The Space Congress® Proceedings 1989 (26th) Space - The New Generation

Apr 27th, 2:00 PM

Paper Session III-A - The Mobile Servicing System - A System Description

Andrew S. Jones
Deputy Director, Canadian Space Station Program

V. K. Agarwal
Systems Engineering, Canadian Space Station Program

R. Hayes
APM Design and Development, Canadian Space Station Program, Remote Manipulator Systems Division, Spar Aerospace Limited, Toronto

Follow this and additional works at: https://commons.erau.edu/space-congress-proceedings

Scholarly Commons Citation

Jones, Andrew S.; Agarwal, V. K.; and Hayes, R., "Paper Session III-A - The Mobile Servicing System - A System Description" (1989). *The Space Congress® Proceedings*. 16.
https://commons.erau.edu/space-congress-proceedings/proceedings-1989-26th/april-27-1989/16

This Event is brought to you for free and open access by the Conferences at Scholarly Commons. It has been accepted for inclusion in The Space Congress® Proceedings by an authorized administrator of Scholarly Commons. For more information, please contact commons@erau.edu.

The Mobile Servicing System – A System Description

Presented at the

26th Space Congress April 25–28, 1989

Andrew S. Jones
Deputy Director, Canadian Space Station Program

V.K. Agarwal
Systems Engineering, Canadian Space Station Program

R. Hayes
APM Design and Development, Canadian Space Station Program
Remote Manipulator Systems Division
Spar Aerospace Limited, Toronto

System Description of Mobile Servicing System (MSS) for Space Station Freedom

Abstract

This paper is a systems description of the Mobile Servicing System (MSS) to be provided by Canada, an International Partner to the NASA Space Station Freedom. The paper describes space segment, ground segment, and support systems.

Spar is the prime contractor to the National Research Council of Canada (NRCC). The MSS will provide the functional capabilities for Space Station Freedom construction, maintenance, deployment, and retrieval of Free Flying Spacecraft and servicing of attached payloads.

1.0 Introduction

The Mobile Servicing System (MSS) is Canada's contribution to the International Space Station – Freedom Programme. The programme is executed by Spar Aerospace, the prime contractor, under the auspices of the National Research Council of Canada (NRCC).

The MSS will play a predominant role in:

i) Space Station construction and assembly;

ii) Transportation on the exterior of the Station;

iii) Payload handling including deployment, retrieval, and berthing of payloads and the NSTS orbiter vehicle.

iv) Space Station maintenance in the EVA environment.

v) Attached payload servicing in the EVA environment.

vi) EVA crew activity support.

vii) Support of Space Station Safe Haven operation.

The overall MSS consists of a space segment, a ground segment and support systems.

The elements of the MSS are described below; and typical MSS operations outlined.

2.0 The MSS – Space Segment

The space segment hierarchy is shown in Figure 1. It consists of three flight elements, the MSC (Mobile Servicing Centre), the SPDM (Special Purpose Dexterous Manipulator), and the MMD (MSS Maintenance Depot) and a sub-element the MCE (MSC Control Equipment).

2.1 The MSC

An overall view of the MSC is shown in Figure 2. The MSC itself is comprised of two elements, the MRS (Mobile Remote Servicer) and the MT (Mobile Transporter). The MT is to be supplied by the United States, and it provides the MSC with translation, turning, and plane change capability on the space station trusses. The MRS is made up of a number of major systems. The MBS (MRS Base System) provides the structure which interfaces with the Mobile Transporter, and supports the remaining systems of the MSC and payloads including the relocatable SSRMS (Space Station Remote Manipulator System) which is provided as a system of the MSC.

The MBS is illustrated in Figure 3. In this figure the SPDM and SSRMS are shown on the MBS in their stowed configuration and the payload support adapters deployed as they would be in service. Some of the key features of the MBS are given in Table 1 below.

Mass = 954 Kg
Size = 6.4 m x 4.6 m x 2.5 m
NSTS Cargo bay length = 2.22 m
(launch configuration)
NSTS interface 2 trunnions and 1 keel fitting

Table 1 MBS Key Features

The construction of the MBS is the subject of a trade study currently in progress between conventional aluminum alloy and composite material construction. The MBS is passively thermally controlled by the use of multi-layer insulation and exposed anodized surfaces. Temperature control is augmented by thermostatically controlled heaters of approximately 80 W. The equipment supported by the MBS during launch or in orbit is listed in Table 2 below.

SSRMS
SPDM
FTS (U.S. Flight Teleoperator System)
EVA Astronauts
Payloads, Payload Pallets, ORUs, etc.
MSC PMDS Power Management and Distribution Subsystem
MSC CS (Lights, CCTVs, Pan & Tilt Units, Antennae, RF equipment)
MSS and User Tools
EVA Workstation

Table 2 MBS Mounted Equipment

The SSRMS has evolved from the Shuttle Remote Manipulator System (SRMS or "Canadarm").

Whereas the SRMS is a six-degree-of-freedom arm fixed at the shoulder end to the orbiter longeron with progressively smaller joints leading to a single end effector at its free end; the SSRMS is a symmetrical seven-degree-of-freedom arm with an end effector at each end. Thus the SSRMS is capable of relocating itself about the space station on appropriately located and outfitted Power Data Grapple Fixtures (PDGFs). PDGFs are also provided as attachment fixtures for MSS relocatable elements/systems on the MSC allowing considerable flexibility in operations. Some key features of the SSRMS are given in Table 3 below.

Mass =	936 Kg
Leading Dimensions (deployed) =	16.8 m length 1.51 m offset
Comprises 7 DOF with two LEEs	
Deployed Frequency (typical)	
Unload	0.005 Hz
Loaded (maximum payload)	0.15 Hz
End point applied force (typical)	80 N
Stopping distance (joint run away worst case)	600 mm

Table 3 SSRMS – Features

The SSRMS is essentially fail operational and fail safe after a second failure, with considerable self monitoring to ensure no uncommanded motions or joint run aways occur. A typical SSRMS joint is shown in Figure 4. Each joint has an integral Joint Electronics Unit (JEU) that provides the servo control of the high speed motor module. The motor torque is transmitted through high speed and low speed gearboxes to the joint structure. The low speed gear box is specially designed to minimize the joint backlash and provide high stiffness in the drive axis. Some key features of the SSRMS joints are listed in Table 4 below.

Mass =	55.3 Kg
Radge of travel =	+/- 180 degrees
Max speed =	0.083 rads/sec (wrist)
Max torque (stall) =	3600 Nm
Gear ration G1 x G2 =	1840
Efficiency – forward =	82%
– back =	78%
Encoder (output) =	18 bit

Table 4 Joint Data (typical)

Each joint is driven by a motor module. The motor module contains prime and secondary drives each with a brushless DC motor. Commutation and rate data being generated by a resolver. Each motor shaft is attached to a brake. The brake is designed "power off – brake on" so as to avoid a free joint in the event of a loss of power. Typical motor module data is given in Table 5 below.

Mass =	5 Kg
Motor torque =	2 Nm
Frictional torque =	0.1 Nm
Brake slip (static) =	1.2 Nm
Motor power =	178 W (at stall)
Brake power =	20 W (continuous)
Resolver =	16 bit

Table 5 Joint Motor Module

At each end of the arm is located a force moment sensor (FMS) to allow control of applied forces. Table 6 below indicates the expected FMS range and accuracy.

	Range	Accuracy
Force	<1650 N	2.0%
Torque	<6500 Nm	0.1%

Table 6 Force Moment Sensor (FMS) Performance

To assist in operations and to allow automated vision system tracking and capturing of payloads a suite of cameras (CCTVs), lights (VLs) and pan and tilt units (PTUs) are required on the arm as indicated in Table 7 below.

CCTV	VLs	PTUs	
1	1	0	At shoulder joint
1	1	0	At wrist joint
2	2	2	At elbow

Table 7 Vision Equipment Location

Each end of the SSRMS is terminated by an end effector. This device grapples the payload, provides power and data transfer to a payload and provides a stiff interface to allow payload maneuvers. The end effector is of a latching type and has typical performance parameters shown in Table 8 below. Currently a weight reduction activity is in place to reduce the LEE mass.

Mass = 99 Kg (including cameras, lights &FMS)
Capture envelope = +/- 102mm and +/- 15 degrees
Capture time = 3.0 sec max
Rigidization time (typical) = 20 sec to 28 sec (max)
Rigidization load = 8 kN
Unlatched load capacity = 1.6 kNm
Latched load capacity = 80 kNm
Services transfer to/from P/L =
1.8 kW @ 120 VDC Power
3 Mbps & 10 Mbps Data
3 channel FOM @ 4.5 Mhz video

Table 8 Latching End Effector (LEE)

The SSRMS electrical system contains following electronics units to command, control and power the system.

- Power Interface Units (2 prime plus 2 backup)
- Data Bus Isolators (2 prime plus 2 backup)
- Arm Computer Units (prime plus backup)
- Joint Electronics Unit (7 prime plus 7 backup)
- LEE Electronics Units (2 prime plus 2 backup)
- Artificial Vision System Power Conditioning Units (prime plus backup)
- Video Power Conditioning Units (4 prime plus 2 backup)
- Vision Processors (prime plus backup)
- Video Bus Interface Units (4 for cameras and 1 for vision processor)
- The SSRMS is powered by 120 VDC Space Station power.

The remaining systems of the MRS are distributed systems consisting of the MSC-PMDS (Power Management and Distribution System), the MSC-DMS (Data Management System), and the MSC-CS (Communications System). These distributed systems interface with the corresponding space station distributed system.

Flight Operations Support Equipment for the MSS consists of the STS Orbiter FSE (Flight Support Equipment), Space Station OSE (Orbital Support Equipment), and Tools.

2.2 The SPDM

The SPDM consists of two small seven-degree-of-freedom manipulator arms patterned after the large SSRMS manipulator arm. End effectors and special tools provide the SPDM with the dexterous manipulation capabilities similar to that of an EVA astronaut. Video cameras mounted on the SPDM provide vision system capabilities to support dexterous operations. A folding body provides the SPDM with extra reach capability. A base consisting of an end effector and Power Data Grapple Fixture provides the SPDM with the capability to be operated at the end of a SSRMS, or to be relocated onto any PDGF. Figure 5 shows an overall view of the SPDM.

2.3 The MMD

The MMD provides a Maintenance Depot for the MSS, as well as a "home base" to store equipment when not in use. The MMD comprises the structural system, and distributed systems that accommodate any of the relocatable elements/systems of the MSS (eg. SSRMS, SPDM, EVA Workstation). The MMD also accommodates MSS Orbital Replaceable Units (ORUs), Tools, MSS maintenance fixtures, and special integration and test equipment.

2.4 The MCE

The MCE comprises an EVA-WS (EVA Workstation) and any special MSS required hardware required to be added to the standard IVA Work Station as well as the special MSS related software that runs in the IVA - WS and the Space Station Data Management System.

3.0 MSS Phasing

The MSS is designed to be implemented in a phased manner onto the space station. The Phase I space station will require approximately twenty shuttle missions consisting of assembly flights, outfitting of modules, and logistics flights for crew rotations and resupply. The assembly of the space station is expected to commence in 1994/95, with completion of Phase I in 1998. The space station will have an Early Man-Tended Capability (EMTC), in that the crew can enter the space station and perform IVA tasks on the fourth flight, and be permanently manned from about the tenth flight or earlier.

Figure 6 shows the MSS space segment phased implementation on the Phase I space station. On flight two the Phase 1 MSC consisting of the MRS with a SSRMS is required to be integrated onto the MT. On later flights the SPDM, MMD and second MSC POA (Payload ORU Accommodation) will be added. As can be seen by the early manifest of the Canadian MSS, it plays an important role in space station assembly.

4.0 MSS Ground Segment

The Canadian support role consists of real time space operations support, initially at the JSC Space Station Control Center (SSCC) with migration to the Canadian Ground Support facilities after the initial assembly of the space station is complete. Figure 7 illustrates the present concept for the MSS ground segment. The MSS ground segment within Canada will consist of an Engineering Support Centre (ESC), and a Utilization and Operations Centre (U&OC) for space station users.

4.1 Engineering Support Centre (ESC)

Within the ESC is a Space Operations Support Centre (SOSS), an an Integrated Logistics System (ILS). Sustaining engineering is on-line and available using dedicated project team personnel. The real time voice, video and data from the space station communications network arrives at the SOSS via a gateway and is processed and distributed to control, recording, and analysis work stations. Parallel playback is possible for off-line activities. MSS simulation and training capabilities are provided by the supporting Manipulator Development and Simulation Facility (MDSF). The overall architecture uses common workstation design as a basis, and this allows for maximum flexibility in facility use. The ILS uses the same networks as the ESC but retains its own workstations for inventory control, analysis and management. Communication links to the U&OC enable program monitor functions to be performed.

4.2 Space Operations Support Functions

4.2.1 On Line

The primary on line ground function is the monitoring and recording of real time flight data in order to provide appropriate input to diagnostics, troubleshooting aids, procedures, performance monitoring systems, and maintenance control systems. The ground provides capability for command and control of the MSS primarily in support of system configuration, and test. This control does not include real time manipulation. The ground provides real time analysis and evaluation of MSS performance that supports fault isolation, troubleshooting, and workarounds.

4.2.2 *Off Line*

A major function on the ground is simulation. The simulation capability, both real time and non-real time, is used for operations planning, procedure validation, crew training, system performance validation, contingency situations, and engineering analysis. The ground also performs off line trend analyses in order to predict failures, on-orbit performance, and support spares analysis. The ground performs spares analysis and recommendation using automated provisioning databases. The ground provides the planning and scheduling capability that is used for strategic, tactical, increment, and execution planning.

5.0 Support Systems

In support of the design, development, verification and operation of the MSS are three systems, the MDSF (Manipulator Development and Simulation Facility), the SSE (the MSS Software Support Environment), and CTMIS (the Canadian Technical and Management Information System).

5.1 MDSF

The MDSF is both a development and validation facility and an operational support and analysis facility. It is a series of processors and graphics hardware and advanced kinematics and control system analysis software that provides both non-real time and real time simulations of system kinematics dynamics, control systems and structural responses. The system has interfaces with flight and engineering model hardware and software to support system verification. It is illustrated in Figure 8.

5.2 SSE

The Software Support Environment is a series of hardware and software items that allow a modern computer aided software engineering development and verification environment for the considerable amount of flight software and ground software. Ada has been baselined as the programming language for flight and ground software.

5.3 CTMIS

The Canadian TMIS is a VAX based network of all major subcontractors, the government (NRCC) and prime contractor. It is a menu driven data base, electronic mail and file transfer system. CTMIS allows program data, news, and messages to be exchanged and maintained on a program wide basis. Links to NASA-TMIS have also been established. CTMIS and SSE are fully integrated and share common hardware and communication links where appropriate.

6.0 MSS - Control

The MSS Operations can be commanded and controlled from IVA - Control station in the station nodes or cupolas, the MSS - EVA - Work Station or from the orbiter control station. The result of these different configurations is that the station DMS and C&T subsystem is often embedded in the overall MSS control loop. There is also the ability to check out the MSS health from the space station control centre on ground. Figure 9 illustrates the complexity of the MSS control paths.

7.0 MSS On-Orbit Operations Functions

Since MSS elements/systems are manifested in a phased manner during the space station assembly, the functional capabilities of the MSS increase accordingly. The following describes the complete MSS on-orbit operations functions.

7.1 Space Station Construction and Assembly

The MSS space station construction and assembly operations include the following:

i) Assembly of modules, nodes, and airlocks onto the space station structure.

ii) Construction of space station truss structures including installation of utilities.

iii) Installation of thermal radiators, RCS modules and tankage, inboard and outboard solar arrays, payload interfaces and payloads.

Assembly activities can be grouped in the following categories:

i) Large scale Manipulation by the use of the SSRMS for grappling, translation, rotation, and positioning of space station hardware.

ii) Dexterous Manipulation by the use of EVA or SPDM for translation, rotation, positioning or grappling of space station hardware requiring man or man-like capabilities.

iii) Transport by the use of the MSC for relocation of space station hardware from one location to another location that is beyond the reach of a manipulator.

iv) Payload Track and Capture/Release by the use of the SSRMS for acquisition of an orbiter or free flyer for the purpose of securing it structurally to the station. Also, the reciprocal action of releasing the vehicle under controlled conditions.

v) Holding or Positioning of payloads by the use of the MSS for restraint or securing of space station hardware temporarily, to enable operations (such as attachment).

vi) Other MSS Operations anticipate the use of MSS for inspection and checkout of space station elements, and use of MSS for deployment of space station hardware such as solar arrays.

7.2 Transportation

The MSC provides the capability to transport suitably outfitted equipment on the space station truss. The MT portion of the MSC provides the mobility mechanisms for translation, turning, and plane changing on the trusswork. Cargo that can be transported on the MSC includes the following:

i) Space station construction and assembly cargo.

ii) Attached payloads.

iii) Free-Flyers, (with and without payloads).

iv) Space station maintenance and logistics cargo (including that for the MSS).

v) EVA astronauts.

Also, growth capabilities will be provided for:

vii) Orbital Maneuvering Vehicle (OMV), (with and without payloads),

viii) Payloads (to be staged/destaged from OMVs, Free-Flyers, Orbital Transfer Vehicle).

Transportation is considered one of the MSS primary functions, as wells as an operations activity associated with other MSS primary functions such as assembly, maintenance, and servicing.

7.3 Orbiter Berthing and Payload Handling

The MSC has the capability to perform orbiter berthing and the following payload handling operations:

i) Capture,

ii) Maneuvering,

iii) Positioning,

iv) Berthing and deberthing,

v) Release.

In performing these operations, the MSS has the capability to limit forces and torques at the end effector interfaces.

7.4 Space Station Maintenance

The MSS provides capabilities to maintain the space station. Space station maintenance also includes MSS maintenance, and hence the MSS is designed to maintain itself on-orbit. The complete MSS consisting of the MSC, MMD, and SPDM under control from the MCE provides for space station maintenance. Space station EV maintenance operations can be categorized as follows:

i) ORU Changeout

- ORU changeout includes gaining access to the ORU, removing the faulty ORU, installing the replacement, and closing out access to the ORU.

ii) Cleaning

- The removal of foreign material (particles or deposits) from the surface of an item.

iii) Inspection

- The visual examination of an item by support direct (EVA crew), or indirect (use of MSS video) observation.

iv) Adjustment and Alignment

- Includes the manipulation of equipment to return equipment to an in-tolerance condition.

v) Lubrication

- The MSS supports this function of introducing lubricant by its dexterous manipulation capability. Lubrication accomplished by replacing sealed units is either ORU changeout or a replenishment activity.

7.5 Attached Payload Servicing

The MSS supports servicing of the space station attached payloads in the extravehicular (EV) environment using special tools and servicing equipment. MSS servicing operations include the following activities:

i) Payload Assembly

- Includes installation (integration), checkout, reconfiguration, upgrade, or disassembly of payloads.

ii) Restoration

- Inspection, safing of hazardous systems, ORU replacement, repair (MSC supports transportation to IVA maintenance work area for ORU repair), testing and calibration on user systems down to the ORU level.

iii) Consumables Replenishment

- Fluids replenishment, re-supply of raw materials, and harvesting of products.

iv) Temporary Storage

- ORUs or ORU pallets, tools or tool pallets, customer furnished servicing equipment.

v) Transportation

- Payloads, ORU pallets, customer furnished servicing equipment.

7.6 Crew EVA Support

The MSC provides the capability to transport and position EVA astronauts about the space station. The provision of an EVA workstation allows an EVA crewmember to control the MSC, either from the MSC, or with the workstation at the end of the SSRMS. A Manipulator Foot Restraint (MFR) is also provided to accommodate an EVA crewmember on the end of the SSRMS.

The MSS provides EVA mobility and translation aids such as handholds, foot restraints, and tether attachments. Also, lighting and video monitoring is provided to support EVA. EVA power tool outlets and tool accommodations are also provided.

7.7 Safe Haven Support

The MSS supports the space station safe haven requirement to provide a means of rescue for crew from isolated modules. A number of safe haven scenarios are being analysed and evaluated by NASA. One of the scenarios is that a node depressurizes and crew become isolated in either the Japanese Experiment Module (JEM), or the JEM Equipment Logistics Module (ELM). Similarly crew could become isolated in the European Space Agency (ESA) module. The MSS rescue scenarios include umbilical hookup to the isolated module(s), transporting the isolated modules to another docking port, or transporting the EVA rescue crew, and the isolated crew after they have donned EMUs (Extravehicular Mobility Units).

8.0 Design and Development Approach

The overall design and development approach is based in many areas on proven methods used for the production of space systems, however, the MSS unlike most space systems (but similar to a number of other space station elements) will have elements that are integrated on orbit without prior ground integration. Thus, physical and functional simulators of interfaces will be produced and used to validate systems prior to launch, both a DMS test bed and integration and checkout of flight hardware and software linked into MDSF simulations will be used in this way.

The overall model philosophy is one established to minimize cost and risks thus primarily a prototype approach is used. Qualification hardware is only produced in support of units that are produced in quantity where a protoflight approach would not be cost effective.

Engineering and breadboard models of critical areas are planned to support engineering development and to resolve areas of technical risk. This includes the rapid prototype of flight systems in Ada.

A complete independent validation and verification of all critical software is planned.

9.0 Advanced Technology Development (ATD)

In parallel to the main MSS program a supportive ATD program has been put in place. This evaluates more advanced concepts or design solutions and prior to each PDR an implementation review is held to consider if a more advanced solution should be incorporated into the baseline. Consideration of technical risk, performance improvements, costs, schedule impact, and fall back options are made. Typical studies at present include:

- Collision avoidance algorithms – Vision systems – Materials Development – Expert System Applications

10.0 Conclusion

The paper provides an overall description of the MSS, a complex and important part of the space Station Freedom. In such an overview many details must be omitted. Further information on the MSS can be found in the references.

11.0 References

1. Mobile Servicing System – Flight Operations and Support

   D.A. Bassett, J.A. Middleton, W.J.G. Brimley and T.W. Young 39th Internal Congress of the IAF, 8 October 1988

2. The role of the MSS on Space Station

   H.L. Werstiuk and D. Gossain, IEEE International Conference on Robotics and Automation, 30 March 1987

3. Technology Research and Development associated with the MSS. F.R. Vigneron, R.D. Coswell, S.S. Sachdev, R. Ravindran, 4th CASI Conference on Astronautics, 3 November 1987

4. The Structural Design of the MSS under Multiple Constraints

   E. Quittner, et al; 6th CASI Conference

5. Concept Design of the SPDM of the MSS

   M. Brouillette et al; 5th CASI Conference on Astronautics, 15 November 1988

6. MSS Operations on the Space Station, W.J. Brimley, G. Beyer, H. Kleinburg 4th CASI Conference on Astronautics, 3 November 1987

Acknowledgments

The work presented in this paper has been performed at Spar Aerospace Limited, Remote Manipulator Systems Division under DSS/NRCC Space Division. The authors thanks NRCC, Spar and its subcontractors for their contribution to the work described.

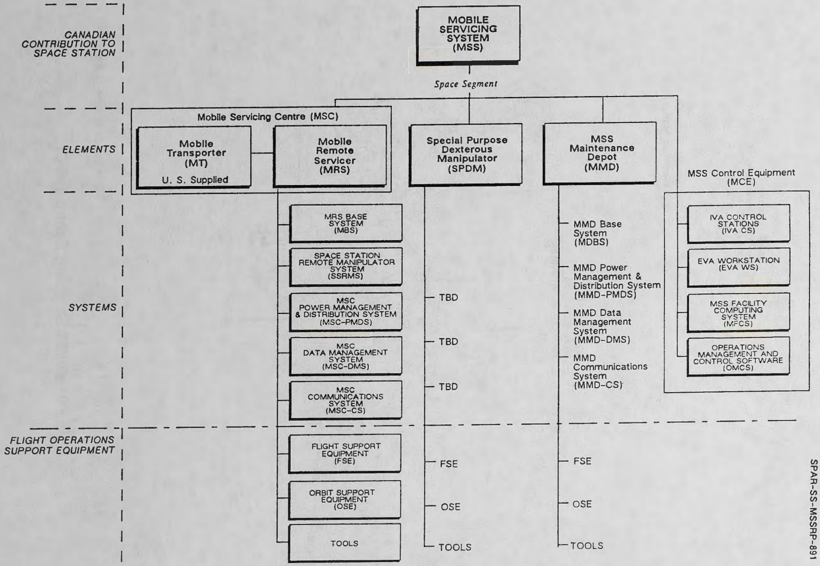

Figure 1 Mobile Servicing System (Space Segment) Hierarchy

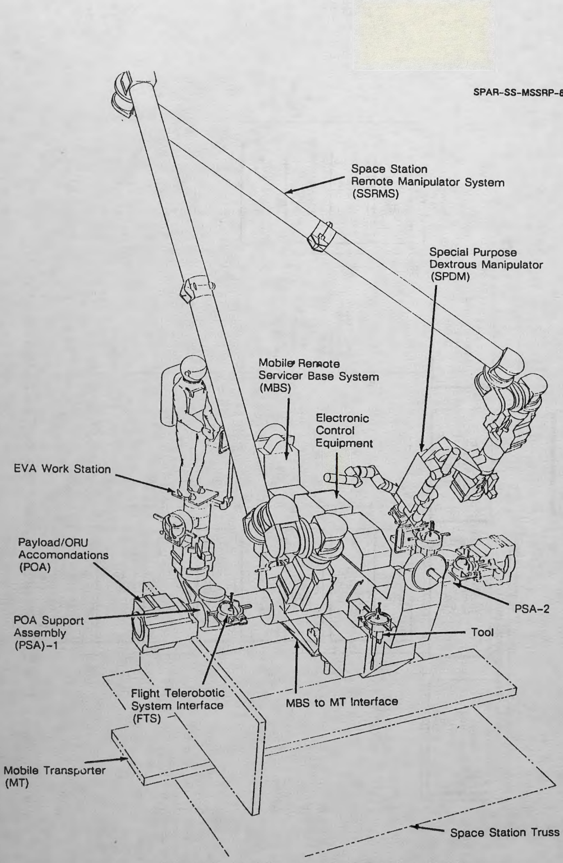

Figure 2 Mobile Servicing Centre (MSC)

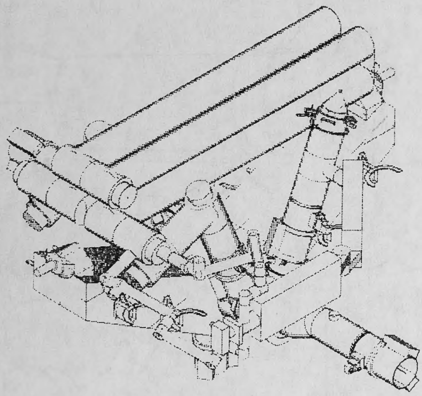

Figure 3 MRS Base System (MBS)

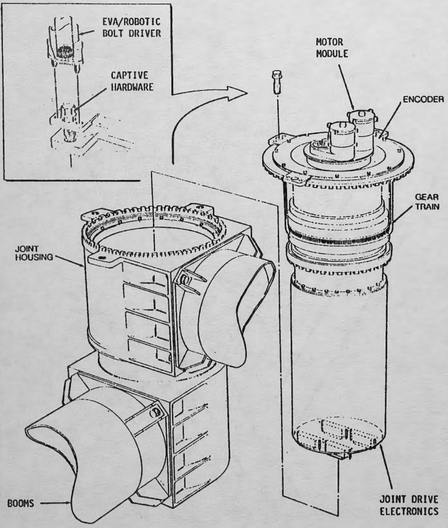

Figure 4 Typical Joint

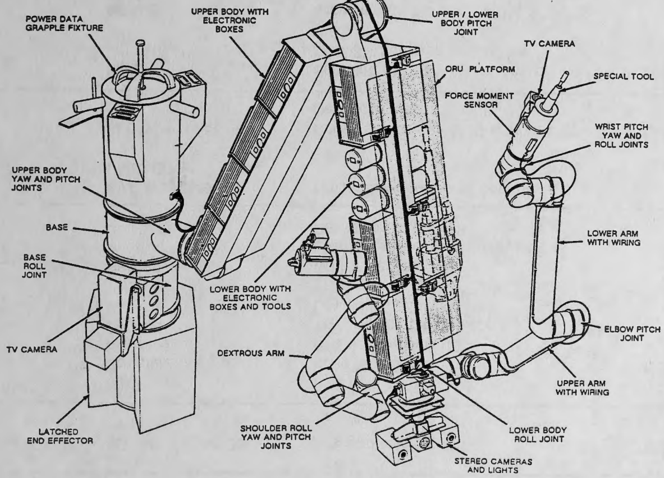

Figure 5 SPDM Configuration

MSS Phase	Equipment	Capabilities	Flight
(SS Phase I) 0	MT, IVA CS, MFCS	**IVA Controls for MSS**	MB–1
1	**MBS**		
	Structure	Base for SSRMS	MB–2
	Interfaces	FTS accomodation	
	POA–1	Transporting payloads on SS	
	Tools	Limited P/L servicing	
	SSRMS	Orbiter berthing Loading/unloading payloads Relocation of SSRMS	
	EVA WS, PMDS, DMS, CS	Limited EVA control of operations	
2	**SPDM**	limited servicing of MSC without EVA Dexterous tasks	L–1
3	**MMD**	Servicing of MSS at fixed location MSS ORU storage capabilities	L–3
	POA–2	Simultaneous transport of P/L and P/L ORU cradle on MSC	

Figure 6 MSS Equipment and Capabilities by Phasing

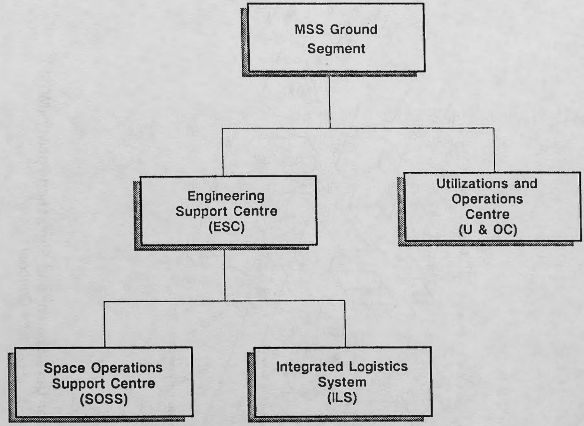

Figure 7 Current MSS Ground Segment Organization

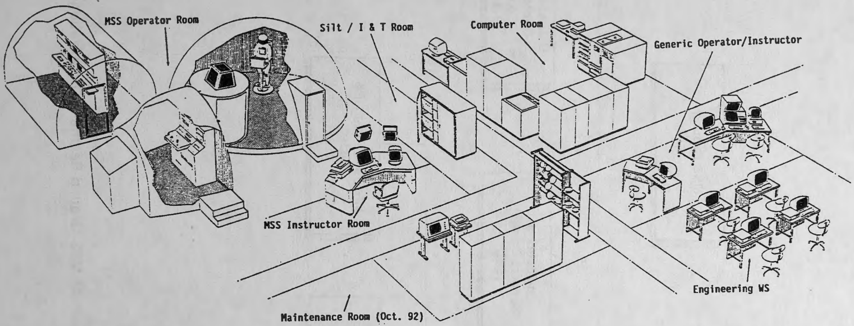

Figure 8 Manipulator Development and Simulation Facility (MDSF)
- Artist's Concept

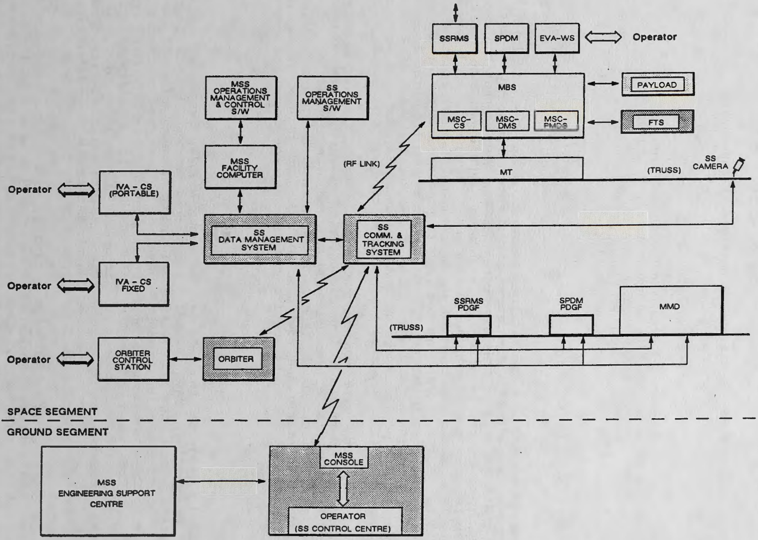

Figure 9 MSS Command & Control Architecture