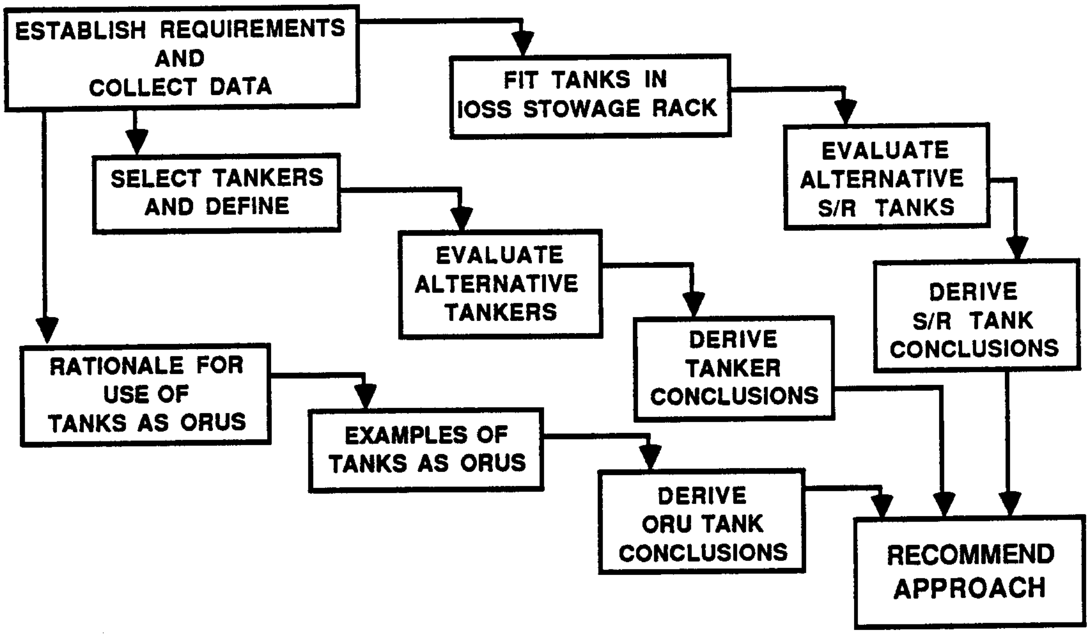

Figure 1.5-1 Trade Study Approach

Table 1.5-3 Trade Study Conclusions

All three approaches can be integrated into a maintenance and servicing system - Tanks in IOSS stowage rack for many monopropellant missions - OSCRS tankers for bipropellant and larger quantity monopropellant missions - Tank ORU exchange reserved for special situations
Fluid interfaces designed so that fluid can be transferred in either direction between OMV, tankers, IOSS, and serviced spacecraft
OSCRS type avionics system could be used for IOSS fluid resupply
Stacking tankers and maintenance system may exceed OMV attitude control system capability during multiple dockings

It is recommended that tankers such as the OSCRS be used for bipropellants and for the larger quantities of monopropellants as might be required for resupply of the Mark II Propulsion Module, or if multiple spacecraft are to be resupplied with monopropellants on a single mission. It is recommended that the use of tanks as ORUs be reserved for those special cases where the disconnect problem can be worked around or accepted, e.g., the OMV propulsion module.

To increase the overall system capability by permitting various combinations of IOSS stowage racks, tankers, and the OMV to be assembled, it is recommended that the fluid transfer interfaces between these elements be designed so that fluids can be transferred in either direction. An example is that tanker fluids could then be used by the OMV to permit it to perform more energetic missions. Alternatively, the OMV fluids could be transferred via the IOSS umbilical to the serviced spacecraft, thereby giving the IOSS a bipropellant servicing capacity without the need to carry along a bipropellant tanker (the bipropellant catch tanks could be on the IOSS stowage rack). The result of using this type of intervehicle fluid transfer device is that a great deal of operational flexibility is obtained for little cost. However, this approach implies the need to scar, or modify, the OMV so it could transfer fluids to and from the fluid resupply form of the IOSS. Areas that should be addressed include: bipropellant connections between the OMV propulsion module and the short range vehicle, bipropellant connections to the IOSS, monopropellant and pressurant connections to the IOSS, and additional mechanical and electrical fluid management equipment.

The result of the tank/tanker trade study is a set of elements that can be assembled in various ways to satisfy both the ORU exchange and fluid resupply requirements for a wide variety of missions.

1.5.3 OMV Kit Definition

Based on the tank/tanker trade study, monopropellant tanks in the ICSS stowage rack and OSCRS monopropellant and bipropellant tankers were recommended. Additionally, the combination of these elements with the IOSS and OMV was introduced to provide a larger variation in fluid resupply capability.

The recommended approach is a series of building blocks that can be assembled in different configurations depending on the mission requirements. In all cases, the OMV is a part of the configuration as it is needed to transport the IOSS and the fluid resupply elements to the spacecraft to be serviced. The IOSS is also part of each mission as it is required for ORU transfer and for positioning the umbilicals. For missions that require a small amount of fluid to be transferred, the fluid would be stored in one or two tanks in the IOSS stowage rack (Figure 1.5-2). The IOSS stowage rack can be configured to hold up to three monopropellant tanks. Two OSCRS configurations are recommended: one for monopropellants, and one for bipropellants. For missions requiring even larger amounts of propellant, two OSCRS type tankers could be used. The other alternative is to configure tanks as ORUs that can be exchanged by the IOSS servicer mechanism as with any other ORU.

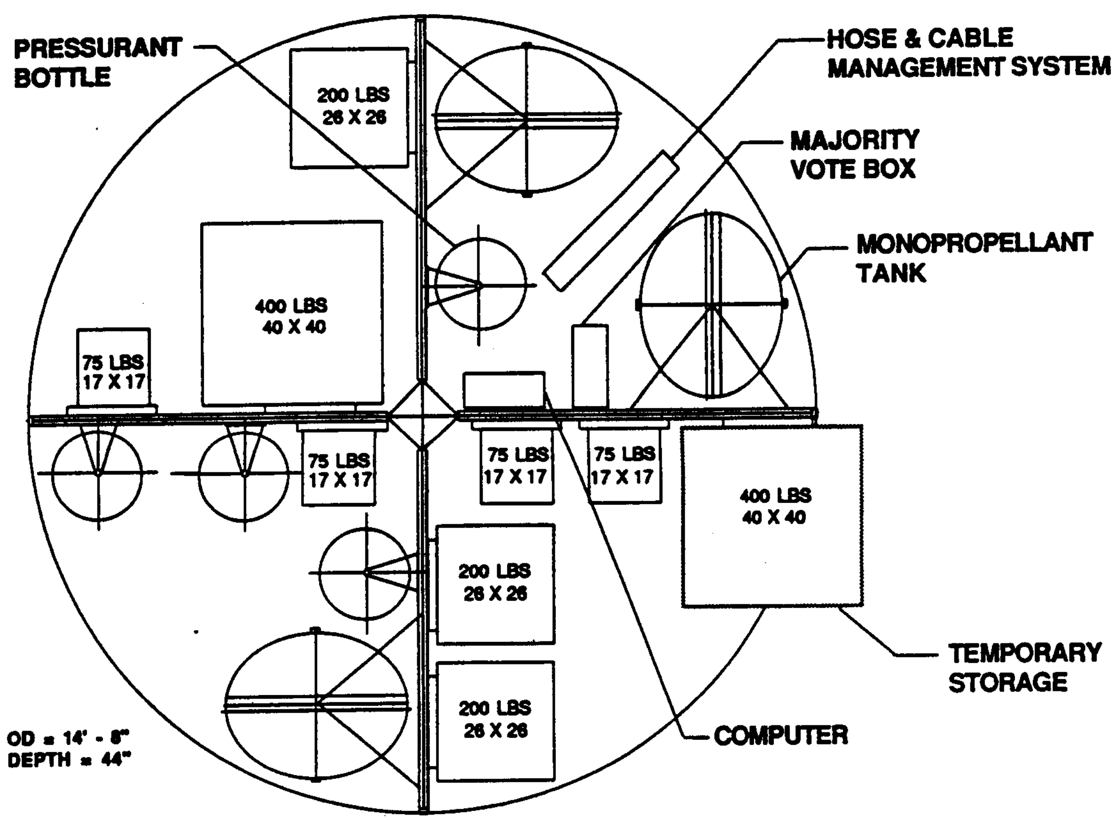

Figure 1.5-2 IOSS Stowage Rack with Fluid Resupply Tanks

Figure 1.5-3 shows the four OMSS configurations that have been conceptualized. The Type A configuration is discussed at the beginning of Section 1.0. The Type B configuration adds a five tank OSCRS monopropellant tanker to the Type A configuration. The addition of the five tank OSCRS monopropellant tanker to the fully loaded IOSS stowage rack and the OMV significantly expands the monopropellant capability of the system. In this configuration, monopropellant is manifolded from the five OSCRS monopropellant tanks and flows through an intervehicle fluid transfer device to the H&CMS in the fluid resupply stowage rack and finally to the spacecraft. Also, monopropellant can be transferred in the reverse direction to the OMV to meet propulsion needs, especially those involving docking maneuvers. The Type B configuration will easily handle the Mark II Propulsion Module single mission requirements and should be able to handle a wide range of single missions to resupply multiple spacecraft.

The Type C configuration, as shown in Figure 1.5-3, adds a six tank OSCRS bipropellant tanker to the Type A configuration. The addition of the six tank OSCRS bipropellant tanker and the fully loaded IOSS stowage rack provides a significant capability for supplying bipropellants, while maintaining a modest monopropellant capacity. In this configuration, bipropellants can flow to the IOSS fluid resupply stowage rack through two H&CMSs to the spacecraft or flow through intervehicle fluid transfer devices to the OMV to increase the range of resupply missions. Monopropellant from the three stowage rack tanks can also be directed to the spacecraft or the OMV.

The Type D configuration, sketched in Figure 1.5-3, is the highest capacity configuration and combines a five tank OSCRS monopropellant tanker and a six tank OSCRS bipropellant tanker with the Type A configuration. In this configuration, monopropellant, bipropellants, and pressurants can be transferred in either direction between the OMV, OSCRS tankers and the IOSS. This configuration should provide the maneuvering and resupply capability to service multiple spacecraft on a single mission.

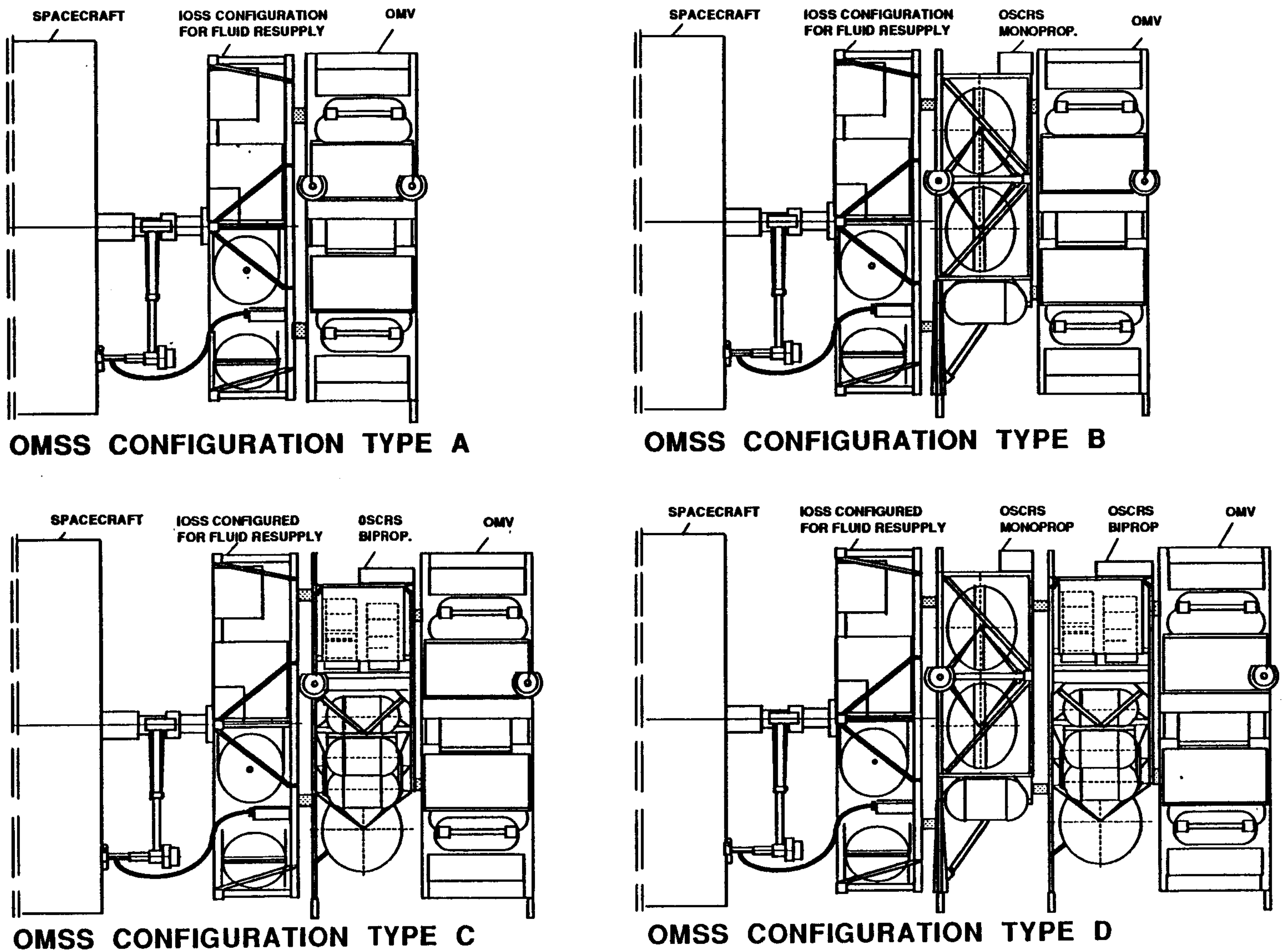

Figure 1.5-3 OMSS Configurations

Each of the four types of OMSS has eight variations to form a total of 32 configurations. The available fluid quantities for the 32 potential OMSS configurations, including and excluding 10,120 lbs of OMV fluids, are graphed in Figure 1.5-4. The 32 configurations are separated into four types (A thru D) of combinations of the major elements (IOSS, OMV, OSCRS monopropellant tanker, and OSCRS bipropellant tanker).

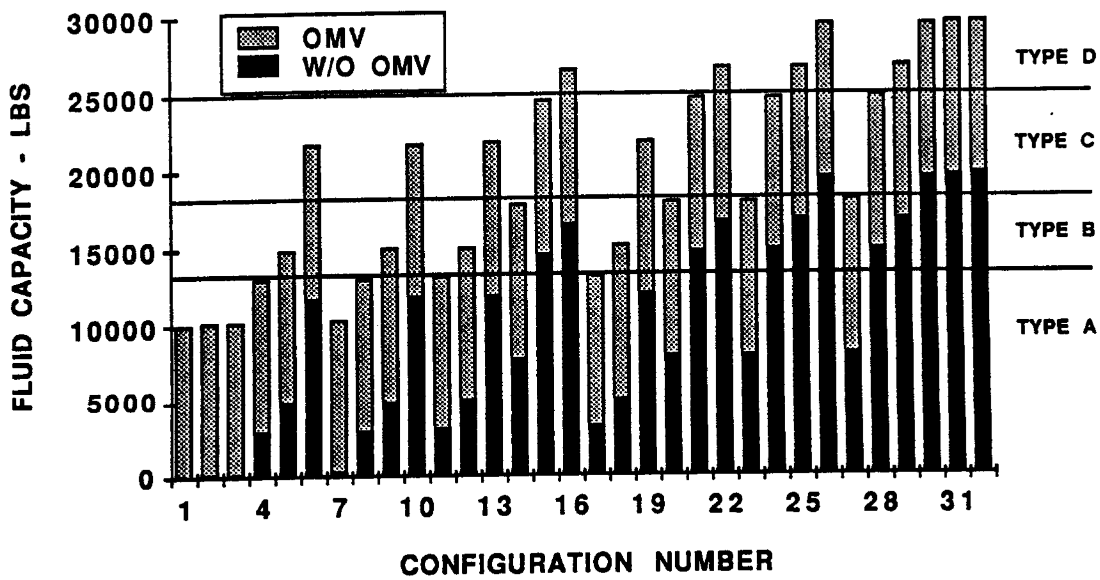

Figure 1.5-4 Potential Configurations - Fluid Capacity

1.5.4 Interfaces and Operations

The interfaces between major system elements were broken down into two categories; straightforward interfaces and more complex interfaces. The straightforward interfaces are primarily assembled on the ground and remain intact for the duration of the mission. The more complex interfaces either require new technology or complicated implementation. An examination of the range of mission scenarios showed the role of the servicing mission within the mission scenario and highlighted the events within the servicing mission. The resulting scenarios prompted a study of the mission operations that, in turn, revealed items that require further development.

Interfaces were identified by examining the interaction of the major OMSS elements, as well as the tracking and data relay satellite system and the OMSS control station. Figure 1.5-5 shows the elements centered about the IOSS. Above the IOSS is the spacecraft to be serviced, the target of the OMSS mission. At the sides of the IOSS are elements that support the fluid resupply function of the OMSS. The monopropellant and bipropellant OSCRS tankers, and the stowage rack liquid and gas tanks provide the capacity for fluid resupply. The hose and cable management system transfers fluids to the spacecraft. The ORU tanks provide spacecraft pressurant resupply. These elements are stacked on the OMV, which provides the system with maneuvering capability. The OMSS is operated from the OMV control station through the tracking and data relay satellite system and the OMV communications system.

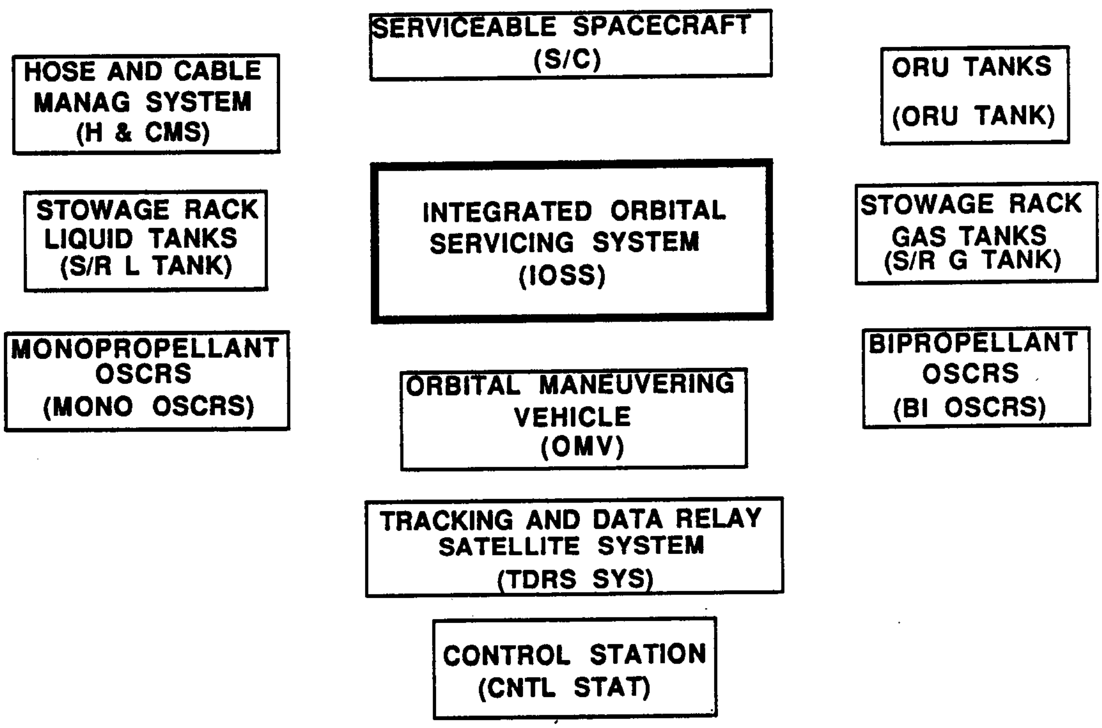

Figure 1.5-5 Major Elements for Fluid Resupply

The actual servicing operation begins with the OMSS maneuvering to within visual range of the target spacecraft, and ends with separation from the serviced spacecraft. Figure 1.5-6 shows the basic servicing scenario:

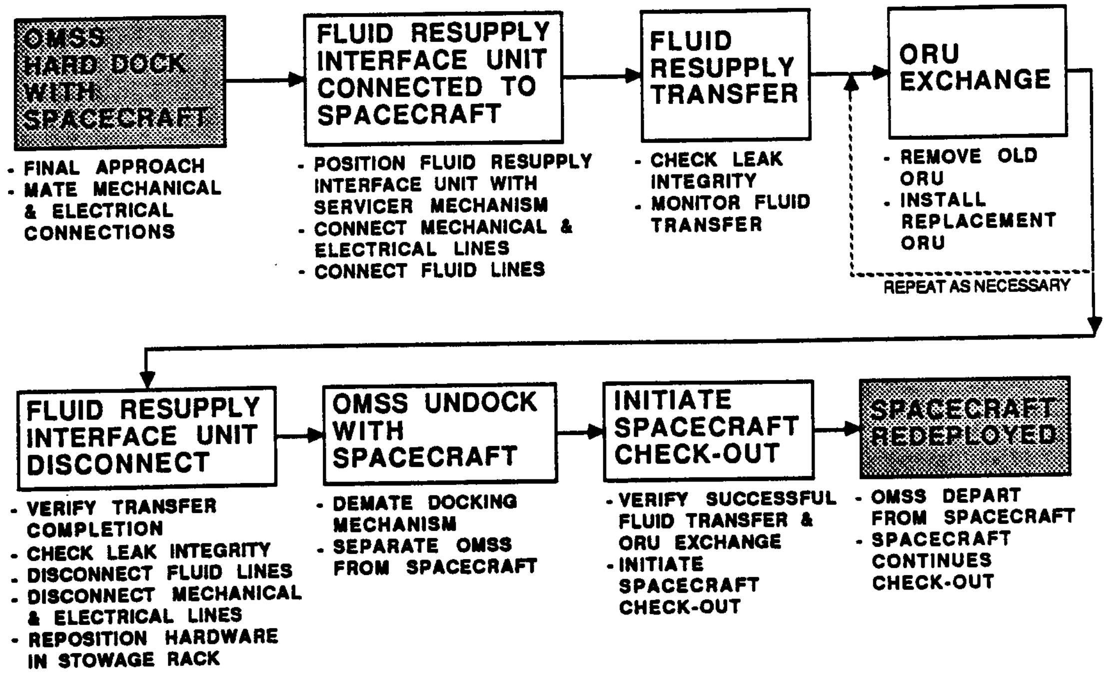

Figure 1.5-6 Servicing Scenario

Fluid resupply is initiated by the operator by connecting the fluid resupply interface unit to the spacecraft. The operator uses the servicer mechanism end effector to grasp the fluid resupply interface unit at the top of the IOSS stowage rack. The command is given to release the H&CMS from its secured position in the stowage rack. The fluid resupply interface unit is lifted with the servicer mechanism and concurrently flipped outward in the H&CMS bending plane. With the fluid resupply interface unit positioned correctly (pointing upward toward the spacecraft), the servicer mechanism moves the unit out of the H&CMS stowage plane to under the spacecraft fluid interface.

The fluid resupply interface unit is rotated to match the orientation of the spacecraft interface. The unit is translated, mechanical contact initiates removal of disconnect dust covers, electrical contact verifies mate, and final movement secures the fluid disconnects. After the interface is successfully mated, leak integrity is verified and fluid transfer is initiated.

A review of the mission and servicing scenarios, combined with our knowledge of orbital operations, revealed a number of operational considerations that should be addressed more completely in the future. Many of the items discussed (Table 1.5-4) are items that have been solved for other programs, but which have not been addressed elsewhere in this study.

Table 1.5-4 Operational Consideration Items

Mission planning
Orbital operations
Onorbit storage and reconfiguration
Space station operations
Adaptability to expendable launch vehicle operations

1.5.5 Hose and Cable Umbilicals

The hose and cable umbilical components within the OMV kit play a key role in the development of the OMSS conceptual design. The types of hoses and fluid disconnects that are currently being used were examined, as well as plans for future development. Also, devices that incorporate these components in the OMSS design are described.

A summary of the hose and cable management system requirements includes the following:

1) Prevent hoses and electrical cables from tangling or abrading;
2) Prevent hoses and cables from interfering with the servicer elements or spacecraft structures;
3) Assure hoses and cables are not overstressed or allowed to bend more tightly than the minimum bend radius;
4) Minimize the number of bends;
5) Minimize the total length of the H&CMS;
6) Maximize the working envelope for the servicer mechanism;
7) Have H&CMS deployment motion compatible with the servicer mechanism range of motion;

8) Store H&CMS entirely within the stowage rack;

9) Keep H&CMS design simple and reliable.

The H&CMS consists primarily of a hose and cable carrier that contains as many as four fluid hoses and two electrical cables. The carrier design allows bending in one plane only, with a minimum bend radius no smaller than any of the hose or cable allowable bend radii, assuring that hoses and cables are not overstressed.

The fluid and electrical disconnects are incorporated into a device that provides the translation motion for disconnect mate and demate with the spacecraft fluid interface. This device, called the remote umbilical mechanism, is shown in Figure 1.5-7. The RUM was designed, built and tested by Martin Marietta, and provides automated mate/demate for fluid and electrical connectors. It is part of the space station advanced development program and was developed for shuttle cargo bay operations in which a satellite is retrieved by the remote manipulator system (RMS) and latched into the cargo bay on the GSFC support ring (part of the MMS flight support system). The RUM has two main active

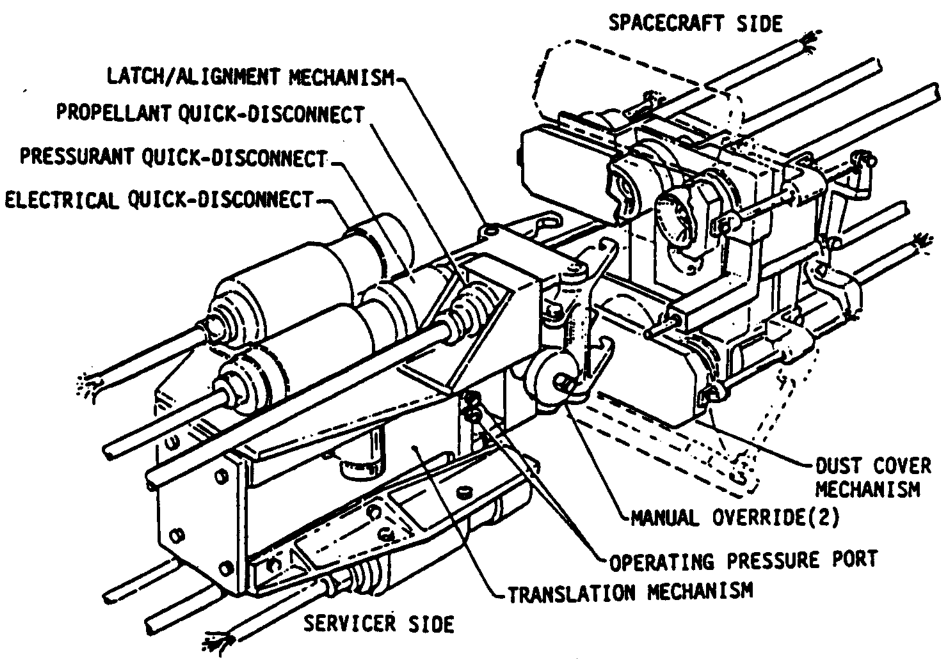

Figure 1.5-7 Remote Umbilical Mechanism

functions: 1) latch to the satellite receptacle assembly to provide final umbilical alignment and latching, and 2) translate umbilical connectors on the servicing side to engage the receptacles on the satellite side for electrical, gas, and liquid circuits.

Although the RUM was designed for use at the orbiter, it can be readily incorporated into the OMSS design for in-situ spacecraft servicing. As part of the FRIU, the RUM satisfies the following requirements:

1) Positive mechanical attachment of the FRIU at the spacecraft interface;
2) Self alignment capability to allow for ± 3/4 in. lateral offset and ± 15° angular misalignment prior to attachment (same as IOSS design capture volume);
3) Minimum risk of jamming disconnects during mate and failing to disengage under normal retraction forces;
4) Allows for intermediate stops during translation to verify status of fluid disconnect seals and for purging and venting operations;
5) Volume occupied by mate/demate mechanism less than 1 cubic ft of internal spacecraft volume.

The integration of the RUM into the FRIU is detailed in the next section, Ground Demonstration Concepts.

1.5.6 Ground Demonstration Concepts

The existing servicer engineering test unit, that was delivered to NASA Marshall Space Flight Center under the IOSS contract, is well suited to being the basis for fluid resupply and ORU exchange ground demonstrations. It has been used for ground demonstrations of ORU exchange for a number of years and has a sophisticated capability for demonstration of these functions including a refined control system and ancillary equipment such as a lightweight module servicing tool.

A view of the fluid resupply interface unit arrangement is shown in Figure 1.5-8. The right-hand side of the figure shows the Martin Marietta form of fluid interface unit called the remote umbilical

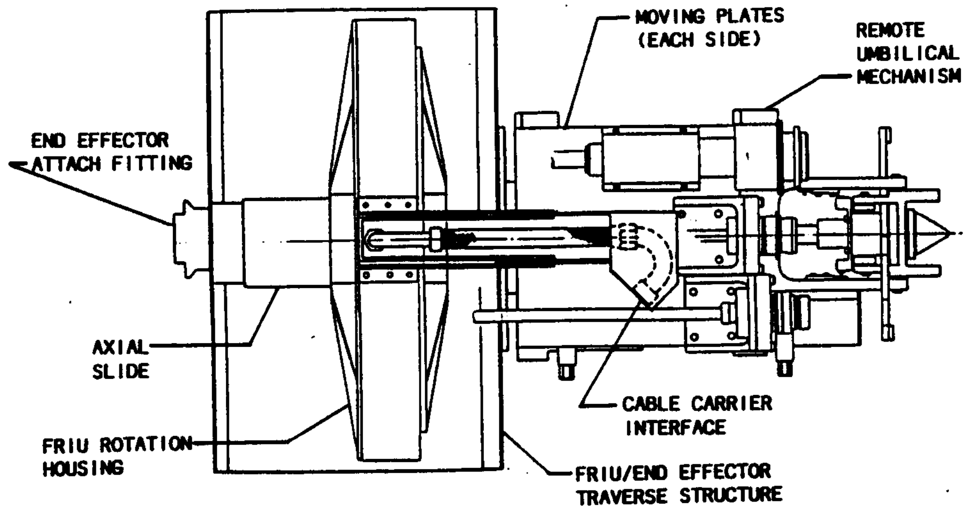

Figure 1.5-8 FRIU Arrangement

mechanism, or RUM. Attachment to the spacecraft, or to the stowage rack is by the jaw arrangement used on the ETU end effector. The ETU end effector attach fitting is used on the left hand end of the FRIU so it will be compatible with the ETU. A fluid disconnect and an electrical cable connector are shown on the facing side of the RUM, although only one of each of these elements will be used for the 1-g fluid resupply demonstrations (the electrical connector on one side and the fluid disconnect on the other side).

The hose and cable lines pass from the RUM through the traverse structure to a cutout in the FRIU rotation housing. The hose and cable exit from the side of the FRIU rotation housing and then pass to the cable carrier interface. The cable carrier interface is at an angle of 45 deg to the FRIU centerline to avoid reverse bending of the cable carrier. The cable carrier can be bent 180 deg as it leaves the FRIU, when in the stowed position, and the cable carrier will not extend outside the stowage rack when the end effector attach fitting is just above the top of the stowage rack.

An H&CMS upper tilt axis is incorporated in the FRIU design. The upper tilt axis is set off from the FRIU centerline (out of the plane of the paper) so that the 45 deg travel of the tilt axes can be accommodated. The axial slide that guides and stabilizes the FRIU rotation housing is shown to the left.

A plan view of the general arrangement of the ETU and fluid resupply equipment for the ground demonstration of fluid resupply is shown in Figure 1.5-9. The quadrant shown for the location of the fluid resupply equipment is away from the usual viewing area, but it is the better of the two quadrants remaining.

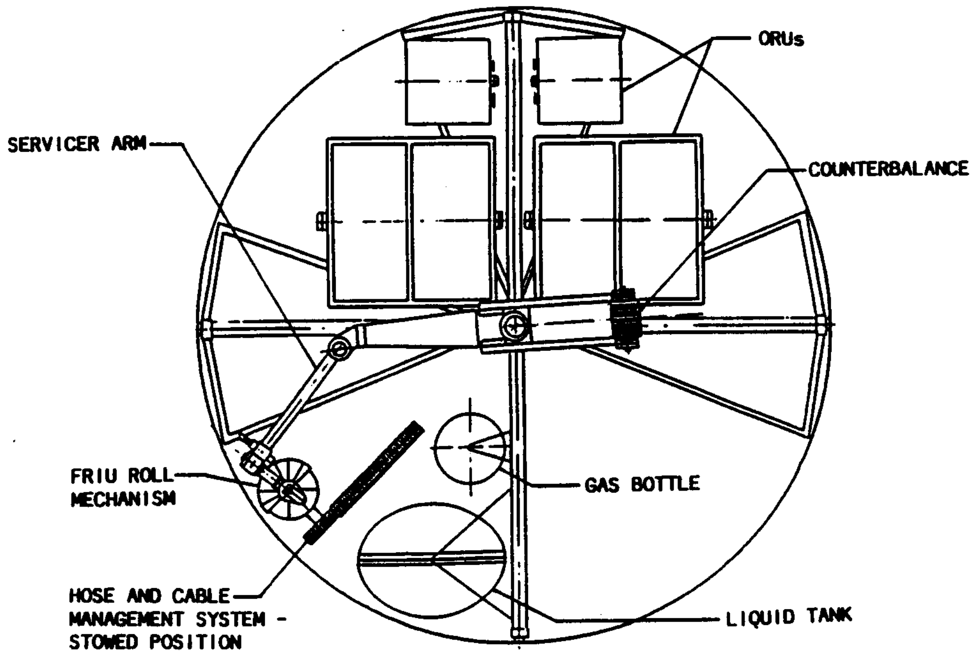

Figure 1.5-9 H&CMS General Arrangement

The recommended location of the hose and cable management system is shown along with the location of the servicer mechanism at the point of picking up the FRIU from its stowed location. The FRIU is offset from the cable carrier to avoid interference between these two elements during the stow/unstow and flip operations. An open area exists on the spacecraft mockup that is generally above the stowage rack rib in the left hand side of the figure. This location could be used for the fluid resupply interface on the spacecraft mockup. An alternative is to use the innermost axial ORU location on the spacecraft for the fluid resupply interface. The recommended concept can reach either location.

The stowed configuration of the hose and cable management system is shown in Figure 1.5-10 in two views. The tangential view, on the right, shows the position taken by the cable carrier in the stowed position. The vertical upright on the right of the hose and cable carrier rack acts as a stop when the H&CMS is being removed from or placed into the hose and cable carrier rack. This rack has a space frame outline so that the cable carrier will tilt the rack and thus bend the hose that connects from the cable carrier to the base of the ORU stowage rack. For a flight unit, the hose and cable carrier could be stabilized with a clamping arrangement during launch and reentry.

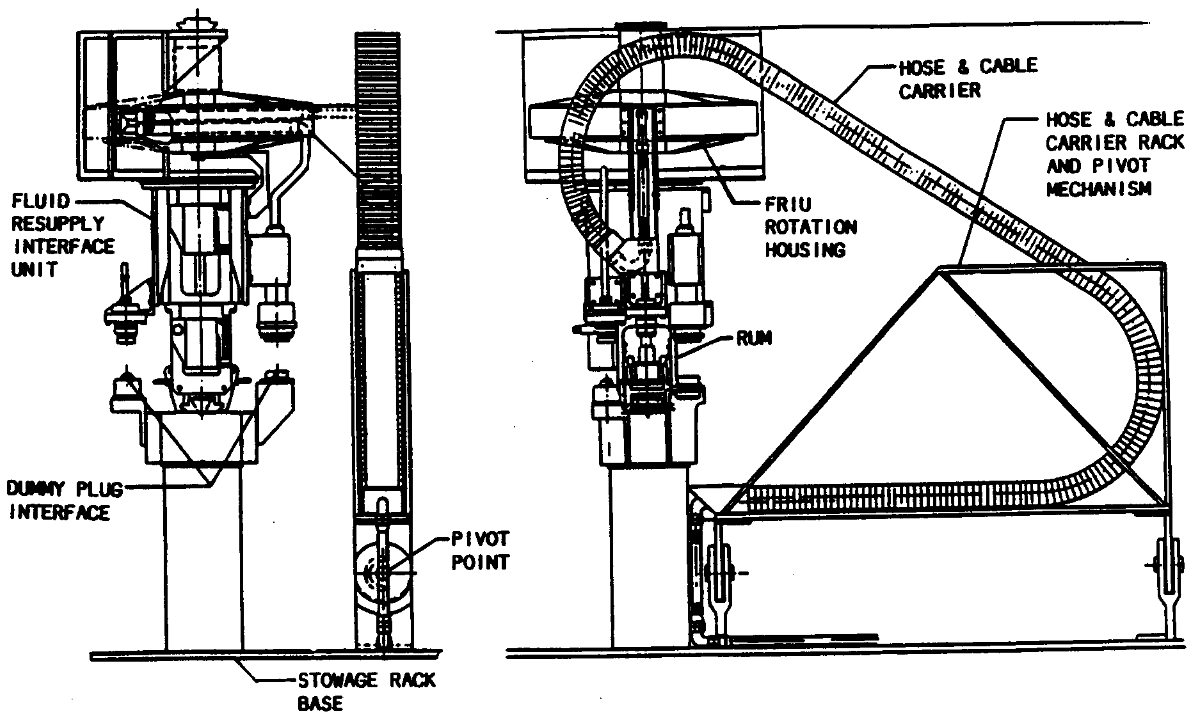

Figure 1.5-10 Hose and Cable Management System - Stowed Configuration

The FRIU rotation housing and the remote umbilical mechanism of the FRIU are shown in both views in the figure. The radial view of the stowed position is shown on the left hand side. The pivot point and short length of flexible hose from the stowage rack base to the cable carrier, past the pivot point, are shown in both the radial and tangential views. The offset between the FRIU and the cable carrier can be seen along with the upper tilt pivot, which is in phantom behind the cable carrier.

1.6 SUGGESTED ADDITIONAL EFFORT

A review of the study efforts and conclusions identified a number of areas that merit consideration for additional effort. In addition to the items listed below, it is assumed that the tracking and data relay satellite system (TDRSS) program and the OMV program including a docking system, payload rigidization system, and ground control station will continue. The need for a more general docking system that can absorb energy, as compared to the berthing systems that are currently being considered for use with the OMV, cannot be overstated.

1.6.1 Fluid Resupply Tasks

The following additional efforts are related to fluid resupply tasks and the related equipment:

1) Development of the orbital maintenance and servicing system, as conceptualized in this report, should be initiated;
2) Development of both monopropellant and bipropellant OSCRS systems should be continued;
3) Development of a hose and cable management system should be initiated;
4) Development of the fluid resupply interface unit should be continued;
5) Development of fluid disconnects, that are suitable for use on the FRIU, in a 3/4 in. size for liquids and in a 1/4 in. size for gases should continue;
6) Development of the elements of the intervehicle fluid transfer device in a variety of sizes should be initiated;
7) Development of a fluid disconnect suitable for use with the tank as an ORU concept should be initiated.

1.6.2 Servicing Mechanism

The following additional effort is related to the servicing mechanism:

1) The interface between the servicer end effector and the ORU interface mechanisms, tools, adapters, fluid resupply interface unit, and the fluid interface on the spacecraft should be standardized.

1.6.3 Ground Demonstrations

The following additional efforts are related to ground demonstrations:

1) Initiate the preliminary design of equipment for the ground demonstration of fluid resupply using the engineering test unit in the MSFC Robotics Laboratory for the servicer mechanism;
2) Extend the preliminary design to final design, fabrication, assembly and operation of a set of equipment for the ground demonstration of fluid resupply using the onorbit servicer engineering test unit.

2.0 INTRODUCTION AND BACKGROUND

The fluid resupply form of onorbit servicing has been addressed in a number of studies in recent years (Ref 2-1, 2-2). These studies have shown how fluid resupply might be accomplished, the quantities and types of fluids of interest and examples of specific spacecraft that might desire fluid resupply. The economic advantages of fluid resupply, by itself, have not been very clear. However, the advantages of fluid resupply when combined with onorbit maintenance in the form of orbital replacement unit (ORU) exchange, are numerous and the process is economic. Prior to this study there has been little done to investigate the combination of fluid resupply and ORU exchange. Fluid resupply via ORU exchange where the fluid is contained in a tank that is exchanged was suggested as part of the Integrated Orbital Servicing System (IOSS) studies. Also, the transport of fluid in tanks in the IOSS stowage rack and then transfer of the fluid to the serviced spacecraft via an umbilical that would be positioned by the IOSS servicer mechanism has been suggested. However, neither of these concepts had been addressed in much detail or as part of a more inclusive consideration of integrating fluid resupply with ORU exchange. The purpose of this study is to examine the effects of adding fluid resupply to the capabilities of the IOSS.

This study is part of a series of tasks involving onorbit servicing and the engineering test unit (ETU) of the onorbit servicer. The ETU is a full-scale operational version of the IOSS including a control system and the necessary software. The objective of the broader activity is the advancement of orbital servicing by expanding the Spacecraft Servicing Demonstration Plan (SSDP) to include detail demonstration planning utilizing the multimission modular spacecraft (MMS) and upgrading the engineering test unit control system. The work expanded and updated the Servicer Development Program Plan to include high fidelity ground, in-bay, and free-flight demonstrations of a servicer system. The effort also included verification of the updated control system of the ETU by demonstrating module exchange between the spacecraft and stowage rack mockups, utilizing three control modes--Supervisory, with and without operator action steps and Manual-Augmented. Control system upgrading was based on a combination of software used by MSFC and that used during the ETU design acceptance review conducted at Martin Marietta.

The servicer system/multimission modular spacecraft 1-g demonstration definition effort was expanded in terms of selection of the overall configuration, design of specific demonstration equipment, and preparation of schedule and cost estimates.

The effort was further expanded to include the preparation of drawings, fabrication of MMS module mockups and related equipment, and installation of the mockups and equipment at the MSFC Robotics Laboratory. The software developed under the basic contract was complemented with a second set of software for the demonstration of MMS module exchange. These activities, along with a separate activity for the design and fabrication of a 1-g version of the MMS module servicing tool, led to a demonstration of MMS module exchange using the three control modes.

A preliminary Servicer System User's Guide that may be used as an engineering and planning document for emerging spacecraft projects was prepared.

Software for an improved operator interactive control system with the capability to: 1) manually override anomalies that inhibit continuation of Supervisory mode trajectories, 2) manually override anomalies that prevent initiation of a Supervisory mode trajectory sequence, and 3) initiate Supervisory mode trajectories from selectable locations was prepared. A data acquisition, analysis, control and display (DAACD) system was provided that is compatible with the improved control system and existing servicer and control console. The DAACD was integrated at MSFC and the control system improvements were demonstrated.

The effort addressed in this report is an analysis to define an orbital maneuvering vehicle (OMV) front end kit capable of performing in-situ fluid resupply and modular maintenance of free flying spacecraft based on the integrated orbital servicing system concept. This integration analysis, with respect to missions that combine module exchange and fluid resupply, involved analyses and tradeoff studies to identify equipment configurations, interfaces between major elements, mission scenarios, and operational considerations. The exchange of tanks and the transfer of fluids through umbilical connectors were considered as options. The analysis also addressed the compatibility of the IOSS to perform gas and fluid umbilical connect and disconnect functions utilizing connector systems currently available or in development. A conceptual approach to the demonstration of fluid transfer in 1-g using the engineering test unit in the MSFC Robotics Laboratory was identified and recommended to NASA.

2.1 OBJECTIVE AND GUIDELINES

The broad objectives of this Servicer System Demonstration Plan and Capability Development study are to identify all major elements and characteristics of an onorbit servicing development program and to integrate them into a coherent set of demonstrations, to upgrade the engineering test unit control system for basic and module exchange demonstrations, to upgrade the MSFC servicing demonstration facility mockups to permit the exchange of MMS modules, to prepare a Servicer System User's Guide, to upgrade the ETU control system for easier operator interaction, and to perform an analysis of the integration of fluid resupply and module exchange.

The last study objective is the focus of this report. More explicitly, the objective of this phase of the contract, as shown in Table 2.1-1, is to define an orbital maneuvering vehicle front end kit that is capable of performing both fluid resupply and module exchange at a spacecraft in its operational orbit. The term "module" is used in the same sense as orbital replacement unit in this document. The objective also includes the determination of the compatibility of the integrated orbital servicing system to perform gas and liquid umbilical connect and disconnect functions. The third part of the analysis objective is to address methods of demonstrating fluid transfer in 1-g using the engineering test unit.

Table 2.1-1 Objective and Guidelines

<u>Objective</u>

Define an orbital maneuvering vehicle front end kit capable of performing, in-situ, both fluid resupply and modular maintenance

<u>Guidelines</u>

Base on Integrated Orbital Servicing System concept

Include gases, hydrazine and bipropellants

Consider for tanks and tankers
- Orbital Maneuvering Vehicle
- Mark II Propulsion System
- Space Platform Expendables Resupply Concept
- Orbital Spacecraft Consumables Resupply System

Evaluate both exchange of tanks and fluid transfer through umbilicals

The guidelines for the integration analysis are also given in Table 2.1-1. These guidelines were taken from the contract statement of work for this fluid resupply integration analysis. The integrated orbital servicing system concept emphasizes ORU exchange by a servicer mechanism, or manipulator system. The servicer mechanism can be used to position a fluid resupply interface device (quick-disconnects) with attached umbilical hoses to a range of attachment locations on the spacecraft to be serviced. The fluids of concern were purposely limited to gases, hydrazine, and bipropellants as these are the fluids that appear most often in prior mission models. The set of four tankers listed in Table 2.1-1 are the major candidates that have been studied recently. The OMV equipment considered as a tanker was the removable bipropellant tank set. The Mark II Propulsion Module is part of the Multi-mission Modular Spacecraft system. Rockwell International performed the Space Platform Expendables Resupply Concept (SPERC) study for MSFC. The Orbital Spacecraft Consumables Resupply System (OSCRS) was studied for JSC by three contractors, including Martin Marietta. The tanker studies each considered a range of tanks for incorporation in their designs, thus the data was available in those study reports for the selection of tanks to be installed in the IOSS stowage rack.

2.2 BACKGROUND

One of the justifications for the space transportation system (STS) was its potential for supporting the repair or recovery of failed spacecraft. This approach was extended to the concept of making less expensive spacecraft, accepting the higher predicted failure rates, and using the Shuttle to permit repair of those spacecraft that did fail. This spawned a large number of government, industry, and academic studies on how spacecraft might be configured for onorbit servicing. The whole gamut from recovery and ground refurbishment, through repair at the orbiter, through remote operations in low earth orbit, to repair in geosynchronous orbit were addressed. All of the concepts discussed now were addressed then except for space station related operations. A good summary of the early work is given in Reference 2-3.

The major elements and results of the orbital servicing background are summarized in Table 2.2-1. This background (including References 2-4 and 2-5) shows overwhelming economic and operational benefits resulting from an onorbit servicing capability. These benefits are recognized by all current studies as well. An extensive set of servicing system hardware and components has been defined.

The servicer system configuration shown in Figure 2.2-1 was evolved through a series of iterations during which a very wide range of alternatives were considered. The design is compatible with maintenance of most spacecraft of the STS era. Adapters may be used to accommodate support structure differences across the applications. The design has only two major components: a servicer mechanism and a

Table 2.2-1 Major Results of Prior Orbital Servicing Studies

Cost benefits of unmanned onorbit satellite servicing are high
Development activities were initiated in the early 1970's
A variety of servicing system concepts have been defined and evaluated
Module exchange is a major servicing activity
The IOSS study identified a promising servicer mechanism
A 1-g servicing demonstration facility was built and is in continuing use
A three-phase onorbit servicing development plan was prepared

stowage rack for module transport. A docking mechanism is also shown for reference and so that the mechanical interface aspects may be more readily visualized. Stowage racks can be configured and loaded for particular flights prior to attachment to the carrier vehicle. It may be desirable to have several stowage racks available for this purpose. The stowage rack shown mounts directly to the OMV.

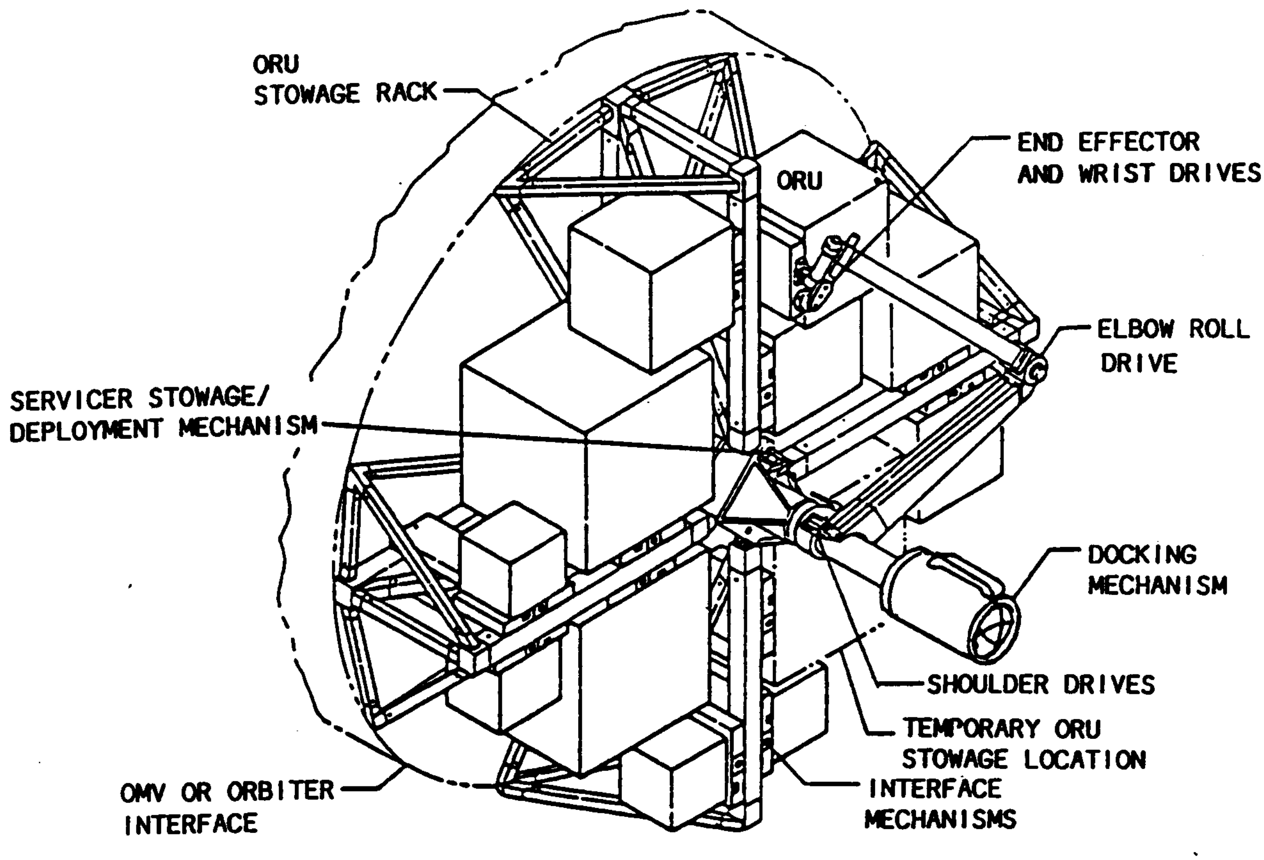

Figure 2.2-1 IOSS Onorbit Servicer Configuration

The Space Platform Expendables Resupply Concept study (References 2-1 and 2-6) investigated, for MSFC, a remote resupply module (RM) for the OMV. The study considered that the remote resupply alone of low Earth orbit (LEO) satellites is of potential economic benefit, but fluid resupply combined with ORU exchange is much more beneficial. The need for a LEO propellant storage depot with a space-based OMV/RM was emphasized. The economic value of fluid resupply to geosynchronous Earth orbit (GEO) depends on the characteristics of the communications service cost and revenue stream. Again, it is beneficial to update the satellite when it is refueled. A concept for a large (approximately 45,000 lb of propellant) resupply module was prepared that used stretched orbital maneuvering system (OMS) tanks to contain the propellants. A flight demonstration program was defined and costs were estimated. The primary study emphasis was on missions and economics.

The Orbital Consumables Resupply System study was performed by three contractors, including Martin Marietta Corporation (Reference 2-2). The primary mission was to resupply the Gamma Ray Observatory (GRO) with monopropellant from the orbiter cargo bay using astronauts on EVA to connect the fluid umbilicals. A significant concern was system safety. The initial OSCRS monopropellant capability was extended to bipropellants and pressurants. Future propellant transfers were to be accomplished remotely using tankers in conjunction with the OMV and space station. The major study emphasis was on requirements and design.

2.3 APPROACH

Our approach to the fluid resupply integration analysis was organized into the six subtasks shown in Figure 2.3-1. In the Data Collection and Requirements Identification subtask, data were to be collected for each of the major elements involved in fluid resupply and module exchange. These included: IOSS, orbital maneuvering vehicle, the four tankers listed in Table 2.1-1, candidate tanks, candidate fluid transfer umbilicals, and hoses. Much of the data was readily available. Concurrently with the data collection, sets of requirements for each of the major equipments and functions involved were prepared.

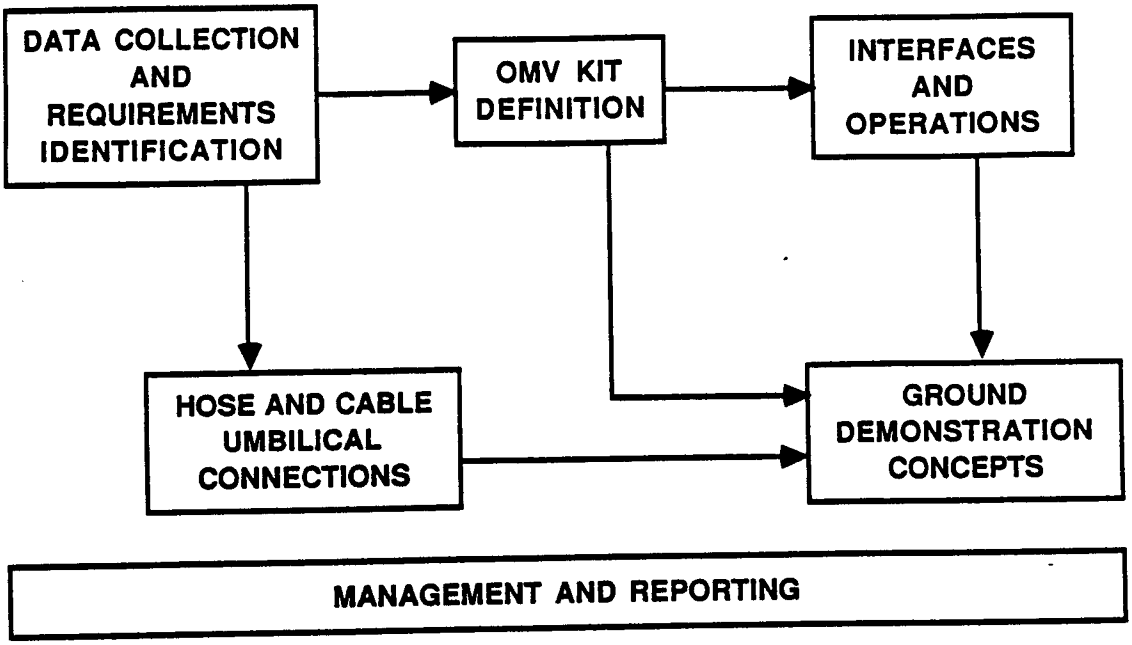

Figure 2.3-1 Task Flow Chart

The OMV kit definition activity started with the identification of candidate systems. These systems were combinations of the IOSS, OMV, tankage, and fluid transfer systems. Candidates were identified and defined sufficiently to conduct trade studies. Our experience and discussions with NASA personnel were used to identify the candidate systems.

A set of three interrelated trade studies were conducted on the candidate OMV kits to identify significant characteristics of the candidate systems and to obtain a better understanding of the candidates.

The candidate OMV kits were then evaluated against the system and subsystem requirements identified above and a set of selection criteria. The selection criteria were identified from our experience on similar programs, the criteria expressed in the Space Platform Expendables Resupply Concept and the Orbital Spacecraft Consumables Resupply System reports, and from discussions with MSFC personnel.

A recommended concept was selected based on the results of the evaluation. The results of this selection process, along with the selection rationale, were presented to MSFC at the Mid-Term Review. The selected concept was further defined including conceptual drawings and lists of characteristics.

The interfaces and operations activity was conducted in three parts. The first part was identification and definition of interfaces between the major elements of the selected concept. This identification and definition process was based on our prior experience on similar concepts, including the IOSS. The second part was the preparation of mission scenarios for the selected concept. This activity was similar to that which we conducted for the Tumbling Satellite Retrieval study. The scenario development activity resulted in the identification of additional system and subsystem requirements that were added to those prepared initially. The third part was the identification and definition of operational considerations for the selected concept. These operational considerations flowed from the mission scenario development.

The hose and cable umbilical connection work started with identification of requirements and their documentation. These requirements were based on prior IOSS work along with those documented in the SPERC and OSCRS reports. Alternative gas and fluid connect and disconnect systems currently available, or in development, were identified, descriptive material on each was collected, and this material was summarized for comparison. A gas and fluid umbilical connector concept was selected and recommended to MSFC for use in the candidate fluid resupply and module exchange concept. While this umbilical connector emphasizes gases and liquids, it also involves electrical connections as well, as it is necessary to control valves and monitor pressures and temperatures during fluid transfer.

Concepts for the ground demonstration of gas and liquid resupply using the engineering test unit of the onorbit servicer in the MSFC Robotics Laboratory were identified and described. These concepts were based on prior IOSS work and on Independent Research and Development tasks conducted in 1986. A major variable was to determine whether the fluid lines could be bent and twisted, or whether they must be constrained from twisting when they are bent. This latter restriction pertains to hoses incorporating metal convolutions (as in a bellows). If the hoses can not be bent and twisted at the same time, then a more complex restraint system would be necessary. The other obvious problem was identification of a method for counterbalancing the variable hose weight and moment as it is moved around. A conceptual approach for the 1-g demonstration of gas and liquid resupply using the engineering test unit in the MSFC Robotics Laboratory was selected and a recommendation made to MSFC.

The management subtask included the management, MSFC coordination, planning, report preparation, reproduction and distribution, and travel activities.

The interrelations between the subtasks are shown on the figure and are straightforward. The three subtasks in the upper row form one sequence of activity and the two subtasks in the left column form another sequence of activity. Information from the three subtasks shown flows into the ground demonstrations subtask to help define what should be demonstrated in 1-g.

3.0 DATA COLLECTION AND REQUIREMENTS

One guideline for the study was that we should use as much data from the literature as we could so as to not expend study resources repeating work that had been done and also to get any detail information from the literature. The major data sources used in the analysis are listed in Table 3.0-1. All of this information was directly available to us. While the Servicer System User's Guide has most of the required IOSS data, it was complemented by our extensive IOSS data base. It was difficult to obtain current data on the orbital maneuvering vehicle (OMV) as it was being defined at the time and much of the data was not definite. Fortunately, not much specific data was required. The data was a mixture of TRW OMV data and older MMAG OMV data. In particular, MMAG OMV data was used for the tanks considered in the tank trade study.

Table 3.0-1 Data Sources

Integrated Orbital Servicing System - Servicer System User's Guide
Orbital Maneuvering Vehicle - User's guide and other capabilities data
Space Platform Expendables Resupply Concept - 1984 concept definition study - 1985 study addendum
Mark II Propulsion Module - 1982 AIAA paper by J. F. Haley, Jr.
Orbital Spacecraft Consumables Resupply System - MMAG final report in eight books

The Space Platform Expendables Resupply Concept (SPERC) study data available was a complete set of the study reports including presentation handouts. Unfortunately, certain specific information, such as the length of the stretched tanks (orbiter orbital maneuvering system (OMS) tanks) was not available and had to be estimated from statements of tank capacities. The effect of estimation errors was not critical, as the OMS tanks, regular or stretched (112 in. long), are too large for use in the IOSS stowage rack.

The Mark II Propulsion Module information in the noted paper was adequate for the level of analysis conducted. While Martin Marietta builds the Mark II Propulsion Module, specific data is difficult to obtain because of the application of the module.

The major source of information on tanks and candidate tankers was contained in the eight book final report of the Martin Marietta Astronautics Group Orbital Spacecraft Consumables Resupply System (OSCRS) team. This data is extensive and thorough, covering both monopropellants and bipropellants. As would be expected from the timing and size of the study, the OSCRS data includes the results and approaches developed in prior studies and gives answers that fit current mission model requirements. Some OSCRS data from the other two contractors, Rockwell International and Fairchild Space Company, was also available to the integration analysis team members.

The requirements for a fluid resupply system that would be integrated with the IOSS have been collected from a variety of sources over a period of time. The bulk of them were presented in a Martin Marietta Independent Research and Development (IR&D) report. The OSCRS requirements were also included, as were some requirements from our space station activity. The level of applicability varies from the top level to specific details regarding the 1-g demonstration. Table 3.0-2 provides a summary of the requirements as they existed at the Mid-Term presentation. A full compilation of all of the requirements is given in Appendix B.

Of the total of 130 requirements (Mid-Term status), the major groupings are for system requirements for the operational servicer, hose and cable management subsystem, fluid and electrical connector requirements, and ground demonstration requirements. Of the requirements used for the Section 4.0 trade studies, most were from the system requirements group.

Table 3.0-2 Fluid Resupply Requirements Summary

System requirements for operational servicer (21 items)
Non-propellant cryogenic fluid transfer (5 items)
Contamination related (3 items)
Thermal control (6 items)
Standardized spacecraft interfaces (3 items)
Safety (12 items)
Reliability and maintainability (2 items)
Cost (2 items)
Hose and cable management subsystem (19 items)
Connector requirements (32 items)
Command and control and software (4 items)
Ground demonstrations (21 items)

3.1 DATA COLLECTION

Four major reports (References 3-1, 3-2, 3-3, 3-4) that document the Integrated Orbital Servicing System (IOSS) are listed in Figure 3.1-1. These reports, prepared by Martin Marietta, provided IOSS background information that was used in performing the tank and tanker trade studies, and in developing the OMV front end kit definition.

The Servicer System User's Guide describes the IOSS, including basic functions and spacecraft design considerations. The basic function of the IOSS is to perform orbital replacement unit (ORU) exchange. The IOSS major components are a stowage rack, a docking probe, and a servicer mechanism. The IOSS volume is defined mainly by the stowage rack, which is 14.7 ft in diameter and deep enough to stow 40 in. ORUs. The docking probe extends a total of 60 in. from the stowage rack. The servicer mechanism is attached to the docking probe 30 in. from the stowage rack and has an effective reach of 11.2 ft with a stowed length of 27 in. The entire system weighs approximately 629 lbs.

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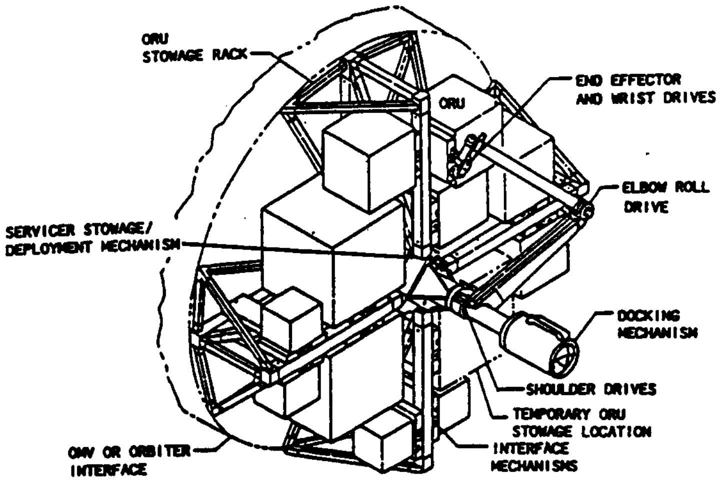
CONTRACTOR:
MARTIN MARIETTA



DATE	DOCUMENT TITLE	CONTRACT #	REPORT #
07/86	SERVICER SYSTEM USER'S GUIDE	NAS8-35625	MCR-86-1339
07/86	ONORBIT SERVICING	IR&D D-64S	S86-41564-001
12/85	FINAL TECHNICAL REPORT	NAS8-35625	MCR-85-1365
06/78	FINAL TECHNICAL REPORT	NAS8-30820	MCR-77-246

Figure 3.1-1 Data Sources - Integrated Orbital Servicing System

In addition to the description of the system and its basic function, IOSS requirements have been used in this fluid resupply integration analysis. The onorbit servicing IR&D task D-64S (Reference 3-2) was used to identify applicable system and subsystem requirements including those for fluid resupply. The largest single spacecraft fluid resupply requirements are defined as 5000 lb for monopropellant and 7000 lb for bipropellant.

The system must also meet requirements (temperature, pressure, and flow rate) that are discussed in more detail in this section.

The orbital maneuvering vehicle was being defined during this integration analysis activity, making it difficult to extract specific capabilities. The documents listed in Figure 3.1-2 offer the best information available. Although the data is preliminary, it was adequate for this phase of analysis.

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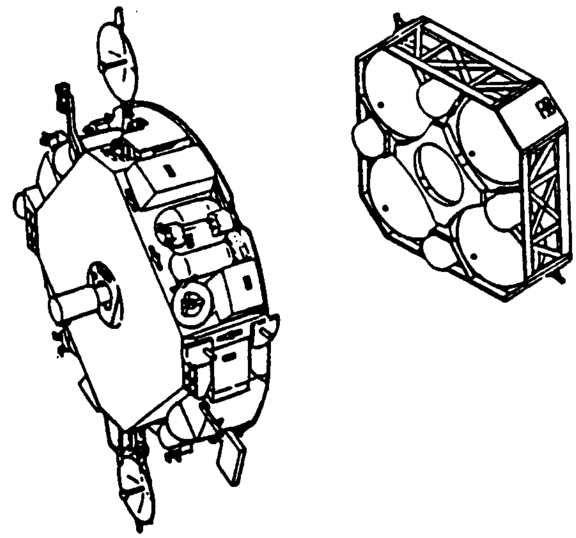
CONTRACTOR:
TRW



DATE	DOCUMENT
06/87	OMV - THE NASA SATELLITE SERVICING VEHICLE, SATELLITE SERVICING WORKSHOP III, PAPER #8 (MAC MORRISON, TRW)
04/87	OMV DESIGN CHARACTERISTICS - DRAFT (JIM TURNER, MSFC)
12/86	USER'S GUIDE FOR ORBITAL MANEUVERING VEHICLE (MSFC)

Figure 3.1-2 Data Sources - Orbital Maneuvering Vehicle

The first document, OMV - The NASA Satellite Servicing Vehicle (Reference 3-5), from the Satellite Servicing Workshop III, was used to obtain the latest OMV data from TRW, the Phase C/D contractor. OMV capabilities are discussed, including electrical power and payload interfaces. The OMV will provide electrical power from a dedicated battery to supply 5 KWh of energy and 1 KW of peak power to docked or attached payloads. The OMV will interface with the payload to provide command and data relay communications and attitude control. Payloads may be attached to the OMV by several methods: a remote grapple docking mechanism uses a remote manipulator system (RMS) snare end effector, a three-point ring attachment, a cantilever STS transport attachment, or by any customized configuration designed by the user to interface with available attachment devices.

The second document, the draft of OMV design characteristics (Reference 3-6), was used to ascertain approximate design characteristics. OMV propellant weight capabilities (8775 lbs of bipropellant, 1180 lbs of monopropellant, and 165 lbs of GN_2) were updated and size parameters (56 in. wide by 176 in. in diameter) were confirmed, during a June 22, 1987 telephone conversation with Mr. William Galloway of the MSFC OMV office.

The third document (Reference 3-7), The User's Guide for Orbital Maneuvering Vehicle, provided general information about OMV operations. The primary control of OMV will be from a ground station via a two-way link through the Tracking and Data Relay Satellite System (TDRSS). Space station will control only those operations in close proximity to the station. A later version of the OMV User's Guide (Reference 3-20) was obtained after the tank/tanker trade study was complete as was an analysis of the OMV as a tanker resupply system (Reference 3-21).

The tank trade study, one of the tasks defined in this fluid resupply integration analysis statement of work, used data from previous tank studies performed by Martin Marietta Corporation and Rockwell International. These data were used to avoid time-consuming, repetitious research of basic tank information.

Martin Marietta studied a number of tanks for use in the Orbital Spacecraft Consumables Resupply System program. The OSCRS Final Report (Reference 2-2), listed in Figure 3.1-3, provided data on the monopropellant and bipropellant configurations that were selected. The monopropellant configuration consists of three, 41 in. diameter TDRSS tanks. The bipropellant configuration utilizes six, 45 in. diameter L-SAT tanks; two for monomeythlhydrazine (MMH), two for nitrogen tetroxide (NTO) and two empty catch tanks. The OSCRS Requirements Definition document (Reference 3-8) quantified monopropellant tank parameters for GRO, Mark II Propulsion Module, communications and weather satellites, as well as bipropellant tank parameters for OMV, L-SAT, OMS, and the Mark II Propulsion Module.

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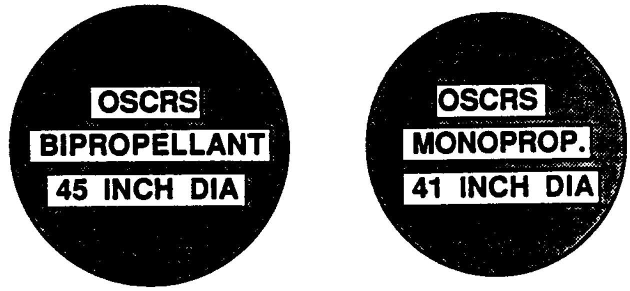

ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM

11/86	FINAL REPORT - STUDY RESULTS	NAS9-17585	MCR-86-1351
03/86	REQUIREMENTS DEFINITION	NAS9-17585	MCR-86-1323

SPACECRAFT PLATFORM EXPENDABLES RESUPPLY CONCEPT

10/85	SUPPLEMENTAL STUDY - REVIEW	NAS8-35618	
03/85	TECHNICAL REPORT	NAS8-35618	STS85-0174

Figure 3.1-3 Data Sources - Tanks

Additional data were obtained from Rockwell reports on the Spacecraft Platform Expendables Resupply Concept study (Reference 2-1). The SPERC Supplemental Study Report (Reference 2-6) updated the March 1985, Technical Report and suggested changing the SPERC capacity from 45,500 to 7,000 lb.

The tanker trade study task of this fluid resupply integration analysis used information from the sources shown in Table 3.1-1. This integration analysis considered five candidate tankers; the Mark II Propulsion Module, the OSCRS monopropellant tanker, the OSCRS bipropellant tanker, SPERC, and the OMV propulsion module. Information was obtained about length of tanker life, operating pressure capabilities, avionics, adaptability to remote operations and EVA backup, and the other selection factors discussed in Section 4.3.

Study results showed that the OSCRS monopropellant and bipropellant tankers scored better than the other tankers. Additionally, only limited detail was available on SPERC. Based on these results, the OSCRS monopropellant and bipropellant tankers were recommended for continued analysis.

Table 3.1-1 Data Sources - Tankers

Orbital Spacecraft Consumables Resupply System		
Martin Marietta/Johnson Space Center		
04/87	Follow-on Task 1 Review	NAS9-17585 (Ref. 3-9)
11/86	Final Report - Study Results MCR-86-1351 (Ref. 2-2)	NAS9-17585,
Mark II Propulsion Module		
Martin Marietta/Goddard Space Flight Center		
07/81	Journal of Spacecraft (Ref. 3-10)	AIAA 81-1411R
Spacecraft Platform Expendables Resupply Concept		
Rockwell/Marshall Space Flight Center		
10/85	Supplemental Study	NAS8-35618 (Ref. 2-6)
03/85	Technical Report STS85-0174 (Ref. 2-1)	NAS8-35618
Orbital Maneuvering Vehicle propulsion module		
TRW/Marshall Space Flight Center		
12/86	OMV Design Characteristics - Draft (Jim Turner, MSFC) (Ref. 3-6)	

The orbital spacecraft consumables resupply system is being studied by Martin Marietta, Rockwell, and Fairchild. The documents listed in Table 3.1-2 provided the OSCRS data used in the fluid resupply integration analysis. The majority of the information was obtained from Martin Marietta's eight book final report (References 2-2, 3-8, 3-14, 3-15, 3-16, 3-17, 3-18, and 3-19). Basic tank and tanker data were examined, along with requirements. Additionally, Rockwell and Fairchild requirements were reviewed to assure reasonably consistent OSCRS requirements.

The tank/tanker trade study performed for this fluid resupply integration analysis used the OSCRS mission model (Table 3.1-3) to define boundary conditions for propellant resupply requirements. The OSCRS mission model incorporated data from the Space Transportation Architecture Study (STAS) that projected requirements for serviceable

Table 3.1-2 Data Sources - Orbital Spacecraft Consumables Resupply System

NASA Office: Johnson Space Center		
Martin Marietta		
04/87	Follow-on Task 1 Review	NAS9-17585 (Ref. 3-9)
11/86	Final Report - Study Results MCR-86-1351 (Ref. 2-2)	NAS9-17585,
03/86	Requirements Definition MCR-86-1323 (Ref. 3-8)	NAS9-17585,
Rockwell		
10/86	Preliminary Design Report STS86-0268 (Ref. 3-11)	NAS9-17584,
Fairchild		
03/87	Preliminary End Item Spec 339-SS-1000B (Ref. 3-12)	NAS9-17586,
10/86	Preliminary Design Review 339-SR-1000A (Ref. 3-13)	NAS9-17586,

spacecraft expected to be operational between 1990 and 2010. Therefore, servicing systems must be constructable with current technology to be operational in the 1990's with the capability to expand to meet servicing needs until 2010. The basic results show that the maximum single-spacecraft mission requirements are 5000 lb of hydrazine (N_2H_4) monopropellant and 7000 lb of monomethylhydrazine (MMH) and nitrogen tetroxide (NTO), resulting from the Mark II Propulsion Module and DoD 1 satellite resupply missions.

However, the OSCRS Final Report - Study Results (Reference 2-2) noted that mission models were affected by the shuttle disaster and that far reaching ramifications have not been completely determined. Additionally, the Space Based Interceptor of the Space Defense Initiative (SDI) may significantly expand future servicing requirements. It will be essential for future developers of the servicer system to monitor changing satellite program needs.

Table 3.1-3 OSCRS Mission Model

IOSS utilized OSCRS mission model for trade study OSCRS utilized Space Transportation Architecture Study and considered OMV mission models STAS mission models - Civil and DoD models with varying growth options - Spacecraft operating from 1990 to 2010 - Civil model -- Space station and industrial space facilities -- Polar and 28.5 degree platforms -- Geosynchronous satellites - DoD model -- New spacecraft designs -- Block changes to existing designs -- Excludes moderate growth option and SDI Maximum resupply requirements - Monopropellant: Mark II, 5000 lb N_2H_4, 40 lb GN_2 - Bipropellant: DoD 1, 7000 lb MMH & NTO

Several types of hoses and umbilical connectors were investigated. No new types of hoses were found for the orbital maintenance and servicing system (OMSS) application. Convoluted metal (bellows) and teflon-lined hose types remained candidates. As shown in Table 3.1-4, information on convoluted metal hoses was obtained from Metal Bellows Company, and data on teflon-lined hoses was gathered from Stratoflex, Inc. and Aeroquip Corp. Research and analysis has shown that both types of hoses are capable of meeting basic design requirements. However, the metal bellows type was recommended because of its current high pressure capability, the climate of the engineering community favors the use of metal for fluid transfer in space, ease and thoroughness of cleaning, and the ability of the hose to handle cryogenic fluids.

Table 3.1-5 shows that no new fluid connectors have been located. Fairchild Control Systems Company is recognized as the standard for fluid disconnects that are used in space applications. Fairchild Stratos provided information that the NASA disconnect (P/N 76300002) used in the Apollo program, could be redesigned to meet the requirements for bipropellants and pressurants. Additionally, Fairchild and Moog are working on a 3/4 in. hydrazine disconnect being developed in conjunction with the OMV.

Table 3.1-4 Data Sources - Hose Types

Company	Product	Features
Metal Bellows Corp. Moorpark, CA	Convoluted metal hose - Long formed bellows, encased in woven wire braid for axial support.	May be bent in one plane only.
Stratoflex, Inc. Fort Worth, TX	Teflon-lined hose - Extruded tetra-fluoroethylene with multiple braids of corrosion resistant steel wire for axial support and high pressure capability.	May be bent and torqued.
Aeroquip Corp. Jackson, MI	Teflon-lined hose - Spiral extruded teflon resin with multiple braids of Type 300 series stainless steel.	May be bent and torqued.

The other disconnect that was examined is Moog's RSO (Rotary Shut-Off) disconnect. This disconnect is a new concept that has some functional advantages. It allows straight line flow, and thus avoids the pressure loss associated with poppet valve disconnects. Seal redundancy may be achieved by incorporating several rotating valves in series. Moog does not yet have any flight qualified disconnects, but is working on a NASA

Table 3.1-5 Data Sources - Connectors

Company	Product	Features
Fairchild Control Systems Company	NASA disconnect (P/N 76300002) OMV disconnect (P/N 87352004)	Used in current space applications. Poppet valve.
Moog, Inc.	RSO disconnect	No leak, minimal pressure drop. Developing cryogenic disconnect for current NASA contract.
Deutsch Company	Push-pull electrical coupling	Readily integrated into OMSS system.

contract to develop a flight qualifiable disconnect for cryogenic fluid flow. Moog is also developing a 3/4 in. hydrazine disconnect in conjunction with OMV.

Data on electrical connectors and cables was obtained from the Deutsch Company.

Finally, data was collected for the ground demonstration conceptual design. In addition to the hose and connector data, information was obtained on the remote umbilical mechanism (RUM) and various hose and cable carrier systems. The RUM was designed, built, and tested by Martin Marietta and has been referred to in previous IOSS reports by other names. As part of the OMSS conceptual design, it was incorporated in the fluid resupply interface unit (FRIU) to provide mating and demating at the spacecraft interfaces. The hose and cable carrier was used to provide stability and to assure that hoses and cables bend in only one plane at a time. The minimum bend radius of the recommended hose and carrier system corresponds to the bend radii of recommended flight components. Table 3.1-6 summarizes ground demonstration data sources.

Table 3.1-6 Data Sources - Ground Demonstration Equipment

Company	Product	Features
Martin Marietta Denver, CO	RUM	Provides mate/demate for as many as 4 fluid disconnects and 2 electrical connectors.
Graham, Inc. Englewood, CO	Hose and Cable Carrier	Provides support for metal bellows type hose, assuring that no out of plane bending occurs.

3.2 REQUIREMENTS SUMMARY

This fluid resupply integration analysis was performed with consideration given to many requirements, which have been separated into the categories shown in Table 3.2-1. More detailed lists of requirements are given in Appendix B, and specific examples of requirements are provided in this section.

Table 3.2-1 Requirements Categories

System requirements for operational servicer - Multiple spacecraft serviced on a single mission - Maximize servicer capabilities to minimize spacecraft requirements Non-propellant cryogenic fluid transfer Contamination related requirements Thermal control Standardized spacecraft interfaces Safety Reliability and maintainability Cost Hose and cable management subsystem - Minimize length and number of bends; limit bending radius - Simple and reliable design, shall exceed 200 servicing missions Connector requirements - Standardize for all functions and modes of servicing - EVA override, redundant remote release, quick disconnect Command and control and software Ground demonstrations - Represent onorbit servicing, axial docking, axial ORU exchange - Real time control functions: mate/demate, leak test, fluid pressures

The tank/tanker trades were performed primarily at the system level. Therefore, system requirements were most actively involved. The two major system requirements are the ability to service multiple spacecraft on a single mission, and maximizing servicer capabilities while minimizing spacecraft requirements. Fewer restrictions on spacecraft design will provide a greater range of application, resulting in maximum system utility.

Additionally, hose and cable management system requirements and connector requirements have impacted the OMV kit definition activity of this fluid resupply integration analysis. Developing a simple and reliable hose and cable management system will be essential to the successful functioning of the servicer system. The selection of a hose type, discussed as part of the hose and cable management system in Section 7.0, significantly affects the selection of the hose and cable management system. The connector standardization requirement (also called fluid interface standardization) affected the work reported in Sections 5.0 and 6.0.

Four major top level requirements, specified in the statement of work for this fluid resupply integration analysis, are listed in Table 3.2-2. The first major requirement is that the fluid resupply system shall use the IOSS. In satisfying this requirement, many additional requirements, shown in the table, are automatically satisfied. The hard dock requirement, the type of operating modes, the range of servicer operations, and onboard processing are all features of the currently defined IOSS. The second major requirement is for fluid servicing to be performed in conjunction with ORU changeout. This will mean that the spacecraft mission can be extended by consumables replenishment, equipment repair, and instrumentation upgrading, all on one servicing mission. The third major requirement is the ability to interface with the orbiter and the space station, in addition to using the OMV in the primary system configuration for in-situ servicing. The range of system applicability is significantly broadened by the

Table 3.2-2 Top Level Requirements

Servicer shall utilize IOSS*
Fluid servicing in conjunction with module changeout*
Interface with OMV, orbiter, and space station*
In-situ fluid resupply and module exchange*
Hard dock capability with space platforms to be serviced
Operate from manual teleoperation to autonomous modes
Servicer operation to be between 2.5 and 11.2 ft from docking axis
Communicate with ground, space station, or orbiter
Provide onboard processing
Fluid servicing in less than 6 hours
Resupply 5000 lbs monopropellant, 7000 lbs bipropellant
* Specified in statement of work

addition of this capability. The fourth major requirement is that the servicer shall operate in-situ. OMV will provide the maneuvering capability to meet this need, with the possibility of expanding the orbital range by transferring tanker propellant to provide additional OMV propulsion energy.

A discussion of system requirements for the operational fluid resupply system is a natural follow-on to top level requirements and is used as our first example. These requirements are listed in Table 3.2-3, which shows that the operational servicer system shall adhere to a variety of constraints.

Table 3.2-3 System Requirements for the Operational Servicer

Interface with OMV or tanker - Simple design for easy integration - Include standard fluid and electrical disconnects, and attachment devices
Resupply spacecraft with various tank orientations and fluid acquisition systems
Monitor and control fluid transfer, maintaining fluid temperature and pressure
Be capable of verifying leak integrity of interface seals between two disconnect halves before fluid is admitted to interface cavity
Incorporate provisions for resupply, maintenance, and upgrade by robotic or manned activities into the fluid management system

First, the operational servicer shall interface with the OMV, an IOSS compatible tanker, or a combination of OMV and one or more tankers. The OSCRS tanker was chosen in the trade study. It represents a design that will be OMV compatible. With some second order changes to the design, it should be IOSS compatible. This system will have a simple design, so that the various components can be easily integrated into a variety of configurations. Additionally, the OMV/tanker/IOSS interfaces shall provide the fluid, electrical, and mechanical connections required for onorbit servicing.

Second, the operational servicer shall be capable of resupplying fluids to spacecraft with fluid tanks in any orientation with respect to the docking receptacle and with a variety of fluid acquisition, or propellant management devices. The user spacecraft may also locate its fluid interface within a range of locations defined by the reach of the servicer mechanism and constraints of the hose and cable management system.

The system shall monitor and control the fluid transfer. Fluid temperature and pressure limits, vital to successful transfer, shall be maintained by the system. Pressure limits assure that seal and tank strength tolerances are not exceeded. Temperature limits assure against auto ignition of monopropellants and avoidance of fluid freezing. The system will verify the integrity of interface seals prior to initiating fluid flow within the fluid connector interface cavity.

The last requirement concerns the approach to effecting the resupply, maintenance, and system upgrade functions. These functions must be achievable through robotic or manned operations. The primary approach must be robotic because of the requirement for operations at the failed spacecraft. However, the addition of a direct manned capability will provide an extra level of redundancy for operations at the orbiter and the space station.

Our second example is a subset of the system requirements and pertains to the thermal control subsystem. Table 3.2-4 illustrates the requirements for this subsystem.

First, it is essential that control of fluid temperature be adequate to prevent freezing or overheating. Fluids that have been allowed to freeze do not transfer well through hoses, and propellant overheating may cause catastrophic combustion. Specifically, the temperature of non-cryogenic propellants must be maintained between 50 and 90 deg F.

Table 3.2-4 Thermal Control Requirements

Design of fluid interfaces and hose management system shall provide adequate thermal protection to prevent freezing or overheating of fluids being handled
Fluid resupply system shall condition Earth storable propellants to 70 ± 20 deg Fahrenheit
Servicer shall provide thermal control of serviced spacecraft during transfer operations, using the electrical connection across the fluid resupply interface
Servicer design shall minimize transfer of thermal loads to the spacecraft being serviced
Servicer thermal control system shall maintain subsystem temperatures between 32 and 120 deg Fahrenheit
Servicer thermal control system shall not interfere with the OMV thermal control system

Second, the servicer thermal control system shall not interfere with the OMV thermal control system, and shall minimize thermal loading on the spacecraft. The servicer shall utilize the electrical connection across the fluid resupply interface to provide thermal control of the serviced spacecraft during fluid transfer.

Finally, the servicer system temperature must be maintained within 32 and 120 deg F in order to assure proper system functioning.

4.0 TANK/TANKER TRADE STUDY

The tank/tanker trade study was the major analysis effort leading to the definition of an orbital maneuvering vehicle (OMV) kit that would integrate the fluid resupply function into the orbital replacement unit (ORU) exchange function. The objective of the tank/tanker trade study was to develop a recommended approach for the integration of the fluid resupply function into the integrated orbital servicing system (IOSS) form of onorbit maintenance that emphasizes ORU, or module, exchange. Three alternative, or complementary, approaches were considered. These are:

1) Tanks in the IOSS stowage rack;
2) Tanker concepts prepared by others;
3) Tanks as orbital replacement units.

The tanks in the IOSS stowage rack concept involved allocation of part of the IOSS stowage rack for installation of tanks and the selection of tanks to use. An example of tanks as ORUs is a pressurant bottle with regulator as an ORU.

The tank/tanker trade study was the major effort involved in the first half of the fluid resupply integration analysis. In addition to leading to a recommended fluid resupply approach, the trade study identified significant aspects involved in the integration of fluid resupply with ORU exchange. No concerns that might inhibit the integration of the fluid resupply function into the IOSS form of onorbit maintenance were identified. All three candidate approaches should be integrable into a versatile system.

A flow chart showing the activities involved in the tank and tanker trade study is shown in Figure 4.0-1. Three parallel, and complementary, paths were used to develop a recommended approach for the integration of fluid resupply with module exchange. The three paths are alternative, or complementary, approaches and all three paths start with the same set of requirements and data.

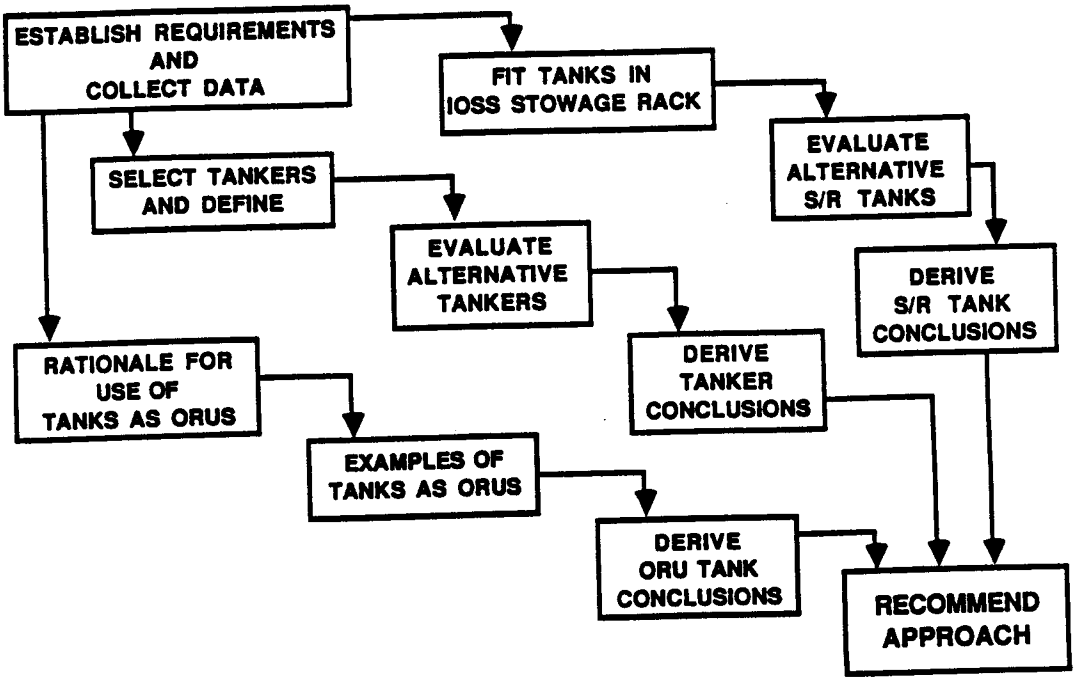

Figure 4.0-1 Trade Study Approach

Applicable data were collected in the first subtask and were used to identify requirements that were applicable for the level of detail needed in the trade study. The upper path addressed fluid resupply from tanks that are installed in the IOSS stowage rack. Fluid transfer would be from these tanks through an umbilical connection with fluid hoses and electrical cables. The first step was to identify tanks that would fit into the IOSS stowage rack. These tanks were then evaluated in a trade study matrix format, and conclusions were drawn. Both monopropellant and bipropellant tanks were considered.

The middle path addressed vehicles that could be considered as tankers, such as OSCRS. A search for candidate tanker vehicles, other than those four called out in the analysis statement of work, failed to uncover any new candidates. Therefore, the candidate vehicles used were those called out in the analysis statement of work. The four tankers were evaluated in a trade study, two as monopropellant tankers, and two as bipropellant tankers. Conclusions regarding which tankers to consider for future integration analysis were developed.

The third path addresses the use of tanks as ORUs and starts with the recognition that the first two paths provided acceptable solutions so a third method might not be necessary. This was a special concern when it is recognized that if a tank is used as an ORU then the quick-disconnects will be under pressure for a long time (years) and that no quick-disconnect has been designed to satisfy this requirement. However, certain examples of tanks as ORUs were identified, and it was possible to recommend how this technique should be considered.

The conclusions from the three paths were then combined into an overall recommended approach. The implications of the recommended approach were extended to further recommendations as to how the concept might be used to extend its capability.

The conclusions from the tank/tanker trade study are listed in Table 4.0-1. All three approaches to the integration of fluid resupply into module servicing that were addressed in the trade study have specific areas of utility. Tanks that are installed in the IOSS stowage rack are more useful for monopropellant resupply. Of the tanks

Table 4.0-1 Trade Study Conclusions

All three approaches can be integrated into a maintenance and servicing system - Tanks in IOSS stowage rack for many monopropellant missions - Tankers for bipropellant and larger quantity monopropellant missions - Tank ORU exchange reserved for special situations
Fluid interfaces designed so that fluid can be transferred in either direction between OMV, tankers, IOSS, and serviced spacecraft
OSCRS type avionics system could be used for ICSS fluid resupply
Stacking tankers and maintenance system may exceed OMV attitude control system capability during multiple dockings

considered, those used in the Martin Marietta Astronautics Group (MMAG) monopropellant OSCRS fit well into the IOSS stowage rack. Four tanks could be used and this arrangement provides good center of mass control. The quantity of propellant that could be carried is sufficient to handle all but the most demanding monopropellant resupply requirements. Most bipropellant tanks use screens or other fluid positioning devices. This means that catch tanks must be provided on the servicer vehicle and there is insufficient room on the IOSS stowage rack for catch tanks. Thus it is recommended that bipropellants not be resupplied from tanks in the IOSS stowage rack.

It is recommended that tankers such as the OSCRS be used for bipropellants and for the larger quantities of monopropellants as might be required for resupply of the Mark II Propulsion Module, or if multiple spacecraft are to be resupplied with monopropellants on a single mission. The tankers have sufficient volume to carry the catch tanks and the large quantities of bipropellant required by the spacecraft in the mission model.

It is recommended that the use of tanks as ORUs be reserved for those special cases where the disconnect problem can be worked around or accepted, e.g., the OMV propulsion module.

To increase the overall system capability by permitting various combinations of IOSS stowage racks, tankers, and the OMV to be assembled, it is recommended that the fluid transfer interfaces between these elements be designed so that fluids can be transferred in either direction. An example is that tanker fluids could then be used by the OMV to permit it to perform more energetic missions. Alternatively, the OMV fluids could be transferred via the IOSS umbilical to the serviced spacecraft, thereby giving the IOSS a bipropellant servicing capacity without the need to carry along a bipropellant tanker (the bipropellant catch tanks could be on the IOSS stowage rack). The result of using this type of intervehicle fluid transfer device is that a great deal of operational flexibility is obtained for little cost. A potential difficulty may be in the need to provide an intravehicle fluid transfer device between the OMV short range vehicle and its propulsion module. The OMV intravehicle fluid transfer device must be able to be mated and demated on orbit, whereas the intervehicle fluid transfer device is only required to be mated on the ground.

The OSCRS avionics system could be reprogrammed to manage fluid transfer from the IOSS stowage rack and save the development of a special unit for use on the fluid resupply form of the IOSS stowage rack.

One potential difficulty from stacking the IOSS and two OSCRS tankers on the front of the OMV is that the OMV attitude control system may not be able to provide the pure lateral translation motions desired during the last part of a docking maneuver. Because the c.g. of the stack will be far forward of the OMV lateral translation thrust line, rotational motions will be induced. It is the propellant required to correct these rotational motions that is of concern, especially when multiple dockings on a single mission are attempted.

The result of the tank/tanker trade study is a set of elements that can be assembled in various ways to satisfy both the ORU exchange and fluid resupply requirements for a wide variety of missions.

4.1 FLUID RESUPPLY REQUIREMENTS

The establishment of a set of top-level requirements started with listing those assumptions that would be used for the trade study and for the rest of the integration analysis. The top-level requirements for fluid resupply were taken from a larger set of more detailed requirements that had been collected (see Appendix B). The specific quantities of fluids to be resupplied were taken from the orbital spacecraft consumables resupply system (OSCRS) study, which in turn drew on the Space Transportation Architecture Study (STAS).

The assumptions used in the tank/tanker trade study are shown in Table 4.1-1. These assumptions were derived from the fluid resupply integration analysis statement of work. It was necessary to rely heavily on prior work so that emphasis could be placed on the integration aspects. Also much of the work had been well done, had produced useful information, and represented the expenditure of significant resources over a long period of time. In particular, the OSCRS work is relatively current, addressed the same general subject, identified the major considerations, and had collected and derived much useful information.

Table 4.1-1 Trade Study Assumptions

Recognize prior work
Servicer system will be configured on the ground
Planned hardware will meet their defined requirements
Detail information will be taken from other studies

The assumption to restrict reconfiguration, or assembly, of the orbital maintenance and servicing system (OMSS) elements to a ground activity was somewhat arbitrary, but is a way of avoiding digressions of how to reconfigure on orbit and thereby maintain the desired study focus. The effects of onorbit reconfiguration can be addressed at a later date when the selected configuration is defined at the next lower level.

Much of the data available represented systems that are in their early conceptual stage. Only one represented flight hardware. Thus it was decided to ignore questions regarding program viability and probability of continuing to flight hardware. We assumed, for the purpose of the trade study, that proposed concepts could be developed to have the characteristics given in the specific reports.

The resources available for this study did not permit us to go into detail about many design aspects. So detail was taken from the references where it was available. Additionally, it did not seem appropriate to redevelop information that was available and appeared to be plausible.

The first four top level requirements listed in Table 4.1-2 were given in the fluid resupply integration analysis statement of work, while the others were taken from the requirements developed in the first subtask. The first four requirements generally define the context of the integration analysis and are coherent with each other. While the requirement is for fluid resupply and ORU exchange to be performed in-situ, this does not prevent these functions from being performed at the orbiter or space station. Similarly, there is no restriction on performing either fluid resupply or module exchange without performing the other. While we generally use the word spacecraft when discussing the target for servicing and maintenance, these functions can also be applied to space platforms.

Table 4.1-2 Top Level Requirements

The servicer shall utilize the IOSS*
Fluid servicing shall be accomplished in conjunction with ORU changeout*
Provide capability to interface with the OMV, orbiter, and space station*
Fluid resupply and ORU exchange is to be in-situ*
Provide capability to hard dock with the spacecraft to be serviced
Provide capability to operate from manual teleoperation to completely autonomous modes
Servicer operation to be between 2.5 and 11.2 ft from docking axis
Provide means of communication to ground, space station, or orbiter
Provide onboard processing
Fluid servicing shall be accomplished in less than 6 hours
Resupply 5000 lbs of monopropellant and 7000 lbs of bipropellant
*Specified in analysis statement of work.

The hard docking capability requirement is used because that was a constraint on the IOSS and represents how the IOSS was designed. The required control modes parallel those available with the IOSS. The servicer mechanism operating reach is that of the IOSS and is to be used for location of the fluid interface connection on the serviced spacecraft.

Communication is to be provided between the various flight system elements and the OMV, which will extend the communications links to the ground through its standard capabilities. The onboard processing is intended to be partially in the IOSS and tankers, and partially in the OMV according to the OMV capabilities.

The fluid servicing time and fluid resupply quantities were taken from the OSCRS studies as they represent the results of the most recent studies of fluid resupply. Perhaps the time limit need not be enforced too strictly as it was based on the maximum duration of an EVA, which is not applicable to an in-situ fluid resupply situation. However, EVA should be considered as a backup mode, where it is feasible. Thus the 6 hour limit should be retained as a goal.

Figure 4.1-1 lists the spacecraft programs used for our mission models. Those above the line have a potential need for monopropellant, or hydrazine, resupply, while those below the line have a need for bipropellant resupply. This data was taken from the OSCRS studies that, in turn, took the data from the Space Transportation Architecture Study reports. The fluid to be resupplied is primarily hydrazine, with some small quantities of gaseous nitrogen also required. With one exception, the maximum amount of hydrazine required for any one spacecraft resupply is 3000 lb. The Mark II Propulsion Module is the exception and it requires up to 5000 lb per resupply. For multiple spacecraft servicing on a single mission, larger quantities of hydrazine could be required. The quantities shown are the capacity of the tanks of the identified spacecraft. It can reasonably be expected

PROGRAM	PROPELLANT RESUPPLY QUANTITY	PRESSURANT REQUIREMENT
GAMMA RAY OBSERVATORY	2500 LB N2H4 (1136 KG)	
SPACE STATION SPARTAN PLATFORM	800 LB N2H4 (364 KG)	
MULTI-MISSION MODULAR S/C	2000 LB N2H4 (909 KG)	
MARK II PROPULSION	5000 LB N2H4 (2273 KG)	40 LB GN2 (18 KG)
GEOPOTENTIAL RESEARCH MISSION	3000 LB N2H4 (1364 KG)	
COSMIC RAY EXPERIMENT	550 LB N2H4 (250 KG)	
EURECA	1700 LB N2H4 (773 KG)	312 LB GN2 (142 KG)
X-RAY TIMING EXPLORER	APPROX. 500 LB N2H4 (227 KG)	
MOBILE SAT-B	1100 LB N2H4 (500 KG)	APPROX. 10 LB GN2 (4.5 KG)
GEO PLATFORM	2100 LB N2H4 (955 KG)	
MOBILE SAT-C	2200 LB N2H4 (1000 KG)	
DOD 1	7000 LB MMH & NTO (3182 KG)	
DOD 2	6000 LB MMH & NTO (2727 KG)	
EOS PLATFORMS	5000 LB MMH & NTO (2273 KG)	
PLATFORM SYSTEM TECHNOLOGY	2000 LB MMH & NTO (909 KG)	

Figure 4.1-1 Candidate Spacecraft for Fluid Resupply

that servicing would be accomplished with some residual in the tanks of the serviced spacecraft, thus smaller quantities than those shown opposite may be appropriate for resupply missions. Note that four satellites could probably be serviced with a resupply quantity of a little over 1000 lb.

The maximum amount of pressurant to be resupplied is 312 lb of nitrogen, which is required for the EURECA spacecraft. However, the next largest pressurant requirement is only 40 lb of nitrogen.

The Gamma Ray Observatory (GRO) was the reference mission for the OSCRS studies. The basic OSCRS requirement is the resupply of up to 3000 lb of monopropellant and up to 7 lb of helium or 50 lb of nitrogen pressurant gas at 500 psi. The growth OSCRS requirement is to resupply up to 5000 lb of monopropellant and up to 35 lb of helium or up to 250 lb of nitrogen pressurant gas at 3000 psi.

Four programs were identified by the STAS that require bipropellant resupply and they are identified below the line on Figure 4.1-1. The largest quantity is 7000 lb combined of monomethylhydrazine (MMH) and nitrogen tetroxide (NTO). The smallest quantity is 2000 lb of these bipropellants. The quantities of bipropellants tend to be larger than the quantities of hydrazine. This result is appropriate as bipropellants tend to be used where larger impulses are required and the higher specific impulse of bipropellants more than compensates for the extra requirements associated with handling two fluids. The specific fluids identified in the figure are hypergolic and thus will ignite if they come in contact in the proper proportions.

Note that there were no needs identified for pressurants for the specific spacecraft shown as requiring bipropellant resupply. However, most bipropellants use nitrogen, or helium, as a pressurant and if the resupply method requires venting the spacecraft tanks, then it will be necessary to resupply pressurant to make up for that which is vented.

The OSCRS studies used 7000 lb of bipropellants as their basic design requirement along with up to 12 lb of helium pressurant or 120 lb of nitrogen pressurant gas at 3000 psi. The growth mission was for up to 11000 lb of bipropellants and up to 50 lb of helium or 350 lb of nitrogen pressurant gas at 5000 psi.

This integration analysis used 5000 lb of monopropellant and 7000 lb of bipropellant as the design requirements. Quantities of pressurant gas were not specifically considered in the tank/tanker trade study except if the need could be satisfied by the OSCRS capabilities.

4.2 TANK TRADE STUDY

The first of the three tank/tanker trade study paths involved the installation of selected tanks in the IOSS stowage rack. These tanks would contain either monopropellant, or bipropellant (different tanks) and the fluids would be transferred to the serviced spacecraft through an umbilical connection. As there have been many tanks built over the years for spacecraft, it was decided to restrict the choice of tanks to those that had been built or minor variations of tanks that had been built. The qualification of minor variations in tank geometry should be easier than qualifying a brand new design. Minor variations include changes in length of a tank cylindrical section or changes in tank thickness.

4.2.1 Tanks Considered

The tanks considered are listed in Table 4.2-1. The OMV tanks considered are those proposed for the Martin Marietta version as this is the data available to us. The tanks to be used on the TRW form of the OMV had not been selected at the time of the analysis so they could not be used. The OMV tanks are for bipropellants and the Mark II Propulsion Module tanks are for hydrazine. The tanks considered during the OSCRS study were divided into a monopropellant group and a

Table 4.2-1 Sources for IOSS Stowage Rack Tanks

OMV (Martin Marietta)
Mark II Propulsion Module
OSCRS Monopropellant - TDRSS - GRO - Mark II Propulsion Module - Typical Communications Satellite - Typical Weather Satellite
OSCRS Bipropellant - OMV (Martin Marietta) - L-SAT - OMS - Mark II Propulsion Module
SPERC

bipropellant group. The main difference is that monopropellant tanks often use bladders, while bipropellant tanks almost always use fluid management systems such as screens and capillaries for fluid capture and positioning at the tank outlet. The Mark II Propulsion Module, manufactured by Martin Marietta, is different in that it is a monopropellant tank that has a fluid management system instead of a diaphragm and thus can be used for either monopropellants or bipropellants.

The L-SAT tank is also made by Martin Marietta and is used in a European satellite built by British Aerospace. The Space Platform Expendables Resupply Concept (SPERC) study tanks are stretched versions of the orbital maneuvering system (OMS) tanks used on the orbiter. Note that some of the basic tank designs show up in several places on the list as different applications sometimes consider the same tank.

Alternatively, some applications evolve through a variety of candidate tanks as their requirements evolve. An example is the Martin Marietta OMV. The evolution of the Martin Marietta recommendation for the specific tanks to be used on the orbital maneuvering vehicle was reviewed to determine the underlying rationale. The material for this review was taken from TMS-SE-03-06, Teleoperator Maneuvering System Mark II Propulsion Module Study, Martin Marietta Corporation, September, 1983, and P85-41001-2, Technical Proposal, Orbital Maneuvering Vehicle Full-Scale Development Phase, Martin Marietta Corporation, December, 1985. The earlier volume summarized the results of a number of prior studies.

The OMV/TMS (teleoperator maneuvering system) started out as a derivative of the Mark II Propulsion Module (PM). A structure was added to bring the PM structure out to where it could be directly fitted into the orbiter cargo bay trunnions. This Concept A had a length of 84 in. and a usable capacity of 5560 lb of monopropellant. The length was felt to be excessive for a vehicle that would have to pay shuttle launch costs that were dependent on vehicle length and also the use of the bridging structure resulted in a high dry weight.

The next version was to take the Mark II PM tanks and lay them on their sides, but to still use a cruciform structure. The result was a 60 in. length, and a lighter vehicle. This was called Concept C. The propellant quantity was held at 5560 lb by the continued use of the Mark II PM tanks.

The next version was to retain the crosswise Mark II tanks, but to replace the cruciform structure with a truss type structure and to repackage the Mark II electronics to permit a narrower vehicle. The resulting Concept E had a monopropellant capacity of 5560 lb and a dry weight of 3015 lb with a length of 48 in.

It was then realized that the propellant load could be reduced to 4600 lb and still satisfy the then-current mission model. The reduced propellant capacity could be packaged in a 36 in. long vehicle. However, it would be necessary to use different tankage.

A cost analysis of the effect of vehicle length on life cycle costs was then made centered on the 36 in. length vehicle. The largest effect was found to be the delivery to orbit cost. It was assumed that a monopropellant tanker could be built to half the OMV length. It was also assumed that bipropellants could be scavenged from the orbiter OMS tanks and thus would have no related launch cost. The potential savings in going to a 2.5 ft length from a 3.5 ft length were a function of the operations approach. When the OMV was ground based and taken to orbit for each mission, the large savings amounted to $37M. When the OMV was space based and propellants were brought to the OMV in a tanker, the smallest savings resulted ($13M). The case where the OMV was ground based for 3 years and then space based for the rest of its life resulted in intermediate savings of $30M. This cost analysis instigated an effort to determine the minimum length vehicle that would satisfy the OMV mission model. The required propellant load was 5200 lb for monopropellant, and 4400 lb for bipropellants. The resulting configurations ranged from 19.4 in. for a bipropellant version to 26 in. for several monopropellant versions. The 26 in. length was considered to be the minimum practical length because the diameter of the scuff plates used with the orbiter trunnions is 26 in. and shorter lengths made the antenna deployment too complex, there was insufficient area for good thermal energy radiation, and there was too little room for growth.

The above indicated that the Mark II tanks did not package well, there were advantages to bipropellants, especially for the more complex growth missions, and a short vehicle length was advantageous. This early work seemed to end up favoring the 36 in. concept, although there were advantages to the 26 in. toroidal tank version called Concept F.

After the completion of the Phase B study, Martin Marietta proposed a quite different configuration for the Full Scale Development Phase. The vehicle length had been increased to 50 in., the propellant capacity was 7000 lb of bipropellants, and a completely new tank design was proposed. The overall length was based on the orbiter trunnion spacing of 43 in. plus a 2 in. allowance for frame thickness, plus a 5 in. allowance for the aft mounting of the propulsion subassemblies. The use of two sets of orbiter trunnions was derived from the cantilevered load specification, the aft mounted propulsion module requirement was derived from a need to be able to easily remove and replace the propulsion modules, and the higher bipropellant requirement was set by a different mission model.

The full scale development proposal included the development of entirely new propellant tanks that were derived from a number of Martin Marietta built tanks including the orbiter reaction control system tanks. These tanks had ellipsoidal heads, a 6 in. barrel section, a 44.6 in. diameter, and a 40.6 in. length.

The above discussion is an illustration of the effect of changing requirements on proposed solutions to satisfy the requirements. The initial requirement to adapt an existing propulsion module (Mark II) to the mission evolved into requirements for higher impulse, cantilevered load in the orbiter bay, and the desire for easy maintenance. These changes in requirements led to the proper solution no longer being a monopropellant Mark II Propulsion Module, but rather being a unique vehicle that would satisfy the evolved requirements. The basic difficulty with the Mark II is that its small diameter makes it inefficient when it is to be transported in the orbiter cargo bay with the orbiter's specific delivery cost structure.

Specific characteristics of the tanks considered by Martin Marietta for the monopropellant version of OSCRS are shown in Table 4.2-2. Only the GRO tank is currently being designed with appropriate hardware for conducting onorbit fluid resupply. Most spacecraft hydrazine propulsion systems contain tankage with elastomeric diaphragm positive expulsion devices that operate in the blowdown mode. Systems may contain one tank or arrangements of multiple tanks that are then manifolded together (and usually cross-connected for operational redundancy). Gas-free propellant flow is provided from the initial

Table 4.2-2 Monopropellant Tanks Considered for OSCRS

	DRY WEIGHT (LBS)	PROPELLANT CAPACITY (LBS)	DIAMETER X LENGTH (IN)	OUTFLOW RATE (LBS/SEC)	CYCLE LIFE	PRESSURANT
TDRSS	120	971	41	0.16 - 2.75	80	GN2
GRO	135	1062	36 X 47	0.2	15	GN2
MK II	190	1375	36 X 65	0.2	50	GN2
TYP COMM	76	820	40 X 32	0.03	50	GN2
TYP WEATH	100	1550	36 X 56	0.0125	50	GN2

blowdown pressure (350 psi) to the propellant depletion condition of 80 - 100 psi. The elastomeric diaphragm approach represents the simplest resupply system from an operational viewpoint and results in little or no venting of propellants during the operation. Other hydrazine propulsion systems make use of tankage with capillary (surface tension), vane, or screen propellant management devices (PMD). PMD elements include screen channels, perforated sheets, baffles, traps, sumps, vanes, galleries, sponges, and troughs assembled together in a host of different arrangements to provide gas-free propellant at the tank outlet. The PMD systems introduce complexities into the resupply process including pressurant dissolving in the fluid and the inability to accurately measure the remaining fluid.

The OSCRS team deleted the typical communications and typical weather satellite tanks from consideration as they were not well enough defined. The Mark II Propulsion Module tank was deleted as it uses a complex PMD that would make resupply operations complex. The TDRSS tank was selected on the basis of cost and length issues. A new tank design was also considered, but it was felt that there was no need to take the increased risk. The GRO tank was almost selected by the OSCRS team during the first study and remains under consideration. The propellant capacities listed in Table 4.2-2 are the amounts that can be loaded. Not all of the propellant can be transferred.

Specific characteristics of the tanks considered by Martin Marietta for the bipropellant version of OSCRS are shown in Table 4.2-3. The development of bipropellant propulsion systems (almost universally using MMH and NTO) has resulted in a diversity of configurations and design parameters as was the case for the hydrazine systems. Each bipropellant system design is specific to the unique requirements of a particular spacecraft. Surface tension-type PMDs have become the norm for these systems that usually use regulated pressurization for propellant expulsion. Significantly higher performance and efficiencies are achievable with these systems when compared to monopropellant hydrazine systems. The resupply of propellants/pressurants has not been a major design consideration for bipropellants, other than for the OMV.

Table 4.2-3 Bipropellant Tanks Considered for OSCRS

	DRY WEIGHT (LBS)	PROPELLANT CAPACITY (LBS)		DIAMETER X LENGTH (IN)	OUTFLOW RATE (LBS/SEC)		CYCLE LIFE	PRESSURANT
		MMH	NTO		MMH	NTO		
OMV	150	1273	2077	41 X 44	0.3	0.5	200	GHE
L - SAT	55	1380	2280	44.7			50	GN2/GHE
OMS	302	4711	7752	49 X 95	13	7	100	GHE
MK II	190	1400	2300	36 X 65			50	GHE

Systems are composed of tank pairs with equal numbers of tanks for fuel and oxidizer. Gas-free propellant is provided in equal volumetric flows from both fuel and oxidizer sides using regulated GHe pressurant. Since these systems do not use blowdown pressurization, complexities for propellant resupply are introduced. Also direct ullage gas contact with the propellant facilitates dissolved pressurant in the propellant, which must be accounted for.

The pressure levels in bipropellant tankage and associated plumbing are currently between 250 and 370 psi and are driven by the operating requirements imposed by the thrusters/engines being used. The resupply of surface tension PMD tankage cannot be accomplished by direct venting as there is no demonstrated way to separate the gas from liquid. Complete propellant offloading and venting of tank residuals may be required. This means that the resupply vehicle must bring along empty catch tanks for the temporary storage of the off-loaded propellant.

The OMS tank was found to be too long for OSCRS and was eliminated. The OMV tank was not used as it was a new design and there was no need to go to the extra costs of qualifying a new tank design. The L-SAT tank was selected over the Mark II on the basis of cost, weight and size. The Mark II Propulsion Module tanks can be used for bipropellants as they have PMDs. As with Table 4.2-2, the propellant capacities listed in Table 4.2-3 are the amounts that can be loaded, which will be greater than the amounts of fluid that can be transferred.

The characteristics of the tanks selected for further consideration are shown in Table 4.2-4. The Mark II Propulsion Module and the selected OSCRS tank (strengthened TDRSS) were the monopropellant tanks selected. The two typical tanks were eliminated as they are new designs, and the GRO tank was not used because it did not fit in the IOSS stowage rack as well as the Mark II tank.

The OSCRS bipropellant tank (L-SAT) was selected as one candidate for further analysis and the Space Platform Expendables Resupply Concept tank (stretched OMS) was selected for another bipropellant candidate. The Mark II Propulsion Module was not selected as a bipropellant tank as it is less weight efficient than the SPERC tank. The OMV tanks were selected as the third bipropellant tank set for further consideration.

Table 4.2-4 Characteristics of Tanks Selected for Fit Checks

TANK SOURCE	DRY WGT LBS *	PROP CAP LBS	NO. TANKS RQD/lbs	FLOW RATE LBS/SEC	TANK SIZE DIA X LEN (IN)	NUMBER OF CYCLES
MK II PROPULSION SYSTEM	190	1375	4 / 5500	0.2	36 X 65	50
OSCRS MONOPROP	120	971	5 / 4850	0.16 - 2.75	41 X 41	80
OMV	150	1273 MMH 2077 NTO	4 / 6700	NTO 0.5 MMH 0.3	41 X 44	200
OSCRS BIPROPELLANT	75	MMH 1446 NTO 2401	4 / 7694	MMH 2.56 NTO 3.28	45 DIA	80
SPACE PLATFORM EXPENDABLES RESUPPLY CONCEPT	353	MMH 5733 NTO 9434	6/45500	MMH 0.6 NTO 1 N2H4 0.138	49 x 112	100

* EACH TANK

The OMV as well as the OMS, or SPERC, tanks could be used for monopropellants, but they were not selected for this purpose as they use PMDs rather than bladders for fluid expulsion. Bladders are preferred for monopropellants as they are operationally simpler.

The result is two monopropellant tanks and three bipropellant tanks for further evaluation as devices to carry resupply liquids into orbit when installed in the IOSS stowage rack.

4.2.2 IOSS Stowage Rack Characteristics

The reference onorbit servicer system for this fluid resupply integration analysis is the IOSS shown in Figure 4.2-1. While there are a number of maintenance system concepts in the literature, and more than one is likely to be used in the future, the IOSS follow-on study, completed in 1978, recommended that a single servicer system, having the capability to accommodate both low Earth and geosyncronous orbit applications, should be evolved. This requirement has been satisfied effectively by the servicer mechanism, shown in Figure 4.2-1, that was conceptualized during the IOSS studies. The single design is

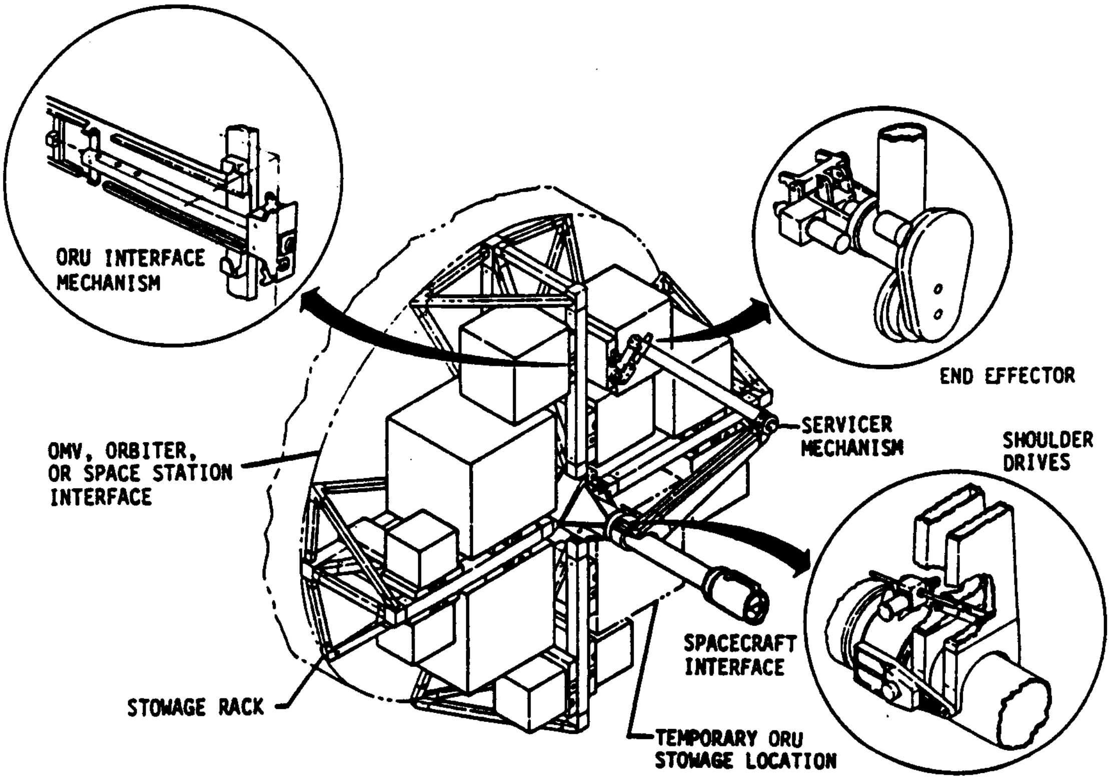

Figure 4.2-1 IOSS Onorbit Servicer Configuration

compatible with maintenance of most spacecraft of the space transportation system era. Adapters are used to accommodate support structure differences across the applications. The single fastener interface mechanism provides a logical and cost effective method of integrating ORUs for easy exchange at all spacecraft.

This design has only two major components: (1) a servicer mechanism, and (2) a stowage rack for ORU transport. A docking mechanism is shown for reference and so the interface aspects can be more easily visualized. The servicer mechanism and the stowage rack were designed separately with interfaces for individual removal and replacement. This allows for simple removal for maintenance and also for quick ground reconfiguration. Stowage racks can be configured and loaded for particular flights prior to attachment to the carrier vehicle. It may be desirable to have available several stowage racks for this purpose. The stowage rack shown mounts directly to an upper stage such as the OMV.

The servicer arm has an effective reach of 11.2 ft and the stowage rack to spacecraft separation distance is 5 ft. The complement of ORUs can be reduced for those missions where it is desired to carry tanks for fluid resupply. Most ORU exchange missions will only involve a few ORUs per serviced spacecraft. Thus space is available for fluid resupply tanks.

Figure 4.2-2 shows one layout for the IOSS stowage rack when it is configured to carry a large number of ORUs. Analyses were conducted for a variety of serviceable spacecraft designs to determine representative ORU sizes. The selected typical sizes shown represent

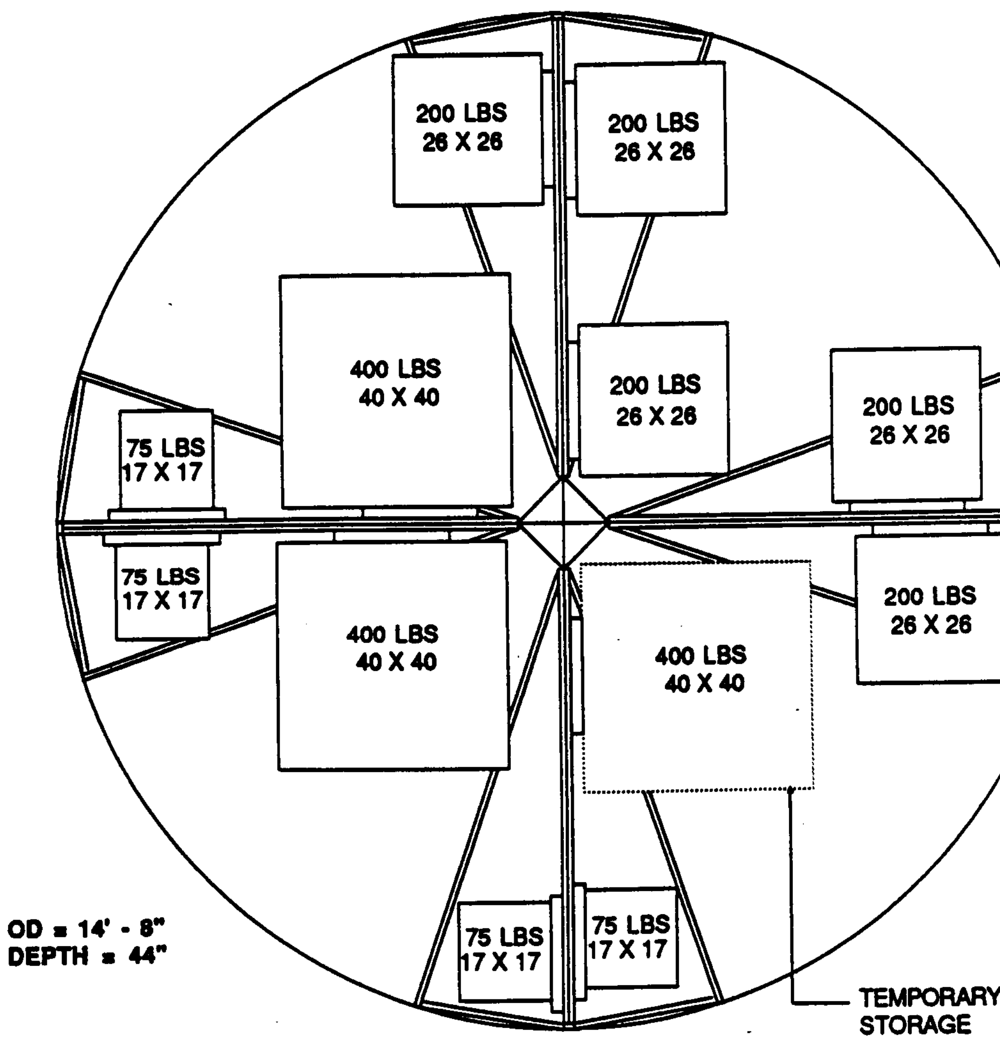

Figure 4.2-2 Plan View of IOSS Stowage Rack with ORUs

cubes with side dimensions of 17, 26, and 40 in. The analyses included estimates of numbers of each size of ORU that might be required on representative servicing missions. The ORU complement shown represents the high end of the expected needs. Note that one space is left vacant, designated temporary storage, and it is used by the failed ORU from the spacecraft being serviced. Once the good ORU has been taken from its place in the stowage rack and installed on the spacecraft, then the ORU in the temporary location is moved to the position vacated by the good ORU. This technique requires only one temporary ORU location, but it must be as large as the largest ORU to be removed from any serviced spacecraft on that specific mission.

The cruciform structural arrangement, where the arms of the cross are trusses perpendicular to the plane of the paper, was selected as the most weight efficient arrangement as well as providing a large mounting surface for the ORUs and significant flexibility in arrangement of the ORUs. A number of representative missions were analyzed to determine the adequacy of the structural arrangement shown. The selected arrangement could easily handle all of the ORU contingents considered. In general there was room left over. The largest demands are placed by large observatories when a major change in instrumentation is planned (upgrading) and a number of equipment partial failures are to be corrected. Multiple spacecraft servicing on a single mission also tends to result in relatively full stowage rack situations. Note that the case of replacing all three modules of a Multi-Mission Modular Spacecraft (MMS) can be accommodated.

Figure 4.2-3 shows the space allocated in the IOSS stowage rack for fluid resupply tanks. As the intent is to combine the functions of ORU exchange and fluid resupply on one mission, then only part of the space can be allocated to fluid resupply tanks. The temporary storage location for the failed ORU must be retained, otherwise module exchange cannot be effected. The desire to control the location of the IOSS center of gravity during fluid transfer implied that two diagonally opposite regions be allocated for the fluid resupply tanks. The ORU stowage rack space requirements analyses discussed in conjunction with

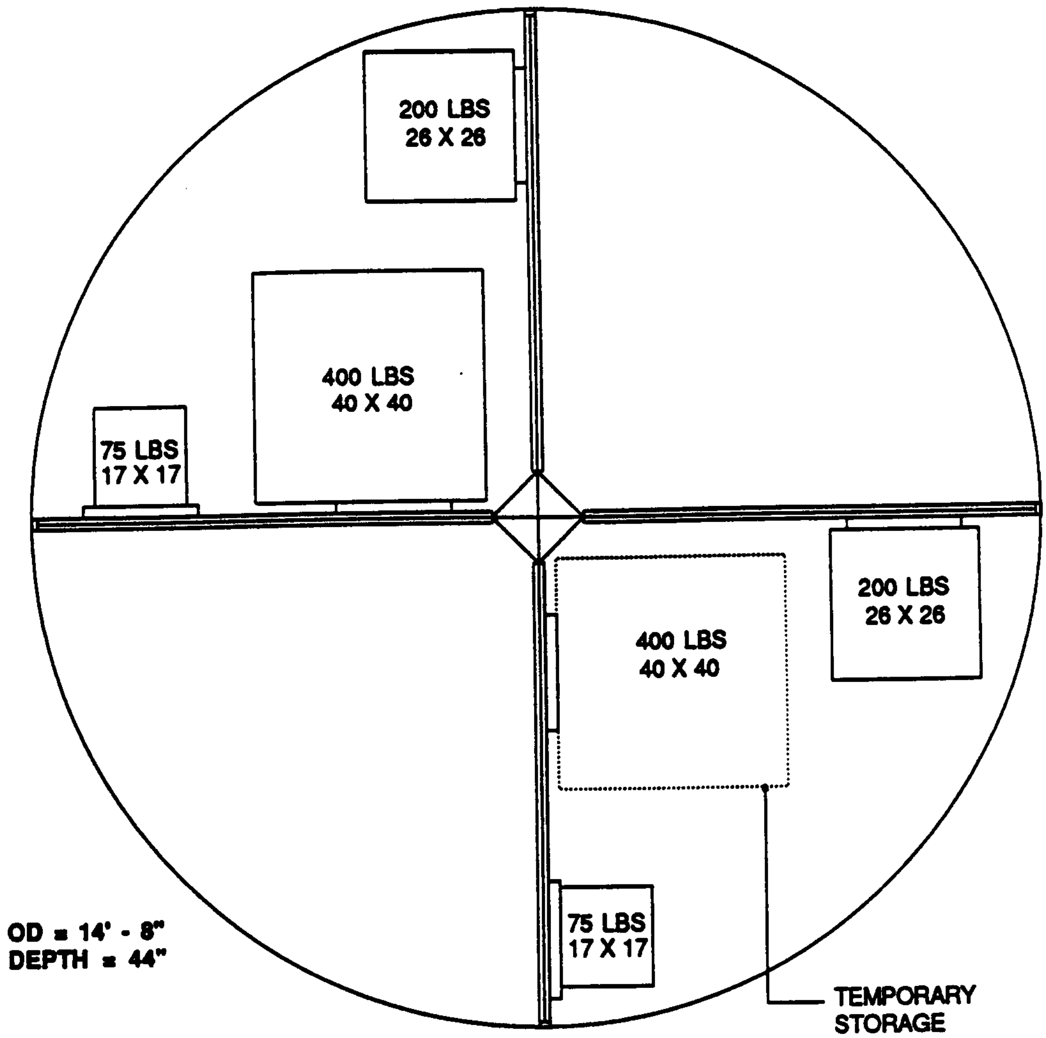

Figure 4.2-3 IOSS Stowage Rack Space Allowance for Resupply Tanks

Figure 4.2-2 indicated that a large part of the stowage rack volume could be allocated to tanks. Another consideration is that room near the fluid tanks must be available for the hose and cable management system that constrains the umbilicals, as well as for a place to fasten the fluid resupply interface unit during all flight phases other than fluid transfer, and for location of the fluid management avionics system. When a preferred set of tanks has been identified and the other fluid resupply equipment located, then there may be space for locating some ORUs in the two fluid resupply quadrants.

The result of these considerations was to allow the space shown on the figure for the fluid resupply tanks. The depth of the stowage rack, 44 in., must also be considered in fitting tanks into the IOSS stowage rack. The stowage rack outside diameter was selected to fit within the orbiter cargo bay and thus is 14 ft 8 in.

4.2.3 Tank Arrangements

The process used for preliminary screening of the five tank types of Table 4.2-4 is given in Table 4.2-5. The decision to limit the stowage of fluid resupply tanks to two quadrants of the IOSS stowage rack implies that there are clear limits on the sizes of the tanks that can be used. In particular, the OMS tank and its stretched version used for the SPERC will not fit in one quadrant of the IOSS rack.

Table 4.2-5 Preliminary Tank Screening

IOSS stowage rack size limits tank dimensions
- Fluid resupply equipment limited to two quadrants
Existing qualified tanks can be resized to satisfy fluid resupply requirements
Trade study used OSCRS selections plus one other of each type for monopropellants:
- Mark II Propulsion Module
- OSCRS selection of TDRSS tank
For bipropellants:
- OMV (MMAG)
- OSCRS selection of L-SAT tank
OMS tank is too large

The second point is that there are enough existing qualified tanks, and their resized derivatives, to provide an adequate group for evaluation. There is no need to design and develop a new tank for this application when the resulting cost differential is considered.

The remaining tanks from Table 4.2-4 consist of the tanks selected for the two Martin Marietta versions of OSCRS and one other tank of each type. The tanks to be continued in this part of the trade study are listed in Table 4.2-5 for monopropellants and for bipropellants.

Figure 4.2-4 shows the relative size of the tanks selected for further consideration along with the OMS tank at the same scale. As can be seen, the OMS tank is much too large. Where two numbers are given for size, the larger number is the tank length. Tank dimension numbers are in inches. The weights shown on the figure are the total weight of tank and fluid. The sizes are nominal tank sizes with no allowances for fittings, nozzles, etc.

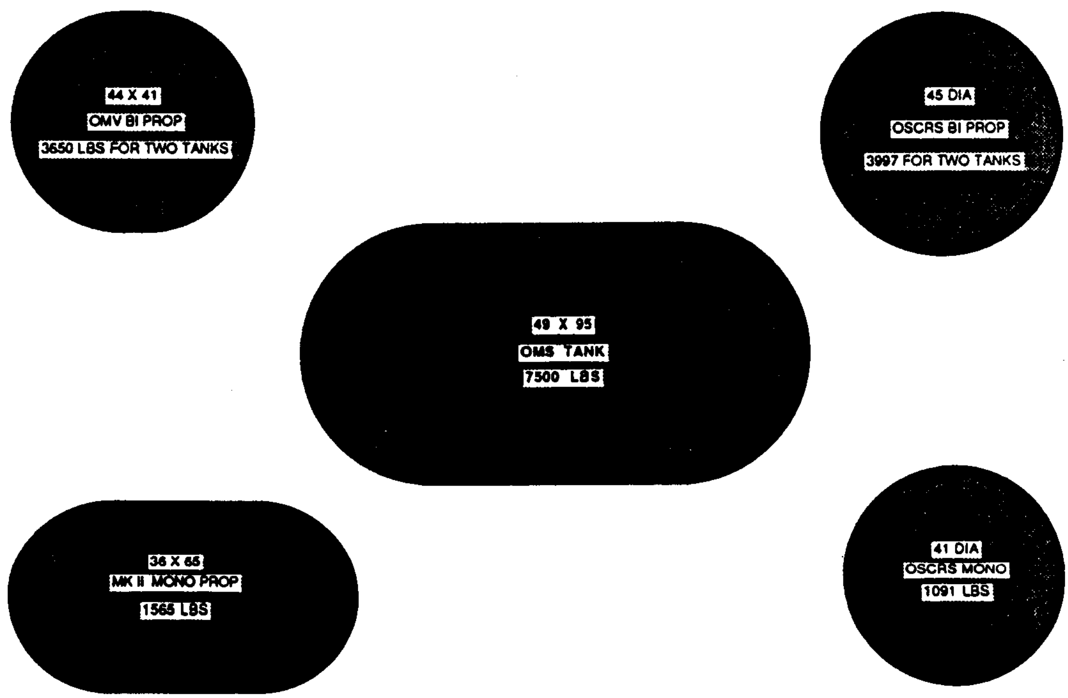

Figure 4.2-4 Useful Tank Sizes

The Figure 4.2-4 sketches of tank sizes are used on Figure 4.2-5 to demonstrate how the various tanks can be fitted into the IOSS stowage rack where the tanks are at the same scale as the IOSS stowage rack.

Figure 4.2-5

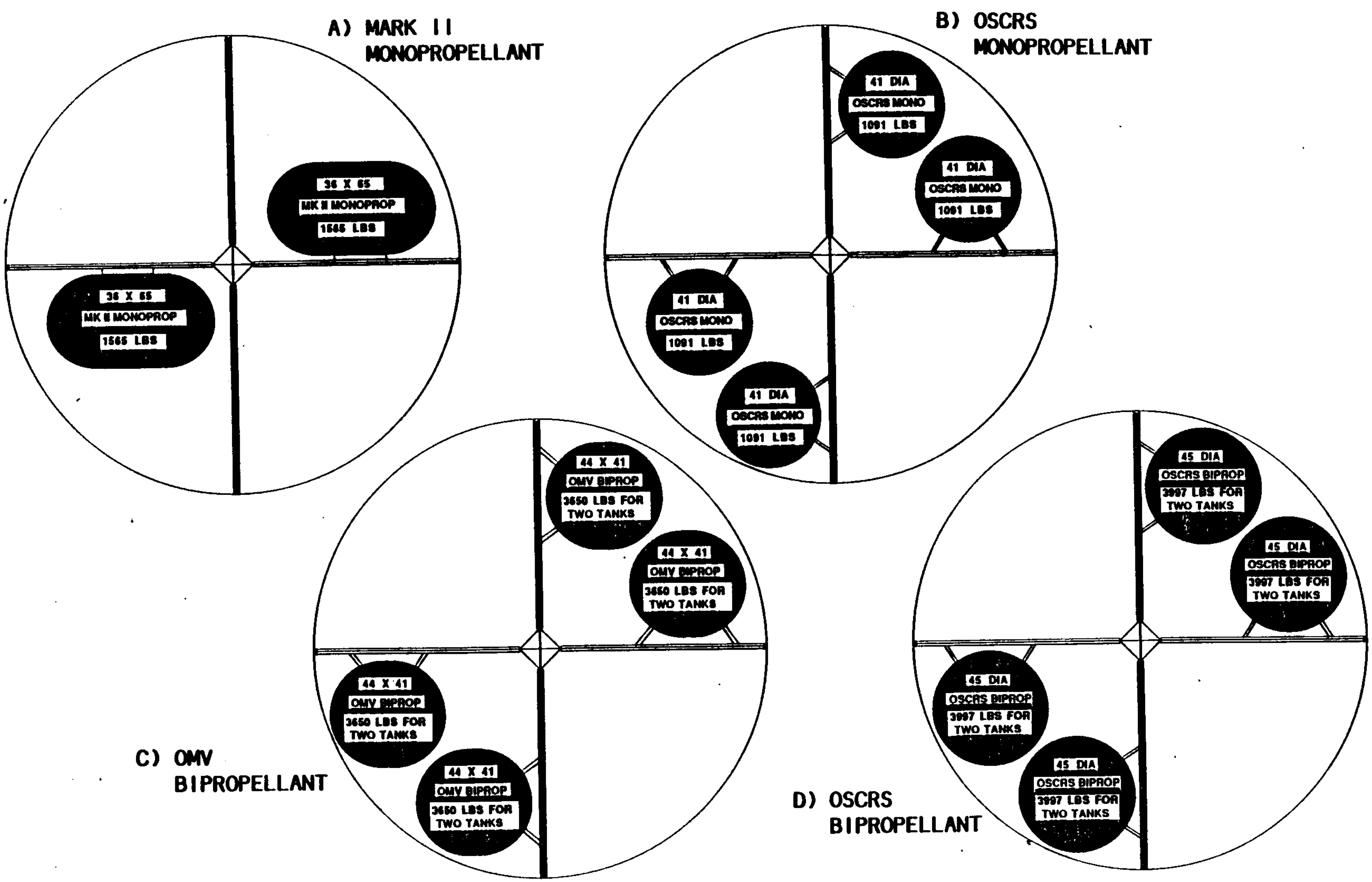

Figure 4.2-5 Candidate Tank Arrangements for IOSS Stowage Rack

Figure 4.2-5 a) shows how the Mark II Propulsion Module tanks can be fitted into the IOSS stowage rack. There is adequate room for one tank in each quadrant, but a second set of tanks could not be fitted in. The tank dimensions are in inches and the weights shown are for tank and fluid. This arrangement could have been used for bipropellants, but as noted earlier, this tank is heavy for its size as compared to the tank alternatives selected for bipropellants. The Mark II Propulsion Module tanks are acceptable from an installation viewpoint.

Figure 4.2-5 b) shows how the OSCRS monopropellant tanks (TDRSS tanks) fit into the IOSS stowage rack. There is room for a total of four tanks in the two quadrants. It was found that six TDRSS tanks would almost fit into the IOSS stowage rack, but there was no room for nozzles, supports, insulation, etc. The weights shown are for a tank full of hydrazine. The OSCRS tanks are acceptable from an installation viewpoint.

Figure 4.2-5 c) shows how the Martin Marietta orbital maneuvering vehicle bipropellant tanks can be fitted into the IOSS stowage rack. There is adequate room for two sets of tanks. The tank dimensions are in inches with the larger dimension being the tank length. It was found that six tanks would not fit even if the tanks were turned on end. The weights shown are for two tanks full of fluid. Weights for tank pairs are shown because of the different densities of the fuel and the oxidizer. The ability to install two pairs of tanks means that one pair can be used as catch tanks if the fluid transfer system requires the use of catch tanks. The OMV bipropellant tanks could have been used for monopropellants except that it was desired to avoid the use of tanks with PMDs for hydrazine. The Martin Marietta OMV tanks are acceptable from an installation viewpoint.

Figure 4.2-5 d) shows how the OSCRS bipropellant (L-SAT) tanks can be fitted into the IOSS stowage rack. There is adequate room for two sets of tanks. The tank diameter shown is in inches. While the tank diameter is slightly larger than the IOSS stowage rack depth, that point has been set aside because the IOSS stowage rack could be increased in depth slightly to accommodate the OSCRS tanks, or the tanks could be allowed to project slightly above the stowage rack and the servicer mechanism trajectories could be adjusted slightly to allow for the protrusion. The weights shown are for two tanks full of fluid. Weights for tank pairs are shown because of the different densities of the fuel and the oxidizer. The ability to install two pairs of tanks means that one pair could be used as catch tanks if the fluid transfer system requires the use of catch tanks. The OSCRS bipropellant tanks could have been used for monopropellant except that it was desired to avoid the use of tanks with PMDs for monopropellants. The OSCRS tanks are acceptable from an installation viewpoint.

4.2.4 Tank Selection

Table 4.2-6 shows the ten factors chosen for selecting monopropellant and bipropellant tanks to be used for fluid resupply out of the IOSS stowage rack. The two tanks on the left are monopropellant tanks and

Table 4.2-6 Factors for Tank Selection

	MK II	OSCRS MONO	OMV	OSCRS BIPROP
MINIMIZE DIFFICULTY IN QUALIFYING TANKAGE FOR MULTIPLE LAUNCHES AND PRESSURE/EXPULSION CYCLES (80 SERVICING MISSIONS)	50	80	?	80
MINIMIZE DIFFICULTY IN MEETING MAXIMUM EXPECTED OPERATIONAL PRESSURE OF 500 PSIA/HYDRAZINE AND 150 PSIA/BIPROPELLANT	400 MONO	500	350 BI	150
EXISTING TANKAGE IS DESIRED	YES	PLANNED	PLANNED	PLANNED
TANK MASS FRACTION SHOULD BE MAXIMIZED	0.88	0.89	0.9	0.96
MINIMAL COST IS DESIRED ($/LB OF PROPELLANT)	320	180	300	220
TANK SHAPE AND SIZE SHOULD PACKAGE WELL INTO IOSS CONFIGURATION WHERE PAYLOAD LENGTH IS THE MAJOR DRIVER	36 X 65	41	41 X 44	45
CAN PROVIDE PRESSURANT TO BOTH MONOPROPELLANT AND BIPROPELLANT SYSTEMS	YES	YES	YES	YES
EASE OF IOSS INTEGRATION	BEST	BETTER	GOOD	GOOD
TANKS SHOULD BE INSTALLED IN PAIRS FOR EASY CG MAINTENANCE	SIZE CONST-RAINTS	YES	YES	SIZE CONST-RAINTS
PROPELLANT CAPACITY (LBS)	2750	3884	6700	7694

the two on the right are bipropellant tanks. The factors are arranged with the most important being at the top. The requirement for number of launches and pressure/expulsion cycles is 80 and was taken from the OSCRS work. The value for the OMV tanks was not available. Satisfaction of the expected operational pressure is the next consideration. It should be recognized that most of these tanks can be made slightly thicker to accommodate higher pressures.

Each of the tanks being considered either has been built, or is a modification of an existing tank, except for the OMV tank, which under our assumptions can be assumed to be developable into a flight qualified system.

Tank mass fraction is the weight of fluid expelled divided by the weight of tank and fluid. It is a measure of tank structural and expulsion efficiencies. The cost data is the recurring tank cost divided by the pounds of propellant that the tank can hold. For the bipropellant tanks, an average propellant weight was taken for the fuel and the oxidizer tanks. The tank shape and size considerations were addressed in Figure 4.2-5.

The ability to provide pressurant was addressed by considering whether there appeared to be adequate space for pressurant tanks of the sizes used for OSCRS. Ease of tank integration has to do with the space left over after the tank is installed in the IOSS stowage rack and whether the space was such that it could be easily used for the hose and cable management system.

In each of the cases addressed, the tanks could be installed in pairs, but two of the tank sets did not fit as well as the others. The propellant capacity data assumes that all tanks can be filled to capacity and that catch tanks are not required by the fluid transfer process used.

The results of the tank selection scoring process, which follows the Kepner-Tregoe approach, are shown in Table 4.2-7. The factors are the same as discussed in Table 4.2-6. The relative weight (WGT) assigned to each factor is shown on the figure and varies between six and ten, with ten being the highest value. Each tank type was then scored for each factor. The best tank for each factor was given a score of ten, and the other tanks were scored comparatively to the best tank. The weighted scores are the sum of the products of the weighting factor and the score.

Table 4.2-7 Tank Selection Scoring

	WGT	MK II	OSCRS MONO	OMV	OSCRS BIPROP
MINIMIZE DIFFICULTY IN QUALIFYING TANKAGE FOR MULTIPLE LAUNCHES AND PRESSURE/EXPULSION CYCLES (80 SERVICING MISSIONS)	10	8	10	8	10
MINIMIZE DIFFICULTY IN MEETING MAXIMUM EXPECTED OPERATIONAL PRESSURE OF 500 PSIA/HYDRAZINE AND 150 PSIA/BIPROPELLANT	10	8	10	10	10
EXISTING TANKAGE IS DESIRED	9	10	8	8	8
TANK MASS FRACTION SHOULD BE MAXIMIZED	8	7	8	9	10
MINIMAL COST IS DESIRED ($/LB OF PROPELLANT)	8	6	10	7	9
TANK SHAPE AND SIZE SHOULD PACKAGE WELL INTO IOSS CONFIGURATION WHERE PAYLOAD LENGTH IS THE MAJOR DRIVER	8	9	10	10	8
CAN PROVIDE PRESSURANT TO BOTH MONOPROPELLANT AND BIPROPELLANT SYSTEMS	8	10	10	10	10
EASE OF IOSS INTEGRATION	8	10	8	6	6
TANKS SHOULD BE INSTALLED IN PAIRS FOR EASY CG MAINTENANCE	6	8	10	10	9
PROPELLANT CAPACITY (LBS)	6	6	7	9	10
WEIGHTED SCORE	810	670	742	702	730

The maximum possible weighted score is 810. Of the two monopropellant tanks, the OSCRS tank scored significantly higher than the Mark II tank. The OSCRS monopropellant tank score is reasonably close to the maximum possible (92%). The OSCRS monopropellant tanks scored low only on the question of propellant capacity. However, they have a larger capacity than the Mark II Propulsion Module tanks. The OSCRS tanks have a slightly higher mass fraction, while the Mark II tanks can be more easily integrated into the IOSS stowage rack. The OSCRS monopropellant tank is the selected tank. Additionally, the OSCRS monopropellant tank uses a bladder type expulsion system, while the Mark II Propulsion Module uses a complex propellant management device.

The OSCRS bladder system is preferred because it is operationally simpler.

The OSCRS bipropellant tank scored higher than the OMV bipropellant tank and has a score that is reasonably close to the maximum possible (90%). The unknown number of servicing missions that the OMV tank is capable of gave it a lower score on this factor. The OSCRS tanks have a better mass fraction and a lower cost per pound of propellant. The OSCRS tank diameter is slightly greater than the IOSS stowage rack depth, while the OMV tanks fit into the IOSS stowage rack. The OSCRS tanks carry more propellant than the OMV tanks. The OSCRS tank was selected based on its higher score and the fact the OMV tank is not a derivative of an existing tank and would represent a higher development risk and cost.

As was expected, the OSCRS tanks came out well in an evaluation based on criteria similar to those used in the OSCRS study tank selection process. If the OSCRS tanks had not scored well, then there would have been reason for concern.

The conclusions and recommendations from the tank trade study are shown in Table 4.2-8. The OMS tank and the stretched version used in the

Table 4.2-8 Conclusions from Tank Trade Study

OMS tank (SPERC) is too large
Maximum of two Mark II tanks limits their use to monopropellant
For monopropellants, OSCRS scored better than Mark II
OSCRS monopropellant tanks satisfy most resupply requirements
OMV bipropellant tanks are limited by potential need for catch tanks
OSCRS bipropellant tank fit is marginal
OSCRS avionics system may be usable with IOSS
<u>Recommended IOSS Stowage Rack Candidates</u>
- Continue with OSCRS monopropellant tanks
- Do not continue any bipropellant candidates

SPERC are too long to fit into the IOSS stowage rack. As only two of the Mark II tanks will fit into the IOSS stowage rack, they cannot be used for bipropellants if catch tanks are required.

The OSCRS monopropellant tanks (TDRSS tanks) scored better than the Mark II Propulsion Module tanks against the criteria used by about 10%. The OSCRS monopropellant tanks with a 3767 lb expulsion capacity can satisfy all monopropellant resupply requirements except for the Mark II that has a 5000 lb tank capacity. The OSCRS tank capacity is 75% of the Mark II tank capacity, which might be the proper amount for a resupply mission that would be performed before the Mark II Propulsion Module tanks were totally depleted.

The OMV, or OSCRS, bipropellant tank use is potentially limited by the possible need for catch tanks. In which case, the maximum bipropellant that could be transferred would be less than 3700 lb. The fit of the OSCRS bipropellant tank is marginal, however the OSCRS did score better than the OMV against the criteria used. Both bipropellant transfer systems are more difficult to operate than the monopropellant systems because of their use of propellant management devices rather than bladders for fluid expulsion.

The recommended approach to be carried for the rest of the integration analysis, with regard to the IOSS stowage rack candidates, is to continue with the OSCRS monopropellant tanks, but not to use any bipropellant tanks in the IOSS stowage racks. Bipropellants are mainly used where impulse requirements are high, which means the fluid quantities are high while the stowage rack capacity is low. Bipropellants should be carried in tankers such as the OSCRS. There is just not enough room in the IOSS stowage rack for probable bipropellant resupply mission requirements.

While not a part of the trade study analysis, it was recognized that there is a need for control of the fluid transfer process and that the OSCRS avionics system was designed to do just that. The OSCRS avionics system was conceptualized as a reprogrammable, highly redundant, system for the control of propellant transfer. As such it could be used in the IOSS stowage rack for control of fluid transfer and certain development costs could be saved. There is room on the IOSS stowage rack for the mounting of pressurant tanks in moderate quantities, if they are required.

4.3 TANKER TRADE STUDY

This tanker trade study is the second of the three paths of the tank/tanker trade study. The first path addressed the use of tanks in the IOSS stowage rack, this second path addresses the use of tankers such as the OSCRS, and the third path considers the use of tanks as ORUs.

The tankers that were considered are:

1) Mark II Propulsion Module;
2) OSCRS monopropellant;
3) OSCRS bipropellant;
4) SPERC;
5) OMV propulsion module.

Each of these tankers was specified for consideration in the fluid resupply integration analysis statement of work. No other candidates were identified during the analysis. The first two tankers are monopropellant tankers, while the last three are bipropellant tankers. The tankers are described and their characteristics are summarized first. This description is followed by a discussion of the tanker selection process and a summary of conclusions from this second study path.

4.3.1 Tankers Considered

The major elements and an assembled configuration of the Mark II Propulsion Module are shown in Figure 4.3-1. The Mark II PM is one element of the Multi-Mission Modular Spacecraft system. The Mark II PM is built by Martin Marietta Astronautics Group and a number have been

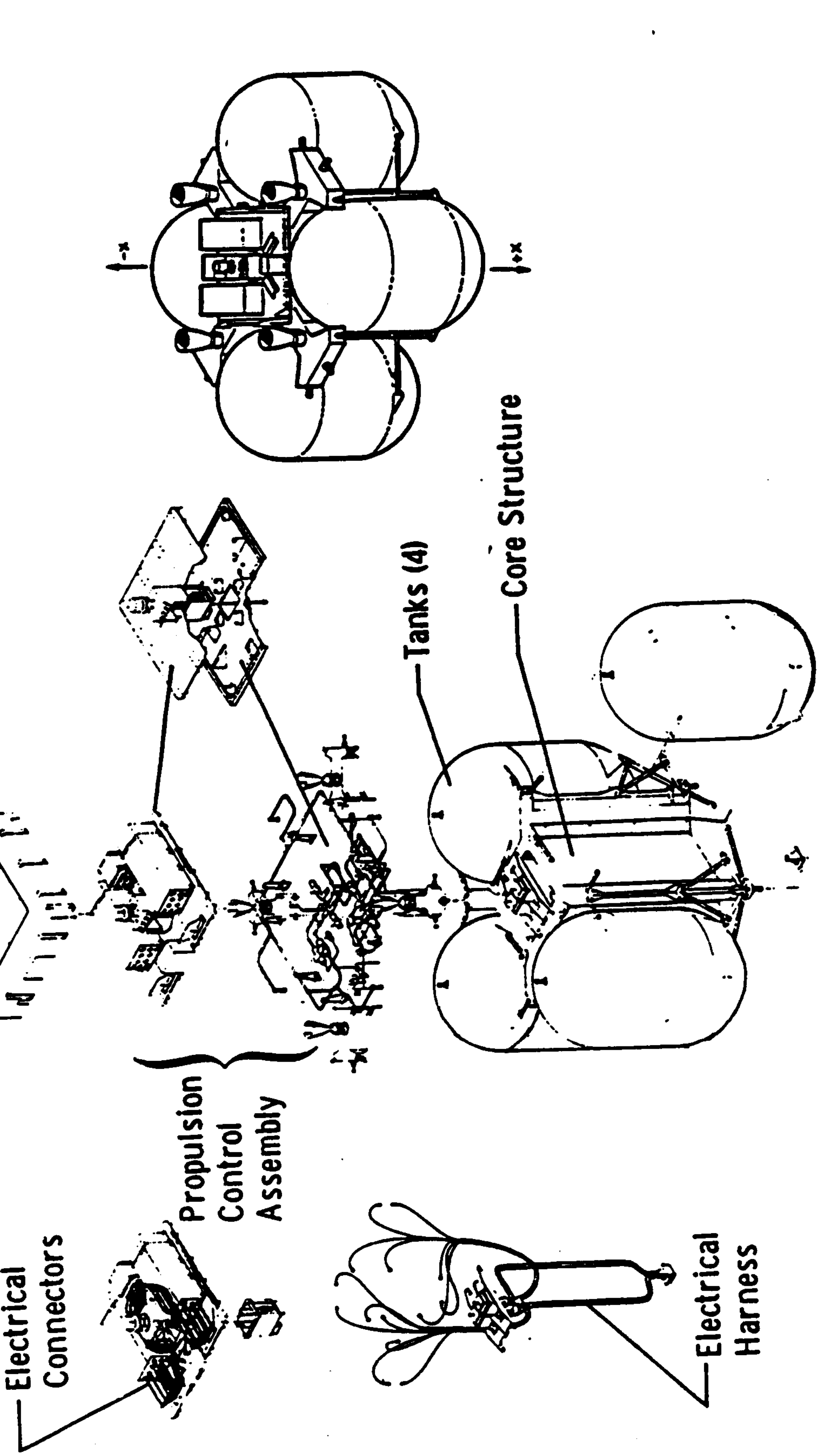

Figure 4.3-1 Mark II Propulsion Module

Figure 4.3-1

delivered to a variety of customers. The left hand side of the figure is an expanded view of the Mark II Propulsion Module, while the right hand side is an assembled view.

The Mark II PM is a complete subsystem requiring only external sources of power and commands to perform its functions of orbit adjust and attitude control. The primary function of the PM is to provide spacecraft thrust control to accomplish: 1) orbit adjust, which consists of orbit transfer for altitude and minor inclination changes as well as orbit maintenance; and 2) attitude control, which consists of spacecraft initial stabilization and sensor acquisition, attitude hold control (limit cycling), roll control during orbit adjust maneuvers, momentum management, and attitude maneuvers. Maximum system width is 100.32 in., length is 72 in. and loaded weight is 6930 lb.

Capability exists to provide all of the above functions by onboard computer (OBC) control or autonomously by analog signals derived from the modular attitude control subsystem (MACS). Pitch and yaw control is maintained by modulating the orbit adjust thrusters in an off-pulsing manner. The attitude control thrusters provide control about the roll axis.

The propellant capacity of the four-tank configuration in the blowdown mode at a 5:1 ratio is 5500 lb. A lower propellant load could be selected with a correspondingly lower blowdown ratio. The PM tanks and structure have been designed to accommodate up to 6200 lb of propellant and additional pressurant spheres.

The steady state specific impulse of the orbit adjust thrusters is estimated to be 234 sec, with an estimated overall average of 228 sec throughout a typical mission life. The steady state specific impulse of the reaction control system is approximately 232 sec, with an estimated overall average of 200 sec or less depending on pulsing duty cycle.

The Mark II, as its name implies, is a propulsion module and not a tanker. This means that it has orbit adjust thrusters and reaction control system thrusters, which are not required for a tanker, and it does not have any fluid transfer equipment, which is required for a tanker.

The assembled configuration of the Martin Marietta version of a monopropellant OSCRS is shown in Figure 4.3-2 with the major subsystems and subsystem elements identified. The three propellant tanks and two pressurant bottles that make up the basic fluids capability are

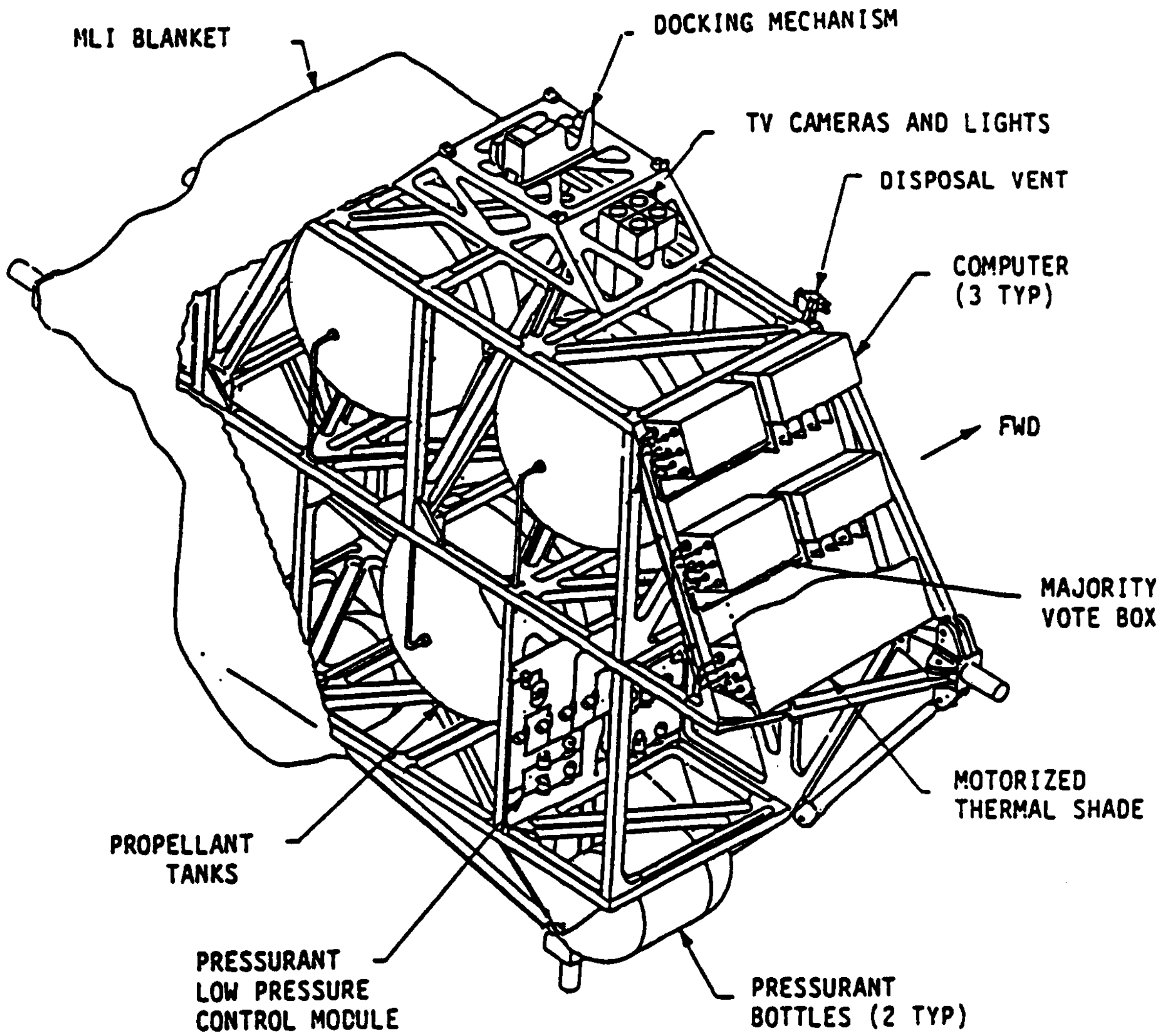

Figure 4.3-2 OSCRS Monopropellant Tanker

visible. The fluid couplings and electrical connectors are stowed on the port side and are hidden in this view. Primary components of the avionics subsystem are shown in their mounted location along with the avionics and motorized thermal shade. A representative valve and plumbing panel is shown in the second tier of the structure. Similar modular panels will be installed for the options to the basic OSCRS for added propellant and pressurant load capability.

The fluid subsystem provides the necessary storage and transfer capability for resupplying hydrazine, and GN_2 or GHe, to spacecraft users. A simple pressure fed approach to expel propellants into user tankage was selected for the baseline design. Capability for overboard venting of residual propellants and propellant-contaminated pressurants through catalytic vents mounted to the OSCRS structure is also provided.

The OSCRS avionic subsystem is designed to provide the man-machine interface and to control and monitor the OSCRS during fluid resupply to a satellite. Electrical interfaces to the receiving satellite and to the orbiter are included. Power distribution, control, and monitoring is available for both the OSCRS and the satellite. OSCRS and satellite valve control and monitoring are provided. The avionics also has a capability for control and monitoring of mechanisms associated with the berthing, emergency separation, and operation of automatic interface systems. Instrumentation and signal conditioning are provided as is the man-machine interface in the orbiter aft flight deck. The avionics system is triply redundant and has a two-fault-tolerance capability for commanding valves and monitoring the propellant transfer operation.

The OSCRS configuration is modularized to support three, four, or five tanks without major structural change. A three point attachment to the orbiter is used. The basic OSCRS monopropellant design focused on GRO resupply at the orbiter using EVA for fluid and electrical line connection. There are two growth versions that use the larger number of propellant tanks and pressurant bottles. The most advanced growth version includes use on the OMV for in-situ fluid resupply away from the orbiter.

The assembled configuration of the Martin Marietta bipropellant OSCRS is shown in Figure 4.3-3 with the major subsystems and subsystem elements identified. The six propellant tanks and the six pressurant bottles that make up the basic fluids capability are visible. The fluid couplings and electrical connectors are shown in their stowed positions. Primary components of the avionics subsystem are shown in their mounted location on the starboard side. A docking mechanism (Payload Retention Latch Assembly), tool box, and docking camera are shown on the top of OSCRS.

The fluid subsystem provides the necessary storage and transfer capability for resupplying MMH and NTO propellants and GN_2 and GHe pressurant to spacecraft users. A simple pressure-fed approach was adopted to expel propellants into user tankage for this bipropellant configuration. Capabilities for overboard venting of residual bipropellants and bipropellant-contaminated pressurants through a bipropellant burner on a fold-out structure are also provided. The L-SAT type bipropellant storage tanks use surface tension propellant management devices. One empty catch tank for each commodity is provided.

The avionics system for the bipropellant OSCRS is a growth version of the avionics system for the monopropellant OSCRS. The bipropellant OSCRS requires four majority-vote valve drive boxes and additional expansion chassis in the microcomputers.

Features of the structures and mechanisms design include: 1) a machined aluminum truss with the structural capability of carrying up to 4 tanks of fuel or oxidizer, plus two catch tanks, and ten bottles of high pressure gas, 2) L-SAT tanks, 3) use of the Payload Retention Latch Assembly as a docking mechanism, 4) five point attachment to the orbiter, 5) a minimum of 80 missions of service life, and 6) a length of 61 in.

The basic bipropellant OSCRS design also focused on operations at the orbiter using EVA for fluid and electrical line connections. Growth versions involve extension to operation on the OMV for in-situ fluid resupply away from the orbiter.

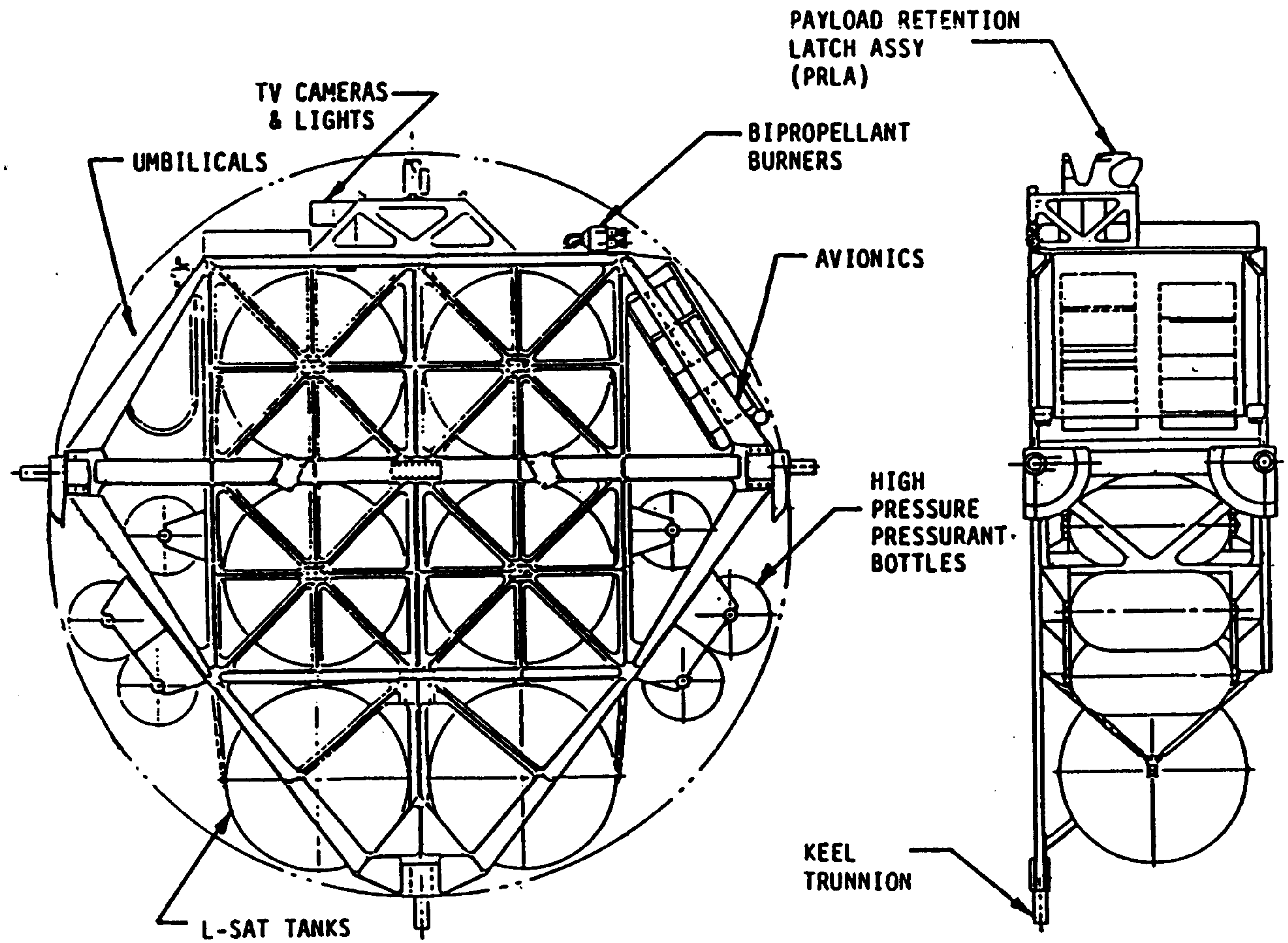

Figure 4.3-3 OSCRS Bipropellant Tanker

Figure 4.3-3

The assembled configuration of the large version Space Platform Expendables Resupply Concept is shown in Figure 4.3-4 along with some important characteristics of the concept. The concept shown was selected by Rockwell International from among several competing approaches primarily on the basis of overall structural efficiency and for its use of existing hardware to provide low development cost. The resupply module is supported at its forward end by an existing inertial upper stage (IUS) forward cradle. This cradle includes a load equalization capability that reduces the structural redundancy between the resupply module and the orbiter. It also allows a minimum weight impact on the resupply module for attachment to the orbiter payload bay longerons and keel at its forward end. The resupply module uses six stretched OMS tanks with a modified ullage positioning propellant management device for ullage bubble position control.

Ullage exchange was selected as the best option for the NTO/MMH fluid transfer process. This approach is applicable to all potential receiver propulsion subsystem and acquisition types through appropriate modifications. It minimizes pressurant resupply requirements, involves no adiabatic compression (explosion hazard), requires no waste or hazardous effluent scavenging, and provides constant pressure resupply.

The basic structural components of the SPERC are very simple, yet very efficient. All fore and aft loads and part of the vertical loads are supported at two payload bay longeron attachment points in the main structural bulkhead. As a representative attachment to the OMV, six bolts are provided. The main bulkhead also has a keel attachment for the orbiter payload bay.

A pressurant transfer analysis showed that it was better to use four pressurant bottles in cascade on the SPERC side as compared to using a single bottle and a pump with batteries. The ullage transfer system selected for propellant transfer requires the use of a transfer pump. The pump analysis indicated that a gear pump would be better than a peristaltic or centrifugal pump. Magnetic coupled pumps are very large and consume large amounts of power (approximately four times that required for a gear or centrifugal pump).

Figure 4.3-4

- UMBILICAL PURGE
  - DRIBBLE VOLUME PURGE
    - SIMPLE DESIGN
    - LOW SYSTEM WEIGHT
    - QUICK PURGE TIME
- PRESSURANT TRANSFER
  - RECOMMEND FOUR PRESSURANT BOTTLES
  - USE CASCADE APPROACH
- PROPELLANT TRANSFER PUMPS
  - RECOMMEND GEAR PUMP
  - MAGNETICALLY COUPLED PUMPS REQUIRE MASSIVE ELECTRICAL POWER
- QUICK DISCONNECT
  - AUTOMATED Q.D. DEVELOPMENT IN NASA PLANNING
- INSTRUMENTATION
  - TEMPERATURE
  - PRESSURE
    - NO NEW DEVELOPMENTS REQUIRED

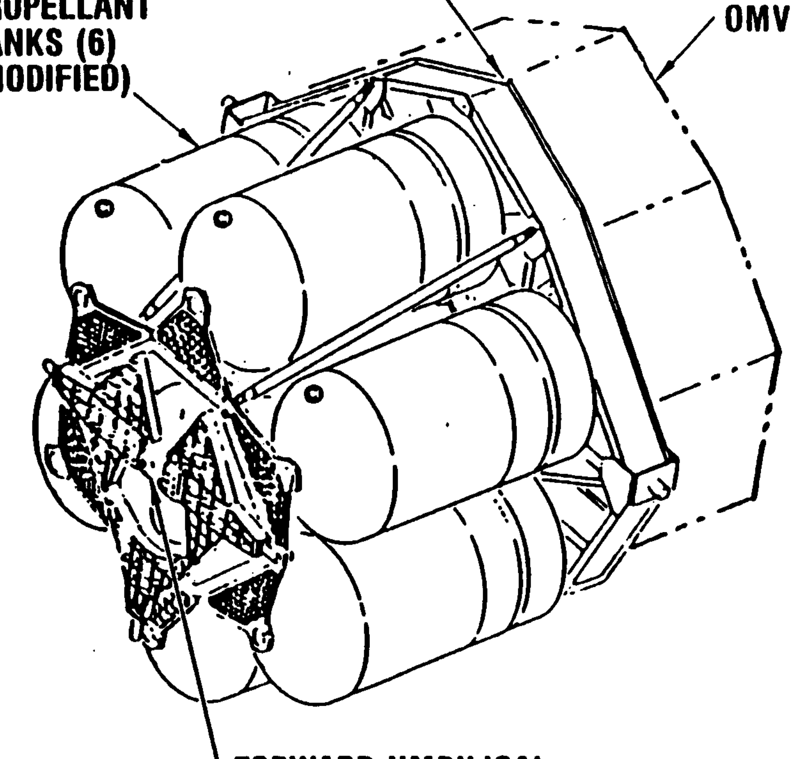

Figure 4.3-4 SPERC Bipropellant Tanker

The addendum to the SPERC study suggested reducing the SPERC capacity from 45,000 lb to 7,000 lb by the use of orbiter reaction control system tanks instead of the stretched OMS tanks. Unfortunately, little other information was provided for the smaller tanker. The 7,000 lb capacity figure for a bipropellant capacity agrees well with the OSCRS requirement.

A sketch of the orbital maneuvering vehicle and its propulsion module is shown in Figure 4.3-5. The OMV short range vehicle is shown to the left of the figure and the propulsion module is to the right. The OMV is designed to provide servicing flexibility at the launch site and on orbit. The vehicle is modular: 1) the main delta velocity propulsion module is removable allowing the bipropellant system to be serviced and refueled in parallel with the short range vehicle (SRV) during prelaunch or post launch processing; 2) the avionics ORUs have mechanical and electrical connectors to the OMV that allow removal and replacement by either robotic or manual methods. Additionally, the manifolded reaction control system ORUs are scarred for fluid disconnects in the hydrazine system; 3) the ORU designs drive towards easily removable internal black boxes. This allows replacement of failed units during prelaunch processing and leads to servicing at an orbiting facility.

The propulsion module design, which permits replacement of the total bipropellant delta velocity system, allows the OMV to be space based without requiring onorbit bipropellant fluids transfer. The PM has only mechanical and electrical connections with the SRV. There are no propellant lines across the interface. The propulsion module empty weight is 2120 lb and it can carry 8775 lb of bipropellants. The bipropellants have a specific impulse between 280 and 300 sec. The propellants are contained in four tanks and the helium pressurant is also contained in four tanks but at a pressure of 4500 psi. A surface tension start basket is used for propellant management and it can be complemented with reaction control system (RCS) engine settling if required. The propellant tanks in an early version of the OMV used an adaptation of the TDRSS tanks. The PM is approximately 55 in. deep, 136 in. across the corners, and 111 in. across the flats.

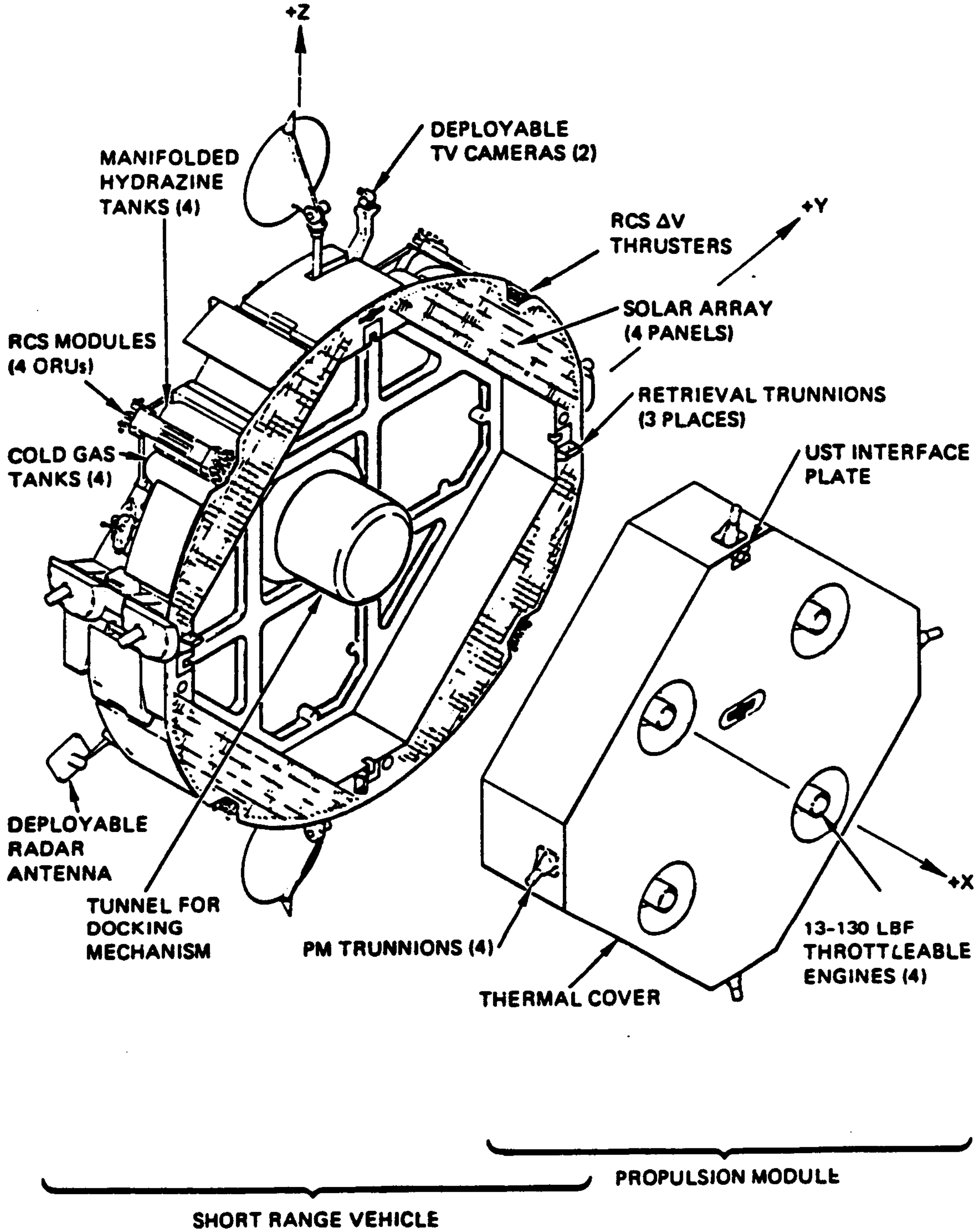

Figure 4.3-5 OMV Configuration

Like the Mark II Propulsion Module, the OMV propulsion module is also a propulsion module with orbit adjust thrusters that are not required for a tanker application. Also, it does not have any fluid transfer equipment, which is required for a tanker.

A summary of the characteristics of the four tankers selected for further analysis is shown in Table 4.3-1. The OMV propulsion module was not continued in the analysis because: 1) the available data was changing, 2) it is not configured to use all of the orbiter cargo bay diameter, 3) it would be difficult to adapt to the IOSS because of its smaller diameter, 4) it would need to have a number of functions added such as avionics, fluid transfer and electrical connectors on each side, and 5) the engines would need to be removed.

Table 4.3-1 Tanker Characteristics

TANKERS	DRY WGT LBS	PROP CAP LBS	NO. TANKS	FLOW RATE LBS/SEC	PRESSURANT	NUMBER OF CYCLES
REQUIREMENT		MONO- 5000 BIPROP - 7000		MONO - 0.23 BIPROP - 0.32		80
MK II PROPULSION SYSTEM MONO	1390	6200 W/ EXT. PRESS. 5500	4	0.2	GN2, 40 LBS	50
OSCRS MONO	2466 - 5 TANKS 1954	(1940 - 4850) 2910 (BASIC)	2, 3, 4, 5 3 (BASIC)	0.16 - 2.75	GN2, 250 LBS AT 3000 PSIA or GHE, 36 LBS	80
BI	3185	7000 - 11250	2, 4, or 6	MMH - 2.56 NTO - 3.28	GN2, 253 LBS GHE, 13 LBS	80
SPACE PLATFORM EXPENDABLES RESUPPLY CONCEPT BI	7200	45000 (84) 7000 (85)	6	MMH 0.6 NTO 1 N2H4 0.138	GHE, 1171 LBS	100

The requirements for propellant capacity, propellant flow rate, and number of operating cycles are shown in the table for reference. As can be seen, the Mark II Propulsion Module and the growth version of the OSCRS can satisfy the monopropellant requirements. Similarly, the bipropellant OSCRS and the SPERC can satisfy the bipropellant requirements. However, the early (1984) capacity of the SPERC at 45,000 lb is much too large. The later (1985) SPERC report indicates that a better sizing would be at a 7,000 lb capacity and could be accomplished by replacing the OMS tanks with orbiter reaction control system tanks. The larger version was used in this analysis because the data available on the smaller version was incomplete. The two OSCRS tankers offer a variety of fluid capacities depending on the number of tanks that are carried. There are two candidates for each type of propellant tanker.

4.3.2 Tanker Selection

Table 4.3-2 lists the factors used in selecting tankers for further analysis along with the specific numbers for each of the candidate tankers. The two tankers on the left are monopropellant tankers and the two on the right are bipropellant tankers. The factors are arranged with the most important at the top. The requirement for number of launches and pressure expulsion cycles is 80 and was taken from the OSCRS work. The value for the SPERC was not available. Satisfaction of the expected operational pressure is the next factor. While the Mark II tank does not satisfy the requirement, it could be made thicker and then satisfy the requirement. Each of the tankers being considered uses tanks, or modifications of tanks, that have been built. However, the Mark II is not a complete tanker system, it is a propulsion module and thus would need to be redesigned to become a tanker.

The OSCRS plans to have excellent avionics, but the other two tankers would need to have their avionics redesigned to satisfy the mission needs. Each of the tankers is planned for EVA and remote operations except for the Mark II. The OSCRS mass fractions are lower than the others. The Mark II has the lowest unit cost and capability, and the SPERC has the highest unit cost and capability.

Table 4.3-2 Factors for Tanker Selection

	MK II	OSCRS MONO	OSCRS BI PROP	SPERC
MINIMIZE DIFFICULTY IN QUALIFYING TANKER FOR MULTIPLE LAUNCHES AND PRESSURE/EXPULSION CYCLES (80 SERVICING MISSIONS)	50	80	80	–
MINIMIZE DIFFICULTY IN MEETING MAXIMUM EXPECTED OPERATIONAL PRESSURE OF 500 PSIA/HYDRAZINE AND 150 PSIA/BIPROPELLANT	400 PSI MONO	500 PSI	150 PSI	257 (EST)
EXISTING TANKER IS DESIRED	PARTIAL	PLANNED	PLANNED	PLANNED
AVIONICS PROVIDED FOR EACH MISSION	SOME	YES	YES	SOME
ADAPTABILITY TO REMOTE OPERATIONS AND EVA	MMS CAPABILITY	REMOTE GROWTH	REMOTE GROWTH	PLANNED
TANKER MASS FRACTION SHOULD BE MAXIMIZED	0.8	0.67	0.69	0.86
MINIMAL COST IS DESIRED (UNIT COST IN 1986 $ M)	10	13	17	21
TANKER SHOULD AFFORD MAXIMUM USER FLEXIBILITY FOR PROPELLANT TRANSFER - PARTIAL FLUID LOADS - MULTIPLE SPACECRAFT SERVICING - FLUID TRANSFER TIME LESS THAN 6 HOURS	0.2 #/SEC	0.16 TO 2.75 #/SEC	MMH 2.56 #/SEC NTO 3.28 #/SEC	0.13 #/SEC MONO 1.8 #/SEC BI
TANKER SHAPE AND SIZE SHOULD PACKAGE WELL INTO AN OVERALL SERVICER CONFIGURATION WHERE PAYLOAD LENGTH IS THE MAJOR DRIVER	72"	50"	61"	180" (EST)
PRESSURANT STORAGE PRESSURE OF 4500 PSI	GROWTH	YES	YES	5000 - 6000
EASE OF INTEGRATION WITH IOSS	POOR	BEST	BETTER	GOOD
EASE OF INTEGRATION WITH OMV	POOR	GROWTH	GROWTH	GROWTH
EASE OF REPROGRAMMING AVIONICS FOR EACH MISSION	POOR	BEST	BEST	GOOD
ADAPTABILITY TO ON ORBIT STORAGE (FREE-FLYING OR AT SPACE STATION)	WITH MMS	GROWTH	GROWTH	YES
BIPROPELLANT AND MONOPROPELLANT CAN BE SERVICED BY ONE SET OF TANKAGE	YES	NO	NO	YES

The eighth factor in the table has to do with user flexibility for propellant transfer and was addressed using the items shown.

The ninth item in the table recognizes the fact that the shuttle launch costs are partly based on length occupied in the orbiter cargo bay. Also considered was the diameter of the candidate tanker as compared to the diameter of the IOSS stowage rack. The pressurant storage pressure factor recognizes the expected storage pressures on the serviced spacecraft and was taken from the OSCRS work.

Ease of integration with the IOSS has to do with berthing interfaces, adaptability of fluid interfaces, avionics design, and ability to pass electronic signals to and from the IOSS and the OMV. Ease of integration with the OMV has to do with berthing interfaces, adaptability of fluid interfaces, and ability to pass signals to and from the OMV.

As each ORU exchange and fluid resupply will be different, it is important that the avionics software be easy to reprogram.

The adaptability to onorbit storage, either free-flying or at the space station, is important for future mission flexibility. Some missions may not require a full load of propellant, but it could be cheaper in terms of launch cost to leave the tanker on orbit and then pick it up again for the next required mission.

The last factor is the ability to use a single set of tankage that could be used for monopropellants or bipropellants for different missions. This is not an easy thing to do at the systems level when all parts of the fluid system are considered, in addition to just the tanks.

The results of the tanker selection scoring process (based on Kepner-Tregoe) are shown in Table 4.3-3. The factors are the same as in Table 4.3-2. The relative weight (WGT) assigned to each factor is shown and varies between six and ten with ten being the highest value. Each tanker was then scored for each factor. The best tanker for each factor was given a ten and the other tankers were scored comparatively to the best tanker. The weighted scores are the sum of the products of the weighting factor and the score. The maximum possible score is 1230.

Of the two monopropellant tanker candidates, the OSCRS scored significantly higher than the Mark II PM. The OSCRS monopropellant score is 94% of the maximum score and thus the OSCRS does not need to

Table 4.3-3 Tanker Selection Scoring

	WGT	MK II	OSCRS MONO	OSCRS BIPROP	SPERC
MINIMIZE DIFFICULTY IN QUALIFYING TANKER FOR MULTIPLE LAUNCHES AND PRESSURE EXPULSION CYCLES (80 SERVICING MISSIONS)	10	8	10	10	7
MINIMIZE DIFFICULTY IN MEETING MAXIMUM-EXPECTED OPERATIONAL PRESSURE OF 500 PSIA/HYDRAZINE AND 150 PSIA/BIPROPELLANT	10	8	10	10	7
EXISTING TANKER IS DESIRED	9	10	8	8	4
AVIONICS PROVIDED FOR EACH MISSION	9	5	10	10	5
ADAPTABILITY TO REMOTE OPERATIONS AND EVA BACKUP	9	5	10	10	9
TANKER MASS FRACTION SHOULD BE MAXIMIZED	8	9	8	8	10
MINIMAL COST IS DESIRED	8	10	8	6	5
TANKER SHOULD AFFORD MAXIMUM USER FLEXIBILITY FOR PROPELLANT TRANSFER - PARTIAL FLUID LOADS - MULTIPLE SPACECRAFT SERVICING - FLUID TRANSFER TIME < 6 HOURS	8	9	10	10	10
TANKER SHAPE AND SIZE SHOULD PACKAGE WELL INTO AN OVERALL SERVICER CONFIGURATION WHERE PAYLOAD LENGTH IS THE MAJOR DRIVER	8	8	10	9	5
PRESSURANT STORAGE PRESSURE OF 4500 PSI	8	5	10	10	10
EASE OF INTEGRATION WITH IOSS	8	5	10	9	7
EASE OF INTEGRATION WITH OMV	8	5	9	9	8
EASE OF REPROGRAMMING AVIONICS FOR EACH MISSION	7	5	10	10	8
ADAPTABILITY TO ON ORBIT STORAGE (FREE-FLYING OR AT SPACE STATION)	7	10	9	9	10
BIPROPELLANT AND MONOPROPELLANT CAN BE SERVICED BY ONE SET OF TANKAGE	6	10	8	8	10
WEIGHTED SCORE	1230	913	1153	1121	928

be improved significantly as compared to an ideal as defined by the factors used. The OSCRS monopropellant tankers scored a little low (8) on four factors. It is not an existing tanker as it is in the conceptual stage without a firm plan for development. The OSCRS mass fraction is not as high as the SPERC because it was not as structurally efficient and it has more avionics and fluid resupply hoses. The OSCRS cost is not as low as that of the Mark II PM, but it is a more complete tanker. No attempt was made to adjust costs to where each tanker had the same capabilities. The OSCRS monopropellant tanker does not use the same tankage as the bipropellant OSCRS as it was desired to use the operationally simpler elastomeric diaphragm for propellant expulsion.

The Mark II Propulsion Module scored a five on six items: 1) complete mission avionics was not provided, 2) it has no ability to accommodate either EVA or remote operations, 3) high pressure pressurant storage is only available in the growth version, 4) it is not easy to integrate with the IOSS, 5) it is not easy to integrate with the OMV, and 6) the avionics software cannot be easily reprogrammed for each mission.

The OSCRS monopropellant tanker was selected to be carried further in the analysis primarily because it was conceived to do all the functions expected of a fluid resupply tanker.

Of the two bipropellant tanker candidates, the OSCRS scored significantly higher than the SPERC. The OSCRS bipropellant tanker's score is 91% of the maximum score and thus the OSCRS bipropellant tanker does not need to be improved significantly as compared to the ideal defined by the factors used. The OSCRS bipropellant tanker scored low (6) on one factor: minimal cost is desired. The OSCRS scored low because it is a bipropellant system and has many features not contained in the high scoring Mark II PM. The OSCRS scored better than the SPERC bipropellant tanker.

The OSCRS bipropellant tanker scored a little low (8) on three factors. It is not an existing tanker as it is in the conceptual stage without a firm plan for development. The OSCRS mass fraction is not as high as the SPERC because it is not as structurally efficient and it has fluid resupply hoses and more avionics. The OSCRS bipropellant tanker does not use the same tankage as the monopropellant OSCRS as it was desired to use the operationally simpler elastomeric diaphragm for propellant expulsion on the monopropellant OSCRS. Note that both of the OSCRS tankers scored lower on the same factors.

The SPERC tanker scored very low (4) regarding desirability of an existing tanker because it is still in the conceptual stage and the most recent report noted a desire to go to a much smaller capacity (45,000 to 7,000 lb) and change from the stretched OMS tanks to the RCS tanks. The result is a low level of definition of the concept. The SPERC scored low (5) on three items: 1) the avionics was not defined, 2) it was the highest cost design because of the large tanks and structural efficiency, and 3) it was the longest tanker because of its high capacity. The SPERC also scored a 7 on three factors as shown in Table 4.3-3.

The OSCRS bipropellant tanker was selected to be carried further in the analysis primarily because it was conceptualized to do all of the functions expected of a fluid resupply tanker.

As one would expect, the OSCRS tankers did well in a trade study using criteria similar to those used for the OSCRS design activity.

Before going to the conclusions from the tanker trade study, the question of pressurant gas resupply is addressed. The two gases used as pressurants are helium and nitrogen. Helium is lighter, but it tends to leak through smaller holes and more of it dissolves in the propellants. The spacecraft pressurant storage bottles operate at a variety of pressures, but 4500 psi is fairly common. The servicer vehicle must store pressurant at a higher pressure than the serviced spacecraft unless a pump is used.

Four methods of transferring pressurant from the servicer vehicle to the serviced spacecraft are listed in Table 4.3-4 along with their primary disadvantages. The cascade blowdown approach involves having a number of pressurant tanks on the servicer for each pressurant tank on the spacecraft. The servicer tanks are blown down into the receiver one at a time and each tank is isolated after it is blown down. The result is a more efficient transfer of gas. Unless the servicer tanks operate at high (10,000 psi) pressure, a large number of tanks (4 to 6) is required on the servicer. When pumps are used, only one tank of pressurant on the servicer is required, but it must be complemented with a compressor and an electrical energy source. The compressor design is not easy if a low leak system is to be obtained and the energy storage system can be heavy. None of the solutions is very satisfactory.

Table 4.3-4 Pressurant Resupply Transfer Approaches

High pressure (10,000 psi) cascade blowdown (heavy tanks)
Medium pressure (5,000 psi) cascade blowdown (many tanks)
Medium pressure blowdown and OMV powered compressor (compressor weight and OMV electrical energy limit)
Medium pressure blowdown and OSCRS battery powered compressor (battery and compressor weight)

The OSCRS team did a tradeoff analysis and concluded that medium pressure cascade blowdown tanks with a compressor powered by energy from the orbiter was optimum. For the case considered in this analysis, the compressor energy would have to come from the OMV, the OSCRS, or both.

The resulting design concerns are:

1) Development of a 3 to 1 ratio compressor;
2) Source of compressor energy;
3) System weight (less batteries) is 5 times receiver tank weight.

Even after the design and development problems are solved, the resulting system, not including battery weight, would weigh five times as much as the receiver tank would weigh. This is a significant penalty. An alternative approach is suggested in Section 4.4.

The conclusions and recommendations from the tanker trade study are shown in Table 4.3-5. The monopropellant Mark II Propulsion Module can be used for bipropellants as it has a PMD, but it will require modification of the pressurization system and perhaps some seals if it is to be used with bipropellants. The Mark II is not compatible with the IOSS or with the OMV as its diameter is too small, the rocket engines would need to be removed, and an avionics system would have to be added.

Table 4.3-5 Conclusions From the Tanker Trade Study

Monopropellant Mark II Propulsion Module will require modification for use with bipropellants and is not compatible with OMV or IOSS
Monopropellant OSCRS scored better than Mark II Propulsion Module
Limited detail available on SPERC
Bipropellant OSCRS scored better than SPERC
Both of the OSCRS were designed for fluid resupply and each should integrate readily with OMV and IOSS
<u>Recommendations From Tanker Trade Study</u>
- Continue with monopropellant OSCRS tanker
- Continue with bipropellant OSCRS tanker

The monopropellant OSCRS scored 26% higher than the Mark II PM. The Mark II Propulsion Module had six low scores, mostly with regard to middle level factors such as low pressurant storage level. The OSCRS monopropellant tanker scored at least an eight on all factors.

While all of the SPERC reports were available to us, it was difficult to find specific data to enter in the comparison charts. Also the most recent SPERC report suggested a drastic reduction in its tank capacity with little corresponding change in design information. A 7,000 lb capacity SPERC might well have been more of a challenge to the bipropellant OSCRS. The large SPERC scored a 7, or less, on seven of 15 factors and the OSCRS score was 21% better than the SPERC score. The OSCRS bipropellant tanker scored a six on minimal cost and at least an eight on all other factors. The SPERC cost is greater than that of the bipropellant OSCRS. Both bipropellant tankers have high costs because two fluids are to be handled and the need for PMDs.

The tanker trade study recommendation is to continue with the two OSCRS tankers as they are better than the other candidates, which is due to the fact that they (OSCRS) were designed to the same general requirements as were used in this integration analysis. While the IOSS stowage rack can carry a significant amount of monopropellant, that quantity is not sufficient for the larger mission requirements.

4.4 TANKS AS ORUs

The rationale for why tanks might be considered for use as ORUs is given in Table 4.4-1. The first two paths of the trade study involving tanks in the IOSS stowage rack and tankers resulted in at least two good ways of performing the fluid resupply function. The tanker studies, particularly, developed approaches to provide most of the functions required for complete fluid resupply for both mono- and bi-propellant requirements. The approaches developed for the tankers can be extended to the first path involving tanks in the IOSS stowage rack. Also use of the IOSS, with its servicer mechanism, opens up the

Table 4.4-1 Rationale for Use of Tanks as ORUs

Tanker studies developed approaches towards satisfaction of all fluid resupply requirements
The tanker approaches can be used for tanks in the IOSS stowage rack
Tanks as ORUs generally require a continuously (years) pressurized disconnect
No design for this type of disconnect is available
<u>Recommendation</u>
Limit use of tanks as ORUs to those cases where the continuously pressurized disconnect can be avoided or accepted because of other advantages

range of possible fluid interface locations on the serviced spacecraft as well as permitting module exchange while the fluid is being transferred.

When tanks are used as ORUs, there generally is a requirement for a quick-disconnect to transfer fluid to the rest of the spacecraft and this fluid disconnect must operate for extended periods of time - numbers of years. Design of a disconnect with these properties is a difficult challenge and has not been done to our knowledge. The conventional method for connecting fluid piping on spacecraft is to weld the pipes together as welds are strong, can be made with very small, or no, leaks, are easy to clean, and can be relied on to not change their characteristics after inspection.

These two arguments lead to the recommendation that the use of tanks as ORUs be limited to those cases where the continuously pressurized disconnect can be avoided, or where the disconnect can be accepted because of other advantages and adequate confidence in the reliability of the disconnect can be developed through series parallel redundancy. Examples where tanks as ORUs can be useful are given next.

Two examples of how fluid tanks, or combinations of tanks and thrusters might be used as ORUs are given in Table 4.4-2. The first example is the propulsion module on the orbital maneuvering vehicle. This ORU consists of four bipropellant engines, four bipropellant tanks, four pressurant tanks, structure, and electronics. All of the fluid lines are contained on the ORU, so no fluid disconnects are involved. There are mechanical attachments and electrical disconnects to transfer data and control signals as well as electrical power. TRW is considering a fluid disconnect for a growth version of this ORU. A fluid disconnect is needed if the OMV, with its bipropellant ORU, is to be connected to the rest of the IOSS fluid resupply system.

Table 4.4-2 Example of Tanks and Thrusters as ORUs

OMV propulsion module has only electrical connections
Reaction control thrusters packaged with hydrazine tanks
- Can be packaged compactly in four ORUs
- Only electrical connections
- Replace thruster valves during fluid resupply
- Replace engine catalysts during fluid resupply
For fluid transfer between ORU tanks
- Add fluid disconnects
- Isolate disconnects with valves
- Open isolation valves only during cross flow

Another example is the use of reaction control thruster quads packaged with hydrazine tanks. The fluid part of the RCS could be packaged in four ORUs giving full three axis attitude control with some redundancy. Only electrical connections would be required, and then for data, command, and power transfer. The critical thruster valves and engine catalysts would be replaced along with the other engine and tank components. If desired, the four hydrazine tanks could be cross connected with fluid disconnects, but the fluid disconnects could be isolated with series redundant valves that would be opened only when fluid quantity equalization was required. In this way, the requirements on the fluid disconnects would be lower and more manageable. The disconnects would only be in use for a small part of the ORU onorbit life and any small amounts of leakage may be acceptable.

A third example considers the transfer of fluid from an ORU tank to the rest of the spacecraft through a fluid disconnect and methods for mitigating the effects of the disconnect. The spacecraft could be fitted with a smaller accumulator tank that would be used for direct connection to the thrusters. The small accumulator would then be recharged periodically from the ORU tank. This process is similar to the "day" tanks used on some ships. The day tanks are positioned so that they provide a positive head to the auxiliary engine pumps. The day tanks are filled one or more times per day from the larger storage tanks that are located further away in the ship. The disconnects could be isolated by a series of redundant valves that would only be opened when flow is necessary.

As discussed with regard to Table 4.3-4, the transfer of pressurants through umbilicals has design concerns. One other consideration is that the umbilical will have to be designed for the highest pressure it might ever see, which will be at least the storage pressure in the receiver tank.

An alternative (Table 4.4-3) is to package the tank(s) along with their pressure regulator(s) as an ORU. This approach means that the fluid disconnect would only see the operating pressure of the system and not the storage pressure - 350 psi vs 4500 psi. The major advantage is that the servicer vehicle would only need to carry one pressurant tank

Table 4.4-3 Example of a Pressurant Bottle as an ORU

Transfer of pressurants through umbilicals has design concerns
An alternative is to package tank(s) and pressure regulators as an ORU
Advantages
- Lighter weight package on servicer vehicle
- Can replace regulators when pressurant is resupplied
Disadvantage
- Need for continuously operating disconnect
Mitigating approaches
- Redundant disconnects
- Isolate disconnects with valves
- Open isolation valves only during pressurant use periods

for each pressurant tank on the serviced spacecraft. When the support structure and regulator weight are included, the ORU tankage weight would be on the order of 1.3 times the receiver tank weight as compared to a system that is more than five times the receiver tank weight as planned for OSCRS or SPERC. Not only is a significant servicer vehicle weight savings obtained, but also the regulator itself is replaced along with the pressurant.

The disadvantage of this approach is that a continuously operating disconnect must be used. The items at the bottom of the table can be used to mitigate the negative aspects of the continuously operating disconnect. The disconnects can be made redundant so that if one leaks, the other can be used. The disconnects can be isolated with valves, so that the disconnects are only pressurized when it is necessary to maintain propellant tank pressure and any leak at the disconnect can be isolated. Pressure sensors in the isolated parts of the disconnect lines can be used to monitor for leaks. Also leaks of pressurant gas are not as damaging as propellant leaks might be in terms of contamination. When the disconnects are only in use for a short period of time their probability of failure is less for a given mean time to failure.

The result is that treating a pressurant bottle with its pressure regulators as an ORU may be a useful alternative to resupplying pressurants via an umbilical.

The conclusions and recommendations drawn from this third trade study path are given in Table 4.4-4. While the difficulty in designing a long-term zero-leakage fluid disconnect is a concern, enough mitigating approaches have been identified that the concept of a tank as an ORU need not be discarded.

A tank as an ORU can be directly integrated into the IOSS system just like any other ORU. It would have electrical connections to the IOSS for status monitoring during transport and would have to fit within the size and weight constraints of other IOSS ORUs. This should be no

Table 4.4-4 Conclusions Regarding Tanks as ORUs

The approach has merit for selected applications
Can be directly integrated into IOSS
- Just another ORU as long as size is less than a cubic meter
Recommendation is to reserve technique for special cases
- Propellant tanks with thrusters
- Pressurant tanks with regulators
- Cryogenic dewars with sensors
- Superfluid helium

problem as pressurant bottles are not as large as the largest ORU size. Safety considerations may make it desirable to protect pressurant bottles against damage should the bottle contact any structure while being exchanged.

The recommendation is to reserve the tank as an ORU technique for special cases such as those shown in Table 4.4-4. The first two examples have been discussed in conjunction with Tables 4.4-2 and -3. The resupply of cryogens is more difficult than the resupply of pressurants in terms of fluid transfer efficiency because of the need to cool down the fluid transfer lines and the receiver tank. The suggestion is to design the cryogenic dewar and the optical system sensor as a package so that there is no need for a cryogenic fluid disconnect. Also, the sensor can be upgraded when the new load of cryogen is sent up. While at first glance it seems to be a difficult design challenge to integrate the cryogen tank with the sensor, it may turn out to be practical.

The superfluid helium resupply situation is like that of the cryogen resupply except that very large amounts of helium are boiled off to bring receiver tanks, lines, sensors, and vents down to the superfluid helium temperatures. If the tank as an ORU concept can be applied, then the helium savings may be worth the effort.

4.5 CONCLUSIONS FOR TANK/TANKER TRADE STUDY

The recommendations from the tank and tanker trade study were drawn from the conclusions and recommendations for the three paths of the trade study and are shown in Table 4.5-1. The concept of resupplying monopropellants from tanks in the IOSS stowage rack should be continued for the rest of the integration analysis. However, the quantities of bipropellants required, and the possible need for catch tanks suggests that the concept of bipropellant tanks in the IOSS stowage rack be deleted from further analysis. Two modified TDRSS, or GRO, tanks that are planned for use on OSCRS could be integrated into the IOSS stowage rack and could satisfy a significant part of the STAS mission model involving monopropellant resupply. These tanks should be installed in pairs so that fluid can be drawn from the tanks in parallel and control over servicer vehicle center of mass location can be maintained.

Table 4.5-1 Recommendations From Tanks and Tanker Trade Study

Continue concept of resupplying monopropellants from tanks mounted in IOSS stowage rack
- Use TDRSS, or GRO, tanks as planned for OSCRS
- Can handle significant part of mission model
- Install tanks in pairs for c m control
Continue integration of OSCRS tankers with IOSS
- Include both mono- and bi- propellant versions
Use OSCRS avionics for fluid transfer management
Reserve the tanks as ORUs concept for special cases

Elastomeric diaphragms should be used for fluid transfer control because of the method's simplicity. The use of existing tanks should reduce development cost for the fluid resupply form of the IOSS and a monopropellant fluid resupply IOSS should have a lower overall length, and thus a lower launch cost, than the combination of an IOSS and a monopropellant OSCRS tanker.

Integration of both monopropellant and bipropellant OSCRS tankers should be continued. The monopropellant tankers to handle the few requirements for larger quantities of fluid, such as the Mark II Propulsion Module or servicing multiple spacecraft on a single mission, and the bipropellant tankers to handle all bipropellant resupply requirements. Bipropellant resupply quantity requirements are expected to be larger.

The OSCRS avionics should be considered for use on the IOSS stowage rack for control of fluid transfer management as the concept: 1) appears suitable for the need, 2) it can be reprogrammed for the IOSS application, 3) it would simplify the operator's learning, and 4) it should be cheaper than the development of new equipment.

The concept of tanks as ORUs should be reserved for special cases where the need for a long term disconnect operation can be avoided, or where the advantages of the concept are significant and the disadvantages can be worked around or accepted.

When the above recommendations are accepted, then certain growth implications can be developed. An outline of considerations related to growth is given in Table 4.5-2.

When the concept of tanks in the IOSS stowage rack and the use of tankers, all of which are to be carried on the front of an OMV, is accepted, then certain growth possibilities open up. If the OSCRS fluids are to be transferred to a spacecraft via an umbilical handled by the IOSS, then there must be a fluid and electrical connection between the OSCRS and the IOSS. This same fluid and electrical connection could also be used between the IOSS and the OMV, and between the OSCRS and the OMV. Once these fluid and electrical disconnects are established, then it would be possible to transfer fluids to a serviceable spacecraft, via the IOSS umbilical, from the IOSS, the OSCRS tanker, or the OMV tanks, or combinations of these fluid

Table 4.5-2 Growth Considerations

Integration of OSCRS tanker with IOSS fluid transfer umbilical implies an intervehicle fluid connection
Could use the same intervehicle fluid connection between IOSS and OMV and between OSCRS and OMV
Implies ability to transfer fluids from IOSS, OSCRS, or OMV to serviced spacecraft
Also implies ability to stack OSCRS tankers to increase quantity of transferrable fluids
May be desirable to redesign fluid interfaces and management system so that fluids can be transferred in either direction among stacked elements and serviced spacecraft
Stacking tankers and servicer system may exceed RCS capability of OMV during multiple dockings

carriers. One result is a wide spectrum of available fluid capacities. The device containing the fluid disconnects for the fluid, or fluids, to be transferred is called an intervehicle fluid transfer device.

It is not much of an extension to add the ability to stack OSCRS tankers in the configuration so that larger quantities of fluids could be transported and transferred. An example is two OSCRS bipropellant tankers. Significant increases in total fluid quantities could be obtained in this way.

The next extension is to arrange it so that fluids could flow in either direction through the intervehicle fluid transfer devices, either towards the serviceable spacecraft, or towards the OMV. Significant increases in OMV impulse could be obtained with propellants from stacked units of the larger growth versions of the OSCRS. This approach is not as efficient as propulsion staging as the tanks cannot be easily jettisoned when they are empty.

One limiting consideration is that as more and more equipment and fluid is stacked on the front of the OMV, the OMV attitude control system may no longer be able to compensate for the rotations induced when the OMV tries to effect translation maneuvers during docking.

The general concept of stacking fluid resupply components on the OMV and of being able to transfer fluids between components and to the serviced spacecraft appears useful and to be obtainable for minimum cost. The result is a set of elements, e.g., IOSS, OSCRS, OMV, that can be assembled in various ways to satisfy the ORU exchange and fluid resupply requirements for a wide variety of missions. This concept is expanded and described further in Section 5.0.

5.0 OMV KIT DEFINITION

In Section 4.0, a trade study was performed to examine the candidates for tanks and tankers. Based on this study, tracking and data relay satellite system (TDRSS) monopropellant tanks, and orbital spacecraft consumables resupply system (OSCRS) monopropellant and bipropellant tankers were recommended. Additionally, the combination of these elements with the integrated orbital servicing system (IOSS) and orbital maneuvering vehicle (OMV) was introduced to provide a fluid resupply capability.

A sketch of a candidate system combining fluid resupply and module exchange is shown in Figure 5.0-1. The recommended approach is to develop a series of building blocks that can be assembled in different configurations depending on the mission requirements. In all cases, the OMV is a part of the configuration as it is needed to transport the IOSS and the fluid resupply elements to the spacecraft to be serviced. The IOSS is also part of each mission as it is required for orbital replacement unit (ORU) transfer and for positioning the fluid resupply umbilicals. For missions that require a small amount of fluid to be transferred, the fluid is stored in one or two tanks in the IOSS stowage rack. Larger fluid quantities are stored in the OSCRS tanker shown. The IOSS stowage rack can be configured to hold up to three monopropellant tanks. Two OSCRS configurations are recommended: one for monopropellants, and one for bipropellants. For missions requiring even larger amounts of propellant, two OSCRS type tankers could be used. Another alternative is to configure tanks as ORUs that can be exchanged by the IOSS servicer mechanism, using the same procedures involved in the exchange of any other ORU.

Fluids can be transferred between any of the resupply elements so that any extra propellant in the OMV can be used for propellant resupply and so that missions requiring more propellant than the OMV capacity can be accomplished using fluid from the OSCRS. The large hydrazine capacity of the OMV may make this feature attractive. Fluid is transferred to the serviced spacecraft via an umbilical connection where the fluid

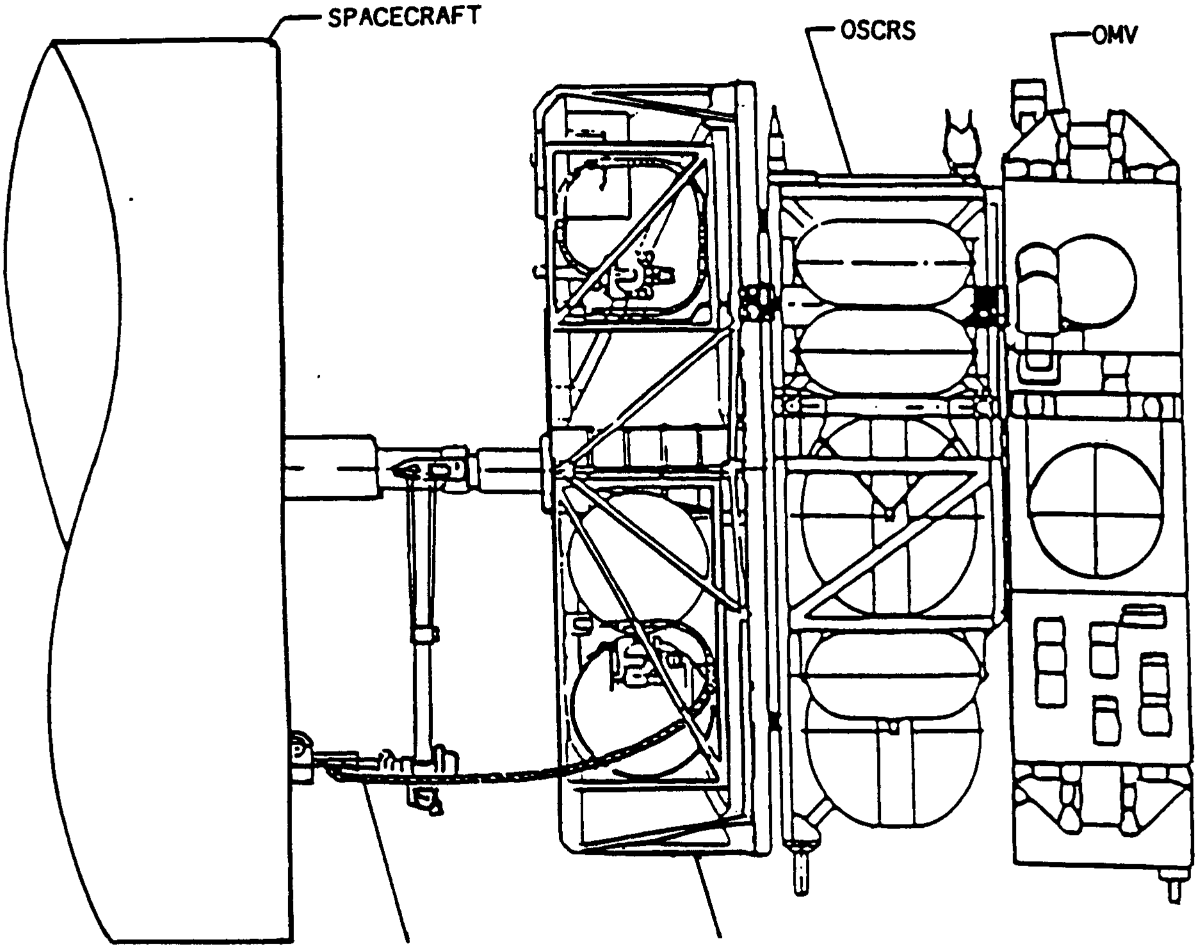

Figure 5.0-1 Candidate Configuration from Previous Study

resupply interface device is positioned by the IOSS servicer mechanism. The umbilical is constrained and guided by a hose and cable management system on the IOSS. Up to two hose and cable management systems with fluid resupply interface units could be used. Fluid management is controlled by an electronics system that is part of the OSCRS on OSCRS missions or is carried in the IOSS for non-OSCRS missions. The flexibility to carry a variety of fluid quantities and types enhances the system's capability for multiple spacecraft fluid resupply on a single mission.

This section details the definition of a kit for the OMV, characterizes basic elements and examines potential configurations. The OMV kit will expand the IOSS, capable of spacecraft ORU exchange, to an onorbit maintenance and servicing system (OMSS), capable of spacecraft fluid resupply and ORU exchange.

Kit definition is performed first by developing the features to be included in the system. Flexibility in the system configuration, spacecraft interface design, and system operation was consistently emphasized in the development of the OMSS. After the features were developed, OMSS elements that provide system flexibility and other recommended features were characterized. Finally, alternatives for configuring the OMSS were categorized into four basic types that cover the spectrum of element combination and spacecraft resupply missions.

5.1 FEATURES

Based on system requirements analysis, the tank/tanker trade study, and growth considerations, a set of desirable characteristics was developed. From these characteristics a recommended approach was evolved. Finally, features of the onorbit maintenance and servicing system were derived.

5.1.1 Desirable Characteristics

Table 5.1-1 lists characteristics that are desirable for the onorbit maintenance and servicing system. In addition to in-situ fluid resupply, the system should be able to perform ORU exchange functions at the shuttle and space station, as well as ORU exchange at the spacecraft in its orbital location. The servicing of multiple payloads on a single mission should be accommodated by the system in order to permit efficient use of carrier vehicle propellant.

A characteristic that promotes efficient servicing of multiple payloads is bidirectional fluid flow. This enhances the flexibility for configuring a system to meet a wide range of mission needs. When servicing satellites in low and medium earth orbits, propellant flow from OMV through OSCRS to the spacecraft increases the fluid available for resupply. Likewise, propellant flow from OSCRS to OMV allows for a wider range of orbital maneuvering.

Finally, it is desirable to operate the servicer from either the shuttle or space station, and to control the servicer from either the same ground station that OMV uses or from the space station. Control from the same station for both OMV and the servicer allows for better coordination for monitoring and controlling resupply operations.

Table 5.1-1 Desirable Characteristics

Retain all module exchange functions including operations at shuttle and space station
Satisfy in-situ spacecraft fluid resupply requirements in low and medium Earth orbits
Ability to service multiple payloads on single mission
Permit efficient mission planning to optimize carrier vehicle propellant use
Extendable to geosynchronous missions
Operable from shuttle or space station
Controllable from ground or space station
Ability to use tanker propellants for OMV thrusting
Ability to transfer fluids from OMV tanks to serviced spacecraft

5.1.2 Recommended Approach

In order to incorporate desirable characteristics into the system design, the approach shown in Table 5.1-2 is recommended. Flexibility in configuring system elements can be achieved by assuring that each stackable element may be combined with any other stackable element, greatly enhancing the capability of the servicer.

Table 5.1-2 Recommended Approach

Ability to combine elements into a variety of configurations Each stackable element combinable with any other stackable element Fluid Types - Hydrazine - MMH - NTO - Helium - Nitrogen Minimum fluid resupply capability results from tanks on IOSS stowage rack Maximum fluid resupply results from combination of two tankers plus IOSS and OMV tanks Up to two umbilical connections to serviced spacecraft Standard intervehicle interfaces - Mechanical - Electrical - Fluid (by type)

The system should be able to handle the three propellant types (hydrazine, monomethylhydrazine, and nitrogen tetroxide) and the two pressurant types (helium and nitrogen) most commonly encountered in spacecraft. Also, the use of up to two fluid umbilical connections between the servicer and the spacecraft will allow separate transfer of fuel and oxidizer. Each fluid umbilical connection may have more than one fluid disconnect so that liquids and gases may be transferred simultaneously and for redundancy for each fluid type.

The configuration of multiple vehicles must also be considered in recommending an approach. The standardization of mechanical, fluid, and electrical intervehicle interfaces improves the ability to reconfigure the system for changing mission requirements. Using the same IOSS to OSCRS interface for the OSCRS to OMV interface facilitates the addition or subtraction of OSCRS tankers to the servicer system.

The recommended approach can meet a wide range of fluid resupply needs. The minimum single spacecraft mission need may be satisfied by an OMV plus IOSS with stowage rack tanks. The maximum system capability can be achieved by combining tank capacity from OMV, two OSCRS tankers, and the IOSS stowage rack.

An important consideration within the recommended approach, the location of the spacecraft fluid interface, is outlined in Table 5.1-3. Two basic alternatives, highly specific standardization and general standardization, were studied and a recommendation selected.

Table 5.1-3 Spacecraft Fluid Interface Location

Two alternatives
- Standardized for each fluid and all spacecraft
- Selectable by spacecraft designer within general limits

Standardized location
- Difficult to establish standard
- Separate standards needed for each fluid type
- Need to accommodate location tolerances
- Need to standardize electrical connectors
- Minimum hypergolic fluid line separation
- Difficult to package and operate with IOSS

Selectable location
- Use servicer mechanism to position fluid interface unit
- Need to manage hoses
- Larger volume and weight allowances required on IOSS

<u>Recommendation</u>
- Permit spacecraft designer to select fluid interface design and location within set of limits established by servicer system

The first alternative proposes complete standardization throughout all serviceable spacecraft with a separate standard for each fluid to be resupplied. Several problems are inherent in this approach. The establishment of reasonable standards is generally a time-consuming, iterative process where many organizations are involved.

The second alternative allows the fluid interface location to be selected by the spacecraft designer within general limits. This would require hose management, and larger volume and weight allowances on the IOSS to accommodate the different fluid line types. However, the increased IOSS volume and weight does not present a significant enough problem to dissuade the selection of this alternative. Therefore, location of the fluid interface within general limits is recommended.

It may be noted that the complete standardization approach is being used by the OSCRS program to simplify the design of the OSCRS (Ref. 3-17).

5.1.3 Recommended Features

Table 5.1-4 shows the features that are recommended for the onorbit maintenance and servicing system, resulting from the characteristics and approach. The system will be reconfigurable prior to launch in order to satisfy mission requirements. It will be capable of servicing multiple spacecraft on a single mission. Although the system will be operated primarily from the OMV, it will also be operable from either the shuttle or space station, depending on user needs. It will be

Table 5.1-4 Recommended Features

Retain ORU exchange capabilities including exchanging tanks as ORUs
Reconfigurable before launch to satisfy mission requirements
Multiple spacecraft maintenance and servicing performed on single mission
OMV utilized as primary carrier vehicle
Operable from shuttle or space station
Controllable from ground or space station
Flexibility in fluid transfer direction
Fluid types - Hydrazine - Helium - MMH - Nitrogen - NTO
Selectable spacecraft fluid interface location and design
Standardized intervehicle fluid transfer devices

controllable from either the ground or from space station, depending on the region of operation and availability of communication links. The OMSS will be capable of bidirectional transfer of hydrazine, MMH and NTO propellants, and helium and nitrogren pressurant gases.

Finally, the interface features will dictate few constraints to allow servicing of a wide range of spacecraft. To accomplish this, selection of the fluid interface location will be performed by the spacecraft designer within general limits. The intervehicle fluid transfer device, in addition to the mechanical and electrical interfaces, will be standardized to allow flexibility in configuring the OMSS.

5.2 SYSTEM CHARACTERISTICS

The recommended features have been incorporated into an onorbit maintenance and servicing system. Flexibility in the configuration and operation of the system, as well as minimization of constraints imposed on the spacecraft designer, has been consistently emphasized in the system. The system includes the IOSS, OSCRS monopropellant and bipropellant tankers, OMV, and control stations. Figure 5.2-1 lists the key OMSS-related elements in each of these subsystems, establishes the nomenclature for the various equipment, and shows the equipment relationships.

Discussion of OSCRS monopropellant and bipropellant tankers, and the OMV is limited to their interfaces with the IOSS. OSCRS (monopropellant and bipropellant versions), and the OMV must be modified slightly to include: 1) intervehicle fluid transfer devices; 2) IOSS/OSCRS/OMV berthing devices; and 3) fluid and electrical connections and pass throughs.

The IOSS subsystem is most significantly impacted by the addition of the fluid resupply capability. Therefore, definition of the OMSS focuses on the new elements of the IOSS that provide the basis for fluid resupply. These elements include: 1) pressurant tanks that are

Figure 5.2-1

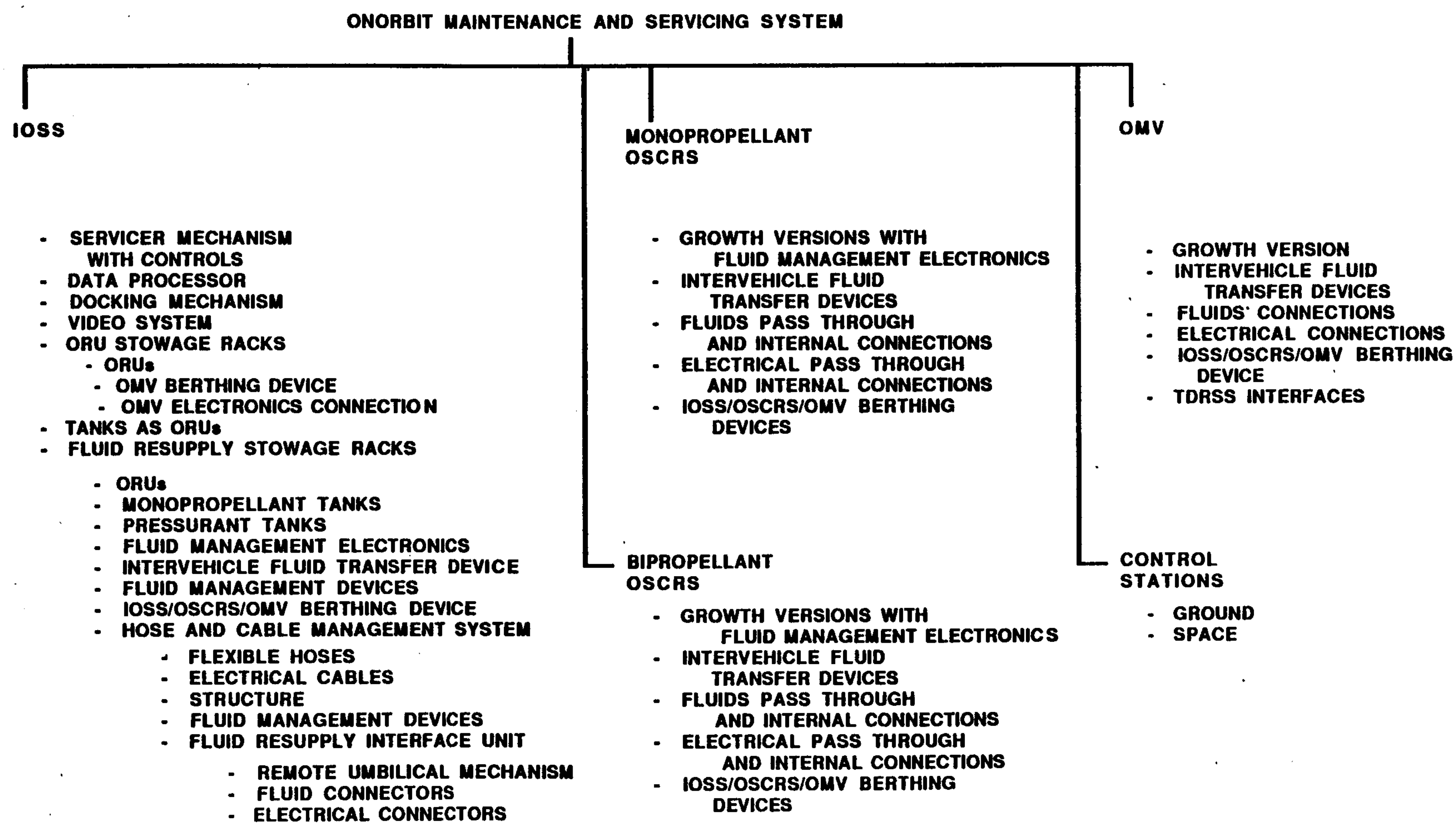

Figure 5.2-1 Onorbit Maintenance and Servicing System Elements

transferred to replace spent tanks, using the ORU exchange procedure; 2) the fluid resupply stowage rack; 3) the intervehicle fluid transfer device; 4) fluid management devices; 5) hose and cable management system; and 6) the fluid resupply interface unit.

5.2.1 Pressurant Tanks as ORUs

The use of tanks as ORUs stowed in the IOSS stowage rack is one method of pressurant resupply. The IOSS servicer mechanism is used to replace the spacecraft pressurant tanks and pressure regulators with a new tank set from the IOSS stowage rack. Pressure regulators and isolation valves may be included in the ORU tank system so that fluid disconnects are only exposed to the operating pressure of the system (350 psi from the regulator) and not the storage pressure (4500 psi in the pressurant tank). Table 5.2-1 lists characteristics for the use of pressurant tanks as ORUs. If multiple pressurant tanks are replaced as a single ORU, then manifolding and interconnections between tanks would be included in the ORU tank set.

Table 5.2-1 Tank as an ORU - Characteristics for Pressurant Use

- Single fastener interface mechanism (MMAG) for structural attachment
- Tank, or tank set, size up to 40 in. dimension
- Provide manifolding, interconnections, pressure regulator(s), and isolation valves
- Structure between components
- One half of fluid connector(s)
- One half of electrical connector(s)
- Number of connector halves depends on redundancy requirements
- Instrumentation as appropriate
- Electrical heaters as needed for thermal control

The ORU tank set will incorporate the Martin Marietta Astronautics Group single fastener interface mechanism for attachment to the spacecraft and to the IOSS stowage rack. The servicer mechanism end effector will attach to the ORU tank set at the fastener and position the tank set at the spacecraft. The tank set will be secured to the spacecraft mechanically, followed by mating of the electrical and fluid connectors.

5.2.2 Fluid Resupply Stowage Rack

The next element to be examined is the IOSS stowage rack, configured for fluid resupply. Fluid resupply stowage rack characteristics are discussed in Table 5.2-2. A configuration that incorporates these characteristics is shown in Figure 5.2-2. Two quadrants are used for stowage of ORUs (including tanks as ORUs discussed in the previous section). The remaining two quadrants are reserved for fluid resupply equipment; including three monopropellant tanks, two pressurant gas bottles used to transfer the monopropellant, two additional pressurant bottles for pressurant resupply, and an OSCRS type computer and majority vote box for fluid management and data processing (Ref. 3-14).

Table 5.2-2 Fluid Resupply Stowage Racks - Characteristics

- Two quadrants for regular ORUs
- Allowance for temporary stowage of largest ORU (may extend outside stowage rack boundary)
- Servo electronics and data processing to/from OMV
- TV video processing to OMV
- ORU status monitoring and data processing to OMV
- Relocatable ORU interface mechanism receptacles with electrical connector halves
- Two quadrants for fluid resupply equipment
- Three OSCRS monopropellant tanks
- Two OSCRS type pressurant bottles (with provisions for two additional bottles)
- OSCRS type fluid management electronics
- Intervehicle fluid transfer device
- Fluid management devices (valves, lines, filters, etc.)
- IOSS/OSCRS/OMV berthing devices
- Structure for transferring loads to IOSS/OSCRS/OMV berthing device
- Hose and cable management system (one or two as required)

The IOSS stowage rack is also adapted to include an intervehicle fluid transfer device, fluid management devices, and as many as two hose and cable management systems. These elements are defined further in the following sections.

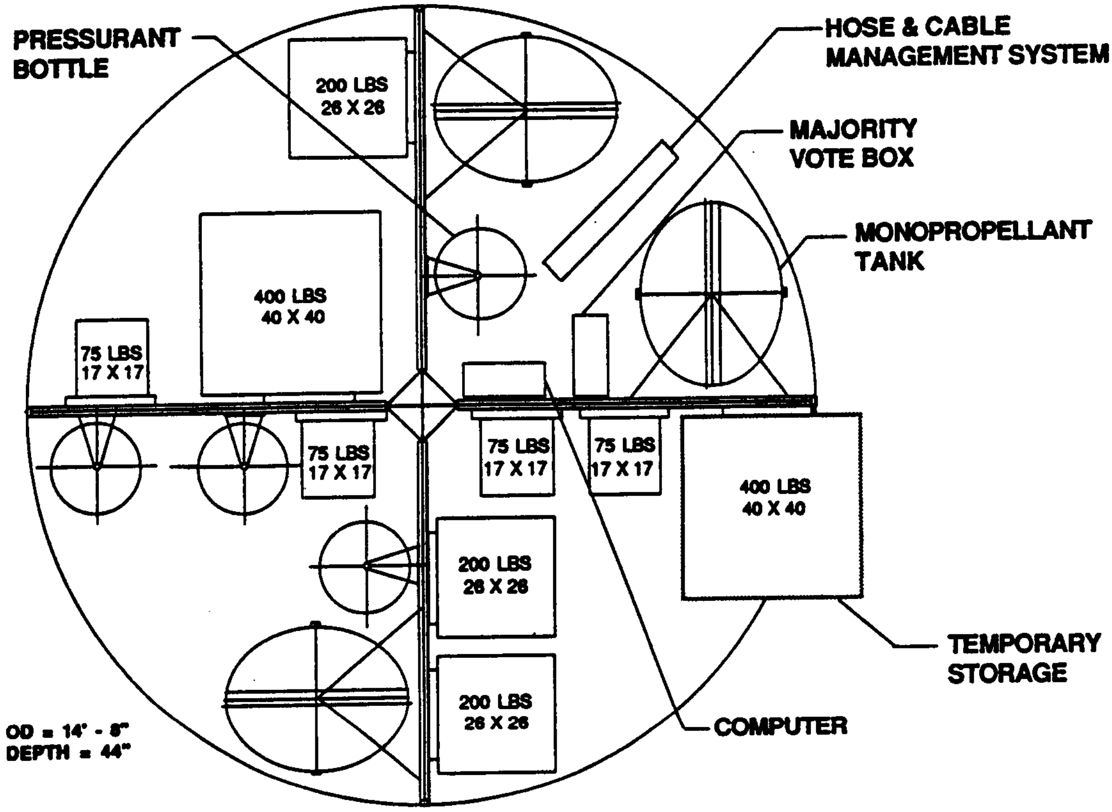

Figure 5.2-2 IOSS Stowage Rack Space Allowance for Fluid Resupply Tanks

5.2.3 Intervehicle Fluid Transfer Device

The intervehicle fluid transfer device provides a capability for transferring fluids in both directions between the IOSS stowage rack, OSCRS monopropellant and bipropellant tankers, and the OMV. Table 5.2-3 lists the characteristics of this fluid transfer device. Standardized male and female halves facilitate the addition and deletion of OSCRS tankers.

The device incorporates six connectors to provide connection of redundant electrical lines, and mate of monopropellant, bipropellant, and pressurant lines. The connectors are self aligning and motion for a sequential mating process is provided by the device. First, the mechanical attachment is achieved, followed by connection of redundant

Table 5.2-3 Intervehicle Fluid Transfer Device - Characteristics

- Applications
  - -- Movable female half on IOSS stowage rack
  - -- Fixed male half on forward side of monopropellant and bipropellant OSCRS
  - -- Movable female half on aft side of monopropellant and bipropellant OSCRS
  - -- Fixed male half on forward side of OMV
- Incorporates six connectors
  - -- Redundant electrical connectors (2)
  - -- Monopropellant connector
  - -- Hypergolic fuel connector
  - -- Hypergolic oxidizer connector
  - -- Pressurant connector
- Fixed half is self aligning
- Movable half is self aligning and provides motion for sequential connector mating
- Selectable connector mating sequence
- Demating sequence is inverse of mating sequence
- Connector mating/demating is a manned operation
- Manually assemblable/removable dust covers for each connector half
- Instrumentation provided for leak detection after assembly
- No-spill fluid connectors
- Scoop-proof electrical connectors

electrical cables. Next, the mating of fluid disconnects is monitored, followed by verification of leak integrity and transfer of propellant and pressurant fluids (Ref. 5-1). The intervehicle fluid transfer device demating sequence is performed in reverse order of the mating sequence.

The mating and demating of connectors is a manned operation to be performed during ground test and checkout operations. Connector dust covers must protect each connector half, and allow manual assembly and removal.

5.2.4 Fluid Management Devices

The intervehicle fluid transfer device provides a fluid flow path between the IOSS stowage rack, OSCRS monopropellant and bipropellant tankers, and the OMV. Fluid management devices provide the fluid flow path from the intervehicle fluid transfer device and from tanks in the

IOSS stowage rack to the hose and cable management system. The IOSS stowage rack will house several fluid management devices required for spacecraft fluid resupply. A list of characteristics for fluid management devices is given in Table 5.2-4.

Table 5.2-4 Fluid Management Devices on IOSS Fluid Resupply Stowage Rack - Characteristics

- Provides fluid flow path to hose and cable management system from intervehicle fluid transfer device and from tanks in the IOSS stowage rack - Each fluid entry point isolatable with dual redundant manual valves - Separate fluid management devices for: -- Monopropellant -- Hypergolic fuel -- Hypergolic oxidizer -- Pressurant - Manually assemblable/removable caps for the free ends of each fluid line - Replaceable fluid filters as necessary - Manifolding for up to three monopropellant tanks in the stowage rack - Manifolding for up to four pressurant tanks in the stowage rack - Instrumentation for fluid transfer management - Fluid fill/drain connections - Valving for control of direction of fluid flow through filters

Dual redundant manual valves will be employed at each fluid entry point so that fluid flow is completely controllable, even if a single failure occurs at any of the valves or connectors. Each type of fluid will be managed separately to prevent fluid contamination and to limit the opportunity for ignition of hypergolic bipropellants.

Caps are provided to seal the free ends of each fluid line, with the capability for manual assembly and removal for reconfiguration of the fluid system during ground test and checkout. The system includes manifolding capability for as many as three monopropellant tanks. Manifolding is also provided for up to four pressurant tanks.

A schematic for fluid resupply is illustrated in Figure 5.2-3. The schematic shows fluid flow from three monopropellant tanks to the fill and drain, to the intervehicle fluid transfer device (IVFTD), and to the hose and cable management system. Pressurant gas is used to drive the flow from the monopropellant tanks with diaphragm propellant management devices as shown in the single tank representation. Electrical valves are used to control the flow and directional filters prevent contamination.

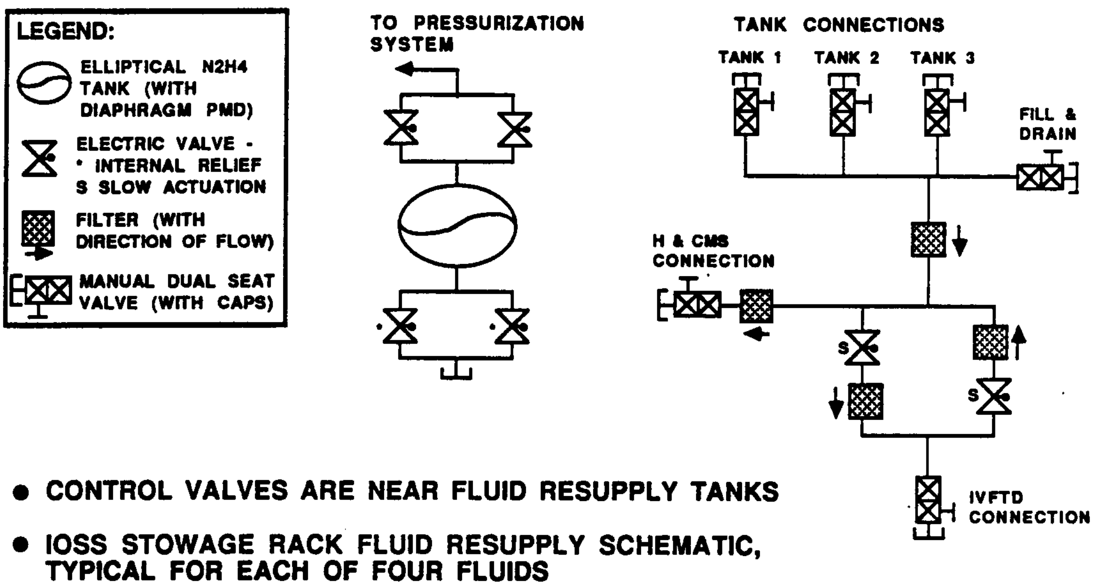

Figure 5.2-3 IOSS Stowage Rack Fluid Resupply Schematic

There would be additional pressurization system connections and valving to provide the required degree of redundancy. The required degree of redundancy will depend on whether man is involved and the importance of having a successful mission. Safety considerations are very important for operations at the orbiter.

Fill and drain operations would be conducted on the ground and thus the fill and drain valves, and caps, need only be suitable for manual operation. Similar manned fill and drain valves would be used with the pressurant gas bottles. Pressure, temperature, and flow sensors would be added for the flight system.

While not shown, an abbreviated fluid schematic is appropriate for either of the bipropellants. In particular, there would be no connections to tanks, or gas bottles in the IOSS stowage rack.

5.2.5 Hose and Cable Management System

The hose and cable management system is incorporated to transfer fluids from the fluid management devices on the IOSS stowage rack to the fluid resupply interface unit at the spacecraft. Four fluid hoses and two electrical cables are combined into a single system to simplify the fluid transfer and to support the hoses and cables structurally, so that hose bending capabilities are not exceeded. Characteristics of the H&CMS are shown in Table 5.2-5.

Table 5.2-5 Hose and Cable Management System - Characteristics

- Purpose is to combine hoses and cables together, constrain them so they can be connected to the serviceable spacecraft, and provide fluid and electrical interfaces to the serviced spacecraft
- Interfaces with IOSS fluid resupply stowage rack
- Hose flexibility will be compatible with IOSS servicer mechanism motion requirements
- Hoses will be replaceable so that a complement suitable for the planned mission can be assembled
- Redundant electrical cables wired to redundant electrical connectors on the fluid resupply interface unit
- Electrical cabling for control and statusing of the fluid resupply interface unit
- Structure to interface the H&CMS to the IOSS fluid resupply stowage rack and to contain the H&CMS during launch and reentry
- Fluid management devices to split the fluid flow from the IOSS fluid resupply stowage rack into two paths for control and introduction into redundant hoses
- Up to four sets of fluid management devices can be installed for use by up to four fluid types. Unused line branches can be capped
- Liquid hose diameter of 3/4 in.
- Pressurant hose diameter of 1/4 in.
- Fluid resupply interface unit

The bending capabilities of selected hoses and cables must be arranged to be compatible with the IOSS servicer mechanism motion required to move the unattached end of the H&CMS from an initial position in the stowage rack to a final position at the spacecraft fluid resupply interface.

Design of the H&CMS will allow for reconfiguration of any combination of four hoses, including 3/4 in. diameter propellant hoses and 1/4 in. diameter pressurant hoses. If the servicing mission calls for resupply of monopropellant and/or pressurant, then only one H&CMS with two sets of redundant hoses is required. If the mission includes resupply of bipropellants, then two H&CMSs may be employed if separation of the hypergolics is desired. Redundant MMH hoses will be installed in one H&CMS, with redundant NTO hoses installed in the other H&CMS. Resupply of monopropellant and pressurant fluids can be included in the two H&CMS configuration by packing redundant hydrazine hoses with the MMH hoses and combining redundant pressurant hoses with the NTO hoses.

In order to accommodate redundant hoses in the H&CMS, fluid management devices on the IOSS stowage rack will split the fluid flow into two paths. In addition to interfacing the H&CMS with the fluid management devices on the IOSS stowage rack, the OMSS design will include structure for containing and supporting the H&CMS during launch and reentry.

The H&CMS will include redundant electrical cables wired to redundant electrical connectors on the fluid resupply interface unit that attaches to the spacecraft. Electrical signals will be multiplexed, enabling a reduction in the number of wires, and thus the cable diameter, required. Data transmitted across the electrical cables will include monitoring the status of the fluid resupply interface unit during the mating of the fluid disconnects, controlling the fluid flow through the interface, and monitoring the status of the H&CMS and the spacecraft during fluid transfer.

5.2.6 Fluid Resupply Interface Unit

The interface between the H&CMS and the spacecraft is accomplished by the fluid resupply interface unit. The unit is separated into two halves that contain the active and passive halves of the electrical and fluid connectors. The active half of the unit is located at the end of the H&CMS, while the passive half resides in the spacecraft. The IOSS end effector grasps the male half of the unit and the servicer mechanism moves it to the female half. As the halves approach, misalignment is gradually eliminated until a firm mechanical attachment is made. Subsequently, two redundant electrical connectors are mated by a translation motion. After positive system status is verified, translation of the interface continues, mating as many as four fluid disconnects. Demating is accomplished by reversing the order of the steps followed during mating.

As part of the definition process, the degree of standardization of the fluid resupply interface unit must be addressed as shown in Table 5.2-6.

Table 5.2-6 Fluid Resupply Interface Unit Standardization

Two alternatives
- Standardize fluid, electrical, and mechanical connectors
- Standardize mechanical attachment device only

Standardize all connectors
- Difficult to establish standard
- Separate standards needed for each connector type
- Need to accommodate interface tolerances
- Restrictive to spacecraft designer

Standardize Mechanical Attachment Device Only
- Fluid and electrical connectors selectable within general limits
- Larger volume and weight allowances required for variety of fluid lines

Recommendation
- Standarize only mechanical attachment device, equivalent of IOSS end effector mechanical attachment

The first alternative is to require standardization of the fluid, electrical, and mechanical connectors. In addition to the basic problems inherent in standardization (time-consuming, many voters, iterative), separate standards would have to be defined for each connector type, interface tolerances would have to be accommodated, and restrictions on the spacecraft designer would be imposed.

The second alternative is to standardize the mechanical and basic electrical connectors within the fluid transfer interface. Allowances would be made for fluid and specific electrical connectors required by the spacecraft. This would allow some flexibility for the spacecraft designer to select fluid and electrical connectors (within general limits) to optimize the spacecraft design. Larger volume and weight allowances for the fluid transfer interface would be required to allow for the range of fluid lines that may be encountered.

However, based on the negative aspects of full standardization and the small impact of slight increases in size and weight, the second alternative is recommended. The equivalent of the IOSS end effector mechanical attachment device should be standardized and specific fluid and electrical connectors included in various configurations as required.

Table 5.2-7 displays the characteristics of the recommended FRIU. The unit will be adaptable to a variety of electrical and fluid connectors, depending on the spacecraft to be serviced and types of fluids to be

Table 5.2-7 Fluid Resupply Interface Unit - Characteristics

- Interfaces with hoses and cables of hose and cable management system
- Provides for firm mechanical attachment to a mating fitting on the serviceable spacecraft
- Provides for selectable, sequential, remotely-controlled mating of electrical and fluid connectors
- Connector demating in the inverse order of mating
- Provides for two redundant electrical connectors and up to four fluid connectors
- Adaptable to a variety of electrical and fluid connectors
- Mated connector location selectable
- Provides a fitting for firm grasp by IOSS servicer mechanism

resupplied. Additionally, the location of this interface on the spacecraft will be selectable by the designer within limits (approximately one quadrant on the front face of the spacecraft, between 2.5 and 8 feet from the docking post) (Ref. 3-1). These characteristics will allow spacecraft designers more flexibility in selecting and positioning connectors, in order to best fit the overall spacecraft design.

5.3 POTENTIAL CONFIGURATIONS

The intention of the OMSS is to provide a system that can be readily tailored to meet specific fluid resupply mission requirements. This section will discuss a range of possible configurations and their corresponding capabilities.

5.3.1 OMSS Element Combinations

The following list of basic OMSS elements provides a natural starting point for examining potential configurations:

1) Integrated orbital servicing system (IOSS);
2) Orbital maneuvering vehicle (OMV);
3) Hose and cable management system (H&CMS);
4) Pressurant tank set, exchanged as an ORU (Tank as ORU);
5) Set of two pressurant resupply bottles (press. bottles);
6) Set of three monopropellant tanks and two pressurant bottles, stowed in the IOSS stowage rack (IOSS MP TANK);
7) OSCRS monopropellant tanker (MONO OSCRS);
8) OSCRS bipropellant tanker (BI OSCRS).

The IOSS and OMV are included in all servicer configurations, while elements 3 through 8 have been added to provide fluid resupply capability. Selection of the H&CMS is dependent on the selection of elements 4 through 8, resulting in a total of five independent variables to be chosen. Combination of the five independent variables yields a total of 32 distinct OMSS configurations.

Table 5.3-1 lists available fluid quantity, in pounds, by type of fluid, total system weight, and effective mass fraction for each configuration (Ref. 3-1, 3-14, 3-20). The fluid quantity is the sum of fluid available for resupply and fluid available for maneuvering propulsion. Because the OMSS allows bi-directional fluid flow between storage tanks and/or spacecraft and/or OMV, fluids may be used for spacecraft resupply and/or OMV propulsion. The total system weight does not include the weight of regular ORUs that may be contained in the stowage rack, because comparison of fluid resupply configurations is being emphasized in this analysis. The effective mass fraction is calculated by dividing the available fluid quantity by the total system weight.

The available fluid quantities for the 32 configurations, including and excluding 10,120 lbs of OMV fluids, are graphed in Figure 5.3-1. The 32 configurations are separated into four types (A thru D) of combinations of the major elements (IOSS, OMV, OSCRS monopropellant tanker, and OSCRS bipropellant tanker). This results in four levels of available fluid quantities. These types are described in detail in Sections 5.3.2 through 5.3.6.

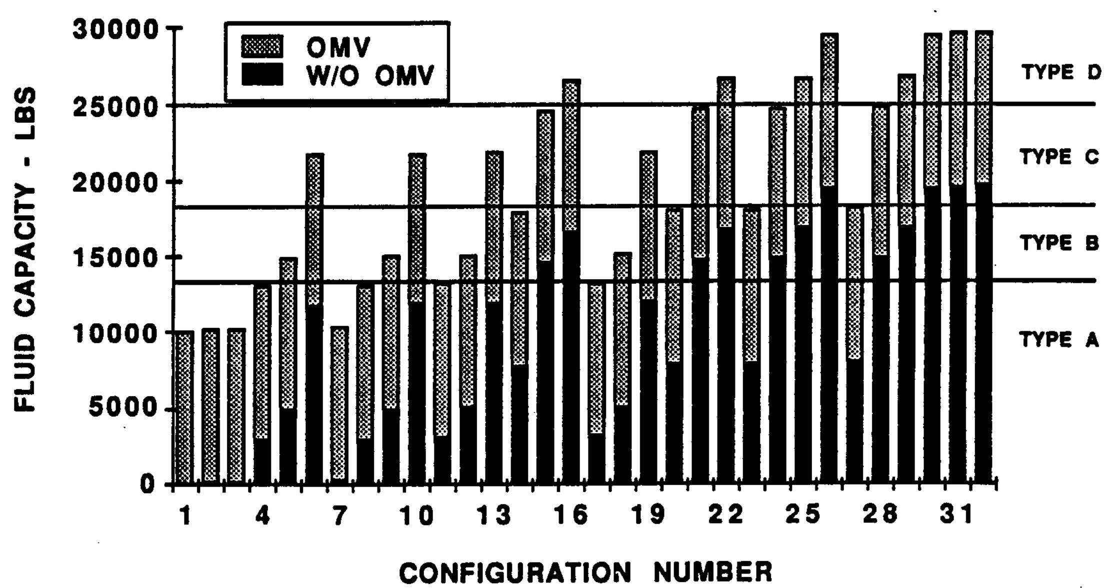

Figure 5.3-1 Potential Configurations - Fluid Capacity

Table 5.3-1 Potential Configurations

CONFIGURATION #	1	2	3	4	5	6	7	8	9	10	11
IOSS DRY WT.	630	630	630	630	630	630	630	630	630	630	630
OMV DRY WT.	7880	7880	7880	7880	7880	7880	7880	7880	7880	7880	7880
- MONOPROP	1180	1180	1180	1180	1180	1180	1180	1180	1180	1180	1180
- BIPROP	8775	8775	8775	8775	8775	8775	8775	8775	8775	8775	8775
- GN2	165	165	165	165	165	165	165	165	165	165	165
H & CMS (QUANT.)			1	1	1	2	1	1	1	2	1
- DRY WT.			150	150	150	300	150	150	150	300	150
TANK AS ORU DW.		80					80	80	80	80	
- GN2		90					90	90	90	90	
TWO PRESS. BOTTLES			160				160				160
- GN2			180				180				180
IOSS MONO TANK DW.				545				545			545
- MONOPROP				2910				2910			2910
MONO OSCRS DW.					2550				2550		
- MONOPROP					4850				4850		
BI OSCRS DW.						3800				3800	
- BIPROP						11400				11400	
- GN2						270				270	
SUBTOTALS											
- DRY WEIGHT	8510	8590	8820	9205	11210	12610	8900	9285	11290	12690	9365
- MONOPROP	1180	1180	1180	4090	6030	1180	1180	4090	6030	1180	4090
- BIPROP	8775	8775	8775	8775	8775	20175	8775	8775	8775	20175	8775
- GN2	165	255	345	165	165	435	435	255	255	525	345
TOTAL WEIGHT	18630	18800	19120	22235	26180	34400	19290	22405	26350	34570	22575
MASS FRACTION	0.54	0.54	0.54	0.59	0.57	0.63	0.54	0.59	0.57	0.63	0.59

CONFIGURATION #	12	13	14	15	16	17	18	19	20	21	22
IOSS DRY WT.	630	630	630	630	630	630	630	630	630	630	630
OMV DRY WT.	7880	7880	7880	7880	7880	7880	7880	7880	7880	7880	7880
- MONOPROP	1180	1180	1180	1180	1180	1180	1180	1180	1180	1180	1180
- BIPROP	8775	8775	8775	8775	8775	8775	8775	8775	8775	8775	8775
- GN2	165	165	165	165	165	165	165	165	165	165	165
H & CMS (QUANT.)	1	2	1	2	2	1	1	2	1	2	2
- DRY WT.	150	300	150	300	300	150	150	300	150	300	300
TANK AS ORU DW.						80	80	80	80	80	80
- GN2						90	90	90	90	90	90
TWO PRESS. BOTTLES	160	160				160	160	160			
- GN2	180	180				180	180	180			
IOSS MONO TANK DW.			545	545		545			545	545	
- MONOPROP			2910	2910		2910			2910	2910	
MONO OSCRS DW.	2550		2550		2550		2550		2550		2550
- MONOPROP	4850		4850		4850		4850		4850		4850
BI OSCRS DW.		3800		3800	3800			3800		3800	3800
- BIPROP		11400		11400	11400			11400		11400	11400
- GN2		270		270	270			270		270	270
SUBTOTALS											
- DRY WEIGHT	11370	12770	11755	13155	15160	9445	11450	12850	11835	13235	15240
- MONOPROP	6030	1180	8940	4090	6030	4090	6030	1180	8940	4090	6030
- BIPROP	8775	20175	8775	20175	20175	8775	8775	20175	8775	20175	20175
- GN2	345	615	165	435	435	435	435	705	255	525	525
TOTAL WEIGHT	26520	34740	29635	37855	41800	22745	26690	34910	29805	38025	41970
MASS FRACTION	0.57	0.63	0.60	0.65	0.64	0.58	0.57	0.63	0.60	0.65	0.64

CONFIGURATION #	23	24	25	26	27	28	29	30	31	32	
IOSS DRY WT.	630	630	630	630	630	630	630	630	630	630	
OMV DRY WT.	7880	7880	7880	7880	7880	7880	7880	7880	7880	7880	
- MONOPROP	1180	1180	1180	1180	1180	1180	1180	1180	1180	1180	
- BIPROP	8775	8775	8775	8775	8775	8775	8775	8775	8775	8775	
- GN2	165	165	165	165	165	165	165	165	165	165	
H & CMS (QUANT.)	1	2	2	2	1	2	2	2	2	2	
- DRY WT.	150	300	300	300	150	300	300	300	300	300	
TANK AS ORU DW.					80	80	80	80		80	
- GN2					90	90	90	90		90	
TWO PRESS. BOTTLES	160	160	160		160	160	160		160	160	
- GN2	180	180	180		180	180	180		180	180	
IOSS MONO TANK DW.	545	545		545	545	545		545	545	545	
- MONOPROP	2910	2910		2910	2910	2910		2910	2910	2910	
MONO OSCRS DW.	2550		2550	2550	2550		2550	2550	2550	2550	
- MONOPROP	4850		4850	4850	4850		4850	4850	4850	4850	
BI OSCRS DW.		3800	3800	3800		3800	3800	3800	3800	3800	
- BIPROP		11400	11400	11400		11400	11400	11400	11400	11400	
- GN2		270	270	270		270	270	270	270	270	
SUBTOTALS											
- DRY WEIGHT	11915	13315	15320	15705	11995	13395	15400	15785	15865	15945	
- MONOPROP	8940	4090	6030	8940	8940	4090	6030	8940	8940	8940	
- BIPROP	8775	20175	20175	20175	8775	20175	20175	20175	20175	20175	
- GN2	345	615	615	435	435	705	705	525	615	705	
TOTAL WEIGHT	29975	38195	42140	45255	30145	38365	42310	45425	45595	45765	
MASS FRACTION	0.60	0.65	0.64	0.65	0.60	0.65	0.64	0.65	0.65	0.65	

5.3.2 OMSS Reference Configuration

A configuration of the basic IOSS and OMV, not capable of fluid resupply, is used as a reference to which the four configuration types are compared. The reference configuration, illustrated in Figure 5.3-2, shows the IOSS configured strictly for ORU exchange. This configuration, number 1 of Figure 5.3-1, could be expanded slightly to provide fluid resupply. An ORU tank set could be added to provide pressurant resupply, and the H&CMS could be included in the stowage rack to allow resupply of propellant and pressurant fluids from the OMV.

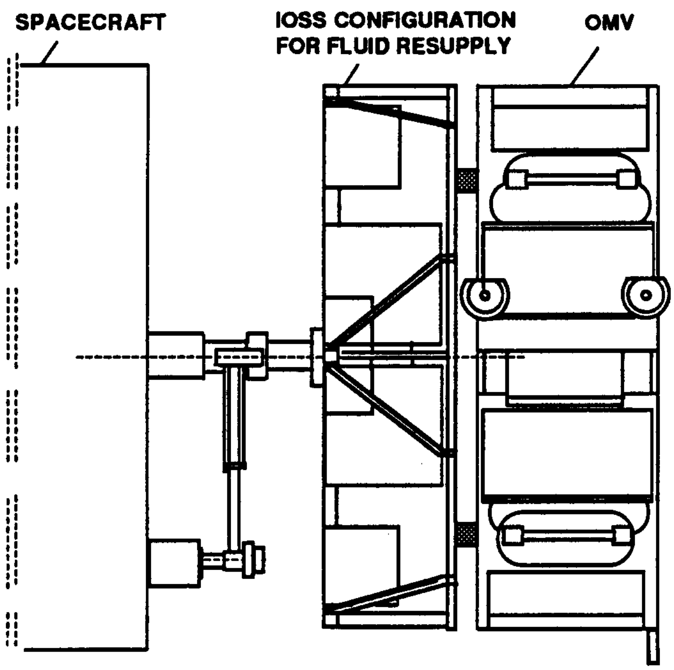

Figure 5.3-2 OMSS Reference Configuration

5.3.3 OMSS Configuration Type A

The Type A configuration, shown in Figure 5.3-3, adds various fluid resupply equipment to the OMSS reference configuration. Configuration numbers 2, 3, 4, 7, 8, 11, and 17 from Figure 5.3-1 fall in the Type A category. Number 17 provides the highest fluid capacity for Type A configurations. In this configuration a set of three monopropellant tanks and two pressurant bottles for driving the propellants, two pressurant bottles for pressurant resupply, an ORU tank set, and an H&CMS are stored in two opposing quadrants of the IOSS stowage rack.

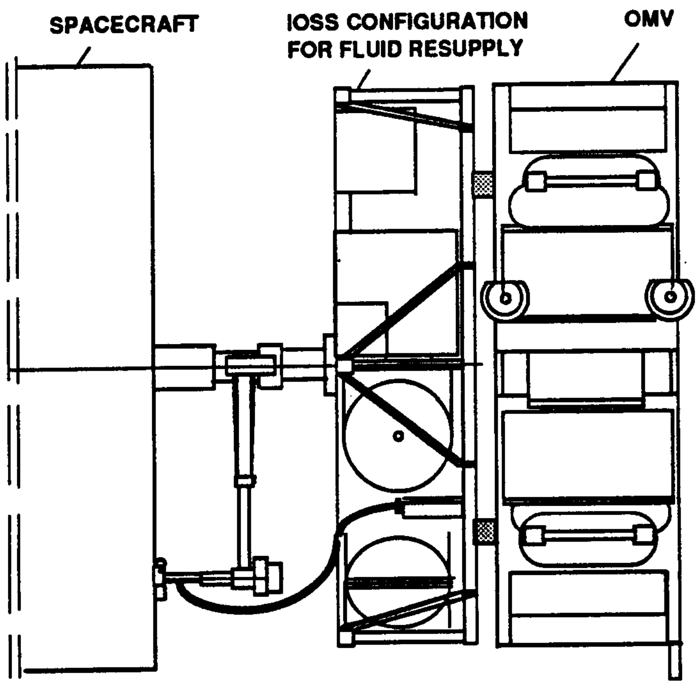

Figure 5.3-3 OMSS Configuration Type A

Monopropellant is supplied from three manifolded tanks driven by gas from two pressurant bottles. Pressurant gas pushes against the N_2H_4 tank bladder to drive the fluid from the tanks to the spacecraft. Two additional pressurant bottles are manifolded together and can provide gas to refresh the spacecraft pressurant system. The ORU tank set maybe exchanged for the spent spacecraft pressurant tank and related plumbing. The H&CMS transfers the fluid through redundant liquid and gas lines. Two redundant electrical cables control and monitor the flow.

Configuration number 17 can provide the following fluid quantities for resupply or propulsion:

	w/o OMV	w/OMV
Monopropellant	2910 lbs	4090 lbs
GN_2*	135 lbs	175 lbs
Bipropellants	--	8775 lbs

*Assumes a four to one ratio of pressurant gas carried to pressurant gas resupplied, and a full transfer of pressurant gas exchanged as an ORU tank set.

This configuration can handle all of the single mission monopropellant resupply needs except for the Mark II Propulsion Module mission. The configuration could be expanded slightly by adding an extra H&CMS to give additional redundancy or to provide four pairs of redundant umbilicals to transfer OMV fluids (NTO and GN_2 in one H&CMS, and MMH and N_2H_4 in the second H&CMS). Also, more ORU tank sets could be added to increase the pressurant resupply capability.

5.3.4 OMSS Configuration Type B

The Type B configuration, illustrated in Figure 5.3-4, includes an IOSS stowage rack configured for fluid resupply and the five tank OSCRS monopropellant tanker, in addition to the reference configuration. Configurations 5, 9, 12, 14, 18, 20, 23, and 27 from Figure 5.3-1 belong in the Type B category. Number 27 yields the greatest fluid capacity of the Type B configurations. The addition of the five tank OSCRS monopropellant tanker and the fully loaded IOSS stowage rack significantly expands the monopropellant resupply capability of the system.

In this configuration, monopropellant is manifolded from the five OSCRS monopropellant tanks and flows through an intervehicle fluid transfer device to the H&CMS in the fluid resupply stowage rack and finally to the spacecraft. Stowage rack fluids can be supplied to the spacecraft as described in Section 5.3.3.

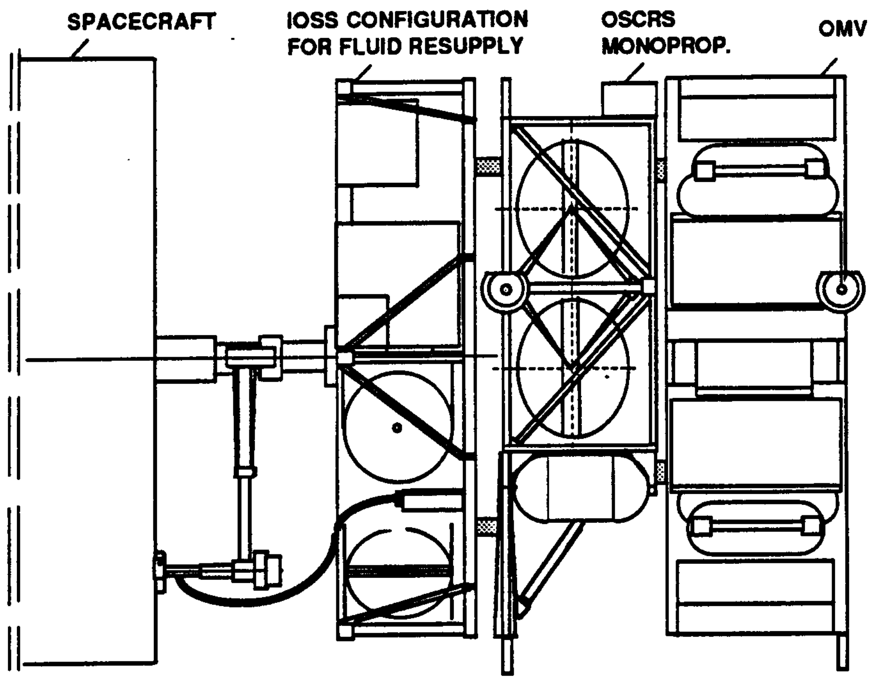

Figure 5.3-4 OMSS Configuration Type B

Also, monopropellant can be transferred in the reverse direction to the OMV to meet propulsion needs, especially those involving docking maneuvers.

Configuration number 27 provides the following fluid quantities for resupply or propulsion:

	w/o OMV	w/OMV
Monopropellant	7760 lbs	8940 lbs
GN_2*	135 lbs	175 lbs
Bipropellants	--	8775 lbs

*Assumes a four to one ratio of pressurant gas carried to pressurant gas resupplied, and full transfer of pressurant gas exchanged as an ORU tank set.

This configuration will easily handle the Mark II Propulsion Module single mission requirement and should be able to handle a wide range of single missions to resupply multiple spacecraft (Ref. 3-17).

5.3.5 <u>OMSS Configuration Type C</u>

The Type C configuration, shown in Figure 5.3-5, adds an IOSS fluid resupply stowage rack and a six tank OSCRS bipropellant tanker to the reference configuration. Configurations 6, 10, 13, 15, 19, 21, 24, and 28 from Figure 5.3-1 fit the Type C classification. Number 28 gives the largest fluid capacity for Type C configurations. The addition of the six tank OSCRS bipropellant tanker and the fully loaded IOSS stowage rack provides a significant capability for supplying bipropellants, while maintaining a modest monopropellant capacity.

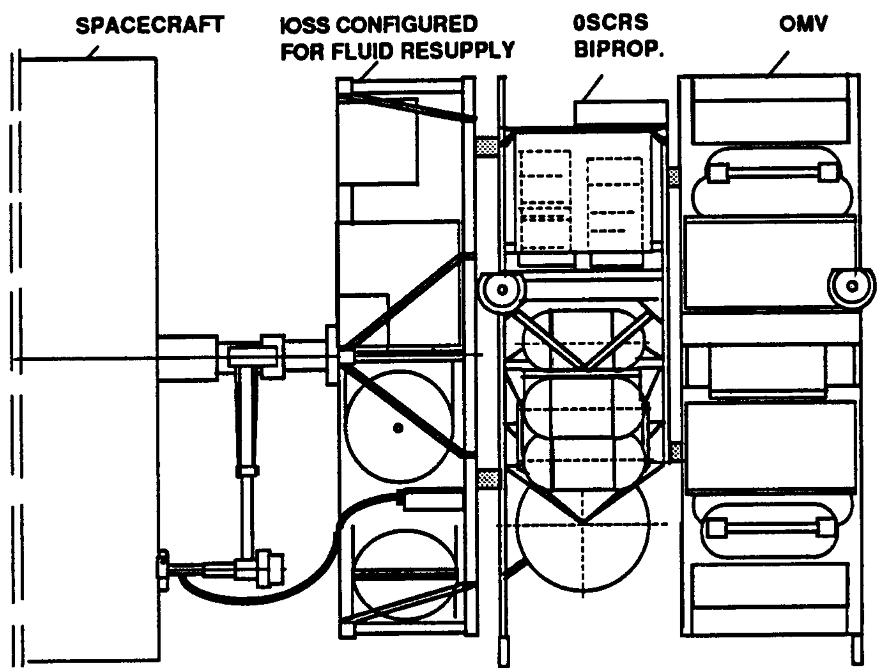

Figure 5.3-5 OMSS Configuration Type C

In this configuration, bipropellants can flow from the bipropellant OSCRS or the OMV, though the IOSS fluid resupply stowage rack, through two H&CMS to the spacecraft, or bipropellants from the OSCRS can flow through intervehicle fluid transfer devices to the OMV to increase the range of resupply missions. Monopropellant from three stowage rack tanks can also be directed to the spacecraft or the OMV.

Configuration 28 provides the following fluid quantities for resupply or propulsion:

	w/o OMV	w/OMV
Monopropellant	2910 lbs	4090 lbs
GN_2*	200 lbs	240 lbs
Bipropellants	11400 lbs	20175 lbs

*Assumes a four to one ratio of pressurant gas carried to pressurant gas resupplied, and full transfer of pressurant gas exchanged as an ORU tank set.

This configuration exceeds the largest single mission bipropellant requirement (7000 lbs by DOD 1 mission), while meeting all of the single mission monopropellant requirements except for the Mark II Propulsion Module.

5.3.6 OMSS Configuration Type D

The Type D configuration, sketched in Figure 5.3-6, combines the ICSS fluid resupply stowage rack, a five tank OSCRS monopropellant tanker, and a six tank OSCRS bipropellant tanker with the reference configuration. Configurations 16, 22, 25, 26, 29, 30, 31, and 32 from Figure 5.3-1 are included in the Type D classification. Configuration 32 incorporates all of the system elements listed in Section 5.3.1.

Configuration 32 provides the following fluid quantities for resupply or propulsion:

	w/o OMV	w/OMV
Monopropellant	7760 lbs	8940 lbs
GN_2*	200 lbs	240 lbs
Bipropellants	11400 lbs	20175 lbs

*Assumes a four to one ratio of pressurant gas carried to pressurant gas resupplied, and full transfer of pressurant gas exchanged as an ORU tank set.

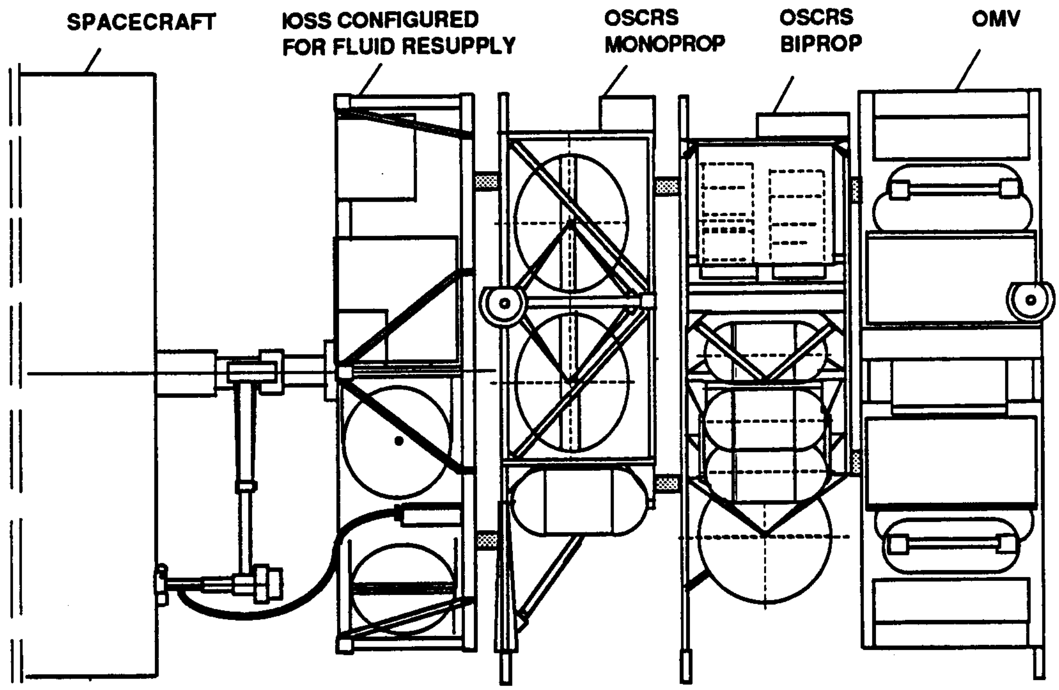

Figure 5.3-6 OMSS Configuration Type D

In this configuration, monopropellant, bipropellants, and pressurants can be transferred in either direction between the OMV, OSCRS tankers and the IOSS. This configuration exceeds both the largest single mission monopropellant requirement (5000 lbs by Mark II Propulsion Module mission) and the largest single mission bipropellant requirement (7000 lbs by DOD 1 mission).

Because the capability of configuration type D exceeds single mission requirements, it is a good candidate for servicing multiple spacecraft on a single resupply mission.

5.3.7 Summary

Potential OMV front end servicer kits that provide fluid resupply are broken down into four configuration types (A through D). Each configuration type is bordered by the IOSS and the OMV. Configuration type A includes only the IOSS and the OMV. Type B consists of the

IOSS, an OSCRS monopropellant tanker, and the OMV. Type C has the IOSS, an OSCRS bipropellant tanker, and the OMV. Type D includes all four elements - the IOSS, both types of OSCRS tankers, and the OMV. Fluid capacities for each configuration are summarized in Table 5.3-2.

Table 5.3-2 Fluid Capacity Summary

	Monopropellant	GN_2*	Bipropellants
Excluding OMV fluids			
Type A	2910	135	---
Type B	7760	135	---
Type C	2910	200	11400
Type D	7760	200	11400
Including OMV fluids			
Type A	4090	175	8775
Type B	8940	175	8775
Type C	4090	240	20175
Type D	8940	240	20175

*Assumes a four to one ratio of pressurant gas carried to pressurant gas resupplied, and full transfer of pressurant gas exchanged as an ORU tank set.

6.0 INTERFACES AND OPERATIONS

Section 5.0 covers the elements of the onorbit maintenance and servicing system (OMSS) and the variety of ways these elements may be combined. This section focuses on the interfaces between the elements, the variety of mission scenarios to be encountered, and the considerations that must be addressed during system development due to fluid resupply operations.

The interfaces between major system elements were broken down into two categories; straightforward interfaces and more complex interfaces. The straightforward interfaces are primarily assembled on the ground and remain intact for the duration of the mission. The more complex interfaces are either connected onorbit or involve methods not previously addressed. A good example of the second type of interface is the long-term, no-leak fluid connector that will be used with the pressurant tank as an orbital replacement unit (ORU). In this configuration the pressurant tank and fluid line are replaced as an ORU. The disconnect that attaches to the spacecraft plumbing must be leak-proof during launch and maneuvers to the spacecraft and after final seating in the spacecraft.

Following the identification and definition of OMSS interfaces, it is useful to examine the range of mission scenarios. This examination shows the role of the servicing mission within the mission scenario and highlights the events within the servicing mission. The resulting scenarios prompted a study of the mission operations that, in turn, revealed potential problems that are documented in Section 6.2.3. An important consideration is the role of the operator in the OMSS mission. Operators must be trained to deal with communication loop delay times and fatigue encountered during lengthy missions. Fail-safing the system against communication black-outs is another operational consideration. Results from the analysis of interfaces and operations are included in the requirements in Appendix B.

6.1 INTERFACES

The interfaces between OMSS elements were analyzed through interface identification and definition.

6.1.1 Interface Identification

Interfaces were identified by examining the interaction of the major OMSS elements discussed in Section 5.0, and the tracking and data relay satellite system (TDRSS) and the OMSS control station. Figure 6.1-1 shows the elements centered about the integrated orbital servicing system (IOSS). Above the IOSS is the spacecraft to be serviced, the target of the OMSS mission. At the sides of the IOSS are elements that support the fluid resupply function of the OMSS. The monopropellant and bipropellant orbital spacecraft consumables resupply system (OSCRS) tankers, and the stowage rack liquid and gas tanks provide the capacity for fluid resupply. The hose and cable management system transfers fluids to the spacecraft. The ORU tanks provide spacecraft pressurant resupply. These elements are stacked on the orbital maneuvering vehicle (OMV), which provides the system with a maneuvering capability. The OMSS is operated from the OMV control station through the tracking and data relay satellite system and the OMV communications system. The symbols in parenthesis in the blocks of Figure 6.1-1 are used in subsequent figures in this section.

The recommended fluid resupply configuration was developed to simplify system elements and minimize the number of element interfaces. To limit the onorbit interfacing of the hose and cable management system to the spacecraft side only, it was necessary to fix the servicer side of the hose and cable management system to the IOSS stowage rack. This necessitated the transfer of fluids through a set of stowage rack pipes from tanks on the stowage rack and from tanks on the OSCRS tankers to the hose and cable management system. Fluid flow to and from the OMV can be effected through OSCRS and the IOSS stowage rack piping.

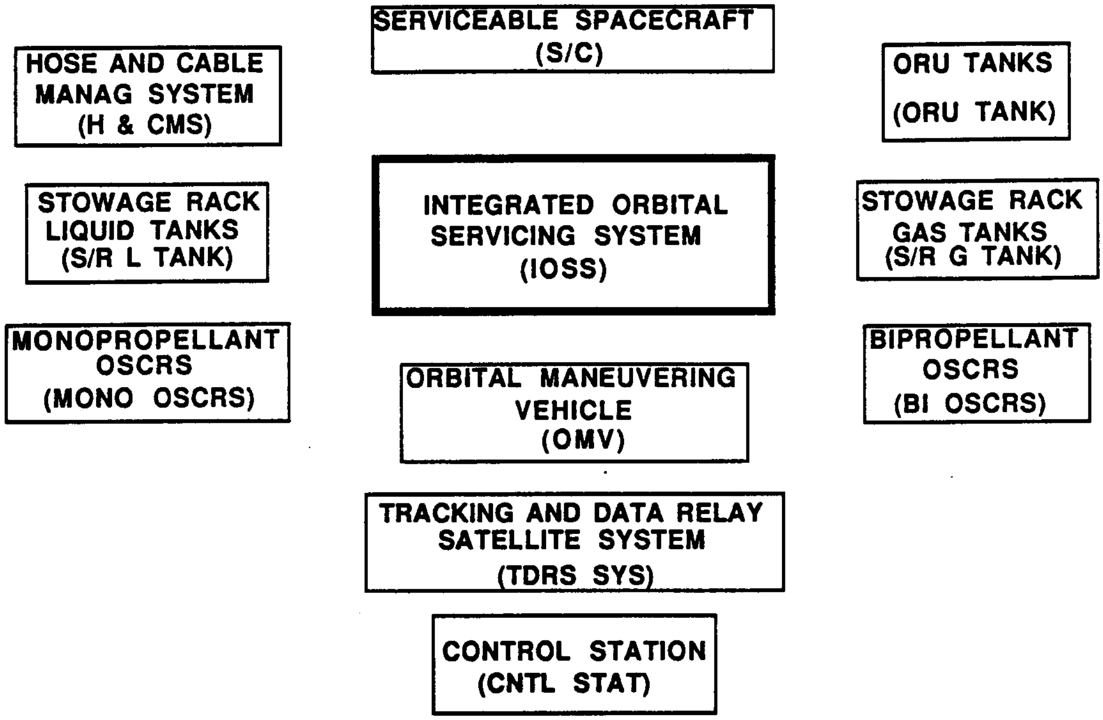

Figure 6.1-1 Major Elements for Fluid Resupply

Defining the interfaces between elements is critical to the design of the servicing system. The introduction of fluid resupply into the system heightens the complexity of interfaces between elements. Figure 6.1-2 lists six interface types and shows the interfaces resulting from the recommended fluid resupply servicing system configuration.

The mechanical interface provides the structural integrity of the system. Whether connected prior to launch or in space, the system structure must survive orbital maneuvers and resupply stresses and provide required alignment accuracy. The liquid interface provides the connection for monopropellant and bipropellant fluids transfer. The integrity of this interface is critical to a successful resupply mission. The gas interface, for pressurant gas resupply, must cope with high pressures. The electrical interface relays signals that are vital to safe fluid resupply. Video and communications are relayed between the IOSS and the control station through the OMV and TDRSS.

SPACECRAFT										
IOSS	ME 1									
ORU TANK	ML GE 2	ME 4								
S/R L TANK	-	ML E 5	-							
S/R G TANK	-	MG E 6	-	-						
H & CMS	ML GE 3	ML GE 7	-	-	-					
MONO OSCRS	-	MLG EV 8	-	-	-	-				
BI OSCRS	-	MLG EV 9	-	-	-	-	MLG EV 11			
OMV	-	MLG EV 10	-	-	-	-	MLG EV 12	MLG EV 13		
TDRS SYS	-	-	-	-	-	-	-	-	CV 14	
CNTL STAT	-	-	-	-	-	-	-	-	-	CV 15
	S/C	IOSS	ORU TANK	S/R LIQ TANK	S/R GAS TANK	H & CMS	MONO OSCRS	BI OSCRS	OMV	TDRS SYS	CNTL STAT

INTERFACE TYPES

M - MECHANICAL
L - LIQUID
G - GAS
E - ELECTRICAL
C - COMMUNICATIONS
V - VIDEO

Figure 6.1-2 Potential Interfaces

The boxes at the intersections between a row and column show the type of interfaces involved between the row element and the column element. To identify all interfaces for a particular element, both the row and column for that element must be checked. A dash in a box implies that there is no interface involved. The underlined numbers in each box are used to assist in tracking each of the 15 specific interfaces on the following pages.

Figure 6.1-2 illustrates the basic interfaces that result from the recommended servicer configuration. The fifteen interfaces can be reasonably grouped into a set of eight interface types, shown in Table 6.1-1.

The spacecraft involves three interface types. It will mechanically hard dock with the IOSS, with docking status transmitted electrically. A tank system (tank and related plumbing) as an ORU will be structurally attached to the spacecraft with electrical signal feedback

Table 6.1-1 Set of Interface Types

Spacecraft/IOSS hard dock (#1)
Spacecraft/ORU tank exchange (#2)
Spacecraft/hose and cable management system fluid resupply (#3)
ORU tank/IOSS stowage rack interface (#4)
Fluid resupply tank/IOSS stowage rack interface (#5, 6)
Hose and cable management system/IOSS interface (#7)
OMV/OSCRS/IOSS berthing device (#8, 9, 10, 11, 12, 13)
IOSS/OMV/control station RF data link (#14, 15)

and connected fluid lines. The hose and cable management system will be connected to the fluid interface on the spacecraft to allow flow from the resupply tanks through the IOSS stowage rack and hose management system.

The IOSS stowage rack has three interface types. First, the ORU replacement tank is structurally attached to the stowage rack with an electrical connection to monitor ORU tank status. Second, the fluid resupply tanks are mated to the IOSS stowage rack with a mechanical interface support, an electrical link for status feedback, and fluid lines to allow the transfer of liquid or gas to the stowage rack for subsequent transfer to the spacecraft. Third, the hose and cable management system will be directed by IOSS avionics to manage the fluid flow from the IOSS stowage rack to the spacecraft fluid interface.

Also included in the system are standard berthing devices for the OMV to OSCRS connection, the OSCRS to IOSS connection, and the OMV to IOSS connection. Finally, the RF data link between the IOSS, OSCRS, OMV, TDRSS, and the control station transmits video and communications data. The numbers in Table 6.1-1 correspond to the interfaces shown in Figure 6.1-2.

6.1.2 Interface Definition

Table 6.1-2 lists the four interface types that are considered straightforward. These interfaces do not represent new technology and their assembly on the ground is not expected to be complicated. Placement of the ORU tank set in the IOSS stowage rack should be uncomplicated. Structure to support the ORU tank set will be provided so that launch, orbital maneuvering, and landing stresses will not threaten the integrity of the OMSS structure. The interface will also provide an electrical connection to sensors on the ORU tank set to monitor the status of the ORU tank set during launch and approach to the spacecraft.

Table 6.1-2 Straightforward Interfaces (Prelaunch Assembly)

- ORU tank/IOSS stowage rack mate
  - -- Tank exchange during mission operations utilizing standard ORU exchange procedure
- Fluid resupply tank/IOSS stowage rack mate
  - -- Fluid transferred between fluid resupply tank and IOSS
  - -- One set of fluid valves contained within IOSS
- Hose and cable management system/IOSS mate
  - -- Fluid transferred between H&CMS and IOSS
  - -- One set of valves in H&CMS at spacecraft interface
- IOSS/OMV/control station RF data link
  - -- IOSS data and video information downlinked through OMV to control station
  - -- Control station commands uplinked through OMV to IOSS

The second interface type, labelled straightforward, is the stowage of fluid resupply tanks in the IOSS stowage rack. Monopropellant tanks and pressurant gas bottles are mounted prior to launch during assembly of the IOSS stowage rack. The monopropellant tanks are manifolded with fluid lines to the H&CMS for spacecraft resupply, to the intervehicle fluid transfer device (IVFTD) for OMV resupply, and to the fill and drain port for prelaunch preparation; as shown in the fluid resupply schematic, Figure 5.2-3. Additionally, gas bottles are connected to the monopropellant tanks to drive bladder type propellant management devices. Pressurant bottles are also connected to the H&CMS, to the IVFTD, and to fill and drain valves.

Sensors for gas and liquid tanks in the stowage rack must be connected electrically to the IOSS computer so that temperature, pressure, and fluid levels can be monitored throughout the mission (Ref. 3-14). One set of redundant fluid valves is located on the IOSS side of the interface.

The third straightforward interface type is the connection between the H&CMS and the IOSS fluid resupply stowage rack. The H&CMS must be securely mounted into the IOSS stowage rack, and completely contained during the launch and landing phases of the mission. The fluid lines within the H&CMS should be purged for these phases. The H&CMS must have propellant and pressurant connections to the IOSS stowage rack to enable fluid transfer to the spacecraft from either tanks in the IOSS, OSCRS, or the OMV. A set of redundant valves in the H&CMS at the spacecraft interface controls the flow of fluid through the H&CMS. The H&CMS must also have sensors, connected electrically to the IOSS, to control and monitor fluid flow through the H&CMS and to relay data from spacecraft sensors.

The fourth straightforward interface is the data link between the IOSS, OSCRS, OMV and the ground control station. System status is monitored by IOSS, OSCRS, and OMV avionics to be transmitted through TDRSS to the control station. Control station commands are linked in the opposite direction. The video signal from the IOSS camera is sent through OSCRS to OMV for transmission to the control station.

Table 6.1-3 lists the four interface types that are more complex. These interfaces either require new technology or demand complicated implementation. The first complex interface is the hard dock between the IOSS and the spacecraft. Figure 6.1-3 shows two docking methods being examined for use on OMV (Ref. 3-5). The remote manipulator system (RMS) snare end effector is used by the remote grapple docking mechanism (RGDM) to berth with the spacecraft. The three point docking (TPD) mechanism can be utilized for berthing with spacecraft that have flight support system (FSS) type attachments.

Table 6.1-3 Complex Interfaces

- Spacecraft/IOSS Hard Dock
  - -- Positioning tolerance
  - -- Peak impact force
  - -- Energy absorption requirements
- Spacecraft/ORU Tank Exchange
  - -- Functions included in ORU
  - -- Long-term no-leak fluid connector
- Spacecraft/Hose and Cable Management System Fluid Resupply
  - -- Fluid interface device
  - -- Fluid and electrical connectors
  - -- Redundancy requirements
- OMV/OSCRS/IOSS Berthing Device
  - -- Berthing methods
  - -- Fluid and electrical connector mating system
  - -- Number and types of fluid interfaces

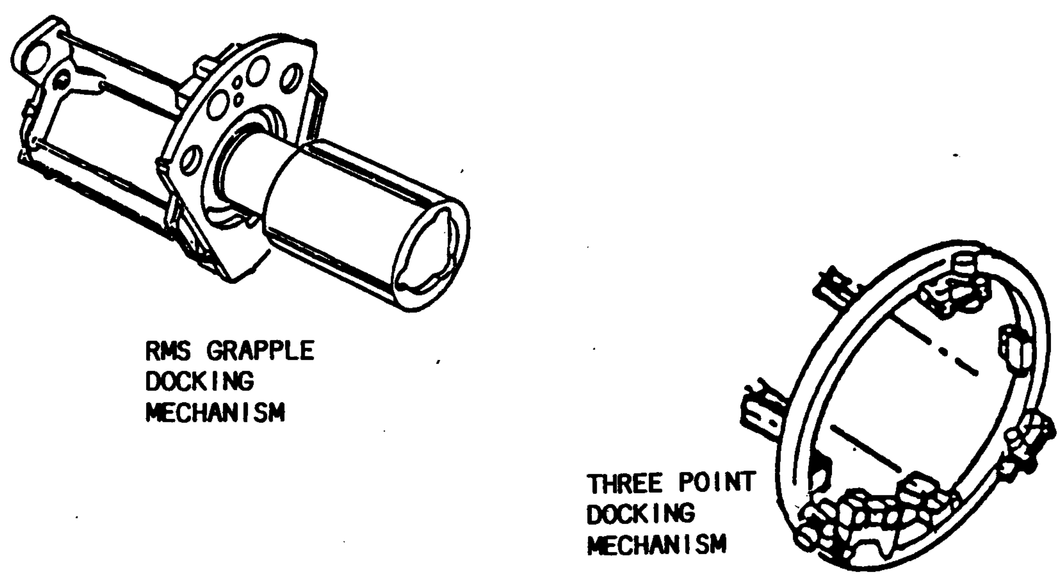

Figure 6.1-3 OMV Docking Systems

The RMS end effector is a hollow, light-gauge aluminum cylinder that contains a remotely controlled motor drive assembly and three wire snares. The drive system provides the ability to capture, rigidize and release a payload. The capture/release function is achieved by a rotating ring at the open end of the end effector that opens and closes the wire snares around the spacecraft mounted grapple fixture. Interface rigidization is achieved when the snare assembly is withdrawn into the end of the end effector pulling the spacecraft into full contact with it.

The mating grapple fixture consists of a long shaft, three alignment cam arms, and a target fixture. The rigid shaft, when grappled by the snare wires, provides the structural integrity between the OMV and spacecraft.

The three point docking mechanism is adapted from its design use for supporting MMS spacecraft during launch and for their deployment from the orbiter. The three latches are a two-finger mechanism where the fingers wrap around a mating pin on the spacecraft. There is no energy absorption device, nor any way of providing a separation force. The wide spacing of the latches, and their rugged construction provides a very stiff and accurate attachment.

Figure 6.1-4 illustrates a third docking concept, the general purpose docking system (Ref. 6-1). Because the RMS end effector is not intended for docking use, it does not allow for closing velocities, impact energy reduction or separation velocities. It also does not have the hard dock latching capability necessary to react IOSS operational loads during servicing. The general purpose docking system is a conventional probe/drogue concept. The drogue is located on the docking spacecraft with the probe unit mounted on the IOSS.

Initial contact can be made by the probe and drogue in a misaligned and offset condition. As the probe enters the drogue, the drogue gimbal partially aligns with the probe and depresses the spring loaded

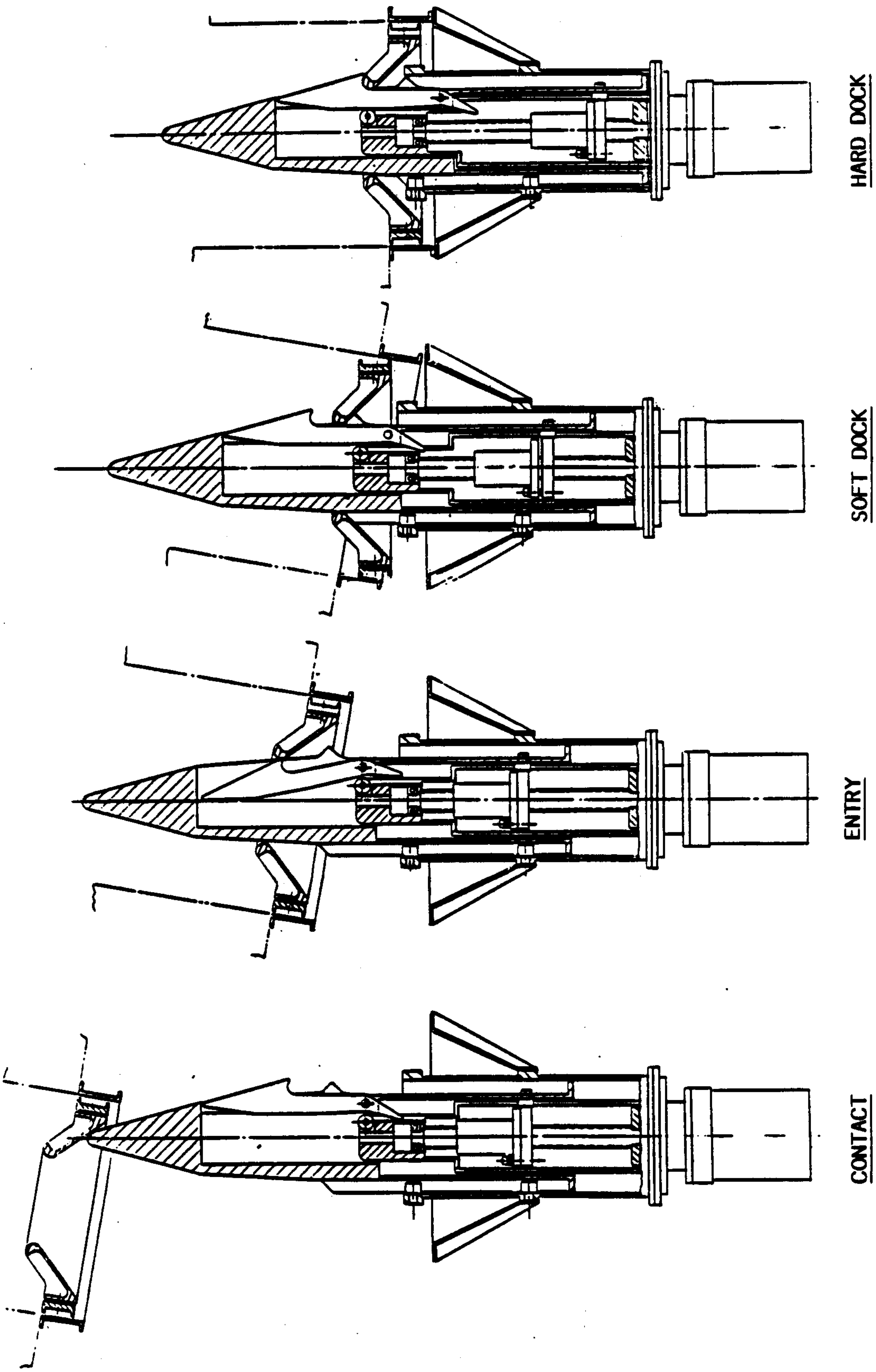

Figure 6.1-4 General Purpose Docking System

Figure 6.1-4

latches. Final soft dock is realized when the drogue bottoms out on the translation probe ring. At this time, the shock isolation springs are compressed, and the motor is removing the docking energy. On completion of soft dock, the motor is actuated to draw the translation probe back, the latches contact the drogue, the outer drogue ring contacts the rigidizing cone and the two spacecraft reach final alignment. The motor then applies the 3,000 pound preload of final hard dock. When power is shut off to the motor, the power-off, fail-safe brake sets lock the spacecraft in place.

Release and separation is accomplished by simply applying full power to the motor in the release direction. As the translation probe moves forward, the latches move away from the drogue ring. The drogue ring then contacts the probe ring, accelerating the two spacecraft apart. When the translating probe reaches the end of its travel and stops, the two spacecraft have reached separation velocity and are moving apart. At this point, the three latches are in their retracted position allowing the spacecraft to freely move apart.

The design of the general purpose docking system has many advantages including establishment of a strong connection between the OMSS and the spacecraft. However, the current design does not seem to include a roll (about the docking axis) angle alignment feature. Knowledge of the docked roll angle is very important to successful completion of preplanned ORU exchange trajectories by the IOSS. Before the general purpose docking system can be used with the OMSS, its design must be extended to include a roll angle alignment feature.

A second complex interface results during the ORU tank exchange in which the replacement tank and pre-attached plumbing is moved into the spacecraft position vacated by the old ORU. As the structural mate is made, the electrical and fluid connection will also be made. After the connections are achieved, the replacement tank will be ready for operation. Several details of this system must be explored further. Determining what tank plumbing elements should be included in the ORU will be vital in defining the functions that will be performed by the tank ORU. Development of a long-term, no-leak fluid connector is essential for some applications of the system. Resupply missions that service multiple spacecraft will have to use fluid disconnects that maintain fluid seal integrity during inter-spacecraft travel, and upon spacecraft connection they must allow free flow of fluids with no contamination. Candidate functions included in the ORU are described in detail in Section 5.2.1.

The third complex interface type is connection of the H&CMS to the spacecraft. This interface has been called the fluid resupply interface unit and is described in detail in Section 5.2.6. It will provide a firm mechanical attachment between the H&CMS and a mated fitting on the spacecraft. It will also provide fluid transfer capability, with redundant electrical connections to control and monitor the servicing operation.

The fourth complex interface connects between the OMV, OSCRS, and the IOSS. At this point in the study, the intervehicle connections are assumed to be made prior to launch. The mechanical berthing device is expected to be similar to the method used on OMV (either a three or four point attachment). The intervehicle interface must also accommodate fluid and electrical pass throughs. The intervehicle fluid transfer device, described in Section 5.2.3, incorporates these capabilities.

The final interface discussed is between the OMSS and the orbiter. The OMSS configuration includes two sets of trunnion pins and scuff pads for attachment to the orbiter payload bay (Ref. 3-20). As illustrated in Figures 5.3-3 to 5.3-6, one set is located on the farthest edge of the OMV with a second set positioned on the side of the element next to the IOSS stowage rack. The distance between sets of trunnion pins and scuff pads is maximized to provide the most secure stowage possible. The cantilever capability of the OMV is more than adequate to support the IOSS weight.

6.2 OPERATIONS

OMSS operations are broken down into general mission operations, specific servicing scenarios, and analysis of operational considerations that result in additional system requirements.

6.2.1 Mission Scenarios

The study of mission scenarios and operations provides insight into the OMSS design and is useful in revealing problem areas. Figure 6.2-1 displays the entire mission scenario from pre-launch assembly to post-launch disassembly and refurbishment (Ref. 6-2). OMSS elements would be stored at a launch site facility similar to planned OMV ground storage accommodations. Elements would be selected and assembled based on specific mission requirements. A large capacity resupply mission would require the use of OSCRS tankers, while a minimum resupply mission might be satisfied by the simple combination of the OMV and IOSS.

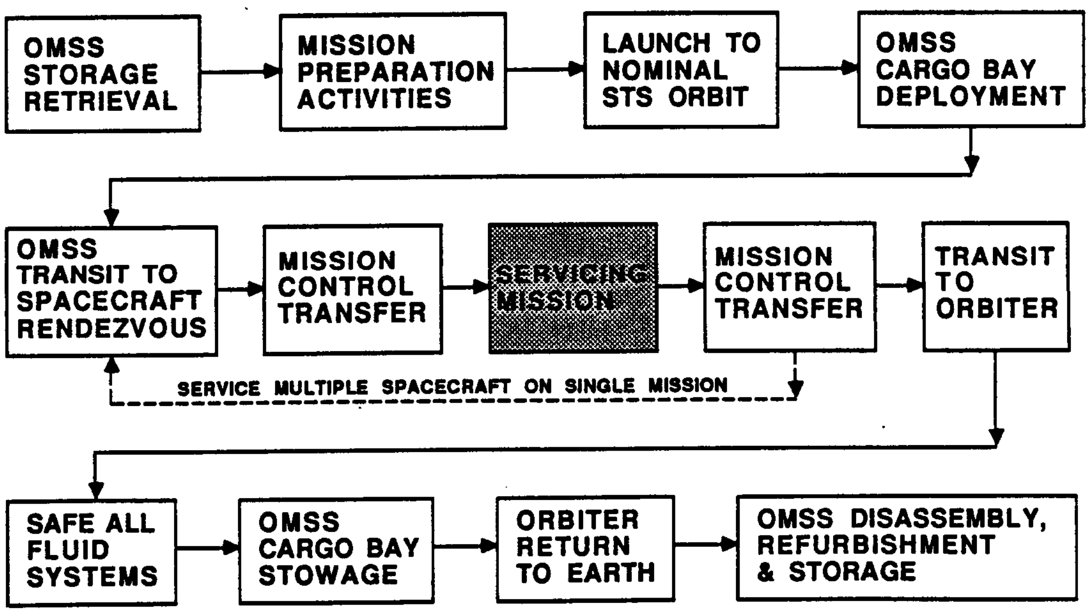

Figure 6.2-1 Mission Scenario

For each mission the required subsystem elements would be assembled in the OMV front end kit assembly area and ground tested, using OMSS kit ground support equipment. Following assembly and checkout at the ground support facility, the OMSS kit would be transported to the STS payload processing facilities at the STS launch site.

At the launch facility the OMSS elements would undergo further test and checkout prior to a mating with the OMV in the horizontal or vertical payload processing sequence. The assembly and checkout approach recommended for the OMSS kit is to emphasize ground testing and verification, with necessary adjustments and replacements done on the ground. If OMSS kit subsystems were to fail during onorbit checkout, it would be difficult to replace them at the orbiter. Following the launch into a operating/standby orbit, the OMSS/OMV will be deployed from the cargo bay with the orbiter RMS. The orbiter will then be maneuvered away from the OMSS to a safe distance for the OMV orbit transfer. The OMV will then transport the servicer system to a rendezvous with the target spacecraft.

The actual servicing operation will commence with visual sighting of the spacecraft. The OMV will maneuver to within visual range of the spacecraft and commence actual servicing operations. The specific operations are described in Section 6.2.2. The onorbit satellite servicing operations will be controlled from the ground-based OMV Operations Support Center (OSC), so mission control is transferred to the OSC at this time.

After the spacecraft is maintained and serviced, the OMSS maneuvers to the next spacecraft to be resupplied or, if the resupply activity is complete, to the orbiter. All fluid systems are examined and safed, prior to the OMSS being restowed in the orbiter cargo bay. Fluid seals are rechecked, pressures and temperatures are verified within safe limits and fluid lines are purged for OMSS reentry and return to Earth. After landing the OMSS elements are disassembled and refurbished. Elements are returned to the storage facility and would be available for follow-on resupply missions.

For a single spacecraft resupply mission, the mission time is a function of the time required to transfer between orbits. Orbital maneuvering between two altitudes requires proper phasing to achieve successful rendezvous. Figure 6.2-2 shows total mission time resulting from possible servicing times for GRO servicing (Ref. 3-21), where servicing time is the time from docking with the spacecraft to be serviced to the undocking from the spacecraft. Proper phasing for return to the orbiter may required the OMSS to continue in the spacecraft orbit (after completing the servicing) so that orbital transfer timing will match the time and position of the orbiter. For servicing multiple spacecraft in a single mission, plateaus would be defined by the various orbital altitudes and positions of these spacecraft.

The figure was taken from "OMV Tanker Resupply System, Preliminary Analysis" NASA, MSFC, November, 1986. The mission times are based on orbital phasing at either a 100 n.m. altitude or at the altitude of the satellite being serviced.

Several observations can be made from the figure. For the cases shown, the plateaus indicate that there is no mission time penalty for wide ranges in servicing time. This is because once a certain angular separation is reached, it takes no longer to wait until the angular separation reduces naturally. The minimum orbital transfer time (2 way) was selected at 2.5 hr. The right hand edge of all of the plateaus can be connected by a straight line that gives the maximum allowable servicing time for a given total mission time. The servicing times and total mission times are reasonable.

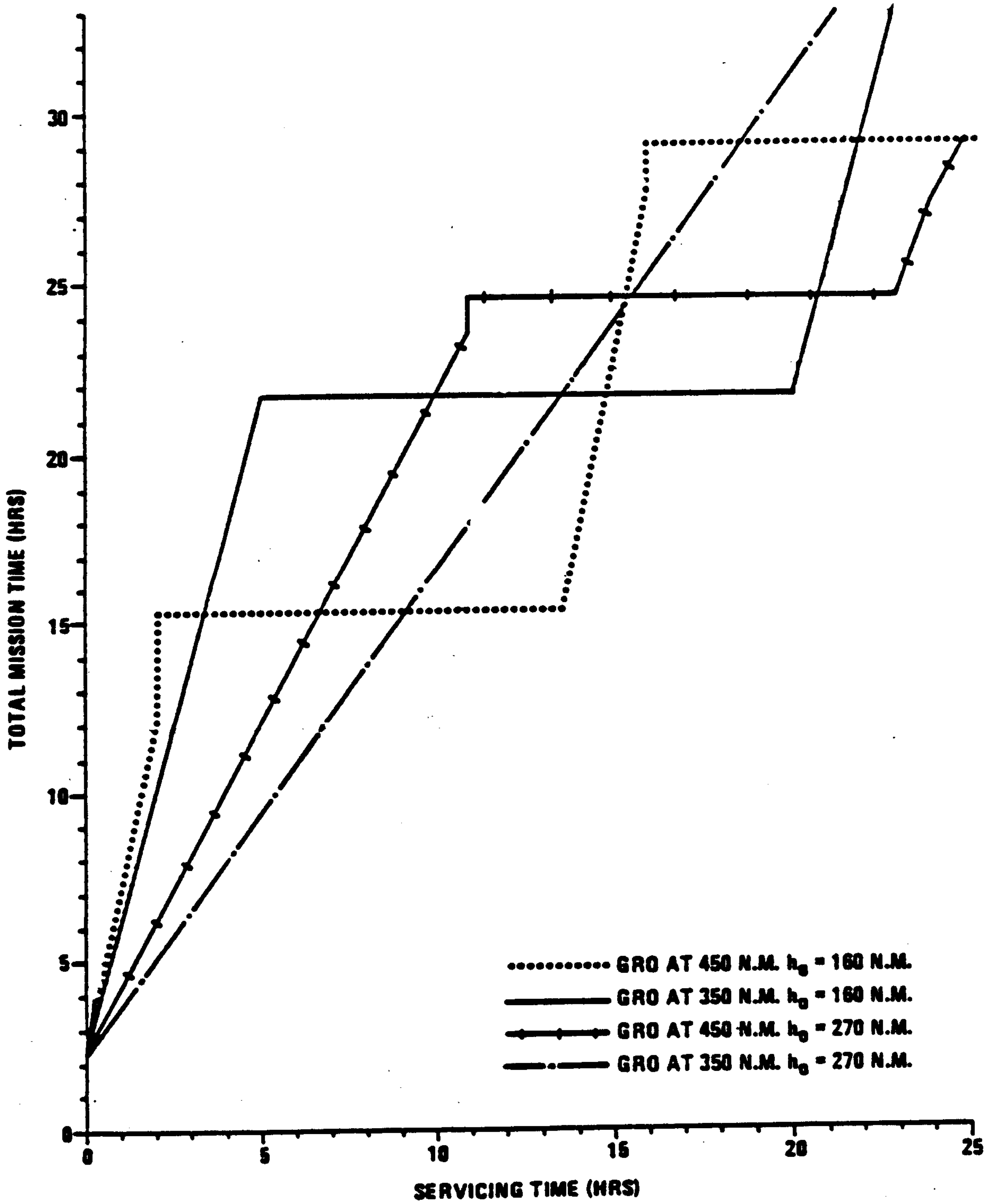

Figure 6.2-2 Total Mission Time as a Function of Servicing Time for Satellite Servicing Missions

6.2.2 Servicing Scenarios

The actual servicing operation begins with the OMSS maneuvering to within visual range of the target spacecraft, and ends with separation from the serviced spacecraft. Figure 6.2-3 shows the basic servicing scenario.

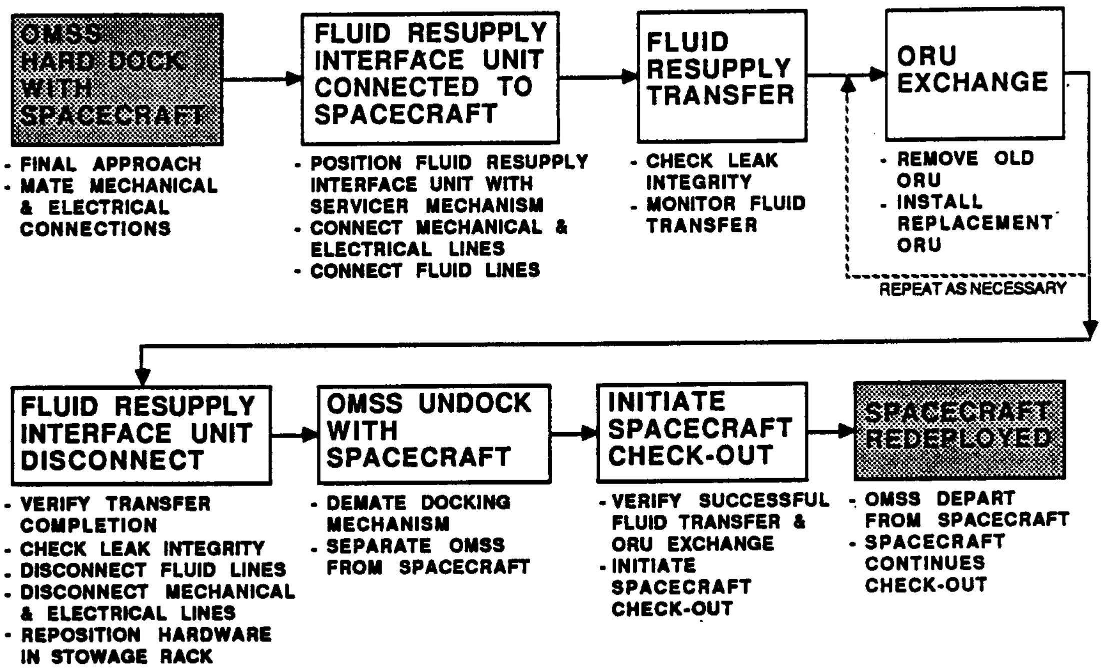

Figure 6.2-3 Servicing Scenario

Control of the system is transferred to the OMV control station after the spacecraft is sighted. The operator moves the OMSS to the spacecraft proximity and matches spacecraft motion. The OMSS is maneuvered through a final approach to a 0.01 ft/sec docking velocity (Ref. 3-20). Docking is initiated at impact by performing a mechanical hard dock and an electrical connection.

After hard dock with the spacecraft is achieved, the operator stabilizes system attitude rates using the OMV attitude control system. Once the system (OMSS/spacecraft) is stabilized, servicing may commence with steps that best suit mission needs. Typically, the operator will initiate fluid resupply, followed by ORU exchange, and end with fluid resupply termination.

Fluid resupply is initiated by the operator by connecting the fluid resupply interface unit to the spacecraft. The operator uses the servicer mechanism end effector to grasp the fluid resupply interface unit at the top of the IOSS stowage rack. The command is given to release the H&CMS from its secured position in the stowage rack. The fluid resupply interface unit is lifted with the servicer mechanism and concurrently flipped outward in the H&CMS bending plane. With the fluid resupply interface unit positioned correctly (pointing upward toward the spacecraft), the servicer mechanism moves the unit out of the H&CMS stowage plane to under the spacecraft fluid interface.

The fluid resupply interface unit is rotated to match the orientation of the spacecraft interface. The unit is translated, mechanical contact initiates removal of disconnect dust covers, electrical contact verifies mate, and final movement secures the fluid disconnects. After the interface is successfully mated, leak integrity is verified and fluid transfer initiated. Fluid temperature, pressure and flow rate are monitored at the sending and receiving tanks and in the transfer lines. If fluid is transferred too rapidly, cooling may be inhibited, resulting in temperature and pressure rise, which may threaten ignition of propellants.

During the transfer of fluid to the spacecraft (up to six hours), there is time for ORU exchange. The servicer mechanism end effector detaches from the fluid resupply interface unit, leaving it securely attached to the spacecraft. The servicer mechanism and end effector are available for ORU exchange. The operator issues standard commands to remove the old ORU, move it to the temporary storage location in the IOSS stowage rack, install the new ORU, and place the old ORU into the space vacated in the stowage rack by the replacement ORU (Ref. 3-1).

6.2.3 Operational Considerations

A review of the mission and servicing scenarios, combined with our knowledge of orbital operations, revealed a number of operational considerations that should be addressed more completely in the future. Many of the items discussed are items that have been solved for other programs, but which have not been otherwise addressed in this study.

6.2.3.1 Mission Planning - Operational considerations related to mission planning can start with the need for a ground maintenance and refurbishment facility for the elements of the orbital maintenance and servicing system. This type of facility will be similar to that planned for the OMV in that there will be a need for: equipment storage, equipment assembly and disassembly, equipment checkout, a repair capability, and transportation equipment.

Mission planning itself will require knowledge of the orbital characteristics of the failed spacecraft so that the orbital mechanics of the mission can be developed. Many of the mission planning considerations were touched on in the discussions of mission and servicing scanarios. There is also a need to address the mission plan reserves in terms of impulse, time, and electrical power. Mission time is important for those flights involving multiple spacecraft and operations from the orbiter with its limited onorbit stay time.

The quantities of equipment to be produced will have to consider the expected number of missions per year, turn around time, operations from one, or both, launch sites, and the number of combined operations that might be planned. The relative location of the other orbital element (OMV and OSCRS) processing facilities, whether they are close or remote, can also affect the quantity of OMSS equipment required.

It is expected that the OMSS will not be mounted directly into the orbiter, rather that it will be cantilevered off the front of the OMV. It is expected that the OMV will be mounted on two sets of orbiter sill trunnions and that its cantilever capability will be adequate for the OMSS, even when it is using a refueling type of stowage rack. The OMSS can be similarly cantilevered off the front of the OSCRS if the OSCRS is provided with an appropriate interface with the OMSS. The OSCRS is also mounted in the orbiter using two sets of sill trunnions. The best method for mounting the various OMV/OSCRS combinations in the orbiter sill trunnions will have to be determined.

All of the operations in proximity to the orbiter involving combinations with the OMSS should be similar to those proximity operations involving the OMV. These would include predeployment checkout, deployment using the RMS, backaway using the orbiter, OMV engine firing, OMV safing, approach by the orbiter, recovery by the RMS, securing all equipment in place, and powering down.

6.2.3.2 Orbital Operations - The OMSS rendezvous and docking operations will be based on those of the OMV, as the OMV is the propulsive vehicle for these operations. It also has the necessary guidance and attitude control equipment. There may be a need to evaluate the OMV attitude control system response when the most complex stack is being maneuvered during the final stages of docking. The problem arises because the combined center of mass of the stack will be far from the OMV's translational thrust axes.

It is expected that control of the fluid resupply and ORU exchange processes will be from the ground and will involve supervisory control where the operator commands major segments of activity and the onboard system executes the finer steps in the processes. This means that the effects of communications system delays are only of importance when the primary system has failed and operations are being conducted in the backup mode. Fatigue should not be a problem with the operators as they are on the ground and they can be given frequent breaks either by delaying operations during the break or by using alternate operators. The control system is not sensitive to lighting conditions.

The TV cameras are used to provide reassurance information to the operator and are not necessary for the primary supervisory control. Also the TV system has its own lights for dark side operations and the TV camera uses a charge coupled device with an auto iris lens so it can operate in bright sunlight as well.

The development of failsafe approaches is somewhat complex, but it can be based on the approaches used for the OSCRS system. OSCRS was designed to meet the stringent safety requirements posed by EVA operations at the orbiter, and the requirements on the OMSS, designed primarily for in-situ operations, should be easier. The need for return to earth in the orbiter and for the use of EVA for backup operations at the orbiter and at the space station may mean that the OMSS requirements will be similar to the OSCRS requirements. Failures during communications blackouts may be no more difficult to handle than any other failures because of the ability of the system to operate by itself for selected sets of operations.

Thermal control during orbital operations will require careful design and mission planning. During the transfer phases of orbital operations, the temperatures of the various ORUs and fluids can be maintained by changing the attitude of the OMV and thereby changing the radiative view from the various elements, i.e., more or less sunlight. This approach can work if the thermal requirements are not too stringent. The problem is more acute when docked to the failed spacecraft as both the OMV and the spacecraft will have their own separate thermal requirements that must be satisfied. Also, if the spacecraft thermal design is based on cold biasing with heater power used to maintain temperatures, then the heater power will have to come from the OMV and this may put a drain on the energy-limited OMV batteries. It is also likely that the fluid transfer lines and valving will need to be heated before fluid flow can begin. Any ORUs that are being transferred will not have to be heated during the exchange process if they were at the proper temperature before the exchange was begun and the transfer process was not unduly delayed.

It is expected that the serviced spacecraft will have its own attitude control system operating up to and during the docking process. It will be advisable to turn off the spacecraft's attitude control system after docking by the OMV is complete so that the two attitude control systems do not fight each other and waste energy. The spacecraft attitude control system can be turned off by an umbilical connection that is made when docking is complete and it can be turned on again by ground operations after the fluid resupply, ORU exchange, and undocking operations are complete.

It is expected that when all fluids have been transferred, the fluid disconnects will be drained before the disconnects are separated. Similarly the fluid lines will be drained before the fluid resupply interface unit is disconnected. This will result in a safe system as well as smaller forces required to stow the hoses if they are unpressurized.

6.2.3.3 Onorbit Storage and Reconfiguration - The value of onorbit storage and/or reconfiguration should be addressed. If the OMSS cannot be stored onorbit, as is planned for the OMV, then it may not be possible to complete some of the longer multiple spacecraft servicing missions because of the limited stay time of the orbiter. This is primarily a conventional tradeoff between mission time and propulsive energy. Another consideration is a type of failure that could not be solved until after the orbiter had to return to Earth.

With regard to reconfiguration, it may be that a mission could be completed with significant amounts of propulsion left and it would be desirable to leave the propulsion units on orbit. Thus, there might be a need to be able to remove the OMSS, and possibly an OSCRS or two, from the OMV and return all but the OMV to Earth. This would mean that the fluid resupply and ORU exchange equipments would have to be reassembled with the OMV on some later flight. Onorbit reconfiguration might also have some utility for space station operations.

6.2.3.4 Space Station Operations - Operation of the OMSS from the space station opens up more possibilities and presents more challenges. Mission planning becomes more complex as it involves the usual elements of mission planning along with the need to have the fluids and ORUs at the space station when needed. This is one of the basic problems in logistics, how many spares to have and where to store them. The problem is compounded by the cost of transporting items to the space station and the delay involved if they have to be scheduled on a later logistics flight.

The need to be able to reconfigure the OMSS/OSCRS/OMV combinations onorbit is more important for space station operations than it is for orbiter operations. It should be possible to design the OMSS elements for onorbit assembly and disassembly. Loading of ORUs into the IOSS at the space station does not seem to present much of a problem, especially if the ORU storage area at the space station is similar in concept to an IOSS storage rack. ORUs can be brought to the space station in the logistics modules and then stored on the exterior of the space station. Some micrometeorite protection will be required along with thermal control and some form of health monitoring. The methods that can be used for transporting fluids to the space station and their storage on the station have been addressed in the space station studies and in the OSCRS follow-on work.

Operation of the OMSS components at the space station can be extended to operation at an untended warehouse. The untended warehouse has been considered in some Space Defense Initiative studies. The problems are similar to those at the space station, although there is less likelihood of the OMSS being reconfigured during missions. Most missions would be generally similar in that the same type of spacecraft would be serviced. As man could not be used for backup, those special requirements applicable for EVA would not be necessary.

6.2.3.5 Adaptability to Expendable Launch Vehicle Operations - The OMSS concept should be extendable for use with expendable launch vehicles (ELV). The obvious problem is that the OMSS equipment would also be expended. However, an onorbit storage capability might allow the OMSS to be put into orbit on an ELV and then recovered at a later date by the orbiter. The cost of launch of an ELV will be less than the cost of launching the orbiter, but this reduced cost will be offset by the loss of the expended OMSS equipment. It will require an analysis of specific cases to determine whether it is more advantageous to conduct OMSS missions from the orbiter or from an ELV. In particular, the recurring costs of the OMSS elements must be assessed.

The ELV is capable of placing the OMSS into an elliptical orbit with the ELV burnout at perigee. An OMV will be required for the apogee burn and conducting the other rendezvous and docking operations. It may also be desirable to use the OMV to initiate reentry of the OMSS so that the residual OMSS equipment is removed from space and would no longer be a hazard to other spacecraft including the space station.

7.0 HOSE AND CABLE UMBILICALS

Section 5.0 describes the elements that define the orbital maneuvering vehicle (OMV) kit, which integrates fluid resupply and module exchange capabilities. Several components within the onorbit maintenance and servicing system (OMSS) play a key role in the development of the conceptual design. This section examines the types of hoses and fluid disconnects that are currently being used, as well as plans for future development. Also, devices that incorporate these components in the OMSS design are described in this section.

7.1 HOSE AND CABLE MANAGEMENT SYSTEM

In order to maximize the use of the the servicer mechanism range of motion, the umbilical that incorporates fluid hoses and electrical cables must be flexible. The flexibility requirement complicates the umbilical design when combined with constraints for a no-leak, high pressure system. This situation was solved by defining hose requirements, analyzing currently available hose types, recommending a type of hose, and designing a hose and cable management system that satisfies both the hose and the carrier system requirements.

In order to select a hose type, the following requirements were considered. Hoses must be compatible with propellants (MMH, NTO, and N_2H_4) and pressurants (GN_2 and GHe). Hoses must operate with maximum pressures of 150 psi for MMH and NTO, 500 psi for N_2H_4, and 4500 psi for GN_2 and GHe. Materials used to construct the hoses must be suitable for the vacuum environment (no outgassing materials). The hose minimum bending radii should be sufficiently small to allow room for the stored hose within the stowage rack (a desired bend radius of 1 ft was estimated). Finally, operating life of the hose should withstand the bending cycles that may occur during 200 servicing missions.

Two hose types were examined: convoluted metal (bellows) hoses, and Teflon-lined hoses; both types reinforced with external braids to increase pressure capacity. The metal bellows type of hose, shown in Figure 7.1-1, meets fluid compatibility and pressure requirements (Ref. 7-1). The Teflon-lined hose type, shown in Figure 7.1-2, meets all but two requirements (Ref. 7-2). First, the 4500 psi pressurant hose requirement is being worked by Stratoflex, Inc. as part of a contract awarded by the Navy. Second, the polyester covering on the Teflon-lined hose may have to be replaced to eliminate outgassing concerns. Neither of these changes is expected to be a problem. The 3/4 in. metal bellows hose has a minimum bend radius of 8 in., and the 3/4 in. Teflon-lined hose has a minimum bend radius of 6.5 in. Both types of hoses are within the 12 in. bend radius desired.

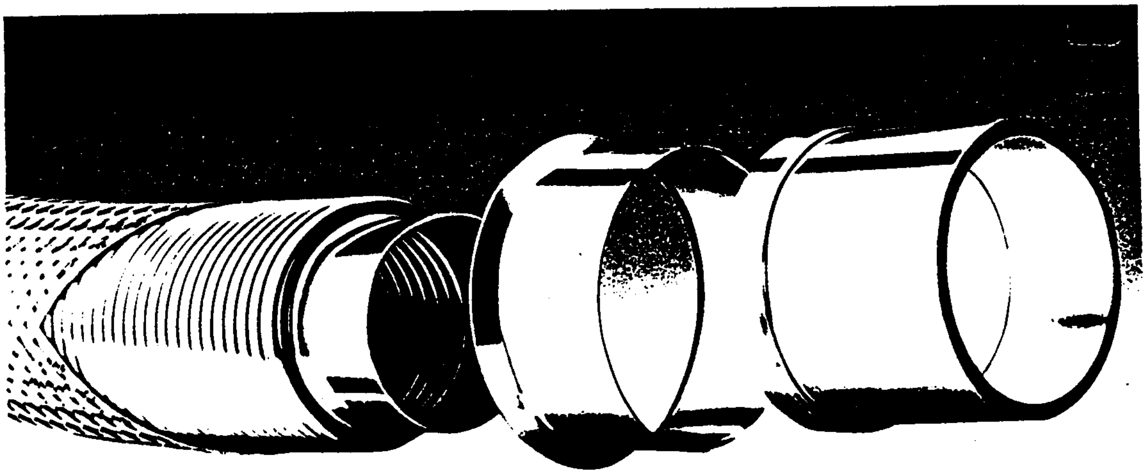

Figure 7.1-1 Metal Bellows Hose

Because both types of hoses (either in current or proposed configurations) satisfy the basic requirements, the selection process was expanded by considering additional factors. First, metal pipes and hoses have been used more frequently as propellant lines in space applications. Metal lines have welded joints that can be tested to provide greater assurance that no leaks will occur in space. Second, the expected expansion of requirements, to include the transfer of cryogenic fluids, favors the use of a metal type of hose. Third, the Teflon-lined hose is difficult to clean completely at the crevice between the lining and the metal end fitting (Ref. 3-1). Based on these requirements and considerations, the metal bellows type of hose is recommended for use in the OMSS.

Figure 7.1-2 Teflon-lined Hose

Electrical cables and connectors were also investigated. Electrical cables must have minimum bending radii no larger than the metal bellows hose bending radius of 8 in. Cables should withstand bending cycles from 200 servicing missions. To achieve this flexibility, the OMSS cabling configuration differs slightly from the scheme developed in the orbital spacecraft consumables resupply system (OSCRS) study. The OSCRS configuration included approximately 90 wires bundled into three cables, providing redundant lines to 16 fluid valves, 12 temperature sensors, and 12 pressure sensors; along with three redundant power lines and three single returns. Devices that multiplex signals and data may be incorporated into the OMSS system to reduce the number of wires. This approach requires additional mass and volume on the spacecraft for the devices to decode/encode the data being transmitted. OSCRS chose to accept increased cable diameter and stiffness over the spacecraft mass and volume penalty (Ref. 3-14). However, the OMSS flexibility requirements favor signal and data multiplexing to reduce the number of wires required. Although the exact cable size has not been determined, two loose bundles of ten to fifteen wires each are expected to adequately meet cable requirements. The signal and data wires can be 22 gauge with individual shields and protective jackets. The requirements on the wires to transfer electrical power for heating are hard to estimate, but it should be possible to use a number of smaller, stranded wires, rather than a few large wires to keep the bundle flexible. It is also likely that the signal and data wiring will be bundled separately from the power wiring.

The management system that incorporates metal hoses and electrical cables must be addressed. Requirements for the hose and cable management system (H&CMS) are listed in B.1.10 of the appendices. A summary of the requirements includes the following:

1) Prevent hoses and electrical cables from tangling and abrading within the system;
2) Prevent hoses and cables from interfering with the servicer elements or spacecraft structures;
3) Assure hoses and cables are not overstressed or allowed to bend more tightly than the minimum bend radius;
4) Minimize the number of bends;
5) Minimize the total length of the H&CMS;
6) Maximize the working envelope for the servicer mechanism;
7) H&CMS deployment motion compatible with the servicer mechanism range of motion;
8) H&CMS stored entirely within the stowage rack;
9) H&CMS design simple and reliable.

The H&CMS consists primarily of a hose and cable carrier that contains as many as four propellant hoses and two electrical cables. The carrier design allows bending in one plane only, with a minimum bend radius no smaller than any of the hose or cable bend radii, assuring that hoses and cables are not overstressed. Figure 7.1-3 illustrates the H&CMS in its stowed position. A single larger loop provides two dimensional motion in the H&CMS plane. The end effector attaches to the fluid resupply interface unit (FRIU), and the servicer mechanism flips the FRIU 180 degrees to achieve the desired FRIU attitude (normal to the docking face of the spacecraft). Bending out of the stowed H&CMS plane is provided by free pivots at the base of the H&CMS, and controlled by the position of the end effector/FRIU. As the H&CMS plane is tilted, the FRIU attitude moves away from its position normal to the spacecraft. The FRIU attitude is readjusted with a free pivot at the FRIU. The FRIU is oriented to match the alignment of the spacecraft interface by a rotation device within the FRIU. The H&CMS configuration provides motion with six-degrees-of-freedom.

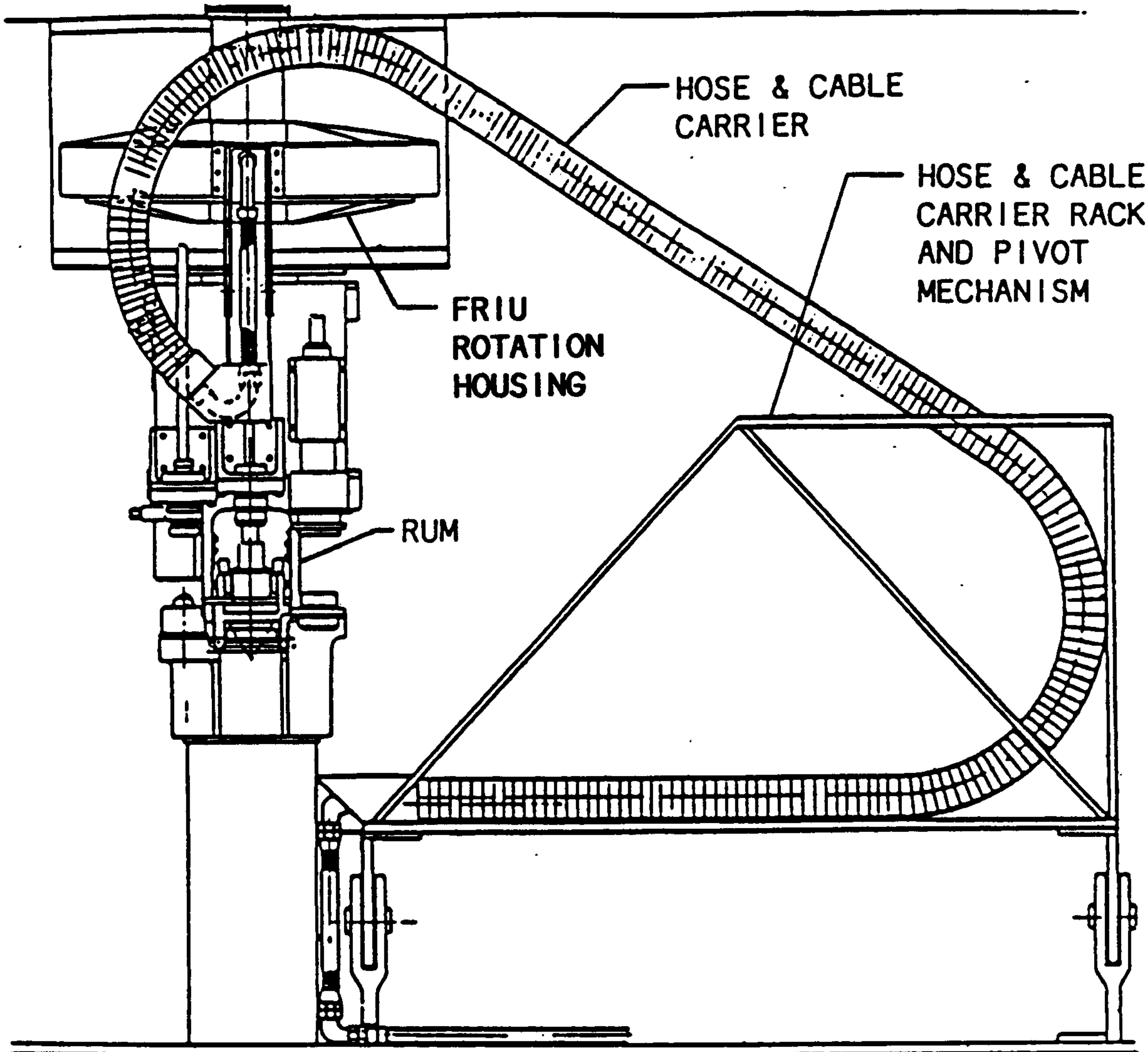

Figure 7.1-3 H&CMS Stowed Configuration

Hoses and cables may be jacketed with Teflon to minimize the friction that might cause entanglement and abrasion. The H&CMS length, as well as the range of interference with servicer and spacecraft structures, is minimized. The number of H&CMS bends is the fewest required to achieve six degrees-of-freedom. The system design is simple and reliable, as the H&CMS is free to move while driven by the motion of the servicer mechanism end effector. Because the system is controlled within the basic H&CMS plane, restowage of the H&CMS is a simple process. When the servicer mechanism end effector returns the FRIU to its stowed position, the H&CMS is automatically restowed.

7.2 FLUID RESUPPLY INTERFACE UNIT

The fluid resupply interface unit was defined in Section 5.0. The types of fluid disconnects, and the device that controls the mate and demate process with the spacecraft, are addressed in this section to provide greater detail of the FRIU conceptual design. First, candidate disconnects are examined. Second, the incorporation of the disconnects in the mate/demate device is detailed.

The examination of candidate disconnects began with a review of fluid disconnect requirements. Two types of disconnects are required; a 3/4 in. liquid disconnect for propellants (NTO, MMH, N_2H_4) and a 1/4 in. gas disconnect for pressurants (GN_2 and GHe). No fluid disconnects that meet OMSS requirements are currently available. Therefore, the development of candidate disconnects must be pursued as the OMSS design matures.

The requirements for fluid disconnects are listed in B.1.11 of Appendix B. Several requirements are common to both propellant and pressurant disconnects. Both disconnects are required to incorporate three inhibits to limit external leakage. The leak rate shall be less than 10 cc/hr when tested at 0-400 psi with GN_2, for mated or demated configurations. The mate/demate stroke must be less than 3 in. The allowable lateral offset is 1/16 in., and allowable misalignment is less than $\pm$ 5 deg. Disconnects must withstand operating pressures of 150 psi for MMH and NTO, 500 psi for N_2H_4, and 4500 psi for pressurants GN_2 and GHe. Requirements that apply only to liquid disconnects include a flow rate of at least 100 lbs/min and a pressure drop less than 50 psi at the rated flow. Table 7.2-1 lists the requirements for and current information on candidate disconnects.

Table 7.2-1 Fluid Disconnect Parameters

Parameter	Requirement	Fairchild NASA #76300002	Fairchild OMV #87352004	Moog RSO 50E560
- Space Rated	Yes	Yes		No
- Remotely Actuated	Yes	Yes	Yes	Yes
Mate/Demate Stroke (< 3 in. translate)	< 3in.			1.8 in.
- Resupply Cycle				
Servicer Side	300 cycles			1000 cycles
S/C Side	25 cycles			1000 cycles
- Misalignments				
Angular	± 5°	± 5°	± 3°	
Lateral	.0625 in.	.06 in.	.062 in.	
Axial	--	--	.062 in.	
- Flow Rates Mono & Biprop	≥ 100 lb/min	78 lb/min		100 lb/min (H_2O)
- ΔP	< 50 psid	25 psid		0.75 psid
- GN2/GHe Pressure	4500 psi	N/A	N/A	
- BIPROP Pressure	150 psi	300 psi	N/A	620 psi
- MONOP Pressure	500 psi	N/A		620 psi
- Verify Leak Integrity Prior to Demate	Yes			Yes
- External Leak Inhibits	3	< 3		3 when connected
- Leak Rate @ 0-400 psi GN2	10 cc/hr	.4 cc/hr	.6 cc/hr	$4x10^{-5}$ cc/hr GHe @ 620 psi
- Line Size PROP.	3/4 in.	1/2 in.	3/4 in.	
PRESS.	1/4 in.	N/A	N/A	
Dev. Stage I Designed, II Built, III Tested	–	III		III
Separation Force/Capture Force		400 lbf		20 lbf
Interface Volume		.14 cm^3		
Construction		INCONEL		ALUMINUM or CRES
Spillage Volume				.07 cm^3

A search for candidate disconnects was initiated with the examination of the spacecraft platform expendables resupply concept (SPERC) and OSCRS reports. These reports generally focussed on two disconnects; Fairchild's gamma ray observatory (GRO) and Moog's RSO (rotary shut-off). The GRO type connector designed by Fairchild Control Systems Company was designed for extravehicular activity (EVA) use, and requires a rotation of the Type I half of the connector in order to complete the coupling sequence (Ref. 3-14). This type of motion is not compatible with the FRIU design, which mates as many as four disconnects in a single translation motion. Also, the protective caps that cover the GRO coupling halves are not readily removed in an automated scheme.

Previous IOSS studies refer to a fluid disconnect designed by Fairchild Stratos for NASA, shown in Figure 7.2-1 (Ref. 3-1). Its features include an external swivel with semi-balanced sleeve/poppet that provides relatively low pressure-induced separation forces (approximately 1/3 standard unbalanced design), only one close tolerance sealing diameter, relatively short engagement, and reasonably low interface volume. Correspondence with Fairchild's Engineering Project Manager, Mr. W. E. Stalnecker, indicated that this disconnect was originally designed for transfer of hypergolic propellants at low pressure through 1/2 in. lines (Ref. 7-3). Mr. Stalnecker also indicated that the unit could be redesigned to meet 3/4 in. bipropellant and 1/4 in. pressurant requirements; although the pressurant redesign would be slightly more involved. Additionally, he noted that a 3/4 in. hydrazine disconnect is being developed by Fairchild in conjunction with the OMV. This disconnect is a push-pull, sleeve poppet design with a self-aligning swivel joint capable of handling $\pm$ 3 deg angular, $\pm$0.062 in. lateral, and $\pm$0.062 in. axial misalignments. These data are summarized in Table 7.2-1.

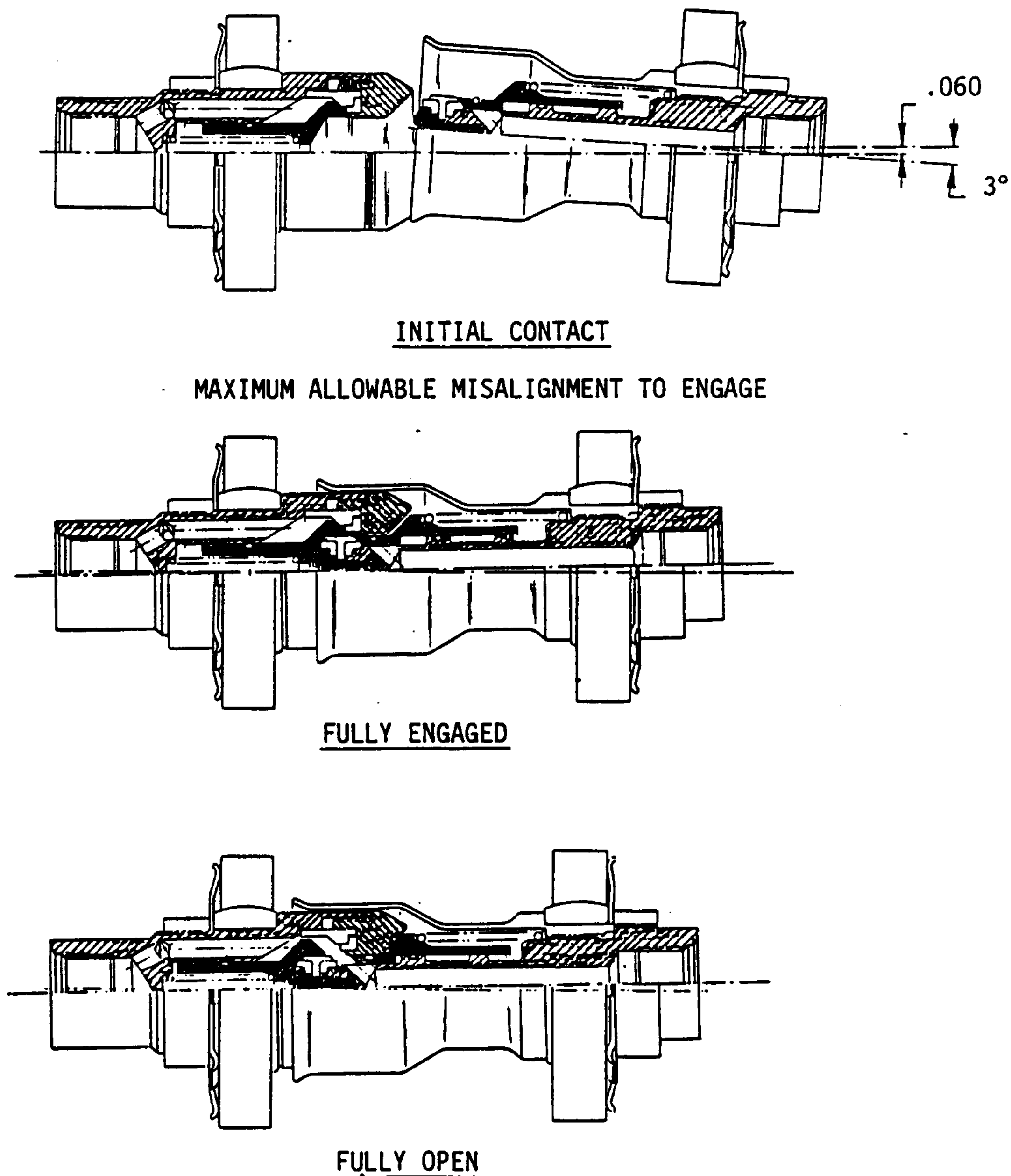

Figure 7.2-1 Fairchild Stratos NASA Disconnect (P/N 76300002)

The other type of disconnect that was researched is designed by Moog, Inc. (Ref. 7-4). Moog's RSO disconnect design is the product of a two year IR&D effort. This design has the main advantage of straight line flow, yielding a pressure drop that is nearly zero. A second feature that is being incorporated into the design is a vent/purge port that extracts any fluid in the interface prior to disconnect. This port also serves as a leak check, by testing interface seals with pressurant gas prior to the final mating and subsequent transfer of propellants through the interface. The RSO disconnect uses spherical valves that rotate when engaged, and create a straight path for fluid flow. Model 50E565 includes vent/purge ports, and is illustrated in Figure 7.2-2. Data for Model 50E560 (without vent/purge ports) are shown in Table 7.2-1. Although, the RSO line of disconnects is not currently space rated, Moog is working with NASA in an effort to achieve the space rating. Moog is also developing a 3/4" disconnect in conjunction with the OMV, although no specific information about its design was located.

The selection of fluid disconnects will be determined during later stages of the OMSS development. The information that has been collected on potential candidates shows that, although no satisfactory disconnect currently exists, development work is being pursued to meet OMSS requirements.

Electrical connectors were also investigated. Connector requirements include the following:

1) Scoop proof to avoid the possibility of jamming and/or short circuiting;
2) Push-pull coupling;
3) Mate/demate stroke length less than 2 in.;
4) Size compatible with FRIU;
5) Withstand 300 resupply cycles for servicer half, and 25 cycles for spacecraft half.

Based on the requirements, the G&H Technology connectors that OSCRS selected are not feasible for the OMSS application (Ref. 7-5). The 90 deg rotation used to secure connector halves is incompatible with the recommended FRIU design. Deutsch Company push-pull connectors were also examined. Deutsch connectors are FRIU compatible and show promise

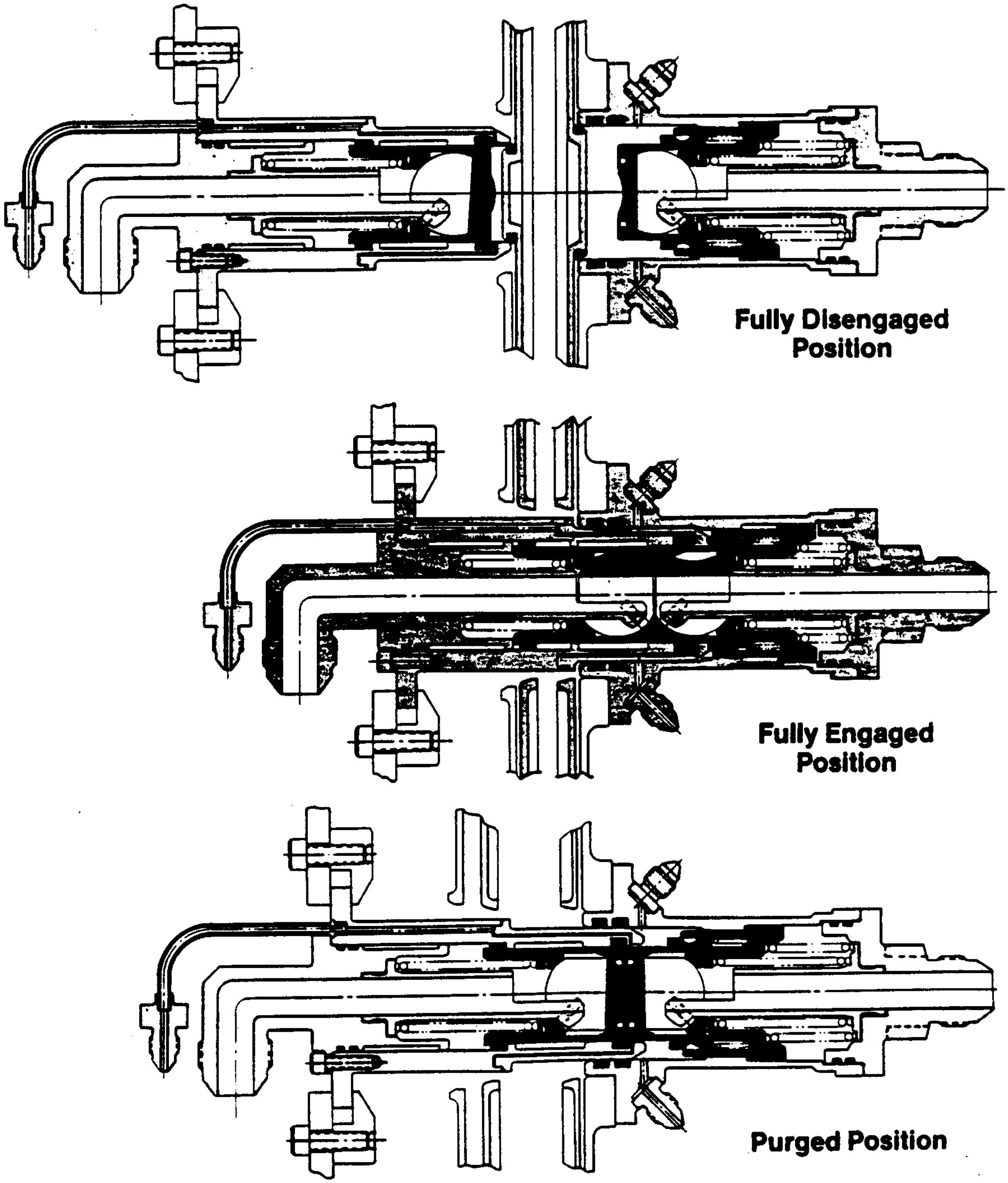

Figure 7.2-2 Moog Model 50E565 RSO Disconnect

for the OMSS application (Ref. 7-6). Final connector selection will depend on the final cable configuration (wire gauge and quantity) to be determined in future OMSS design efforts.

The fluid and electrical disconnects are incorporated into a device that provides the translation motion for disconnect mate and demate with the spacecraft fluid interface. This device, called the remote umbilical mechanism (RUM), is shown in Figure 7.2-3. The RUM was designed, built and tested by Martin Marietta, and provides automated mate/demate for fluid and electrical connectors (Ref. 3-9, and also see Fig. 1.5-8). It is part of the space station advanced development program and was developed for shuttle cargo bay operations in which a satellite is retrieved by the remote manipulator system (RMS) and latched into the cargo bay on the GSFC support ring (part of the multi-mission modular spacecraft (MMS) flight support system). The system has two main active functions: 1) latch to the satellite receptacle assembly to provide final umbilical alignment and latching, and 2) translate umbilical connectors on the servicing side to engage the receptacles on the satellite side for electrical, gas, and liquid circuits.

The system was designed to accept the type of connectors necessary for a particular mission. Figure 7.2-3 shows the non-flight hardware configuration that has been tested at Martin Marietta. The gas and liquid connections are poppeted, no-spill Fairchild units identical to those used between the lunar excursion module (LEM) ascent and descent stages during the lunar landings. The electrical connectors are sixty pin Deutsch rack and panel connectors. There are dual units mounted for redundancy.

In operation, the latch/translation assembly is fixed to the GSFC ring or similar berthing device. As the satellite to be serviced is positioned and latched in place, the latching mechanism cone engages the cone receptacle on the reception assembly. The alignment mechanism on the receptacle assembly, being a six degree of freedom device, allows the receptacle assembly to move into place. This freedom of movement allows for a sizeable servicer to spacecraft mismatch, both linearly and angularly. Prior to the latching operation, considerable angular and linear misalignment remains. Remaining misalignment is removed and solid latching is achieved as the latches close. The

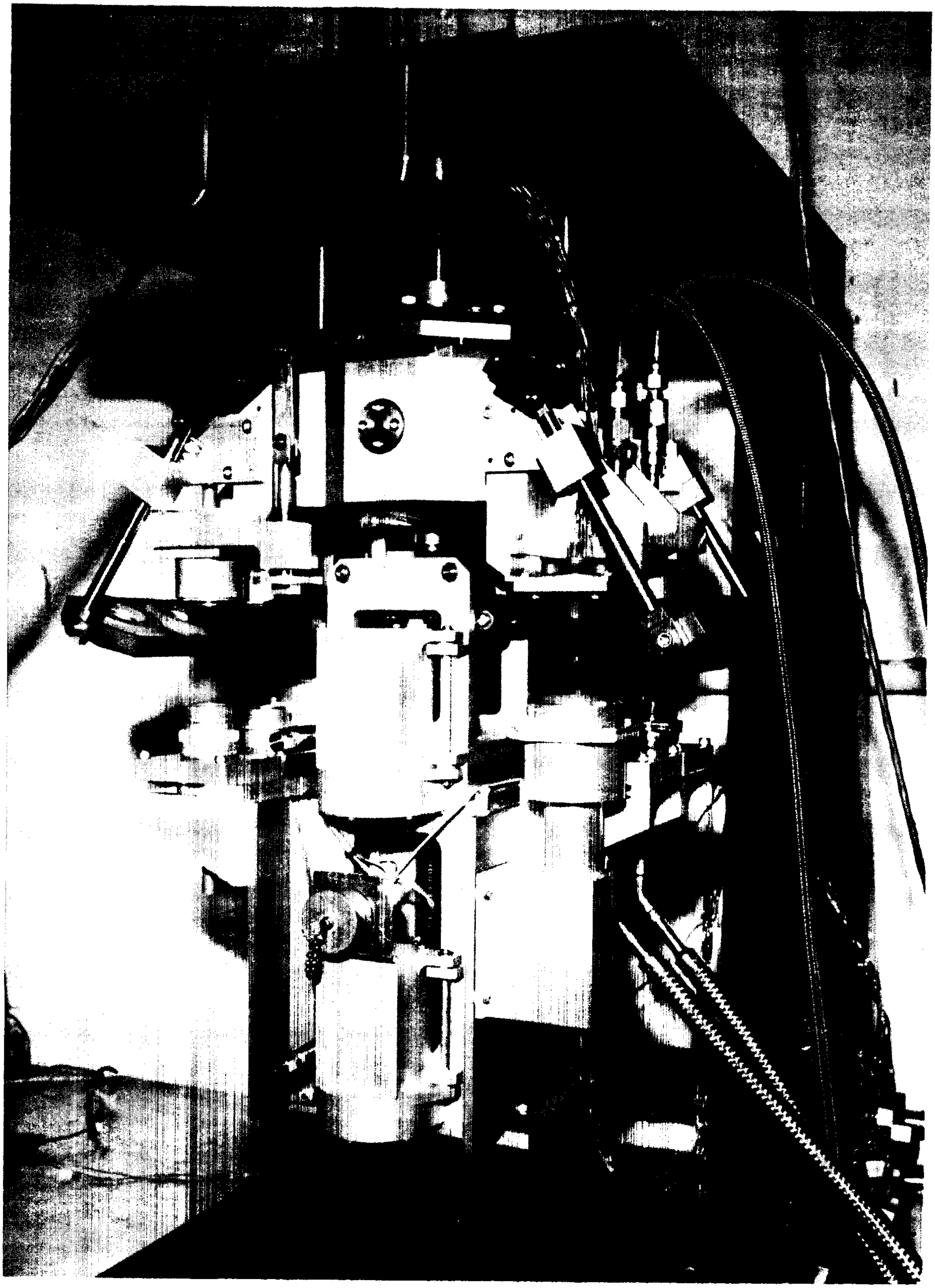

Figure 7.2-3 Remote Umbilical Mechanism

alignment receptacle is rectangular in shape, and forces the mating assemblies into final alignment.

As the latches are closing, the dust cover actuation pads contact the dust cover push pads which automatically retract the dust covers out and up, opening the way for connector translation and engagement. The device is partially translated until an electrical connection is established. Sensors relay interface status through the connection to the IOSS avionics. After verification of positive interface status, the translation continues until the fluid disconnects are mated. Table 7.2-2 summarizes RUM operations and capabilities.

Table 7.2-2 Remote Umbilical Mechanism

Parameters		Remote Umbilical Mechanism (MMAG)
Weight*		Servicer Side 15 lbs Spacecraft Side 7 lbs
Alignment Capabilities	Axial	0.625 in.
	Lateral	0.875 in.
	Angular	5.0 deg
	Rotary	15.0 deg
No. of Connectors		6
Contamination Covers on Connectors		Yes on P/L Side Only
Manual or Robot Operated Override		Yes
Individual Connector Misalignment		Yes
Motor Type		28 v dc gear motor
Power Requirements		14.4 watts nominal
Time of Operation		15 sec latch up 15 sec translation
Ability to mate electrical connectors for system checkout prior to mating fluid connectors		Yes

*Weights are an approximation of current test hardware with potential for one-half reduction in weights for flight hardware.

Although the RUM was designed for use at the orbiter, it can be readily incorporated into the OMSS design for in-situ spacecraft servicing. As part of the FRIU, the RUM satisfies the following requirements:

1) Positive mechanical attachment of the FRIU at the spacecraft interface;
2) Self alignment capability to allow for ± 3/4 in. lateral offset and ± 15° angular misalignment prior to attachment;
3) Minimizes risk of jamming disconnects during mate and failing to disengage under normal retraction forces;
4) Allows for intermediate stops during translation to verify status of fluid disconnect seals and for purging and venting operations;
5) Volume occupied by mate/demate mechanism less than 1 cubic ft of internal spacecraft volume.

The integration of the RUM into the FRIU is detailed in Section 8.0, Ground Demonstration Concepts.

8.0 GROUND DEMONSTRATION CONCEPTS

Ground demonstrations are an important element in the development of an operational onorbit spacecraft fluid resupply and ORU exchange system. A well designed and implemented ground demonstration program can reduce the overall program cost, by checking out solutions inexpensively before flight demonstrations are conducted. The ground demonstrations unit of the fluid resupply and ORU exchange system can also be used for operator training and problem solving for the flight demonstrations and after the servicer becomes operational. The existing servicer engineering test unit (ETU), that was delivered to NASA Marshall Space Flight Center under the integrated orbital servicing study (IOSS) contract, is well suited to being the basis for fluid resupply and ORU exchange ground demonstrations. It has been used for ground demonstrations of ORU exchange for a number of years and has a sophisticated capability for demonstration of these functions including a refined control system and ancillary equipment such as a lightweight module servicing tool.

The objective of this section of the report is to describe the thought process used to arrive at a recommended configuration of the engineering test unit with a set of equipment for demonstration of fluid resupply while maintaining the existing capability to demonstrate ORU exchange with the ETU. The fluid resupply equipment is to be representative of the flight design, be adaptable to the ETU, emphasize the umbilical connection and restow aspects, and be inexpensive to implement.

The recommended overall arrangement of the fluid resupply demonstration equipment in the ETU facility is shown in Figure 8.0-1. The existing spacecraft mockup, stowage rack mockup, and servicer mechanism with counterbalance are shown. The fluid resupply equipment would be mounted in a quadrant of the stowage rack not currently used by the ORUs, so the ORUs are deemphasized in the figure. The hose and cable management system (H&CMS) support structure is shown in the stowage

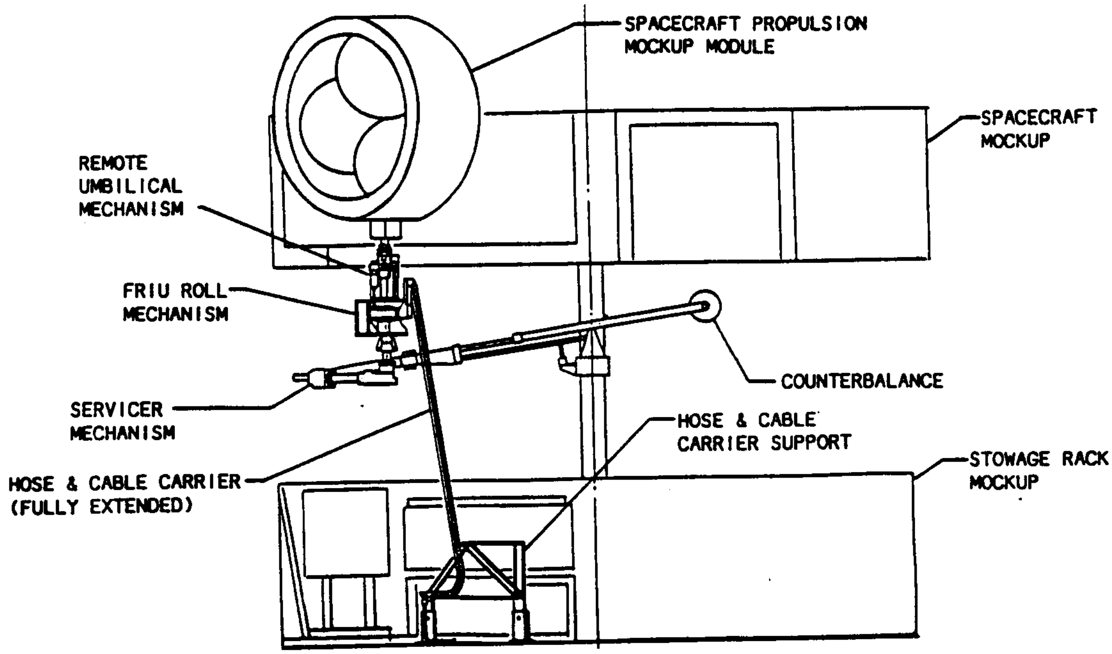

Figure 8.0-1 General Arrangement for Fluid Resupply Demonstrations

rack. The hose and cable carrier and the fluid resupply interface unit (FRIU) would also be positioned in the stowage rack between demonstrations. The FRIU, with its roll mechanism, is shown attached to the spacecraft, as would be the situation during fluid transfer. The cable carrier is shown fully extended to indicate that it will be almost straight in this condition. However, the actual bend in the cable carrier is not as sharp as indicated by the perspective of the figure, the bend will be more like that shown at the lower end of the cable carrier. A mockup of a spacecraft propulsion module is also indicated to help make the concept more realistic.

The total concept will need to include tanks in the stowage rack and in the spacecraft as well as a pump for transferring fluid to the spacecraft and a drain for returning the fluid to the stowage rack upon completion of the demonstration. A number of things such as the pumps and tanks have not been addressed in this conceptual design as they are felt to be fairly straightforward to design and their conceptualization would have taken away from the proper emphasis on the hose and cable management system and its interfaces with the ETU. Similarly, the control and monitoring functions for the fluid transfer, the method for draining the hoses before fluid disconnect demate, the sensors and electrical functions in the FRIU, the need for optical targets, software requirements, and EVA considerations have not been addressed. With regard to the fluid to be used, it should be non-toxic, non-flammable, colored for visibility, easy to handle, inexpensive, and easy to clean up any spills. Colored water would seem to be a good choice.

This report of the study effort starts with a recap of requirements for the flight and ground demonstration equipments. Next is a description of the characteristics of the two basic elements - the fluid resupply interface unit and the hose and cable carrier. This is followed by a review of alternative arrangements that Martin Marietta has conceptualized in the past. No attempt was made to conduct a trade study of candidate concepts, rather it was decided to examine what had been done in the past and then to build on those results. The recommended configuration is developed next in terms of general arrangement, derived characteristics, FRIU arrangements, H&CMS arrangement including the stowed configuration, and counterbalance considerations.

8.1 REQUIREMENTS

The requirements for the ground demonstration concept were taken from the requirements given in Appendix B, along with some that were derived as the recommended concept evolved. The requirements for the flight unit are addressed in the trade studies of Section 4.0, in the fluid resupply kit concepts of Section 5.0, and in the hose and cable discussions of Section 7.0. This section discusses the requirements for the flight unit first and follows those with requirements specific to the use of the engineering test unit for the ground demonstration of fluid resupply.

8.1.1 Flight Unit Requirements

The requirements for the flight version of the fluid resupply equipment are given in Appendix B, and Sections 5.0 and 7.0. Specific requirements that directly affect the identification of a ground demonstration concept for fluid resupply are discussed here. The servicer mechanism is used to position the fluid hose and cable management system so it does not need to be powered. The H&CMS must be flexible enough and have sufficient degrees of freedom to be easily positioned by the servicer mechanism over the desired range of positions.

The range of interface locations on the serviceable spacecraft was selected to be a segment of a quadrant on the lower surface of the spacecraft with the apex of the quadrant on the docking post centerline. The radial edges of the quadrant were to lie over the edges of the stowage rack quadrant containing the H&CMS. The minimum radius of the quadrant corresponds to the minimum reach of the servicer mechanism, or 26 in. The maximum radius of the quadrant corresponds to the outer radius of the spacecraft, or 90 in.

Requirements for the H&CMS flight unit are summarized in Section 7.1, and that summary is repeated here for convenience. The summarized requirements include:

1) The hoses and cables shall be constrained to prevent their tangling or abrading;
2) The hoses and cables shall be prevented from interfering with the servicer elements or the spacecraft or stowage rack structures;
3) The hoses and cables shall not be overstressed or allowed to bend more tightly than the minimum allowable bend radius;
4) The number of bends of the flexible hoses and cables shall be minimized;
5) The total length of the H&CMS shall be minimized;
6) The working envelope of the servicer mechanism shall not be reduced significantly;

7) The H&CMS deployment motion shall be compatible with the servicer mechanism range of motion;
8) The H&CMS shall be stored entirely within the spare ORU stowage rack;
9) The H&CMS design shall be simple and reliable.

Additionally, the H&CMS shall be designed for 200 missions. Each of these requirements can be translated into requirements for the ground demonstration equipment.

Requirements for the flight version of the fluid resupply interface unit are given in B.1.11 of Appendix B and are summarized in Section 7.2. That summary is not repeated here. Both electrical connectors and fluid disconnects must be mated and demated. Up to four fluid disconnects and two electrical connectors shall be operated by one FRIU. The active side of the fluid interface shall be on the H&CMS side while the passive side shall be on the serviceable spacecraft.

For the flight unit, the liquid hoses are expected to be the metal bellows type with a 3/4 in. nominal diameter. The 3/4 in. diameter metal bellows hose has a minimum bend radius of 8.0 in. The gas hoses are also expected to be the metal bellows type, but with a 1/4 in. nominal diameter. The electrical cable size is more difficult to estimate at this time, although two loose bundles of ten to fifteen wires each is reasonable. The signal and data wires can be 22 gauge with individual shields and protective jackets. The requirements on the wires to transfer electrical power for heating are hard to estimate, but it should be possible to use a number of smaller wires, rather than a few large wires to keep the bundle flexible. It is also likely that the signal and data wiring will be bundled separately from the power wiring.

8.1.2 Engineering Test Unit Requirements

The requirements for the ground demonstration of fluid resupply need not be as stringent as those for the flight unit in terms of number and sizes of hoses and cables. Also, the specific characteristics of the engineering test unit of the onorbit servicer need to be considered so as to minimize its modification.

Specific constraints of the ETU include its segment lengths, joint order, joint travel, and joint zero location. The torque and force capabilities for handling unbalanced moments and forces must also be addressed. In particular, the wrist pitch drive is limited to 50 ft lb of torque and the shoulder pitch, or elevation drive, is limited to handling weights at the wrist end effector of 30 lb. Also, it is desirable to not disturb the ability to demonstrate single and dual fastener ORU exchanges. The existing control system capability should be extended to include the fluid resupply demonstration requirements rather than devising a different approach. The FRIU shall be designed so it interfaces directly with the existing ETU end effector and to minimize obstructing the field of view of the existing TV camera and lights.

The fluid resupply interface location on the spacecraft mockup was taken to be anywhere within a 26 to 82 in. radius corresponding to the reach of the ETU. A 90 deg central angle range was selected to correspond to that selected for the flight unit. It is recommended that the eventual demonstrations use only one location within this range to minimize equipment costs. However, the ground demonstration equipment should be suitable for use over the full quadrant. The angle of the fluid resupply interface (clocking angle) with respect to the radius vector should be $\pm$ 90 deg to demonstrate that the spacecraft designer can be given this much freedom. The centerline of the fluid resupply interface receptacle on the spacecraft mockup should be parallel to the docking post to correspond to an axial motion of the servicer system. The elevation of the fluid resupply interface on the spacecraft should be even with the lower edge of the spacecraft, as is done with the other axially located ORUs.

The stowage rack mockup related requirements were addressed next. All parts of the H&CMS, except for the end effector attachment interface fitting, should be lower than the upper edge of the stowage rack to permit the demonstration of ORU exchange without any software changes. All parts of the H&CMS and any counterbalance system should be higher than the base of the stowage rack to simplify installation and maintenance, and to minimize any rework of the Robotics Laboratory floor.

The next set of requirements are for the hose and cable management system. The base of the H&CMS should be in a plane containing the docking post and midway between two ribs of the stowage rack as this is the arrangement selected for the flight unit. One electrical cable shall be used as one cable will be lighter and it can adequately represent the functions of the multiple cables that might be used in the flight unit. The cable will be a bundle of eight number 22 stranded and shielded wires in a loose sheath of vinyl tubing. This arrangement will provide an adequate number of wires while keeping the cable flexible and reducing loads on the ETU. The single hose will be a nominal 1/2 in. size, with an elastomeric lining, and will use standard flared fittings. The size was selected to reduce cost and its flexibility should reduce ETU loads.

The general appearance of the resulting demonstration equipment shall be such that it represents the flight version of the fluid resupply activity and so any artifacts of the demonstration, such as the counterbalance system, do not distract unduly from the overall representation. The demonstration equipment shall be designed for 400 demonstrations. The cable carrier size shall be selected so as to constrain the ground demonstration hoses to a bend radius comparable to that for the flight hoses, which is 8 in.

8.2 GROUND DEMONSTRATION ELEMENTS

The normal complement of equipment for the demonstration of ORU exchange includes: the servicer mechanism, the spacecraft mockup, the stowage rack mockup, the servicer servo drive console, a computer with software, several ORU mockups, the lightweight module servicing tool, a closed circuit TV system, and control and display equipment. To this must be added the equipment necessary to demonstrate fluid resupply. No attempt has been made to identify the fluid transfer equipment other than that involved in the H&CMS and in the fluid resupply interface unit as the other equipment such as tanks, pumps, hoses, fittings, valves, and even the control logic should be fairly straightforward to design.

The part of the FRIU designed to perform the required electrical connector and fluid disconnect coupling functions is the remote umbilical mechanism (RUM). The RUM was designed a few years ago at Martin Marietta to do just the functions that we require. Two versions of the RUM have been built - one is powered electrically, and the other is powered pneumatically. The electrically powered version is preferred as it will be simpler to incorporate into the overall design. The design is shown in Figure 8.2-1. It incorporates the same mechanical interface as is used for the end effector of the ETU, which simplifies its use with the ETU. The RUM jaws are powered electrically

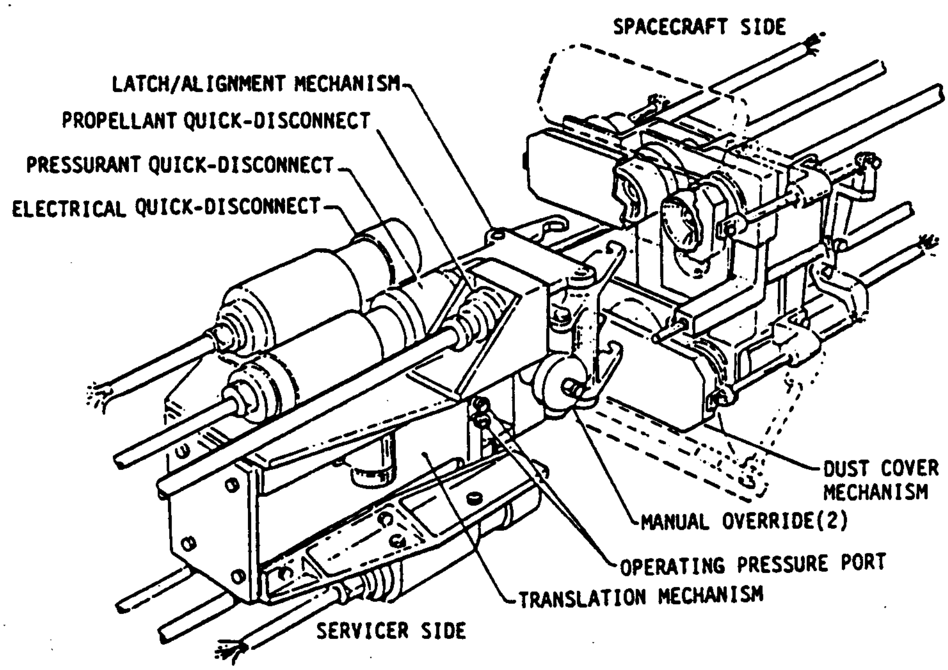

Figure 8.2-1 Remote Umbilical Mechanism

and grasp the same fitting as is used for the standard single fastener ORU. A full set of drawings of the Martin Marietta form of RUM are available and the device has been built and operated successfully.

The electrical connectors and the fluid disconnects are mounted on a pair of slides that move together. Any combination of up to six electrical and fluid connectors can be used. For the fluid resupply demonstration, it is recommended that one of each type of disconnect be used to minimize weight. The slides can be moved so as to make the electrical connection before the fluid connection and to break the fluid connection before the electrical connection. This feature can be used to verify the electrical connection before the fluid connection is made, and to verify the spacecraft fluid system after the fluid connection is broken. The RUM is relatively compact with a length of 15 in., and appears to weigh between 15 and 20 lb.

The cable carrier suggested in our earlier IR&D work still appears to be useful. It is a commercially available part (Figure 8.2-2) that is made in a variety of sizes, lengths, and materials. It has a generally rectangular cross section with rounded corners. The outer covering is loosely connected so that it can be bent back and forth. However, the version we intend to use has a metal strip fastened along one of the wide sides. Thus, the cable carrier can only be bent in one direction, it cannot be bent backwards, nor can it be bent from side to side. This property means that any hose inside the cable carrier cannot be bent and twisted at the same time, which is a restriction placed by the use of metal bellows hoses.

This cable carrier provides the interesting property of acting like an extendable link with pitch joints at either end. It provides three degrees of freedom for the H&CMS in a very simple package. The potential savings in weight and volume are significant. The extension and joint effects result because the radius of curvature of the cable

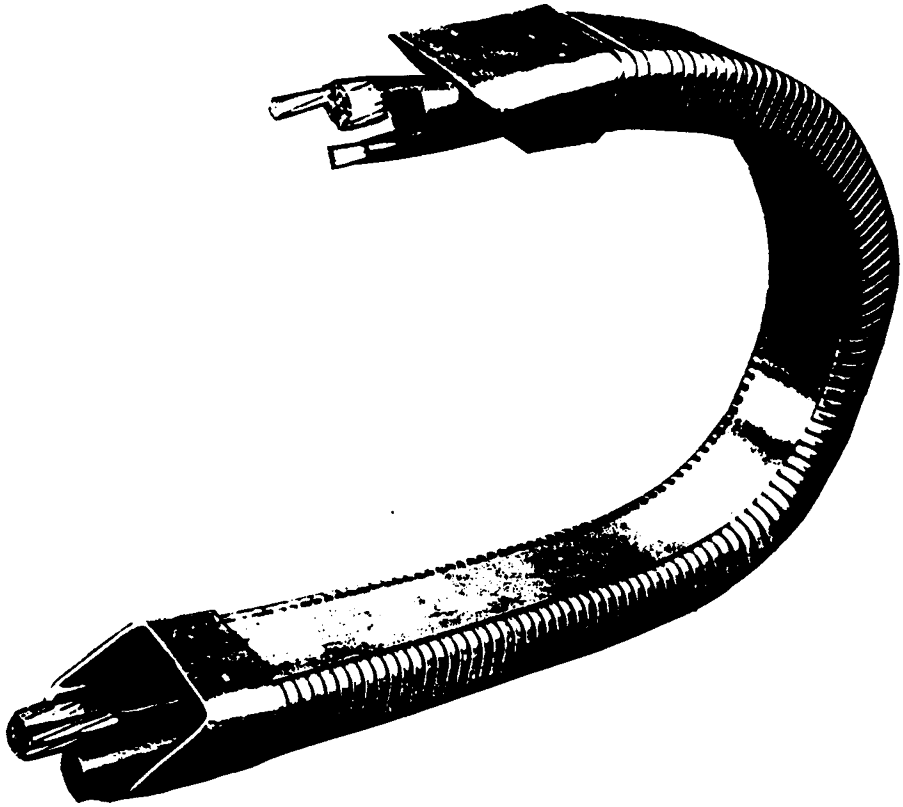

Figure 8.2-2 Selected Cable Carrier

carrier can be varied along its length and can be anywhere from a selected minimum to infinity (stretched out straight). The ground demonstration application involves a much greater length to width ratio than is shown in the figure. The bends will not use up as much of the overall length as is indicated in the figure. The cable carrier was selected to have a minimum radius of curvature suitable for a 3/4 in. metal bellows hose, which is the hose size selected for the flight unit. The ground demonstration cable carrier is representative of the flight unit in terms of minimum bend radius.

8.3 ALTERNATIVE ARRANGEMENTS

Rather than conduct a trade study on alternative arrangements, it was decided to use our experience to arrive at a recommended configuration. Several configurations had been investigated in the past and they are discussed here. One of those arrangements is shown in Figure 8.3-1. It was decided to use the cable carrier described in Section 8.2 because it was commercially available and one of the designers had successful experience with it. The constraints of the metal bellows hose were also used in developing the early concepts. In all cases, the H&CMS was mounted in the stowage rack, but it was mounted so that the plane of operation of the stowed cable carrier was parallel to one of the stowage rack ribs. This arrangement permitted use of the ETU wrist yaw drive to perform the flip maneuver. The ETU wrist yaw drive is stronger than the ETU pitch drive and can handle a greater degree of unbalance. Also, the flip was made to the inside, instead of the outside as is done for ORUs.

The H&CMS was unpowered in all of the arrangements, the ETU is used to move the FRIU. In all cases, the Martin Marietta form of the RUM was used in the FRIU for the reasons given in Section 8.2. A single location for the attachment point on the spacecraft was used that had been selected for demonstration suitability, and so it would not inhibit ORU exchange demonstrations. In all the alternative cases, the same joint arrangement was used for the H&CMS as shown in Figure 8.3-2. A yaw joint was used next to the FRIU, which allowed the plane of the cable carrier to tilt up to 35 deg on one side of the vertical. A linkage was used so that the hose was constrained to bend in only one plane. The next joint was equivalent to end effector roll and was accomplished by constraining the hoses with a set of links. The roll travel was $\pm$ 50 deg. A similar form of third joint was used to correspond to wrist pitch. The result was a fairly complex and bulky arrangement at the FRIU end of the H&CMS. The arrangement also offset the structure so that the H&CMS roll joint axis would be close to being colinear with the end effector roll joint axis. The configuration did attach the H&CMS to the fluid connector slides of the FRIU so that the slide motion would be taken up by an extension (uncurling) of the cable carrier. This design also limited the travel of the middle joint (see Section A-A of Figure 8.3-2) to well under $\pm$ 90 deg so there was no possibility of encountering gimbal lock.

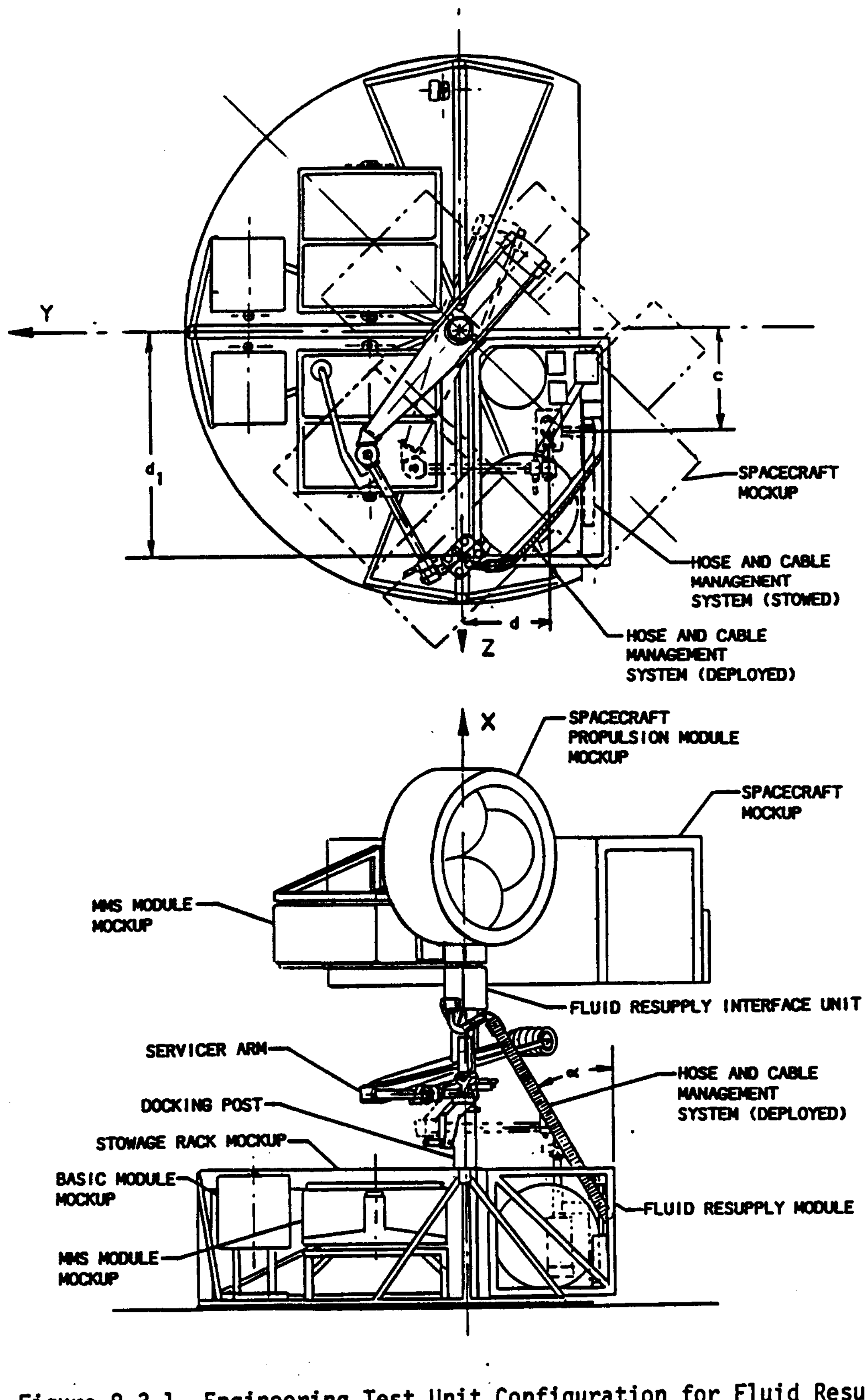

Figure 8.3-1 Engineering Test Unit Configuration for Fluid Resupply Demonstrations

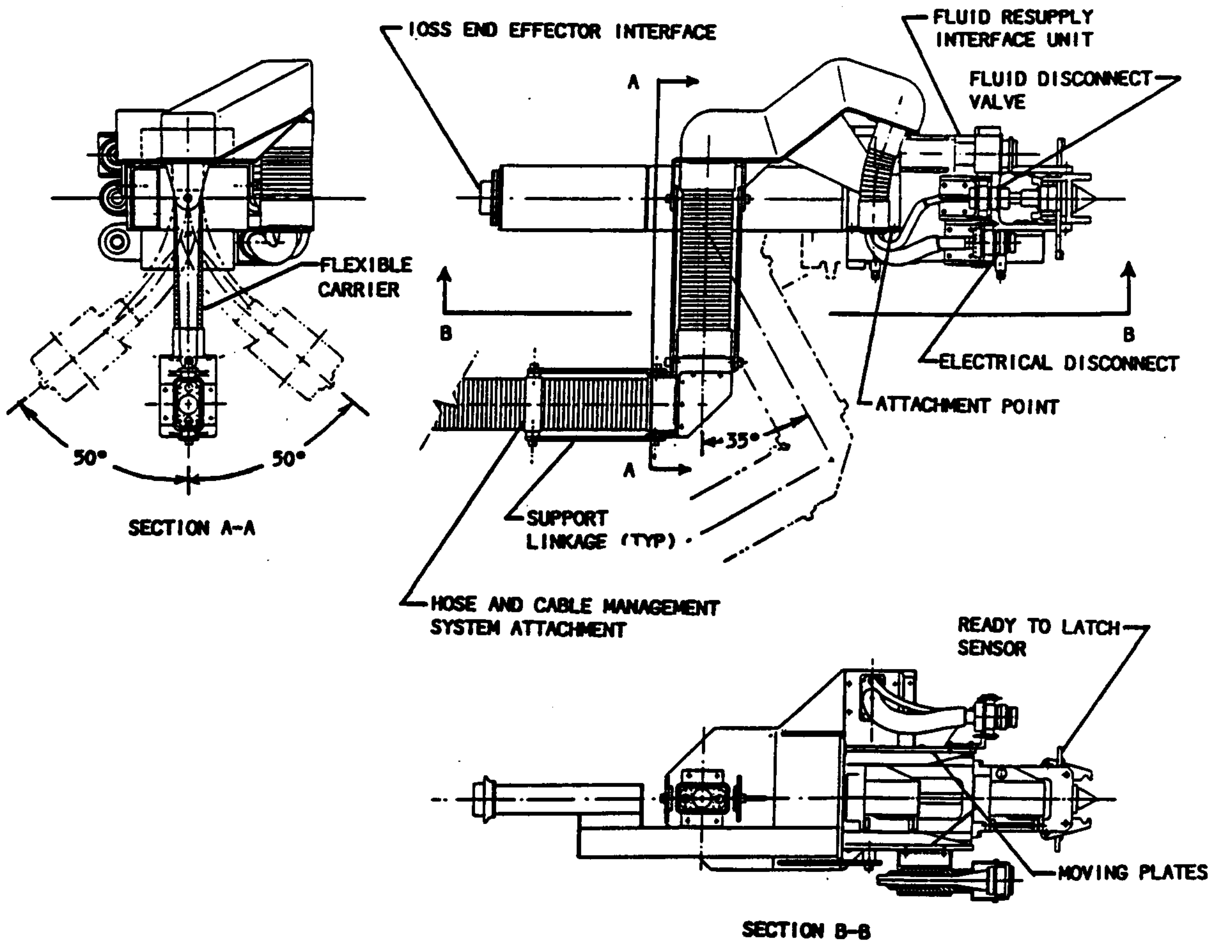

Figure 8.3-2 Hose and Cable Connections to the Fluid Resupply Interface Unit

Four counterbalance concepts were considered. The first (Figure 8.3-3) used a wire rope attached to the FRIU that passed through the mating fitting at the spacecraft. The wire rope could then be passed over a set of pulleys and attached to a counterweight. A major disadvantage is that it would appear that the wire rope was doing the guiding. While a variable counterbalance force could be provided by using links and variable diameter drums, there was no easy way to reconfigure the system if it was desired to relocate the system elements.

The second counterbalance approach was to apply tension to a wire rope wrapped on the outer curvature of the cable carrier. The rope tension would tend to straighten out the curved cable carrier and thus lift up

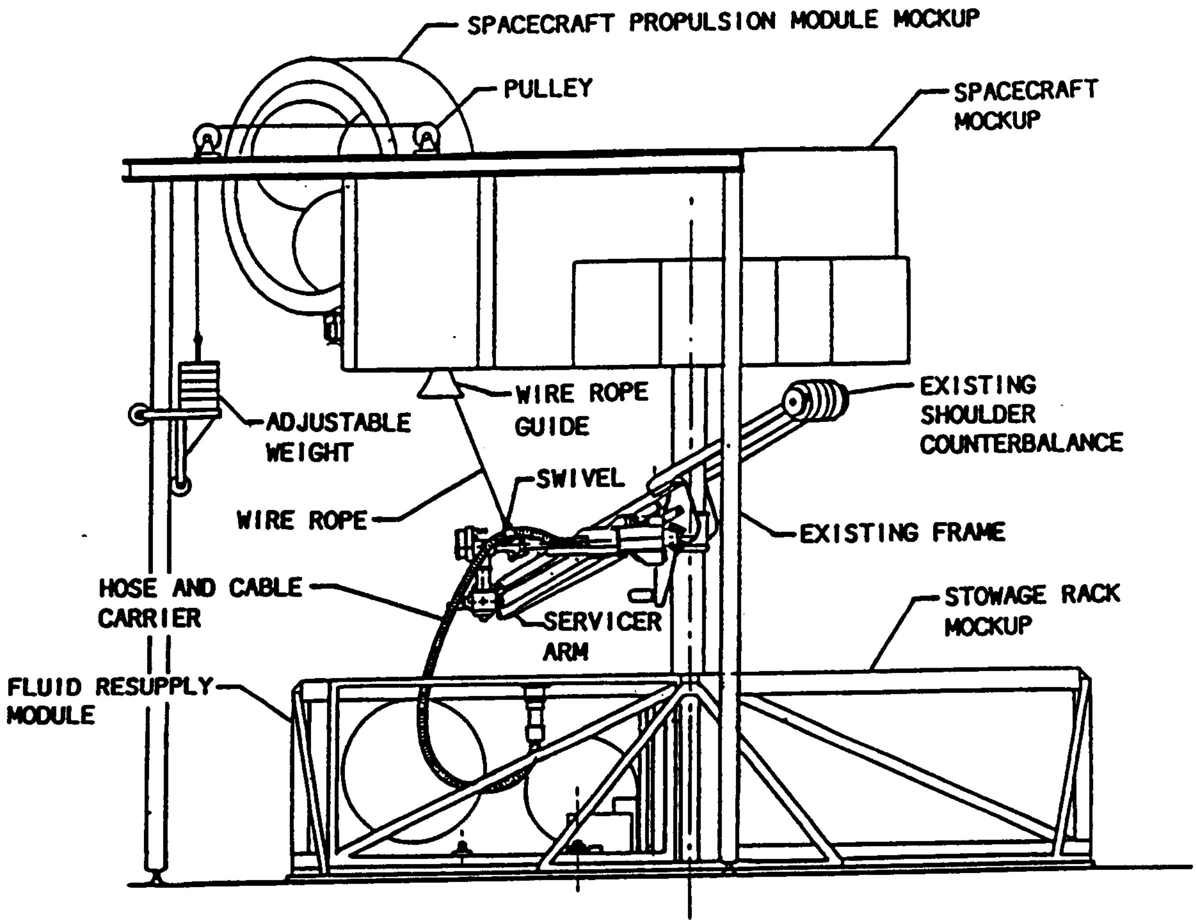

Figure 8.3-3 Wire Rope and Pulley Counterbalancing System

the FRIU. The effective lift goes to near zero as the FRIU approaches the spacecraft and becomes destabilizing for some FRIU positions. The concept requires a high wire rope tension even if the wire rope is spaced away from the cable carrier to obtain more leverage. Undesirable side forces are also exerted on the ETU.

The third approach involved the use of a pair of large pullies in the H&CMS. The cable carrier is wrapped around the two pullies in the stowed position. A wire rope is also wrapped around the two pullies, is fastened to the cable carrier at the cable carrier's lower end, and fastened to the stowage rack base at the cable's other end. The two pullies are also mounted in a sliding track arrangement that is counterbalanced. As the cable carrier is unwrapped, the counterbalance causes the two pullies to be raised, which causes the cable carrier to be raised. However, this arrangement of the counterbalance system was judged to be too complex and it also lacked flexibility in terms of the cable carrier configuration.

The fourth approach was simply a recognition that a powered system could be developed to position the elements of the H&CMS. The effect would be similar to constructing the equivalent of another ETU. This approach was also judged to be too complex.

One consideration that made these early counterbalance concepts difficult was a high estimate of the expected weight of the FRIU and of the hose guidance linkages near the FRIU. This was compounded by the need for a long extension to the FRIU so that the end effector would not interfere with the cable carrier. The combination of high weight and large moment arm implied the need for a counterweight attached to an extension of the FRIU near the end effector. It then turned out that a significant vertical force was necessary to overcome all of the weight.

Several other arrangements of the H&CMS were derived, including a scissors type linkage system in place of the cable carrier, but all of the arrangements were judged to be too complex and bulky. Most of the arrangements did include a H&CMS tilt axis located near the floor of the stowage rack. This feature permitted the FRIU end of the cable carrier to be moved out of the stowed plane of the cable carrier. It was decided to not use any of these early arrangements directly, but rather to derive a new arrangement that used some of the better features of the early concepts, and to attempt to find a lighter concept that would be easier to counterbalance.

8.4 RECOMMENDED CONFIGURATION

The recommended configuration was derived from the alternative arrangements discussed in Section 8.3, along with the experience of the analysts and designers. The Section 8.3 configurations identified a number of good features that were incorporated into the recommended configuration. There were a number of other concepts identified that indicated better solutions should be sought. The recommended configuration presents better ideas in these areas.

8.4.1 General Arrangement

Any discussion of the general arrangement should start with a consideration of the overall geometry of the mechanism - in this case with the geometry of the hose and cable management system. While it is not powered as a manipulator is, the H&CMS must have gimbals much like a manipulator does. It needs to have three translational degrees of freedom, and with the requirements that have been established, it also needs to have three rotational degrees of freedom at the fluid resupply interface unit end.

The selected form of cable carrier is interesting in that it acts like an extendable link with a pitch joint at either end. The recommended design capitalizes on this feature. It is only necessary to add a second joint at the base of the cable carrier to give the H&CMS the three translational degrees of freedom. This second joint is called the lower tilt axis. It is one of the good features from the Section 8.3 alternatives. The resulting arrangement is shown in Figure 8.4-1. The lower tilt axis is implemented with a pair of hinges. The cable carrier lower pitch axis is a property of the cable carrier, as is the equivalent link extension and the cable carrier upper pitch axis. An upper tilt axis is added at the FRIU attachment end of the cable carrier. This joint axis is kept parallel to the lower tilt axis by the properties of the cable carrier when the FRIU roll axis is parallel to the docking post. The FRIU roll axis was selected to be perpendicular to the upper tilt axis. The cable carrier upper pitch axis is also perpendicular to the upper tilt axis. As the upper tilt axis travel need be no greater than 45 deg, the cable carrier upper pitch axis and the FRIU roll axis can never be parallel to each other and the condition of singularity is avoided.

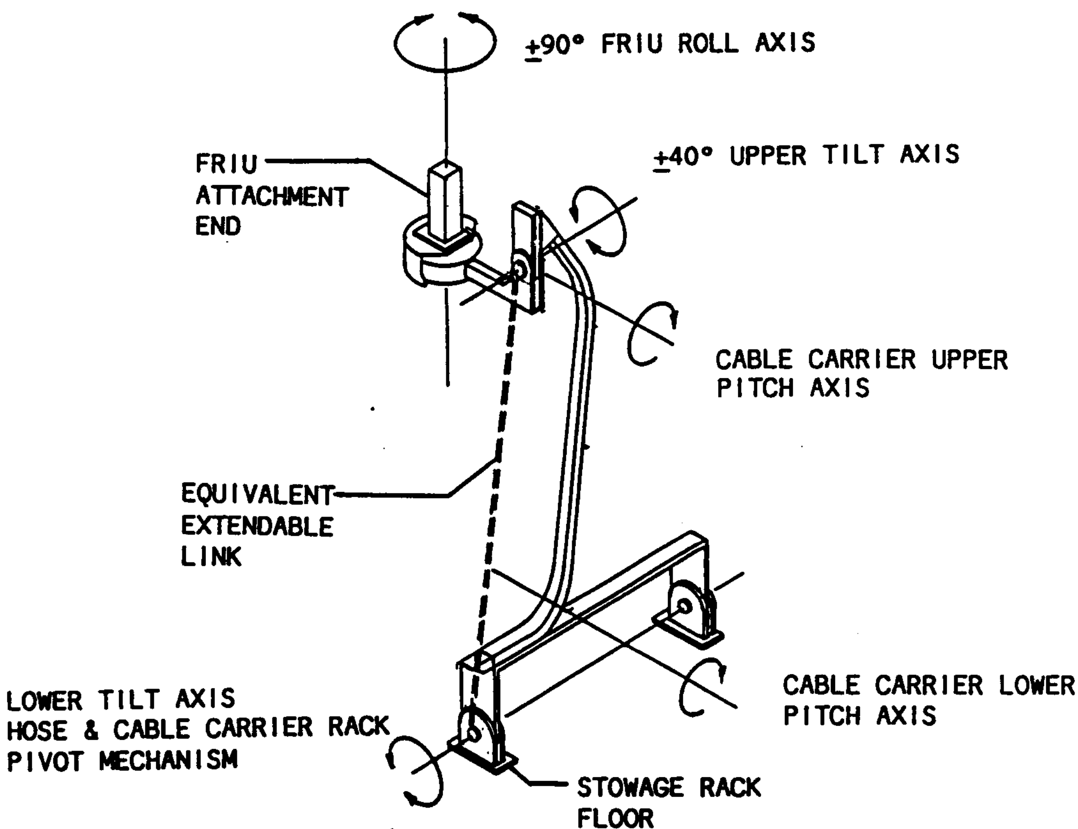

Figure 8.4-1 H&CMS Geometry

The selected order of gimbal axes is different from that used in the Section 8.3 alternatives. One result is a larger allowable travel of the FRIU roll axis. The ability to avoid a singularity at the FRIU end of the H&CMS is a second fortuitous result and it means that the designer has a greater freedom in where the flip position can be located with respect to the H&CMS stored location.

The length of the cable carrier and its angle of attachment at the FRIU end is addressed next. If the angle of attachment of the cable carrier is selected too small, then the cable carrier will be required to fold back on itself, which it cannot do. If this angle is selected to be too large, then the distance between the end effector and the FRIU becomes too large because it is desirable to keep the cable carrier below the top of the stowage rack when the H&CMS is stowed. The cable carrier length considerations are outlined in Figure 8.4-2.

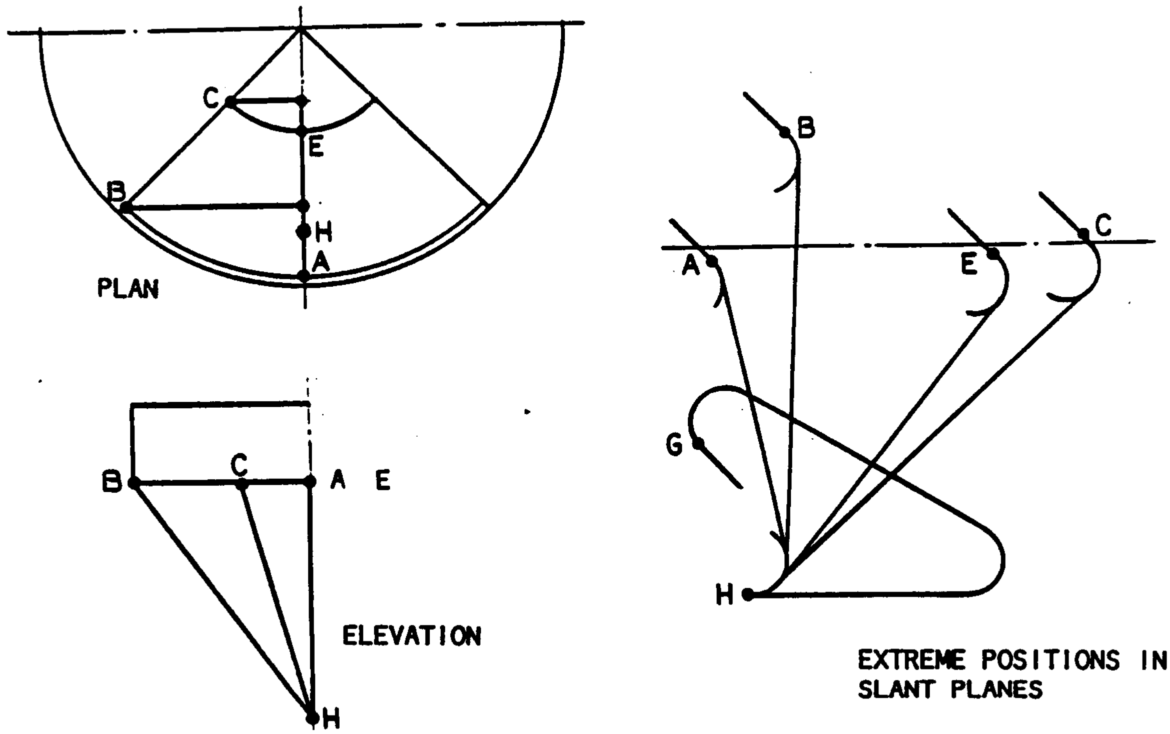

Figure 8.4-2 Cable Carrier Length Considerations

The FRIU extreme locations, for one half of its range, are shown in the plan view of the figure. The points A and E are directly above the H&CMS stowed location, while the B and C points are above the stowage rack rib at the extreme of central angle range for fluid resupply. A and B are at the outer radius, while C and E are at the minimum radius for fluid resupply to the spacecraft. The relative location of these points in a vertical plane, looking towards the docking post, is shown in the elevation view of the figure along with point H, which is the location of the lower end of the cable carrier. The third sketch shows the relative minimum lengths of the cable carrier for the four locations of the plan view. These lengths are shown in their respective slant planes to show true length. The circular arcs represent minimum bend radii.

The distance from H to B is the longest and set the length of the cable carrier at approximately 8 ft. The condition at point A has the minimum positive curvature of the cable carrier, especially when the full length of the cable carrier is considered, and it set the angle of attachment of the cable carrier to the FRIU at 45 deg as shown on the sketch. This attachment angle means that the cable carrier will not be required to fold back on itself.

8.4.2 Derived Characteristics

As part of the geometrical considerations, a number of derived characteristics were determined. The elevation sketch of Figure 8.4-2 was used to determine the range of travel of the lower tilt axis. It was found that ± 45 deg was adequate and should be easy to accomplish in the design. This value is also used for the upper tilt axis travel, as the upper axis need only compensate for the motion of the lower tilt axis. The FRIU limit directions are straight down for stowage, and straight up for fluid resupply to the spacecraft. Both of these directions are parallel to the docking post.

The shape of the cable carrier was also sketched out for the selected length for each of the cases shown in Figure 8.4-2. In each case, the length could be represented by a minimum bend radius shape near the FRIU, one, or two, straight lengths, and a second bend of greater than the minimum bend radius. This shape also applied to the stowed configuration. For each point, there was at least a slight positive wrap at the FRIU end.

As noted in Section 8.1, a FRIU roll range of ± 90 deg is required. The method of obtaining this travel using hoses constrained to the limits of metal bellows hoses is shown in Figure 8.4-3. The technique uses a pair of hoses that are fastened together at one end and that end is allowed to move, as shown in the left hand sketch of the figure. One of the other ends of the hoses, call it the upper end, can be moved along a circular arc (the radius of this circular arc is less than the

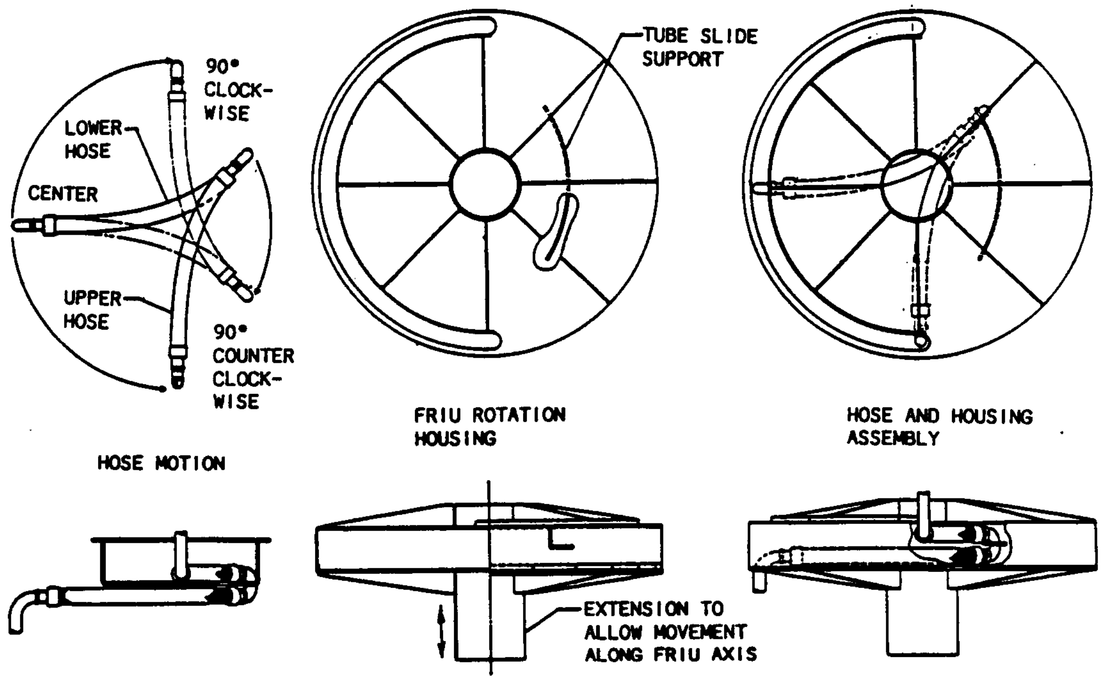

Figure 8.4-3 FRIU Roll Mechanism Elements

length of the hoses). The other end of the second hose, call it the lower end, is fixed so that it cannot move. The solid lines in the left hand sketch show a 90 deg counterclockwise position for the upper hose with the one end of the lower hose in the reference, or zero, position. Similarly, the phantom lines in the sketch show the upper hose in a 90 deg clockwise position. At the 0 deg position, the two hoses would lie on top of each other. At the extreme positions, each hose takes the form of a parabolic segment. The length of the hoses can be selected so that the minimum bending constraint of the hoses is not violated in the extreme positions.

The middle and right hand sketches of the figure show how a housing could be placed around the hoses so that a structural link between the ETU end effector and the FRIU could be obtained. The housing has been given an extension so that it can slide up and down with the slides on the FRIU that mate and demate the connectors. The effect of the connector motion is absorbed by the straightening/bending of the cable carrier. This approach avoids the need for a separate mechanism to allow for the connector sliding motion, and the approach was taken from the concepts discussed in Section 8.3.

An analysis was made to select a location for the flip motion. It was decided to use the usual 82 in. radius for the flip so that the maximum clearance from the spacecraft and stowage rack mockups could be obtained. The elevation will be at the mid-position between the spacecraft and stowage rack mockups, again to provide as much clearance as possible. Depending on the length of the FRIU and its standoff, it may be necessary to do part of the flip at one elevation and the rest at another elevation as is done for one of the Multi-Mission Modular Spacecraft ORU trajectories. It is preferred to perform the flip using the wrist pitch drive to kept the flip step the same as for the ORUs, even though the wrist pitch drive torque capability is marginal.

The selection of the 82 in. radius for the flip location means that the wrist pitch drive axis will not be perpendicular to the cable carrier plane. The axis will be 17 deg from perpendicular. If the perpendicular condition had been obtained, then the wrist pitch motion would have been accommodated entirely by the cable carrier unrolling (cable carrier pitch). With the 17 deg bias, the ETU end effector flip motion must be accommodated by all six degrees of freedom of the H&CMS, instead of just the three associated with the cable carrier. The two H&CMS tilt axes will tilt off to an angle just under 17 deg and then come back to the zero position at the end of the flip. The FRIU roll angle will increase steadily during the flip to a value just over twice the 17 deg. This angular travel can be readily accommodated with the angular travel selected for the H&CMS joints. The specific central angle value for the ETU end effector at the beginning of the flip can be determined during the final design.

8.4.3 Fluid Resupply Interface Unit Arrangement

A tangential view of the fluid resupply interface unit arrangement is shown in Figure 8.4-4. The right hand side of the figure shows the Martin Marietta form of remote umbilical mechanism, or RUM, discussed in Section 8.2. Attachment to the spacecraft, or to the stowage rack, is by the same jaw arrangement used on the ETU end effector. The ETU end effector attach fitting is used on the left hand end of the FRIU so it will be compatible with the ETU. While not shown, it may be that the ETU connector positioner will be used to provide the control and monitoring signals to the FRIU. An alternative is to use the cables passing through the H&CMS to provide these functions. A hose disconnect and a cable connector are shown on the facing side of the RUM, although only one or the other of these elements will be used on each side for the 1-g fluid resupply demonstrations.

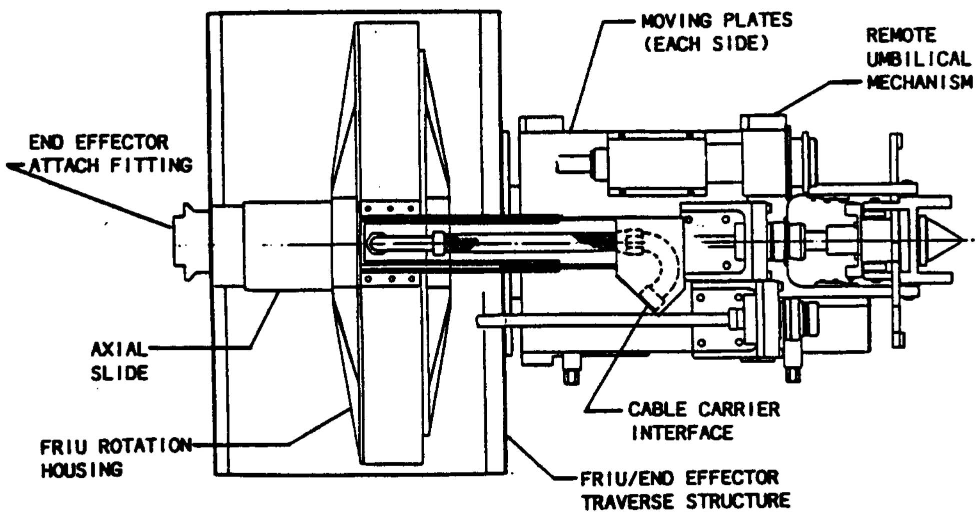

Figure 8.4-4 FRIU Arrangement - Tangential View

The hose and cable lines pass from the RUM through the transverse structure to the cutout in the FRIU rotation housing (see Figure 8.4-3). The hose and cable will likely be fastened together so that the hose can guide the cable during the rotations of the FRIU. The hose and cable exit from the side of the FRIU rotation housing and then pass to the cable carrier interface. The cable carrier interface is at an angle of 45 deg to the FRIU centerline to avoid reverse bending of the cable carrier. The cable carrier interface was extended towards the RUM from the FRIU stationary housing, rather than towards the ETU end effector to minimize the need for an extension between the FRIU and the ETU end effector. The cable carrier can be bent 180 deg as it leaves the FRIU, when in the stowed position, and the cable carrier will not extend outside the stowage rack when the end effector attach fitting is just above the top of the stowage rack. This is the end effector attach fitting location for all of the ORUs in the stowage rack.

A radial view of the FRIU arrangement is shown in Figure 8.4-5. The elements in this figure are similar to those in the previous figure. The path of the fluid line from the disconnect to the FRIU roll mechanism can be easily seen. The electrical cable from the connector on the side opposite from the fluid line would be brought over to the fluid line and the two would be fastened together as they pass through the FRIU. A plate transition structure is shown connecting the FRIU

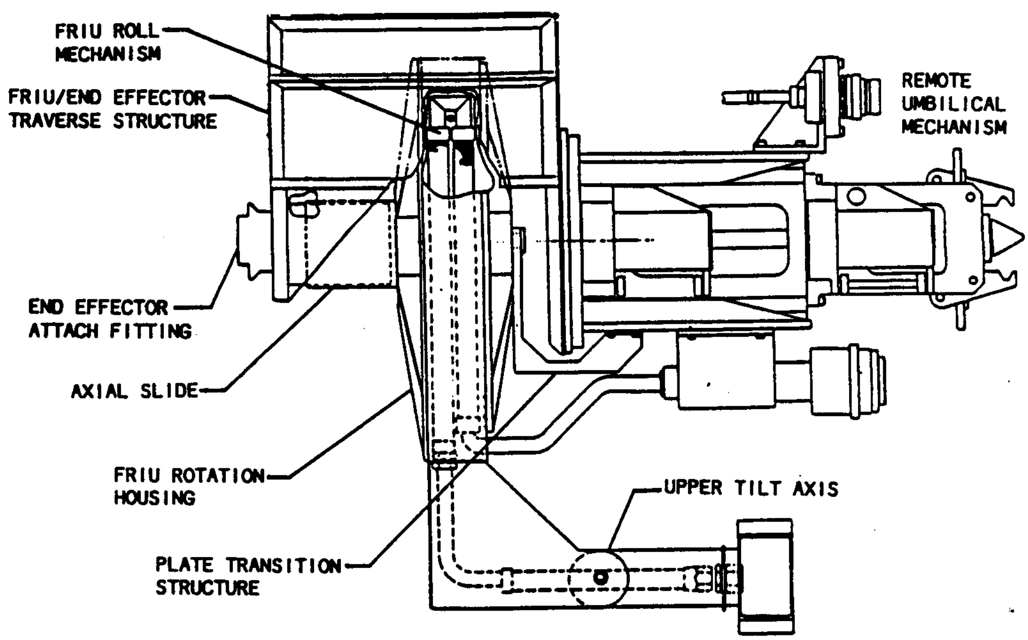

Figure 8.4-5 FRIU Arrangement - Radial View

rotation housing to the RUM sliding plate so that as the fluid connector is mated and demated, the plate transition structure will transfer the motion to the FRIU rotation housing and reduce potential loads on the fluid line. The H&CMS upper tilt axis is shown clearly in this figure. The upper tilt axis is set off from the FRIU centerline so that the 45 deg travel of the tilt axes can be accommodated. The axial slide that guides and stabilizes the FRIU rotation housing is shown to the left.

8.4.4 Hose and Cable Management System Arrangement

A plan view of the general arrangement of the ETU and fluid resupply equipment for the ground demonstration of fluid resupply is shown in Figure 8.4-6. An elevation view of the same equipment is shown in Figure 8.0-1. The existing active locations for the ORUs in the

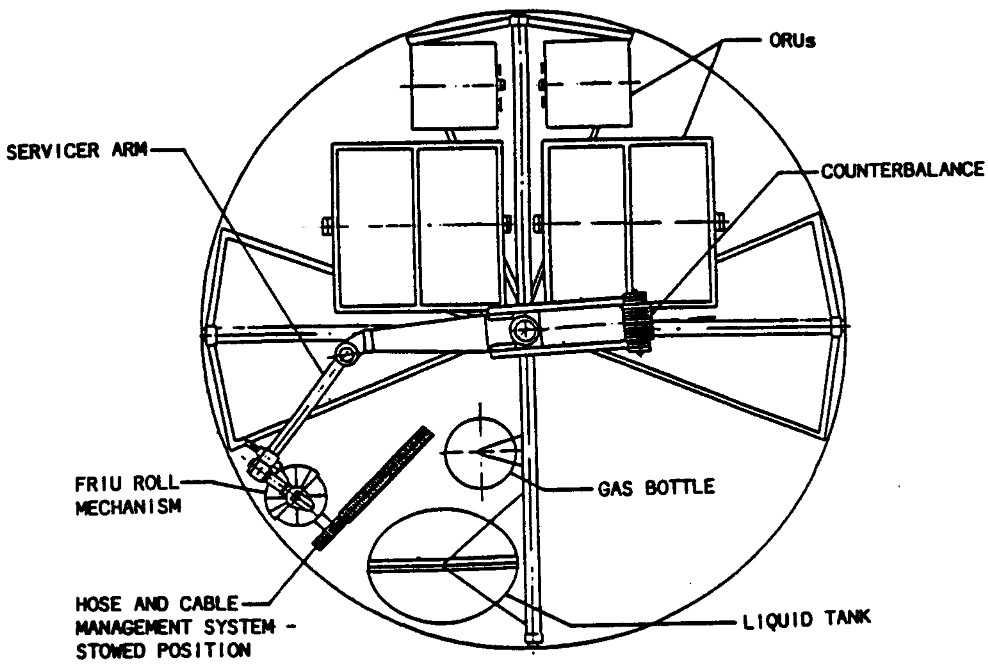

Figure 8.4-6 H&CMS General Arrangement - Plan View

stowage rack are shown in the figure. The quadrant shown for the location of the fluid resupply equipment is away from the usual viewing area, but it is the better of the two quadrants remaining. The left hand ORU quadrant, in front of the fluid resupply equipment, is used for temporary ORU stowage and would be empty during demonstrations of fluid resupply. The dummy ORUs currently located along one side of the fluid resupply quadrant could be left in place, or removed, depending on the effect desired.

The recommended location of the hose and cable management system is shown along with the location of the servicer mechanism at the point of picking up the FRIU from its stowed location. The FRIU is offset from the cable carrier to avoid interference between these two elements during the stow/unstow and flip operations. The offset also permitted the shortening of the distance between the FRIU and the ETU end effector as discussed in Section 8.4.3. Mockups of a liquid (propellant) tank and of a gas (pressurant) bottle are shown to the same sizes as are recommended for the flight system. Additional tank and bottle mockups could be used to obtain a better representation of the recommended flight concept, if desired.

An open area exists on the spacecraft mockup that is generally above the stowage rack rib in the left hand side of the figure. This location could be used for the fluid resupply interface on the spacecraft mockup. An alternative is to use the innermost axial ORU location on the spacecraft for the fluid resupply interface. The recommended concept can reach either location. A mockup of a fluid tank on the spacecraft could also add to the realism. It is not recommended that either of the fluid tank mockups discussed should be the location of the tanks that would hold the fluid to be transferred. Filling, draining, visibility, and the effect of leaks and spills should be considered in determining the location of these active tanks.

The stowed configuration of the hose and cable management system is shown in Figure 8.4-7 in two views. The tangential view, on the right, shows the position taken by the cable carrier in the stowed position. The curve of the cable carrier near the FRIU has the allowable minimum bend radius as does the other curve. The intermediate segments are straight. The vertical upright on the right of the hose and cable carrier rack acts as a stop when the H&CMS is being removed from or placed into the hose and cable carrier rack. This rack has a space frame outline so that the cable carrier will tilt the rack and thus bend the hose that connects from the cable carrier to the base of the ORU stowage rack. The placement and sizing of the pivots is such that the short length of hose will not be bent at less than its minimum allowable bending radius. For a flight unit, the hose and cable carrier could be stabilized with a clamping arrangement during launch and reentry.

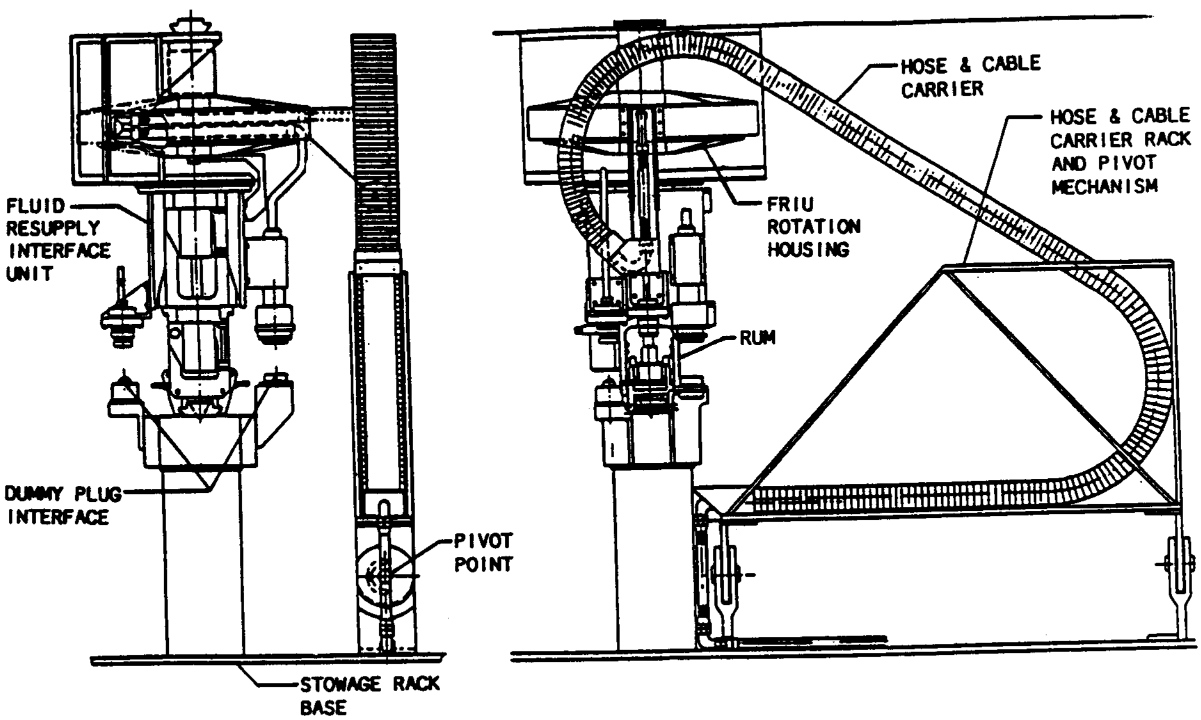

Figure 8.4-7 Hose and Cable Management System - Stowed Configuration

The FRIU rotation housing and the remote umbilical mechanism of the FRIU are shown in both views in the figure. The radial view of the stowed position is shown on the left hand side. The pivot point and short hose configuration is also shown in this tangential view. A slot and bolt is used in the pivot mechanism to provide limit stops at ± 45 deg. A dummy plug interface is shown as an attachment interface for the FRIU in the stowed position. Protective covers are not needed for the dummy plug interface as the connectors are only uncovered during the fluid transfer process. Covers may be needed during ground maintenance of the flight unit. The offset between the FRIU and the cable carrier can be seen along with the upper tilt pivot, which is in phantom behind the cable carrier. Extra fluid disconnects and electrical connectors are shown on the RUM, even though only one of each is recommended for the ground demonstration of fluid resupply. The electrical and fluid connectors shown would be connected in the stowed configuration.

8.4.5 Counterbalance Considerations

A number of methods for counterbalancing the fluid resupply equipment were considered, several of which are discussed in Section 8.3. Each of the early suggestions were brought up again in this study. None were found to be acceptable. It was strongly desired that the counterbalance not intrude too much on the overall appearance of the demonstration. It should also work over a wide range of FRIU positions - from the stowed position, through the flip, and to a range of positions at the spacecraft. The counterbalance system should not be tailored to operate over just one trajectory. It was the range of FRIU positions, when combined with the variable weight as the cable carrier unrolled from its support on the cable carrier rack, that made a good counterbalance system, associated only with the fluid resupply equipment, difficult to design. The early analyses had also considered a heavy FRIU, a heavy cable carrier with its hoses and cables, and a long standoff between the FRIU and the ETU end effector. Each of these aspects have been eased with the current design.

While Martin Marietta built two versions of the RUM, apparently it was not weighed. We were unable to located the RUM and weigh it. However, an examination of the drawings indicates that it might weigh less than 20 lb with only one fluid disconnect and one electrical connector mounted on it. It might also be possible to reduce its weight by cutting out any excess material. It is estimated that the FRIU rotation mechanism would weigh less than 10 lb and the weight contribution of the cable carrier with its electrical cable and empty hose would be less than 5 lb. These lighter weights make is possible to think about readjusting the ETU counterbalances so the ETU could handle the fluid resupply equipment directly.

A very preliminary analysis indicated that the fluid resupply equipment weight and moment arm are in excess of the capability of the ETU wrist pitch drive, which is used during the flip motion. A value of 50 ft lb has been used as the wrist pitch drive capability. If some sacrifice in speed is accepted, then this capability could be increased. It is also possible to put an extension on the FRIU, off to one side, so that it could be extended past the ETU wrist and a counterbalance placed on this extension. An alternative is to build an extension on the back of the ETU wrist with a counterbalance that would only be added for the fluid resupply demonstrations. The extent of the need and the validity of these potential solutions could be addressed during a detail design. It may also be possible to increase the wrist pitch drive capability by raising the servo drive amplifier capabilities.

The addition of the fluid resupply equipment, and any necessary wrist counterbalance weight, would increase the loads on the shoulder pitch drive. The shoulder pitch drive capability is taken to be $\pm$ 30 lb. The total increase in carried weight during a fluid resupply demonstration is very likely to exceed this capability. There are at least two possibilities. One is to add weight to the shoulder pitch counterbalance just during the fluid resupply demonstrations. The weight could be designed for easy addition or removal, and it would not need to be obvious. The effect of the added counterbalance weight would be a reduced ability to push down and an increased ability to lift up. A second approach would be to revise the shoulder pitch drive amplifier characteristics, especially the selection of output transistors, to pass more current though the motor. The electro-mechanical characteristics of this drive are much greater than the $\pm$ 30 lb capability used. The design was limited initially because of a potential overtemperature concern and because the 30 lb was adequate to handle the range of ORUs considered at the time.

It has not been possible to develop a firm recommendation for the counterbalance design as was done with the H&CMS conceptual design. Rather, the approach was to conceptualize a lightweight H&CMS and thereby reduce the demands on the counterbalance system. Also, a number of approaches to a counterbalance design have been evaluated, most of which have major disadvantages. However, the approach of reducing the weight of the fluid resupply equipment increases the likelihood that the ETU can handle this equipment directly with some modifications to the ETU counterbalances, philosophy of operation, and/or the servo amplifier design. The effectiveness of this approach must await a detail design.

APPENDIX A REFERENCE DOCUMENTS

No.	Title
2-1	Space Platform Expendables Resupply Concept Definition Study, STS 85-0174, Volumes I, II, and III, Rockwell International Corporation, Downey, CA, March 1985
2-2	Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Volume II, Study Results, MCR-86-1351, Martin Marietta Denver Aerospace, Denver, CO, March 1987
2-3	Proceedings of the Second Conference on Payload Interfaces, MDC G4818, McDonnell Douglas Astronautics Company, Huntington Beach, CA, September 6-7, 1973
2-4	Integrated Orbital Servicing System (IOSS) - Final Report, MCR-75-310, Martin Marietta Corporation, Denver, CO, September 1975
2-5	Integrated Orbital Servicing and Payloads Study, Final Report, COMSAT Laboratories, Clarksburg, MD, September 1975
2-6	Space Platform Expendables Resupply Concept Definition Study, STS 85-0174 Addendum, Rockwell International Corporation, Downey, CA, December 1985
3-1	Servicer System User's Guide, MCR-86-1339, Martin Marietta Denver Aerospace, Denver, CO, July 1986
3-2	On-Orbit Servicing, IR&D Task D-64S, S86-41564-001, Martin Marietta Denver Aerospace, Denver, CO, July 1986
3-3	Servicer System Demonstration Plan and Capability Development - Final Technical Report, MCR-85-1365, Martin Marietta Aerospace, Denver, CO, December 1985
3-4	Integrated Orbital Servicing Study Follow-on - Final Report, MCR-77-246, Martin Marietta Corporation, Denver, CO, April 1978
3-5	M. R. Morrison, "OMV - Springboard to Satellite Servicing" - Presented at Satellite Servicing Workshop III at GSFC, June 9-11, 1987
3-6	OMV Design Characteristics, Private Communication from J. R. Turner, MSFC, April 1987
3-7	User's Guide for Orbital Maneuvering Vehicle, NASA-MSFC, Marshall Space Flight Center, AL, December 1986
3-8	Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Requirements Definition Document, MCR-86-1323, Martin Marietta Denver Aerospace, Denver, CO, March 1986

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3-12 Monopropellant Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Preliminary End Item Specification, 339-SS-1000B, Fairchild Space Company, Germantown, MD, March 1987

3-13 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Final Report Volume II, 339-FR-1000A, Fairchild Space Company, Germantown, MD, March 1987

3-14 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Study Results, Monopropellant Preliminary Design Report, MCR-86-1333A, Martin Marietta Denver Aerospace, Denver CO, November 1986

3-15 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Study Results, Monopropellant End Item Specification, MCR-86-1335B, Martin Marietta Denver Aerospace, Denver CO, November 1986

3-16 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Study Results, Monopropellant Program Plan, MCR-86-1337A, Martin Marietta Denver Aerospace, Denver CO, November 1986

3-17 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Study Results, Bipropellant Preliminary Design Report, MCR-86-1340A, Martin Marietta Denver Aerospace, Denver CO, November 1986

3-18 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Study Results, Bipropellant End Item Specification, MCR-86-1345, Martin Marietta Denver Aerospace, Denver CO, November 1986

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3-20 SE21-OMV Payload User's Guide 51000.87.320-005, TRW Space and Technology Group, Redondo Beach, CA, June 1987

3-21 OMV Tanker Resupply System, Preliminary Analysis, NASA-MSFC, Marshall Space Flight Center, AL, November 1986

3-22 Mechanism Connects and Disconnects Lines Remotely, NASA Tech Briefs, MSC-21086, NASA-JSC, Houston, TX Undated

5-1 Orbital Spacecraft Consumables Resupply System (OSCRS) Study, Monopropellant Application to Space Station and OMV Automatic Refueling Impacts of ELV Launch, MCR-87-1339, Martin Marietta Denver Aerospace, Denver CO, September 1987

6-1 G. D. Kyrias, "General Purpose Docking System," Martin Marietta Denver Aerospace, Denver CO, August 1985

6-2 Concept Definition Study for Recovery of Tumbling Satellites, Exectuive Summary, Study Results, MCR-86-1329, Martin Marietta Denver Aerospace, Denver CO, June 1986

7-1 Metal Bellows Corporation catalog and letter (Reference PMB file 04-4288-08-073), Moorpark, CA, September 28, 1987

7-2 Stratoflex Incorporated catalog and letter (Reference 57-87-819), Fort Worth, TX, September 17, 1987

7-3 Fairchild Control Systems Company letter (Reference EC87:217), Manhattan Beach, CA, September 10, 1987

7-4 Moog Incorporated catalog and letter (Reference HP-4425-87), East Aurora, NY, August 31, 1987

7-5 G&H Technology Incoporated catalog, Santa Monica, CA, undated

7-6 Deutsch Company, Electronic Components Division catalog (VSMF), Banning, CA, undated

APPENDIX B - REQUIREMENTS

An analysis was performed to define the requirements for the satellite servicer system, including the integration of a fluid resupply system, and for other subsystems affecting its design, such as the fluid resupply interface with the spacecraft, the servicer mechanism, the servicer end effector, the fluid disconnects, the in-line couplings, and the electrical connectors. The system level requirements for the operational (free flight) system are presented first and they are followed by specific requirements for its subsystems. The ground demonstration specific requirements are presented separately.

B.1 OPERATIONAL SERVICER

B.1.1 System Requirements

The following requirements affecting the function and the design of the satellite servicer system apply to the operational, free-flight spacecraft servicing system:

1) The servicer system shall be designed so that different types of servicing operations can be performed during the same mission, such as fluid resupply and orbital replacement unit (ORU) exchange;
2) The servicer configuration shall allow minimizing the mission duration. One way of accomplishing this is by performing more than one task at a time, such as resupplying more than one fluid at a time or performing ORU exchange while resupplying fluids;
3) The servicer system shall be capable of servicing more than one spacecraft on a single mission for increased operational flexibility. The system shall allow resupply of fluids to spacecraft with various tank orientations and fluid acquisition systems;
4) A solid docking interface between the spacecraft and servicer is required. Mating and demating of the disconnect(s) shall be performed while the servicer is hard-docked to the spacecraft;

5) The servicer system shall be designed for easy on-orbit integration for the mission, by EVA and/or robotics, at the space station or in the orbiter cargo bay as well as for easy ground operations and support. Its construction shall be modular to provide the required operational flexibility;

6) Monitoring and control of the operational servicer shall be from a ground control station. The servicer control system shall allow for an automated mode of control with operator supervision as well as a computer assisted manual control mode and a back-up manual mode. The ground control station may be common with the carrier vehicle (orbital maneuvering vehicle (OMV)) ground control station;

7) The carrier vehicle shall provide the following functions to the servicer:

   a) rendezvous and docking,
   b) propulsion and attitude control,
   c) guidance and navigation,
   d) monitoring and control,
   e) data handling and communication,
   f) electrical power,
   g) monopropellants for some resupply missions;
   h) bipropellants and pressurant gas for some resupply missions,
   i) structural support for the stowage rack;

8) The servicer system shall be able to interface with the OMV or with the tanker. The interface shall be simple, for easy integration, and shall include standard fluid and electrical disconnects and attachment devices;

9) The servicer system shall be able to perform all the remote fluid resupply and servicing missions projected to 2010 and beyond, when used in conjunction with the OMV, orbital transfer vehicle, and a suitable fluid tanker. It shall be easily reconfigured to be able to resupply different fluids. Typical expendable fluids to be resupplied are shown in Table B-1;

Table B-1 Expendable Fluids to be Resupplied

FLUID	TRANSFER PRESSURE	TRANSFER TEMPERATURE	SERVICE QUANTITY
Propellants:			
o Nitrogen (N_2)	500 psi		
o Hydrazine (N_2H_4)	500 psi	70 ± 20°F	70-5000 lbs
o Nitrogen Tetroxide (N_2O_4)	500 psi	70 ± 20°F	5000 lbs
o Monomethyl Hydrazine ($N_2H_3CH_3$)	500 psi	70 ± 20°F	3000 lbs
o Liquid Oxygen (LO_2)	760 torr	90°K	
o Liquid Hydrogen (LH_2)	760 torr	20°K	
Pressurants:			
o Nitrogen (N_2)	3000-4500 psi		
o Helium (H_e)	3000-4500 psi		
Coolants:			
o Superfluid Helium (HeII)	20 torr	1.8°K	10000 liters
o Hydrogen*	760 torr	20°K	3000 liters
o Liquid Nitrogen	760 torr	77°K	
o Argon*	760 torr		
o Liquid Oxygen	760 torr	90°K	
o Methane*	760 torr	36°K	
o Carbon Dioxide*			
o Ammonia*			
o Liquid Xenon			
Lubricants:			
o TBD			

* Transferred as liquid and converted to a gas

10) The system shall be capable of transferring 7000 lbs of bipropellant or 5000 lbs of hydrazine in less than six hours;

11) Means must be provided for verifying leak integrity of the interface seals between the two disconnect halves before admitting fluid to the interface cavity. Warning indication of any fluid leakage during resupply, and automatic circuitry for correcting any resulting hazardous condition, shall also be provided;

12) Means shall be provided for preventing any leakage of the transferred fluid from contaminating the serviced spacecraft, the servicer and its carrier vehicle, the orbiter or the space station. Maximum spill volume shall be less than 1 cc;

13) Disconnect valve leak test and purge lines shall be connected to a non-propulsive, catalytic vent and/or a catch tank to prevent spillage;

14) Design of the disconnect and the resupply system shall be such that the presence of propellant vapor pockets or bubbles in the disconnect, or elsewhere in the system, is minimized and their rate of pressure increase is limited to preclude detonation by adiabatic compressive heating of such vapor or vapor/gas mixtures;

15) The fluid resupply interface shall include electrical disconnects in addition to the fluid disconnects to provide electrical power, heater power control, and valve commands to receiving spacecraft and pressure and temperature monitoring from the serviced spacecraft;

16) The servicer fluid management system shall provide for the monitoring and control of fluid transfer and maintenance of fluid temperature and pressure;

17) The servicer fluid management system shall provide storage and transfer capability for all fluids required;

18) The fluid management system shall conform to the space station proximity operations contamination requirements;

19) The fluid management system shall include an interface to the OMV for health and status monitoring. This will include fluid and pressure level indicators and leakage detection and warning;

20) The fluid management system design shall incorporate provisions for resupply, maintenance, and upgrade by robotic or manned activities;

21) All ORUs shall be easily accessed, incorporate quick-disconnects, and have standard interfaces that are compatible with robotic or EVA servicing of ORUs.

B.1.2 Non-Propellant Cryogenic Fluid Transfer Requirements

The following requirements apply to the non-propellant cryogenic fluid transfer system:

1) Provisions shall be made for prechilling transfer lines to transfer temperatures;
2) Chill down gas shall be routed to a safe disposal area;
3) Spillage shall be minimized, but it is not a design driver;
4) Transfer time shall be nominally 8 hrs for a prechilled receiver;
5) Electrical connections shall be provided across the servicing interface for valve actuation and status monitoring.

B.1.3 Contamination Requirements

Contamination of the serviced spacecraft, of the servicer and its carrier vehicle, or of the fluid being transferred is a major concern. The following requirements apply:

1) The fluid resupply system shall be designed to perform seal leak tests prior to fluid transfer and purging after resupply. All fluid spillage and propellant vapor from the pressurant gas shall be vented without contaminating other spacecraft surfaces. Maximum spill volume is 1 cc;
2) The fluid resupply system design and operational procedures shall prevent contamination of the fluid being supplied to the spacecraft, by controlling and minimizing the effect of contamination causes such as:
   a) improper cleaning and flushing procedures,
   b) contaminated fluid flow from the serviced spacecraft,

c) improper lubricants and incompatible materials,

d) inadequate filtration;

3) Catch tanks for vented fluids and catalytic vents shall be provided to allow venting at a safe distance from a contamination sensitive, serviced spacecraft.

B.1.4 Thermal Control Requirements

Thermal control during fluid resupply is critical. The following requirements apply:

1) The design of the disconnects, mate/demate subsystem and the hose management system shall provide adequate thermal protection to prevent freezing or overheating of the fluids being transferred;
2) The fluid resupply system shall condition the earth storable propellants to 70 ± 20 deg F;
3) The servicer system shall provide thermal control of the serviced spacecraft during transfer operations, using the electrical connection across the fluid resupply interface. A significant quantity of heat, generated during tank pressurization, must be dissipated without overheating the tank or the fluid;
4) The satellite servicer shall be designed to minimize transfer of thermal loads to the payload being serviced;
5) The satellite servicer thermal control system shall maintain structure, mechanisms and subsystems between 32 and 120 deg F;
6) The satellite servicer thermal control system shall be compatible (non-interfering) with the OMV thermal control system.

B.1.5 Serviceable Spacecraft Requirements

The servicer system shall have minimum impact on the design of the serviceable spacecraft, in terms of where to locate the fluid resupply interfaces, type of fluid acquisition devices, tank orientation, or design of the spacecraft monitoring and control systems. The following standardization requirements apply to the fluid resupply system:

1) A standard fluid resupply interface, for each type of fluid shall be used for onorbit fluid resupply. The interface shall be the same, whether the servicing is performed on orbit, at the orbiter or space station or on the ground, for operational flexibility. The interface shall include electrical and fluid disconnects, dust covers and an attachment mechanism;
2) The following interface functions and processes shall be standardized:
   a) leak checks of couplings before initiating flows,
   b) verification of inhibits/leak checks before demating couplings after servicing,
   c) transfer process for pressurants and propellants (flow rates, stabilization, duration, inhibits, etc),
   d) offloading process for propellants,
   e) venting process for spacecraft tank conditioning,
   f) electrical connectors,
   g) instrumentation signal conditioning,
   h) command, data and power interfaces,
   i) software and software/hardware interfaces,
   j) spacecraft temperature and pressure sensors, valves and thermal control heaters used (powered) by the servicer system during fluid resupply;
3) Standard optical targets shall be provided at all servicing attachment points of the spacecraft and servicer stowage rack.

B.1.6 Safety Requirements

The safety requirements for the fluid resupply system are:

1) The fluid resupply system shall be able to complete the mission after one failure and to remain safe after two failures. To meet these system safety goals, the design shall provide:
   a) redundant fluid loops with a high degree of failure tolerance,
   b) independent contingency umbilical disengagement, using redundant remote or EVA overrides,
   c) system status and safety verification before starting resupply;

2) The design of the fluid resupply system shall assure the safety of the crew during ground or emergency EVA operations as well as the safety of the orbiter, or the space station and of the serviced spacecraft. Representative operational hazards are listed in Table B-2;

Table B-2 Fluid Resupply Operational Hazards

A. Tank Explosion
B. Leakage
C. Contaminants
D. Overpressure
E. Power Source
F. Hypergolic Reaction
G. Incorrect Valve Sequence
H. Purging Problem
I. Grounding
J. Adiabatic Compression
K. Other

3) During resupply operations or demonstrations in the orbiter cargo bay, in case of emergency, the servicer system shall be safed and demated in less than one hour;
4) The reactive fluids hoses and disconnects shall be separated and dissimilar and/or keyed disconnects shall be used;
5) Explosive atmosphere detection, during transfer of explosive fluids shall be provided;
6) Disconnects carrying hazardous fluids shall incorporate appropriate caution flags, markers or plates for both ground and flight crew recognition;
7) Stored energy sources shall not be incorporated in the design of the fluid resupply servicer if EVA crew interfaces are anticipated, or they shall be designed so that the EVA crew can safely deactivate such sources;

8) The fluid resupply system design shall eliminate adiabatic compression detonation potential. Significant quantifies of gas may come out of solution if the propellant tank is vented. Bubble formation in undesirable areas shall be prevented;
9) The materials used in the fluid resupply system shall provide long design life and low corrosion potential;
10) The system shall be designed for maximum loads/pressures with appropriate safety factors;
11) Reversal of the umbilical orientation or an attempt to connect to a wrong fluid resupply interface shall not create a potentially hazardous condition;
12) Venting reaction forces shall be controlled.

B.1.7 Reliability Requirement

1) The fluid resupply system shall have a life of at least 24 resupply missions, for each of its different configurations, before failure.

B.1.8 Maintainability Requirements

1) The system shall be maintainable on the ground as well as at the space station or at the orbiter, for multiple reuse and refurbishment.

B.1.9 Cost Requirements

1) A compromise shall be made during design, between the servicer system growth capability and operational flexibility and its complexity and cost;
2) Cost reduction and reduction of up-front costs shall be achieved through modularization that provides operational flexibility and later system expansion capability.

B.1.10 Hose and Cable Management Subsystem Requirements

The following requirements apply to the flexible fluid lines or hoses, electrical cables and their management system for the operational fluid resupply servicer:

1) The length of the fluid transfer/electrical lines shall be kept to a minimum in order to minimize their weight, pressure/voltage drop, thermal protection and the potential for damage;
2) The hoses and the electrical cables shall be prevented from tangling, abrading each other, or interfering with the servicer mechanism, docking probe, stowage rack or other equipment or structures of the servicer or of the serviced spacecraft;
3) The number of bends in the hoses or cables shall be kept to a minimum;
4) The management system shall assure a suitable minimum bend radius of the hoses or cables;
5) The hose and cable management system shall assure servicing of all required locations (different spacecraft and/or multiple servicing locations) without overstressing the flexible hoses or the cables;
6) The hose and cable management system shall be simple and reliable;
7) The life of each hose or cable in terms of number of bending cycles shall exceed the required life of the fluid resupply system of 200 servicing missions;
8) The materials used for hoses shall be compatible with the fluid to be transferred to prevent fluid contamination and corrosion;
9) If flexible metal hoses are used, the following limitations shall apply to their installation:
   a) the maximum torsional deflection for a typical 3/4 in. diameter hose shall be limited to less than 0.5 deg/ft,
   b) out-of-plane motion of a bent hose shall be very small, since it produces torsion,
   c) "in-line" or axial motion of the hose shall be arranged such as to prevent stretching or loosening the braid,
   d) sharp bends, particularly near the end fittings shall be avoided,

e) stress in the metal hose shall be minimized by spreading the flexing over the entire working length, rather than localized flexing,

f) the hose installation shall be such as to maintain the recommended minimum bend radius or greater;

10) The hose shall withstand, with a proper margin of safety, the stresses from bending and fluid pressure including the starting and stopping surges;

11) The hose and cable management system shall provide adequate thermal control for the flexible fluid lines;

12) The hose and cable management system shall be as compact as possible to allow a maximum working envelope for the servicer mechanism;

13) The deployment motion of the hose and cable management system shall be compatible with the maneuvering capability of the servicer mechanism and with its reach envelope;

14) The hose and cable management system shall not protrude beyond the "top" of the stowage rack in its stowed position, to avoid interference with the servicer mechanism operation;

15) Suitable support and latching of the hose and cable management system shall be provided in its stowed configuration during launch and reentry/landing of the orbiter, during deployment from and return to the orbiter or space station and during docking with the serviced spacecraft;

16) The hose and cable management system shall provide suitable support and positional control to the hoses and cables in the deployed, stowed and all intermediate positions;

17) The number of hoses and cables of the system shall be determined from the redundancy and venting/purging requirements of each mission;

18) The type and the general design of the hose and cable management system shall be the same for all missions, except for variations in the number and size of the hoses, their thermal protection and other mission or type-of-fluid specific requirements;

19) The following requirements shall apply to the transfer lines for non-propellant, cryogenic fluids:
   a) counter flow chiller shall be used for liquid helium,
   b) insulated lines shall be used for other liquids,
   c) thermal mass shall be minimized,
   d) length shall be minimized.

B.1.11 Fluid Resupply Interface Unit Requirements

The following requirements apply to the fluid resupply interface unit, comprised of fluid disconnects, electrical disconnects, the mate/demate mechanism and the attach/alignment mechanism:

1) The fluid resupply interface unit shall be designed with commonality for all modes of servicing, such as on-orbit servicing and servicing in the orbiter cargo bay or at the space station;
2) The same interface shall be used for all functions, such as connecting fluid disconnects or electrical connectors for power and signal transfer;
3) EVA override or redundant remote actuation shall be provided for the demating of the mate/demate and attachment subsystems in contingent situations;
4) The attachment/alignment subsystem shall include an auto indexing feature to ensure the correct mating of disconnect halves and to prevent connection of the wrong umbilical, or connection in the wrong orientation;
5) Commonality of design concepts and of servicing interfaces shall be emphasized while the disconnects shall be specifically developed and designed for each type of fluid;
6) The active side of the mate/demate subsystem shall be located on the servicer side with only a small, self aligning, passive attachment and positioning device on the spacecraft side, in order to minimize the impact on spacecraft design;
7) The envelope of the fluid resupply interface unit shall be as small as possible to allow maneuvering for connection in volume limited areas of the spacecraft;

8) The fluid resupply interface unit shall be small, lightweight, low cost, reliable and of simple, standardized design;
9) Visual confirmation of fluid resupply pre-mate alignment shall be provided, using a TV camera and a standard optical target;
10) Positive locking of the fluid resupply interface unit shall be provided by the servicer;
11) The fluid resupply interface unit and its components shall be designed for a life of 300 fluid resupply cycles for the servicer side and 25 cycles for the spacecraft side;
12) The attach/alignment mechanism shall have a self alignment capability to allow for $\pm$ 3/4 in. lateral offset and $\pm$ 15° angular misalignment prior to attachment;
13) The fluid resupply interface unit shall be designed to withstand, with a suitable margin of safety, all the loads from mating the disconnects, from hose and cable management system reactions, from forces applied by the servicer mechanism or by the EVA crew member, as well as from acceleration during launch and landing of the orbiter, if the attach/alignment mechanism is also used for latching hoses and cables in their stowed position;
14) The design of the mate/demate mechanism and of the disconnects shall minimize any possibility of jamming while connected, and failing to disengage under normal retraction forces;
15) The mate/demate mechanism shall allow for intermediate stops while engaging or disengaging the fluid disconnects for performing leak tests of each seal and for purging and venting operations, with proper indication of the mating status;
16) The attach/alignment mechanism shall have a ready-to-attach sensor;
17) The fluid resupply interface unit shall have thermal protection suitable for the type of fluid being transferred and for mechanism functions;
18) Three inhibits shall be provided to prevent external leakage of propellant from each disconnect half. Leak rate (mated or demated) shall be less than 10 cc/hr at 0-400 psi GN_2 leak test;
19) Flowrates for mono- and bi-propellant quick-disconnects shall be at least 100 lbs/min;

20) Pressure drop shall be less than 50 psi at rated flow;

21) Maximum required mate/demate stroke of the disconnect shall be less than 3.0 in.;

22) The fluid resupply interface unit shall be designed for an allowable lateral offset of the disconnect prior to engagement of 1/16 in.;

23) The fluid resupply interface unit shall be designed for an allowable misalignment of the disconnects, prior to mating, of $\pm$ 5 deg;

24) The force required for mating/demating the fluid and electrical disconnects shall be kept to a minimum;

25) Maximum volume occupied by the disconnect valve(s) and the mate/demate mechanism shall be less than a 12 in. cube of internal spacecraft volume;

26) Dust covers, or other means, shall prevent the mating surfaces of the disconnects from contamination at all times during the mission, except during the fluid resupply operations;

27) The electrical disconnects used in the fluid resupply interface unit shall be compatible with the attach/align and mate/demate mechanisms' alignment capability and their installation shall be such as to permit individual seal leak tests and purging while mated;

28) Redundant fluid and electrical disconnects shall be provided at the interface to be able to continue the mission after one failure;

29) The quick-disconnect materials shall be compatible with the fluid being transferred. Fluids to be transferred and their characteristics are shown in Table B-1;

30) One half of the fluid or electrical disconnect shall mate correctly with any opposite half of the same type disconnect;

31) The fluid resupply subsystem shall be provided with a mechanical attach interface to the servicer mechanism end effector;

32) The non-propulsive cryogenic fluid disconnect valves shall be designed for:

    a) low pressure,

    b) low to zero leakage,

c) minimum spillage, but it is not a design driver,
d) counter flow chiller for liquid helium,
e) minimum thermal mass,
f) remote location/thermal insulation from propellant disconnects,
g) fluid/material compatibility,
h) replaceable, insulated cover doors or caps,
i) internal pressure relief of trapped cryogens,
j) similar alignment requirements as the propellant/gas disconnects.

B.1.12 Command and Control Requirements

1) The following real time control functions of the fluid resupply servicer shall be provided from the ground control station through the communication link of the carrier vehicle:
   a) control of disconnect mate, demate, leak test and purge functions,
   b) control of flow rate(s),
   c) control of liquid and gas pressures,
   d) control of valve on/off sequencing. Provide interlocks for critical functions,
   e) thermal control/conditioning;
2) The following measurements and monitoring of the fluid resupply servicer functions shall be provided:
   a) mass gauging (1/2% accuracy) for fluids in spacecraft and servicer tanks,
   b) critical pressure and temperature measurements in spacecraft and servicer systems,
   c) valve position indication,
   d) status monitoring of spacecraft and servicer systems,
   e) leakage detection and control,
   f) safety monitoring.

B.1.13 Software Requirements

1) The software required for operating the fluid resupply functions of the servicer shall be integrated with the other servicer software;

2) The servicer control software shall be designed for quick change between missions, on the ground or on orbit at the space station or at the orbiter.

B.2 GROUND DEMONSTRATIONS REQUIREMENTS

Ground demonstrations are an important element in the development of an operational onorbit spacecraft fluid resupply and ORU exchange system. A well designed and implemented ground demonstration program can reduce the overall program cost, by checking out solutions inexpensively before flight demonstrations are conducted. The ground demonstrations unit of the fluid resupply and ORU exchange system can also be used for operator training and problem solving for the flight demonstrations and after the servicer becomes operational. The existing servicer engineering test unit (ETU), that was delivered to NASA Marshall Space Flight Center under the Integrated Orbital Servicing Study contract, should be used for fluid resupply and orbital replacement unit exchange ground demonstrations.

The specific requirements of the ground demonstration fluid resupply and ORU exchange system, particularly those affecting the design and operation of the hose and cable management system are as follows:

1) The existing engineering test unit of the IOSS shall be used for all the ground maintenance and servicing demonstration activities;
2) Minimum modifications shall be made to the existing ETU configuration and its control system. The existing end effector shall be used to interface with the fluid resupply unit;
3) The ground demonstration servicer system shall be capable of 1-g demonstration of fluid resupply in addition to the capability of exchanging MMS and single fastener ORUs;
4) The trajectories used during ground demonstrations of fluid resupply and module exchange, as well as the relative position of the servicing system elements shall provide a good representation of the onorbit servicing of an MMS, using lateral docking and axial module exchange;

5) The increased end effector load due to 1-g fluid resupply demonstrations shall not exceed the servicer design load capability;
6) The positioning accuracy of the servicer arm, attached to the fluid resupply interface unit and the hose and cable management system shall be within the capture envelope of the fluid resupply attach/align system;
7) Adequate clearance shall be provided between all servicer system elements;
8) The ground demonstration servicer system shall be capable of 400 complete cycles of fluid resupply demonstrations without refurbishment;
9) Optical targets shall be provided for all locations where the servicer end effector engages module attach interfaces, fluid resupply interfaces, or adapters, at their storage locations;
10) The fluid resupply interface unit, when attached to the servicer end effector shall obstruct as little as possible the field of view of the existing TV camera and lights;
11) High fidelity of the fluid resupply servicer ground demonstration shall be assured by using real flight hardware or accurately duplicated equipment for the servicing interface;
12) The 1-g demonstrations of fluid resupply shall be designed so that this operation can be performed as part of the same overall demonstration as other maintenance and servicing activities, such as ORU exchange or inspection;
13) The fluid resupply servicing interface for 1-g demonstrations shall conform with the industry established fluid resupply standard interface (if a standard interface is established);
14) The mate/demate subsystem of the fluid resupply interface unit shall include an auto-indexing feature to assure the correct mating of the disconnect valves;
15) The hose and cable management system for 1-g fluid resupply demonstrations shall be counterbalanced and shall assure servicing at all required locations;

16) The following real time control functions shall be provided as a minimum for the fluid resupply 1-g demonstrations:

a) control of disconnect mate, demate, leak test, and purge functions,

b) control of liquid and gas pressures,

c) valve position indication;

17) The servicer control modes, Supervisory, Manual-Augmented and Manual-Direct, and the associated control software shall be common to all ground servicing demonstrations including fluid resupply;

18) Separate specific software programs for each demonstration/activity are permissible;

19) Initial ground and flight demonstrations may use water and air at low pressure instead of the actual propellant and pressurant gases in order to minimize risk and cost;

20) A separate line and valving shall be provided in the ground demonstration system for returning the water from the spacecraft to the stowage rack tank after completion of fluid resupply demonstrations;

21) In subsequent phases of ground demonstrations, as the disconnect valves, flexible hoses and other specific hardware become available, resupply of the following fluids may be demonstrated:

a) earth storable propellants (N_2H_4, MMH, N_2O_4),

b) pressurant gases (GHe, GN_2),

c) cryogenic fluids,

Propellants (LH_2, LO_2),

Coolants (LHe, SfHe, LH_2, etc., see Table B-1).