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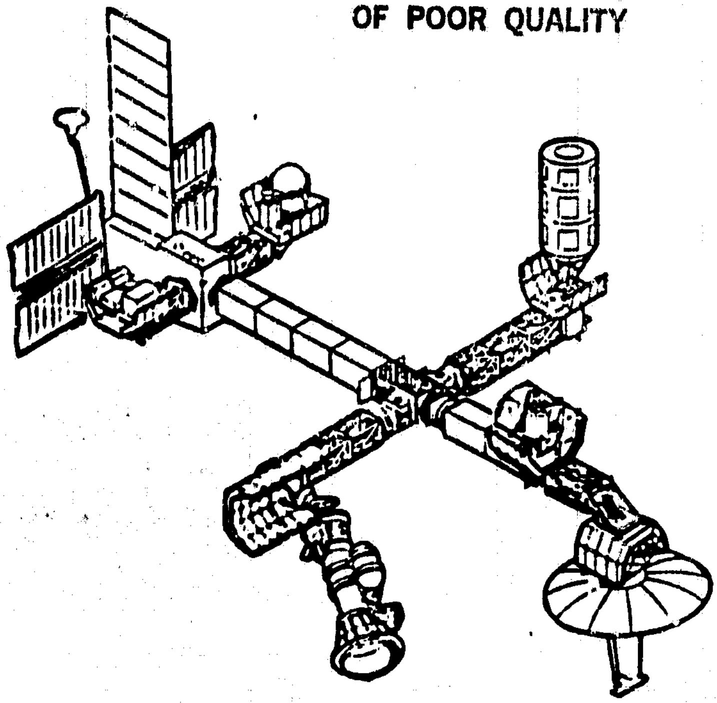

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EVOLUTIONARY SPACE PLATFORM CONCEPT STUDY

VOLUME II – TECHNICAL REPORT
PART A – SASP SPECIAL EMPHASIS TRADE STUDIES

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS
CORPORATION

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EVOLUTIONARY SPACE PLATFORM CONCEPT STUDY

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APPROVED BY: FRITZ C. RUNGE
STUDY MANAGER

PREPARED UNDER NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION CONTRACT NAS 8-33592

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FOREWORD

The Evolutionary Space Platform Concept Study encompassed a 10-month effort to define, evaluate and compare approaches and concepts for evolving unmanned and manned capability platforms beyond the current Space Platform concepts to an evolutionary goal of establishing a permanent-manned presence in space.

The study included three parts:

- Part A - Special emphasis trade studies on the current unmanned SASP concept
- Part B - Assessment of manned platform concepts
- Part C - Utility analysis of a manned space platform for defense-related missions

In Part A, (covered in this Volume IIA) special emphasis trade studies were performed on several design and operational issues which surfaced during the previous SASP Conceptual Design Study (reference: MDC G9246, October 1980) and required additional studies to validate the suggested approach for an evolution of an unmanned platform. Studies conducted included innovative basic concepts, image motion compensation study and platform dynamic analysis.

The major emphasis of the study was in Part B, which investigated and assessed logical, cost-effective steps in the evolution of manned space platforms. Tasks included the analysis of requirements for a manned space platform, identifying alternative concepts, performing system analysis and definition of the concepts, comparing the concepts and performing programmatic analysis for a reference concept.

The Part C study, sponsored by the Air Force Space Division (AFSD), determined the utility of a manned space platform for defense-related missions. Requests for information regarding the results of Part C should be directed to Lt. Lila Humphries, AFSD.

The study results from Parts A and B are reported in these volumes:

- Volume I - Executive Summary
- Volume II - Part A - SASP Special Emphasis Trade Studies
- Volume II - Part B - Manned Space Platform Concepts
- Volume III - Programmatics for Manned Space Platform Concepts

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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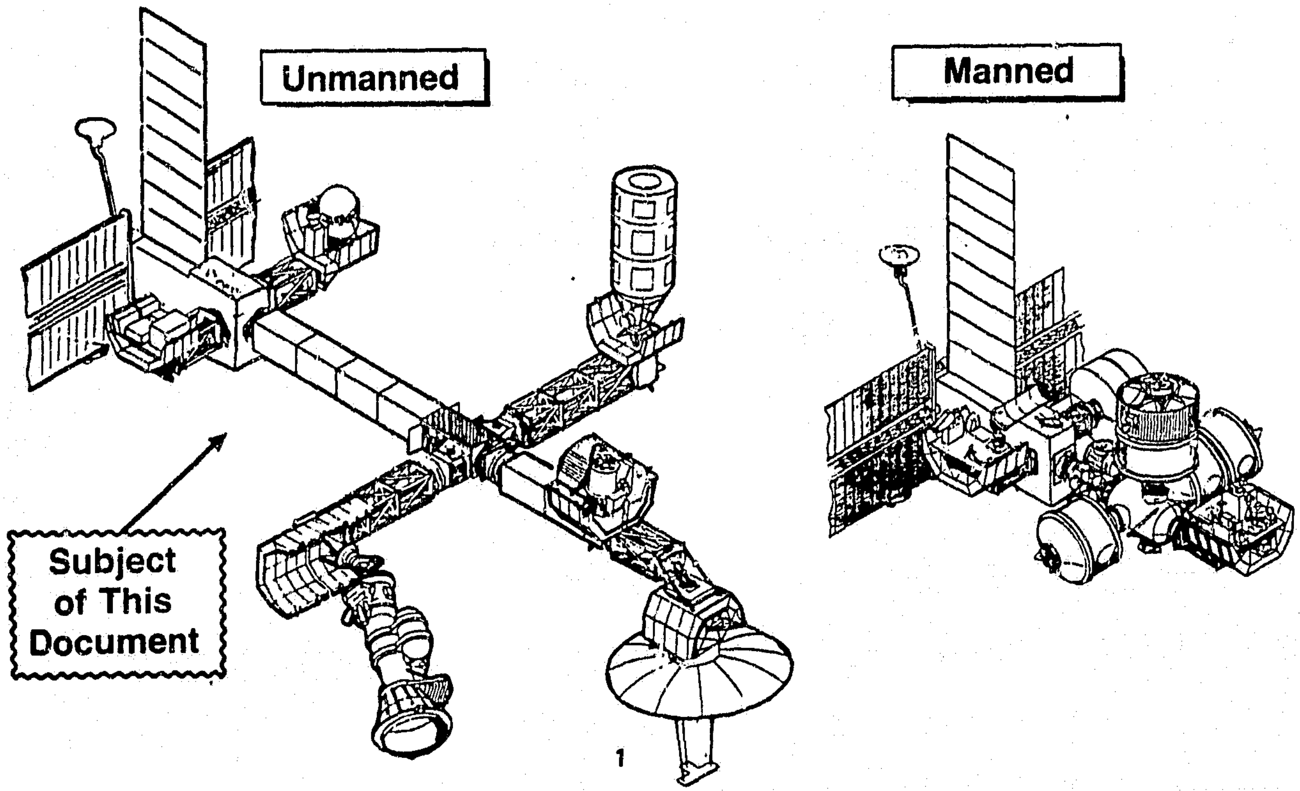
INTRODUCTION

The recent launches of the Space Shuttle and the anticipated operation of the Spacelab in the near future are bringing new capabilities to the science and applications communities to accomplish missions in space. These new systems will facilitate the launch, retrieval, refurbishment and reflight of scientific payloads. While the Spacelab sortie mode of operation will continue to be an important tool for the science and applications users, efforts are also in progress to define an approach to provide a simple and cost-effective solution to the problem of long-duration space flight. This approach involves a Space Platform in low earth orbit, which can be tended by the Space Shuttle and which will provide, for extended periods of time, stability, utilities and access for a variety of replaceable payloads.

This study addressed the feasibility of an evolutionary space system which would cost-effectively support unmanned or manned payloads in groups, using a Space Platform which provides centralized basic subsystems, as shown in Figure I-1 below. This document specifically addresses only the unmanned platform shown.

Figure I-1

EVOLUTIONARY SCIENCE AND APPLICATIONS SPACE PLATFORMS



The Space Platform may be replicated for use in other orbits and for dedicated or multi-discipline missions. This growth platform is called the Science and Application Space Platform (SASP) and is the subject of this report. The addition of a pressurized module to the Space Platform will provide a manned orbital system. This system is called the Manned Space Platform (MSP) and is described in Volume II, Part B of this report. The addition of extended arms to the Space Platform will enhance the capability by increasing the number of experiment pallets which can be docked to the platform, by providing a greater payload separation for enhanced viewing, and by providing for the accommodation of large facility-class payloads.

The previous SASP Conceptual Design Study (Reference MDC G9246, October 1980) defined a concept for providing this enhanced, multi-payload, capability. Several design and operational issues surfaced during this past study which required additional analysis to validate the suggested approach for an evolution of an unmanned platform. The objective of this study task (Part A) was to perform these special emphasis trade studies in the areas of (1) innovative basic concepts, (2) image motion compensation and (3) platform dynamics.

Section 1.1 describes the results of the innovative basic SASP concept study which reviewed, once more "from scratch," the basic configuration options for satisfying the multiplicity of payload and system requirements. Here such innovative options as double gimballing, tethering, more congregation, more dispersal, manned-access sections, etc., were reviewed with an eye towards the possible improvement to payload accommodations. Section 1.2 describes the results of the analysis conducted to investigate the critical relationships between high-accuracy pointing payloads and the platform dynamics and the intermediary role of instrument pointing systems. This was a important investigation since there are many high-accuracy pointing payloads in the list of potential platform users. Section 1.3 presents the results of a continued analysis of the structural dynamics of the SASP concept. The analysis included modeling the prospects of a three-arm configuration, as a sequel to the two-arm analysis performed in the prior study. In addition, the potential benefits of selectively-placed dampers were analyzed. Again, here the dynamics of the platform were analyzed in greater depth because of the importance of such information to the high-accuracy pointing group of potential payloads.

This study was performed by the McDonnell Douglas Astronautics Company (MDAC) under a $300,000 contract (NAS8-33592) with NASA/George C. Marshall Space Flight Center, from May 1981 through February 1982. Although a significant effort was devoted to the unmanned platform ($50,000), the primary emphasis was on the manned platform ($250,000). This study constituted a follow-on to one preceding wherein the unmanned platform was emphasized and only a manned adapter module was defined.

The advent of the Shuttle permits the placement and periodic revisitation of space platforms which will cost-effectively fulfill the needs of many payloads. For unmanned payloads, this new mode of flight reaps economics when compared with the provision of individual spacecraft for each payload. For manned payloads, the Space Platform provides a convenient orbital base for the berthing and support of crew habitation modules to support the many payloads which require long-term crew involvement.

For both types of payloads the use of one common space platform affords many cost and efficiency advantages. Particularly in the work of manned missions, the primary subject of this study, the Space Platform permits the provision of long-term manned payload operations in low earth orbit as a sequel and expansion of major dimension to the short, seven-day Spacelab flights on the Shuttle.

Although the worlds of unmanned and manned space missions are broadly different, they do show two major common needs, namely: (1) the same types of subsystem resources (power, thermal control, communications and data handling, attitude control and reboost propulsion) and (2) innovative ways to offset the burdensome problem of funding constraints. The Space Platform provides an integrated solution to these common needs by providing a common, multi-payload carrier with extensive utilities, plus a traffic-reduction advantage to the Shuttle and TDRSS through payload congregation at one orbit location.

Figure I-2 defines the broad objectives of each subtask and Figure I-3 lists the general conclusions of this activity.

The Appendixes provide a list of references (Appendix A) and a list of acronyms and abbreviations used in the document (Appendix B).

Figure I-2

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UNMANNED PLATFORM STUDIES
TASK A

- Innovative SASP Concepts (Subtask A.1)
  - Arm Concepts Description/Rationale
  - Viewing, Pointing, Dynamics and Control
  - Magnetic Arm Coupling
  - Tethered Satellites
- Image Motion Compensation Study (Subtask A.2)
  - SP, APS and IMC Capabilities
  - SP Accommodation of SIRTF with No APS
- Platform Dynamics Analyses (Subtask A.3)
  - Configurations
  - Damping Discussion
  - Results/Further Work Recommendations

Figure I-3

SUMMARY

- Previously Recommended 2nd Order SASP Concept Still Considered Best Approach
- More Integration, More Dispersal, Double Gimballing, Tethers, Manned-Access Elements Evaluated; Pros Did Not Offset Cons
- Many Fine Pointing Payloads Stability Requirements Can Be Met Without an APS
- Coarse Gimballing Capability Is Operationally Desirable for Pointing Payloads
- Structural Dynamics Now Better Understood; Localized Dampers Can Provide Significant System Damping

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The task flow of the overall study including Task A (Unmanned Platform) and Task B (Manned Platform) is shown in Figure I-4. Note that only the $50,000 Unmanned Platform part (Task A) of the study is covered in this document.

Figure I-4

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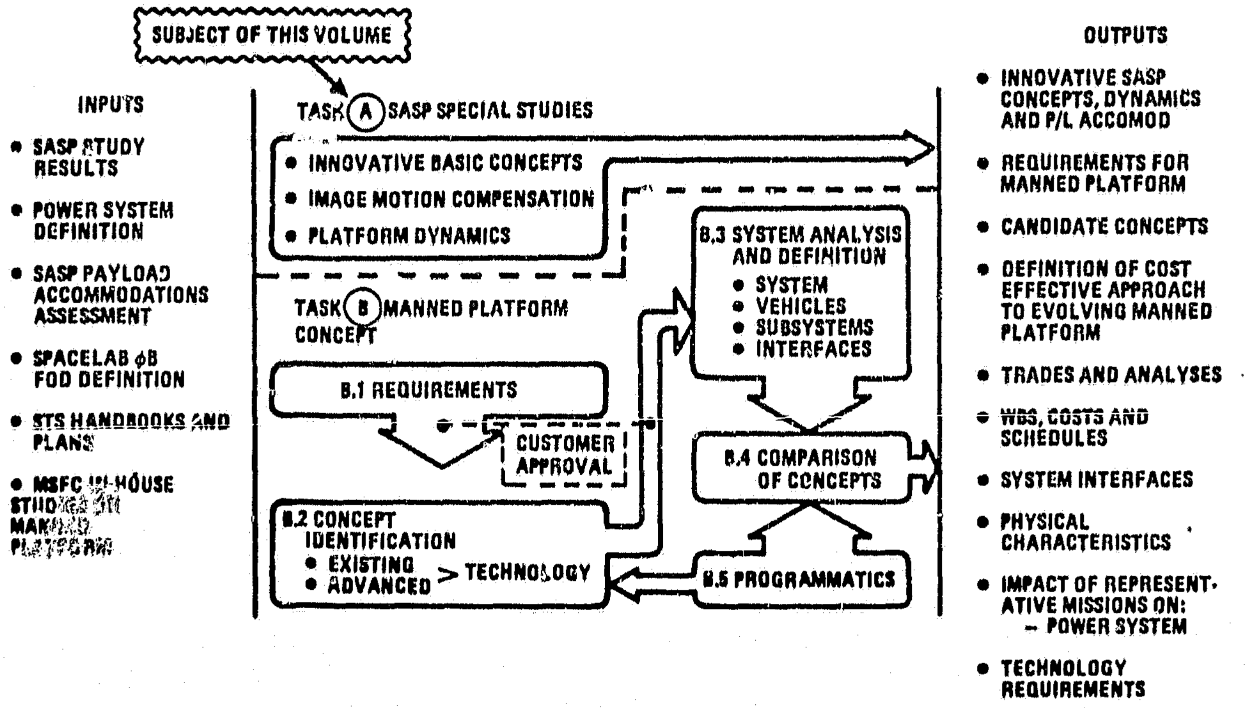
STUDY TASK FLOW



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Section 1

SASP (UNMANNED PLATFORM) SPECIAL EMPHASIS TRADE STUDIES (TASK A)

This task is a continuation of effort performed on the prior study which addressed primarily the accommodation of unmanned payloads on the space platform as pictured below in Figure 1-1.

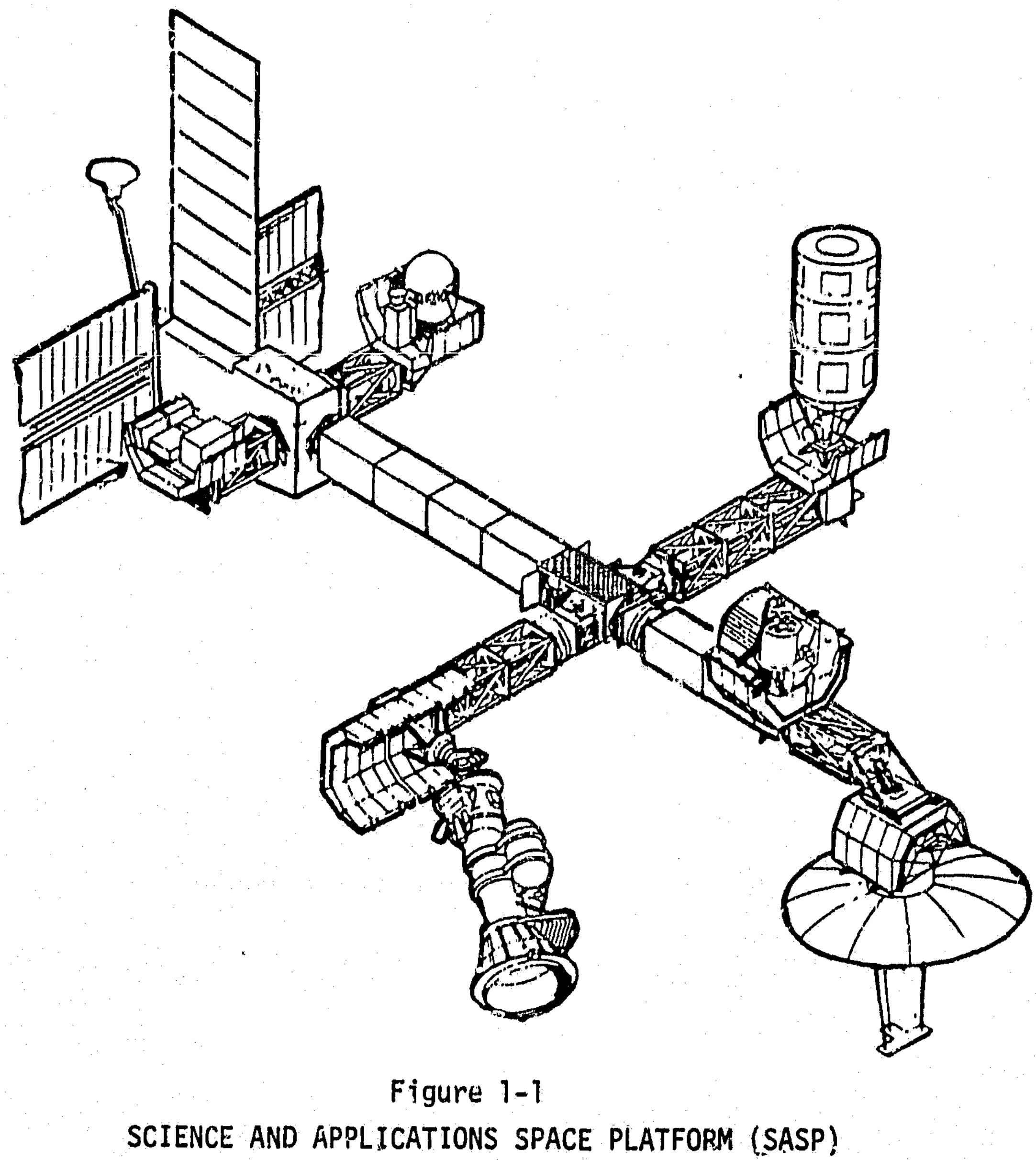

Figure 1-1
SCIENCE AND APPLICATIONS SPACE PLATFORM (SASP)

1.1 INNOVATIVE BASIC SASP CONCEPTS

As an expansion of the SASP concept configuration activities, innovative concepts were evaluated to assure that the basic selected SASP accommodated payloads as well as possible and in a cost-effective manner. The following concepts integrate and/or reshape the combined Power System/Second Order (long arm) Platform in an attempt to provide greater system effectiveness.

- Dual-purpose Arms/Over and Under (payloads and solar panels) (1.1.1.1)
- Gravity Gradient - Double Ender Arms (1.1.1.2)
- Dual-purpose Arms/End-to-End (1.1.1.3)
- Integrated PS/SASP Deployed Solar Array Concepts (1.1.1.4)
- Integrated PS/SASP - Double Gimballed Solar Array Concepts (1.1.1.5)
- Integrated PS/SASP - Spacelab-derived PS (1.1.1.6)
- Second Order SASP - Double Gimbal PS Concept (1.1.1.7)
- Tethered Payload Concept (1.1.3)

Figure 1.1-1 shows a task flow for this portion of the study. Table 1.1-1 shows a summary of the goals of the SASP concept. These goals were used as inputs when inventing the various configurations discussed below.

Figure 1.1-1

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TASK A.1 – INNOVATIVE SASP CONCEPTS

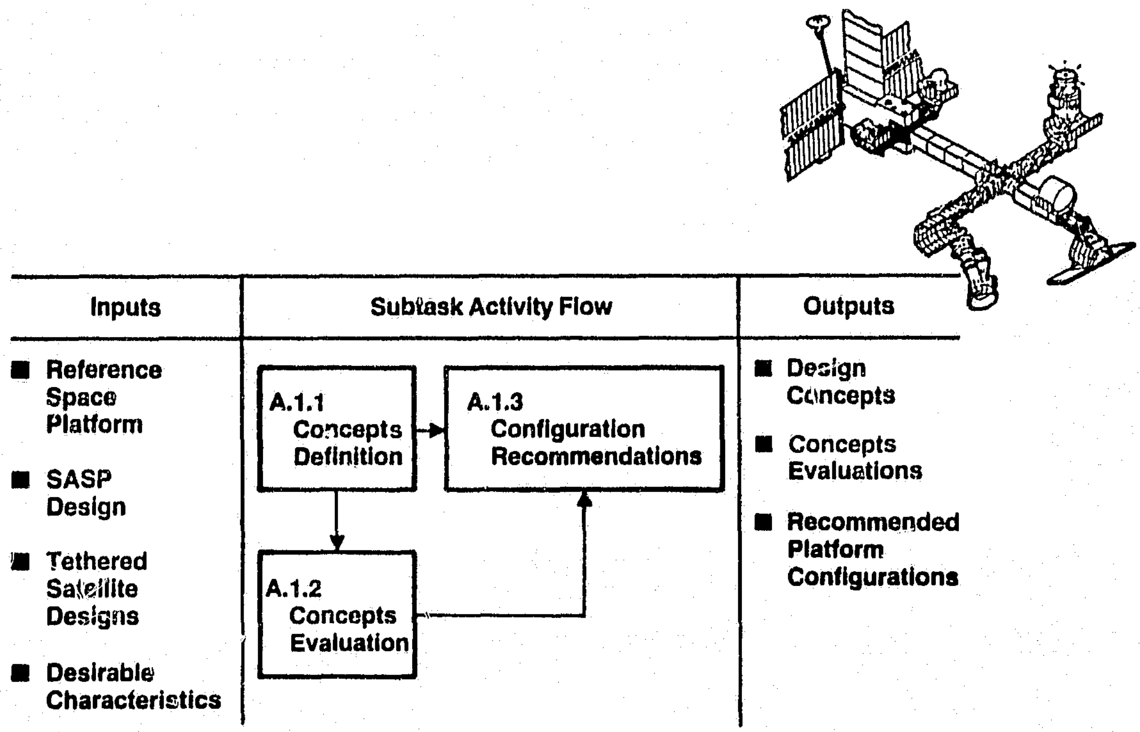

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Table 1.1-1

SASP CONFIGURATION GOALS

- **Centralize Services to Payloads**

- **Minimize Payload-to-Payload and SASP-to-Payload Interference**
  - **Motion Disturbance**
  - **Viewing Field-of-View Obstruction**
  - **Electromagnetic Contamination**
  - **Particle Contamination**
  - **Operational**

- **Minimize Cost/Complexity of SASP Concept**

1.1.1 Alternative Concepts

1.1.1.1 Dual-purpose Arms/Over and Under (Payloads and Solar Panels)

The over/under concept shown in Figure 1.1.1-1 is an attempt to make maximum use of the platform structural beams. Each of the (Y) axis payload beams are mounted on the Power System in the location normally used for the solar array mechanism. The solar arrays are mounted to the underside of the structure with payloads mounted to the upper surface. Each (Y) axis beam would rotate ±180° around the (Y) axis. The (X) axis payload is mounted to a section of deployable structure deployed to provide maximum payload separation. The (X) axis beam also provides ±180° rotation.

Rotation of the payloads mounted on the (Y) axis arms may place the solar arrays in a position restricting power output or if the solar arrays are placed in a maximum power position, the payloads may be restricted. As a result, the concept does not appear feasible.

1.1.1.2 Gravity Gradient, Double Ender Arms

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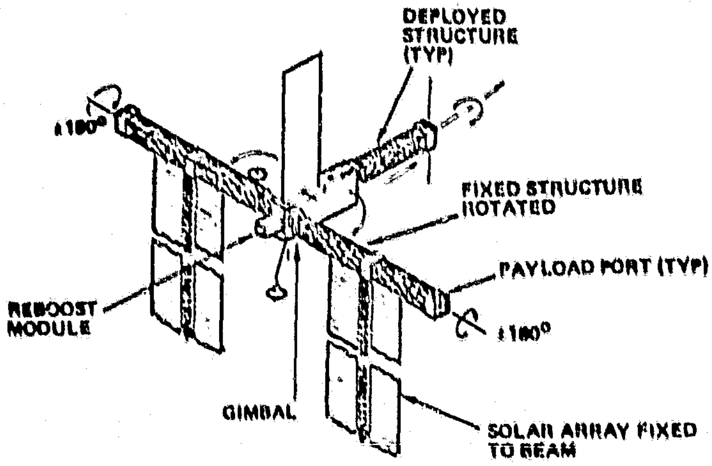
Figure 1.1.1-1

INNOVATIVE SASP CONCEPTS

Integrated Concept (Over-Under)



1.1.1.2.1 Double Platform Concept - The gravity gradient, double platform concept shown in Figure 1.1.1-2 is an attempt to separate the solar viewing payloads in a manner that would remove obstructions caused by the solar arrays and/or other non-solar payloads. The configuration is a basic Power System/ Second Order SASP with a modified platform mounted on the PS (-X) berthing port. The reboost module is relocated from the PS to the forward port of the (-X) platform. The forward mounted platform provides ±180° rotation in both Y axis and the X axis thereby providing full coverage for any solar-oriented payload. The power system shown is unchanged from the basic PS/SASP configuration.

Although the concept is referred to as a gravity gradient configuration, it could fly in other orientations if payload requirements dictate.

The major disadvantage of this concept is the need for multiple launches to assemble the total platform plus multiple berthing operations to place various payload ports within the RMS reach envelope.

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Figure 1.1.1-2

PS/SECOND ORDER SASP — GRAVITY GRADIENT CONCEPTS

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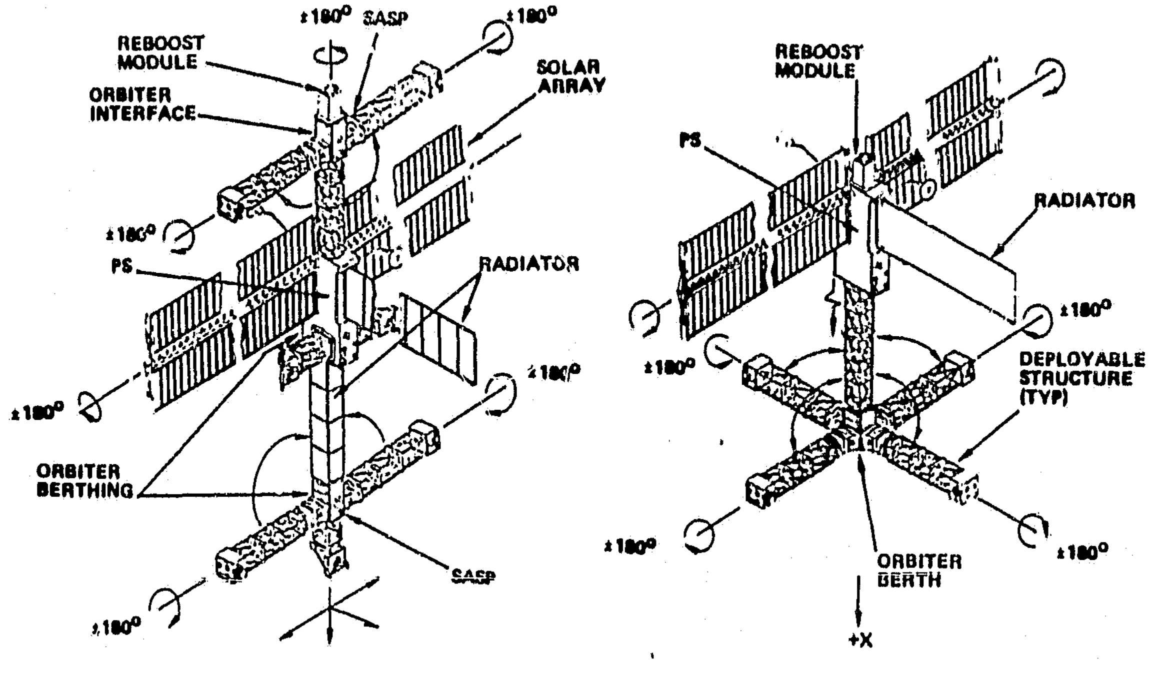


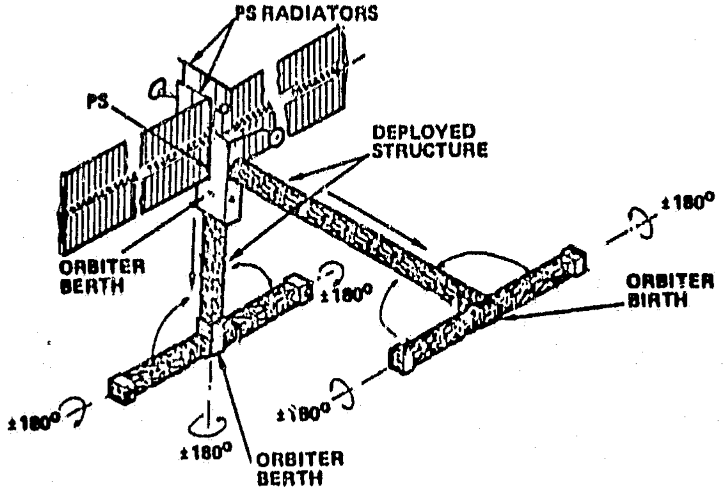
Double Platform   Cruciform

1.1.1.2.2 Cruciform Concept - The cruciform configuration shown in Figure 1.1.1-2 is also an attempt to separate the payloads for improved viewing. Four payload support beams are rotated into position and deployed. The total assembly is deployed from the power system to provide maximum clearance between solar array and payload. The cruciform platform could be sized to package in one Orbiter launch. The power system shown has been modified to remove (±Y) axis payload berthing provisions.

Again, the concept is referred to as a gravity gradient configuration; however, it could fly in other orientations.

1.1.1.2.3 Boom Stabilized Concept - The boom stabilized concept, shown in Figure 1.1.1-3, is a gravity gradient configuration attempting to minimize control system requirements and provide maximum payload separation. The concept incorporates two SASP-type platforms each incorporating deployable structure to separate payloads from the power system. Each platform

Figure 1.1.1-3
INNOVATIVE SASP CONCEPTS



**Boom
Stabilized Concept**

incorporates two arms for payloads with ±180° rotation. The PS is revised to remove the (±Y) axis berthing ports and to remove the radiator in favor of the platform's structure. The radiators are added to the solar array box structure and deployed 90° to the solar array away from the power system.

As was the case in other gravity gradient concepts, size requirements of the platform's arms, may prohibit packaging within the cargo bay limitations; if so, multiple launches would be required thereby reducing the effectiveness of such a concept.

1.1.1.3 Dual-purpose Arms/End-to-End

1.1.1.3-1 Solar Panels Inboard, Payloads Outboard Concept - The dual-purpose arms with the solar panels inboard and the payloads outboard, as shown in Figure 1.1.1.3-1, is another attempt to make maximum use of the platform's payload beams. The solar arrays would be mounted to the arms inboard next to the PS to reduce service lines from the solar array blankets to the subsystem components. The arrays would deploy as the arm deployed.

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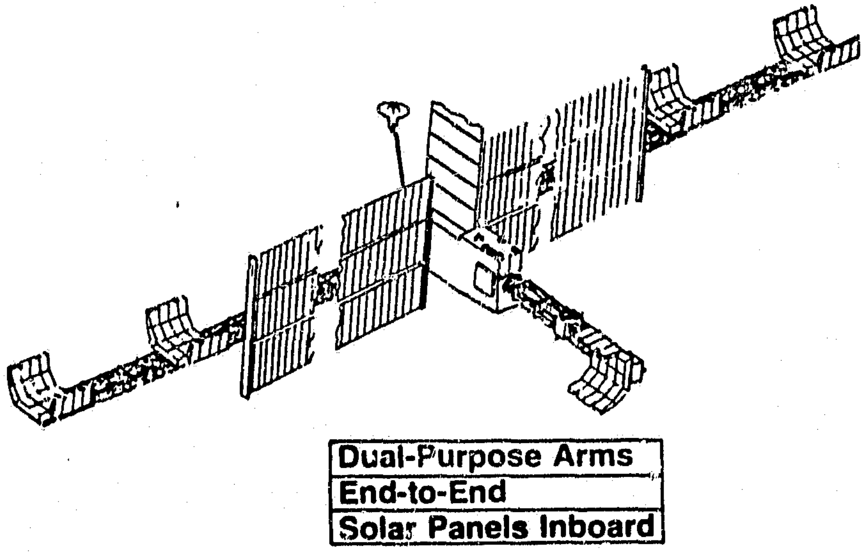
Figure 1.1.1.3-1
INNOVATIVE SASP CONCEPTS



The size of the solar arrays required to provide adequate power would necessitate incorporating a payload beam requiring multiple launches to assemble. In addition, multiple berthing operations would be required to place payloads within the RMS envelope. As a result, the concept does not appear cost effective.

1.1.1.3.2 Solar Panels Outboard, Payloads Inboard Concept - The integrated concept with the solar arrays mounted on the end of the payload support beam, as shown in Figure 1.1.1.3-2, makes maximum use of the beam. Two payloads can be berthed to each arm viewing in opposite directions with $\pm 180°$ rotation. End mounting of the solar array provides minimum obstruction for the payloads and provides opportunity to independently drive the solar array. The arms are rotated into position and deployed to provide maximum clearance between payload and power system.

Packaging limitations of the Orbiter cargo bay may require multiple launches to assemble the concept; if so, the configuration becomes less desirable and less cost-effective. As a result, the configuration does not appear feasible.

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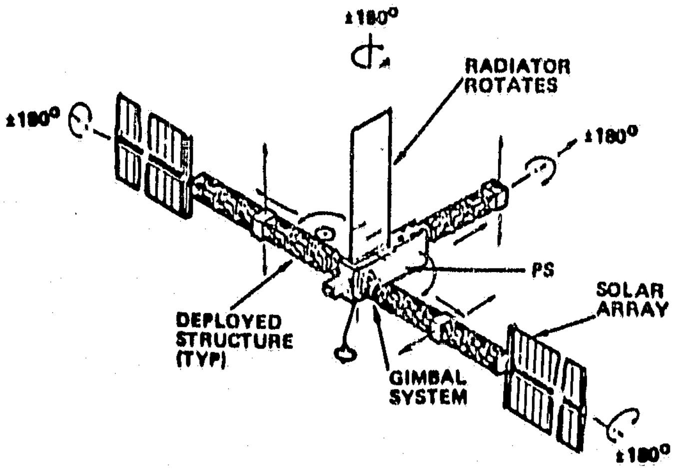
Figure 1.1.1.3-2

INNOVATIVE SASP CONCEPTS

Integrated Concept
(End Mounted Arrays)



1.1.1.4 Integrated PS/SASP-deployed Solar Array Concepts

1.1.1.4.1 +Z Deployment Concept - The (+Z) concept, shown in Figure 1.1.1.4-1, integrates the platform payload arms with the power system and deploys the solar array to a position to minimize obstructing payload viewing.

The power system radiator is removed in favor of a boom-mounted array system. The boom rotates into the +Z axis and deploys the array. Radiators are mounted to the array box structure and are deployed 90° from the array surface. The (±Y) axis payload arms are rotated into position and deployed to provide maximum separation. The aft beam is deployed in the ±X direction. Each arm has ±180° rotation.

It appears the system could be sized to package in the Orbiter cargo bay and be placed on-orbit in one launch. However, the concept requires a major reconfiguration of the power system with minor or no improvement in the payload viewing. Also, multiple Orbiter berthing operations may be required

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Figure 1.1.1.4-1

INTEGRATED PS/SASP — DEPLOYED SOLAR ARRAY CONCEPTS

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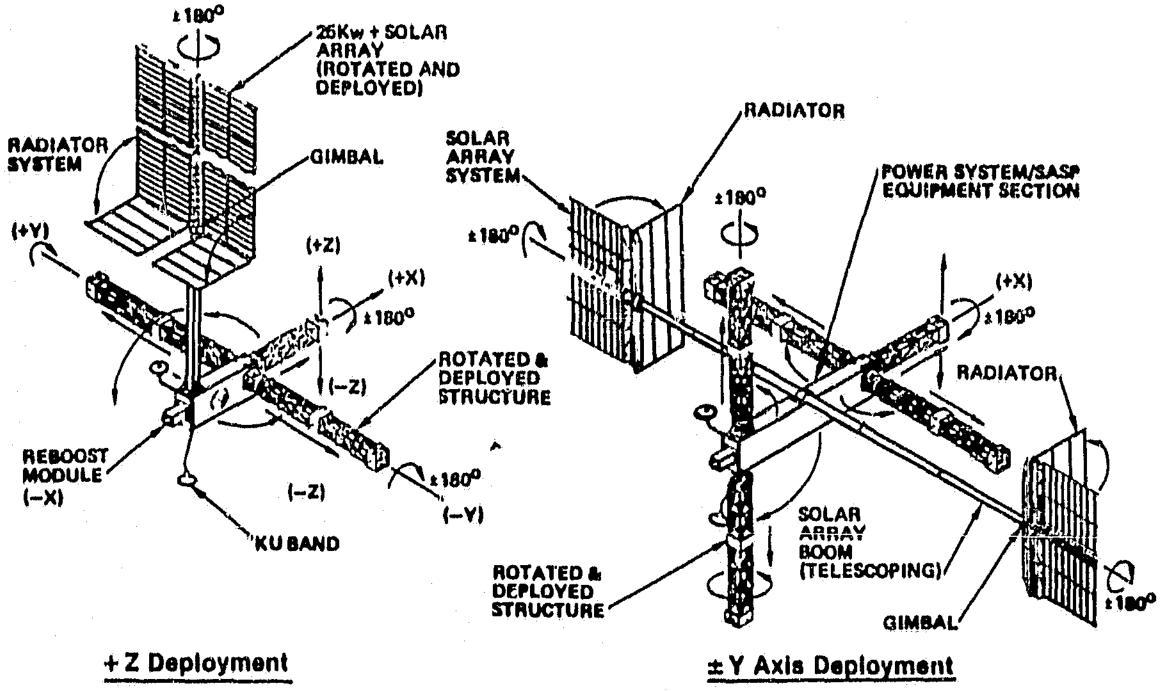


to place payloads with RMS envelope. As a result, the configuration does not appear cost-effective.

1.1.1.4.2 ±Y Deployment Concept - This concept, shown in Figure 1.1.1.4-1, incorporates two Y axis arms and a +X arm mounted on the aft end of an elongated power system/SASP equipment section. The solar arrays are mounted at mid-body on telescoping booms sized to provide maximum separation. Radiators are mounted on the array box structure and deployed 90° to maintain an edge on orientation with the sun.

The configuration shown provides improved viewing; however, it may not package as an integral unit in a single launch. Also, it appears that multiple Orbiter berthing will be required or an onboard manipulator will be required to service and exchange payloads. If these are characteristic of this concept, it appears that deploying the solar array away from the PS is not cost-effective.

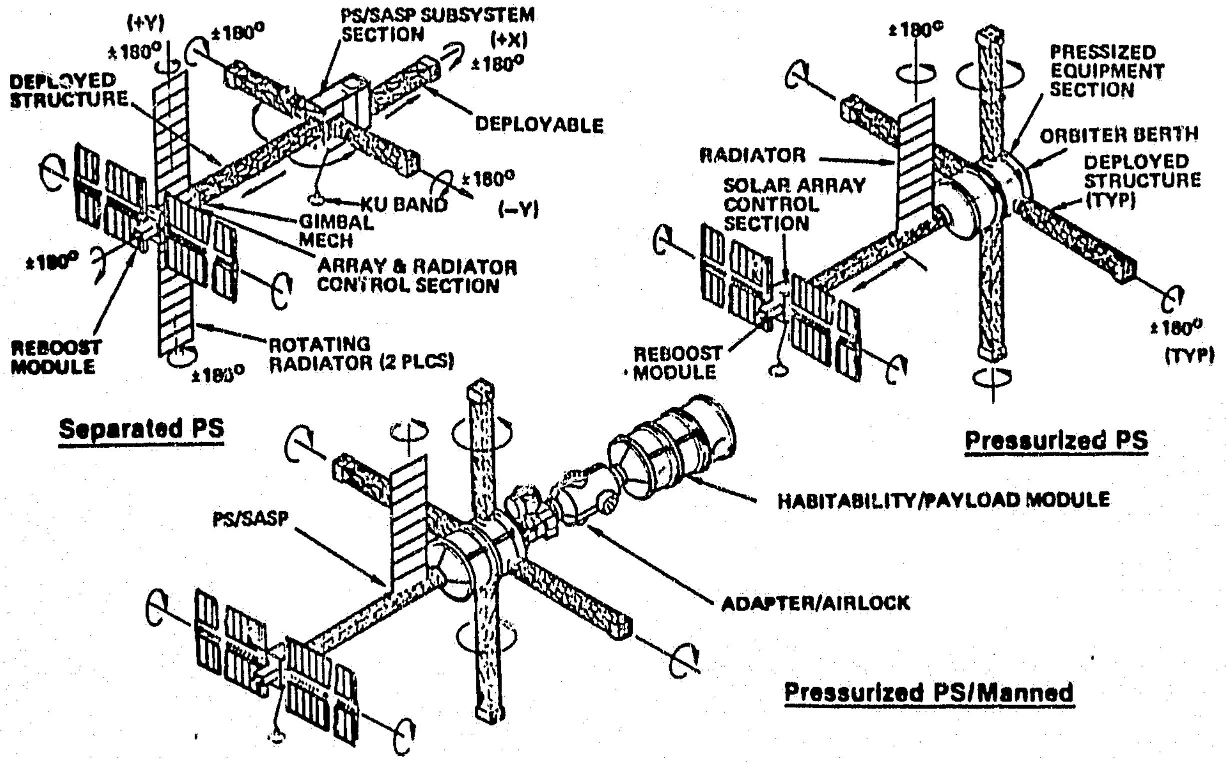
1.1.1.5 Integrated PS/SASP - Double Gimbal Solar Array Concepts

1.1.1.5.1 Separated PS Concept - The separated power system concept, shown in Figure 1.1.1.5-1, divides the power system into two functional sections: (1) Power System/SASP Subsystem section and (2) Solar Array/Radiator Control section. The two sections are joined by a section of deployable structure approximately 1.0 meter square. The PS/SASP subsystem section incorporates the three payload support beams each with ±180° rotation. Also, the Orbiter interface berthing system is incorporated on this section.

The Solar Array/Radiator Control section houses the components required to support these two systems and in addition, incorporates the reboost module. A gimbal mechanism is incorporated to provide X axis gimballing as well as Y axis gimballing of the solar array. The radiator system shown is a dual system which provides adequate cooling regardless of orientation; also if required, the radiator could also be rotated. These additional gimbals enable the solar array to provide max power for max orbit time; also,

Figure 1.1.1.5-1

INTEGRATED PS/SASP — DOUBLE GIMBAL SOLAR ARRAY CONCEPTS



separating the solar array from the payload section enables the array to provide full power during payload interchange, if desired.

The system appears feasible for packaging as an integrated system and delivery in one launch.

1.1.1.5.2 Pressurized PS - Unmanned Concept - The unmanned pressurized power system with a double gimbal solar array, shown in Figure 1.1.1.5-1, again divides the power system into two functional sections. The two sections are: (1) Pressurized Equipment section and (2) Solar Array Control section. The two sections are separated by a deployable structural beam approximately 1.0 meter square. The radiator is mounted between the two sections on a fixed portion of the deployable beam.

The pressurized equipment section houses all the PS subsystem components in a controlled environment which offers the opportunity of servicing the PS in a shirtsleeve environment. The section also incorporates four payload berthing beams, each with ±180° rotation. Orbiter berthing directly to the pressurized section provides direct IVA access from the Orbiter to the PS. The Solar Array Control section incorporates the equipment necessary to control the orientation of the solar panels as dictated by the payload requirements. A gimbal system enables the entire assembly to be rotated ±180° about the X axis. Rotation is also incorporated for the radiator system to maintain edge-on-to-sun orientation.

The configuration shown is an on-orbit assembly concept rather than an integrated system. The payload berthing arms would be assembled to the pressurized section after removal from the cargo bay using the Orbiter RMS. It may be possible for the beams to be sized in order that all units of the configuration could be launched in one Orbiter flight. The size of the payload beams depends on the payloads to be accommodated and may require a separate flight. However, it may be possible to deliver each arm with the payload it will support thereby making the vehicle system effective.

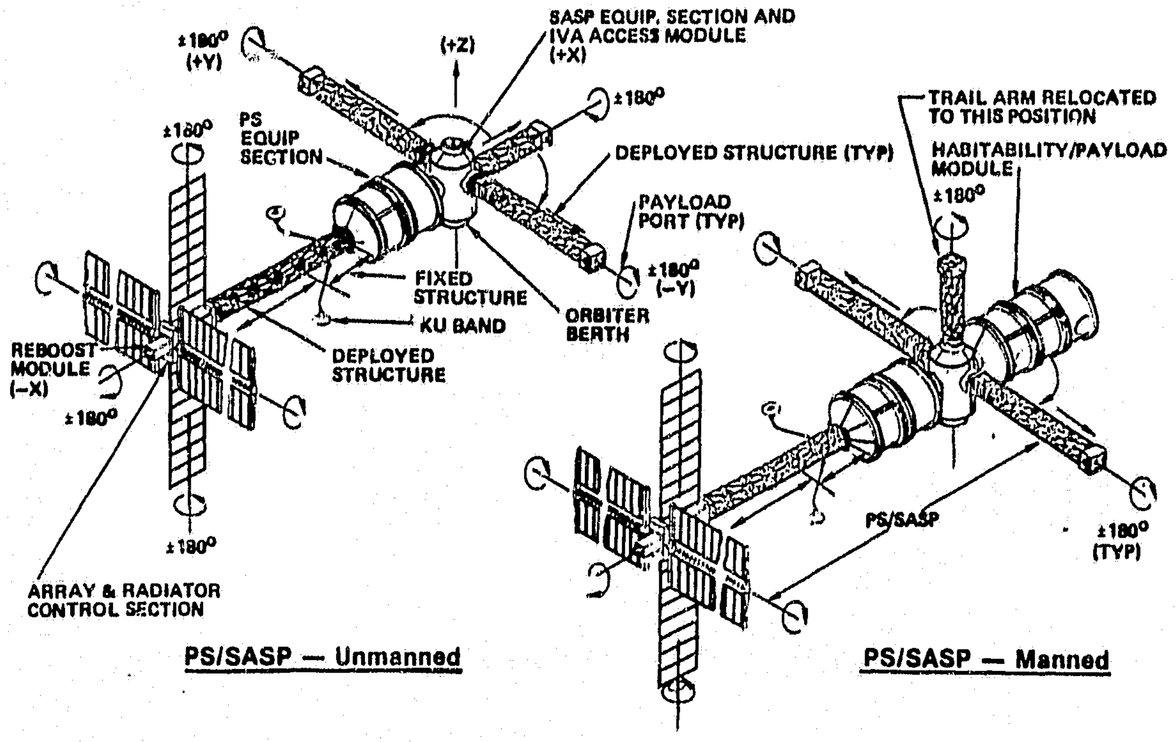
1.1.1.5.3 Pressurized PS - Manned Concept - The pressurizable PS/SASP enables the platforms to be manned without an on-orbit reconfiguration. The manned concept, shown in Figure 1.1.1.5-1, incorporates an airlock/adapter module which interfaces with the PS/SASP and the Orbiter, thus allowing shirtsleeve transfer between all modules of the platform. A Spacelab-derived habitability/payload module is added to accommodate a crew of three or four. Other modules could be added to the adapter with minimum obstruction of external, beam-mounted experiments.

1.1.1.6 Integrated PS/SASP - Spacelab-derived PS

1.1.1.6.1 PS/SASP - Unmanned Concept - The unmanned Spacelab-derived PS/SASP, shown in Figure 1.1.1.6-1, incorporates a Spacelab for the PS equipment section, a deployed Solar Array/Radiator Control section and the SASP equipment section/IVA access module. The SASP equipment section incorporates berthing provisions for three payload arms, Orbiter interface, one selected experiment module and the PS interface. Each of the payload arms are deployable as is the structure that separates the Solar Array/Radiator section from the PS pressurized equipment section. Two axis gimbal is provided for the solar array and single axis gimballing is provided for the radiator.

Figure 1.1.1.6-1

INTEGRATED
PS/SASP — SPACELAB DERIVED PS



PS/SASP — Unmanned **PS/SASP — Manned**

It appears that all elements of this configuration could be launched as an integral unit in one launch. Sizing of the SASP equipment section/access module and payload arms will depend on the nature of the payloads. However, the concept does appear feasible and provides the opportunity to incorporate developed hardware for a major element of the PS.

1.1.1.6.2 PS/SASP - Manned Concept - Man is added to the PS/SASP, as shown in Figure 1.1.1.6-1, with minor reconfiguration of the platform. The trail arm can be repositioned as shown, or returned, thus making the (-Z) port available for logistics, etc. The manned module is added to the SASP equipment section/access module while the access module is berthed to the Orbiter. Development of the access module on the initial unmanned configuration permits its use as a building block element for future growth considerations.

1.1.1.7 Second Order SASP - Double Gimbal PS Concept

The second order SASP, shown in Figure 1.1.1.7-1, is an attempt to improve the PS power output to the payloads with a double gimbal solar array.

Figure 1.1.1.7-1

SECOND ORDER SASP — DOUBLE GIMBAL PS CONCEPT

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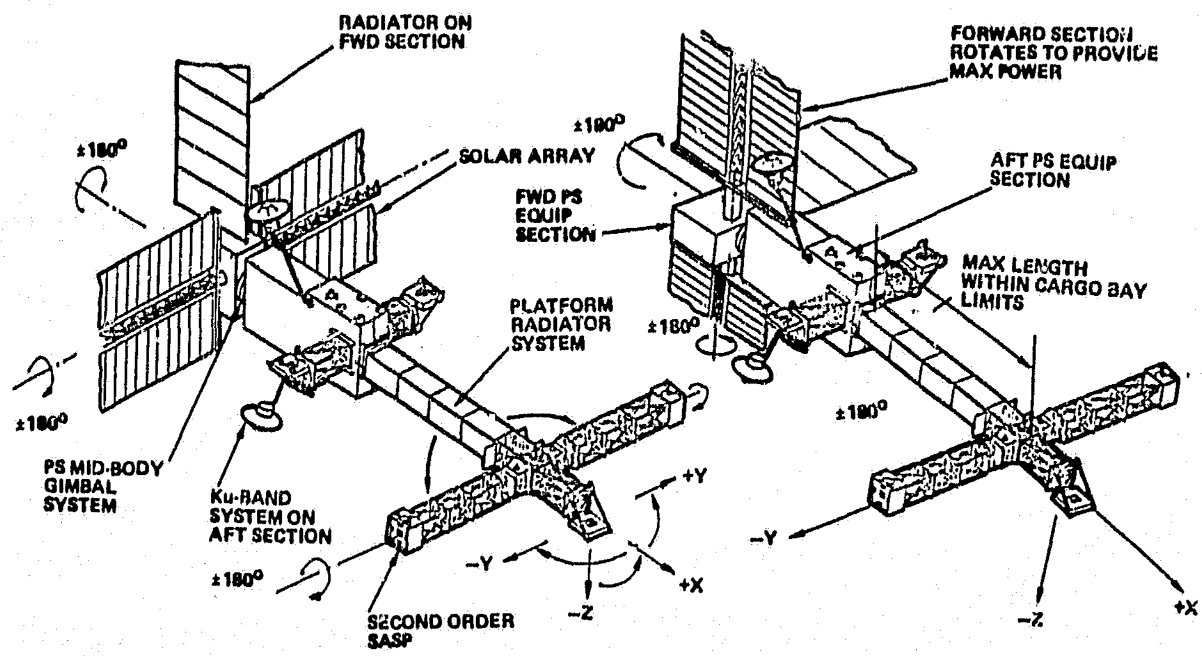

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Addition of a mid-body gimbal enables the solar array to track the sun regardless of orbital inclination or attitude, resulting in max power for a longer period of time. As a result, the PS/SASP could accommodate any payload and/or orbital position from a power viewpoint.

Table 1.1.1.7-1 summarizes the pros and cons described in the previous paragraphs.

Table 1.1.1.7-1

INNOVATIVE SASP CONCEPTS EVALUATION

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Concept	Pro	Con
■ Dual-Purpose Arms (Over & Under)	• Maximizes Use of Support Beam	• Solar Arrays Rotate With Payload Restricting Payload Viewing and/or Power Output • Requires Deployable Structure to be Compatible With Cargo Bay Envelope
■ Gravity-Gradient		
• Double Platforms	• Reduces Obstruction for Solar Viewing Payloads • Forward Platform Provides Full Coverage for Solar Oriented Payloads	• Requires Multiple Launches to Assemble • Requires Multiple Orbiter Berthing Operations for RMS Compatibility
• Cruciform	• Provides Multiple Payload Berthing Provisions in One Launch	• Requires Development of Deployable Structure • Requires Complete Cargo Bay Envelope. No Payload Volume Available
• Boom Stabilized	• Provides Maximum Payload Separation • Reduces Control System Rqmts	• Size May Prohibit Packaging in Cargo Bay • May Require Multiple Launches

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INNOVATIVE SASP CONCEPTS EVALUATION (CONT'D)

VFR290

Concept	Pro	Con
■ Dual-Purpose Arms (End to End)	• Berthing Arm Also Deploys Solar Array	• Requires Multiple Launches • Requires Multiple Orbiter Berthing to Place Payloads on Beam • Size of Array May Require On-Orbit Assembly of Beam
■ Integrated PS/SASP Deployed Solar Array		• Requires Reconfiguring PS
+ Z Deployment	• Maximum Sun Exposure With ± 180° Rotation on + Z Axis	• Requires a Boom Mounted Solar Array • Requires Deployable Beams to Package in Cargo Bay • Requires Multiple Berthing Operations
± Y Deployment	• Provide Improved Viewing	• May Require On-Board Manipulator to Service Payloads • May not Package in Single Launch
■ Integrated PS/SASP Double Gimbal Solar Array • Separated PS	• Enables Solar Array to Deliver Max Power for Max Orbit Time • Provides Max Solar Array/Payload Separation Reducing Restrictions on Both • Appears Feasible for a Single Launch • Radiator Provides Cooling Regardless of Orientation	• Requires Multiple Gimbal Systems • Requires Deployable Structure • Difficult to Service From Orbiter • Requires Multiple Deployment Operations of Main Body Beam
• Pressurized PS-Unmanned	• Enables Shirtsleeve Repair of PS Subsystems • Provides Max Solar Array Output • Reduces Length of Fluid Lines	• Requires On-Orbit Assembly • May Require Multiple Launch to Fully Assemble • Require Long Power Cables
• Pressurized PS-Manned	• Enables PS/SASP to be Manned Without On-Orbit Vehicle Reconfiguration • Shirtsleeve Transfer Possible Between Modules • Min Payload Obstructions	• Same Disadvantages as Listed for the Pressurized-Unmanned System

INNOVATIVE SASP CONCEPTS EVALUATION (CONT'D)

VFR292

Concept	Pro	Con
■ Integrated PS/SASP-Spacelab Derived		
• Unmanned	• Integrates PS/SASP Function Into One Vehicle • No Mods Required to Spacelab • Permits Shirtsleeve Repair of PS/SASP Sub-Systems	• May Require Multiple Launches to Assemble
• Manned	• Man Added With Minor On-Orbit Re-Configuration • Access Module Can be Used as Building Block Element	• Requires Development of Maximum Use Access Module for Future Payload/Module Accommodation
• 2nd Order SASP-Double Gimbal PS	• Enable Solar Array to Track Sun Regardless of Orbital Position • Could Accommodate Any Payload and/or Orbital Position From a Power Standpoint	• Add Complexity to Structural/Mechanical Subsystem • Additional Gimbal Adds Length & Weight to PS

1.1.2 Viewing, Pointing and Stability and Control Considerations

Several alternate SASP configurations have been defined above and certain of their characteristics and potential benefits have been noted. This section summarizes some of the viewing, pointing and stability and control characteristics of the alternate configurations. The alternatives range from variations to the baseline platform standoff structures to magnetic joint payload coupling and tethered payload coupling. The configuration alternatives can be divided into several groupings as follows:

- Gravity gradient concepts which assume a local vertical orientation.
- Integrated concepts which integrate the solar arrays, radiator and payloads on the same standoff structures.
- Double-gimballed Space Platform concepts which add a second solar array gimbal in the body of the Space Platform.
- Magnetic joint connecting the payload to the Space Platform for disturbance isolation.
- Tethered payload connection to the Space Platform for disturbance isolation and viewing obstruction minimization.

Table 1.1.2-1 provides comments on the alternative configurations from a viewing, pointing, and stability and control viewpoint. The gravity gradient concepts (Figure 1.1.2-1 and the "Boom Stabilized," Figure 1.1.2-2) have a lot of flexibility with respect to payload viewing because of the multiple rotating payload arms which maximize payload independence. The independently rotating arms could generate motion disturbances on each other and further analysis is required to define the extent of the problems (as with the baseline SASP configurations). Gravity gradient (local-vertical) orientations would be with the solar array long axis perpendicular-to-the-orbit-plane (POP) during low Beta angle operations and in-the-orbit-plane (IOP) for high Beta angle operations. Mid-Beta angle operations would reduce power/thermal subsystem capabilities unless an inertial orientation could be maintained. A body long-axis POP inertial orientation would likely be possible with the reference Space Platform ACS sizing for mid-Beta angle operations. The Cruciform and Boom Stabilized configurations have the most potential for inertial orientations because of the potential mass distribution in the plane of the radiator which can offset the solar array gravity gradient disturbances.

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Table 1.1.2-1

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INNOVATIVE CONCEPTS: VIEWING, POINTING, AND STABILITY AND CONTROL

CONFIGURATION/ CONCEPT	VIEWING, ORBIT MECHANICS	POINTING	STABILITY AND CONTROL
2ND-ORDER SASP GRAVITY-GRADIENT CONCEPTS			
DOUBLE PLATFORM, CYNCIFORM AND BOOM STABLIZED	■ SIMULTANEOUS SUN AND EARTH VIEWING ■ LESS THAN OPTIMUM POWER AND THERMO AT MID β'S	■ POTENTIALLY LARGE NUMBER OF DISTURB-ANCE GENERATORS ■ SIMILAR TO SASP	■ SOME INERTIAL ORIENT-ATIONS MAYBE POSSIBLE WITHOUT PS MODS ■ POTENTIALLY LOWER FREQUENCY DYNAMICS THAN SASP ■ STABLE ORIENTATION VARIES WITH PAYLOAD COMPLEMENT
INTEGRATED CONCEPTS			
END-MOUNTED SOLAR ARRAY AND "OVER-UNDER"	■ SIMULTANEOUS SUN AND EARTH VIEWING ■ CELESTIAL VIEWING	■ SIMILAR TO SASP	■ "OVER-UNDER" POTENTIALLY LARGER AERO DISTURBANCES THAN SASP ■ CLOSER DYNAMIC COUPLING BETWEEN EXPERIMENTS AND SOLAR ARRAYS
+Z SOLAR ARRAY DEPLOYMENT	■ SIMULTANEOUS SUN, EARTH, AND CELESTIAL VIEWING	■ SIMILAR TO SASP	■ POTENTIALLY LARGE AERO DISTURBANCES
±Y SOLAR ARRAY DEPLOYMENT	■ SIMULTANEOUS SUN, EARTH, AND CELESTIAL VIEWING	■ SIMILAR TO SASP	■ LARGE SOLAR ARRAY INERTIAS MAY INCREASE GRAVITY-GRADIENT DISTURBANCES
DOUBLE-GIMBAL SOLAR ARRAY - SEPARATED PS, PRESSURIZED PS, UNMANNED SPACELAB DERIVED PS	■ IMPROVED VIEWING POTENTIAL OVER SASP ■ OPTIMUM POWER AND THERMAL REJECTION FOR ALL ORIENTATIONS	■ HIGH DOUBLE-GIMBAL DUTY CYCLE COULD CAUSE SIGNIFICANT POINTING DISTURBANCES	■ AERO AND GRAVITY-GRADIENT DISTURB-ANCES MAY BE LARGER THAN SASP
DOUBLE-GIMBAL SOLAR ARRAY - PRESSURIZED PS/ MANNED, SPACELAB DERIVED MANNED PS/SASP	■ SOME VIEWING OBSTRUCTION BY TRAILING AIRLOCK AND HABITABILITY MODULE ■ OPTIMUM POWER AND THERMAL REJECTION FOR ALL ORIENTATIONS	■ MAN DISTURBANCES PRESENT	■ AERO AND GRAVITY-GRADIENT DISTURBANCES LARGER THAN SASP
2ND-ORDER SASP, DOUBLE-GIMBAL PS CONCEPT	■ IMPROVED VIEWING POTENTIAL OVER SASP ■ OPTIMUM POWER AND THERMAL REJECTION FOR ALL ORIENTATIONS	■ HIGH DOUBLE-GIMBAL DUTY CYCLE COULD CAUSE SIGNIFICANT POINTING DISTURB-ANCES	■ SIMILAR TO SASP
TETHERED PAYLOAD	■ GOOD VIEWING POTENTIAL ■ DEPLOY/RETRACT AND ORBIT-KEEPING CONCEPTS UNCERTAIN	■ TETHER DISTURB-ANCE DYNAMICS UNCERTAIN ■ POINTING QUALITY ATTITUDE CONTROL SYSTEM NEEDED FOR PAYLOAD VEHICLE	■ ATTITUDE CONTROL AND ORBIT-KEEPING SYSTEM REQUIRED FOR PAYLOAD

Figure 1.1.2-1

PS/SECOND ORDER SASP — GRAVITY GRADIENT CONCEPTS

VFM154N

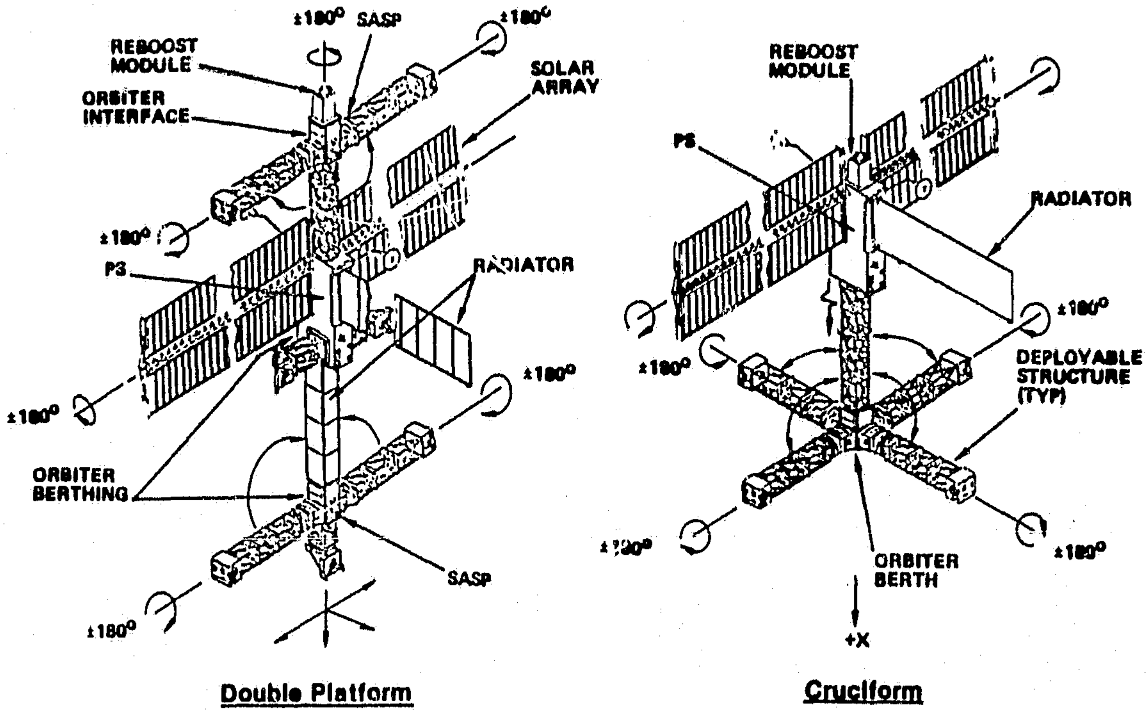
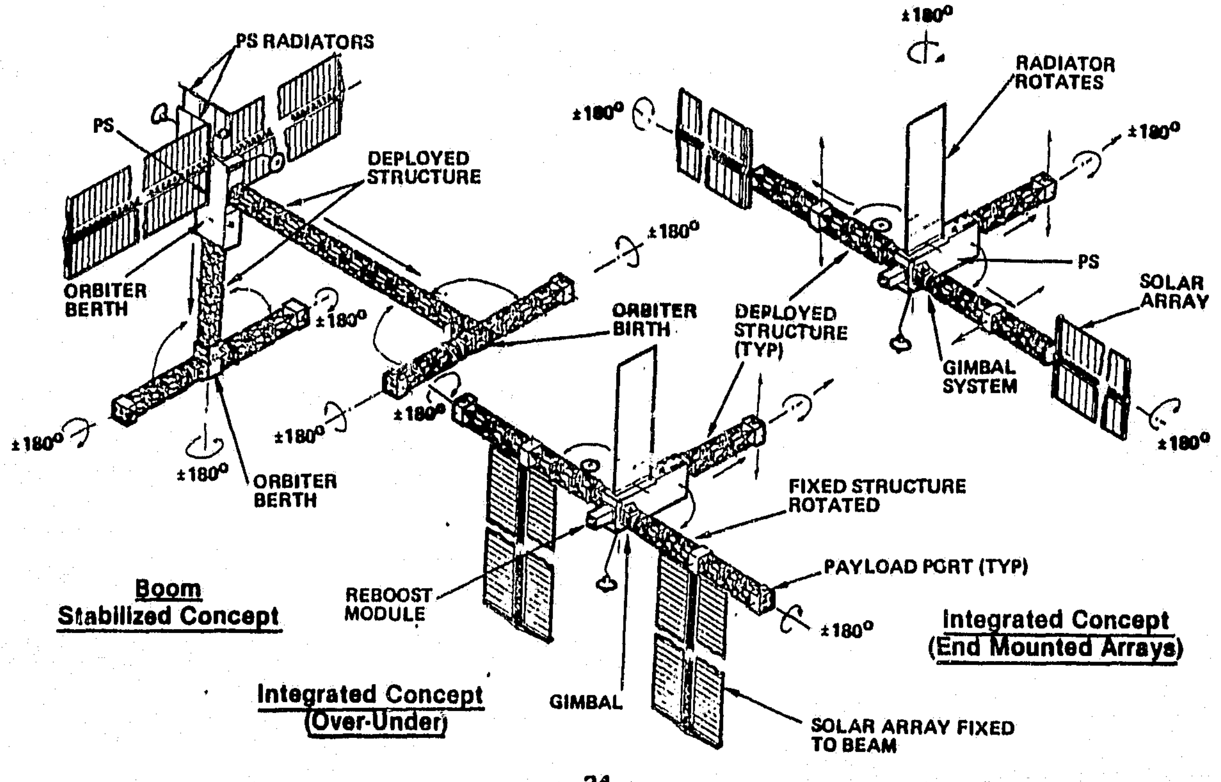


Figure 1.1.2-2

INNOVATIVE SASP CONCEPTS

VFM152N



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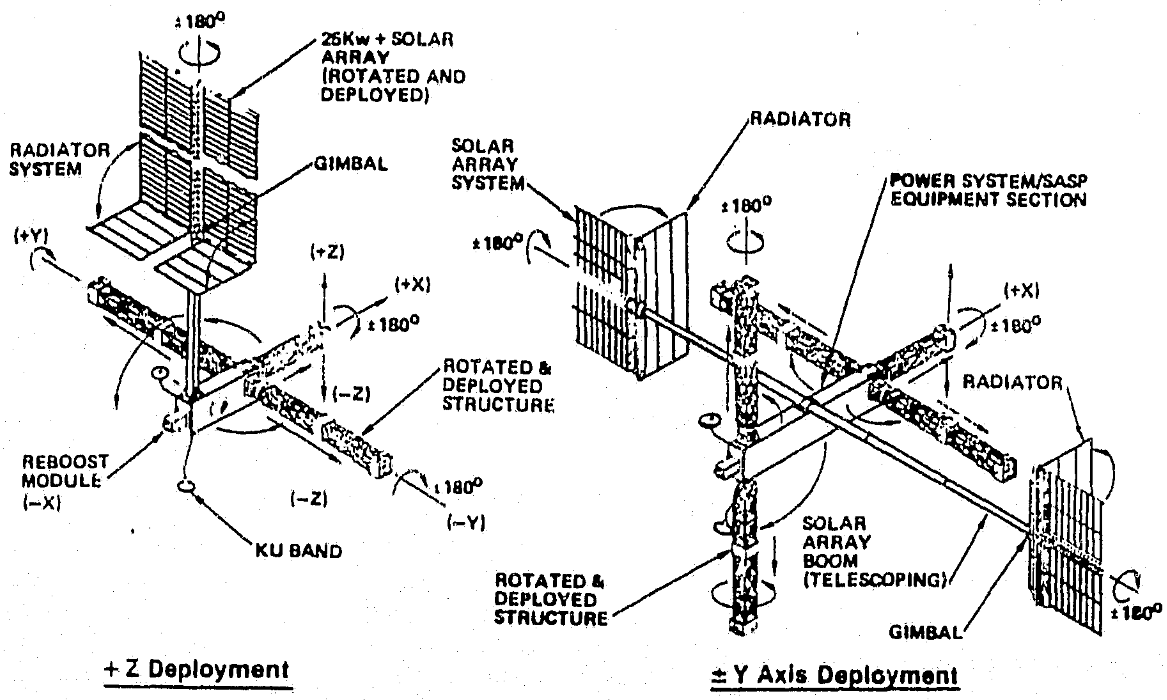
Figures 1.1.2-2 and -3 show configurations with the solar arrays and payload mounting arms integrated and solar arrays and thermal radiator structures integrated. These configurations improve viewing potential by moving the solar arrays and/or radiator further from payloads relative to the SASP. The over-under and +Z Deployment configurations have potentially large aerodynamic disturbances because of the large distances between the solar array center of pressure and the center of mass. The End Mounted Arrays and ±Y Axis Deployment configurations have very large moments of inertia about two axes which can result in very large gravity gradient disturbances. The large aerodynamic and gravity gradient disturbances would result in orientation constraints and/or increased CMG sizing requirements. The long appendages of these configurations would likely lead to low frequency structural dynamics relative to SASP which could degrade Apace Platform pointing performance and/or the performance of payload pointing systems.

Figure 1.1.2-3

**INTEGRATED PS/SASP —
DEPLOYED SOLAR ARRAY CONCEPTS**

VFM155N



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The configurations shown on Figures 1.1.2-4 and -5 integrate the solar arrays and radiator on the same structure and offsets them from the main body of the Space Platform. The configurations include a solar array double gimbal capability relative to the payloads and equipment section. Because of their large dimensions, these configurations have potentially large aerodynamic and gravity gradient disturbance torques and the attendant problems mentioned above. The double gimbal solar array capability allows the solar array and radiator to operate at full capability while the payload end of the vehicle orients itself as desired. There are orientation limitations, however, because the solar array/radiator assembly generates a major portion of the gravity gradient bias torques and so their orientation is not orbitory with respect to CMG sizing. The double gimbal concept is more beneficial when the solar array contribution to the whole vehicle inertia is a lower fraction. The relative size of the Space Platform solar arrays to the rest of the vehicle is larger than on most previously studied large satellites. The presence of men on the manned configurations produces motion disturbances which may not be acceptable to fine pointing payloads.

Figure 1.1.2-4

INTEGRATED PS/SASP —
DOUBLE GIMBAL SOLAR ARRAY CONCEPTS

VFM183N

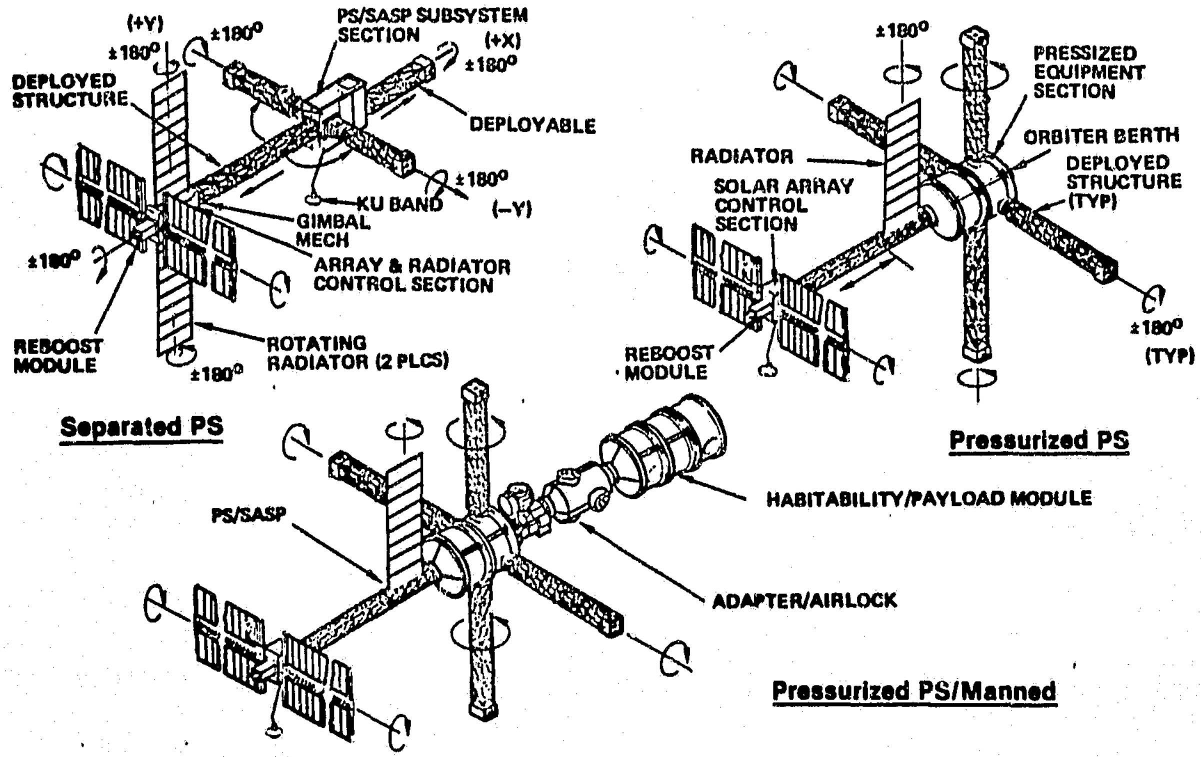

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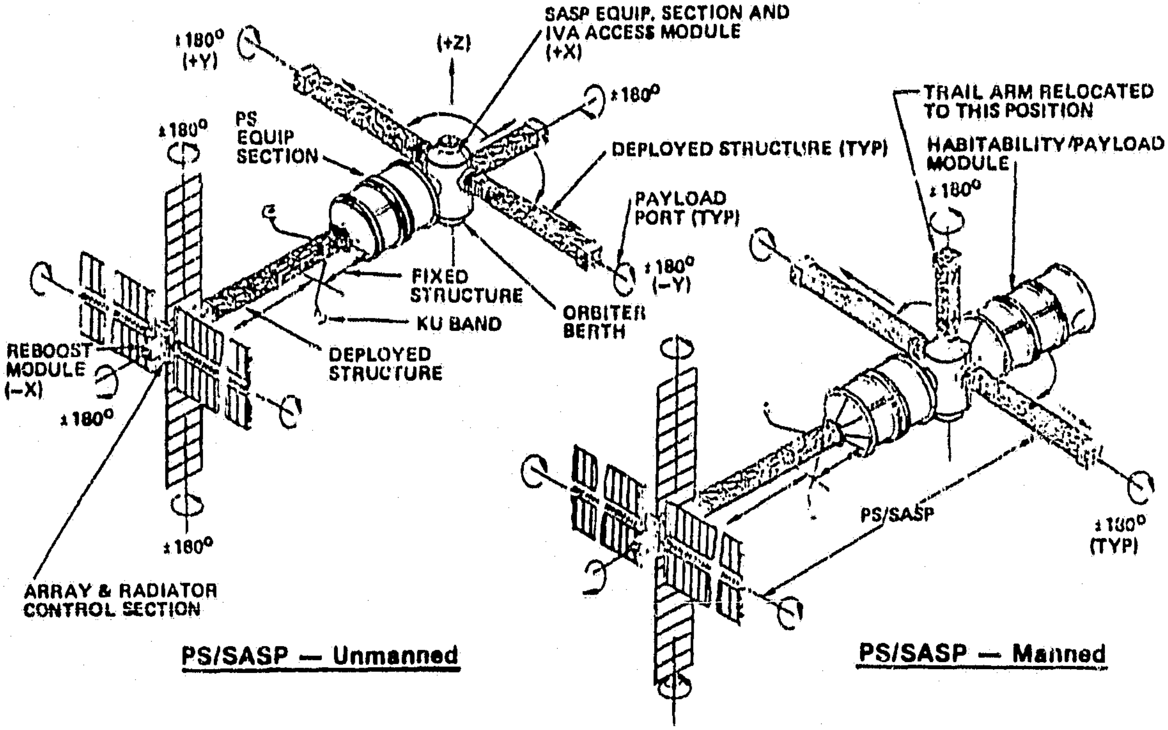
Figure 1.1.2-5

INTEGRATED PS/SASP — SPACELAB DERIVED PS



Another double gimballed solar array approach is shown on Figure 1.1.2-6. This is a more compact configuration than discussed above and has approximately the same viewing, pointing and control characteristics as the second order SASP. Some viewing improvement might result when the solar arrays are in the vertical position (as shown on the right side of Figure 1.1.2-6). A significant fraction of the Soace Platform moment of inertia is being gimballed so dynamic disturbance and the gravity gradient disturbances associated with the gimballed part of the platform may be significant.

Two methods for isolating the payloads from Space Platform disturbances were considered; magnetically suspended joints and tether-connected payloads. The tether approach is discussed in Section 1.1.3. Figure 1.1.2-7 has two magnetic suspension concepts, both being pursued by Sperry. The magnetic joints suspend the payload using active magnetic force/torque control so that no mechanical contact exists between the payload and the Space Platform. There is a six degree-of-freedom isolation for small relative motions. Since the suspension is actively controlled, the effective joint compliances and

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Figure 1.1.2-6

SECOND ORDER SASP — DOUBLE GIMBAL PS CONCEPT

VFM157N

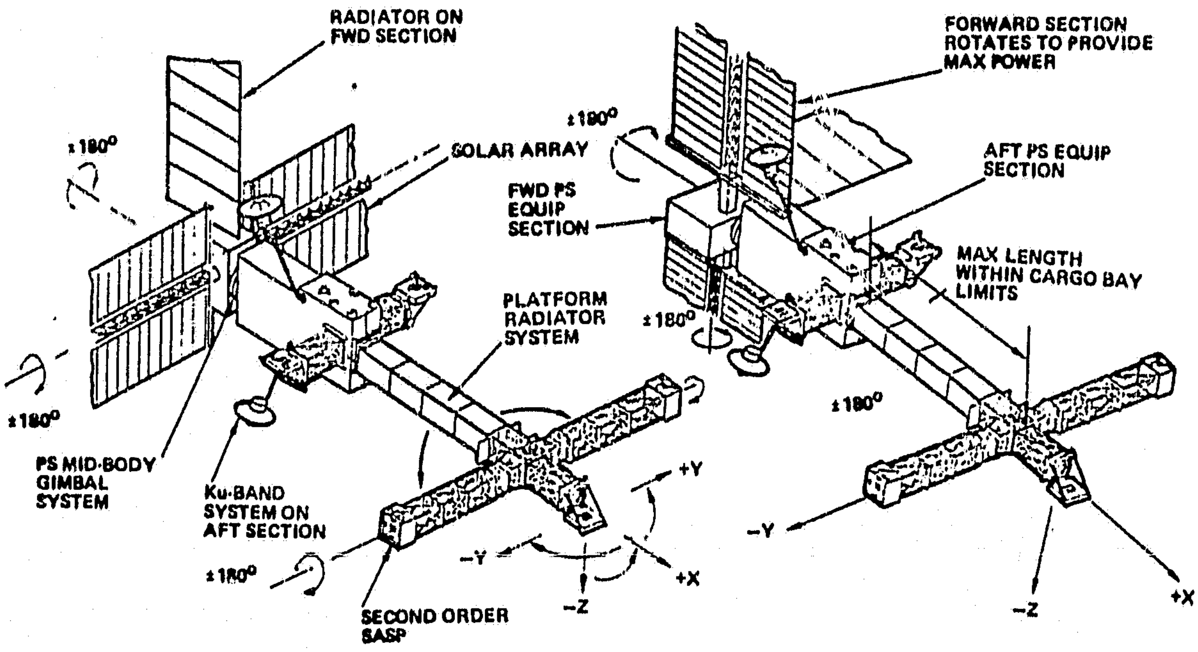


Figure 1.1.2-7

SPERRY CONCEPTS* FOR PAYLOAD/PLATFORM JOINTS

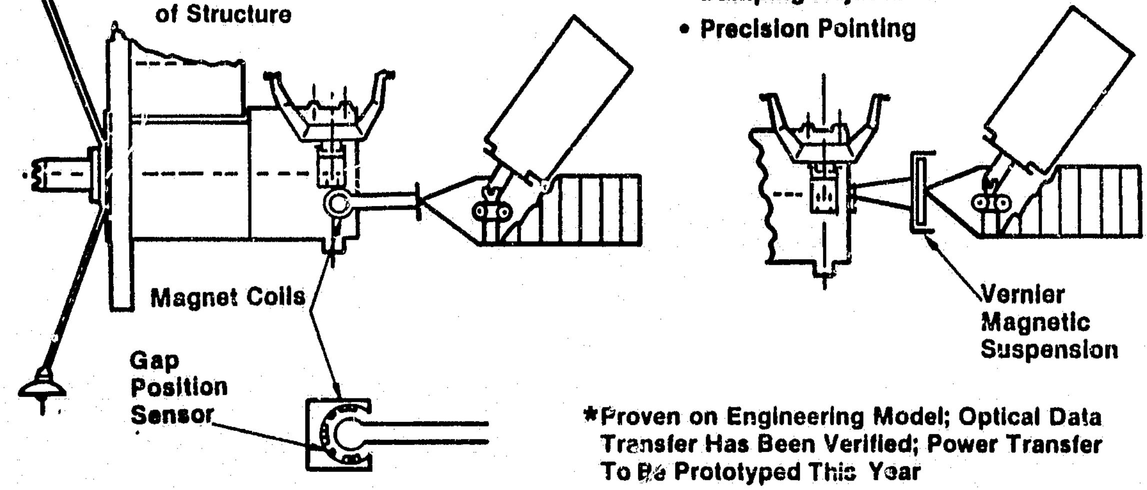
VFM412N

MAGNETIC-JOINT

- Vibration Isolation
- Adjustable Compliance
- Adjustable Damping
- Pointing
- Joints Can Be Distributed at Ends of Each Structure Member for Active Control of Structure

ASPS VERNIER MAGNETIC JOINT

- Six Degrees of Freedom
- Vibration Isolation
- Independent Isolation
- Independent Axis Compliance Adjustment
- Independent Axis Damping Adjustment
- Precision Pointing



*Proven on Engineering Model; Optical Data Transfer Has Been Verified; Power Transfer To Be Prototyped This Year damping can be adjusted and could potentially be adjusted to fit varying payload requirements or even adjusted on orbit to maximize payload isolation based on on-orbit data. The magnetic suspension joints have the potential for very good pointing stability performance and could possibly reduce payload/experiment pointing system/image motion compensation system formance requirements.

The left (Figure 1.1.2-7) magnetic suspension concept has a ball-joint character and can allow for rather large (30° half-cone angle) motions. The Vernier magnetic joint concept (right-hand side of Figure 1.1.2-7) is based on the Sperry/Langley Annular Suspension Pointing System (ASPS) concept. The ball-joint concept is expected to be prototyped during the next year, while the ASPS Vernier joint engineering model is currently operating successfully. The ball-joint concept is potnetially simpler to mechanize and has more applications potential because of its angular motion range and its adjustable compliance and damping potential. Optical data transfer across a magnetic joint has been proven up to a 30 megabits/sec rate. Ironless transformer-coupled power transfer across a magnetic joint is to be verified next year to a 5 kW capability.

1.1.3 Tethered Space Platform Configuration

1.1.3.1 Rationale for a Tethered Space Platform Concept

The platform concepts discussed elsewhere in this report are relatively rigid vehicles. The mechanical couplings between the experiments/payloads and the core satellite are relatively lightweight and easily deployable structures. The whole configuration is relatively compact. This compactness leads to a certain amount of payload-to-payload and core satellite-to-payload interaction/interference. This interaction/interference takes the form of invasion of field-of-views, chemical contamination, electromagnetic interference and dynamic motion disturbance.

An alternate approach to the Space Platform is to allow the payloads to be relatively free of the core central services satellite mechanically. The mechanical connection could be through taut tethers, loose tethers (leashes) or mechanically unconnected but flying in a kind of dynamic formation. The payloads in these tethered concepts could be relatively distant from each other and so minimize interferences/interactions. From a military viewpoint, the distributed tether concept may be advantageous because of decreased vulnerability to attack.

These are negative aspects to the tethered configurations, of course, mostly relating to the operational and dynamic motion complexities and uncertainties. Also, the relative isolation of each payload, while reducing undesirable interactions, tends to complicate the desirable connections with the core central service satellite such as centralized electrical power, thermal control, communication, command, computing, attitude control, orbit-keeping and data processing. Reference 1 addresses the tethered satellite concept in some detail and even proposes an alternative to the current Space Platform concept. These tethered/loosely-connected payload concepts appear to have some definite advantages but do not seem to have the near-term feasibility of the current, relatively simple Space Platform concepts. The tethered/loosely-connected payload concepts can be thought of as a middle ground between free-flying payloads and the current Space Platform concepts.

1.1.3.2 Tethered Space Platform Characteristics

Some kind of tethering is required to assure that the platform payloads stay relatively close to the core satellite. Aerodynamic drag, solar wind and pressure, and gravitational disturbances due to the moon, sun, etc., will eventually disperse a platform group unless some positive configuration-maintaining forces are applied. Tethers can supply these forces either continuously (taut tethers) or periodically (loose or leash tethers). In the leash concept the configuration would be dynamic but could be made cyclic rather than random in nature. The taut tether approach leads to a quasi-rigid spacecraft which maintains its configuration.

The tether can be considered a structural member which is stiff in tension and very weak in compression, bending and torsion. As discussed in Reference 1, tethered configurations can be maintained "rigid" in a single line (1D), a plane (2D) or three-dimensionally (3D) by utilizing gravity gradient and centripetal acceleration approaches. Figures 1.1.3.2-1, -2 and -3 show examples. A "momentum tether" is also defined which has the effect of

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Figure 1.1.3.2-1

EXAMPLES OF SINGLE-LINE TETHERED PLATFORMS

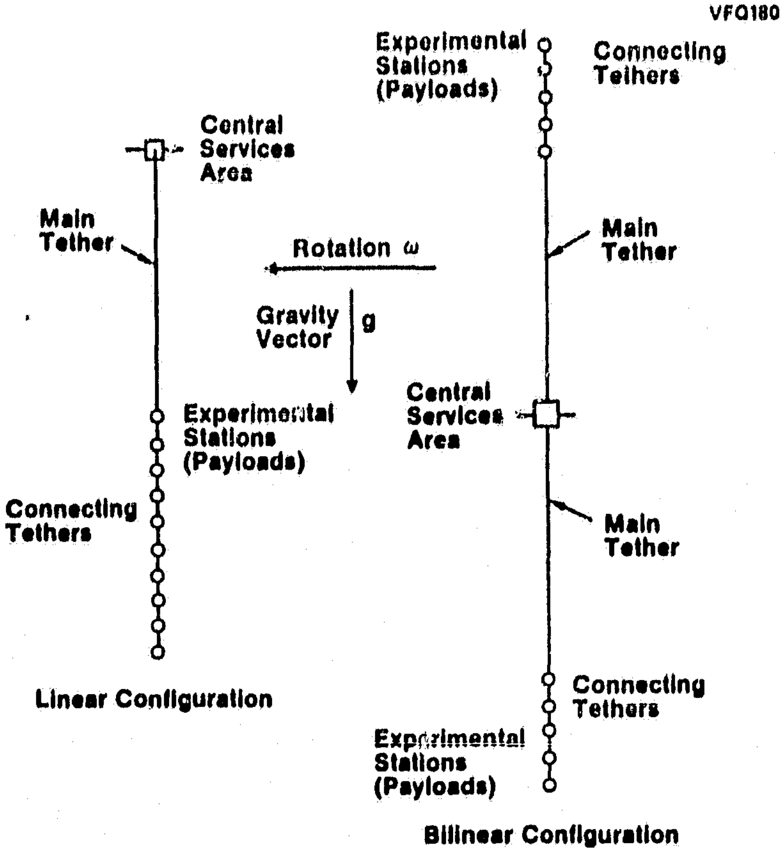

Figure 1.1.3.2-2

EXAMPLE PLANAR TETHERED PLATFORM

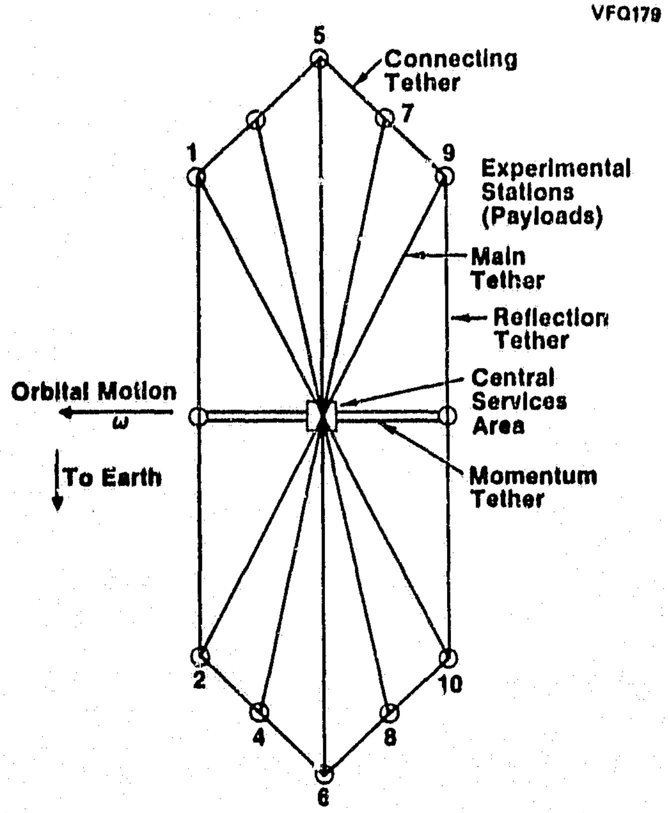

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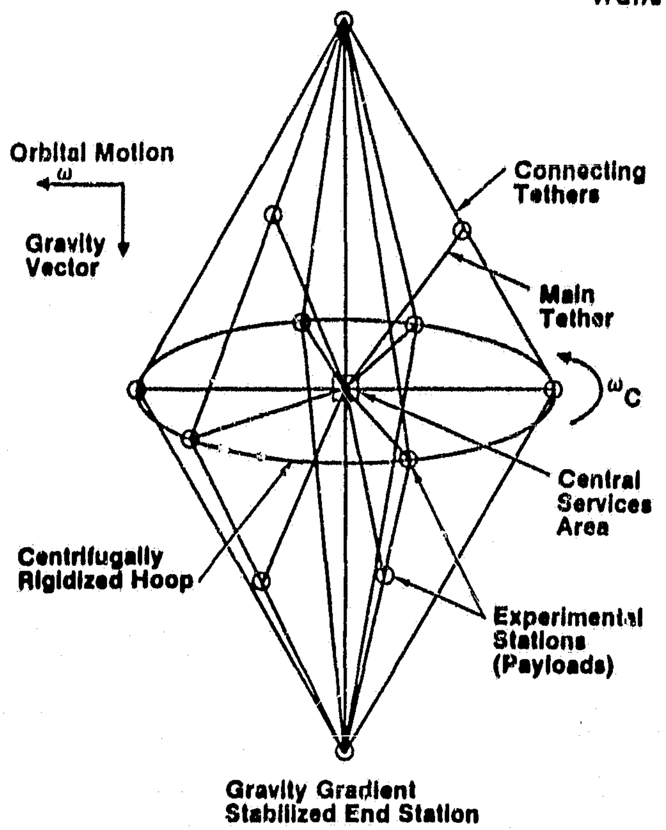
Figure 1.1.3.2-3

EXAMPLE COMBINED CENTRIFUGAL AND GRAVITY GRADIENT 3D RIGIDIZED PLATFORM



giving the tether a resistance to compression forces (included in Figure 1.1.3.2-2). The tether strength requirements are quite small. "Fish-line"-strength tethers could handle the static requirements for satellites with masses of over 10,000 kg. Dynamic strength requirements associated with docking and payload exchange are not easily defined.

Gravity gradient effects are utilized to keep the tethers taut which means the tethered platform group maintains a local vertical-type orientation. The 2D and 3D configurations also require rotation about the vertical axis or "momentum tethers" to maintain the configuration in a stable manner. These orientation constraints could complicate some payload operations.

The effective acceleration away from the center of mass (c.m.) of the taut tethered configuration is proportional to the distance above or below and out of the orbit plane from the configuration c.m. (to a first-order approximation). The acceleration magnitude is constant and the tethers generate the forces which accelerate (relative to a free orbit) the platform components to keep the configuration constant. These effective accelerations can disturb payloads requiring a low-g environment. The proposed platform configuration in Reference 1 (Figure 1.1.3.2-1) had tethers of up to 15 Km long. The effective g-level for Payload 5 (Figure 1.1.3.2-2) is about 7 X 10^{-3} g's which is unacceptable for most "low-g" payloads which require as low as 10^{-5} g's. A solution would be to put the low-g payloads on tethers holding them at the configuration c.m. or to place the low-g payload ahead or trailing the configuration c.m. (e.g., at the altitude of the c.m. for a circular orbit). Another solution would be to use a loose leash approach during operation of low-g payloads.

The taut tether approach doesn't completely remove the inter-payload dynamic motion disturbance problem associated with the current rigid Space Platform. The tether lines transmit forces from platform component-to-platform component. The tether lines could be quite flexible (elastic) which would effectively isolate the payloads dynamically with a very low frequency structure which would alternate all but very low frequency disturbances. Loose leash tethers maximize the dynamic isolation.

Loose tethered or leash concepts result in dynamic configurations. The majority of time, the leashes are loose but periodically the leashes would be tigntened to restore or constrain the configuration. While the leashes are loose, the payloads and core (central services) satellite travel in their own orbits. Satellites in the same orbit but trailing or leading each other maintain the same relative spacing except for long-term drift effects as mentioned earlier. Satellites in orbits with the same period but different inclinations and/or eccentricities and/or semi-major axes vectors move relative to each other during each orbit. The relative motion is cyclic with each orbit except for the long-term drift effects.

1.1.3.3 Tethered Platform Design Considerations

One of the prime tethered platform design considerations is the characteristic size of the configuration. The larger the configuration, the further the platform elements can be separated which minimizes viewing obstructions and probably higher frequency dynamic motion coupling problems. Larger configurations complicate the distribution of services, however. After the characteristic size is determined, the configuration form must be defined. That is, 1D, 2D or 3D shape, loose or taut tethers and location of the platform elements. The platform defined in Reference 1 (Figure 1.1.3.2-2) was a 2D configuration with a 30 km diameter. Momentum tethers were used to provide stiffness along the orbit path direction and normal (tension tethers) and gravity gradient and centrifugal acceleration effects were used to provide stiffness along the orbital radius and perpendicular to the orbit plane. The large size allows for very good unobstructed view potential.

Along with configuration definition, an operational plan must be designed. Significant operations include:

- launch vehicle docking (e.g., Space Shuttle) and
- payload exchange and repair/maintenance

Since configuration-maintaining forces are small relative to the masses involved, docking and payload exchange operations could result in large configuration relative motion disturbance and large loads in the tethers relative to normal operations.

Distribution of services must be considered. Services include:

- electrical power
- command, data processing and communication
- attitude control
- orbit-keeping

An additional service which would be significant for a tethered platform is configuration control. The real-time controlling of tether tensions for nominal operations and deploying and retracting payloads will likely be very complex. The trade studies used to define the services provided <u>to</u> the payloads and <u>by</u> the payloads would possibly be much different for the tethered platform than for the current rigid platform. For example, providing thermal control doesn't seem reasonable at this time. Data links could use multiplexed wire, fiber optic or RF technology. Attitude control would be relatively hard to provide though multiple tethers to each payload possibly could be used to control payload attitude. Providing large power to a payload could require large wiring and/or high voltages. Large wiring would be heavy (and large volume) and greatly complicate the motion dynamics. RF links could possibly be used for power transmission as well as for data/communications. Orbit-keeping seems reasonable if low thrust engines were used on the core vehicle.

The motion dynamics of a tethered platform will be very complex. Effort to-date on the Tethered Satellite Project is providing understanding of tether dynamics for a single-tether configuration. Multiple tethers will likely complicate the situation greatly. Just the potential dynamic motion problems associated with multiple payload tethered platform concept makes the feasibility questionable for the time frame that the current Space Platform Project is planned.

1.1.3.4 Example Tethered SASP Configuration

A tethered payload concept using the Reference Space Platform is shown in Figure 1.1.3.4-1. The tether deployment and retraction mechanism is based on a Tether Satellite concept. The tether provides the electrical power and communication services to the payload, while the payload provides its own

Figure 1.1.3.4-1

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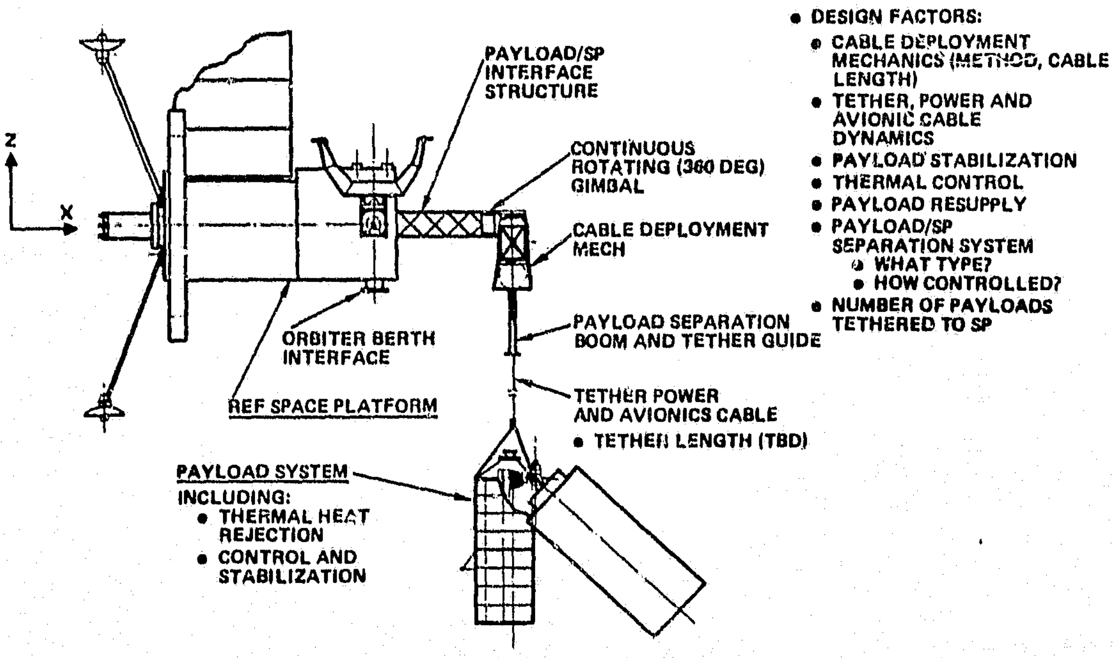
SASP TETHERED PAYLOAD CONCEPT

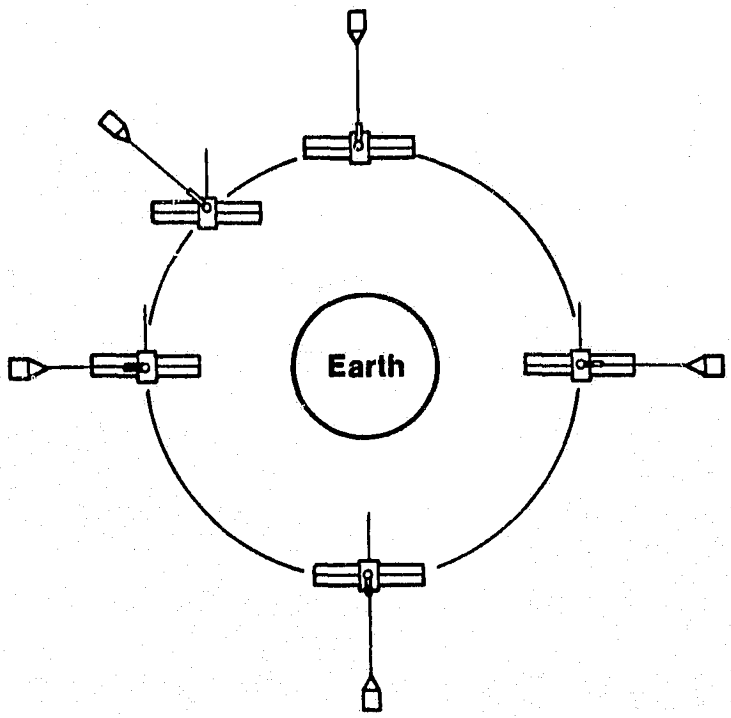


thermal control and attitude control services. The Space Platform flys an inertial orientation (X-perpendicular to the orbit plane, Y-perpendicular to the sunline) while the tether maintains a local vertical relationship relative to the Space Platform. Figure 1.1.3.4-2 shows the orientation history. The payload remains "above" the Space Platform and the gravity gradient keeps the tether taut. The solar arrays are maintained perpendicular to the sunline for maximum power throughout the orbit for all orbit Beta angles. The thermal radiator is also oriented optimally relative to the sun through the orbit. Thus, other payloads could have maximum resources available.

The payload shown in Figure 1.1.3.4-1 is a telescope facility and presumably would want all-sky viewing. An IPS pointing system is shown but the structure that the pointing system is mounted to must be stabilized in order to give the IPS something to react against in order to slew and point the telescope. Potentially, the telescope could be mounted directly to the structure and the whole structure attitude controlled much like a typical free-flying satellite.

Figure 1.1.3.4-2 VFQ177

SASP TETHERED PAYLOAD ORIENTATION



The interface with the tether must allow the payload to orient itself in this case without tangling with the payload or jerking the payload and disturbing the telescope line-of-sight.

For Orbiter docking and payload exchange, the payload is retrieved in a manner similar to that planned for Tether Satellites. An active tether control system controls the tension for a well-behaved payload deployment and retrieval.

The tether length is TBD but large distances would not be required for this example. The telescope would not normally be obscured by the Space Platform since the telescope looks away from the earth and the Space Platform is on the earth side of the payload. A distance of a few hundred meters should be adequate. The gravity gradient induced tension is only 6N for a 5000 Kg payload and a 300M tether length so tether strength is not a problem for the static load. Dynamic loads could be significant.

The electrical power transmission line design is significant to the tether design. For the case of a 300-meter tether and a 3 kW power requirement, a relatively small wire is possible. Assuming a 20 gauge wire and 7 amperes, a 430 volt transmission voltage is required. The wire temperature is around 200 to 300 deg F. A 17% loss factor results from the wire resistance. Increasing the transmission voltage or wire size would be desirable. The mechanical characteristics of the power supply and return wires will likely impact the motion dynamics. The tension force is only about 6N which may not even uncoil the wire. Very flexible wiring may be required. The communication wiring (or fiber optics) may also be significant mechanically.

Obviously, many design problems exist. Further analysis is required to define the basic feasibility of desirability of this concept.

1.1.3.5 Tethered Platform Summary

The tethered platform concept has some obvious advantages over the current platform concept in the areas of isolation. Table 1.1.3.5-1 summarizes the pros and cons of tethered Space Platform concepts. For long tethers, the payloads have many of the advantages of being a free-flying payload. The

Table 1.1.3.5-1

VFR310

TETHERED SPACE PLATFORM CONCEPTS

- **Pros**
  - **Improve Payload Field-of-Views**
  - **Decrease Motion Disturbances**
  - **Decrease Contamination**
  - **Decrease Electromagnetic Interference**
- **Cons**
  - **Dynamic Motion Complexities/Uncertainties**
  - **Operational Complexities**
  - **Complicate I/F with Central Services Vehicle**
  - **Major Development Effort Required**

tethers, however, complicate the centralizing of services which is the main goal of the platform concept. At one end of the specturm, the tethers could provide only a configuration maintenance function with each payload being essentially a free-flyer. The advantage of this would be that a single Shuttle flight could interface with any or all of the payloads making up a particular platform. On the other end of the spectrum, the core (central services) platform element could provide all services and the resulting complex tethers and links would maximize the amount of analysis and technology development required.

Currently, the state of the art favors a "rigid" platform approach for near-term (next 10 years) application. Work on and flight of the Tether Satellite will help define potential feasibility of a tethered platform. Since there are advantages associated with the tethered platform approach, it should be actively pursued for future application.

1.1.4 Conclusions and Recommendations

A cursory evaluation of the aforementioned concepts indicate that many will

operate as a scientific platform in both the unmanned and manned configurations. Some are not feasible for packaging in the Orbiter as an integral unit. Many are beyond the capability of the Orbiter RMS without multiple berthing operations between Orbiter and Power System. As a result of the above, most of the concepts are not system effective and probably not cost-effective. Therefore, it has been concluded that none of the configurations reviewed performs the mission defined for the SASP in a more system-effective or cost-effective manner than does the baseline second order SASP.
Table 1.1.4-1 summarizes the conclusions.

Table 1.1.4-1

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INNOVATIVE PLATFORM CONCEPTS CONCLUSIONS

- No Over All System Effectiveness Advantages Identified Relative to 2nd Order SASP
- Magnetic Joint and Tethered Concepts Require Advanced Technology but Have Promise
- Many Concepts Could be Made to Work but Are More Complex Than 2nd Order SASP

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1.2 PLATFORM/PAYLOAD IMAGE MOTION COMPENSATION INTERFACE

The Space Platform plans to accommodate experiments which need to be pointed. The experiment pointing requirements vary widely and different methods of experiment accommodation are required depending on the severeness of the experiment pointing requirement. It is desirable for the platform to be able to accommodate more than one pointing experiment during a mission and even to allow for more than one pointing experiment to operate simultaneously and independently.

Payload/instruments can be mounted directly to the Space Platform or to an auxiliary pointing system which is mounted to the Space Platform. The payload/instrument may also provide some of its own pointing capability. Figure 1.2-1 illustrates these options. The purpose of this effort is to gain some insight into the pointing capability that should be provided by the Space Platform (SP), auxiliary pointing system (APS) and the payload instrument itself to meet the experiment requirements. Table 1.2-1 outlines these questions. Emphasis will be placed on the potential for eliminating or simplifying the APS role.

Figure 1.2-1

SPACE PLATFORM EXPERIMENT POINTING OPTIONS

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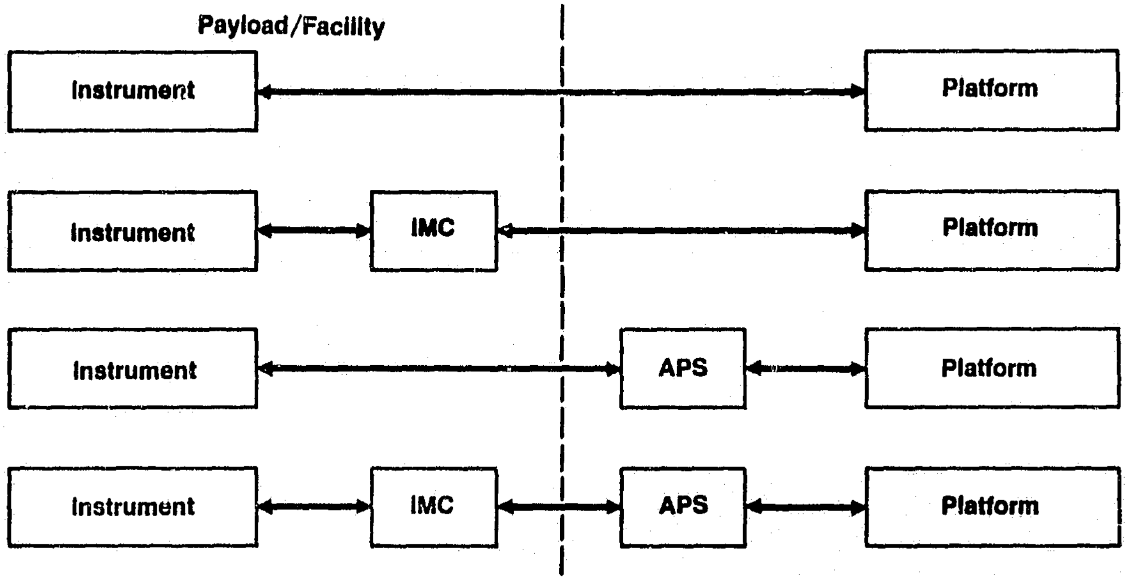

IMC = Image Motion Compensation
APS = Auxiliary Pointing System

Figures 1.2-2 and 1.2-3 show the task flow, objectives and approach for this task (A.2).

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Table 1.2-1

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PLATFORM/PAYLOAD IMAGE MOTION COMPENSATION INTERFACE STUDY

Questions

- **What is Appropriate Division of Labor Between Image Motion Compensation (IMC), Auxiliary Pointing Systems (APS), and Space Platform (SP)?**
- **What Are the Implications/Sensitivities to Increasing the Role of IMC While Reducing the Role of APS?**
- **Same as Above But Increasing the Role of APS or SP and Reducing the Roles of the Remaining Components**

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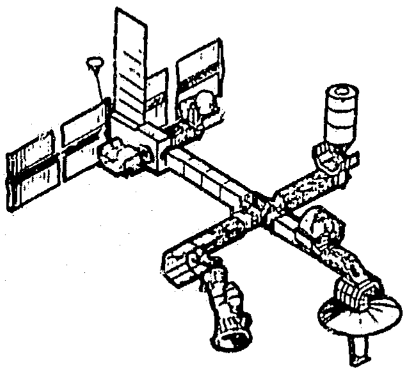
Figure 1.2-2

TASK A.2 — PLATFORM/PAYLOAD IMAGE MOTION COMPENSATION INTERFACE STUDY
(UNMANNED PLATFORM)



Inputs	Subtask Activity Flow	Outputs
■ Discussions With SIRTF and SOT IMC Designers ■ Discussions With Sperry AGS Designers ■ SASP Design and Dynamics ■ Ref PS Design	A.2.1 Discussions With IMC System Designers → A.2.3 A.2.2 Survey Ground- and Space-Based IMC Systems → A.2.3 A.2.3 Define IMC Potential Capabilities/ Constraints → A.2.4 A.2.4 Investigate Pointing Payload Application Using IMC Only	■ Basis for Continuing Dialogue Between Platform and Payload Designers ■ Added Insight Into Overall SASP/Pointing System/ Payload Pointing Requirements ■ Potential IMC Capabilities and Application Example Without a Pointing System

Figure 1.2-3

PLATFORM/PAYLOAD IMAGE MOTION COMPENSATION INTERFACE STUDY (SUBTASK A.2)

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Objectives

- **Gain Insight Into IMC Requirements For Platform Payloads; Particularly When No Auxiliary Pointing System (APS) Is Used**
- **Increase Overall Understanding of Platform, APS, and Payload Pointing Requirements**
- **Establish Dialogue Between Platform and Pointing Payload Designers**

Approach

- **Discuss IMC System Designs and Capabilities With IMC System Designers**
- **Survey Ground- and Space-Based Pointing and IMC System Designs and Operations (Review 35 Papers)**
- **Generate Potential IMC Requirements For Selected Payloads Assuming No APS Used**

Nomenclature - A short aside is needed to clarify the definitions of some of the terms used in this section.

Instrument - The instrument which gathers the science data.

Payload or Facility - A grouping of instruments each using the same basic data source. For example, a telescope facility will view a target and distribute the target energy to various instruments in the science section of the telescope.

Auxiliary Pointing System (APS) - A mechanism with one or more gimbals which is mounted to the Space Platform and has a payload or instrument mounted to it and is used to orient/point the payload relative to the SP.

Image Motion Compensation (IMC) - Pointing capability designed into the payload or facility which controls the facility line-of-sight (LOS) relative to the facility mechanical boresight. Usually, the IMC error feedback is at least partially based on the target image location at the image plane.

1.2.1 Overview

Typical capabilities which must be supplied to a pointing experiment include pointing direction, pointing direction stability over some defined time and pointing direction change/reorientation or slewing. The Space Platform satellite will be able to supply these capabilities to some degree but not completely for some payloads. The platform is a large vehicle with relatively large, flexible appendages (solar arrays, thermal radiator, communication antennas and payload mounting structures) and consequently, the pointing capabilities of the basic satellite will be crude relative to some experiment requirements. Thus, mounting a pointing payload directly to the platform limits the pointing capability provided to the experiment to that achieved by the whole platform. It would be very expensive and possibly not currently feasible to design a platform with the pointing capability to allow direct mounting of all desired experiments. Methods of improving the pointing performance at the instrument allow the instrument line-of-sight to have a degree of independence from the main platform body.

One type of experiment motion relative to the main platform body was baselined in the Science and Applications Space Platform (SASP) study. The arms of the SASP were mounted on single-axis gimbals which allowed the payload/instruments on each arm to rotate relative to the platform main body. These gimbals can be considered as part of the whole Space Platform vehicle. Auxiliary pointing systems can be mounted on the platform to point a payload. The payload is mounted on the auxiliary pointing system. Several pointing systems are currently being designed for Shuttle use. The Dornier Instrument Pointing System (IPS) and Sperry Annular Suspension Pointing System Gimbal System (AGS) are well into development and are expected to work with a wide variety of payloads. These and other pointing systems are discussed in References 24 through 31. These auxiliary pointing systems have different pointing capabilities but could increase the pointing capability over that provided by direct mounting to the platform. Several of the pointing systems have large angle capabilities with motion about two or three axes so large changes in payload line-of-sight are relatively easily accommodated compared to maneuvering the whole Space Platform.

Another method of improving pointing performance to the instrument is to control the facility lenses or mirrors in such a way that the target image is held where desired even though the outside structure may not be pointed in exactly the right direction. For example, a mirror in a telescope can be gimballed so that the effective line-of-sight of the telescope is not coincident with the mechanical boresight of the telescope. Thus, the telescope line-of-sight can remain fixed on the target even though mechanical motion of the telescope structure occurs. This type of pointing system is called an image motion compensation (IMC) system. Many of the references discuss IMC systems; e.g., References 1A, 2, 4, 8, 20 and 22.

1.2.2 Space Platform (SP), Auxiliary Pointing Systems (APS) and Image Motion Compensation Systems (IMC) Capabilities

The Space Platform (SP) is currently in the preliminary design phases. Therefore, its pointing capabilities are not set and the output from studies such as this can influence the intimate SP pointing capabilities. Pointing payloads directly with the SP is desirable since an expensive auxiliary pointing system could be eliminated. Elimating an APS may be feasible if the SP, payload and operational requirements are not greatly impacted by the lack of an APS. Tables 1.2.2-1 and 1.2.2-2 outline typical pointing capabilities of the Space Platform, auxiliary pointing systems and image motion compensation systems.

Table 1.2.2-1

REPRESENTATIVE POINTING COMPONENT DATA

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	Stability (Arc Sec)	Accuracy (Arc Sec)	Amplitude* (Arc Sec)	Bandwidth (Hz)
IMC	<0.01–1	0.1–1	1–10	10–200
APS	0.01–10	0.1–5	60–360	0.1–2
SP	1–120	1–1800	—	0.01–0.5

*Maximum Amplitude For Which Pointing Component Can Compensate

Table 1.2.2-2

TYPICAL POINTING COMPONENT FUNCTIONS/ROLES

VFO806

Image Motion Compensation

- **Small Amplitude, High Bandwidth Stabilization of Target in Instrument Field-of-View**
- **Often Combined With Offset Pointing and Spatial Chopping Functions**
- **Mechanized Within Facility**

Auxiliary Pointing System

- **Medium-Amplitude, Medium-Bandwidth Stabilization of Facility or Target in Instrument Field-of-View**
- **Often Combined with Large Angle Facility Orientation Capabilities**
- **Mechanized External to the Facility**

Space Platform

- **Low Bandwidth Stabilization of the Vehicle**
- **Orientation of Vehicle**

Space Platform - Even though the SP pointing capabilities are not set, representative capabilities can be assumed. The SP will have orientation duration constraints for some orientations. These constraints result from attitude control, electrical power, thermal control or communication subsystem limitations. Some attitude control system constraints are discussed in the Attitude Control and Stabilization section of Volume II, Part B. Thus, a payload mounted directly to the SP may not be able to point at a desired target when or for as long as required. Simultaneous operation of more than one pointing payload mounted directly to the SP greatly complicates the vehicle orientation problem and may be impossible a large fraction of the time. The baseline Science and Applications Space Platform (SASP) allows for single-axis rotation of payloads with respect to each other and relative to the SP which alleviates some of the vehicle orientation problems. Two-axis rotation capability is needed for full orientation independence of payloads with each other and the SP (essentially on APS).

The SP reorientation capability will be a few tenths of a deg/sec at most. Some payloads desire faster slew rates but a few tenths of a deg/sec may be adequate for a majority of payloads, particularly when the long SP mission time is taken into account (fast reorientation requirements usually result from wanting to maximize the data taking over the available mission time; only a few days on Shuttle, for example, but months or years on the SP).

The pointing direction stability of the SP will probably be a few arcsec for periods of a few minutes. Skylab data indicate that pointing stabilities of one arcsec are possible for durations under a minute. Pointing stabilities for longer durations such as half an orbit or several orbits are uncertain because of thermal distortion effects and attitude determination scheme uncertainties. The SP attitude control subsystem (ACS) bandwidth will be in the 0.01 to 0.5 Hz range. Environmental disturbance frequencies are 4×10^{-4} Hz or less and the ACS will be able to adequately compensate for them. SP-generated disturbances due to solar array gimballing, communication antenna gimballing, thermally induced structural deformations, payload motions and flexible dynamic motions have higher frequency content and may impact pointing stability. The magnitudes of these pointing disturbances need further study for definition.

Summarizing the SP pointing capabilities; the SP provides overall orientation control with some limitation on orientation duration for some orientations. A few inertial and local-vertical orientations can be held relatively indefinitely. Reorientations can be accommodated up to a few tenths of a deg/sec maximum. SP pointing stabilities are expected to be in the 1 to 10 arcsec range for durations up to a few minutes after vibrations due to disturbances and reorientations have been damped out.

Auxiliary Pointing Systems (APS) - Many auxiliary pointing systems (APS) have been used and are now in development. Their capabilities vary widely depending on the application. Currently, several APS are under consideration for use with large Shuttle payloads. References 25 through 31 define some of their capabilities. Reference 24 discusses the APS used on Skylab which probably could be adapted for large payloads on the Space Platform (SP). No APS are currently being designed specifically for an SP application but the

Shuttle-derived designs should be useful for the purposes of this study. Some experiments planned for Shuttle/Spacelab missions are designing their own pointing systems (References 7, 12, 14, 17 and 32 through 34) because of special considerations or because they do not require the high performance or size capabilities of the large, general-purpose Shuttle pointing systems.

A representative general-purpose Shuttle pointing system capabilities range may be represented by the following APS:

- The European Position and Hold Mount (PHM, Reference 30)
- The Dornier Instrument Pointing System (IPS, Reference 25) or the Sperry Annular Suspension Pointing System (ASPS) Gimbal System (AGS, Reference 27)
- The Sperry ASPS Vernier System (AVS, Reference 28)

The Auxiliary Pointing Systems (APS) are listed in order of pointing stability performance; best last. Table 1.2.2-3 compares the APS noted above. The PHM, IPS and AGS can be operated in a low performance mode using gimbal position

Table 1.2.2-3 VFQ076

SHUTTLE GENERAL-PURPOSE POINTING SYSTEM CAPABILITIES

POINTING SYSTEM	DESCRIPTION	MOTION RANGE	LINE-OF-SIGHT POINTING PERFORMANCE**	SLEW RATE
POSITION AND HOLD MOUNT (PHM)	DOUBLE-GIMBAL (AZIMUTH, ELEVATION)	±180 DEG AZIMUTH ± 90 DEG ELEVATION	ACCURACY AND STABILITY OF HOST VEHICLE (NO ATTITUDE SENSORS) 1 ARCMIN ACCURACY (USING SUN SENSOR) 30 ARC SEC STABILITY (USING SUN SENSOR)	GREATER THAN 10 DEG/MIN
INSTRUMENT POINTING SYSTEM (IPS)	3-GIMBAL (AZIMUTH, CROSS ELEVATION, ELEVATION)	±180 DEG AZIMUTH ± 60 DEG CROSS ELEVATION ± 60 DEG ELEVATION	1 ARC SEC ACCURACY 0.4 ARC SEC QUIESCENT STABILITY 0.7 ARC SEC ORBITER DISTURBED STABILITY 20 ARC SEC/SEC PEAK STABILITY RATE 1.6 ARC SEC/SEC RMS STABILITY RATE	3 DEG/SEC
ADVANCED GIMBAL SYSTEM (AGS)	3-GIMBAL (ELEVATION, LATERAL, ROLL)	±100 DEG ELEVATION ± 60 DEG LATERAL ±180 DEG ROLL	0.1 ARC SEC ACCURACY FOR IDEAL ATTITUDE SENSOR 0.2 ARC SEC QUIESCENT STABILITY (1σ) 0.6 ARC SEC DISTURBED STABILITY (PEAK)	10 DEG/SEC GIMBAL CAPABILITY, 1.6 DEG/SEC LIMITING IN S/W
ASPS* VERNIER SYSTEM (AVS)	SIX-DEGREE-OF-FREEDOM, MAGNETICALLY LEVITATED	±0.75 DEG (PITCH, YAW) UNLIMITED (ROLL) ±0.20 INCH (3-AXIS TRANSLATION)	ACCURACY LIMITED BY ATTITUDE SENSOR 0.01 ARC SEC STABILITY (QUIESCENT)	– –

*ANNULAR SUSPENSION POINTING SYSTEM (INCLUDES THE AGS AND AVS; THE AGS MAY BE USED ALONE)
**DEPENDS ON PAYLOAD AND DISTURBANCE CHARACTERISTICS; TYPICAL VALUES GIVEN FOR SHUTTLE APPLICATIONS

feedback only and in that operating mode would have essentially the same pointing performance as the SP. In this mode, payload reorientation could be provided by the APS rather than maneuvering the whole platform. The full-up IPS and AGS hardware/software probably would not be cost-effective when used in this simplified mode, however. The PHM, being simpler and less costly, could be cost-effective in the gimbal angle feedback mode for payloads satisfied with the SP pointing performance. Normally, the IPS, AGS and AVS will be used with an integrating gyro and attitude sensor so that the payload is isolated from the host vehicle (SP) motion.

The isolation is not complete, however. Motion of the SP would disturb the APS and payload but the APS would significantly attentuate the motion. The APS motion attentuation ability is the figure-of-merit with respect to pointing accuracy and stability. The "disturbed" pointing performances shown on Table 1.2.2-3 refer to Orbiter disturbances and should be more severe than the SP disturbances. Therefore, the SP APS performance may be closer to the "quiescent" performances noted. Some reservation is required, however. The SP will have lower flexible dynamic frequencies than the Orbiter which may force lower APS control bandwidths and reduce APS motion isolation capabilities.

The PHM, IPS and AGS provide very good orientation and reorientation (slew) capabilities. At least a π steradian solid angle is available. The AVS has relatively limited reorientation capability but very good pointing stability performance. The AVS is normally used with the AGS and the combination has very good viewing range and pointing stability. The combination is known as the Annular Suspension Pointing System (ASPS).

Image Motion Compensation (IMC) Systems - The capabilities of IMC systems are tailored to individual facility or experiment requirements. References 1A, 2, 4, 7, 10, 12, 17, 18, 20, 22, 23, 32 and 35 discuss IMC systems or requirements for various facilities, many planned for Shuttle flights. The function of IMC systems is to control the line-of-sight relative to the body of the facility. The target image, as seen by a sensor within the facility, is often used as the IMC system feedback sensor. Thus, the image motion relative to the feedback sensor (and also the data gathering instruments) is less than the physical motion of the facility. The moving elements of an IMC system normally are lightweight relative to the facility and operate at a high control bandwidth relative to the APS and SP control bandwidths. Thus, relatively high frequency disturbance motions can be attenuated by the IMC system. Example IMC mechanizations include gimballing a telescope primary mirror (Solar Optical Telescope, Reference 20), gimballing a telescope secondary mirror (Shuttle Infrared Telescope Facility, Reference 4), moving glass wedges (Solar Optical Universal Polarimeter, Reference 22) and electromagnetic deflection of the photoelectrons emitted from the photo cathode of an electronic imaging device (NRL-803 experiment, Reference 7).

The IMC system is normally an integral part of the facility and satisfies other functions in addition to IMC. Typical IMC systems functions include:

- Image motion compensation
- Alignment of facility components
- Offset pointing
- Spatial image chopping

Besides being driven by facility image sensors, IMC system inputs can include signals from pointing system rate-integrating (attitude) gyros as on SIRTF (References 1A and 4). Thus, the IMC system can be a highly integrated subsystem interfacing with the auxiliary pointing system, the facility image sensor(s) and experiment operations.

The pointing capabilities of IMC systems varies widely from application to application. Capabilities of interest are pointing accuracy, stability, control bandwidth and range. The deflected photoelectron beam IMC system example (Reference 7) has relatively moderate capability, about 30 arcsec stability which could easily be accomplished by an expensive APS like IPS or AGS. The Solar Optical Universal Polarimeter (SOUP) experiment IMC system Reference 22) on the other hand, hopes to achieve stability of better than 0.05 arcsec. Other experiments identified during the previous Science and Applications Space Platform (SASP) study identified pointing stability requirements below 0.01 arcsec. The Space Telescope satellite hopes to achieve 0.005-0.007 arcsec stability without an IMC system but if it were mounted on SP would obviously need one.

IMC system pointing accuracies are normally limited by the sensors used. Accuracies to the arcsec level are reasonable. Control bandwidths of IMC systems are set by sensor bandwidths or sensor sample frequencies. The servo component of the IMC system often has a higher bandwidth than required by the IMC because of other requirements such as image chopping transient response. IMC system bandwidths of 10 to 200 Hz are possible though 50 Hz is a more typical maximum IMC system bandwidth.

The IMC system angular range is often larger than required for the IMC function because of additional functions such as offset pointing, image chopping, scanning or small area mapping. Ranges of several arcmin are typical. The Spacelab 2 SOUP experiment (Reference 22) plans on an IMC system range of 0.5 deg to be able to scan the whole solar disk. A similar requirement exists for the Solar Optical Telescope Facility (Reference 20).

The IMC system range is limited by facility geometry as well as experiment considerations. The instrument or IMC line-of-sight (LOS) cannot be moved too far from the facility mechanical LOS (boresight) without resulting in image distortions or aberrations. Facilities viewing infrared sources must minimize unwanted infrared energy sources and moving the IMC LOS from the facility mechanical LOS can increase unwanted infrared radiation due to sources within the facility. Also, infrared radiation gradients across mirrors degrade science data and are aggravated by off-axis IMC LOS operation. The SIRTF IMC range of ±7.5 arcmin is an example. Ten arcmin might be a good maximum value to assume for a SIRTF-type infrared facility designed with a large IMC range in mind.

The IMC system range for the IMC function may not be the same as the full range capability of the line-of-sight motion relative to the facility mechanical boresight. When rate-integrating (attitude) gyros are used, as on SIRTF References 1A and 4), the technique is open-loop. That is, there is no direct feedback to the gyros that the disturbance measured by the gyros was actually compensated for by the IMC system. This is because the gyros do not measure the actual image motion. The image motion is measured by a lower bandwidth image sensor [the fine guidance sensor (FGS) on SIRTF]. The purpose of the gyros is to measure the higher frequency disturbances and compensate as well as possible while the lower frequency or long-term disturbances and drifts are compensated for in a closed-loop manner with the image sensor. The accuracy with which the gyro can command the IMC system articulation is about 5% (based on SIRTF analyses) for disturbances within the bandwidth of the gyros (typically 5-20 Hz). Thus, for example, a transient disturbance of 20 arcsec may only be reduced to one arcsec by the SIRTF IMC system. Thus, the IMC system maximum motion compensation capability is a direction function of the experiment requirements (e.g., if an experiment requires 0.5 arcsec stability, the IMC system can accommodate motion disturbances to 20 x 0.5 = 10 arcsec--the value stated on Table 1.2.2-2). At low frequencies where the image motion sensor dominates, larger motion disturbances could be tolerated.

1.2.3 Space Platform Accommodation of SIRTF Without an Auxiliary Pointing System

The purpose of this study is to gain insight into the potential for eliminating auxiliary pointing systems or at least minimizing the performance requirements for APS for Space Platform-mounted payloads. The need for an APS, of course, depends on payload requirements, SP capabilities and payload IMC capabilities. The previous paragraphs outlined SP, APS and IMC capabilities and noted some payload and experiment requirements. Tables 1.2.2-2 and -3 summarize these discussions. The scope of this effort did not allow for determination of experiment accommodations percentages or a detailed look at accommodating a range of payloads without utilizing an APS. Consequently, no detailed IMC system and SP pointing requirements were generated. It is instructive, however, to consider an SP application with the intention of eliminating the APS. The SIRTF payload was chosen for this exercise because a design for the Shuttle application is comparatively mature and because the SIRTF pointing and operational requirements are fairly broad and stringent. The Summary and Conclusions paragraph (1.2.4) will outline the current conclusions regarding direct-mounting of payloads to the SP.

SIRTF Description - References 1A and 4 through 6 discuss the Shuttle Infrared Telescope Facility (SIRTF) requirements, preliminary designs and operations. Discussions with K. R. Lorell (NASA/Ames) were also helpful. As the SIRTF name implies, the current SIRTF is planned for a Shuttle application. Potential modifications to the SIRTF for long-term SP application are to be studied at

NASA/Ames but were not available at this writing. Figure 1.2.3-1 shows a SIRTF direct-mounted on the reference SP. Figure 1.2.3-2 is a schematic of the overall SIRTF pointing control system as planned for the Shuttle application. The IPS APS is assumed in the schematic though the AGS APS is baselined at this time. The application would be functionally the same with the AGS. The following brief overview of the SIRTF pointing system design is based on Reference 4.

The SIRTF pointing and control system (PACS) operates by combining the outputs of the APS gyros with star-field position error measurements from a CCD array at the telescope focal plane. The gyros provide a high bandwidth, low-noise signal yielding good short-term stability; the CCD fine-guidance sensor (FGS) provides the long-term stability. The result is a system that possesses the desirable characteristics of both devices.

The readout and control of the CCD array is performed by a microcomputer which generates a 3-axes pointing-error signal based on the relationship between the

Figure 1.2.3-1

DIRECT SIRTF MOUNTING TO PLATFORM EXAMPLE APS FUNCTIONS TAKEN BY FACILITY OR PLATFORM

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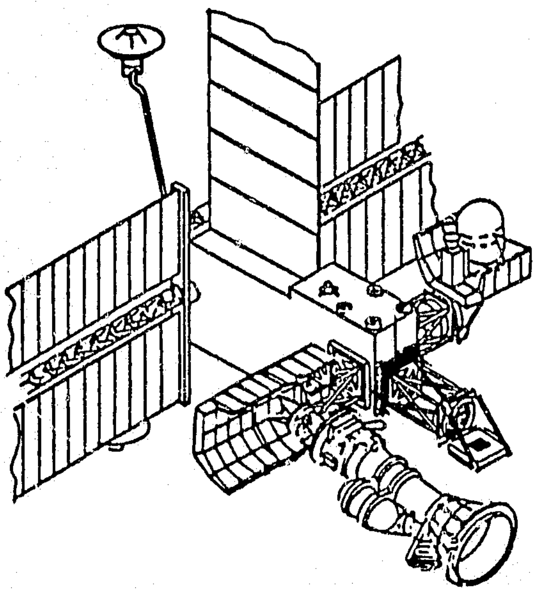
- **Rate Gyros**
- **Star Trackers***
- **Nodding**
- **Slewing**
- **Rastering**
- **Medium Amplitude Image Stabilization**



***Normally Mounted on Facility Even Though Part of APS**

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Figure 1.2.3-2

PRIMARY CONTROL LOOPS FOR THE SIRTF PACS*

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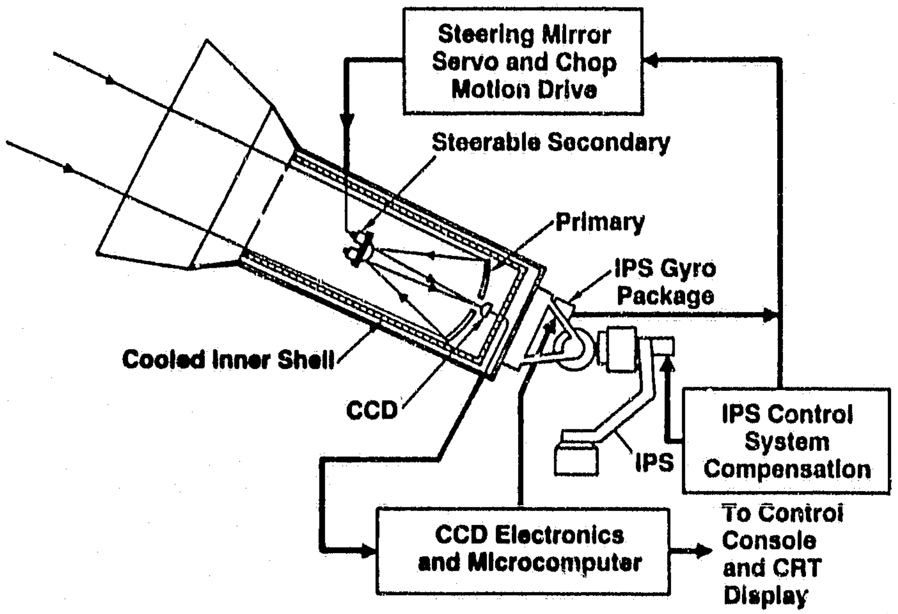

* Pointing and Control System

desired and the current positions of the tracked stars in the FGS field-of-view. Thus, a precise measure of the current orientation of the telescope optical axis is available from the FGS, irrespective of thermal mechanical distortion, or APS star-tracker alignment. The error signal derived from this measurement is processed by a Kalman filter in the SIRTF onboard computer to correct the gyro outputs, both in pointing offset and drift. The time constant for these error corrections is naturally quite long, of the order of tens of seconds.

The problem of short-term, high-bandwidth stability is solved by controlling the image with a gimballed mirror, which functions as the secondary mirror in the Cassegrain optical system of the SIRTF. Using this mirror as an image-steering device is a natural application since it already must have a high-performance servo system in order to spatially chop the image. Any motion of the SIRTF sensed by the gyros but not corrected for by the APS controller will be compensated by moving the steering mirror. The movable mirror increases the system bandwidth by acting on disturbances to which the APS cannot repond. The steering mirror is driven directly in a feed-forward mode by the gyro outputs. This feed-forward loop provides two important advantages: (1) the bandwidth is limited only by the bandwidth of the gyro and of the mirror servo,not by the closed-loop system bandwidth of the APS and (2) the possibility of a SIRTF structural resonance exciting a control system instability is minimized because there is not direct closed loop between the sensor and actuator. Feed-forward loops are, of course, sensitive to errors in scale factor. An analysis of the effects of scale factor error indicates that errors of as much as 5% can be tolerated without affecting performance.

Control loops utilized gy the SIRTF pointing and control system to provide image motion compensation and gyro-drift and position error information are shown in Figures 1.2.3-2 and -3. The controller consists of three interactive loops: (1) the fast image motion compensation loop, (2) the APS gimbal-control loop of moderate bandwidth and (3) the relatively slow outer loop which uses the FGS as the error sensor. By combining the outputs of these three control loops, the overall system bandwidth can be as high as 10 Hz, yet

Figure 1.2.3-3

SIRTF POINTING AND CONTROL SYSTEM BLOCK DIAGRAM

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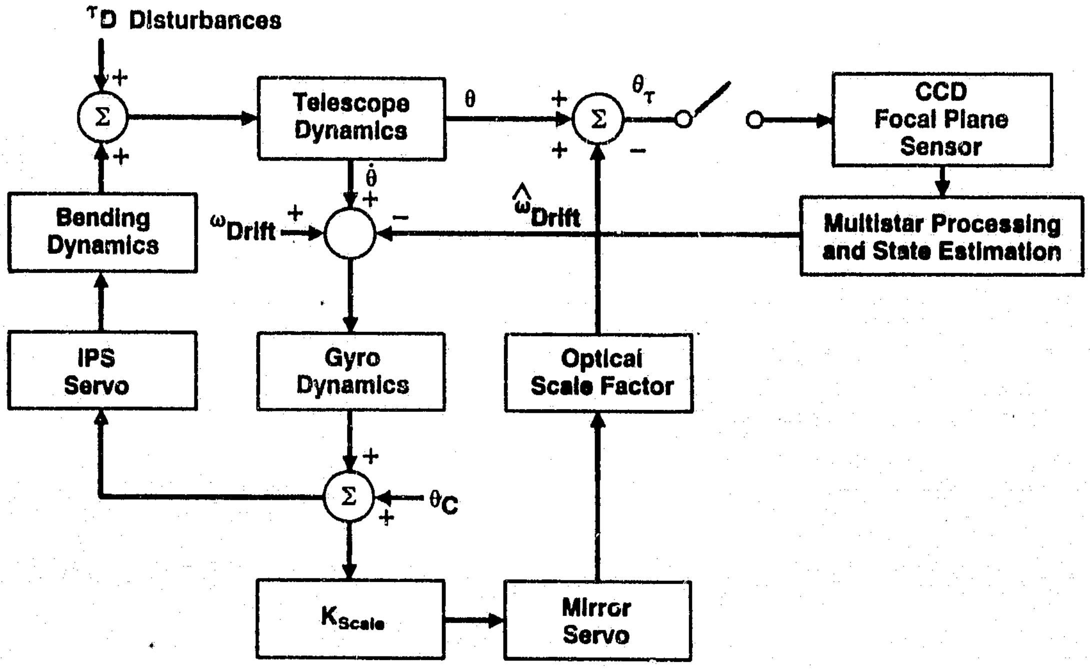


the advantage of star tracking for absolute position error determination, with bandwidths as low as 0.1 Hz, are retained.

Obviously, the SIRTF IMC system and the auxiliary pointing systems are highly integrated.

The basic SIRTF scientific instrument pointing stability requirement is 0.25 arcsec RMS. The fast IMC system loop can attentuate 95% of the higher frequency (10 Hz) facility motion disturbance so the pointing stability requirement for the main body of the facility is 0.25 x 20 = 5 arcsec. The infrared focal plane field-of-view (FOV, maximum FOV available to the science instruments) is 7.5 arcmin. Some of the scientific instruments will require high stability in three axes and the roll about the LOS will have to be considered.

Worst case roll about the LOS stability requirement is about 4 arcmin (corresponds to 0.25 arcsec LOS stability at the edge of the focal plane FOV). There is no IMC for motion about the LOS so the 4 arcmin stability must be achieved by the facility main body.

Thus, to meet the science instrument stability requirements, the main body of the facility must maintain a 5 arcsec LOS stability and a 4 arcmin about the LOS stability. If the SIRTF were mounted to the Space Platform (SP) without an auxiliary pointing system, the SP must provide the above-mentioned stability at the mounting interface.

Target acquisition must be considered. Slewing or reorientation accuracy is critical for a timely target acquisition. The SIRTF slew accuracy requirement includes a 120-degree slew to an accuracy of 10 arcsec. Smaller slews should be somewhat more accurate but not proportionally so because some errors are not a function of slew angle. Accurate slewing is required to minimize the time to find a new target and to simplify the procedure for acquiring the target. Simplifying the procedure is particularly valuable for autonomous acquisition operations. Reference 5 defines conditions when the Shuttle Mission Specialist or ground personnel may be required for acquisition. Possible acquisition end-game techniques include using the science instrument output to "peak-up" on an infrared source, using the FGS and "peaking-up" on the optical signal of the target and the use of guide stars. Guide star techniques use the FGS to acquire guide stars near the infrared target region and then offset pointing to the target.

All these techniques require a high degree of integration of the facility main body pointing system, the IMC system and the various sensor outputs including some science instrument outputs. This integration would include the SP if SIRTF were mounted directly without an APS.

After an infrared target is acquired, orbital operations include scanning, nodding, mapping, searching and calibration. Some of these operations involve movement of the science instrument line-of-sight with the IMC system and/or movement of the facility main body. The motion patterns may be rectangular or spiral and may require motions as large as one degree. The SP would provide the motions associated with the APS if the SIRTF were direct-mounted (without an APS) to the Space Platform. "Nodding" is a case where even small motions must be done with the facility main body. The nodding function is to move the facility an amount equal to the image chopping amplitude (but at a much lower frequency). Chop amplitudes range from 5 arcsec to 7 arcmin. Achieving SP nodding amplitudes of 5 arcsec with any degree of stability/fidelity may be challenging.

Another aspect of SIRTF orbital operations relevant to an SP application is slewing or reorientation time. The Shuttle on-orbit missions are two to four weeks maximum and the availability of the Shuttle to SIRTF would likely be on the order of once a year, so SIRTF operations on Shuttle are designed to maximize the amount of data-taking during a mission. This generates rapid slew requirments and short target acquisition time requirements. The planned Shuttle SIRTF slew capability is about 120 degrees in three minutes. The SP mission would be six to 12 months long and conceivably, the slew time requirements could be relaxed. Discussions with SIRTF people at NASA/Ames indicated they believed that SIRTF was a very desirable facility and investigators would be interested in all the data possible even for a six- to 12-month mission. If the SIRTF were mounted to the SP without an APS, the slew time requirements would have to be eased to avoid placing unreasonable control system requirements on the SP.

As noted previously, the SIRTF IMC system uses outputs from the APS gyros for high bandwidth feedforward compensation (Figures 1.2.3-2 and -3). In the SP application without an APS, these gyros must be replaced. The SP will have high quality gyros but their utilization for the IMC function would be questionable. First, a high sample frequency (50 Hz) data link between the SP gyros and the SIRTF IMC system would be required. This could be a significant consideration for the SP data subsystem. Secondly, and more importantly, the location of the SP gyros would likely be too far from the SIRTF. The motion disturbances measured by the SP would not be the same as experienced by the SIRTF particularly at higher frequencies (1 to 10 Hz). So the gyro commands to the IMC system could not adequately compensate for the actual SIRTF main body motion and image stability requirements would not be met. The difference in motion between the SP gyros and the SIRTF main body are caused by dynamic structural deformation resulting from thermal transients and structural flexibility and looseness. The obvious alternative is to include high quality gyros in the SIRTF main body for use with the IMC system.

SP/SIRTF Integration Summary (No APS) - Tables 1.2.3-1 and -2 summarize the Shuttle-mounted SIRTF requirements, design and operations discussions of the

Table 1.2.3-1

DIRECT SIRTF MOUNTING TO PLATFORM EXAMPLE SHUTTLE-MOUNTED CHARACTERISTICS

VFO787

Required Performance At Science Instrument

Field Of View	**7 Arc Min**
Accuracy	**1 Arc Sec**
Stability	**0.25 Arc Sec For 20 Min**

Fine Guidance Sensor Field-Of-View

30 Arc Min

IMC Characteristics

Range	**5 Arc Sec (APS Gyro Scale Factor Limited)**
Frequency Response	**10 Hz (Gyro Limited)**

Secondary Mirror Driven By APS Gyros

Star Trackers

Uses APS Star Trackers

Wide Field Of View (Several Degrees)

Table 1.2.3-2

SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF)

VFO785

Example: SIRTF Operations/Operational Modes

Point Source Observation
- **Chopping Using Secondary Mirror (5-420 Arcsec)**
- **Nodding Whole Facility (Amplitude of Chopping)**

Mapping
- **Up to 1 x 1-Deg Area**
- **Raster Motion of Whole Facility**

Searching
- **Up to 3 × 3 Arcmin Area**
- **Spiral Search With Secondary Mirror**
- **Move Whole Facility to Center the Source**

Calibration
- **Simultaneous Viewing of a Source by Several Sensors**

Target Acquisition
- **Accurate Slewing to New Target**
- **Use of Guide Stars and Offset Pointing**
- **Man Participation Required Some Times**
- **Scanning/Searching Sometimes Needed**

previous paragraphs. Direct-mounting the SIRTF onto the Space Platform requires the SP and the SIRTF to share the pointing functions that on APS will provide on the Shuttle application. If the APS functions are not completely picked up, an operational impact could result. APS functions which must be picked up by the SP and IMC system are noted on Figure 1.2.3-1 and include: large angle slewing, small angle "nodding" and rastering, high slew accuracy, gyro feedforward IMC signal, and moderate accuracy, wide field-of-view attitude sensing. Any gap between the Space Platform and IMC system pointing accuracy and pointing stability capabilities must be closed. Other APS functions such as the APS computing capability will also have to be considered.

Table 1.2.3-3 outlines some of the potential pointing control problems associated with mounting SIRTF on the Space Platform without an auxiliary pointing system. The Reference SP pointing accuracy at the payload mounting may only be about one degree when errors due to the SP attitude determination and control system, thermally induced deformations, flexibility and misalignments

Table 1.2.3-3

VF0788A

DIRECT SIRTF MOUNTING TO PLATFORM

- **Attitude Initialization**
  - **SP Accuracy Not Within SIRTF FGS Field of View**
- **Replacement of APS Gyros**
  - **SP Gyros Located Relatively Far From Facility**
  - **May Require Facility-Mounted Gyros**
- **IMC Range Capability**
  - **Gyro-To-Image Motion Feed-Forward Gain Errors May Have To Be Reduced**
- **Operations Requiring Rastering and Nodding**
  - **Whole SP Must Move and/or Facility Redesigned for More Secondary Mirror Motion Capability**
- **All-Sky Viewing**
  - **SP Has Limited Orientation and Slew Rate Capabilities**

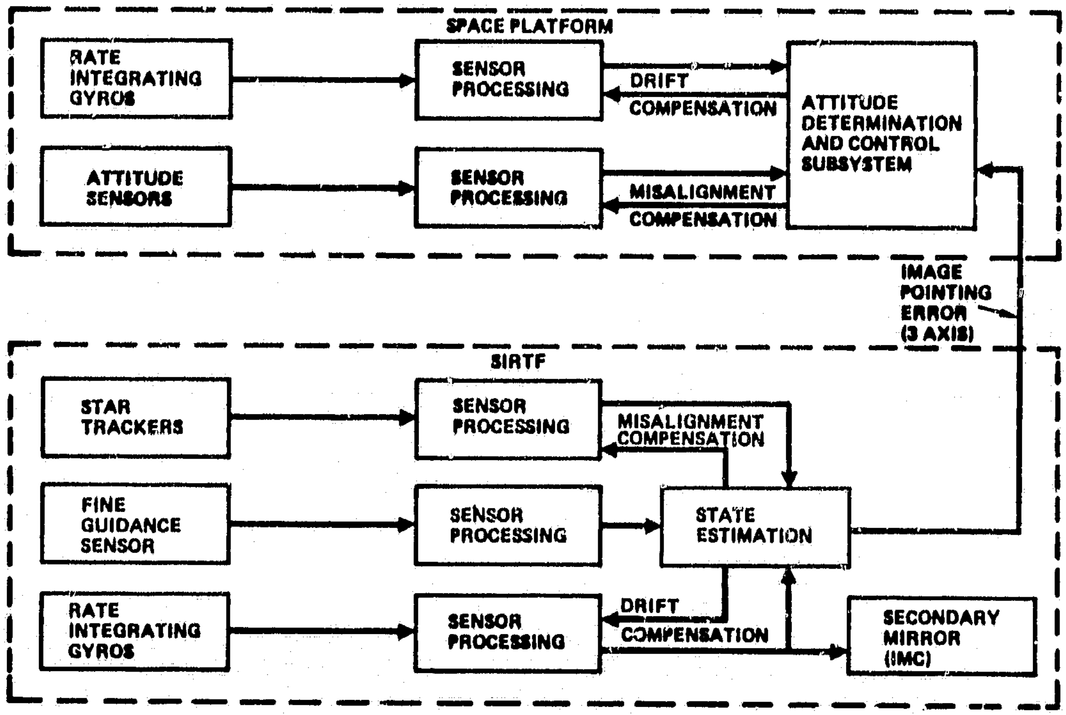
are included. Therefore, a moderate accuracy (10-60 arcsec) attitude sensor with a field-of-view of 1-2 degrees may be required to command the SP to get the targets within the 0.5 degree FOV of the FGS for initialization and reasonable target acquisition times. The APS star trackers provide this function on the Shuttle-mounted SIRTF and are mounted on the exterior of the SIRTF main body. The same sensors and approach could be used for the SP application without an APS. The integration of these sensor outputs, as well as the SIRTF fine guidance sensor and possibly some scientific instrument outputs, with the SP attitude determination algorithms would be required.

Mounting low-noise, low-drift, high-bandwidth gyros on the SIRTF is probably the best approach to replacing the APS gyros. Using the SP gyros would introduce unwanted motions due to transmit thermal deformations and structural flexibility. A complete attitude determination system using the SIRTF-mounted attitude sensors and fine guidance sensor may be required for facility pointing and slewing accuracy. A minimum system of rate gyros controlling two IMC axes with FGS drift compensation and FGS and SIRTF-mounted attitude sensors for SP ACS use may be possible but some attitude reference link will be required. If not the facility mechanical line-of-sight and the image line-of-sight would diverge a minimum of the dynamic structural misalignment between the SP attitude reference and the SIRTF attitude reference. This could be on the order of one degree, as mentioned above, which is well beyond a reasonable range for the IMC. The SP will require some SIRTF-mounted attitude reference and possible signals including the fine guidance sensor, the star trackers (during data gathering as well as for initialization and acquisition), SIRTF-compensated rate-integrating gyro outputs and secondary mirror gimbal angle. The last is effectively a link to the fine guidance sensor. Detailed analyses are required to determine whether a full-up attitude determination system is required in the SIRTF software. Items for evaluation would include IMC system range requirements, slew accuracy, target acquisition times and SP attitude drift. Figure 1.2.3-4 shows a block diagram for the full-up mechanization described.

Figure 1.2.3-4

VFQ109

SP/SIRTF JOINT POINTING CONTROL SYSTEM



Structural deformation dynamics along with SP attitude control subsystem (ACS) errors may result in motion disturbances of the SIRTF main body which are greater than the IMC system capability (5 arcsec as discussed previously). Using FGS feedback to the SP ACS will limit the low frequency disturbance but the FGS feedback loop may not have the bandwidth to compensate for all thermally induced transients and structural flexibility effects. If this occurs then the SIRTF IMC system range must be expanded. The limitation is gyro-to-image motion gain accuracy. Reference 4 and discussions with Ken Lorell at NASA/Ames indicate that 5% accuracy is reasonable but this capability could limit the image motion stability during thermal transients or until structural resonances damped out. Incorporation of the SIRTF rate gyro outputs into the SP ACS is another approach which might reduce the motion disturbance problems at frequencies above the FGS loop bandwidth. Flexible dynamic coupling would be aggravated.

SIRTF scanning or rastering operations requiring motions of the SIRTF body (nodding, mapping) must be implemented by moving the SP. Increasing the angular range of the IMC system would eliminate the need to move the whole facility for some operations. However, large IMC system ranges may not be feasible because of off-boresight abberations and thermal gradients across the secondary mirror which degrade data when secondary mirror gimbal angles are large. Also, some operations require the whole facility to move because of their function. Nodding the whole facility is required for instrumental baseline subtractions for example. The implications of "nodding" the whole SP with its low frequency appendage resonances and massive inertias, are yet to be evaluated. Reference 5 describes scanning programs using the Instrument Pointing System (IPS, References 25 and 26) with the goal of minimizing the amount of time required to cover an area of sky. The Reference SP CMG control system momentum management function would likely be impacted if IPS-equivalent scanning operations were attempted.

The SIRTF desires all-sky viewing. Using orbit regression as the sky scanning mechanism does not provide a timely or flexible way of viewing desirable targets. Reorienting the facility "quickly" from target to target greatly enhances its usefulness. When the SIRTF is direct-mounted (no APS) to the SP, the SP must do the reorienting and hold the new orientation for up to 20 minutes and then repeat the cycle. The Reference SP is not designed for "all-sky" capability with respect to momentum storage capability. Electrical power, thermal control and communication subsystem considerations may also limit the available orientations at a given time. The incorporation of a single-axis gimbal between the SP and the payload (baselined on the larger Science and Applications Space Platform) will improve the viewing potential while eliminating the need to reorient the SP vehicle about this gimbal axis.

As discussed earlier, the Reference SP maneuver rates are limited relative to most APS. This would impact the amount of data-taking over a given time relative to a Shuttle application or an SP application using an APS. This reduced data-taking rate may be acceptable in light of the long SP mission times, but discussions with the SIRTF project people at NASA/Ames indicated maximum data-taking is desirable even for long missions.

The system-level orientation/reorientation question is hard to assess at this point. With a direct-mounted SIRTF, the SP assumes a role similar to the Space Telescope which has been designed for all-attitude hold with unlimited duration. The Reference SP has not been designed for this capability and including this all-attitude, long-duration capability would be a major impact to the sizing of the momentum management system. Other SP subsystems would also be impacted. A SIRTF application without an APS would surely have a lower percentage of time data could be gathered and a limited number of targets available for viewing at any given time relative to an application with an APS. A low pointing performance APS with two or three gimbals with large gimbal angle capability would be of great benefit to a SIRTF-type payload. The operational problems become even more complex when simultaneous operation of a second pointing payload (in addition to SIRTF) is considered.

If the operational constraints are acceptable, however, the SIRTF could be direct-mounted to the Space Platform using a joint SP/SIRTF pointing control system such as that shown in Figure 1.2.3-1.

1.2.4 Summary and Conclusions

The purpose of this effort was to gain insight into the potential of accommodating pointing payloads on the Space Platform without utilizing an auxiliary pointing system. The APS functions are shared by the SP and the facility/payload. The typical pointing system within a facility is an image motion compensation system. A question of interest is whether any gap between the SP and the IMC system pointing performance (normally made up with an APS) can be closed by extending the pointing performance capabilities of the SP and/or facility IMC system. Of particular interest is the pointing stability; is the SP pointing stability provided at the facility mounting location compatible with the facility IMC system performance?

The study approach was to review the Reference SP pointing capabilities, APS capabilities and designs and survey a number of payload IMC system designs. With this background knowledge, an insight into the potential elimination of the APS was gained. The SIRTF payload was selected for more detailed analysis as a potential SP payload application without utilizing an APS. SIRTF was chosen because it has relatively severe pointing performance requirements and a wide range of viewing operations and viewing directions.

The SIRTF analysis indicated that the pointing performance of the SP and SIRTF IMC system could be made compatible. Detail analysis and design is required but qualitatively certain conclusions can be made. The SIRTF would have to incorporate high performance integrating rate gyros for the high bandwidth IMC loop. The gyro-to-image motion feedforward gain accuracy may have to be improved. Attitude sensors (probably star sensors) would also have to be incorporated on the SIRTF and linked to the SP attitude determination system. Their accuracy and field-of-view should be better than an arcmin and about 2 deg x 2 deg, respectively, in order to achieve reasonable initialization and target acquisition times. (Star sensors are also mounted on the SIRTF to perform a similar function when an APS is used.) The SP attitude control and determination system must be compatible with some SIRTF sensor outputs; the star sensors or fine guidance sensor candidates. A low bandwidth secondary mirror gimbal signal interface with the SP may be desirable to command the SP attitude to align the image line-of-sight with the telescope mechanical line-of-sight. A higher bandwidth link between the SP and the SIRTF gyros may also be desirable. The gyro link in combination with the star sensor or FGS link could be used to effectively move the SP attitude reference from the SP to the SIRTF for higher pointing and slew accuracy. Figure 1.2.3-1 shows a block diagram of a possible joint SP/SIRTF pointing control system mechanization.

The exclusion of an APS in the SP/SIRTF application has certain implications (outlined on Table 1.2.4-1). Probably the largest impact is in the viewing operations area. SP orientation constraints and slew and raster rate limitations probably would reduce the number of targets that could be viewed in a given time (relative to using an APS). The fidelity of small (a few arcsec) whole facility maneuvers would also probably be degraded relative to using a high performance pointing system. If the operational constraints are acceptable, however, it is concluded that the SIRTF could be accommodated (from a pointing control viewpoint) by the SP without an APS if the above-mentioned SIRTF modifications and SIRTF/SP interfaces were incorporated.

A few general comments about the implications of attaching a pointing payload to the SP without an APS are shown on Table 1.2.4-1. Payloads with pointing

Table 1.2.4-1

IMPLICATIONS OF MOUNTING PAYLOADS DIRECTLY TO PLATFORM

VFO808

- **IMC Must Be Designed to Compensate for Platform Stability Characteristics**
- **Platform Must Provide Accurate Orientation Control and Slewing From Target to Target**
- **All-Sky Viewing Requires Platform to Have Capability for Holding Large Variety of Orientations**
- **Inceased Operational Conflicts for Simultaneous Operations of More Than 1 Pointing Payload**

requirements less stringent than SIRTF can be accommodated with IMC systems similar to those required for APS use. The SP probably cannot provide payload orientation flexibility or slew rate or rastering-type maneuvering equivalent to that provided by an APS, so viewing operations would be impacted in a negative sense.

Qualitatively, it appears that using a pointing mount (or tilt table) for gross reorientations would be very beneficial to pointing operations for many payloads mounted on SP. The European Position and Hold Mount (PHM, Reference 30) is a good example of a simplified APS with a large angle gimballing available. The conclusions are summarized on Table 1.2.4-2.

Table 1.2.4-2

VFR293

IMAGE MOTION COMPENSATION STUDY CONCLUSIONS

- **IMC System Designs Can Accommodate Many Direct Mounted Pointing Payloads From a Stability Viewpoint**
- **Viewing Operations Make a Large Angle Coarse Gimbal Capability Very Desireable Particularly for Simultaneous Payload Operations**
- **The Payload Will Have to Pick up Certain APS Functions Such as Rate Gyros and Attitude Sensors**
- **A Platform/Payload Attitude Interface May be Required to Update Platform Rate Gyros**

1.3 PLATFORM DYNAMICS

1.3.1 Introduction

The general objectives of this task are noted in Table 1.3-1 and the activity flow and inputs and outputs are shown on Figure 1.3-1. The configuration analyzed in the previous SASP Study and this study are shown on Figure 1.3-2.

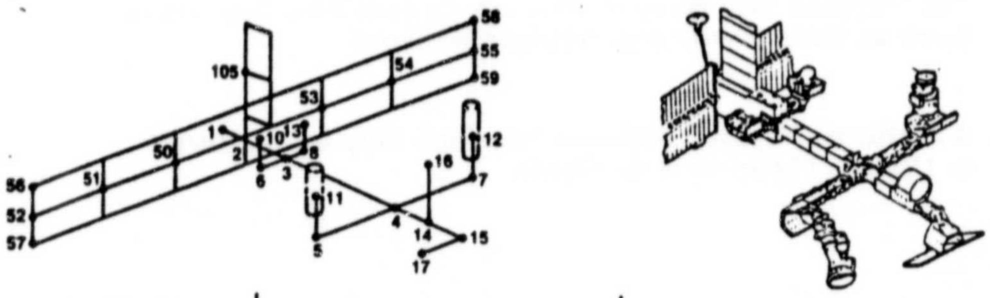
Table 1.3-1

TASK A.3. PLATFORM DYNAMIC ANALYSIS GENERAL OBJECTIVES VFO816

- **Assess Disturbance Sensitivity – Payload Motions (Open Loop)**
- **Provide Controls Reference Model**
- **Perform Damping Benefit Studies**
  - **Disturbance Reduction**
  - **Isolation Effectiveness**
  - **Controllability Improvements**

Figure 1.3-1

TASK A.3 — PLATFORM DYNAMICS ANALYSES VFR215

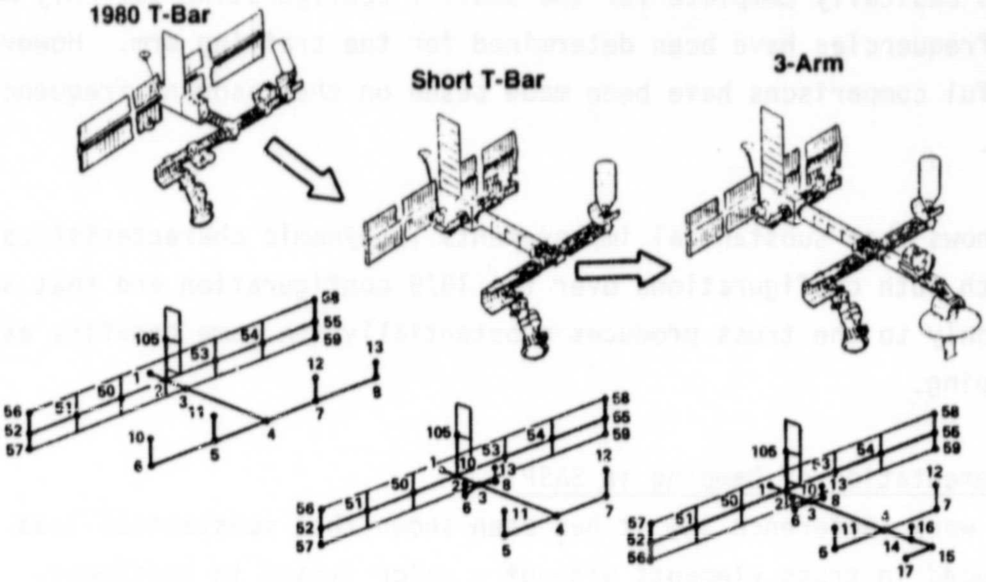


Inputs	Subtask Activity Flow	Outputs
■ Previous SASP Analyses ■ Previous Structural Damping Studies ■ Current SASP Configurations	A.3.1 Update Nastran Models → A.3.2 Perform Modal Analyses → A.3.3 Generate Structural Frequency Responses	■ Dynamic Model Definitions ■ Dynamic Characteristics ■ Localized Damper Potential ■ Data Useable for Control System Interaction Evaluations

Figure 1.3-2

VFR214

DYNAMIC ANALYSIS CONFIGURATIONS



The structural dynamics work of the previous SASP Study primarily addressed the determination of mode shapes and resonant frequencies to develop an understanding of its dynamic characteristics. The configuration chosen for that study was the version most likely to have a large number of low frequency modes.

A limited amount of parametric work was performed on the effects of damping on frequency response, transfer functions and transient response at several points on the platform.

The results showed that a substantial number of elastic modes (approximately 30) below 3 Hz in the free-flying SASP (neglecting solar panel modes) and that incorporation of a moderate amount of damping would produce substantial reductions in the transfer functions from one payload position to another.

The present study addresses two more compact versions of the SASP which relocate payloads on the outer arms of the old configuration and, in one case, adds a third trailing arm with two payloads.

Since the Power System is undergoing a separate evolution, the effect on syst ᷊ damping of adding damping only to the SASP truss struts was investigated in addition to investigation of the uniformly damped characteristics. This work is basically complete for the small T configuration but only mode shapes and frequencies have been determined for the trailing arm. However, several useful comparisons have been made based on the resonant frequencies of the systems.

The study shows that substantial improvements in dynamic characteristics are obtained with both configurations over the 1979 configuration and that addition of damping only to the truss produces substantially the same benefits as uniform damping.

1.3.2 Implementation of Damping in SASP

In previous work (Reference 36) it has been shown that substantial loss factors can be produced in truss elements without a major impact in stiffness. This and other work (Reference 37) have also demonstrated that a certain level of "background" damping is desirable to make up for damping lost because of operation in space and precision of the design. An example truss strut approach along with parametric damping characteristics is shown in Figure 1.3-3. This concept is of minimal complexity and addresses the issues of creep and outgassing by using a flexure which provides both containment and static determinacy. A spacecraft with low damping will have long settling times for transients, high steady state transmissibility and isolation systems will have poor performance. A reasonable level of damping, on the other hand, will mitigate these trends and will produce some point-to-point transmission loss in the structure (Reference 36). The strut damper shown in Figure 1.3-3 would be built into each SASP strut (see Figure 1.3-4 for strut) truss configuration.

The greatest benefits are usually achieved with a uniform distribution of damping in the structure. This approach is very often not achievable for a variety of reasons resulting in a selective damping approach. The separate evolution of the Power System is a significant reason to consider the case of having damping only in the SASP truss. However, it is of value to still consider the uniformly damped case as an optimum (from the damping point of view) reference case.

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Figure 1.3-3

VISCOELASTIC MATERIALS EFFECTIVENESS OF DAMPING TREATMENT ON STRUT EXTENSIONAL DAMPING*

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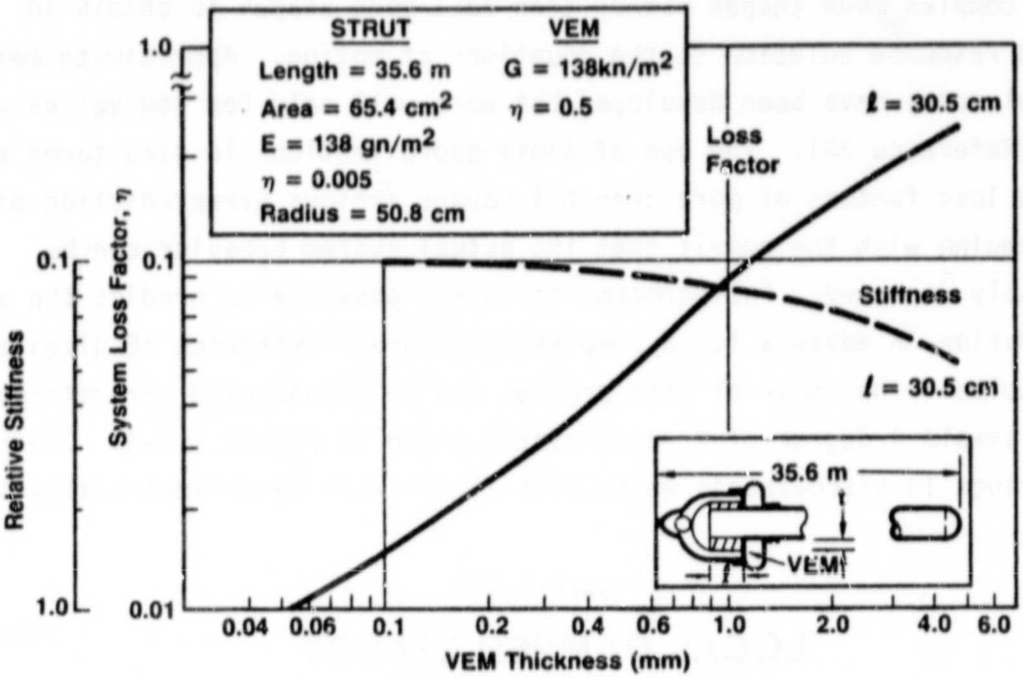
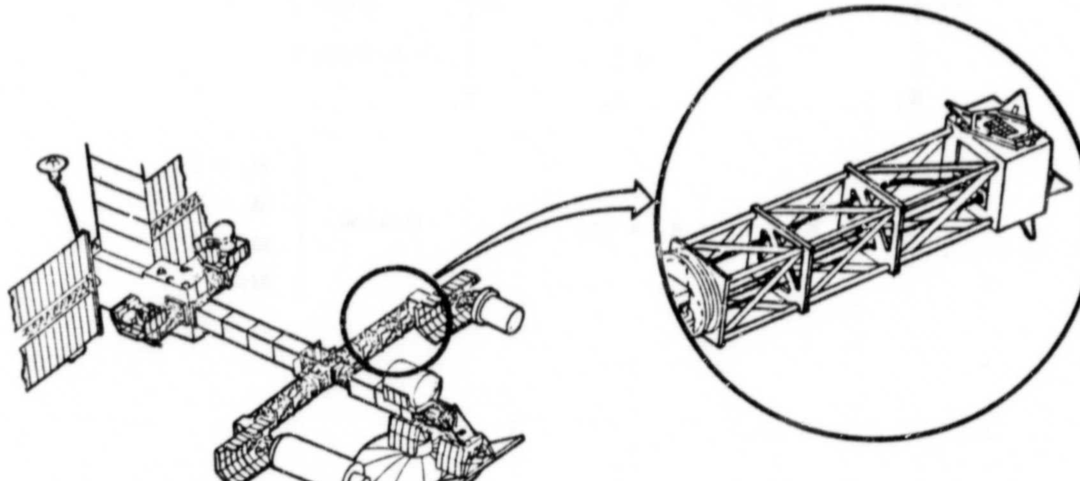


*From AIAA Paper 1980 — 0677, Passive Damping in Large Precision Space Structures/R. Trudell/MDAC

Figure 1.3-4

VISCOELASTIC DAMPER BUILT INTO EACH STRUT

VFR307



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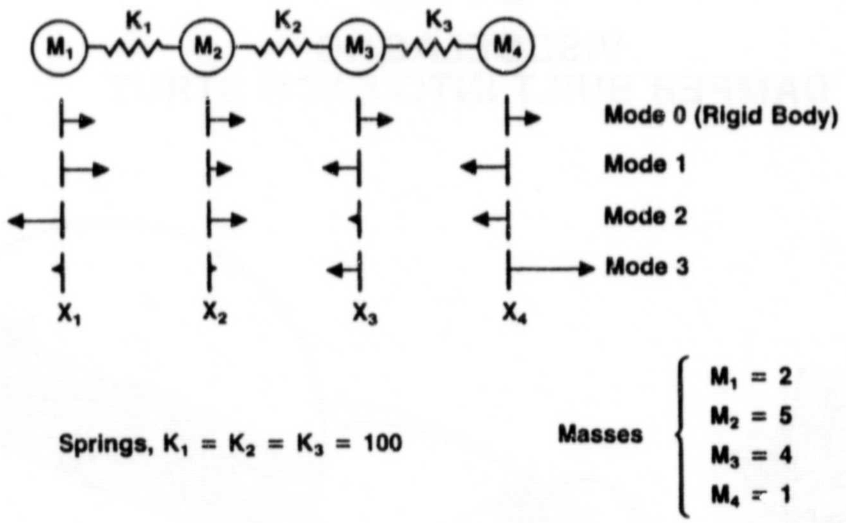
The installation of localized dampers in a structure creates a condition that is often called "non-proportional damping." Analysis of this case is computationally more involved than the usual analysis with modal damping because one must use complex mode shapes rather than real mode shapes to obtain an uncoupled response solution to the equations of motion. Approximate methods using real modes have been developed but work well only for low values of damping (Reference 38). The use of these approximations in structures with localized loss factors of more than 0.1 causes serious overprediction of the system damping with the result that the actual system behavior can be considerably degraded. Furthermore, it is not possible to predict the amount of degradation in advance for a complex structure. Reference 38 gives some good examples. The cause of this problem can be illustrated parametrically with the sample 4-degree-of-freedom system shown in Figure 1.3-5. One of the three springs is viscoelastic whose loss factor will be parametrically varied.

Figure 1.3-5

VFR223

LOCAL DAMPER EFFECT DYNAMIC MODEL



If the center spring (#2) is viscoelastic, then the locus of frequency vs damping will be as shown in Figure 1.3-6. As the spring loss factor increases above 0.1 the frequency of elastic Mode 1 is driven sharply upward and the frequencies of Modes 2 and 3 move toward new asymptotes. The increasing loss factor has the effect of linking Masses 2 and 3 together by bridging the spring. A viscous damper would behave similarly. The corresponding modal damping is also strongly affected as shown in Figure 1.3-7.

Note first that the damping in all modes is less than the spring loss factor. For small values, the modal damping is estimatable from element loss factors using approximate methods which are described in the next section. However, as the forces due to damping become significant relative to the spring forces ($\eta > 0.1$), the actual damping in the modes varies significantly from the approximations and is usually less.

Figures 1.3-8 and -9 show the corresponding case if Spring 3 is made the parametric viscoelastic element. The damping trends are similar but the

Figure 1.3-6

VFR218

LOCUS OF EIGENVALUES VERSUS SPRING LOSS FACTOR (DAMPING IN K_2)

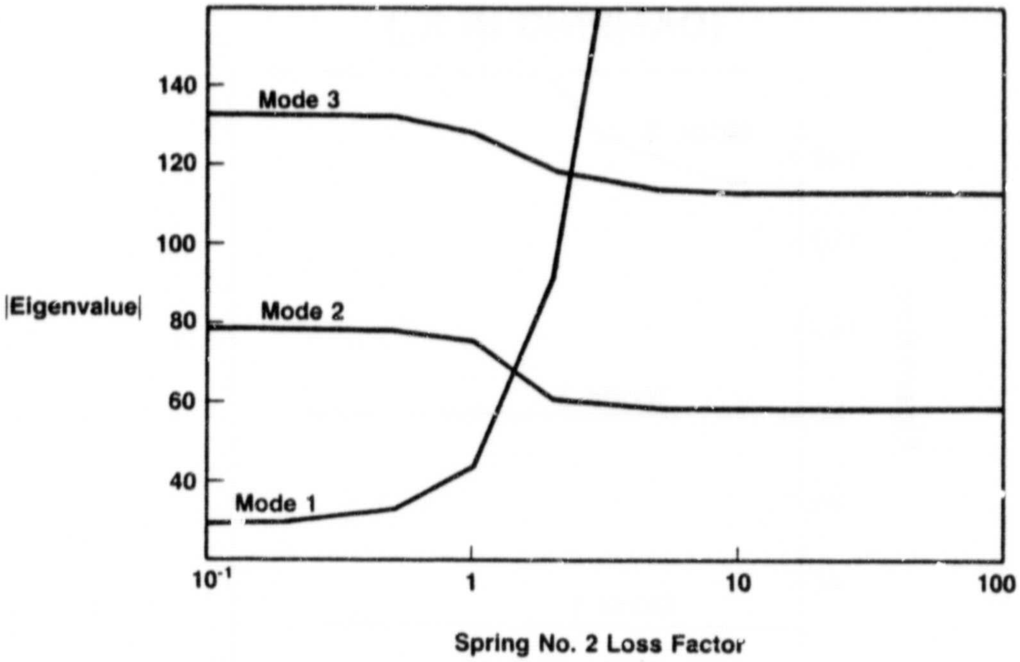


Figure 1.3-7

VFR217

MODAL DAMPING FACTORS VERSUS SPRING LOSS FACTOR (DAMPING IN K_2)

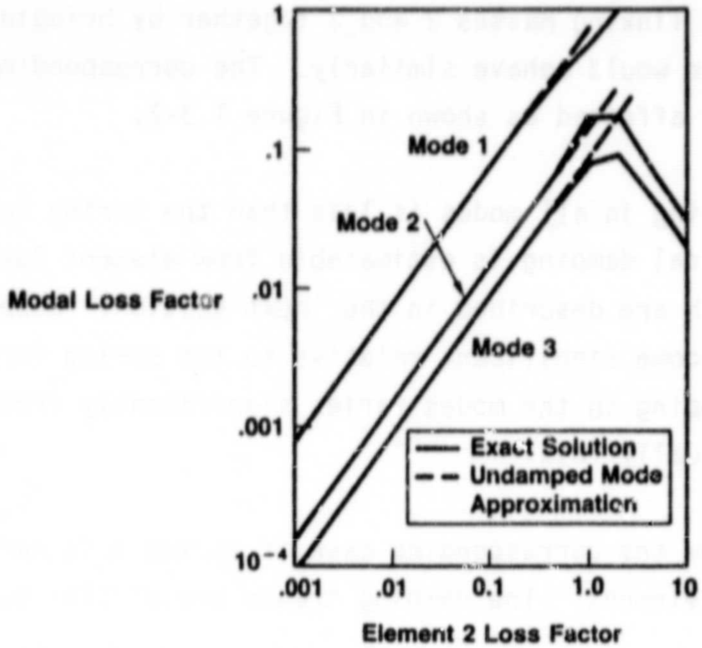


Figure 1.3-8

LOCUS OF EIGENVALVES VERSUS SPRING LOSS FACTOR (DAMPING IN K_3)

VFR222

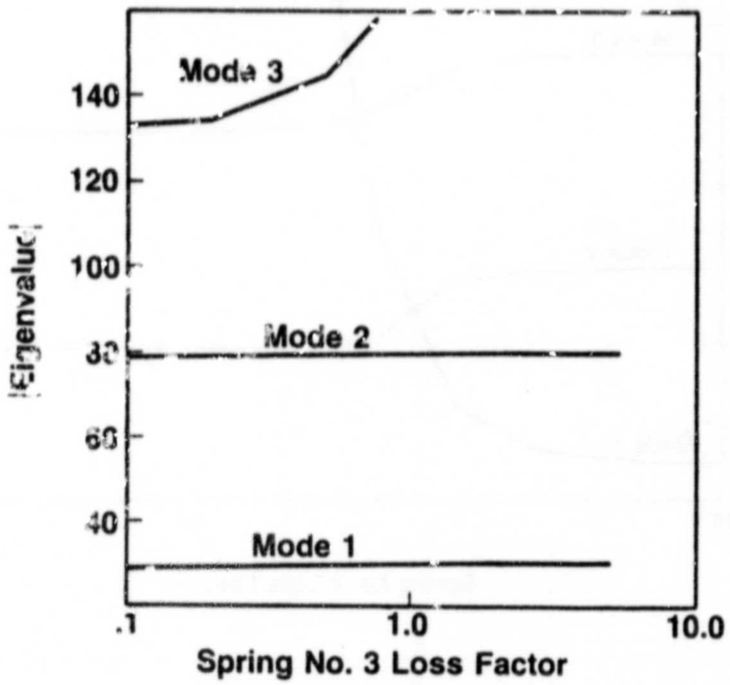
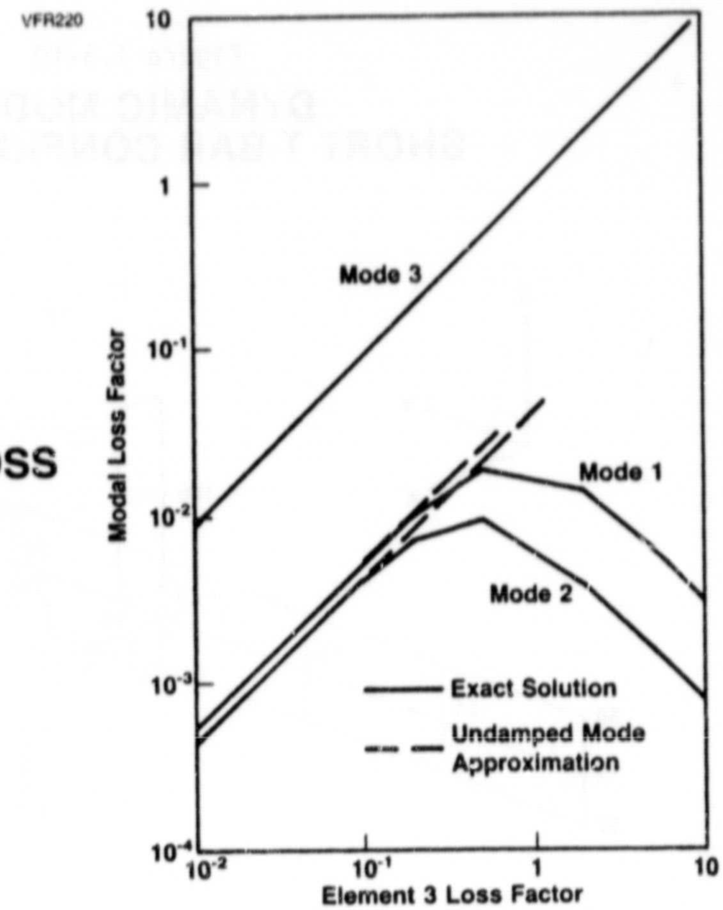


Figure 1.3-9

MODAL DAMPING VERSUS SPRING LOSS FACTOR (DAMPING IN K_3)



frequency behavior is different and the damping errors are larger below $\eta = 1$. When one considers that spacecraft structural dynamic models consist of many dozens or even hundreds of degrees of freedom, it is clear why approximate modal damping models and real mode shapes should not be used. Accordingly, an exact method was used to calculate the frequency response of the non-proportionally damped structure.

1.3.3 Summary of SASP Analyses (including Equations of Motion)

The configuration analyzed during this study is shown in Figure 1.3-10 along with the dynamic models used. Transfer fractions for both frequency responses were calculated for both the proportional and non-proportionally damped cases. The subsequent paragraph discusses the equations and methods used as well as the results of these analyses.

Equations of Motion

A dynamic model which consists of masses [M] and viscoelastic springs [Kr] + i [Ki] can be described with the following system of motion equations.

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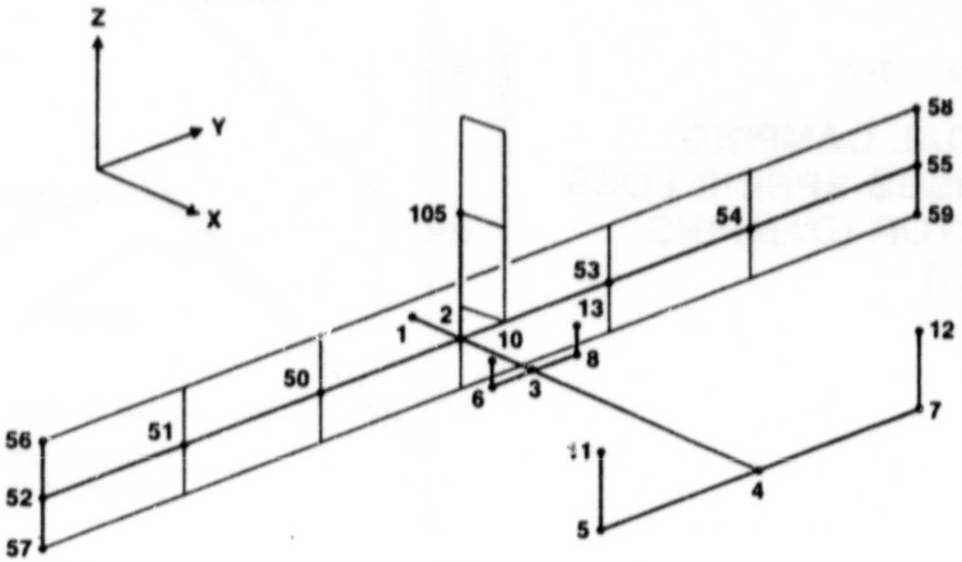
Figure 1.3-10

DYNAMIC MODEL
SHORT T-BAR CONFIGURATION

VFR308



Equations of Motion

A viscoelastically damped system is described by

$$[M]\{\ddot{X}\} + \Big|[K_r] + i[K_i]\Big|\{x\} = \{F\}\, e^{i\omega t} \qquad (1)$$

If the springs all have the same loss factor η, K_i will be a linear, constant factor of K_r and the common factor $(1 + i\eta)$ may be removed from the complex K matrix to yield

$$[M]\{\ddot{X}\} + (1 + i\eta)[K_r]\{x\} = \{F\}\, e^{i\omega t} \qquad (2)$$

This special case is called the uniform proportional damping case because of the scalar nature of the damping factor.

Open loop frequency responses can be conveniently obtained at each frequency by solving a corresponding system of equations

$$[\, I \,]\{\ddot{q}\} + [\, \Omega^2 \,]\{q\} = [\phi]^T\{F\}\, e^{i\omega t} \qquad (3)$$

which are based on the ortho-normal relations,

$$\phi^T M \phi = [\, I \,],\ \phi^T K_r \phi = [\, \Omega^2_{re} \,],\ \text{and}\ \phi^T K_i \phi = \eta[\, \Omega^2_{re} \,] \qquad (4a,b,c)$$

where $\{x\} = [\phi]\{q\}$

$[\phi]$ = matrix of real mode shapes

$\Omega^2 = \Omega^2_{re}(1 + i\eta)$

By letting $\{q\} = \{A\}\, e^{i\omega t}$ (5)

Equation 3 becomes

$$\Big|[\, \Omega^2 \,] - [\, \omega^2 \,]\Big|\{A\} = \phi^T F \qquad (6)$$

and the fully rationalized, non-singular form of the solution, is

$$\left\{A_{re}\right\} = \left[\frac{1 - \frac{\omega^2}{\Omega_{re}^2}}{\left(1 - \frac{\omega^2}{\Omega_{re}^2}\right)^2 + \eta^2} \right] \left[\phi^T\right]\left\{F\right\} \tag{7a}$$

and

$$\left\{A_{imag}\right\} = -i \left[\frac{\eta}{\left(1 - \frac{\omega^2}{\Omega_{re}^2}\right)^2 + \eta^2} \right] \left[\phi^T\right]\left\{F\right\} \tag{7b}$$

$$\left\{X_{complex}\right\} = \left[\phi_{re}\right]\left\{A_{compl}\right\} \tag{8}$$

This well known solution however is not exact with real modes when K_i is not linearly proportional to K_r. This situation exists whenever different structural elements have unequal loss factors. An exact solution can be obtained using complex modes but this doubles the size of the problem with a corresponding increase of a factor of 8 in computation that erases many of the advantages of the uncoupled modal solution. If this alternative is used, complex modes are extracted from the unsymmetric matrix $D = M^{-1} K_{complex}$ which takes the form (after Crout, Banachiewicz and Cholesky)

$$D = \left[\begin{array}{c|c} M & 0 \\ \hline 0 & M \end{array}\right]^{-1} \left[\begin{array}{c|c} K_{re} & -K_i \\ \hline K_i & K_{re} \end{array}\right] \tag{9}$$

The roots of this matrix will be 2N complex conjugate pairs and the loss factor for each mode will be $|\Omega_{imag}^2|/|\Omega_{real}^2|$ and the vectors X will be two 2N order sets of complex conjugate pairs. Orthonormal relationships are based on

$$[\Phi^*]^T[M][\Phi] = \lceil 1+io \rfloor \tag{10a}$$

$$[\Phi^*]^T[K_{com}][\Phi] = \lceil \Omega_{com}^2 \rfloor \tag{10b}$$

where Φ is the real and imaginary part of the modal displacement extracted from the set X.

It has been shown by Ungar and others that for very light but nonproportional damping a satisfactory approximation to modal loss factor may be obtained with

$$\eta_j = \frac{\sum_i u_{ij}\, \eta_i}{\sum_i u_{ij}} \tag{12}$$

where u_{ij} is the element strain energy in the jth mode.

An alternative approximation, if the imaginary part of the stiffness matrix is known, is to let

$$\Omega_i^2 = \text{diag}\,[\phi^T](K_i)[\phi] \tag{13}$$

where ϕ is the matrix of undamped modes and where the off-diagonal elements of Ω_i^2 are arbitrarily made zero. Unfortunately, determination of the errors produced by this process is not feasible without a comparison with the exact solution.

For the SASP problem the most convenient way of obtaining the exact solution is by direct solution of equation 1 at a large number of frequencies using the following relation:

$$\{x\} = \Big[[K] - \omega^2[M]\Big]^{-1}\{F\} \tag{14}$$

Transfer functions are computed using

$$TF_{12} = \frac{A_2}{A_1}\, e^{i(\phi_2 - \phi_1)} \tag{15}$$

Using these relationships a study of the effects of the damping assumptions described above was performed and is described in the following section.

1.3.4 Discussion of Results

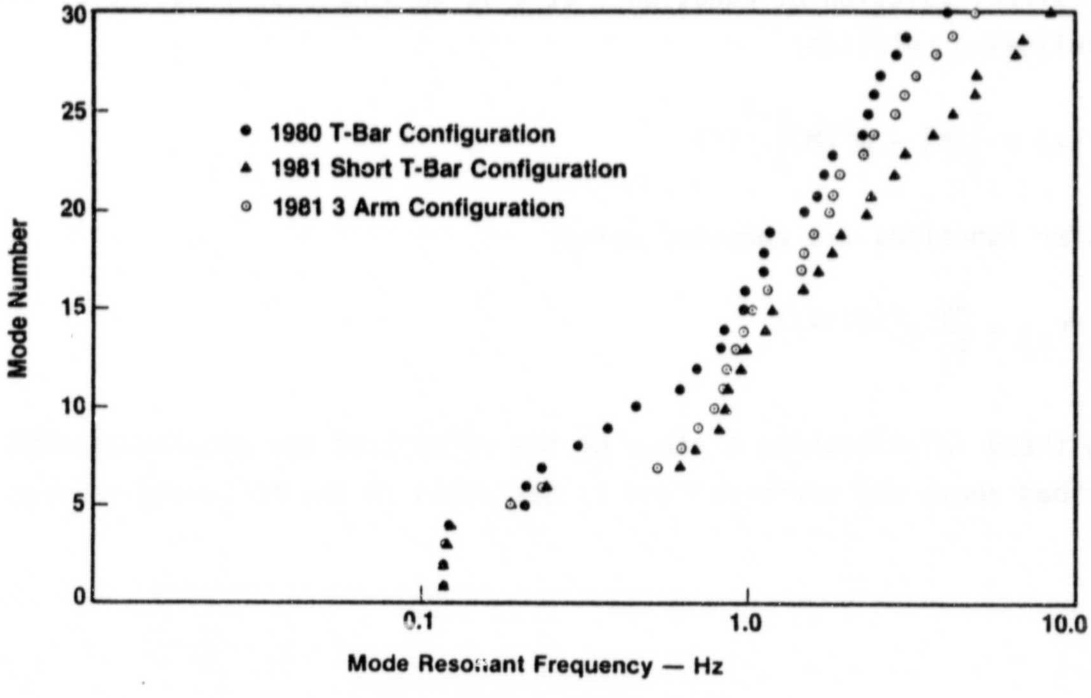
The resonant frequencies of the three versions studied in this and the past effort (Figure 1.3-2) are compared in Figure 1.3-11. This figure illustrates the density of resonant modes and the shape of the line is an index of "dynamic flexibility." The first four resonant modes are mainly solar array, most activity involving very little platform vibration and are common to all modes. The reduction of four payloads to two on the 'T' bar eliminated four modes between 0.235 Hz and 0.53 Hz, leaving more than one octave free of resonances as a result. From 0.53 Hz to 0.8 Hz both new configurations are more similar to each other than to the old version. But at 0.8 Hz the locus of modes moves together to about 1.1 Hz. All versions show a gap from 1.15 to 1.42 Hz where no resonances exist.

Above 1.4 Hz the trailing arm version moves toward the old version. Above 2.5 Hz this representation of the SASP is not accurate and the high modes are used only to obtain good mathematical convergence.

Figure 1.3-11

COMPARISON OF MODAL DENSITY CHARACTERISTICS 3 BAR SASP CONFIGURATIONS

VFR219



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Frequency responses and transfer functions were calculated only for the short T bar configuration (Figure 1.3-10). However, both the proportional and the non-proportional damping cases were analyzed.

Figures 1.3-12 and -13 show the gain and phase response of Node 10 to a unit torque at Node 10 for the proportional damping case. As was shown in the past study, a substantial reduction of motion amplitude and a substantial smoothing of phase/response is obtained with a relatively small amount of damping (η = 0.1) compared to the untreated case (η = 0.001).

Transmission to other areas (such as Node 12) of the platform is greatly reduced as illustrated by the elimination of all of the peaks shown in Figure 1.3-14. The phase change characteristics, though more complicated, are still smoothed by the added damping (Figure 1.3-15).

Figure 1.3-12

**SHORT T-BAR CONFIGURATION
FREQUENCY RESPONSE — ROT X10**

VFR239

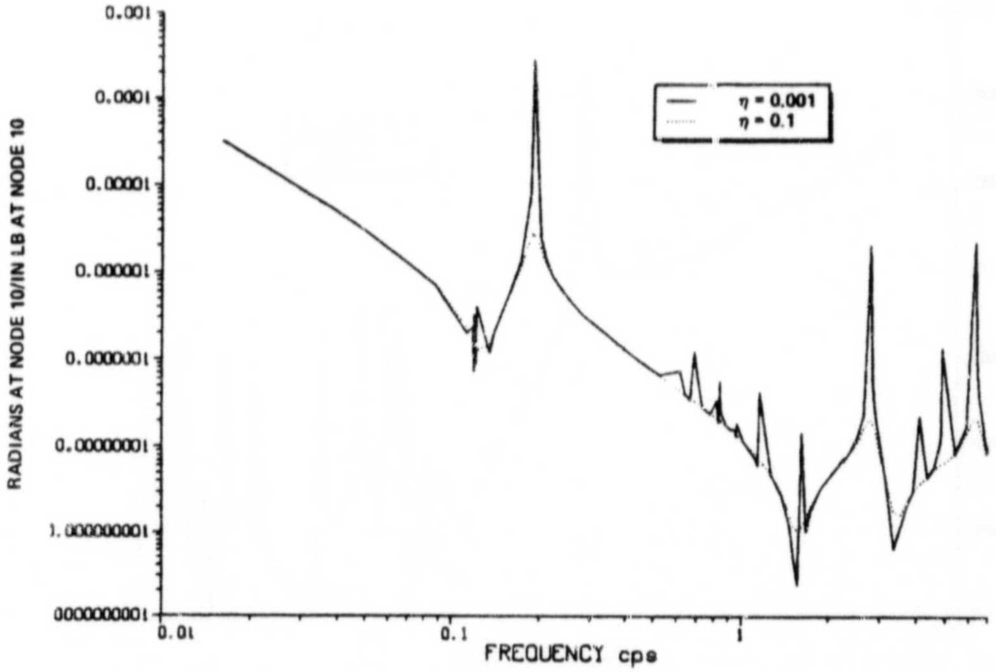

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Figure 1.3-13

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SHORT T-BAR CONFIGURATION
PHASE — ROT X10

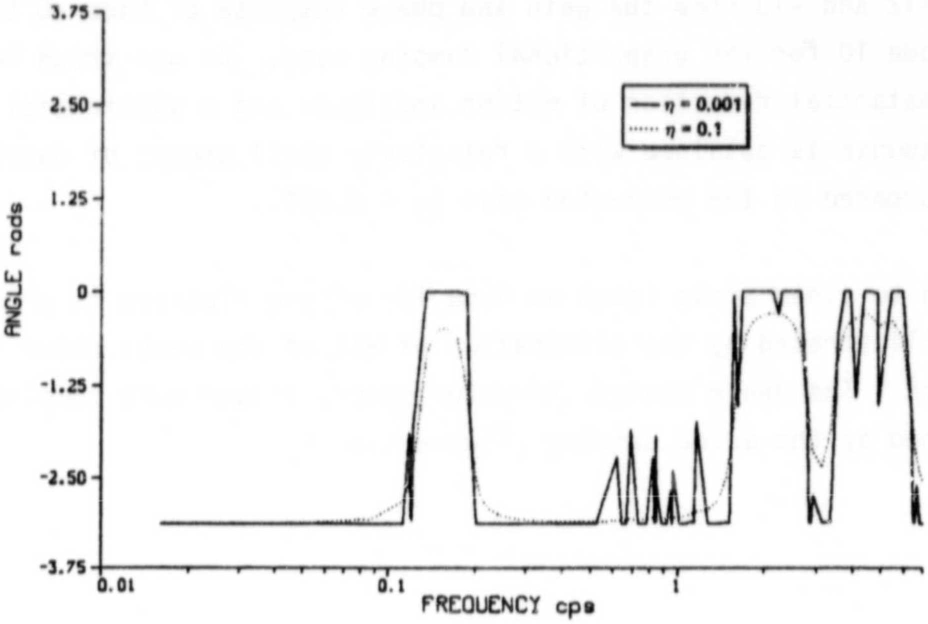


Figure 1.3-14

VFR230

SHORT T-BAR CONFIGURATION
FREQUENCY RESPONSE — ROT X12

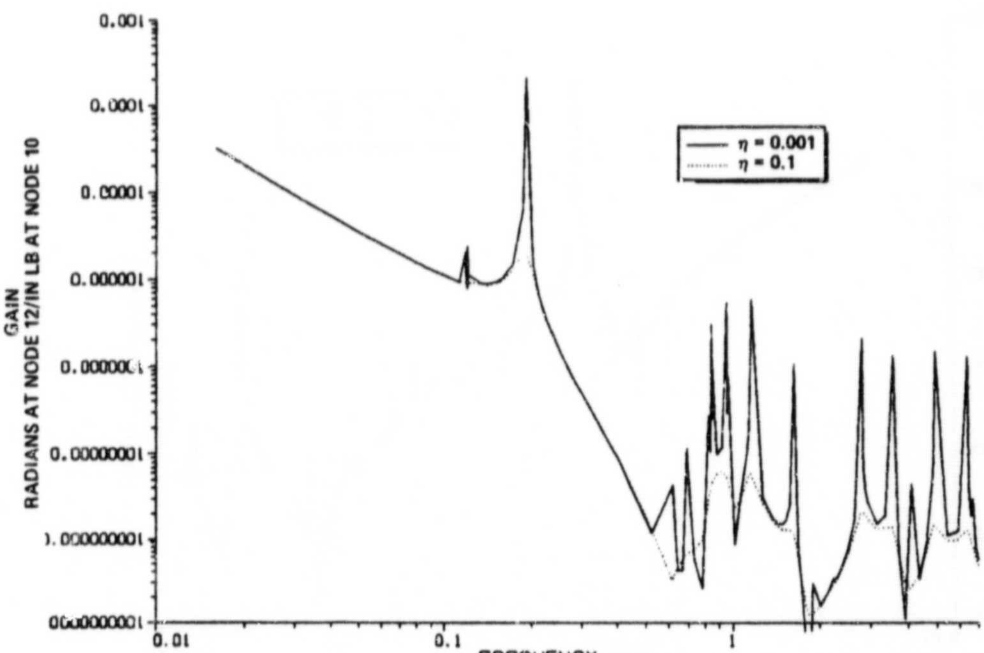
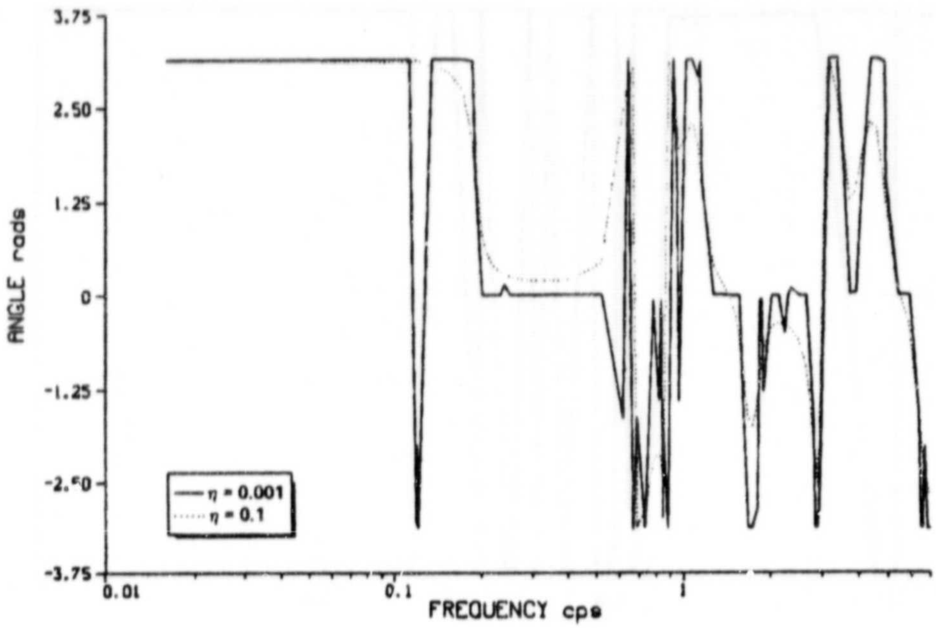


Figure 1.3-15

VFR231

SHORT T-BAR CONFIGURATION
PHASE — ROT X12



It often is not easy to accomplish a uniform proportional damping design in a structure such as the SASP for the reasons discussed above. Therefore, the case was considered where only the SASP truss possessed a significant damping property (η = 0.1) and the solar arrays were left with the small value of η = 0.001. Using the exact methods described above, modal damping values were calculated to gain an insight into the effectiveness of this damping approach. As can be seen in Figure 1.3-16, many of the modes have low damping value but quite a number have been raised to near 0.1, especially in the higher frequencies.

Corresponding frequency responses for this case are shown in Figures 1.3-17 through -20. In the case of Node 10 the phase relation between the applied force and the foundation motion exhibits many of the same characteristics of the η = 0.1 uniform damping case with only an occasional small perturbation in the phase and all of the significant spikes in the amplitude have been reduced. At Node 12, the reduction in response is nearly the same as the uniform case except at five frequencies. In four of the five cases, however,

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Figure 1.3-16

EFFECT OF TRUSS MEMBER DAMPERS ON SYSTEM DAMPING — SHORT T-BAR

VFR221

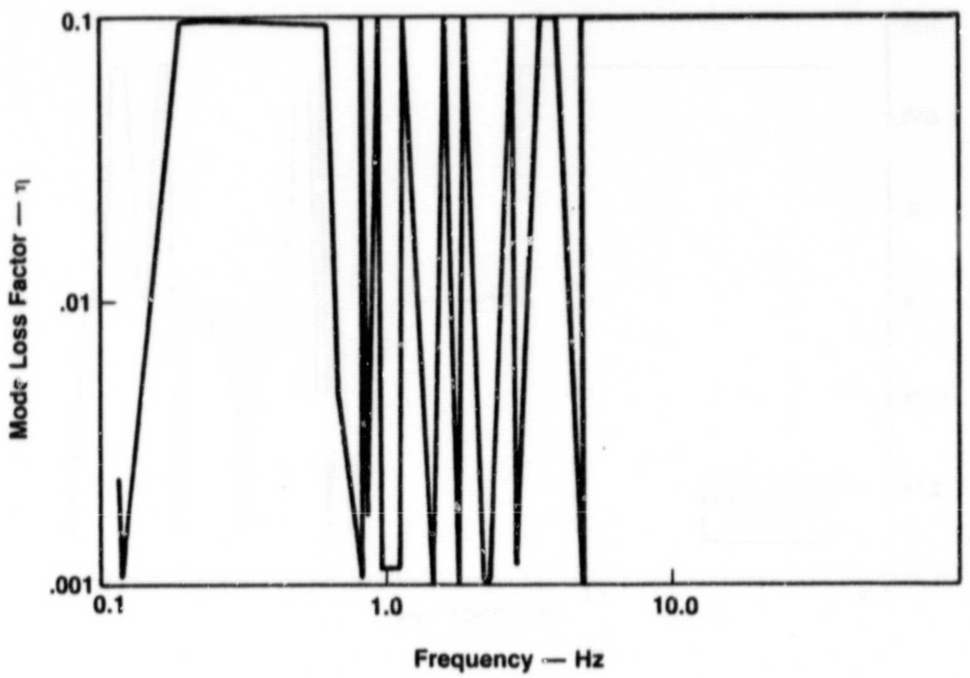

Figure 1.3-17

SHORT T-BAR CONFIGURATION FREQUENCY RESPONSE — ROT X10

VFR232

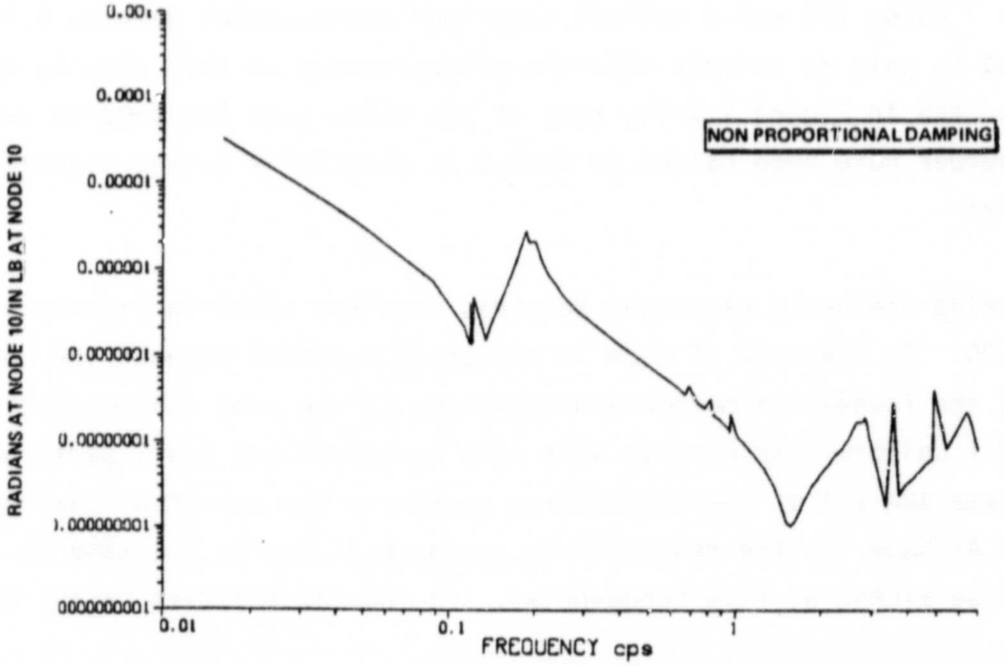

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Figure 1.3-18

SHORT T-BAR CONFIGURATION PHASE — ROT X10

VFR233

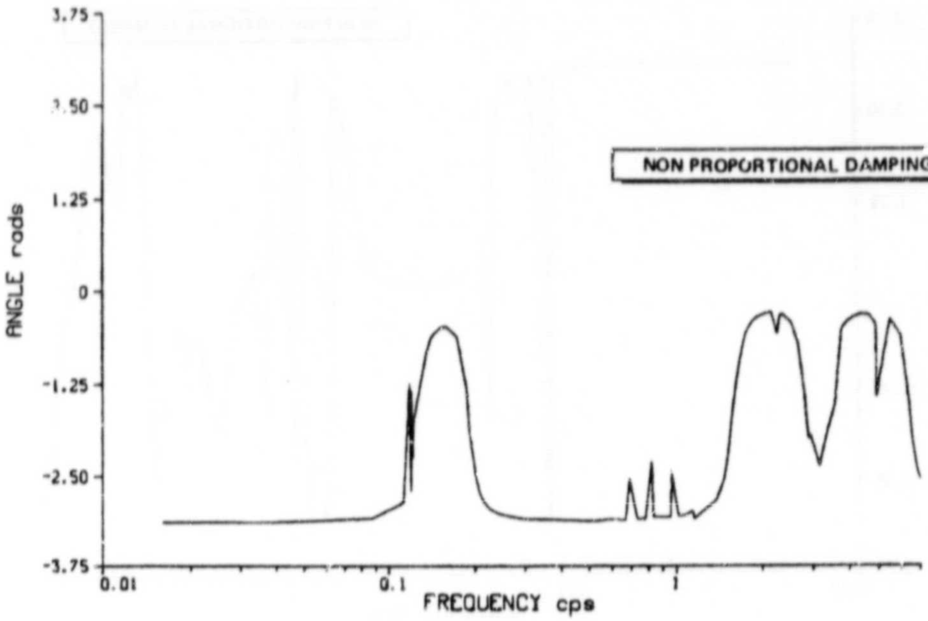

Figure 1.3-19

SHORT T-BAR CONFIGURATION FREQUENCY RESPONSE — ROT X12

VFR234

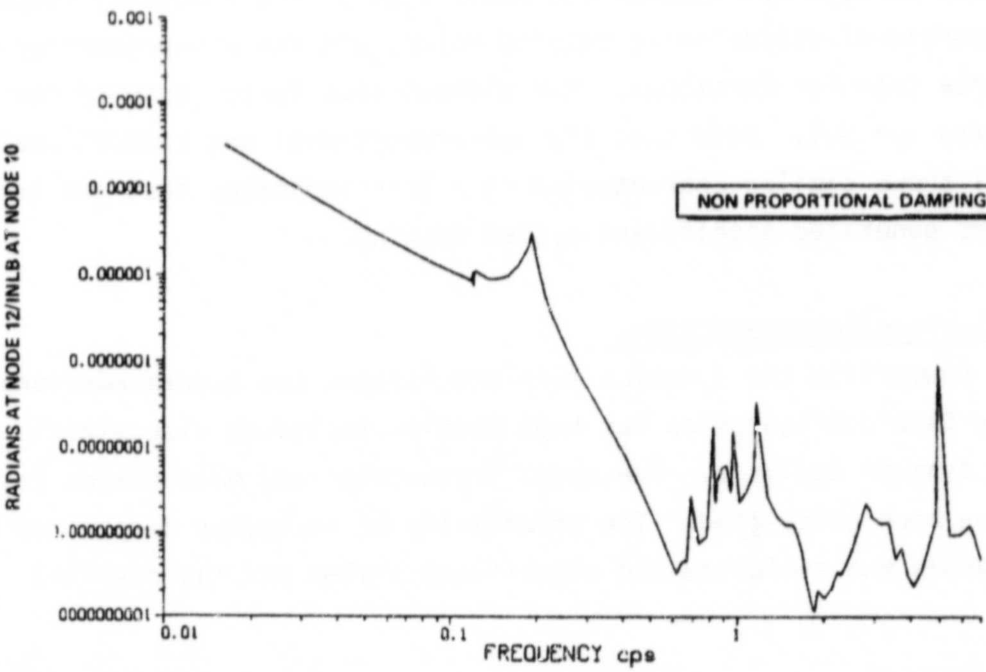

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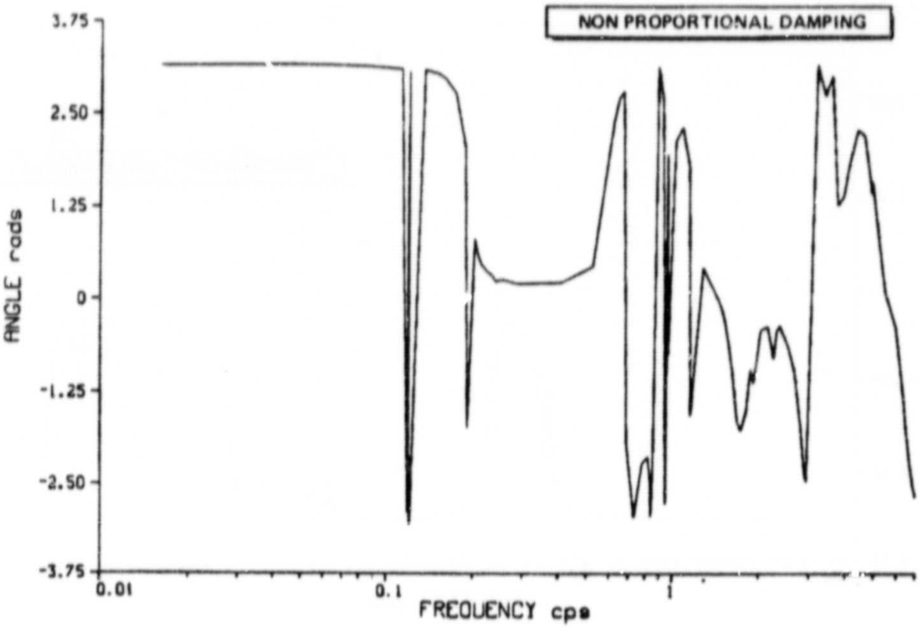
Figure 1.3-20

SHORT T-BAR CONFIGURATION
PHASE — ROT X12

VFR236



the reduction is substantial and the fifth is at a high enough frequency not to be a problem.

Figures 1.3-21 through -23 compose the amplitudes of the frequency responses for two proportional viscoelastic damping values and the non-proportional case for three transfer functions. The element loss factor assumed for each SASP strut was $\eta = 0.1$. Note that the non-proportional and proportional case with $\eta = 0.1$ shows similar characteristics. This indicates that the localized strut dampers generated significant system damping.

1.3.5 Conclusions/Recommendations

Table 1.3-2 summarizes the dynamics task conclusions and recommendations. The second-order SASP configuration has been modeled including viscoelastic damping for dynamic analysis. The modal frequencies and mode shapes (eigenvectors) have been calculated. The effectivity of including dampers in the SASP arm trusses was evaluated and significant system damping resulted.

Figure 1.3-21

SHORT T-BAR CONFIGURATION TRANSFER FUNCTION ROT X12/ROT X10

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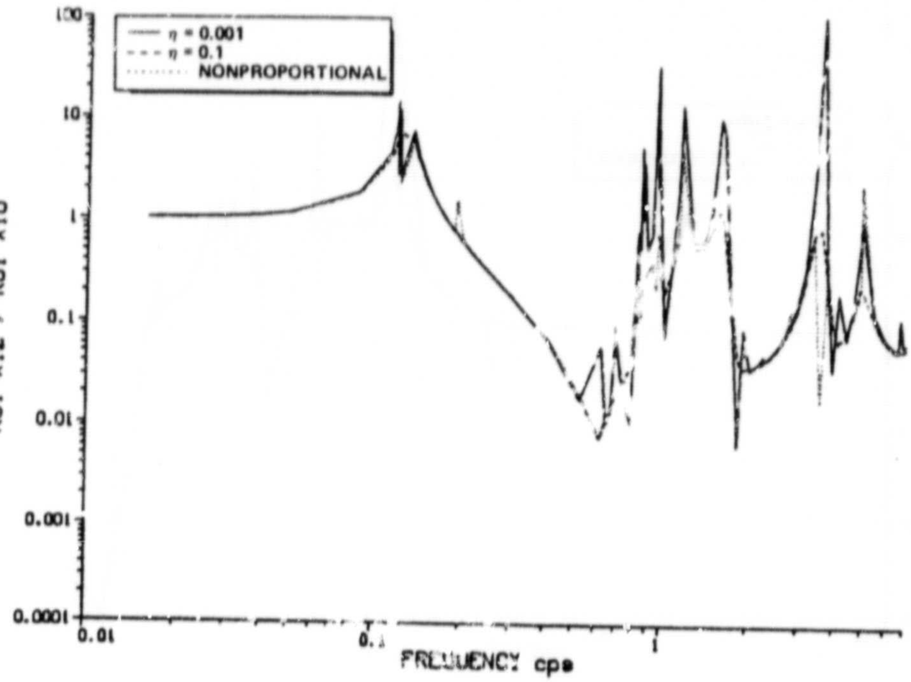

Figure 1.3-22

SHORT T-BAR CONFIGURATION TRANSFER FUNCTION ROT Z12/ROT X10

VFR238

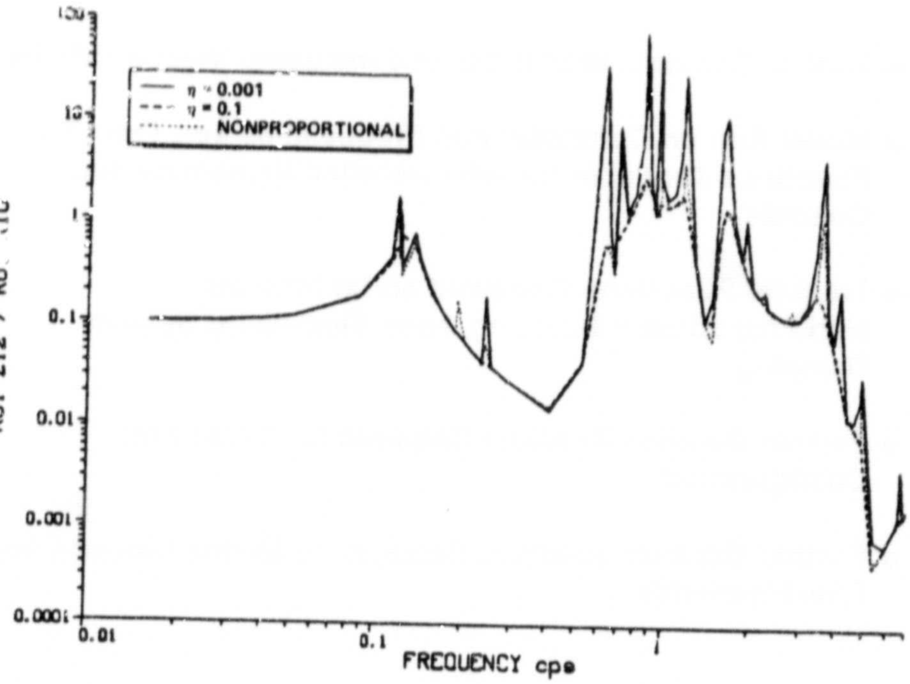

Figure 1.3-23

VFR237

SHORT T-BAR CONFIGURATION TRANSFER FUNCTION-ROT Z12/ROT Z10

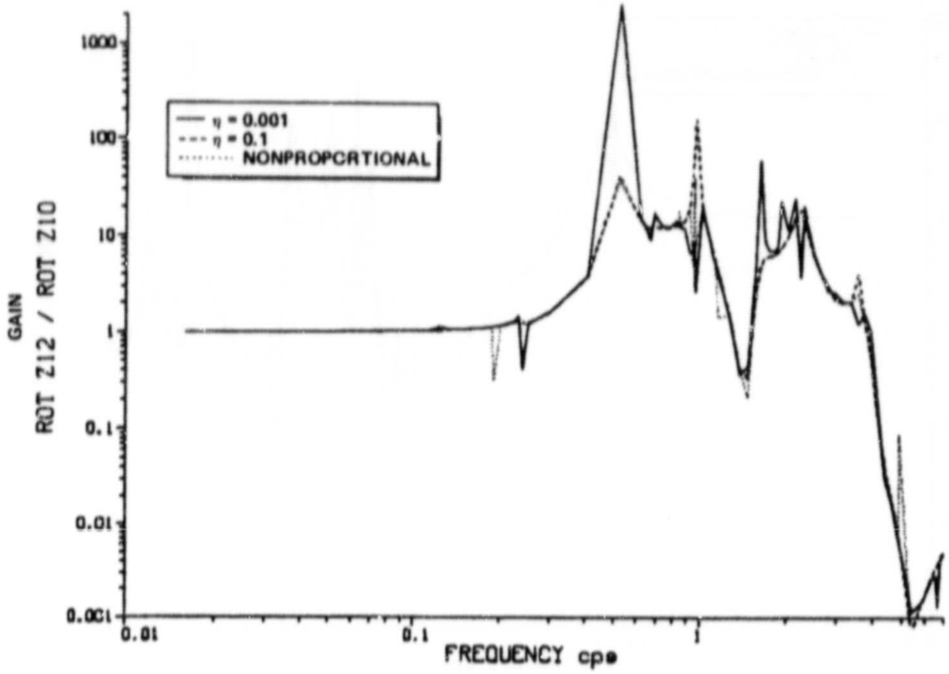

Table 1.3-2

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PLATFORM DYNAMICS ANALYSIS CONCLUSIONS/RECOMMENDATIONS

- **Vehicle Dynamic Model Defined Including Viscoelasticity**
- **Model Run on Computer and Frequencies and Transfer Functions Available for Interpretation (Dynamics and Controls)**
- **Transfer Functions Reviewed so far Indicate Non-Proportional Damping Adds Significant System Damping**
- **Further Detailed Analysis Required for Three-Arm Configuration**
- **Further Controls Analysis Required to Define Closed-Loop Characteristics**

Further analysis is required to characterize the 3-arm configuration dynamics and the benefits of damping and the impacts of flexibility on pointing performance need to be defined.

Appendix A
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Appendix B
ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control Subsystem
AEPT	Atmospheric Emissions Photometric Imaging Experiment
AFSD	Air Force Space Division
AGS	Advanced Gimbal System
APM	Articulated Primary Mirror
APS	Auxiliary Pointing System
ASPS	Annular Suspension Pointing System
AVS	Annular Suspension Pointing System Vernier System
CCD	Charge Coupled Device
CIRRUS	Cryogenic Infrared Radiance Instrumentation for Shuttle
C.M.	Center of Mass
CMG	Control Moment Gyro
CRT	Cathode Ray Tube
DEG	Degree
ELIAS	Earth Limb Infrared Atmosphere Structure
F	Fahrenheit
FGS	Fine Guidance Sensor
FOV	Field-of-View
GIRL	German Infrared Laboratory
HRIS	High Resolution Telescope and Spectrograph
Hz	Hertz
IMC	Image Motion Compensation
IOP	In the Orbit Plane
IPS	Instrument Pointing System
IVA	Intra Vehicle Activity

kM	Kilometers
kW	Kilowatt
LOS	Line-of-Sight
MIN	Minute (angle)
MSFC	Marshall Space Flight Center
MSP	Manned Space Platform
N	Newton
NASA	National Aeronautics and Space Administration
PACS	Pointing and Control Subsystem
PHM	Position and Hold Mount
POP	Perpendicular to the Orbit Plane
PS	Power System
RMS	Remote Manipulator System; Root Mean Square
SASP	Science and Applications Space Platform
SEC	Second (angle or time)
SIRTF	Shuttle Infrared Telescope Facility
SL	Spacelab
SOT	Solar Optical Telescope
SOUP	Solar Optical Universal Polarimeter
SP	Space Platform
SPIE	Society of Professional Instrumentation Engineers
SPIRE	Shuttle Payload Integration and Rocket Experiments
TBD	To Be Determined
VEM	Viscoelastic Material
WINDSAT	Wind Satellite