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ASTROMAG PHASE A ASSEMBLY AND SERVICING OPERATIONS REPORT

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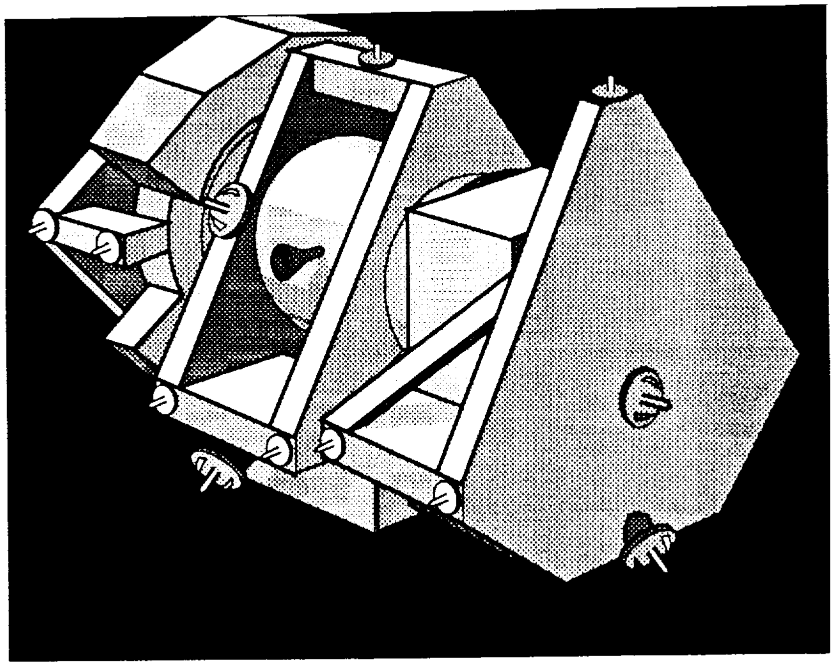

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract NAS5-30546, Task 103

December 31, 1989

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16. Abstract

This document presents operations concepts for the assembly and servicing of the Astromag Attached Payload on the Space Station Freedom. Scenario scripts and graphical representations of the on-orbit operations and equipment are presented for the installation of the Core Facility on the S. S. Freedom, installation of Experiment hardware on the Core Facility, and the Changeout of Experiments on the Core Facility.

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LIST OF ACRONYMS

AC	Assembly Complete
AFD	Aft Flight Deck
APAE	Attached Payload Accommodation Equipment
APS	Astronaut Positioning System
CETA	Crew and Equipment Translation Aide
DOF	Degrees of Freedom
EVA	Extravehicular Activities
FTS	Flight Telerobotic Servicer
FTSA	FTS Accommodation
GSFC	Goddard Space Flight Center
HMIF	Human-Machine Interface
IVA	Intravehicular Operations
JSC	Johnson Space Center
LEE	Latching End Effector
MFR	Mobile Foot Restraint
MRS	Mobile Remote Servicer
MSC	Mobile Servicing Centre
MSFC	Marshall Space Flight Center
MT	Mobile Transporter
NASA	National Aeronautics and Space Administration
ORUs	Orbital Replacement Units
PDGF	Power Data Grapple Fixture
PIA	Payload Interface Adapter
POAs	Payload/ORU Accommodations
RMS	Remote Manipulation System
SIA	Station Interface Adapter
SSRMS	Space Station Remote Manipulator
STS	Space Transportation System

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SECTION 1. INTRODUCTION

This document presents operations concepts for the assembly and servicing of the Astromag Attached Payload on Space Station Freedom. This section contains the purpose, scope, and background of the study.

1.1 PURPOSE

The Astromag Project at NASA's Goddard Space Flight Center is completing its Phase A studies in December 1989. Generation of the Astromag Phase A final report document will require the inclusion of analyses related to the assembly and servicing missions. Development of feasible concepts for the assembly and servicing of the Astromag Attached Payload will provide the Astromag Project with information that will provide input to "design for servicing" guidelines and initiate the development of operations procedures for the Astromag Attached Payload on S. S. Freedom.

1.2 SCOPE

This document presents concepts for the assembly of the Astromag Attached Payload at its operational site, and the planned servicing of Astromag for the replacement of scientific experiments. Detailed discussion of Astromag assembly and servicing concepts are primarily limited to operations conducted at the facility operational worksite. A brief overview of events that occur prior to worksite activities is also provided. This report contains scenario concepts for full length top-level operations on the station, and briefly discusses back-up operations concepts.

1.3 BACKGROUND

The background information in this section is extracted from the "Draft Astromag Technical Advisory Team Report" (Ormes, J. F., et al).

1.3.1 Astromag Scientific Objectives

The goal of the Astromag Attached Payload is to study incident cosmic rays that arrive from beyond our solar system. The study of these very energetic particles is important to understanding the dynamics and evolution of the galaxy. Astromag provides researchers with the means to study the origin, acceleration, and propagation of cosmic rays. Astromag includes the search for antimatter and exotic particles. Detection of these particles could revolutionize our concept of the fundamental physical processes in the universe.

Astromag's scientific objectives are to:

- Investigate the origin and evolution of matter in the galaxy by direct sampling of galactic material.
- Examine cosmological models by searching for antimatter and evidence of dark matter.
- Investigate the origin of extremely energetic particles and their effect on the dynamics and evolution of the galaxy.

1.3.2 Astromag Scientific Concept

The Astromag Attached Payload is a superconducting, magnetic facility designed for particle astrophysics and space physics experiments requiring an intense magnetic field in space. Astromag is envisioned as a research facility for conducting diverse experiments.

Astromag's scientific objectives can be achieved by studying the behavior (paths) of charged, incident particles as they pass through a strong magnetic field (Figure 1-1). Analysis of the paths allows identification of the particles and the estimation of their energy. In the Astromag design concept, a current passes through two parallel, superconducting coils, generating a strong magnetic field. Experiment hardware is placed near each coil to detect incident cosmic rays. Particles pass through this equipment, including sensors such as particle trackers and detectors.

The coils are manufactured from materials that, when cooled to very low temperatures (<4 K), have superconducting characteristics. This low temperature is achieved by circulating superfluid helium around the coils. The coils are connected in series, but with opposing currents to ensure that the magnetic fields are equal and opposing; thus, the net dipole moment of the magnetic fields is minimal. The magnetic field intensity drops off greatly at a few meters from the center of the payload, thus providing minimal impact to the host platform and its sub-elements.

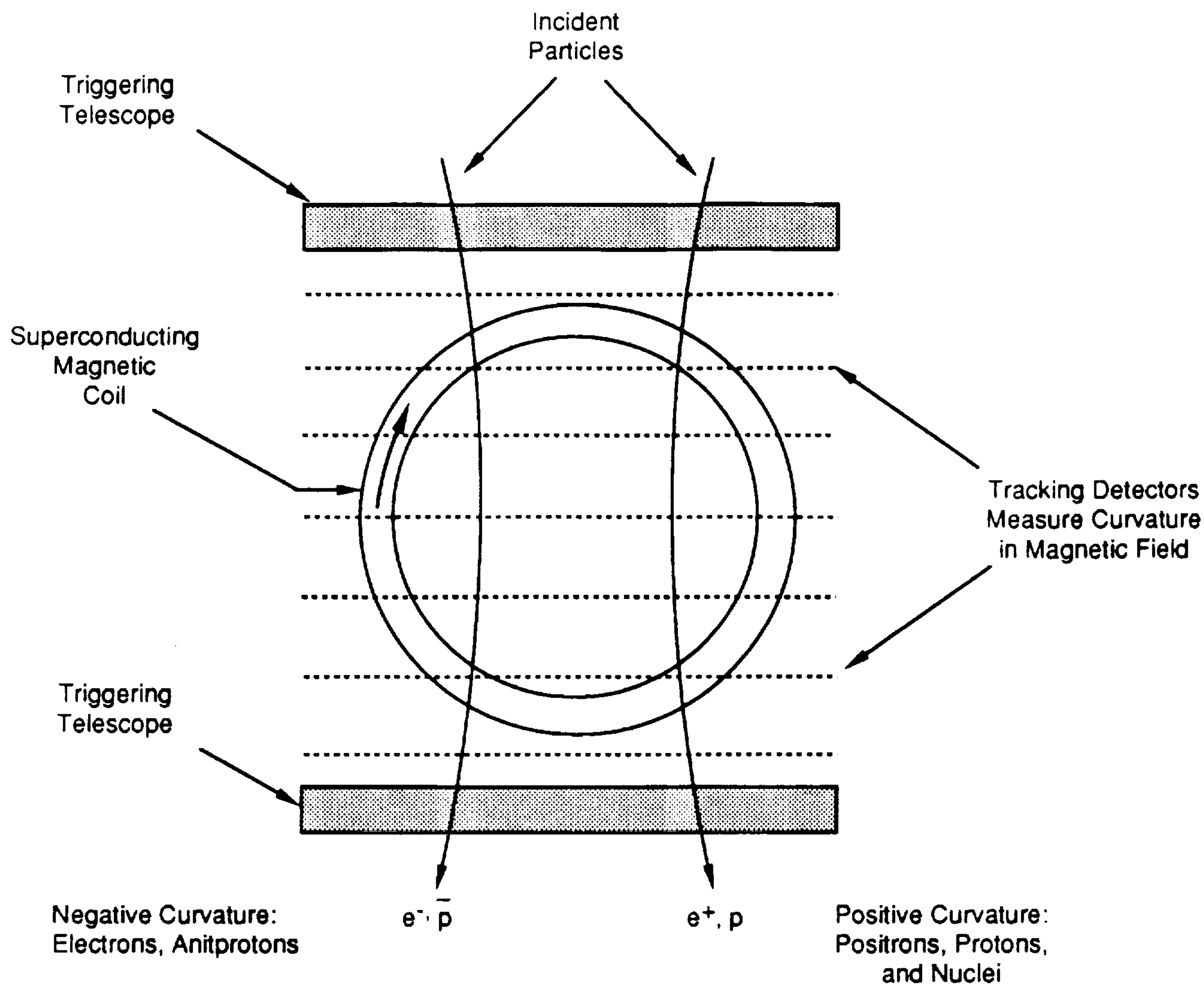


Figure 1-1. Astromag Technique
(From Ormes, J. F., et al, 1988. "The Particle Astrophysics Magnet Facility, Astromag")

The Astromag design concept accommodates two separate experiments at one time. The design of Astromag allows experiments to be replaced periodically over the lifetime of the payload. Thus diverse astrophysics experiments may be conducted through the use of a single attached payload facility. According to the NASA press release concerning the S. S. Freedom flight experiments (July 1989), three Experiments are chosen for use on the Astromag: 1) LISA - "Large Isotope Spectrometer for Astromag", proposed by GSFC; 2) WIZARD - "A Program to Measure the Cosmic Rays including Anti-protons, Positrons, Nuclei, and to conduct a Search for Primordial Antimatter", proposed by New Mexico State University; and 3) SCINATT - "Spectra, Composition, and Interactions of Nuclei Above 10 Tev", proposed by Marshall Space Flight Center (MSFC).

The use of Astromag as a facility for the various Experiments requires a modular configuration so that Experiment changeout may be performed. Astromag Experiments are considered to be Orbital Replacement Units (ORUs), since they are designed for planned changeout operations. The Experiment equipment includes trackers and detectors for determining the type of particle and its energy. Due to their varied objectives, the Experiments differ in overall configuration. Each Experiment will interface with a central facility structure (the Core Facility) and will be capable of transferring power, data, and possibly thermal utilities. The Core Facility, which houses the magnet coils, cryostat, and system control equipment, must be replenished with liquid helium either on-orbit or on the ground. It is these primary considerations that drive the general configuration of the payload as described below.

1.3.3 Astromag System Description

The Astromag Attached Payload, or Astromag, is the space segment part of the Astromag Facility (Figure 1-2). Astromag includes the Core Facility, Experiments, Attached Payload Accommodation Equipment (APAE), and Support Equipment. The current Astromag conceptual design includes three subsystems located on a two-truss bay outrigger on the zenith face of the S. S. Freedom Main Boom (Figure 1-3). The three subsystems are the Core Facility and two Experiments. Each Experiment is attached to one end of the Core Facility. The Experiments include equipment for the data system, power electronics, and thermal distribution system. The heat rejection system for the Core Facility and its Experiments, is yet to be defined. Whether any of the mechanisms will require thermal interfaces will be determined through further studies.

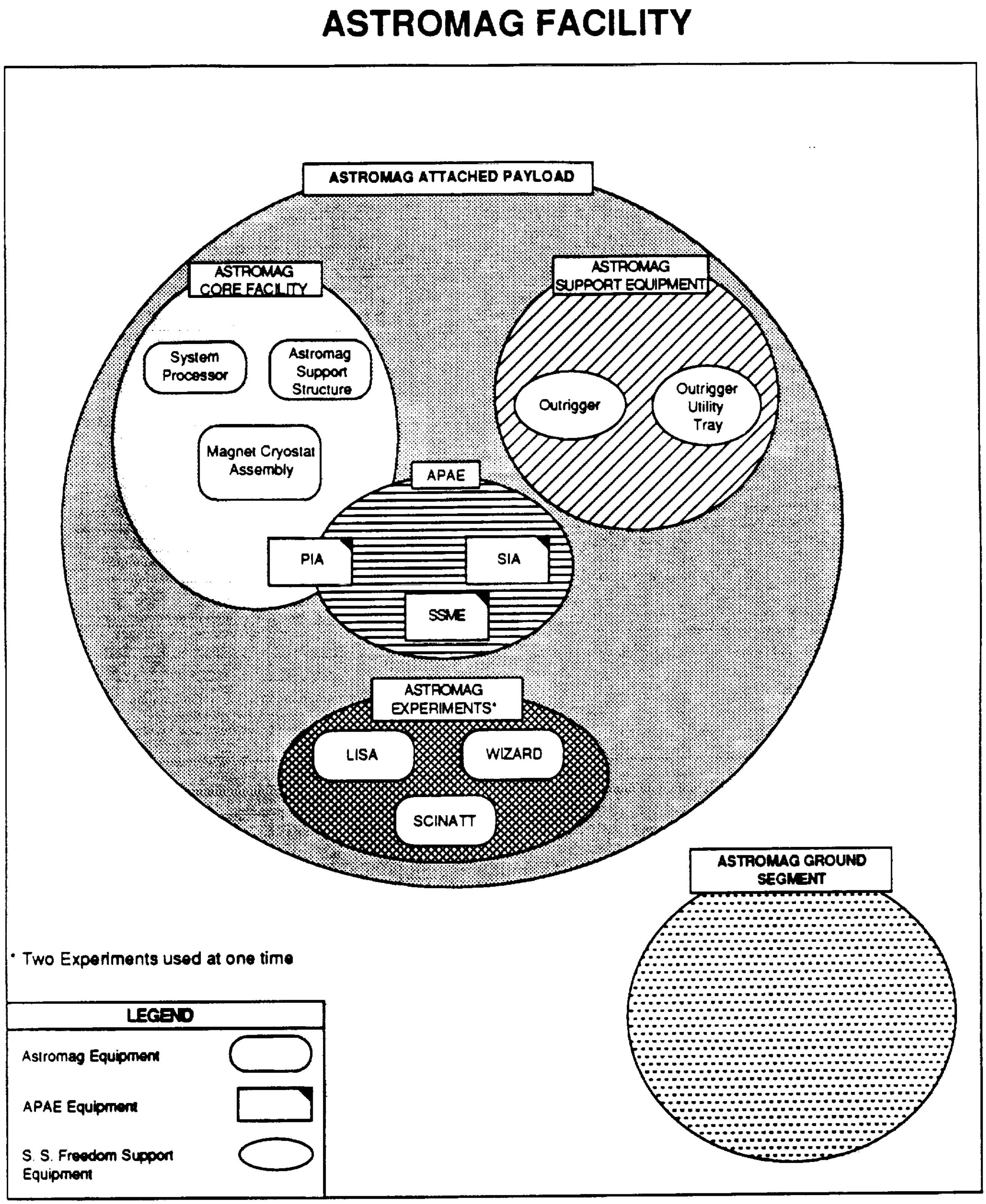
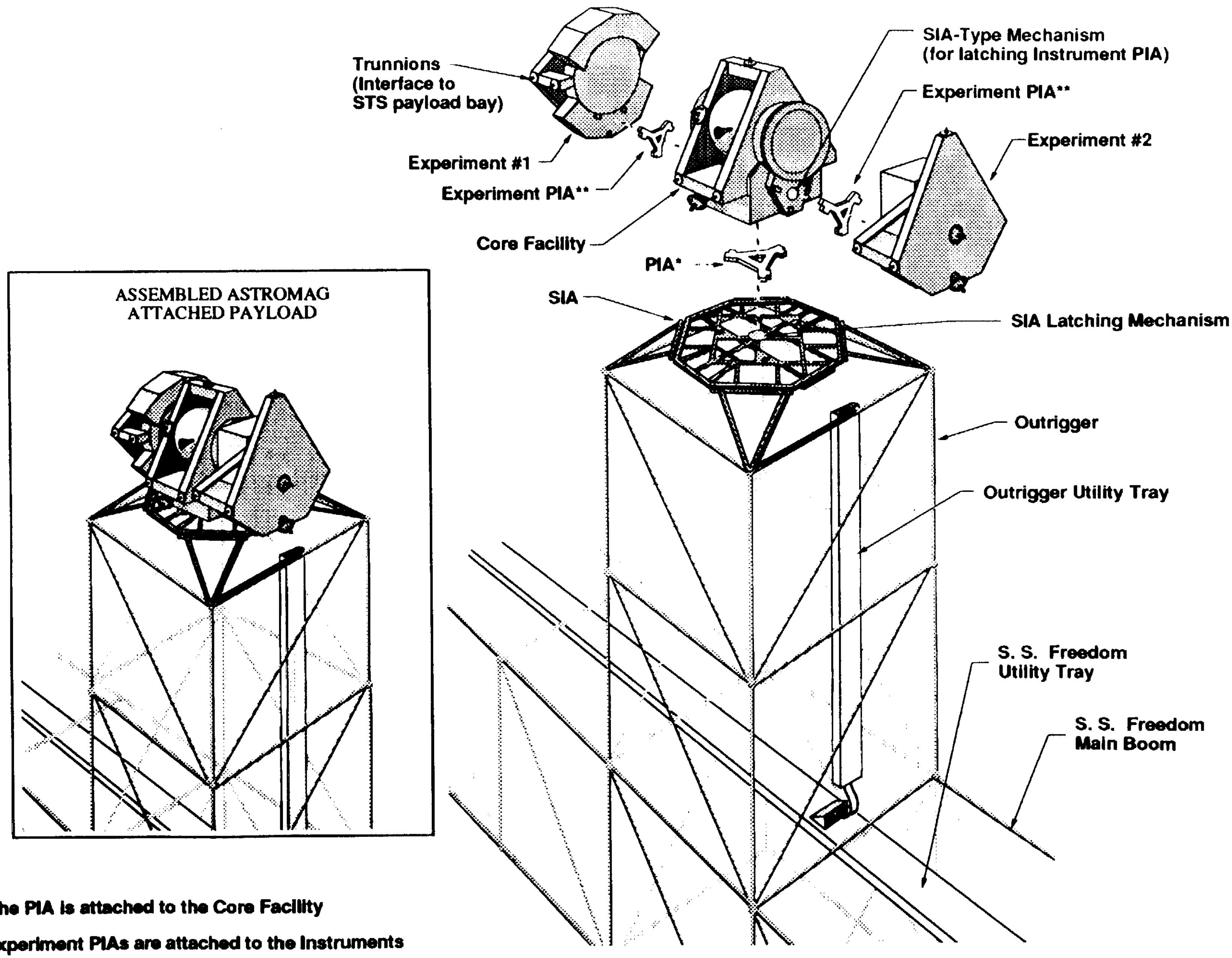


Figure 1-2. Astromag Attached Payload Terminology



* **The PIA is attached to the Core Facility**

** **Experiment PIAs are attached to the Instruments**

Figure 1-3. Assembled and Exploded Views of the Astromag Attached Payload

The Core Facility includes a Magnet-Cryostat Assembly that consists of two superconducting coils and a helium-filled dewar which cool the coils. Astromag subsystems are controlled by a system processor unit which includes the central data processor, and power and thermal (if required) distribution equipment.

The Core Facility interfaces with the S. S. Freedom through the use of two types of equipment, the outrigger and Attached Payload Accommodation Equipment (APAE). The Astromag outrigger consists of two truss bays which extends normal from the main boom in the zenith direction. APAE components, currently developed by Work Package 3, are attached to the outrigger. APAE includes the Station Interface Adapter (SIA) which is attached to the zenith face of the outermost outrigger truss bay. Another APAE component in the Astromag system is the Payload Interface Adapter (PIA) used for structural, power, and data interface to the SIA . The PIA is attached to the underside of the Core Facility prior to launch. The Core Facility, with PIA, is installed on the SIA which contains SIA latching mechanisms, and the active half of the PIA/SIA interface. The Core Facility also contains Power and Data Grapple Fixtures (PDGFs), which allow interface with the SSRMS and MSC.

The Experiments also include PDGFs for use as a grappling interface. For interface to the Core Facility, the Experiments contain Core Facility latching mechanisms. In the current Astromag configuration, the Core Facility/Experiment latching interface consists of PIA and SIA-type latching hardware. The Experiment PIAs provide commonality with other S. S. Freedom equipment. Use of a modified PIA for this interface avoids the development of a new, customized, latching device for the Experiments.

2. APPROACH AND METHODOLOGY

This section contains the assembly and servicing related derived requirements for the Astromag Attached Payload. Also proved in this section is the approach taken to develop the assembly and servicing concepts

2.1 DERIVED REQUIREMENTS FOR ASSEMBLY AND SERVICING

Derived requirements concerning the assembly and servicing of Astromag are generated from the following fundamental requirements for the Astromag Phase A Study concept:

- Astromag shall be based on the S. S. Freedom.
- Astromag shall be launched and retrieved by the STS.
- Astromag shall be configured to enable periodic on-orbit Experiment exchanges.

Given the above conditions, additional requirements may be derived to drive the design and operations for the Phase A Study concept. The following requirements are derived for Astromag assembly and servicing operations:

- Astromag shall interface with APAE for structural and utilities interface with S. S. Freedom.
- Astromag components shall interface with the MSC and SSRMS for assembly and servicing operations.
- Astromag shall be designed so that Experiment changeout may be performed by the Servicing Support Systems (i. e., MSC, SSRMS) on the baseline station.
- All automated latching mechanisms shall have EVA back-up capability for EVA manual operation.

In this report, S. S. Freedom Servicing Support Systems are the MSC, SSRMS, FTS, and EVA and IVA crewmembers and support equipment.

Given the requirements stated above and the general Astromag design concept, on-orbit attached payload assembly and servicing tasks required for Astromag during its operational lifetime are as follows:

Assembly of Astromag

- Installation of the Core Facility
- Installation of Experiments

Planned Servicing of Astromag

- Changeout of Experiments
- Replenishment of Cryogen (not covered in this report)

These tasks are required, assuming that the outrigger truss extension and SIA have been previously installed. This document does not address the cryogen replenishment task due to changing mission requirements. The prerequisite for all Astromag assembly and servicing activities is that, prior to conducting these operations, the magnet is powered down so there is no current in the coils and no magnetic field around the payload during servicing activities.

2.2 APPROACH

The methodology followed in developing Astromag assembly and servicing concepts is illustrated in Figure 4-2. This approach essentially integrates the S. S. Freedom servicing system with the Astromag configuration and servicing requirements. This, in turn, is the basis for the recommended servicing concepts, and scenario scripts.

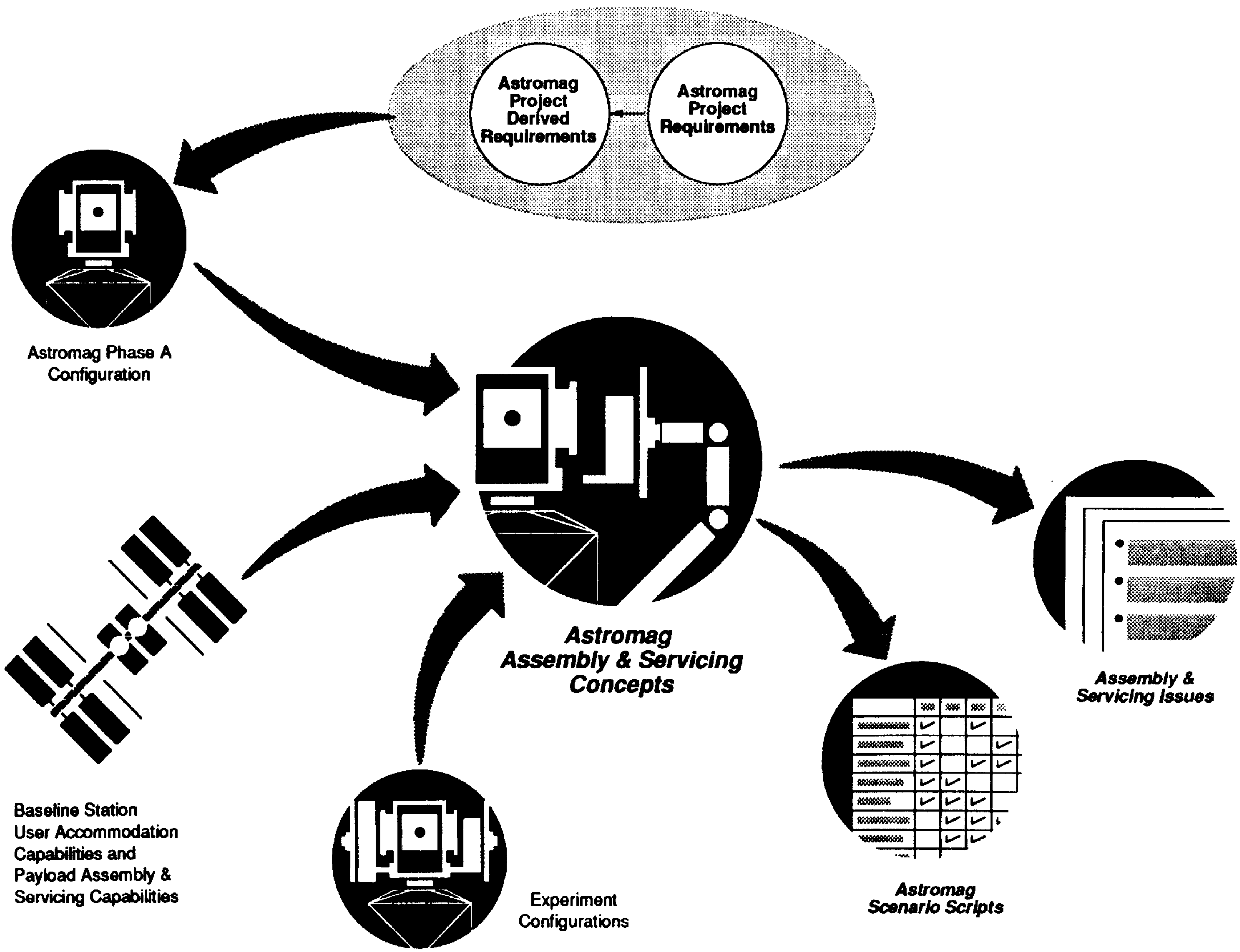


Figure 2-1. Approach to Development of Astromag Assembly and Servicing Concepts

3. ASTROMAG MECHANISMS AND S. S. FREEDOM SERVICING SUPPORT SYSTEM INTERFACES

The Astromag Phase A configuration includes hardware provisions for the assembly and servicing of Astromag. Mechanisms for payload components are included to provide structural and utilities interfaces.

3.1 ASTROMAG S. S. FREEDOM SERVICING INTERFACES

During assembly and servicing activities, many Astromag and station Servicing Support Systems components are required to interface:

- Core Facility and Experiment Trunnions-to-STS longeron and keel fittings
- SSRMS Latching End Effector (LEE)-to-PDGF
- MSC Payload/ORU Accommodation (POA) LEE-to-PDGF
- PIA-to-SIA latching mechanism
- Experiment PIA-to-"SIA-type" latching mechanism

There are four types of interface mechanisms on the Astromag Attached Payload: 1) Longeron and Keel Trunnions, 2) PDGF, 3) PIA/SIA latch, and 4) the Experiment PIA/SIA-type latch (see Figure 1-2).

The longeron and keel trunnions are located on the Core Facility and Experiments for interface with the active longeron fittings (remotely actuated) and keel fittings in the STS payload bay. These fittings secure STS payloads containing trunnions during launch, flight, and landing. An IVA crewmember located at the STS Aft Flight Deck (AFD) Workstation, controls the actuation of the active longeron fittings.

The attachment mechanism required for the interface between the SSRMS and the Core Facility is a PDGF located on the Core Facility's external support structure. The SSRMS grappling device, the LEE, is a snare and rigidize mechanism and an externally mounted latching and connector mechanism. The SSRMS handles and provides utilities for station components containing a PDGF. PDGFs are also located on the Experiments so that they may be grappled by the SSRMS.

The MSC has the capability to transport equipment that contain PDGFs, such as station or attached payload ORUs. MSC transport of Astromag components may be performed by attaching the Core Facility or Experiment to one of two POAs. The POA contains an LEE, similar to that of the SSRMS, allowing the POA to grapple a payload for transport on the MSC. A PDGF on the Core Facility and each Experiment will interface with the MSC POA. Through a PDGF, the SSRMS or MSC POA can provide utilities (if required) for survival power and data, or monitoring health and status of the Core Facility or Experiment during servicing operations. As with most large station components, the Experiments and Core Facility contain at least two PDGFs, so that the component may be grappled by the SSRMS (first PDGF) and attached to the MSC POA for grappling during transport (second PDGF).

As stated in Section 1.3.3, the PIA (and SIA latch) is the attachment mechanism concept for the interface between the Core Facility and the SIA. At the Astromag operational site, the SSRMS installs the Core Facility on the SIA. The SIA contains a motorized latching mechanism that is remotely activated by an IVA crewmember in the S. S. Freedom pressurized environment. The SIA latching mechanism includes the capability for EVA back-up by manual actuation. Specific details concerning the tools and operations required to perform this back-up activity will be developed with the evolution of the PIA/SIA latch design concept.

The Experiment PIA (with SIA-type latch) is a concept envisioned for Astromag for the interface between the Experiments and Core Facility. The Core Facility side of this interface will contain a motorized latching mechanism for structural attachment and mating of connectors (similar to the SIA latch). If required, an additional thermal fluid connector may be included in the Experiment PIA design concept. The SIA-type latching mechanism on the Core Facility contains an EVA back-up capability.

4. ASTROMAG ASSEMBLY AND SERVICING OPERATIONS CONCEPTS

4.1 S. S. FREEDOM SERVICING SUPPORT SYSTEMS FOR REQUIRED ASTROMAG ASSEMBLY AND SERVICING TASKS

To perform Astromag assembly and servicing tasks, specific station Servicing Support Systems have been selected. Figure 4-1 is a matrix providing the required assembly and servicing tasks vs. the station Servicing Support Systems. Baseline Astromag tasks are performed by the MSC, SSRMS, and IVA crewmembers as presented in this document. Back-up activities are performed on failed automatic latching mechanisms. The capability for manual actuation of these failed mechanisms by EVA crewmembers using support tool(s), is a derived requirement. The FTS is envisioned to be used to actuate failed mechanisms to prevent the use of EVA. Detailed discussion of back-up activities are not presented in this document. As previously stated, the cryogen replenishment task is not covered in this report due to changing mission requirements.

4.2 ASSEMBLY AND SERVICING OPERATIONS CONCEPTS

This section contains top-level operations concepts developed for the Astromag assembly and servicing task requirements presented in Section 2.1. Discussion of each task includes assembly and servicing concepts, scenario script, and an illustrated summary of events. The assembly and servicing concepts assume that the Astromag components have been delivered to the S. S. Freedom by the STS. The station is assumed to have the Astromag outrigger and SIA already installed. It is assumed that the staging of contents in the STS payload bay, is performed by the SSRMS based on a fixed PDGF, or "fixed grapple", located on a habitation module. Although no decisions have been made concerning the method of STS staging on the station, this assumption is being used for analysis by NASA and contractor organizations in the S. S. Freedom Program. After staging operations, the SSRMS attaches its free end to the SSRMS Mounting Beam on the MSC, transferring its control base to the MSC. Thus, the SSRMS may begin performing MSC-based operations. Scenario element descriptions and specific assumptions for the development of the scenario concepts are provided in Appendix A.

Astromag Assembly and Servicing Requirements \ Servicing Support Systems and Equipment	MSC	SSRMS	FTS	EVA Crew	STS	IVA Crew (S.S. Freedom)	IVA Crew (STS)	Servicing Tools
ASTROMAG ASSEMBLY								
• Installation of Core Facility	●	●	✱ 1	✱ 2	●	●	●	✱ 1,2
• Installation of Instruments	●	●	✱ 1	✱ 2	●	●	●	✱ 1,2
ASTROMAG PLANNED SERVICING								
• Instrument Changeout	●	●	✱ 1	✱ 2	●	●	●	✱ 1,2

LEGEND:

● - Baseline Assembly and Servicing Activities

✱ - Back-up Activities (either FTS or EVA for manual operations of failed automated latching mechanisms)

1 - FTS Back-up Activities

2 - EVA Back-up Activities

**NOTE: Cryogen Replenishment Task not included here*

Figure 4-1. Assembly and Servicing Tasks vs. Servicing Support Systems

4.2.1 Assembly of the Astromag Attached Payload

Attached payload assembly operations are activities necessary to assemble (if applicable) and install the payload equipment on the station. Astromag is assembled and serviced in-situ. In-situ tasks include: 1) the installation of the Core Facility on the SIA, and 2) the installation of Experiments on the Core Facility.

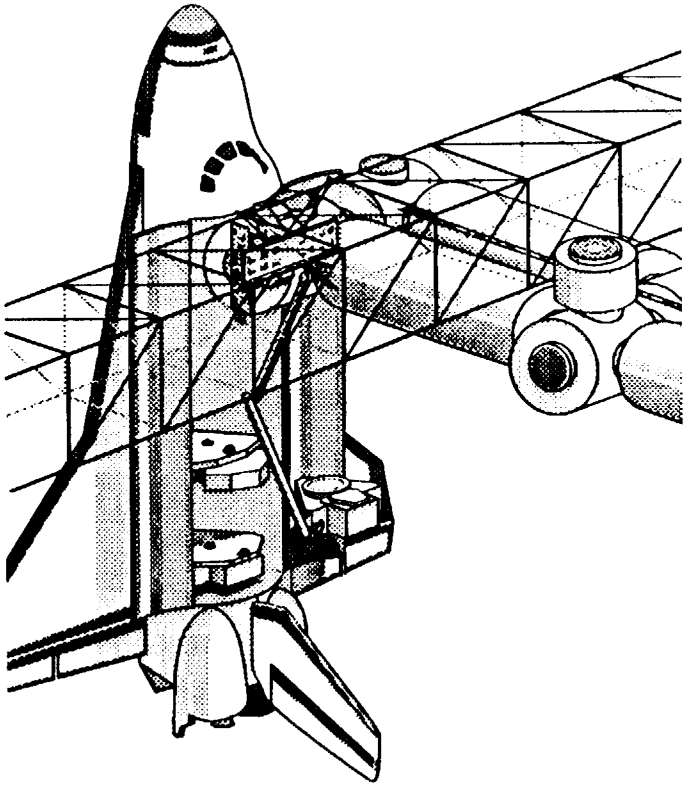
4.2.1.1 Installation of the Core Facility

The Core Facility installation task is performed remotely. The Core Facility is removed from the STS payload bay and placed on an MSC POA by an SSRMS based on a Fixed Grapple (PDGF on a habitation module). The SSRMS translates to the MSC by attaching its free end effector on the MSC SSRMS Mounting Beam. The SSRMS and Core Facility are transported to the outrigger. At the Astromag operational site, the SSRMS grapples the Core Facility (at a PDGF) and removes it from the MSC POA. The SSRMS then positions the Core Facility over the SIA and commences targeting and alignment activities. Installation is achieved as the latching mechanism is activated by an IVA command. Power for the latching operation is supplied to the SIA by the S. S. Freedom. Top-level steps performed for this assembly task are provided in Table 4-1. Figures 4-2 through 4-6 illustrate the operations for the installation of the Core Facility.

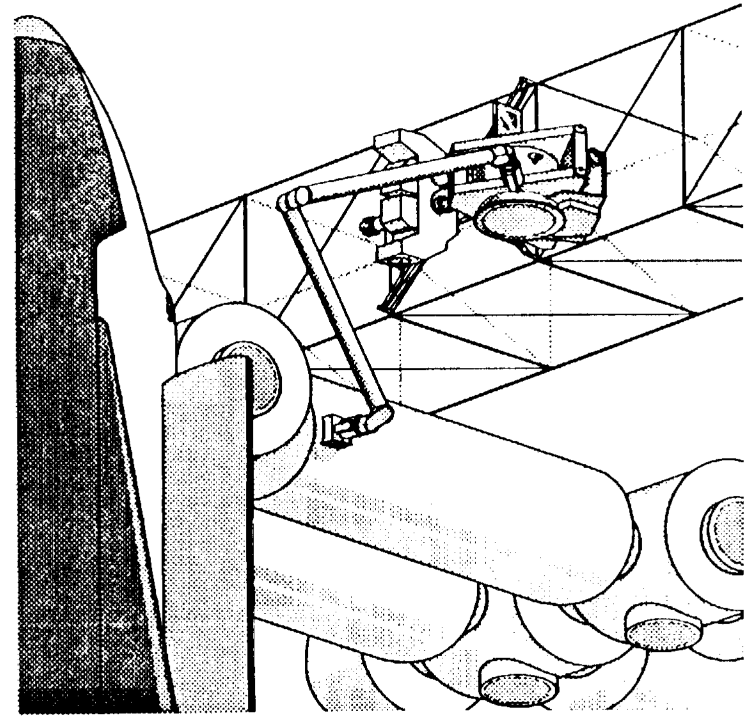
Personnel: IV-1 (in S. S. Freedom), IV-2 (in STS)
Servicing Elements: MSC, SSRMS
Astromag Components: Core Facility, SIA
Scenario Procedure:

1.	MSC:	Translate to STS docking area.
2.	SSRMS:	Grasp Core Facility in STS payload bay.
3.	IV-2:	Unlatch Core Facility from STS via active longeron fittings.
4.	SSRMS:	Remove Core Facility from STS payload bay.
5.	SSRMS:	Position Core Facility at MSC POA #1.
6.	SSRMS:	Install Core Facility on MSC POA #1.
7.	IV-1:	Latch Core Facility to MSC POA #1.
8.	SSRMS:	Release Core Facility.
9.	SSRMS:	Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC).
10.	SSRMS:	Release Fixed Grapple on habitation module.
11.	SSRMS:	Position for MSC translation.
12.	MSC:	Translate to Astromag outrigger main boom truss bay.
13.	MSC:	Turn corner onto outrigger.
14.	MSC:	Translate to Astromag operational site.
15.	SSRMS:	Grasp Core Facility on MSC POA #1.
16.	IV-1:	Unlatch Core Facility from MSC POA #1.
17.	SSRMS:	Remove Core Facility from MSC POA #1.
18.	SSRMS:	Position Core Facility at SIA.
19.	SSRMS:	Install Core Facility on SIA.
20.	IV-1:	Latch Core Facility to SIA.
21.	SSRMS:	Release Core Facility.
22.	IV-1:	Perform check-out of Core Facility.
23.	SSRMS:	Position for MSC translation.
24.	MSC:	Translate to main boom.
25.	MSC:	Turn corner at main boom.
26.	MSC:	Translate to MSC standby location.

Table 4-1. Scenario Script for the Installation of the Astromag Core Facility

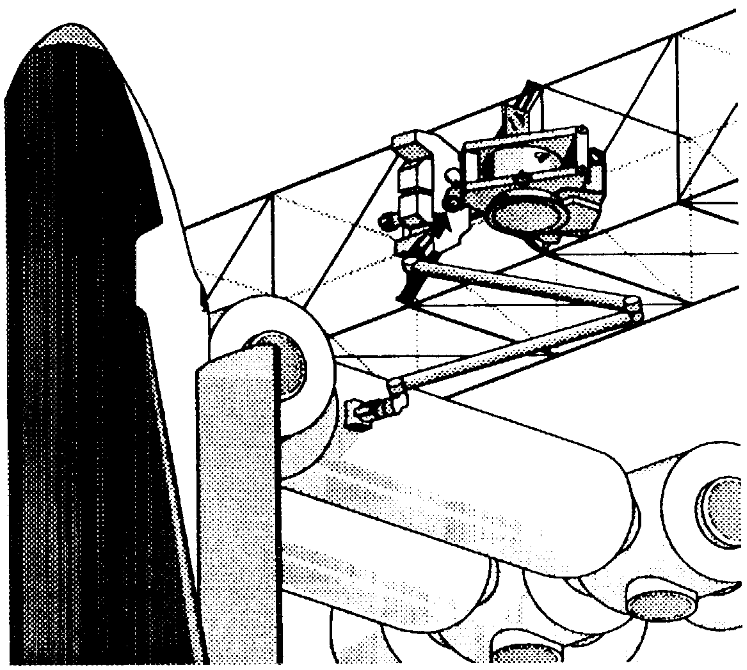


1. MSC: Translate to STS docking area
2. SSRMS: Grasp Core Facility in STS payload bay
3. IV-2: Unlatch Core Facility from STS via automated latching mechanisms
4. SSRMS: Remove Core Facility from STS payload bay

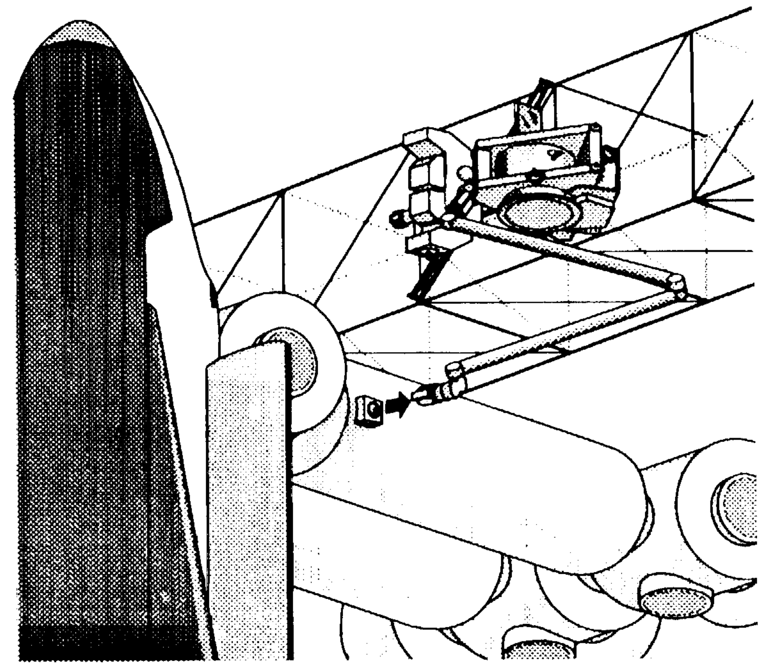


5. SSRMS: Position Core Facility at MSC POA #1
6. SSRMS: Install Core Facility on MSC POA #1
7. IV-1: Latch Core Facility to MSC POA #1
8. SSRMS: Release Core Facility

Figure 4-2. Illustrated Scenario of Installation of Astromag Core Facility



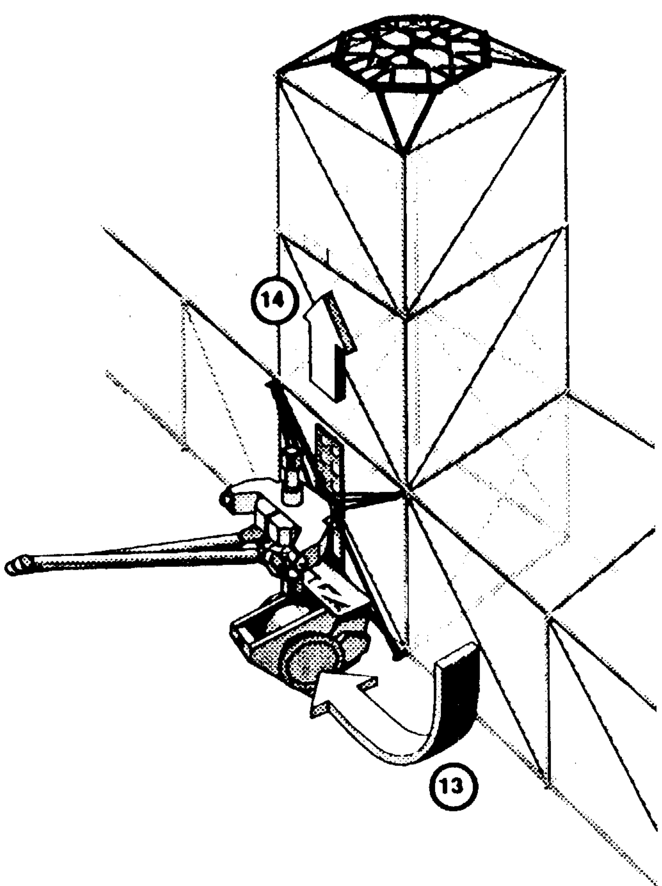
9. SSRMS: Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC)



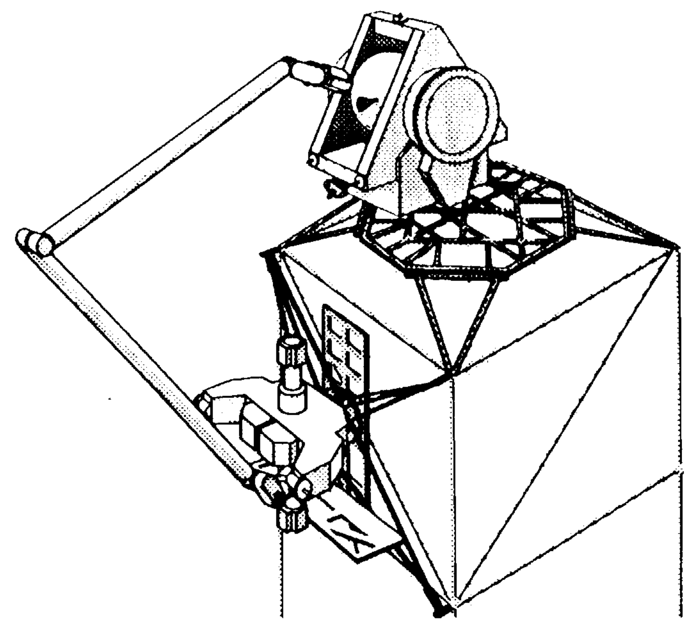
10. SSRMS: Release Fixed Grapple on habitation module

11. SSRMS: Position for MSC translation

Figure 4-3. Illustrated Scenario of Installation of Astromag Core Facility (cont'd)

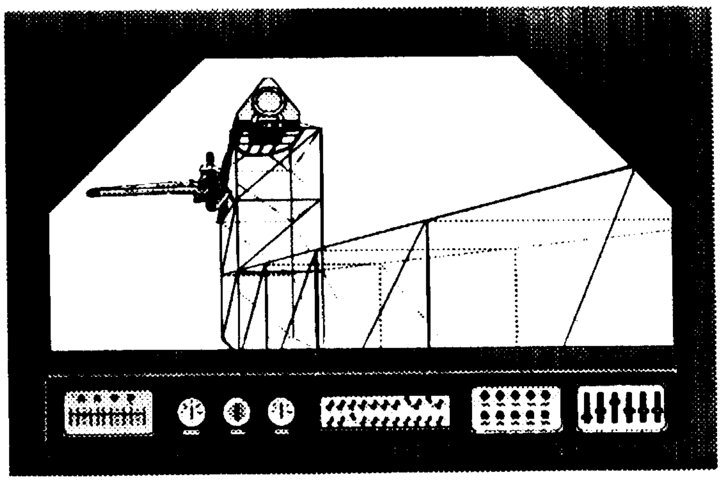


12. MSC: Translate to Astromag outrigger main boom truss bay
13. MSC: Turn corner onto outrigger
14. MSC: Translate to Astromag operational site

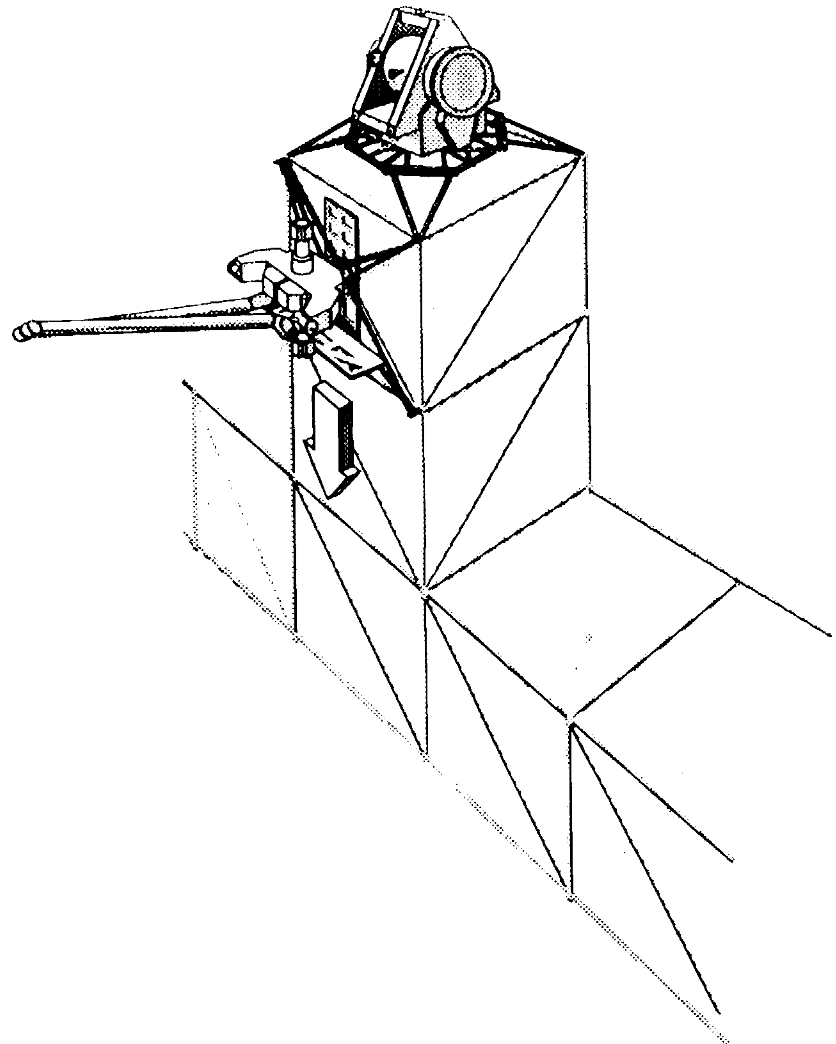


15. SSRMS: Grasp Core Facility on MSC POA #1
16. IV-1: Unlatch Core Facility from MSC POA #1
17. SSRMS: Remove Core Facility from MSC POA #1
18. SSRMS: Position Core Facility at SIA
19. SSRMS: Install Core Facility on SIA
20. IV-1: Latch Core Facility to SIA
21. SSRMS: Release Core Facility

Figure 4-4. Illustrated Scenario of Installation of Astromag Core Facility (cont'd)



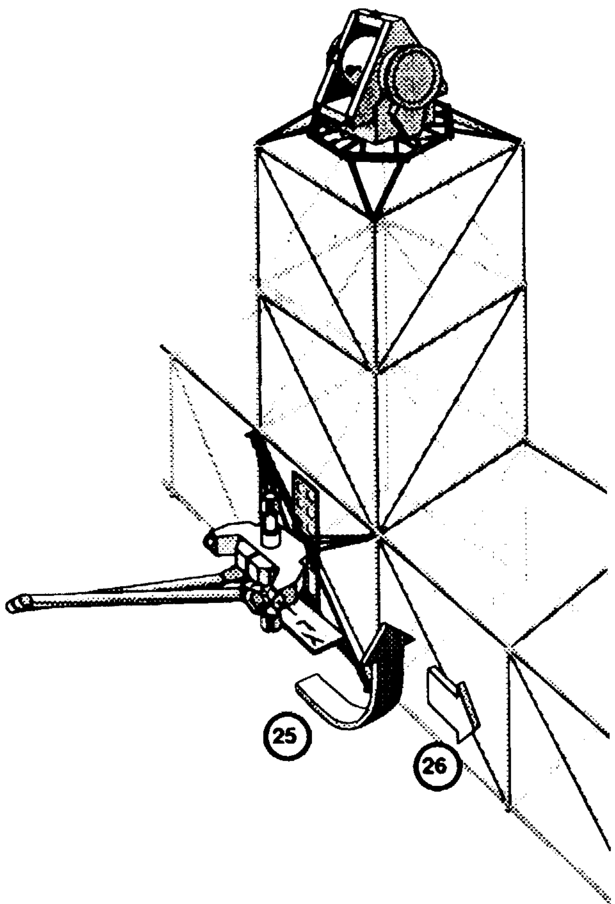
22. IV-1: Perform check-out of Core Facility



23. SSRMS: Position for MSC translation

24. MSC: Translate to main boom

Figure 4-5. Illustrated Scenario of Installation of Astromag Core Facility (cont'd)



25. MSC: Turn corner at main boom

26. MSC: Translate to MSC standby location

Figure 4-6. Illustrated Scenario of Installation of Astromag Core Facility (cont'd)

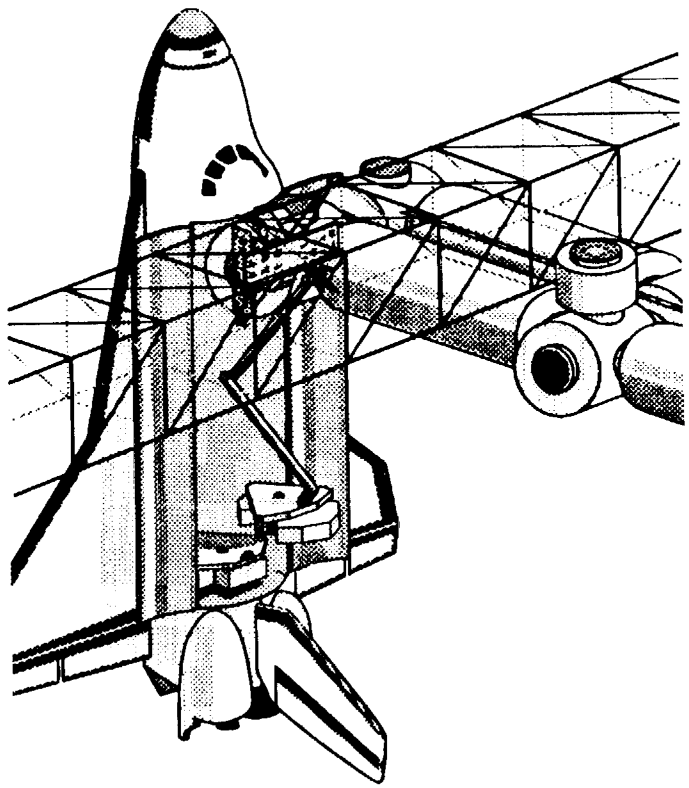
4.2.1.2 Installation of Astromag Experiments

The Experiment installation task is performed remotely. Each Experiment is removed from the STS payload bay and placed on an MSC POA (POA #1 and POA #2) by an SSRMS based on a Fixed Grapple (PDGF on a habitation module). The SSRMS translates to the MSC by attaching its free end effector on the MSC SSRMS Mounting Beam. The SSRMS and the two Experiments are transported to the outrigger. At the Astromag operational site, the SSRMS positions an Experiment near one of the two side faces of the Core Facility. The Core Facility/Experiment interface concept is an Experiment PIA and SIA-type latch. The SSRMS aligns the Experiment directly to the SIA-type latch which is actuated by an IVA command. Power for this operation is supplied to the latching mechanism by the Core Facility (which obtains its power from the S. S. Freedom utility loop through the APAE). Top-level steps for this assembly task are provided in Table 4-2. Figures 4-7 through 4-13 illustrate the operations developed for the installation of Experiments on the Core Facility.

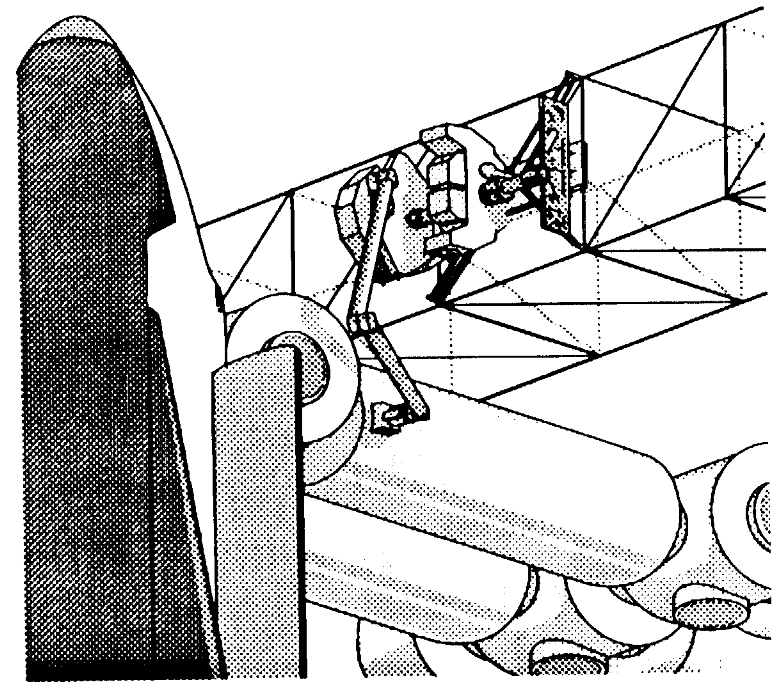
Personnel:	IV-1 (in Freedom), IV-2 (in STS)
Servicing Elements:	MSC (with SSRMS)
Astromag Components:	Experiment #1, Experiment #2, Core Facility
Scenario Procedure:	

1. MSC: Translate to STS docking area.
2. SSRMS: Grasp Experiment #1 in STS payload bay.
3. IV-2: Unlatch Experiment #1 from STS via active longeron fittings
4. SSRMS: Remove Experiment #1 from STS payload bay.
5. SSRMS: Position Experiment #1 at MSC POA #1.
6. SSRMS: Install Experiment #1 on MSC POA #1.
7. IV-1: Latch Experiment #1 to MSC POA #1.
8. SSRMS: Release Experiment #1.
9. SSRMS: Grasp Experiment #2 in STS payload bay.
10. IV-2: Unlatch Experiment #2 from STS via active longeron fittings
11. SSRMS: Remove Experiment #2 from STS payload bay.
12. SSRMS: Position Experiment #2 at MSC POA #2.
13. SSRMS: Install Experiment #2 on MSC POA #2.
14. IV-1: Latch Experiment #2 to MSC POA #2.
15. SSRMS: Release Experiment #2.
16. SSRMS: Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC)
17. SSRMS: Release Fixed Grapple on habitation module
18. SSRMS: Position for MSC translation.
19. MSC: Translate to Astromag outrigger main boom truss bay.
20. MSC: Turn corner onto outrigger.
21. MSC: Translate to Astromag operational site.
22. SSRMS: Grasp Experiment #1.
23. IV-1: Unlatch Experiment #1 from MSC POA #1.
24. SSRMS: Remove Experiment #1 from MSC POA #1.
25. SSRMS: Position Experiment #1 at Core Facility.
26. SSRMS: Install Experiment #1 to Core Facility.
27. IV-1: Latch Experiment #1 to Core Facility.
28. SSRMS: Release Experiment #1.
29. IV-1: Perform check-out of Experiment #1.
30. SSRMS: Grasp Experiment #2.
31. IV-1: Unlatch Experiment #2 from MSC POA #2.
32. SSRMS: Remove Experiment #2 from MSC POA #2.
33. SSRMS: Position Experiment #2 at Core Facility.
34. SSRMS: Install Experiment #2 to Core Facility.
35. IV-1: Latch Experiment #2 to Core Facility.
36. SSRMS: Release Experiment #2.
37. IV-1: Perform check-out of Experiment #2.
38. SSRMS: Position for MSC translation.
39. MSC: Translate to main boom.
40. MSC: Turn corner at main boom.
41. MSC: Translate to MSC standby location.

Table 4-2. Scenario Script for the Installation of Astromag Experiments

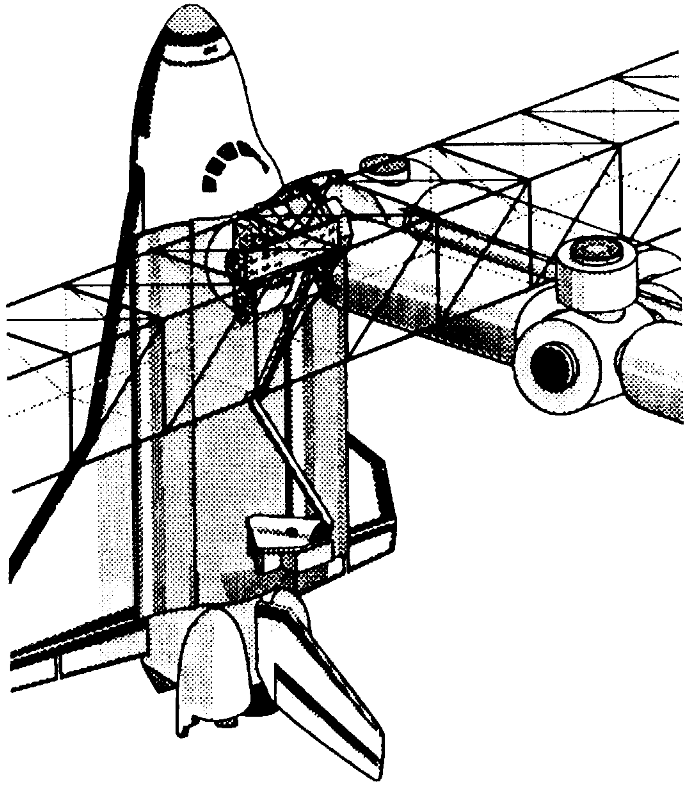


1. MSC: Translate to STS docking area
2. SSRMS: Grasp Experiment #1 in STS payload bay
3. IV-2: Unlatch Experiment #1 from STS via automated latching mechanisms
4. SSRMS: Remove Experiment #1 from STS payload bay



5. SSRMS: Position Experiment #1 at MSC POA #1
6. SSRMS: Install Experiment #1 on MSC POA #1
7. IV-1: Latch Experiment #1 to MSC POA #1
8. SSRMS: Release Experiment #1

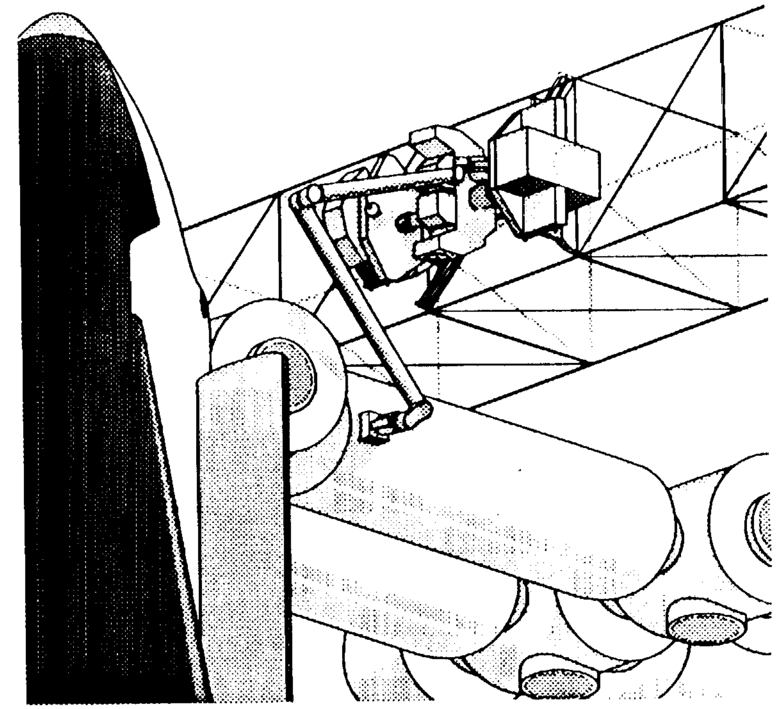
Figure 4-7. Illustrated Scenario of Installation of Astromag Experiments



9. SSRMS: Grasp Experiment #2 in STS payload bay

10. IV-2: Unlatch Experiment #2 from STS via automated latching mechanisms

11. SSRMS: Remove Experiment #2 from STS payload bay



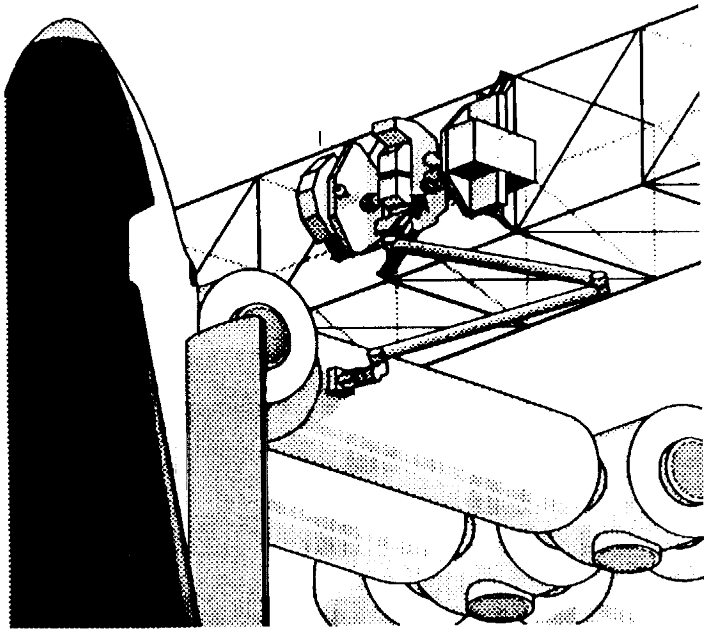
12. SSRMS: Position Experiment #2 at MSC POA #2

13. SSRMS: Install Experiment #2 on MSC POA #2

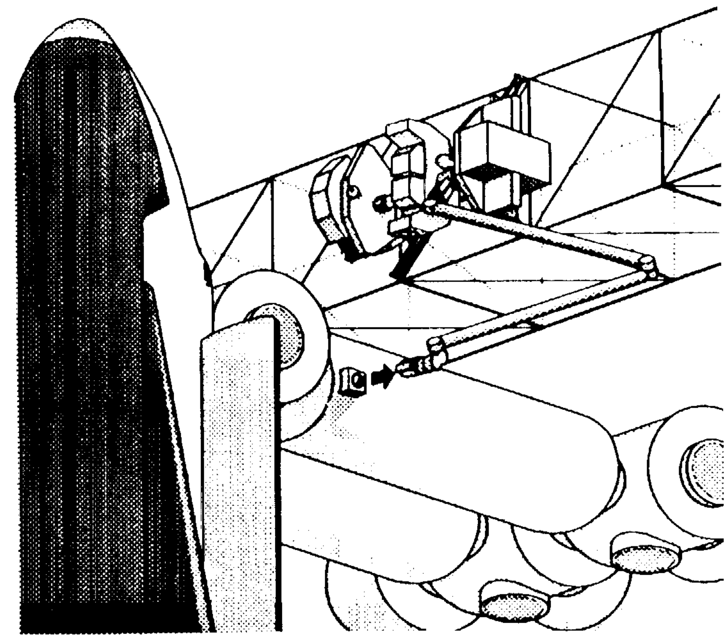
14. IV-1: Latch Experiment #2 to MSC POA #2

15. SSRMS: Release Experiment #2

Figure 4-8. Illustrated Scenario of Installation of Astromag Experiments (cont'd)



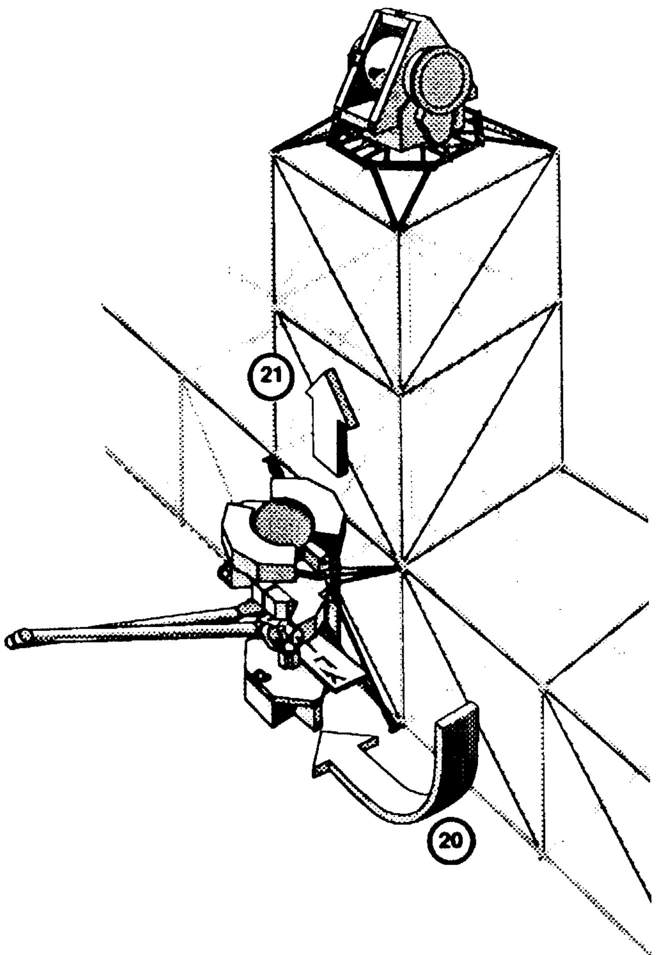
16. SSRMS: Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC)



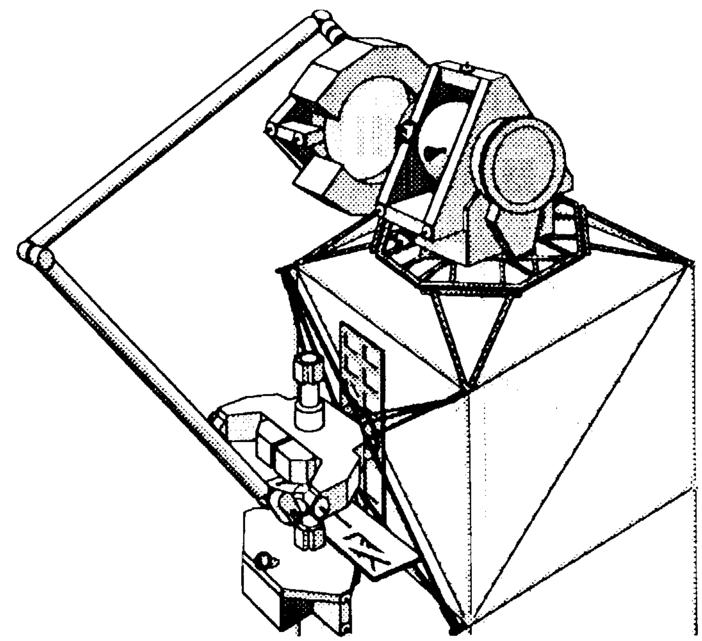
17. SSRMS: Release Fixed Grapple on habitation module

18. SSRMS: Position for MSC translation

Figure 4-9. Illustrated Scenario of Installation of Astromag Experiments (cont'd)

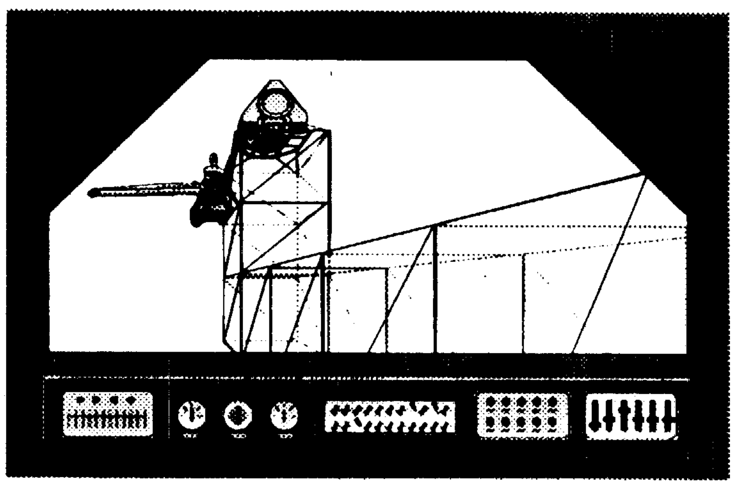


19. MSC: Translate to Astromag outrigger main boom truss bay
20. MSC: Turn corner onto outrigger
21. MSC: Translate to Astromag operational site

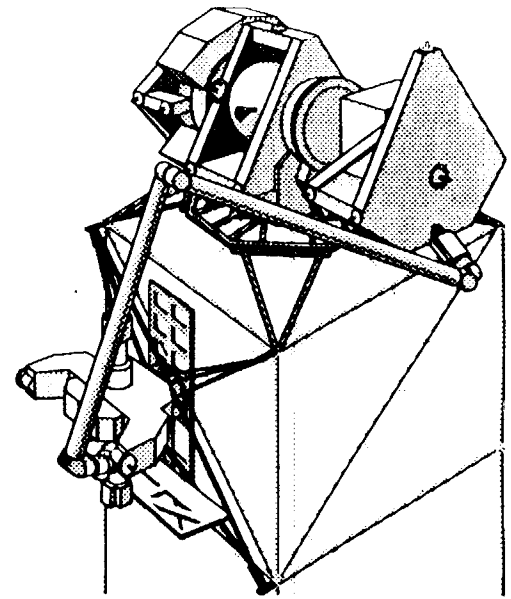


22. SSRMS: Grasp Experiment #1
23. IV-1: Unlatch Experiment #1 from MSC POA #1
24. SSRMS: Remove Experiment #1 from MSC POA #1
25. SSRMS: Position Experiment #1 at Core Facility
26. SSRMS: Install Experiment #1 to Core Facility
27. IV-1: Latch Experiment #1 to Core Facility
28. SSRMS Release Experiment #1

Figure 4-10. Illustrated Scenario of Installation of Astromag Experiments (cont'd)

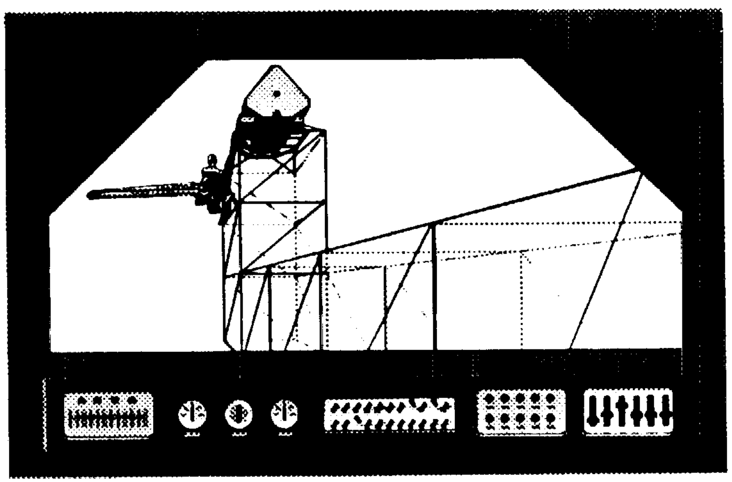


29. IV-1: **Perform check-out of Experiment #1**

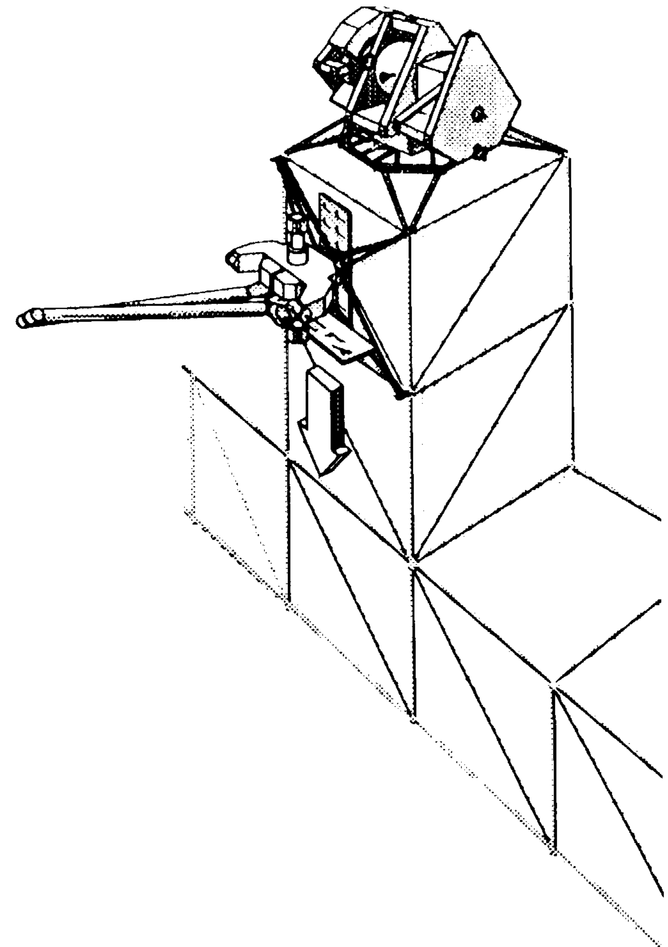


30. SSRMS: Grasp Experiment #2
31. IV-1: Unlatch Experiment #2 from MSC POA #2
32. SSRMS: Remove Experiment #2 from MSC POA #2
33. SSRMS: Position Experiment #2 at Core Facility
34. SSRMS: Install Experiment #2 to Core Facility
35. IV-1: Latch Experiment #2 to Core Facility
36. SSRMS: Release Experiment #2

Figure 4-11. Illustrated Scenario of Installation of Astromag Experiments (cont'd)



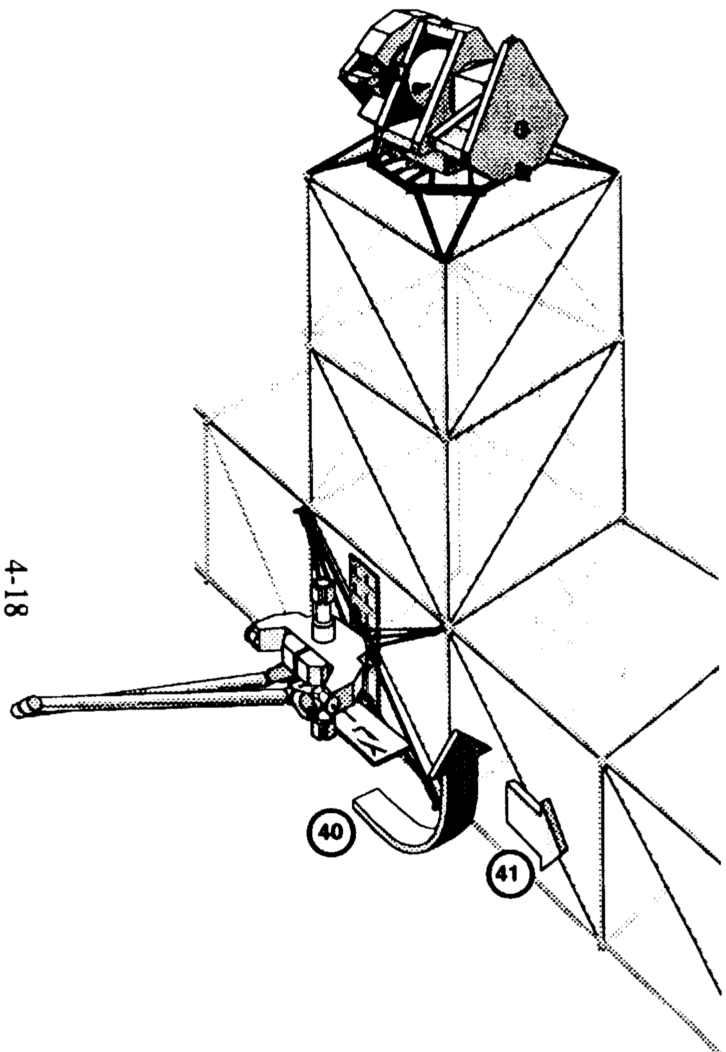
37. IV-1: Perform check-out of Experiment #2.



38. SSRMS: Position for MSC translation

39. MSC: Translate to main boom

Figure 4-12. Illustrated Scenario of Installation of Astromag Experiments (cont'd)



40. MSC: Turn corner at main boom

41. MSC: Translate to MSC standby location

Figure 4-13. Illustrated Scenario of Installation of Astromag Experiments (cont'd)

4.2.2 Planned Servicing of the Astromag Attached Payload

Planned attached payload servicing operations are activities which are conducted to extend the lifetime of the payload. Examples of these operations include the changeout, inspection, and cleaning of payload equipment. Astromag servicing activities include Experiment changeout on the Core Facility (Cryogen replenishment of the Core Facility is considered as servicing, however it is not discussed in this report).

4.2.2.1 Changeout of Astromag Experiments

Experiments located on the Core Facility are replaced as a planned servicing activity so that other experimenters may utilize the Core Facility's magnetic field. The changeout of Experiments is performed remotely. The new Experiment is removed from the STS payload bay and placed on an MSC POA (POA #1) by an SSRMS based on a Fixed Grapple (PDGF on a habitation module). The SSRMS translates to the MSC by attaching its free end effector on the MSC SSRMS Mounting Beam. The SSRMS and new Experiment are transported to the outrigger. At the Astromag operational site, the SSRMS removes the old Experiment from the Core Facility and installs it on MSC POA #2. POA #2 is used as a holding site for the old Experiment during the changeout operations. The SSRMS then installs the new Experiment on the Core Facility. The MSC transports the old Experiment to the STS staging area. The SSRMS transfers its control base to the Fixed Grapple for STS loading operations. Finally, the old Experiment is installed into the STS payload bay for return to ground. Top-level steps performed this servicing task are provided in Table 4-3. Figures 4-14 through 4-20 illustrate the operations developed for the changeout of the Experiments on the Core Facility.

Personnel:	IV-1 (in Freedom), IV-2 (in STS)
Servicing Elements:	MSC (with SSRMS)
Astromag Components:	New Experiment, Old Experiment, Core Facility

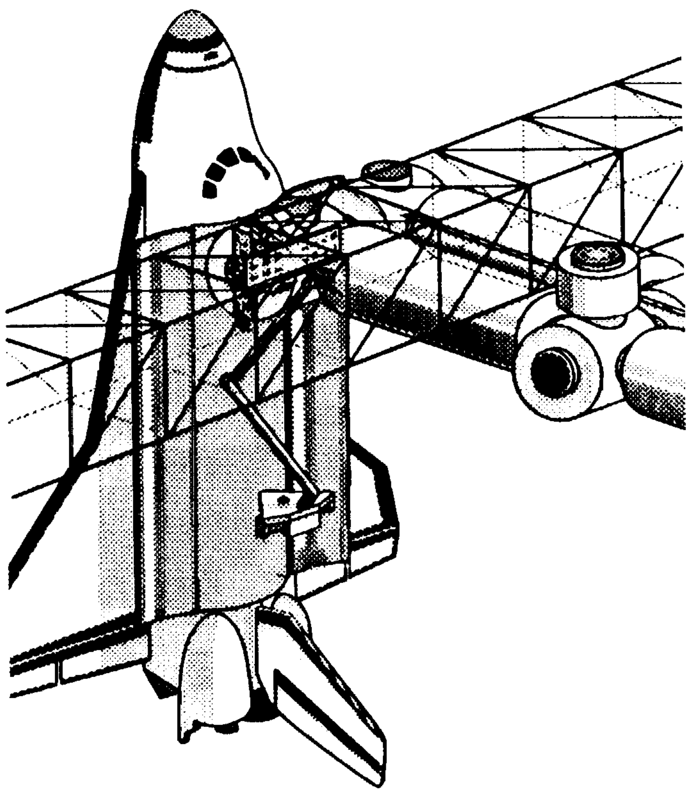
Scenario Procedure:

1.	MSC:	Translate to STS docking area.
2.	SSRMS:	Grasp New Experiment in STS payload bay.
3.	IV-2:	Unlatch New Experiment from STS via active longeron fittings.
4.	SSRMS:	Remove New Experiment from STS payload bay.
5.	SSRMS:	Position New Experiment at MSC POA #1.
6.	SSRMS:	Install New Experiment on MSC POA #1.
7.	IV-1:	Latch New Experiment to MSC POA #1.
8.	SSRMS:	Release New Experiment.
9.	SSRMS:	Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC).
10.	SSRMS:	Release Fixed Grapple on habitation module.
11.	SSRMS:	Position for MSC translation.
12.	MSC:	Translate to Astromag outrigger main boom truss bay.
13.	MSC:	Turn corner onto outrigger.
14.	MSC:	Translate to Astromag operational site.
15.	SSRMS:	Grasp Old Experiment on Core Facility.
16.	IV-1:	Unlatch Old Experiment from Core Facility.
17.	SSRMS:	Remove Old Experiment from Core Facility.
18.	SSRMS:	Position Old Experiment at MSC POA #2.
19.	SSRMS:	Install Old Experiment to MSC POA #2.
20.	IV-1:	Latch Old Experiment to MSC POA #2.
21.	SSRMS:	Release Old Experiment.
22.	SSRMS:	Grasp New Experiment on MSC POA #1.
23.	IV-1:	Unlatch New Experiment from MSC POA #1.
24.	SSRMS:	Remove New Experiment from MSC POA #1.
25.	SSRMS:	Position New Experiment at Core Facility.
26.	SSRMS:	Install New Experiment to Core Facility.
27.	IV-1:	Latch New Experiment to Core Facility.
28.	SSRMS:	Release New Experiment.
29.	IV-1:	Perform check-out of New Experiment.

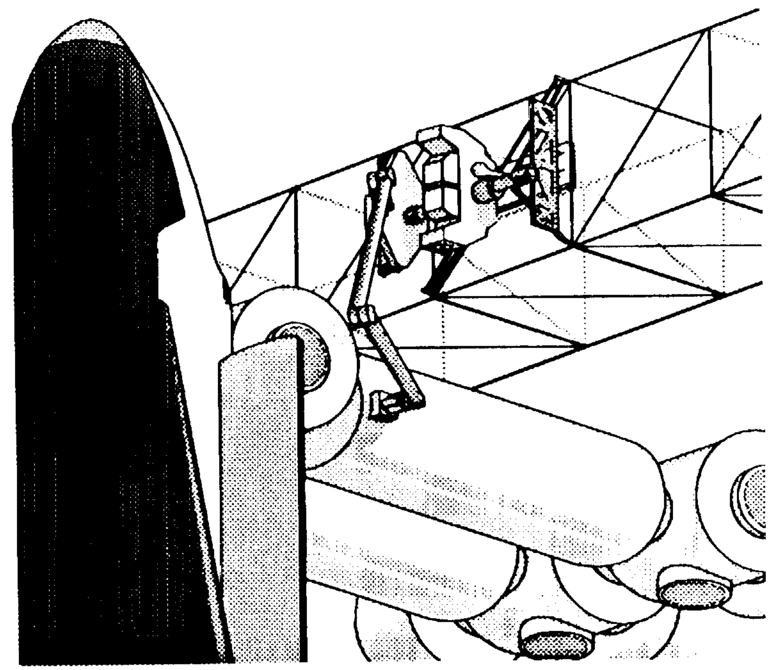
Table 4-3. Scenario Script for the Changeout of Astromag Experiments

30.	SSRMS:	Position for MSC translation.
31.	MSC:	Translate to main boom.
32.	MSC:	Turn corner at main boom.
33.	MSC:	Translate to STS docking area.
34.	SSRMS:	Grasp Fixed Grapple on habitation module (transfer control base to PDGF on habitation module).
35.	SSRMS:	Release SSRMS Mounting Beam on MSC.
36.	SSRMS:	Grasp Old Experiment on MSC POA #2.
37.	IV-1:	Unlatch Old Experiment from MSC POA #2.
38.	SSRMS:	Remove Old Experiment from MSC POA #2.
39.	SSRMS:	Position Old Experiment at STS payload bay.
40.	SSRMS:	Install Old Experiment on STS payload bay.
41.	IV-2:	Latch Old Experiment to STS via active longeron fittings.
42.	SSRMS:	Release Old Experiment.
43.	SSRMS:	Position for MSC translation.
44.	MSC:	Translate to MSC standby location.

Table 4-3. Scenario Script for the Changeout of Astromag Experiments (cont'd)

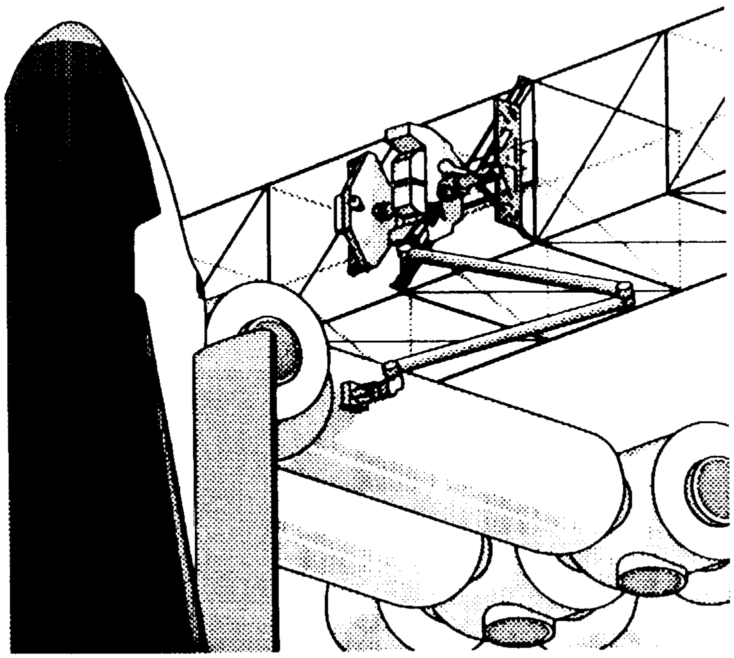


1. MSC: Translate to STS docking area
2. SSRMS: Grasp New Experiment in STS payload bay
3. IV-2: Unlatch New Experiment from STS via automated latching mechanisms
4. SSRMS: Remove New Experiment from STS payload bay

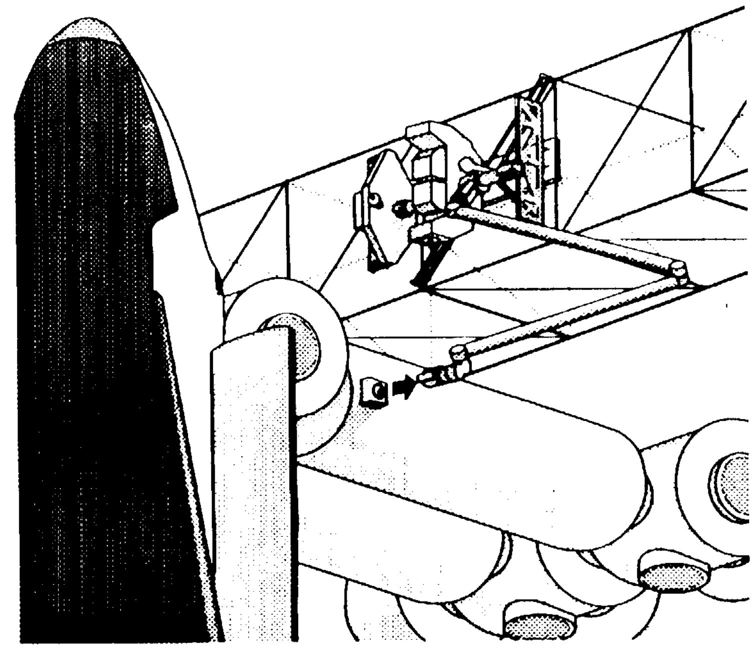


5. SSRMS: Position New Experiment at MSC POA #1
6. SSRMS: Install New Experiment on MSC POA #1
7. IV-1: Latch New Experiment to MSC POA #1
8. SSRMS: Release New Experiment

Figure 4-14. Illustrated Scenario of Changeout of Astromag Experiments



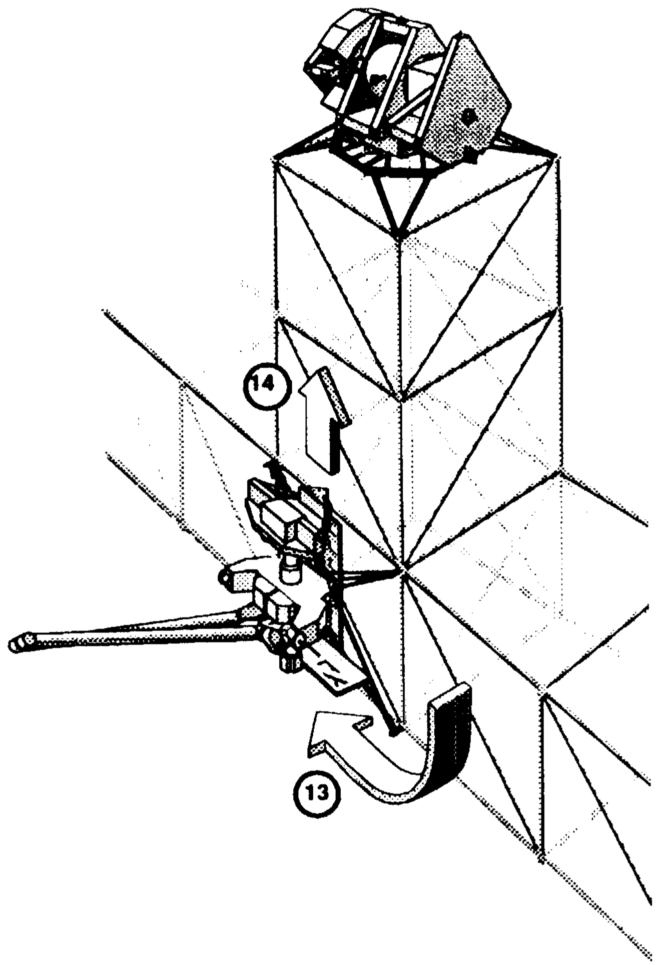
9. SSRMS: Grasp SSRMS Mounting Beam on MSC (transfer control base to MSC)



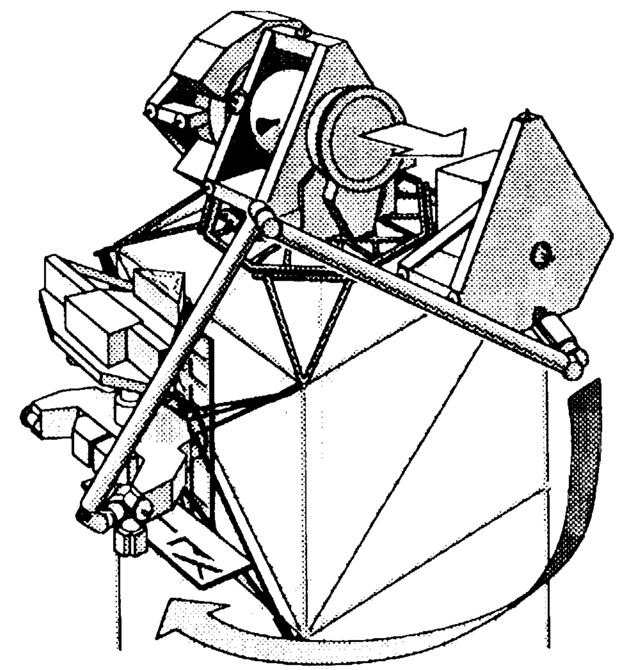
10. SSRMS: Release Fixed Grapple on habitation module

11. SSRMS: Position for MSC translation

Figure 4-15. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)

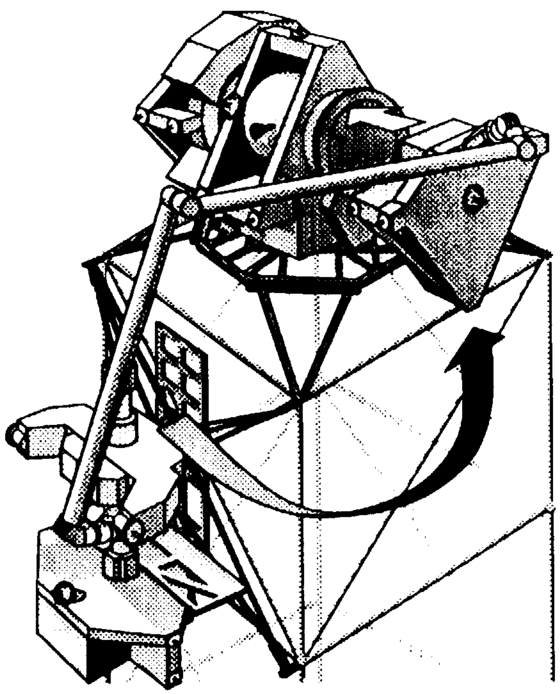


12. MSC: Translate to Astromag outrigger main boom truss bay
13. MSC: Turn corner onto outrigger
14. MSC Translate to Astromag operational site

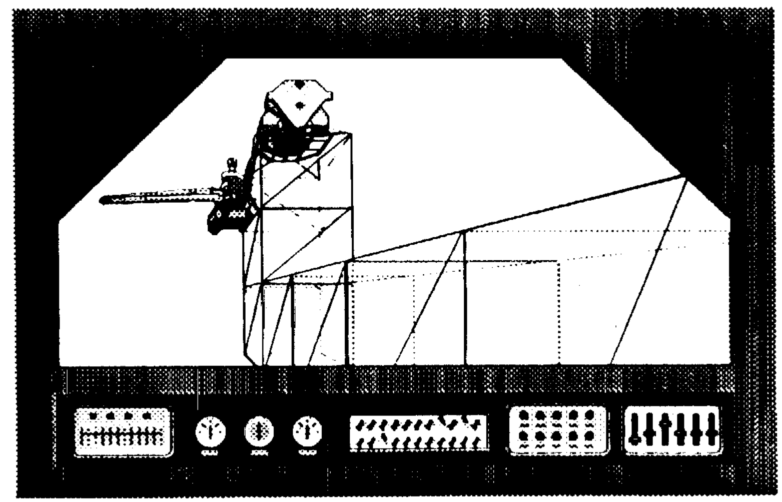


15. SSRMS: Grasp Old Experiment on Core Facility
16 IV-1: Unlatch Old Experiment from Core Facility
17. SSRMS: Remove Old Experiment from Core Facility
18. SSRMS: Position Old Experiment at MSC POA #2
19. SSRMS Install Old Experiment to MSC POA #2
20. IV-1: Latch Old Experiment to MSC POA #2
21. SSRMS: Release Old Experiment

Figure 4-16. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)

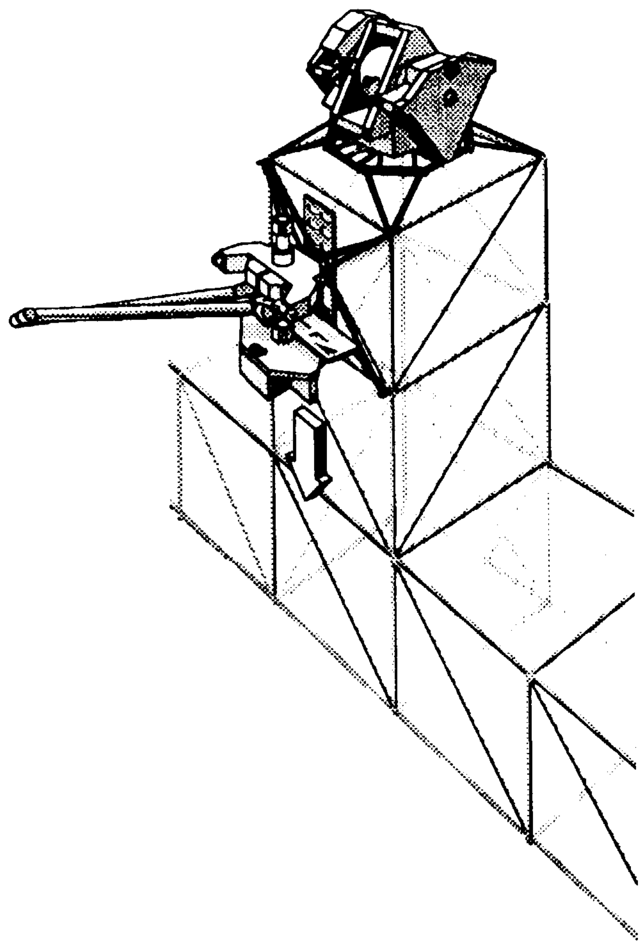


22. SSRMS: Grasp New Experiment on MSC POA #1
23. IV-1: Unlatch New Experiment from MSC POA #1
24. SSRMS: Remove New Experiment from MSC POA #1
25. SSRMS: Position New Experiment at Core Facility
26. SSRMS: Install New Experiment to Core Facility
27. IV-1: Latch New Experiment to Core Facility
28. SSRMS: Release New Experiment



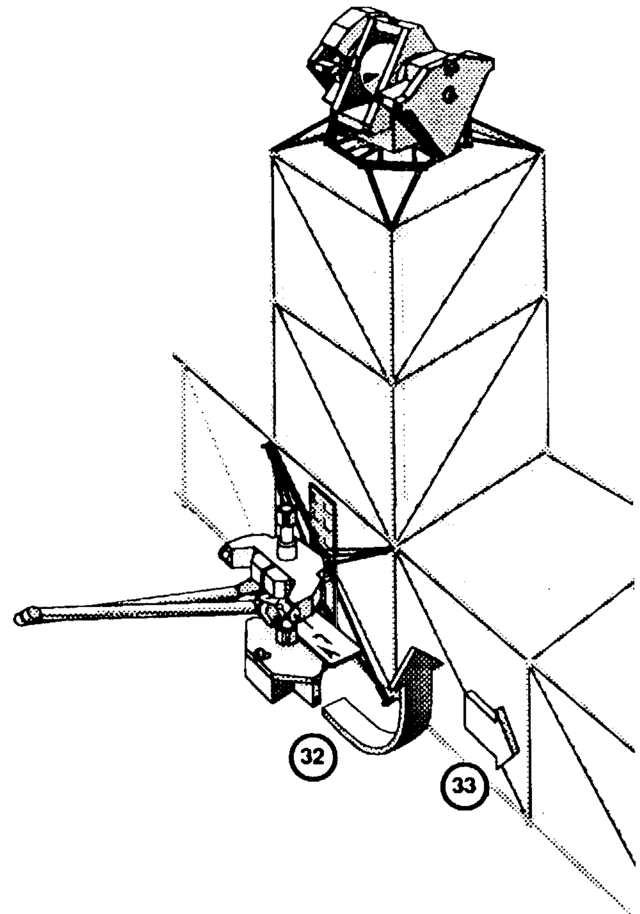
29. IV-1: Perform check-out of New Experiment

Figure 4-17. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)



30. SSRMS: Position for MSC translation

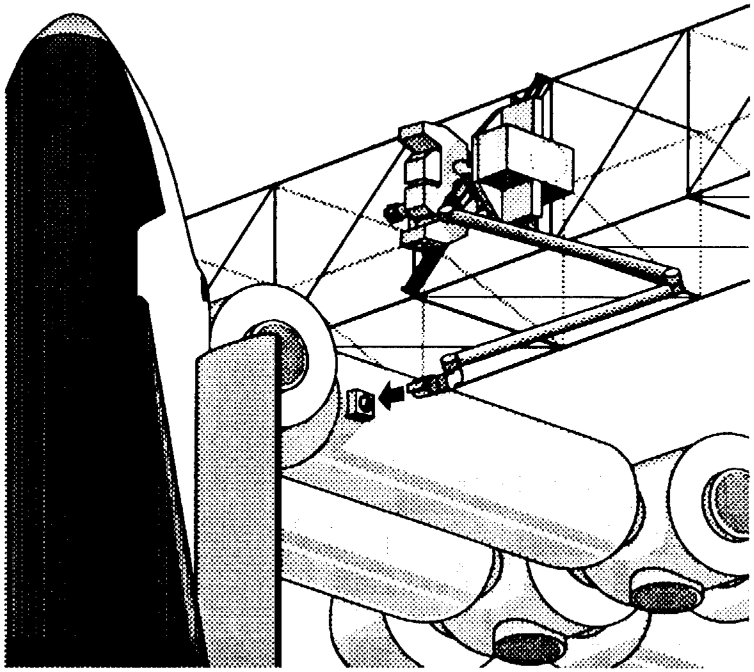
31. MSC: Translate to main boom



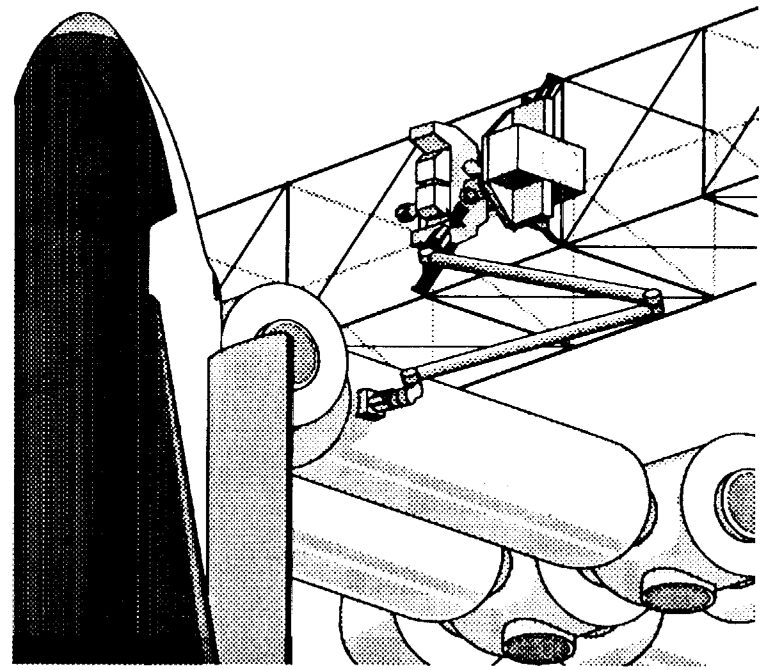
32. MSC: Turn corner at main boom

33. MSC: Translate to STS docking area

Figure 4-18. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)

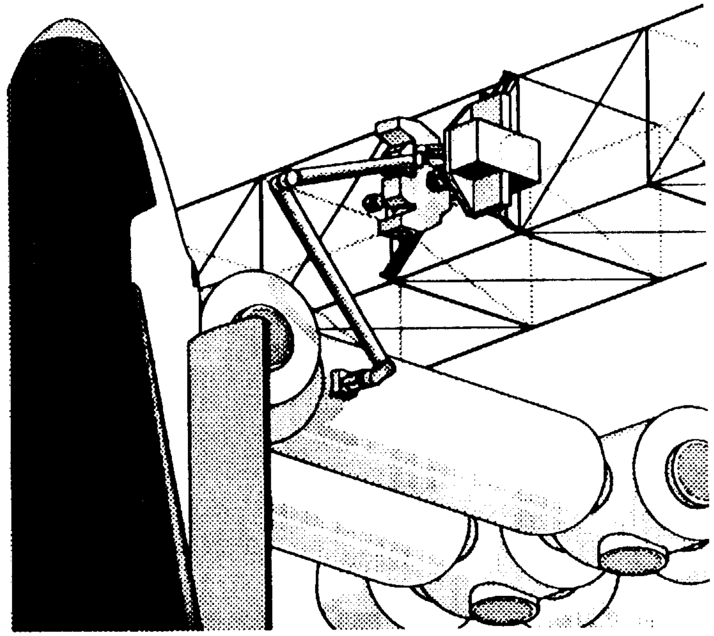


34. SSRMS: Grasp Fixed Grapple on habitation module (transfer control base to PDGF on habitation module)



35. SSRMS: Release SSRMS Mounting Beam on MSC

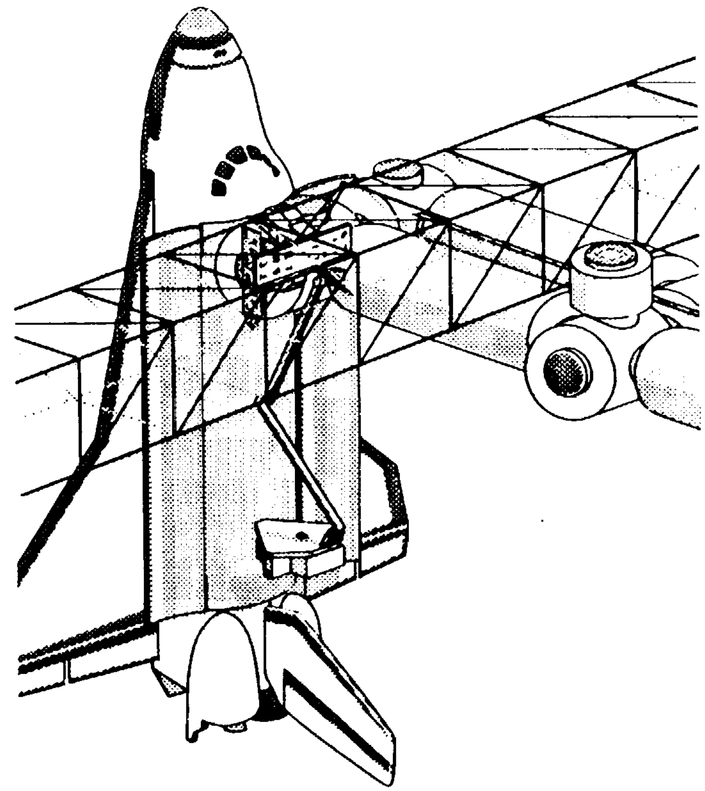
Figure 4-19. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)



36. SSRMS: Grasp Old Experiment on MSC POA #2

37. IV-1: Unlatch Old Experiment from MSC POA #2

38. SSRMS: Remove Old Experiment from MSC POA #2



39. SSRMS: Position Old Experiment at STS payload bay

40. SSRMS: Install Old Experiment on STS payload bay

41. IV-2: Latch Old Experiment to STS via automated latching mechanisms

42. SSRMS: Release Old Experiment

43. SSRMS: Position for MSC translation

44. MSC: Translate to MSC standby location

Figure 4-20. Illustrated Scenario of Changeout of Astromag Experiments (cont'd)

5. SUMMARY OF ASSEMBLY AND SERVICING CONCEPTS

The scenario analysis presented in this report demonstrates the feasibility of assembling and servicing the Astromag attached payload on the S. S. Freedom. Since the S. S. Freedom and Astromag design concepts are in the early phases of development, the results presented in this report are preliminary. Most of the issues that arise from such an analysis will be addressed in the Astromag Phase B Study. Other issues apply to other NASA programs and need to be addressed independent of the Astromag Project. A brief discussion of these issues is presented in the "Astromag Phase A Study Report", Goddard Space Flight Center, December 1989.

APPENDIX A

ASTROMAG AND SPACE STATION FREEDOM ASSUMPTIONS AND DESCRIPTIONS

APPENDIX A

ASTROMAG AND SPACE STATION FREEDOM ASSUMPTIONS FOR DEVELOPMENT OF SCENARIO CONCEPTS

The development of Astromag concepts are based on the assumptions that a) Astromag is installed on a fully assembled, baseline S. S. Freedom configuration (i. e., after Assembly Complete (AC)); and b) the S. S. Freedom provides attached payload assembly and servicing capability via station Servicing Support Systems (these systems include the MSC, the SSRMS, the FTS, and EVA and IVA personnel and support equipment). Assumptions for the Astromag concept and Servicing Support Systems are described in this appendix.

A.1 ASTROMAG ATTACHED PAYLOAD ASSUMPTIONS

The Astromag Phase-A Study concept developed by the GSFC is used as the baseline design for the purposes of this report (Figure A-1). Assumptions for the Astromag concept are listed in Table A-1.

1. A two-bay outrigger, containing typical station truss bays, which extends normal to the station main boom in the zenith direction is in place prior to Core Facility or experiment installation.
2. An SIA is attached to the zenith face (-z side) of the outermost outrigger bay.
3. The outrigger includes a utility tray for extension of the APAE SIA umbilical interface with the station utility tray.
4. Astromag is powered down and in a non-operational state prior to the initiation of Astromag assembly and servicing activities.
5. Assembly and servicing activities are conducted on Astromag's velocity vector face (+x side).
6. Experiments are removed and replaced from Astromag using a PIA/SIA latching interface mechanism concept.
7. The Core Facility and each experiment contains at least two PDGFs.

Table A-1. Astromag Attached Payload Assumptions

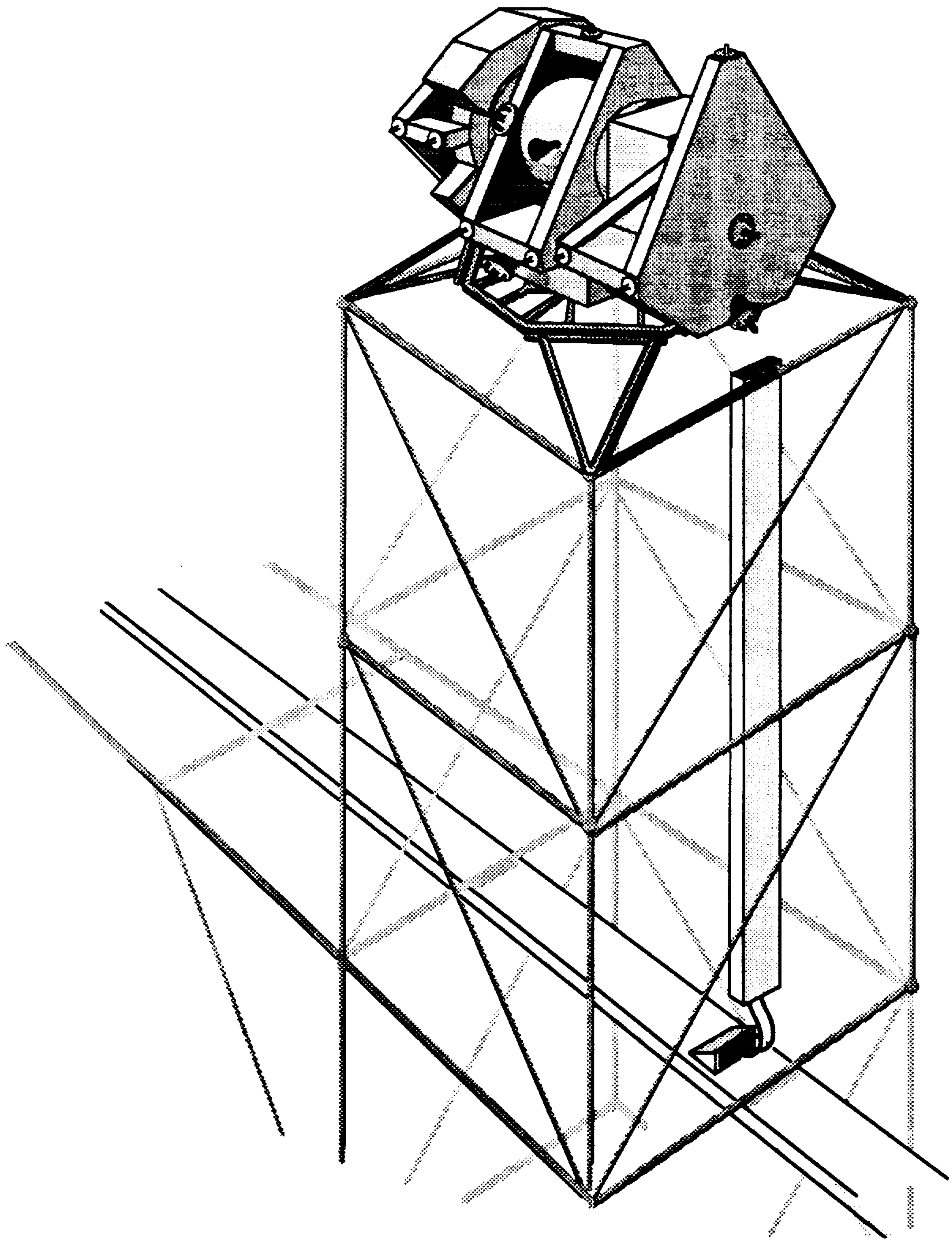


Figure A-1. Astromag Attached Payload

A.2 BASELINE CONFIGURATION OF SPACE STATION FREEDOM

The design of Space Station Freedom is evolving as NASA and contractors finalize their plans for the station. In the interim, the descriptions below are used to define an environment regarding the design and functional capabilities of the Space Station in order to develop Astromag servicing concepts. The baseline configuration of S. S. Freedom is depicted in Figure A-2. Specific assumptions regarding the S. S. Freedom are listed in Table A-2.

1. The fully assembled Space Station Freedom baseline configuration is assumed (i. e., station configuration after Assembly Complete (AC)).
2. S. S. Freedom is, at a minimum, man-tended (#1 above implies that a permanently manned capability already exists at this time).
3. S. S. Freedom accommodates the installation of the Astromag outrigger.
4. A utility port is located near the outrigger site on the main boom.
5. A clear work envelope is provided for all S. S. Freedom Servicing Support Systems.

Table A-2. Space Station Freedom Assumptions

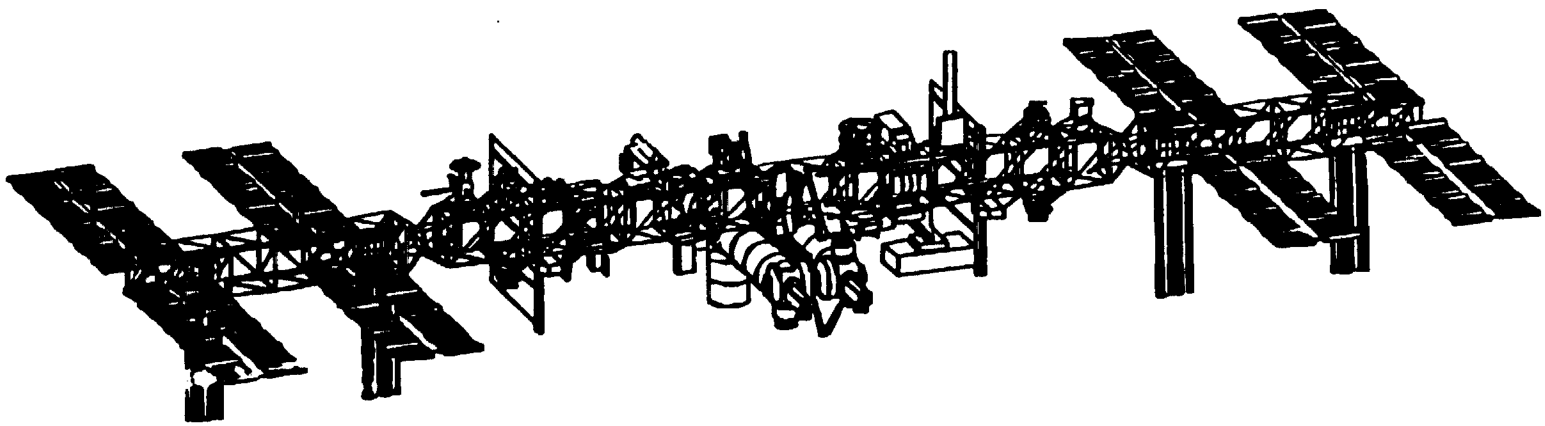


Figure A-2. Space Station Freedom Baseline Configuration

A.3 MOBILE SERVICING CENTER (MSC)

The MSC provides capabilities to transport and position S. S. Freedom elements and support equipment (Figure A-3). The MSC consists primarily of the Mobile Transporter (MT), the Mobile Remote Servicer (MRS), the SSRMS, and an EVA Workstation. The MT is the transportation mechanism for traversing the S. S. Freedom main boom. The MRS is the operational base of the MSC and is attached on the MT.

The SSRMS arm is attached to the MRS at one of four PDGFs on the SSRMS Mounting Beam. The MSC also contains locations for attaching and storing various support equipment including the EVA Workstation, the FTS, and EVA and FTS tools. EVA personnel mount the MSC at the EVA Workstation or fixed foot restraints.

The MSC also contains two Payload/ORU Accommodations (POAs) for the attachment of payloads or ORUs containing PDGFs. The MSC may carry up to two station components (one at each POA) for transport across the S. S. Freedom main boom. Specific assumptions made regarding the MSC are listed in Table A-3.

1. The MSC is operational on the Space Station Freedom prior to the assembly of Astromag.
2. The MSC can traverse the velocity vector face (+x side) of the main boom and turn corners in a plane.
3. The MSC includes one SSRMS arm attached to its structure.
4. The MSC can translate to the outermost truss bay and operate for the period required for assembly and servicing operations.
5. The MSC includes an EVA Workstation with monitoring and control interfaces for MSC components, including the MT and SSRMS.
6. The MSC includes locations to mount EVA fixed foot restraints, FTS, and EVA and FTS tools.
7. The MSC is configured with two POAs, which may grapple equipment containing a PDGF and provide limited power and data utilities.

Table A-3. MSC Assumptions

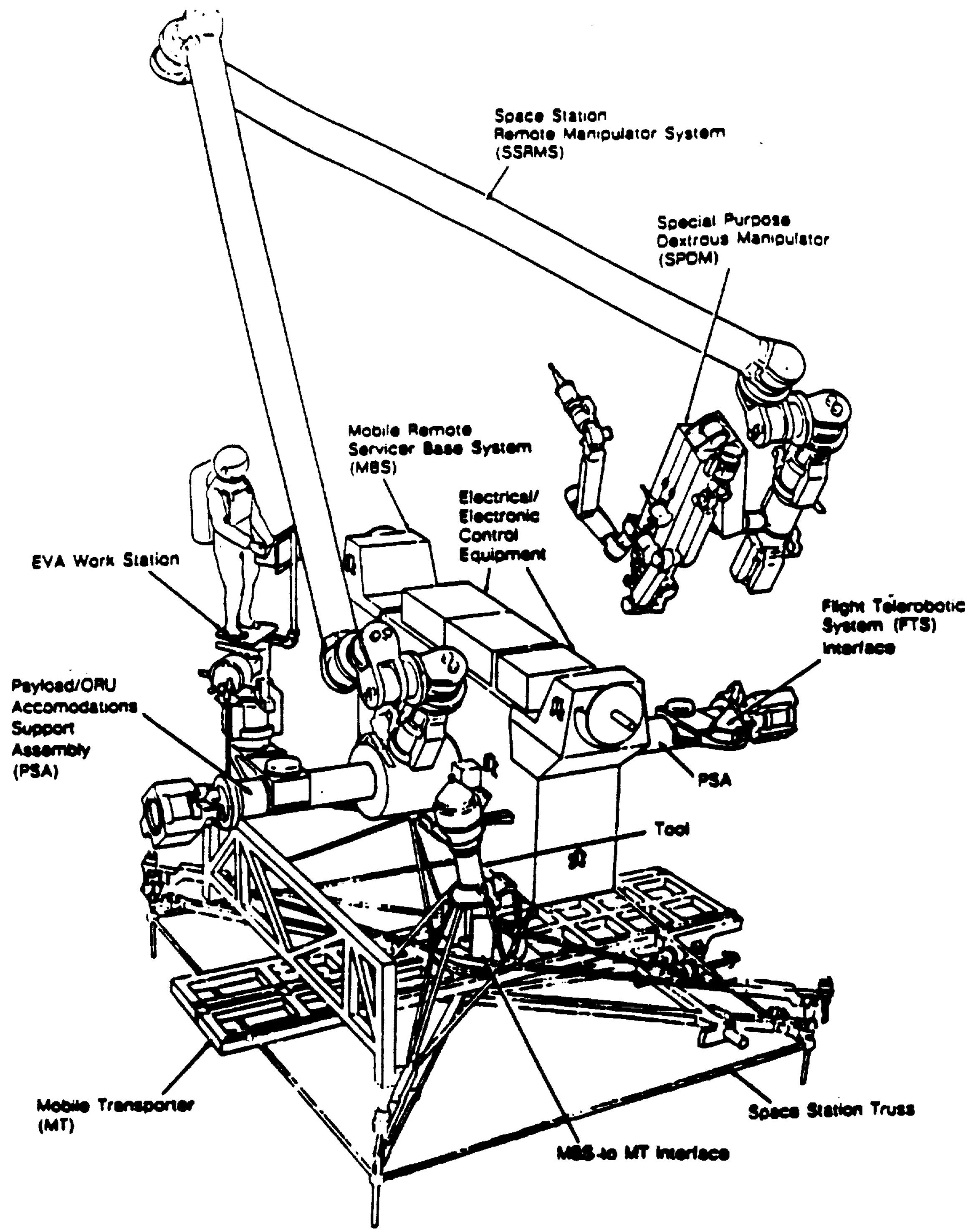


Figure A-3. Mobile Servicing Centre (MSC)

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A.4 SPACE STATION FREEDOM REMOTE MANIPULATOR SYSTEM (SSRMS)

The SSRMS is similar to the Shuttle RMS. SSRMS consists of seven modular rotary joints providing 7 degrees of freedom (DOF). Each extremity of the arm terminates with an end effector, which is a grappling device for manipulating, transferring, and handling Space Station Freedom elements and support equipment. One end effector is normally anchored to the MSC (at the SSRMS Mounting Beam). During staging of equipment in the STS payload bay, the SSRMS is anchored to a PDGF on a habitation module. The free end effector can grapple equipment containing a Power Data Grapple Fixture (PDGF), including the Core Facility and each experiment. The SSRMS can also grapple the FTS, EVA Workstation, and the MFR. An IVA crewmember can control the SSRMS remotely from an IVA Workstation inside the pressurized modules. An EVA crewmember may control the SSRMS from the EVA Workstation located on the MSC, or from the EVA Workstation grappled on the end of the SSRMS. Assumptions regarding the SSRMS capabilities are listed in Table A-4.

1. The SSRMS has an overall length of 17.6 meters (two boom segments 6.64 m in length, and two end segments 2.16 m in length).
2. The SSRMS can grapple, transfer, and position equipment containing a PDGF.
3. The SSRMS is controlled by an astronaut located at a) the IVA Workstation, or b) the EVA Workstation (on the MSC or on the end of the SSRMS).
4. The SSRMS can provide limited power and data capability to grappled equipment.
5. The SSRMS accommodates the EVA Workstation, including grapple, transport, and position, plus power and data interfaces.
6. The SSRMS accommodates the FTS, including grapple, transport, and position, plus power and data interfaces.

Table A-4. SSRMS Assumptions and Performance Parameters

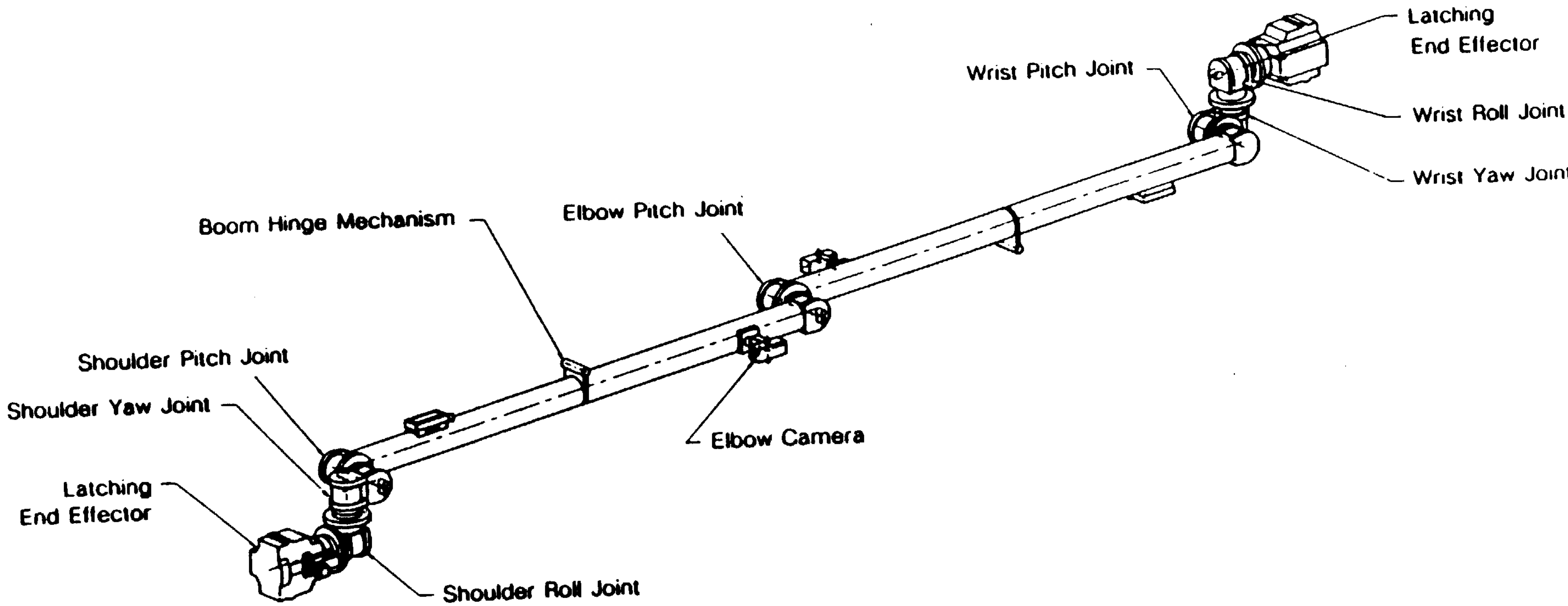

Figure A-4. Space Station Remote Manipulator (SSRMS)
(From SPAR-SS-R-0493)

A.5 FLIGHT TELEROBOTIC SERVICER (FTS)

The Flight Telerobotic Servicer (FTS) is a dual-arm manipulator robot used for performing dextrous servicing activities (Figure A-5). The FTS is envisioned to perform on-orbit tasks that enhance crew servicing activities on the S. S. Freedom. Major components of the FTS include two 7 DOF manipulators and one 5 DOF stabilizing and positioning appendage. The manipulator arms are capable of utilizing end effectors and tools for dextrous operations. The stabilizing and positioning appendage allows the FTS to grasp a structure at a worksite and operate without the benefit of an attached RMS. The FTS also contains cameras, computers, controllers, antennae, and batteries. A PDGF is provided for interface to an STS-RMS or SSRMS.

The FTS is currently being developed by GSFC and the Martin Marietta Corporation. The FTS will be able to operate either from the MSC, the end of the STS-RMS, or the SSRMS. The FTS may also perform tasks without the benefit of an SSRMS by attaching to a location on the station containing an interface to the FTS stabilizer appendage ("fixed base" operations). FTS assumptions are summarized in Table A-5.

1. The FTS is operational on S. S. Freedom.
2. During servicing activities, the FTS is either attached to the end of the SSRMS or attached to a fixture located in the vicinity of Astromag.
3. The FTS is able to attach, transfer, and position certain types of servicing hardware through the use of various end effectors.
4. The FTS may be used in a back-up mode for the "manual" actuation of failed latching equipment.
5. The FTS is attached to a temporary holding site on the MSC when not in use.
6. The S. S. Freedom contains an FTS storage site on the main boom known as the FTS Accommodation (FTSA).

Table A-5. FTS Assumptions

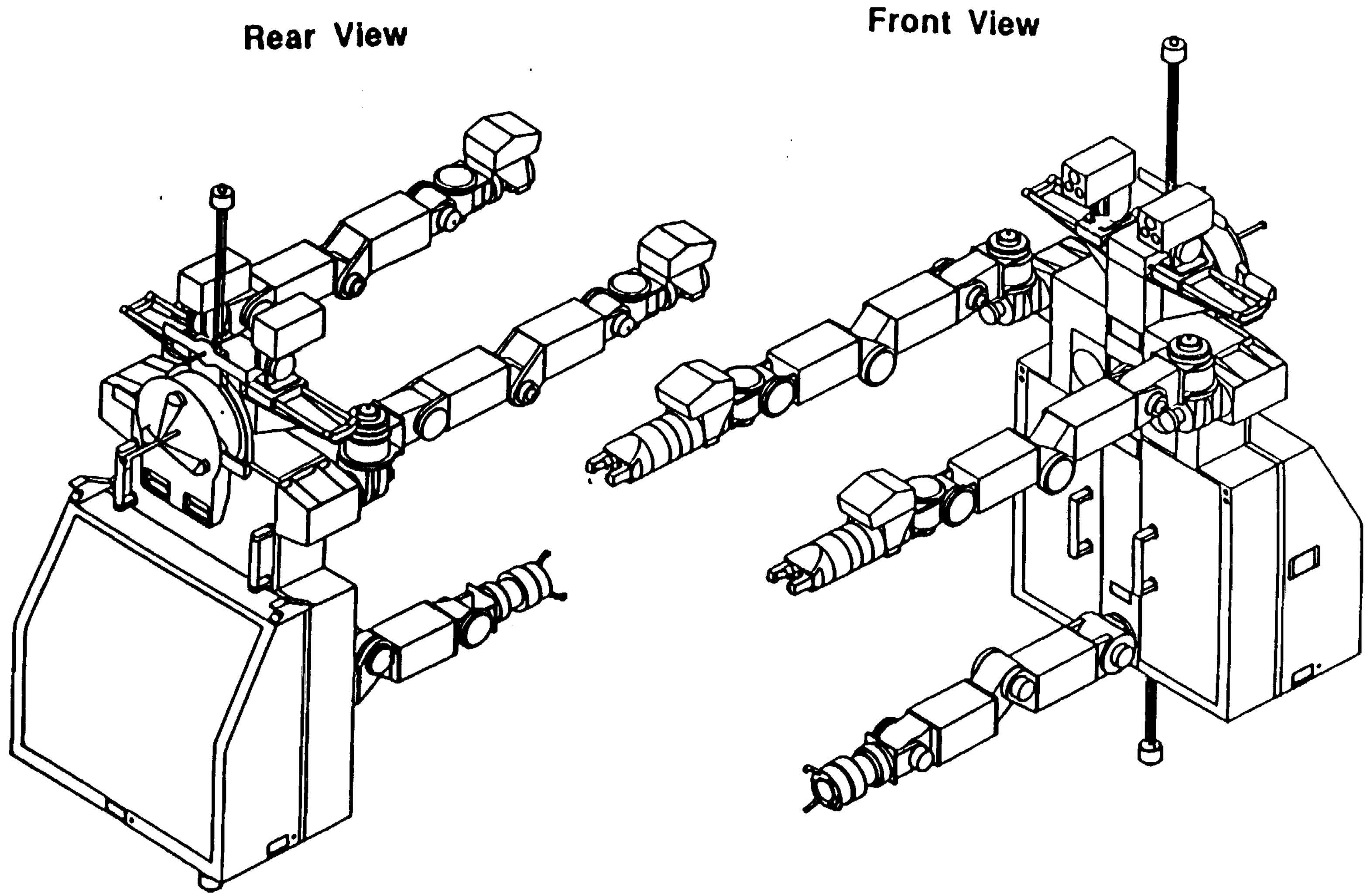

Figure A-5. Flight Telerobotic Servicer (FTS)
(From Martin Marietta FTS Design Criteria Document, February 2, 1989)

A.6 ASTRONAUT EXTRAVEHICULAR ACTIVITIES (EVA)

EVA servicing activities are rigidly structured due to safety and time limit requirements. Each EVA is performed by two astronauts (i.e., the buddy system). Servicing activities may be performed with one astronaut located on the EVA Workstation and the other on the end of the SSRMS. Activities may also be conducted from an EVA Workstation grappled by an SSRMS, thus allowing the astronaut to control the SSRMS in the "cherry picker" mode. Another means of astronaut positioning for servicing is the Astronaut Positioning System (APS). Located on the MT structure, the APS includes two 3 DOF robotic arms, each containing an MFR for crewmember interface. This concept is undergoing development at the Johnson Space Center (JSC).

Crew translation through the main boom truss bays is conducted using the Crew and Equipment Translation Aide (CETA) which is included in the EVA back-up scenarios. The CETA is a hand-powered cart that can transport two astronauts and a limited amount of support equipment through the length of the S. S. Freedom main boom. Specific design characteristics for CETA are currently undefined. It is assumed that EVA crewmembers, using the CETA, can translate to desired locations on the main boom from the habitation modules. EVA servicing assumptions are summarized in Table A-6.

1. EVA operations are in accordance with JSC and S. S. Freedom safety requirements.
2. Two EVA crewmembers perform servicing activities (buddy system).
3. Operations requiring EVA may be conducted through the use of an EVA crewmember stationed on an EVA Workstation (on the MSC or on an MFR on the end of the SSRMS.
4. An EVA crewmember is able to, in a back-up mode, manipulate failed automated latching mechanisms with the proper tools.

Table A-6. EVA Assumptions

A.7 ASTRONAUT INTRAVEHICULAR OPERATIONS (IVA)

IVA Workstations and support equipment provide the Human Machine Interface (HMIF) for control of S. S. Freedom operations. IVA Workstation functions include monitoring of the EVA crew and station systems data, and control of station Servicing Support Systems. The S. S. Freedom IVA Workstations utilized are located in a pressurized environment in the nodes, modules, and cupolas. For Astromag assembly and servicing tasks, station IVA responsibilities include operation of the MSC, SSRMS, and FTS. IVA operations are also performed from the Shuttle Aft Flight Deck (AFD) for STS payload bay activities such as RMS operation and actuation of automatic payload trunnion latches. IVA is assumed to support MSC, SSRMS, FTS, and EVA assembly and servicing operations. Table A-7 provides a summary of IVA assumptions.

1. S. S. Freedom activities are controlled by an astronaut at an IVA Workstation located in a pressurized area of the station, such as the resource nodes, modules, and cupolas.
2. STS activities are controlled by an astronaut at the AFD Workstation (for RMS operations and actuation of automatic payload retention latches).
3. The S. S. Freedom IVA Workstation utilized for Astromag assembly and servicing operations contains controls for operating Servicing Support Systems, supporting EVA, and performing functional checkout of assembled or serviced systems.

Table A-7. IVA Assumptions