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FINAL REPORT

GEOSTATIONARY PLATFORM SYSTEMS CONCEPTS DEFINITION FOLLOW-ON STUDY

VOLUME IIA • TECHNICAL

Task 11: LSST Special Emphasis

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Submitted to
GEORGE C. MARSHALL SPACE FLIGHT CENTER
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

Prepared by
GENERAL DYNAMICS CONVAIR DIVISION
P.O. Box 80847
San Diego, California 92138

&

COMMUNICATIONS SATELLITE CORPORATION
Comsat Laboratories
Clarksburg, Maryland 20734

GEOSTATIONARY PLATFORM

SYSTEMS CONCEPTS DEFINITION

FOLLOW-ON STUDY

FINAL REPORT

VOLUME I	Executive Summary
VOLUME IIA	Technical Analysis, Task 11
VOLUME IIB	Technical Analysis, Tasks 8 & 9
VOLUME III	Costs & Schedules, Task 10

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1 September 1980

James K. Harrison
Task 11 Study Manager
Special Projects Group, PS03
George C. Marshall Space
Flight Center
Huntsville, Alabama

William T. Carey, Chief
Applications Group, PS06
George C. Marshall Space
Flight Center
Huntsville, Alabama

PREFACE

In today's world of expanding communication services, the geostationary orbit is rapidly becoming an extremely valuable and limited earth resource. Nations demand specific positions or "slots" in the orbit corresponding to their geographic longitude, seeking to maximize their territorial coverage and satellite performance. Common carriers within a developed nation demand equal rights for the best slots. Competition has been strong in the developed nations, and the developing nations are now voicing their concern.

At geosynchronous altitude, independent satellites operating at the same frequency must be separated by about 4 degrees of longitude to prevent RF interference (30 dB separation), dictated by the large beamwidths of the small affordable ground antennas now in use. About 90 "slots", therefore, exist around the world, with about 12 over the U.S. and our northern and southern neighbors.

The frequency spectrum is also a valuable and limited resource which is rapidly approaching saturation, particularly in those regions of low noise and freedom from atmospheric attenuation.

Both resources are now allocated worldwide by the International Telecommunications Union operating through subservient multinational and national agencies. Reallocation cannot solve our basic orbital arc and frequency saturation problems. Recent studies have shown projected traffic demands which will saturate both the geostationary orbital arc and the optimal frequency spectra in the near future.

Motivation for the rapid adoption of satellite communications services is primarily economic. Savings can be significant if the cost, complexity, and size of ground stations can be reduced by application of advanced communications and support technologies to a few satellites with expanded capabilities.

What is the solution to our orbital arc and frequency spectrum saturation problems, a solution which also lends itself to reduction of user costs?

One viable solution is the aggregation of many transponders, large antennas, and connectivity switches on board a small number of large orbital facilities. Such facilities, or platforms, can provide common power and housekeeping services to a number of coexistent communications systems, making maximum use of a single orbital slot. Large antennas with multiple spot beams and good isolation, bandwidth reduction, polarization diversity, and system interconnectivity can provide an equivalent transponder capacity over the U.S. at least an order of magnitude greater than the projected traffic demand for the year 2000.

In 1978, NASA initiated feasibility studies to encourage development of geostationary platforms, anticipating the need for increased communications services in the near decades, at lower costs. These studies established the need and requirements for, and the feasibility of, such platforms. NASA's George C. Marshall Space Flight Center has the responsibility for implementing the Geostationary Platform Program.

The initial Geostationary Platform Phase A Study, under the direction of the Marshall Space Flight Center, was performed by General Dynamics Convair Division of San Diego with Comsat Corporation of Clarksburg, Maryland, as subcontractor. The study was completed in June 1980 and dealt primarily with the requirements, missions, concepts, and programmatics of Operational Geostationary Platforms of the 1990s. Objective of the study was to establish a basis for development of an Experimental Geostationary Platform with a mid-1980s launch, paving the way for the Operational Platforms of the 1990s.

A follow-on study with a primary thrust toward definition of the Experimental Geostationary Platform was authorized starting 1 April 1980, overlapping the initial study by three months to accommodate a special task for the Large Space Systems Technology (LSST) program management.

This report documents the results of the LSST Special Emphasis Task, an analysis of structural requirements deriving from the initial Phase A Operational Geostationary Platform study. The remaining volumes of the Follow-on Study Final Report will be published in early 1981, upon completion of the study.

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INTRODUCTION

The George C. Marshall Space Flight Center has the responsibility within NASA to implement the Geostationary Platform program - to initiate conceptual studies, develop feasible concepts, coordinate user needs and technology requirements, and promote activities aimed at system hardware solutions to the projected platform configurations of the 1990s.

In May 1979, NASA/MSFC placed General Dynamics Convair Division under contract for a Geostationary Platform Systems Concepts Definition Study, NAS8-33527, with Comsat Corporation as a subcontractor. Thrust of the study was toward conceptual definition of Operational Geostationary Platforms of the 1990s, to provide a data base for definition of an Experimental Geostationary Platform. Results of the initial study confirmed the need for a follow-on study with respect to definition of an Experimental Platform, and also emphasized the need for greater depth of analysis with respect to technology requirements for operational platforms.

In April 1980, the Initial Study contract was extended to include the Follow-on Study. Objectives of the Follow-on Study were to update the Initial Study; analyze, identify operations, evaluate, and select a preferred Experimental Platform concept; and identify requirements in the area of Large Space Systems Technology (LSST).

To attain their objectives, four tasks were defined in the Statement of Work for this study, continuing the sequence of tasks from the original seven tasks in the Initial Study:

Task 8 - Initial Study Update.
Refine and update results of the Initial Study pertaining to Operational Geostationary Platforms of the 1990s, to reflect updated traffic models, trades, new payload requirements, and configurations.

Task 9 - Experimental Platform Analysis & Definition.
Analyze, identify, and evaluate options for a mid-1980s Experimental Platform; select a preferred concept; and develop a preliminary definition of the preferred concept.

Task 10 - Development of Programmatic (Cost & Schedule) Data.
Define and develop Phase C/D cost and schedule data for the candidate and selected Experimental Platform concepts.

Task 11 - LSST Special Emphasis Task.
Further define candidate Operational Geostationary Platform concepts for the 1990s and identify requirements in the area of Large Space Systems Technology.

At NASA's request (as shown in Figure 1), Task 11 was to be completed first to provide NASA Large Space Systems Technology program management with data for future planning. Also at NASA's request, Task 11 results were to be submitted upon completion of the task as a separate volume of the Final Report, preceding the volumes scheduled for publication at the end of the contract.

Task 11 was completed in July 1980, and is the subject of this report, Volume IIA of the Follow-On Study final report. The remaining volumes, as identified on the inside front cover of this report, will be published in early 1981, upon completion of the study.

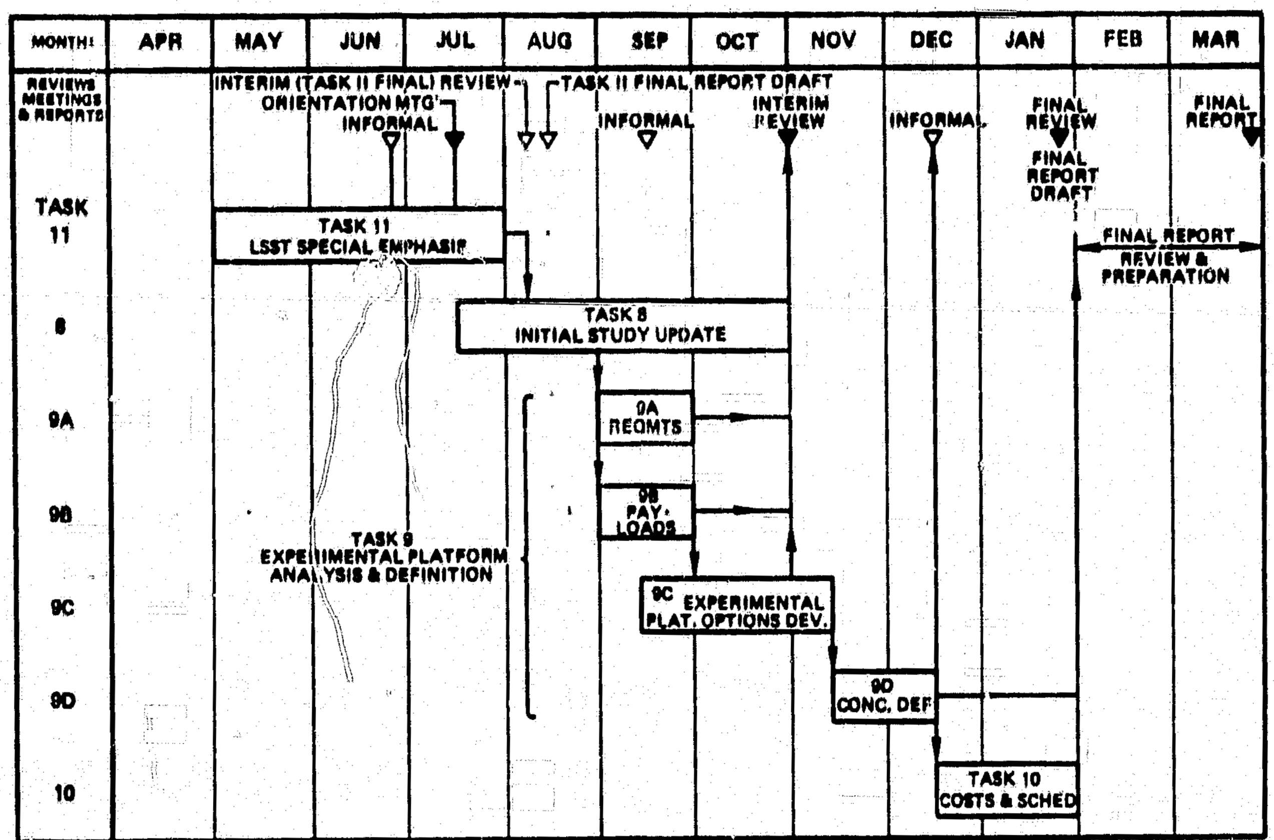


Figure 1. Follow-On Study task and milestone schedule.

TASK 11

LSST SPECIAL EMPHASIS TASK

The Operational Geostationary Platform program has been selected by the NASA Large Space Systems Technology (LSST) program management as a major technology focus mission.

This task, Task 11 of the Phase A Geostationary Platform Follow-On Study, will assist in identifying structural systems technologies that should be developed to complement the evolution of the Geostationary Platforms and other related missions. Results of the study, i.e., the structural system requirements and configuration definitions developed in this task, will be used by structural technologists whose interests lie in construction concepts, methods, and equipment.

Four Operational Platform configurations were selected by NASA for further definition in the Follow-On study, to cover the range of concepts identified in the Initial Study. The range of concepts includes packaged platforms from less than half a Shuttle cargo-bay length to full cargo-bay length for nominal and high communications traffic models, respectively, constellations of platforms vs. docked platform modules, and transfer vehicles from IUS to Centaur and OTVs. The four configurations selected are shown in Figure 2. They are:

Alternative #1 — 26 ft. long, 15,000 lb packaged platform modules accommodating the low traffic model, each delivered to low earth orbit with an attached single-stage expendable OTV, deployed, and transferred to a geostationary constellation of platform modules.

Alternative #2 — Same as #1, but configured for docking at geostationary orbit to form a single large platform.

Alternative #3 — Full cargo-bay, 37,000 lb packaged platform modules accommodating the high traffic model, each delivered to low earth orbit, deployed, mated to a 2-stage reusable OTV delivered to low earth orbit in two additional Shuttle flights, and transferred to a geostationary constellation of platform modules.

Alternative #4 — Same as #3, but configured for docking at geostationary orbit to form a single large platform.

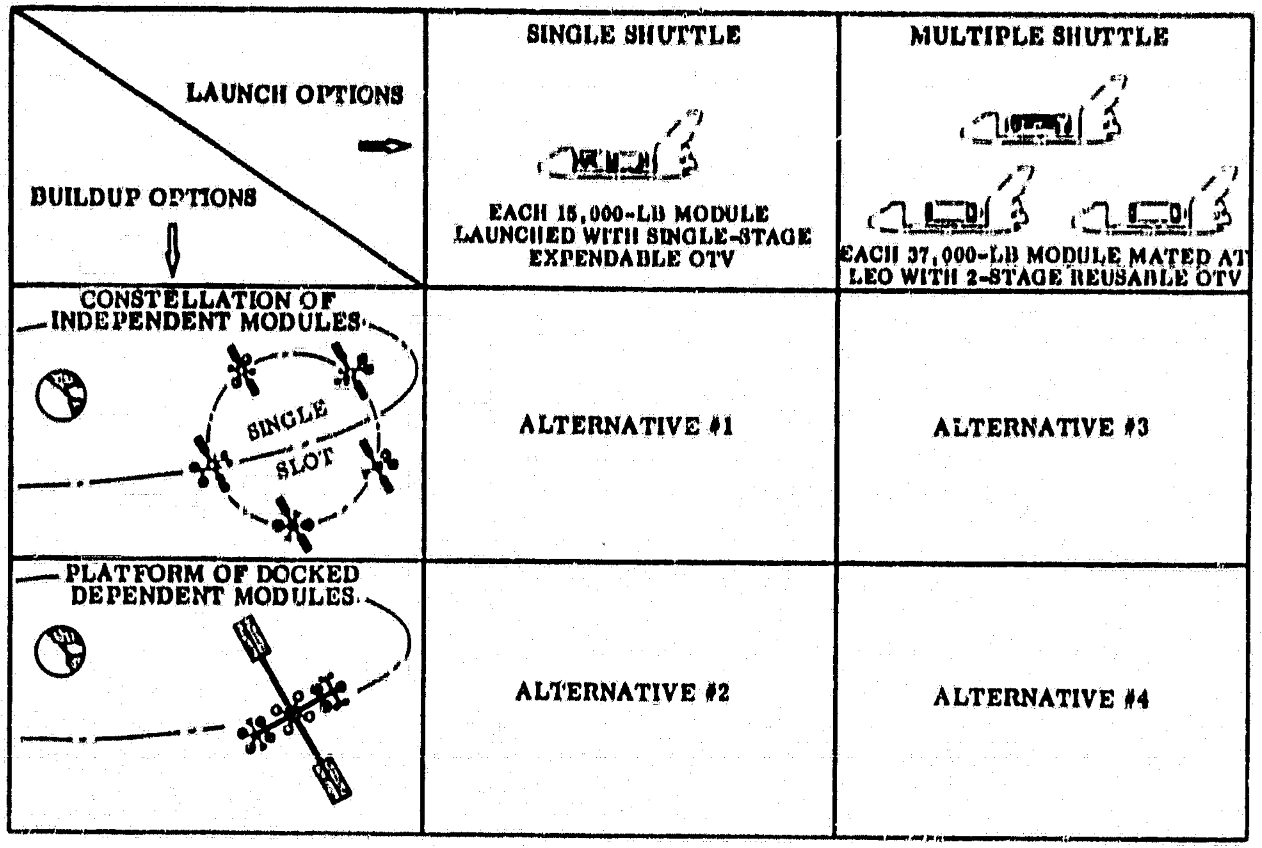


Figure 2. Selected Operational Geostationary Platform configurations.

The purpose of Task 11 is to further define the four alternative concepts selected, emphasizing the structural requirement aspects, and identifying the technology needs in the area of Large Space Systems Technology. Specifically, four subtasks are to be addressed, with emphasis on the first three data development tasks in the structural requirements area. Each subtask is addressed in a separate section of this report, as follows:

Section 1. Utilities Accommodation. Requirements for utilities distribution between platform subsystems and mission equipment, which must be accommodated by or integrated with the structural system, are defined. The utilities items include power distribution busses, signal and data cables, fluid lines, and other equipment which influences the platform structure design. Requirements include the size and number of the utility lines, bend radii, attachment provisions, routing, deployment motions, and joint configurations. Methods for structural accommodation are defined for deployment elements, including expanding masts, telescoping masts, rotating joints, and geniculate or pivoting joints.

Section 2. Interface Requirements. Interface requirements between platform subsystems, mission equipment, and docking and servicing hardware are evaluated for structural impact unique to the geostationary platform. Interfaces equivalent to present day satellite state-of-the-art are not described. Platform-unique interface requirements are addressed in four areas:

1. Assembly (payload components/platform structure) of platform modules in low earth orbit.
2. OTV mating to platform modules in low earth orbit.
3. Docking of platform modules in geosynchronous orbit.
4. Accommodation of orbital servicing (OTV and TMS) interfaces with the platform.

Section 3. Strength and Stiffness. Strength and stiffness requirements are addressed in terms of orbit transfer and maneuver accelerations, docking and servicing-induced loads, requirements for lower bound structural vibration frequencies, requirements for maximum allowable structural distortion resulting from thermal environment, and structural response to induced loads which affect required platform functions. Typical platform structural members are sized for strength, resized for stiffness to meet antenna accuracy requirements, and evaluated with respect to dynamic response.

Section 4. Technology Needs. Requirements in subtasks 1, 2, and 3 are analyzed with respect to technology needs applicable to Large Space Systems structures. Technology requirements are identified and compared to existing or currently planned technology developments, deficiencies are identified, and recommended technology developments summarized. Technology needs in the area of structural materials and components are included in the study.

Section 5. Summary of Results and Recommendations. Structural requirements for the range of Operational Platform configurations analyzed are summarized here, together with recommended technology developments. A summary of specific detailed requirements for Platform No. 1 of Alternative #1 is also included, as representative of a single platform analysis.

In this study, Platform Nos. 1, 2, and 6 of Alternative #1, Western Hemisphere configuration, were analyzed in detail since they represented the most challenging configurations to package and analyze in this concept. Alternative #4, Platform No. 1 of the Western Hemisphere Platform was analyzed with respect to differences from Alternative #1, since this concept uses much larger platform modules, docked together at GEO. Alternatives #2 and 3 were evaluated with respect to Alternative #1 and #4, respectively, to identify any unique structural requirements or technology needs. None were found. Differences existed only in the quantitative values of specific design details, as expected, and had negligible (2 to 4%) influence on structural design for strength. Stiffness proved to be the critical parameter, and will ultimately be determined for each platform structural element as a function of the parameters specified by the individual commercial communication users (antenna design parameters). For this study, these parameters were given assumed, reasonable values; the results are, therefore, considered to be representative of this type of platform configuration, and are not to be taken as quantitative requirements for generic platform configurations developed later in the program.

1

UTILITIES ACCOMMODATION

Large space structures, whether completely deployable or semi-deployable with EVA or RMS-assisted assembly in low earth orbit, require packaging or folding to fit within the dimensional constraints of the Orbiter cargo bay. Accommodation of utility lines for power, data, and fluid transfer, therefore, becomes an integration consideration in the design of the structure.

If the platform is completely deployable with expandable or telescoping structural elements and rotating or geniculate joints, the utility lines must be designed to permit full deployment of the structure without hindering deployment motions or reducing the effectiveness of the lines. Platform Alternative #1 is in this category.

If the platform is a deployable/erectable concept, the utility lines may be incorporated within each structural element, or installed after the structure is deployed. The latter method has the advantage of reducing the number of interconnect fittings needed in joining individual structural elements, but requires more piece-handling and assembly time. Alternative #4 falls in the "deployable/erectable" category, with the utility lines pre-installed within the deployable structural elements.

Studies to date indicate that the near-term geostationary platforms of the 1990s will probably fall into one of the above two categories, with the completely deployable platform being the most attractive.

1.1 TASK OBJECTIVE

The objective of this task is to analyze the Operational Platform concepts previously selected by NASA for further definition in the Follow-On Study, to permit identification of structural requirements data and assist in identifying technologies needed for development of geostationary platforms and related future missions. The data will be used by NASA to develop large space systems construction concepts, methods, and equipment.

1.2 SCOPE

The requirements for utilities which must be connected to the structural system, and the utilities distribution between platform subsystems and mission equipment, are to be identified and determined for typical platform modules of selected concepts. Figure 1-1 identifies the platform subsystems and mission equipment to be investigated, and the relationship of the utilities and data requirements.

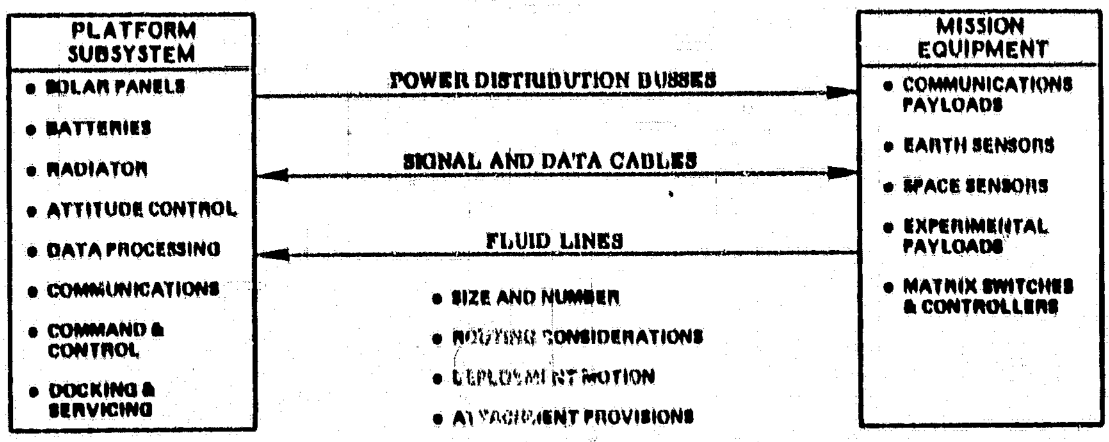


Figure 1-1. Utilities Accommodation – scope of task.

1.3 METHODOLOGY

The study approach followed in the utilities accommodation analysis is summarized in Figure 1-2. For a particular platform module, the payload utility requirements for power, data, and fluids were first calculated, and line routings selected within the platform structure to accommodate the requirements. The combined utilities requirement for each platform structural element was then defined in terms of service functions, utilities weight and cross-sectional area, and deployment motion involved. The most stringent routings with respect to weight, area, and motion were then analyzed in greater detail to identify feasible design solutions. This data was then tabulated for the structural elements involved.

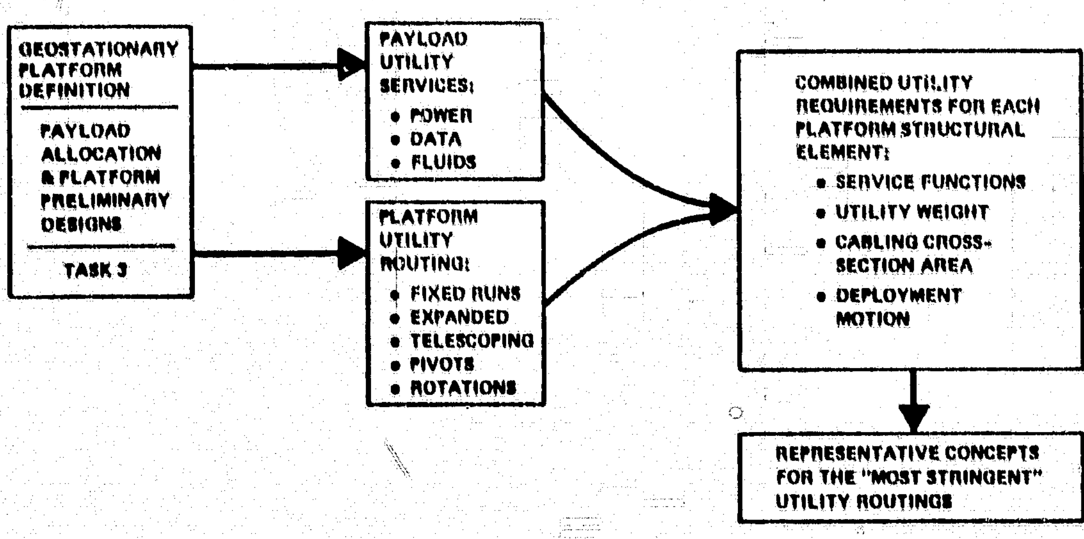


Figure 1-2. Utilities Accommodation – study approach.

For utility line sizing, the following assumptions were made:

a. Power

1. Wiring sized for 1 percent voltage drop - 18 AWG minimum
2. Peak power = 2 × average power
3. Redundant busses, i.e., 4 wires per function (2 hot + 2 return)

b. Data

1. Payload requirements - preliminary estimate
2. 26 AWG TSP used for baseband data
3. Coax cable for broadband RF and video data lines
4. 1.3 mm fiber optics for baseband data and broadband RF transmission lines

c. Actuators

1. Redundant power leads to each actuator, i.e., 2 TSP
2. 22 AWG minimum gage power leads
3. Redundant position sensor leads for each actuator position increment
4. 26 AWG minimum gage sensor leads

d. Fluids

1. Redundant 1 cm dia ACS propellant feed lines
2. 1 cm dia battery & ACS propellant vent lines
3. 2.5 cm dia radiator fluid lines

For descriptive identification of deployable structures, platform structural elements in this study are categorized as:

a. "Extendable" or "Expandable": Arms and masts which can expand in the direction of the central axis, truss-like in nature, with coiled, pivoted, or hinged longerons and struts.
Examples: Astro Research Corp. "Astromast" (Ref. Figure 1-6)
General Dynamics "Space Truss" (Ref. Figure 1-19)

b. "Semi-deployable": Arms and masts which are of fixed length, but which expand in cross-section for rigidity.
Example: General Dynamics "Space Rail" (Ref. Figure 1-5)

c. "Telescoping": Arms and masts which can expand in the direction of the central axis, generally fabricated of nested tubes.

d. "Rotating": Joints which permit angular rotation (of an attached component) in a plane normal to the central axis of an arm or mast.

e. "Pivoting": Joints which permit angular movement between the central axes of arms, masts, components, and the platform.

1.4 TASK RESULTS

1.4.1 ALTERNATIVE #1, PLATFORM NO. 1. The platform designs selected for Alternative #1 are completely deployable; i.e., all systems and subsystems are self-contained within the platform and no EVA or RMS operations are required. The structural arrangement of Platform No. 1, Figure 1-3, consists of a central hub or core containing the major components of the support subsystems, a central mast for antenna reflector support, and radial arms to support payloads and the solar array power generation units.

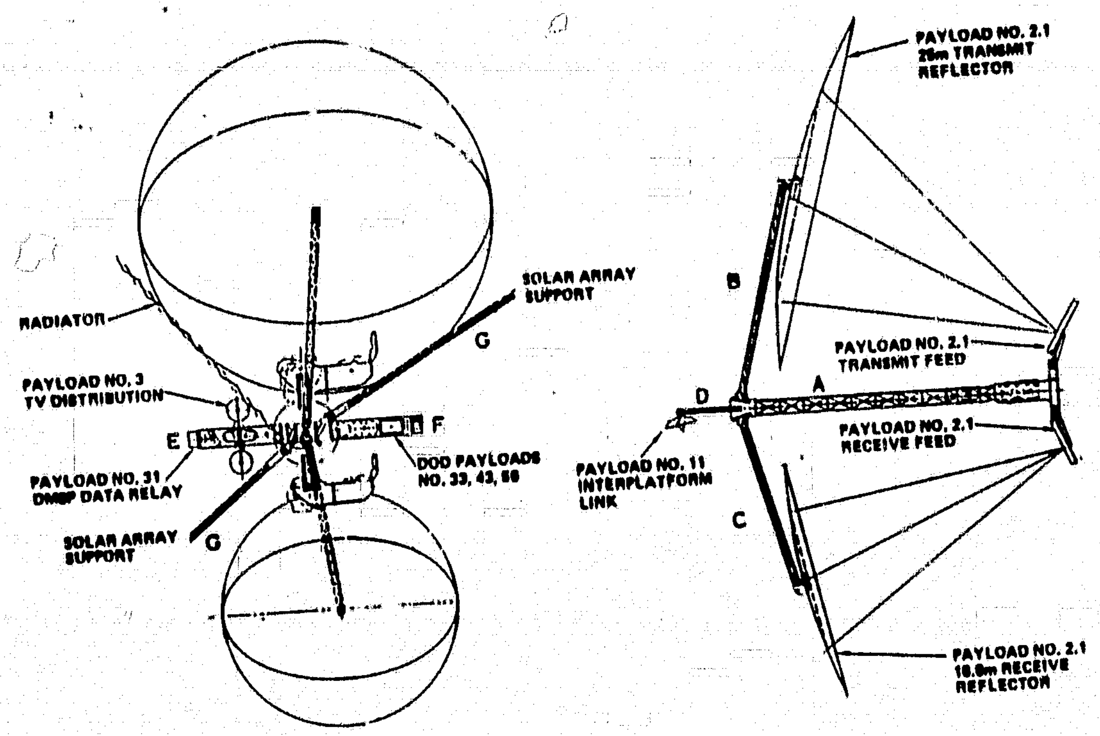


Figure 1-3. Alternative #1, Platform No. 1

For analysis, the platform was separated into its component structural elements with a letter designation for each element:

A - 17.3 m central extendable mast (antenna arms support)
B - 14.9 m extendable arm (25 m dia. antenna support, P/L #2.1)
C - 11.8 m extendable arm (16.8 m dia. antenna support, P/L #2.1)
D - 3.7 m extendable mast (IPL antenna support)
E - Pivoting arm, semi-deployable (P/Ls #3, 11, 31, RC wheels)
F - Pivoting arm, semi-deployable (P/Ls #33, 43, 56, N_2H_4, batteries)
G - 22.3 m pivoting extendable arms (2, solar array support)
H - Feed assembly arms, non-extendable, pivoting (2, P/L #2.1)
Pivoting module (radiator)
Core (disconnect panel, ACS thrusters, yaw RC wheels, avionics, radiator body)

Payloads carried on Platform No. 1, identified by number from the Initial Study, are:

#2.1 - High Volume Trunking, C-band
#3 - TV Distribution
#11 - Interplatform Link
#31 - DMSP Data Relay
#33 - Materials Exposure, Unrecovered
#43 - Magnetic Substorm Monitor
#56 - Fiber Optics Demonstration

To determine the utilities requirements for each of the structural elements, all payloads and subsystems were analyzed with respect to their requirements for power, actuator commands, data transmission, fiber optics, fluid lines, vent lines, and location. Each payload and subsystem utility line requirement was then further analyzed for number and size (diameter or AWG) of busses, cables, leads, twisted wire pairs, optic fiber elements, and tube runs. Requirements were also listed for number and type of each joint that the utility must cross, including angular rotation in degrees, and linear extension in meters.

All data were then posted on a master utilities accommodation chart for the platform to permit gathering of utilities requirements for each of the structural elements, and to permit summing of requirements. These data are included in Appendix A of this report for Platform No. 1 of Alternative #1, as well as for the other platform modules analyzed.

For each of the platform component structural elements, an individual utilities data sheet was also prepared on a standardized format, as shown in Figures 1-4 and 1-5 for the central extendable mast "A" and for the pivoting, semi-deployable arm "E".

POWER: 100 VDC

STRUCTURAL ELEMENT: CENTRAL EXTENDABLE MASTS (A & D)
PAYLOADS SUPPORTED: NO. 2,1 REFLECTORS, NO. 11

Utility Requirements									Utility Combined Weight	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
4	16	6	20	FO	4				1,066	1	120	1	±180			3.7	(D)
4	16	32	66	FO	4	ACS FEED	2	1.0	3,437							17.3	(A)

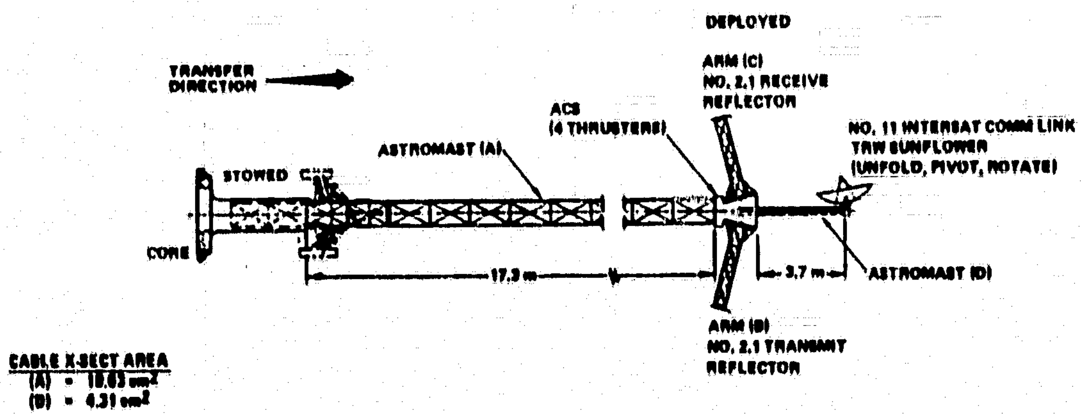


Figure 1-4. Extendable mast "A" utilities accommodation data sheet.

POWER: 100 VDC

STRUCTURAL ELEMENT: PIVOTING ARM (E)
PAYLOADS SUPPORTED: NO. 3 REFL & FEEDS, NO. 31, P&R WHEELS

Utility Requirements									Utility Combined Weight	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
18 4	18 10	36	50	FO	150	RADIATOR FLUID LINES	2	2.5	4,096	1 2	90 15	1	90	1 4 2 1 1	1.6 1.2 1.4 0.6 0.7	(POP-UP SUPPORT TRUSS)	*

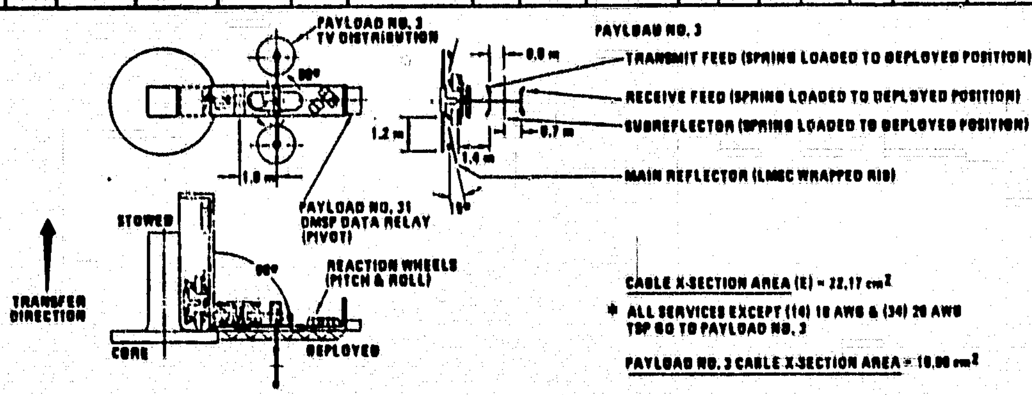


Figure 1-5. Pivoting arm "E" utilities accommodation data sheet.

Data sheets for the other structural elements are included in Appendix A. Each data sheet includes the element configuration, a summation of the detailed utility requirements, type and number of route joints and expansions, combined utility weight per unit length, and combined utility cross-sectional area. From this data, the simplicity or complexity of the utilities accommodation requirements could be observed, viable design solutions evaluated, and technology needs identified.

Figure 1-6, for example, illustrates the type of structure needed for mast "A", a high packaging-density expanding mast similar to the Astromast shown, but of larger diameter or cross-section and using low coefficient of thermal expansion materials such as graphite-epoxy composite. The type of structure is known in this application, but an advancement in technology is needed.

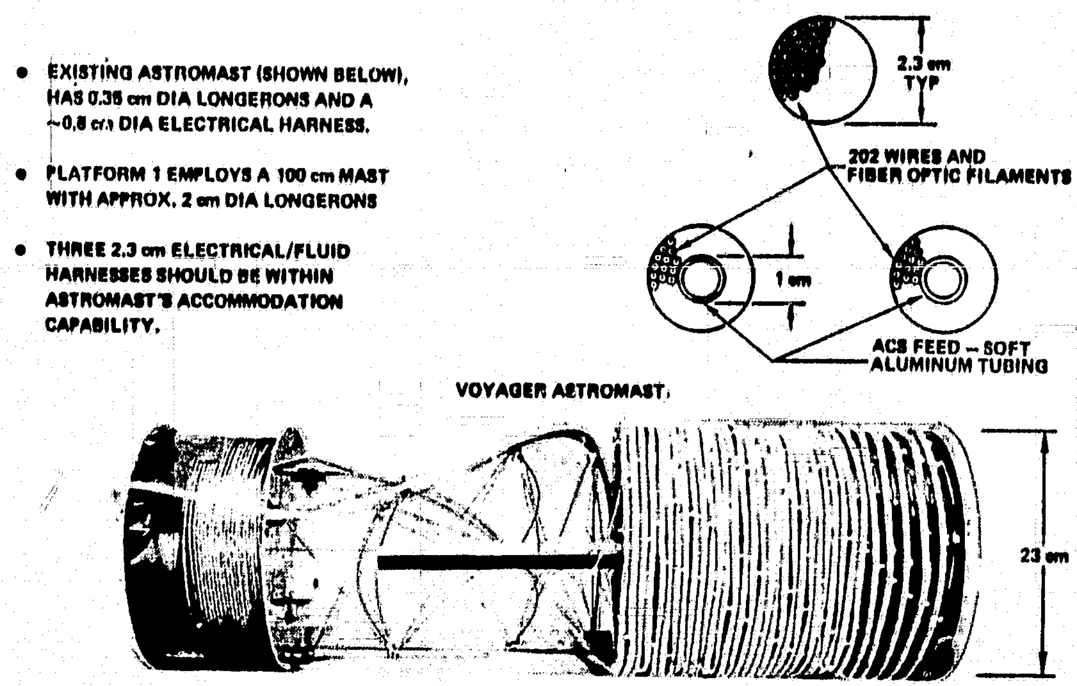


Figure 1-6. Expanding mast structural element.

The requirement for utilities accommodation on a deployable structure with complex motions is best illustrated by structural element arm "E", Figure 1-7. Here, the arm must first rotate down 90° and translate or extend 1.6 meters, followed by a telescoping mast deployment down and rotation of 90° for payload deployment. The utilities accommodation problem here is complex, but can be solved with a properly designed ribbon umbilical configuration, Figure 1-8. The 1" × 6" umbilical is fire-hose stowed in the carriage-retracted position as shown in Figure 1-7. After carriage translation, the umbilical is shown partially extended (in phantom), and after rotation, fully extended in its final position.

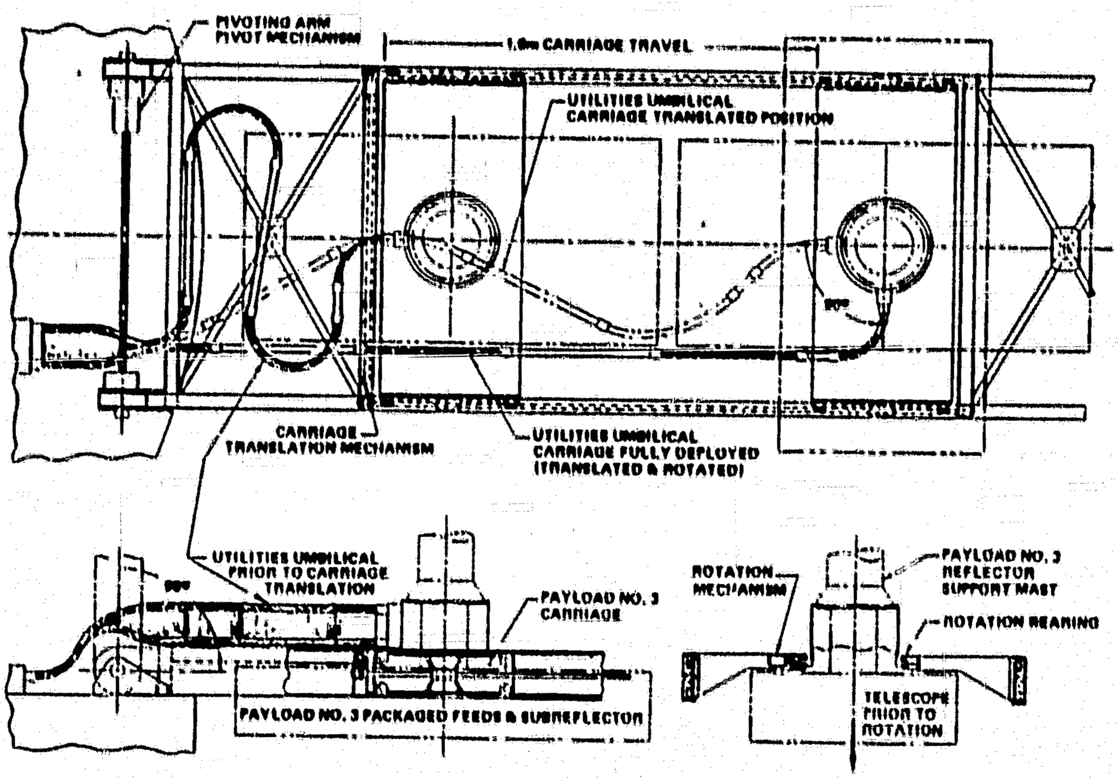


Figure 1-7. Pivoting arm element "E" umbilical carriage.

When analysis of all structural elements was complete, the utilities requirements for the platform were summarized, Table 1-1. The combined utilities weight to be carried by each element was used as input to the strength analysis task (Section 3 of this report) to determine the impact of utilities accommodation on strength and weight requirements for the platform structure.

- UMBILICAL SIZED FOR PAYLOAD NO. 3 AND ITS SUPPORT CARRIAGE SERVICES ONLY.
- CLAMPS INTEGRATE COOLING LINES AND CABLE INTO A SINGLE UMBILICAL.
- CABLING IS ARRANGED AS EIGHT 0.63 cm WIDE STRIPS BY PAYLOAD NO. 3 FUNCTION.
- BENDS IN UMBILICAL ROUTING ARE Δ LENGTH COMPENSATING.
- OTHER ELEMENT E SERVICES (FOR PAYLOAD NO. 3) AND REACTION WHEELS) ARE ACCOMMODATED VIA A SIMPLE PIVOTED SERVICES CABLE.

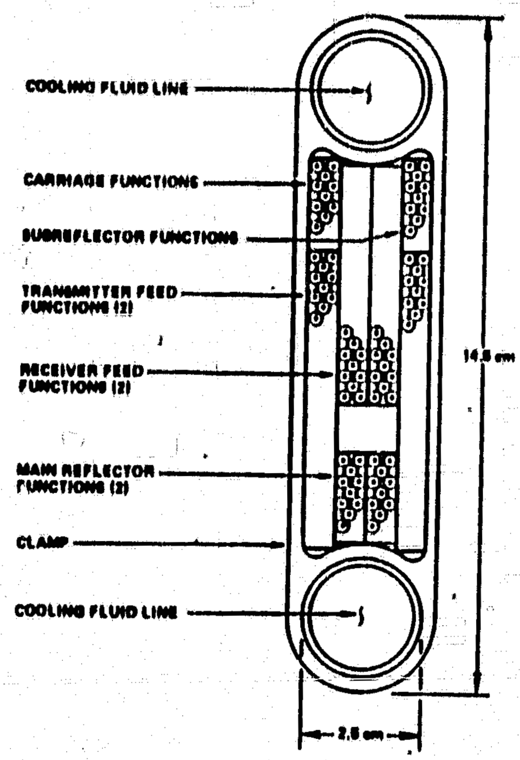


Figure 1-8. Ribbon umbilical concept for extendable structural elements.

Table 1-1. Alternative #1, Platform No. 1 utilities summary.

STRUCTURAL ELEMENT	UTILITY REQUIREMENTS (QTY)				ROUTING REQUIREMENTS (QTY)				COMBINED UTILITIES WEIGHT (kg/m)	COMBINED CROSS-SECTION AREA (cm^2)
	POWER WIRES	DATA WIRES (TSP)	OPTICAL FIBERS	FLUID LINES	PIVOT	ROTATE	TELESCOPE	EXPAND ΔL (m)		
A	4	97	4	2	—	—	—	17.3	3.437	12.20
B	—	24	—	—	1	1	—	14.9	0.707	2.52
C	—	24	—	—	1	1	—	11.8	0.707	2.52
D	4	35	4	—	1	1	—	3.7	1.066	4.31
FEED	4	32	65	—	2	1	—	—	1.231	16.39
E	22	66	150	2	3	1	9	—	4.696	31.99
F	10	64	1	4	1	—	—	—	3.648	14.46
G	6	16	—	—	1	1	—	—	1.592	5.39
RAD	—	23	—	2	19	—	—	—	1.349	12.07

1.4.2 <u>ALTERNATIVE #1, PLATFORM NO. 2.</u> The structural arrangement of Platform No. 2, Figure 1-9, consists of a central core; a three-section telescoping central support mast; an interplatform link telescoping support mast; radial arms for antenna reflectors, subreflectors, and solar array support; and interferometer arms. While completely deployable, Platform No. 2 differs from Platform No. 1 in its concept of antenna dishes mounted off the central core, with feed assemblies and subreflectors supported from the central telescoping mast. The major structural elements in this platform are:

A_3	-	0.75 m telescoping central mast, top section	(P/L #1.1 Receive feeds & subreflectors, P/Ls #7, #27)
A_2	-	1.78 m fixed central mast, mid-section	
A_1	-	4.06 m telescoping central mast, base section	
B	-	12.1 m pivoting arm, telescoping mast (main antenna support, 3)	
C	-	12.7 m telescoping mast (IPL antenna)	
D	-	50.0 m expanding mast (4, P/L #27 RF Interferometer)	
E	-	19.1 m pivoting, rotating, expandable mast (solar array, 2)	
Core	-	(batteries, reaction wheels, propellants, thrusters, matrix switch, disconnect panel, avionics)	

Payloads carried on Platform No. 2, as identified by number in the Initial Study, are:

#1.1	-	Customer Premise Services (CPS), Ku-band
#7	-	Air Mobile communications
#11	-	Interplatform Link
#27	-	RF Interferometer

All payloads on this platform were first analyzed with respect to their requirements for power, actuator commands, data transmission, fiber optics, fluid and vent lines, and location. These requirements were then defined in terms of physical number and size (diameter or AWG) of busses, cables, leads, twisted wire pairs, optic fiber elements, and tube runs. The number and type of each joint that must accommodate the utilities were also listed, with rotation and extension requirements. These data were then posted on the master utilities accommodation chart for Platform No. 2 (Appendix A), and the utilities allocation for each structural element summarized.

Individual utilities data sheets were prepared for each of the platform component structural elements and are included in Appendix A. Two of these are shown in Figures 1-10 and 1-11 for the telescoping central mast "A" and the solar array arms "E", respectively.

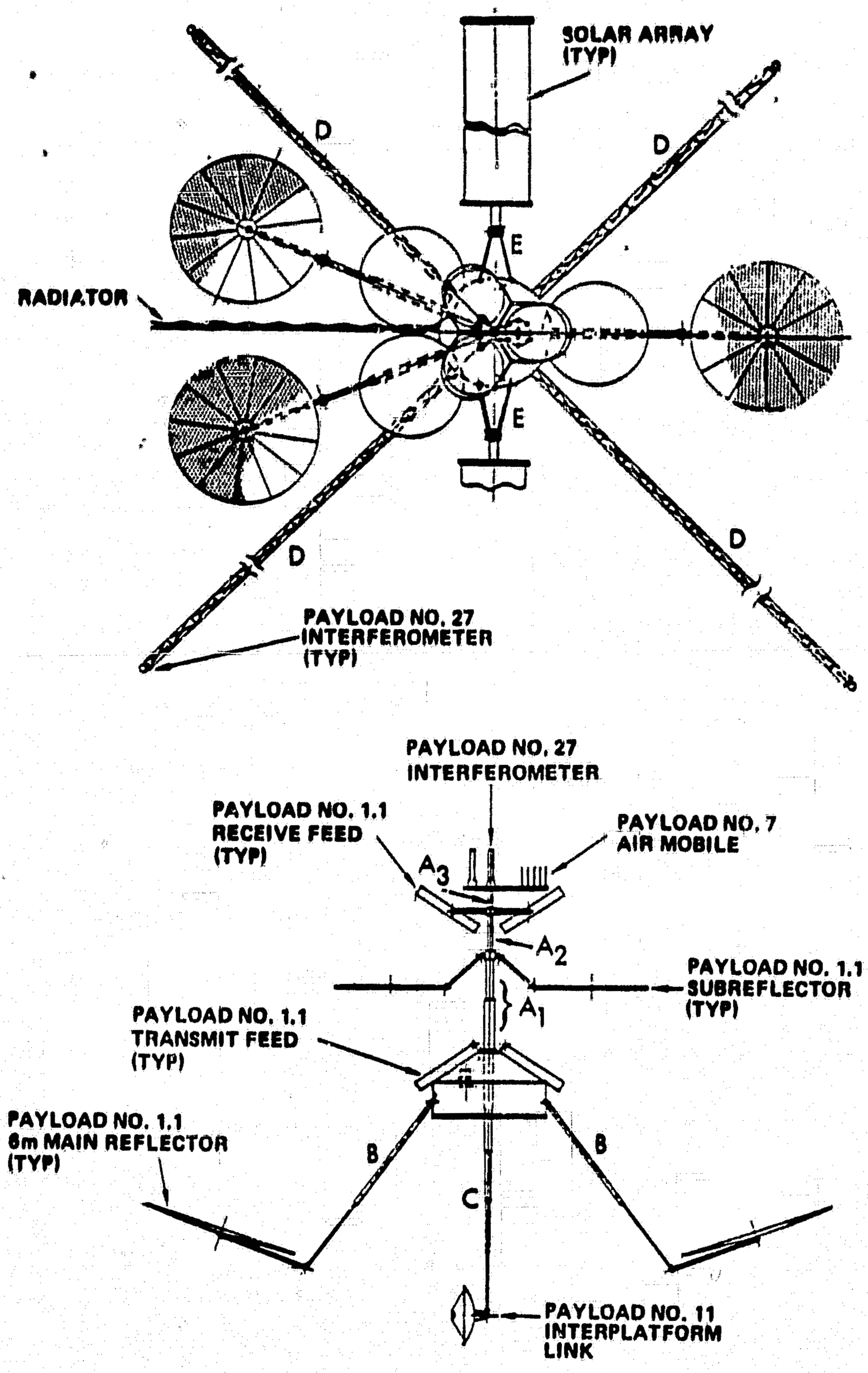


Figure 1-9. Alternative #1, Platform No. 2.

POWER: 400 VDC

STRUCTURAL ELEMENT: <u>CENTRAL TELESCOPING MAST (A)</u>
PAYLOADS SUPPORTED: <u>NO. 1.1 RECEIVE FEED & SUBREFL, NO. 7, NO. 27</u>

Utility Requirements										Utility Combined Weight	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Coax Data		Other Services					Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
8	10	–	8	RG303	3	FIBER OPT	270	1.3 mm		1.020					1	0.50		A_3
12	10	4	12	RG303	6	FIBER OPT	270	1.3 mm		1.603	1	56			1	1.52		A_2
12	10	16	12	RG303	6	FIBER OPT	270	1.3 mm		2.451	2	50			2	3.43		A_1
						ACS FEED	2	1.0				140						

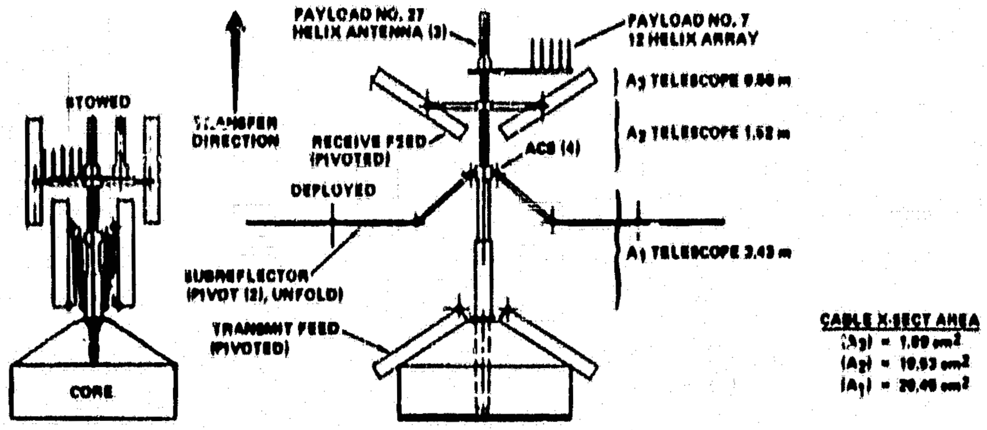


Figure 1-10. Central mast "A", Platform No. 2, utilities data sheet.

POWER: 400 VDC

STRUCTURAL ELEMENT: <u>PIVOTING ARM (E)</u>
PAYLOADS SUPPORTED: <u>SOLAR ARRAY (PLATFORM POWER)</u>

Utility Requirements									Utility Combined Weight	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)
8	16	12	10			ACS FEED	2	1.0	1.272	1	90	1	UNLIM.			17.7 (SOLAR ARRAY)

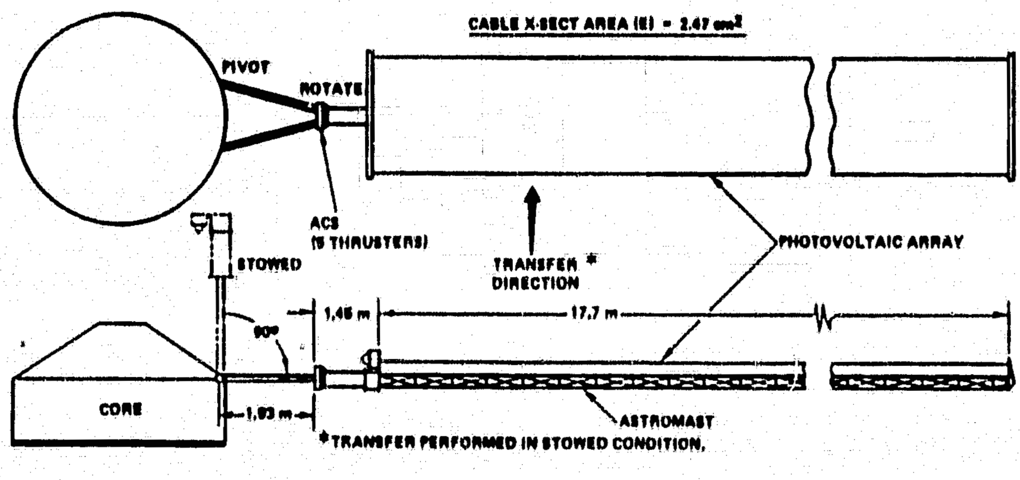


Figure 1-11. Solar array arm "E", Platform No. 2, utilities data sheet.

In element "A", the concept consists of a relatively simple 4-section telescoping mast supporting most of the payloads. Payloads #7 and #27 are fixed installations at the top of the mast. Three feed assemblies for payload #1.1 are supported by a fixed spider, deploying into their final position on trunnions. At mid-mast, three subreflectors for payload #1.1 pivot down and rotate into their final positions. At the base of the mast, the three transmit feed assemblies for payload #1.1 pivot down to their final positions on the core.

The mechanical design itself is straightforward, poses no problems, and involves no new technologies. Accurate positioning of the payload elements is the criterion for success, however, and must be emphasized as a critical design point. Of greater significance is the need for fiber optic utilities to the top of the mast for the Air Mobile payload helix array and the RF interferometer antenna. The requirement here is for a small diameter flexible utility line. Waveguide is neither small, flexible, nor compatible with the telescoping mast geometry. Coax could be used, but in the sizes required for these payloads the attenuation factor would be too great. Accommodation of this utility on the central telescoping mast may prove to be an obstacle requiring redesign in a later iteration of the configuration. If fiber optics technology can make this design and others like it feasible, however, it will simplify overall structural design and allocation of communication payload components for optimum location geometry.

For the solar arrays, Figure 1-11, the structural support element is an astromast, attached through a commutated rotary joint to a pivoted arm. The arm is stowed parallel to the core axis and rotates down 90° for astromast and solar array deployment. Again, there is no structural design problem here. Solar array technology is a requirement, however.

The utilities requirements for all structural elements of Platform No. 2 are summarized in Table 1-2. As was done in the analysis of Platform No. 1, the combined utilities weight to be carried by each element was used as input to the strength analysis task (Section 3), to determine the impact of utilities accommodation on strength and weight requirements for the platform structure.

1.4.3 ALTERNATIVE #1, PLATFORM NO. 6. Platform No. 6, Figure 1-12, consists of a central core, central telescoping mast, and radial arms for payload and subsystem support.

Table 1-2. Alternative #1, Platform No. 2 utilities summary.

STRUCTURAL ELEMENT	UTILITY REQUIREMENTS (QTY)				ROUTING REQUIREMENTS (QTY)				COMBINED UTILITIES WEIGHT (kg/m)	COMBINED CROSS SECTION AREA (cm²)
	POWER WIRES	DATA WIRES (TSP)	OPTICAL FIBERS	FLUID LINES	PIVOT	ROTATE	TELESCOPE	EXPAND ΔL(m)		
A_3	8	11	(2.5 X 5 WAVEGUIDE)		–	–	1	–	1.020	14.30
A_2	12	22	270	–	1	–	1	–	1.003	10.53
A_1	12	34	270	2	2	–	2	–	2.481	22.02
B	–	30	–	–	3	1	1	–	0.033	3.20
C	4	32	4	–	1	1	4	–	0.021	3.00
D	4	8	–	–	–	–	–	60.0	0.212	0.06
E	8	22	–	2	1	1	–	17.7	1.272	4.04

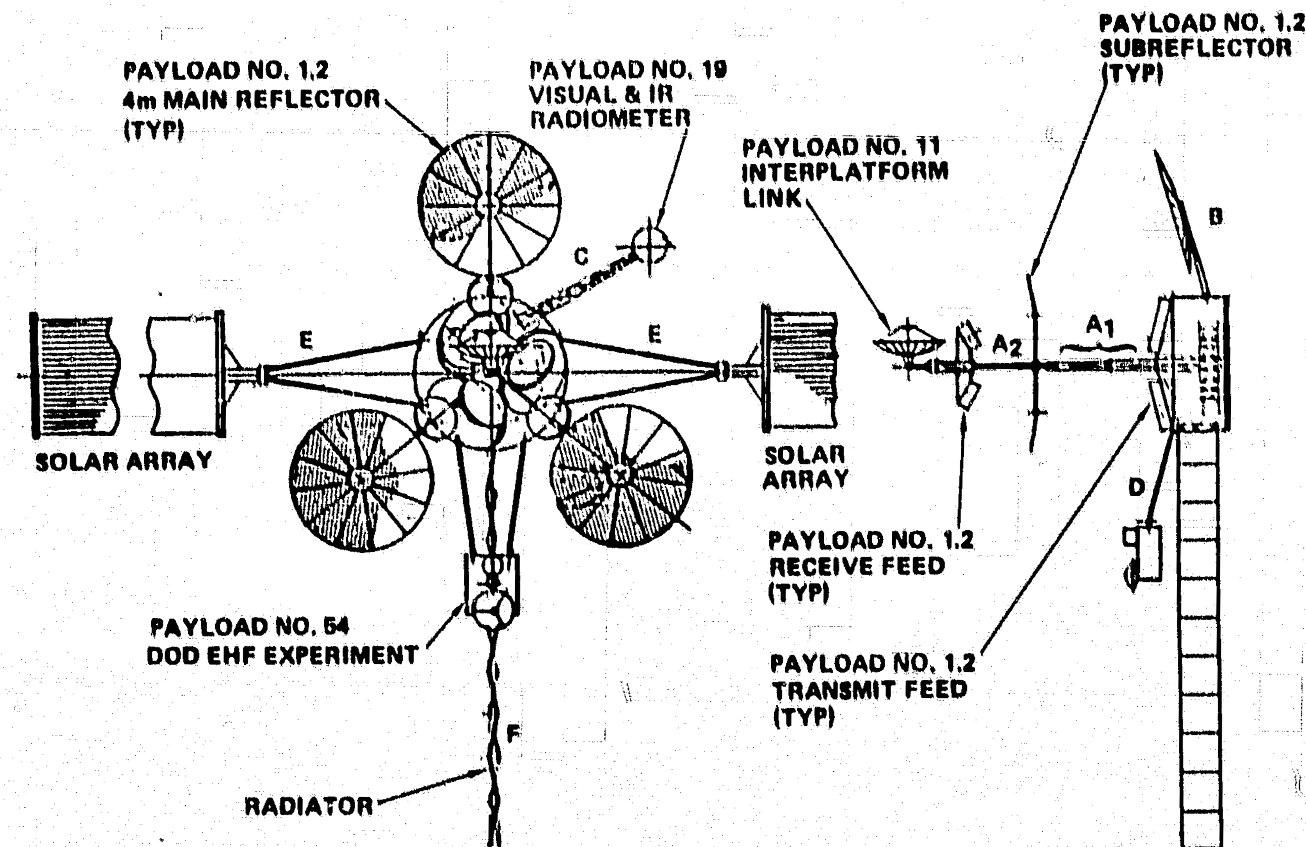


Figure 1-12. Alternative #1, Platform No. 6.

Major structural elements are:

A_2 - 2.01 m central telescoping mast, top section (P/L #11, P/L #1.2 receive feed assemblies (3)).
A_1 - 6.02 m central telescoping mast, bottom section (P/L #1.2 subreflectors (3)).
B - 2.84 m pivoting arms (P/L #1.2 main reflectors, 3)
C - 4.27 m pivoting arm (P/L #19, visual & IR radiometer)
D - 3.05 m pivoting arm (P/L #54, EHF system)
E - 14.9 m pivoting arms (solar arrays, 2)
F - 13.9 m pivoting module (radiator)
Core - P/L #1.2 transmit feed assemblies, 3; batteries, reaction wheels, propellant tanks, thrusters, matrix switch, disconnect panel, avionics

Payloads carried on Platform No. 6 are:

#1.2 - Customer Premise Service (CPS), ka-band
#11 - Interplatform Link
#19 - Visual & IR Radiometer
#54 - DOD Tactical SATCOM package

Analysis and documentation of data for Platform No. 6 follows the same format as Platform Nos. 1 and 2, Appendix A. Two typical structural element data sheets, for telescoping mast "A" and for the pivoting radiator module "F", are shown in Figure 1-13 and 1-16.

POWER: 400 VAC

STRUCTURAL ELEMENT: CENTRAL TELESCOPING MAST (A)
PAYLOADS SUPPORTED: NO. 1.2 RECEIVE FEED & SUBREFL, NO. 11

Utility Requirements									Utility	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services			Combined Weight	Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
8	18	6	33	FO	583				2.486	1	+90 -30	1	+180	1	1.32		A_2
8	18	18	33	FO	583	ACS FEED	2	1.0	3.333	3	170			2	3.66		A_1

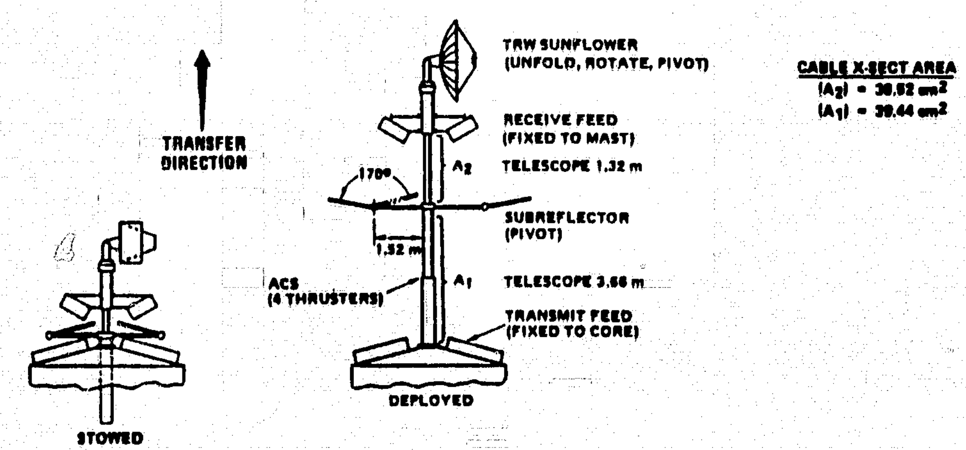


Figure 1-13. Central Mast "A", Platform No. 6, utilities data sheet.

Element "A", Figure 1-13, consists of a 4-section telescoping mast supporting most of the payload components. Payload #11, the Interplatform Link, is a fixed installation at the top of the mast. The three receive feed assemblies for payload #1.2 are also supported near the top of the mast on a fixed spider, in their final orientation. At mid-mast, the three frequency-selective subreflectors for payload #1.2 pivot out 170° from their folded position on three fixed arms, to their final operating positions. The three transmit feeds and the main antenna reflectors for payload #1.2 are core-mounted, as are payloads #19 and #54.

As was noted for Platform No. 2 of Alternative #1, the telescoping mast design presents no mechanical problems or technology needs, only a need for accuracy in positioning the communication payload components. Accommodation of fiber optics on the mast, however, may prove to be a technology requirement that is significant enough to justify redesign of the structure to simplify the fiber optics line routing.

There are numerous techniques for accommodating the utilities lines over a telescoping mast such as that shown in Figure 1-13. One such concept is shown in Figure 1-14. Here, a traveling utilities reel using a flat-ribbon single umbilical floats on one section of the mast, free to slide as the umbilical deploys in both directions. The reel concept is shown in more detail in Figure 1-15. A 1/2" by 12" flat umbilical is double-wound on the reel; there are no umbilical "ends" on the reel. A retarding mechanism is used on the reel as it deploys, to prevent free-wheeling. This same spring-loaded mechanism permits rewinding of the umbilical during mast retraction and repackaging, if there is a mission abort resulting from failure to attain proper checkout.

Module "F" for the radiator, Figure 1-16, is another case of straightforward structural design involving complexity in utility routing. The radiator case rotates 90° to its operating position, and eleven radiator panels pivot through 150°, unfolding to their final required orientation for heat rejection to the space environment. Involved in this mechanical deployment are the rotating joints for the 1" fluid lines. Swivel connections and seals are out of the question for this application. Containment and line integrity indicate flex line installation at the hinge points as a best probable solution.

The utilities requirements for all structural elements of Platform No. 6 are summarized in Table 1-3. The combined utilities weight in kg/meter was used as input to the strength analysis task, Section 3, to determine the impact of utilities accommodation on strength and weight requirements for each platform structural element.

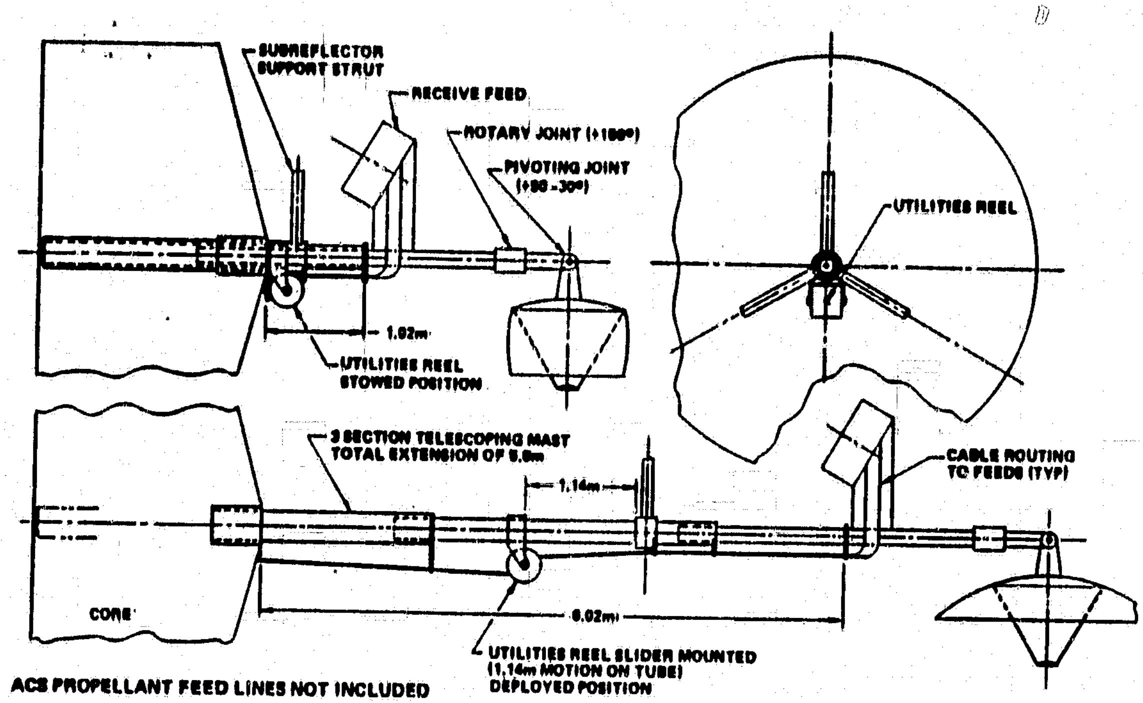


Figure 1-14. Utilities accommodation concept, Mast "A", Platform No. 6.

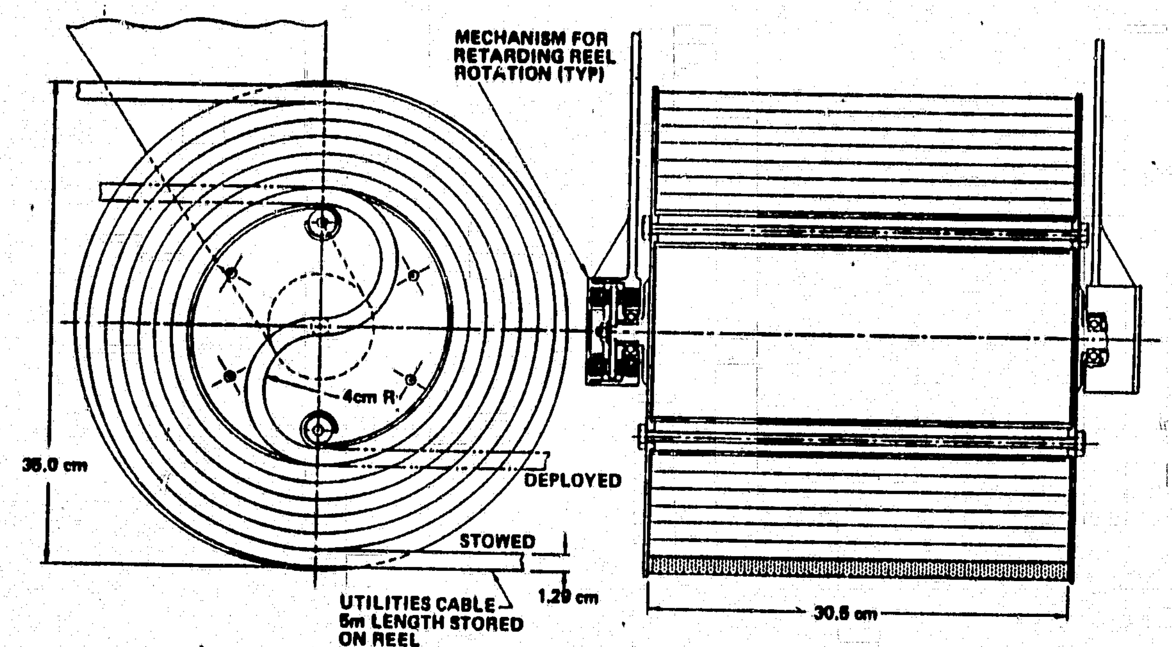


Figure 1-15. Utilities umbilical reel concept, Mast "A", Platform No. 6.

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING MODULE (F)
PAYLOADS SUPPORTED: RADIATOR (PLATFORM THERM. CONT.)

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)
		4	11			FLUID LINES	2	2,5	1.178	1 10	90 180	(RADIATOR PANELS – 13.9 m)				

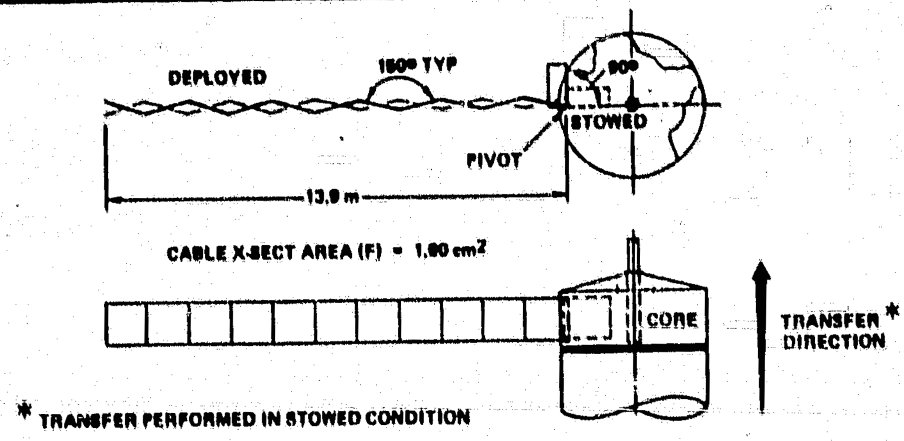


Figure 1-16. Pivoting module "F", Platform No. 6, utilities data sheet.

Table 1-3. Alternative #1, Platform No. 6 utilities summary.

STRUCTURAL ELEMENT	UTILITY REQUIREMENTS (QTY)				ROUTING REQUIREMENTS (QTY)				COMBINED UTILITIES WEIGHT (kg/m)	COMBINED CROSS-SECTION AREA (cm²)
	POWER WIRES	DATA WIRES (TSP)	OPTICAL FIBERS	FLUID LINES	PIVOT	ROTATE	TELESCOPE	EXPAND ΔL(m)		
A_2	8	38	583	–	1	1	1	–	2,485	38,52
A_1	8	61	583	2	3	–	2	–	3,333	41,81
B	–	20	–	–	2	1	–	–	0,718	2,59
C	4	40	8	–	2	1	–	–	1,234	5,01
D	4	20	–	–	2	1	–	–	0,773	2,94
E	8	12	–	–	1	1	–	13,3	0,531	2,20
F	–	16	–	2	11	–	–	–	1,178	11,42

1.4.4 ALTERNATIVE #1, PLATFORM NOs. 3, 4, AND 5. No analysis was performed on Platform Nos. 3, 4, and 5 since they are similar to Platform Nos. 1, 2, and 6 but less complex and less demanding in utilities accommodation requirements.

1.4.5 ALTERNATIVE #4. Platform Alternative #4 consists of three full Orbiter cargo-bay platform modules weighing approximately 37,000 lb each, docked to form a single platform in geostationary orbit, accommodating the projected high communications traffic model for the 1990s. Each module is delivered to low earth orbit in a single Shuttle flight, deployed, and mated in LEO to a 2-stage low-thrust reusable OTV for transfer to geostationary orbit. Two Shuttle flights are required for delivery of the two OTV stages to LEO, or a total of three Shuttle flights to deliver one platform module to GEO, and a total of nine Shuttle flights to place the complete platform in orbit. In the overall Geostationary Platform Program, two platforms are planned, one over the Atlantic, and one over the Western Hemisphere. The Western Hemisphere version is shown in Figure 1-17. Module No. 1 is the largest of the three modules, and carries the total power supply for the complete platform. Module No. 2 is similar to No. 1 but smaller. Module No. 3, which supports most of the heavier DOD and science payloads, is the smallest of the three modules.

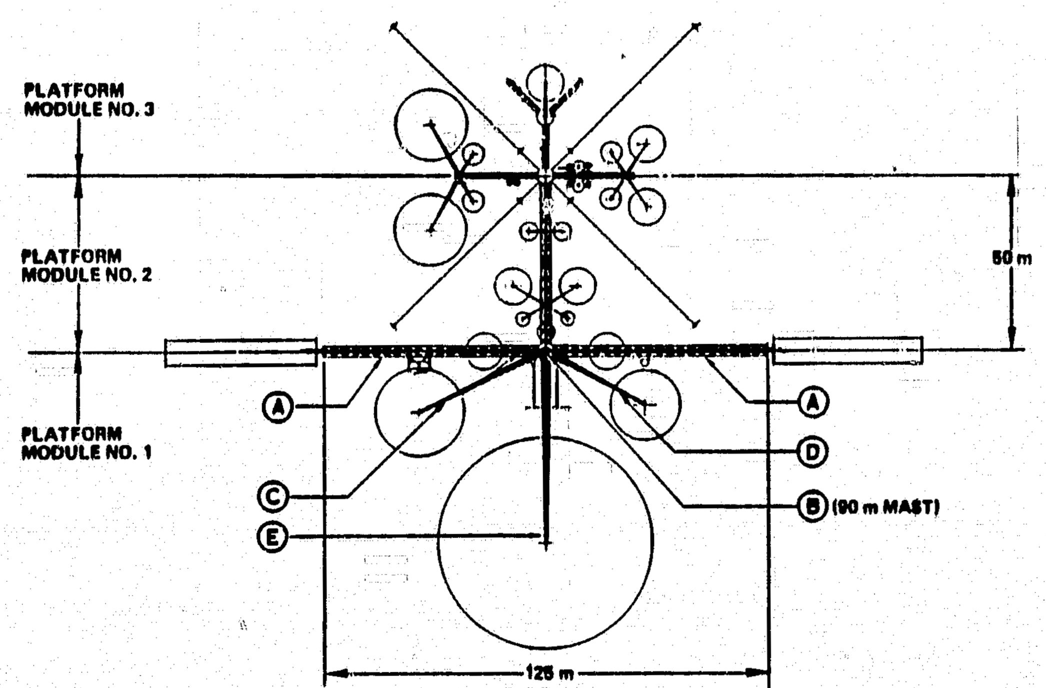


Figure 1-17. Platform Alternative #4.

Module No. 1, Figure 1-18, was chosen for utilities accommodation analysis since it is the largest module, carries the largest payloads, and also carries the power supply equipment. The principal structure in this module is structural element "A", a long diamond-cross-section expandable beam with a central 90 meter expandable mast at its midpoint. This configuration allows most of the active elements such as feed arrays and solar panels to be mounted directly on the main structural beam. Passive elements such as the main reflectors are mounted on the masts. The arrangement minimizes utilities routing on the masts, and concentrates it in the main structural beam. Utilities requirements accommodated on element "A" are summarized in Figure 1-18.

POWER: 400 VAC/400 VDC

STRUCTURAL ELEMENT: EXPANDING ARMS 1
PAYLOADS SUPPORTED: PAYLOAD 6, 12; FEEDS FOR 2.1, 9

Utility Requirements										Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG TSP	Qty of 28 AWG TSP	Fiber Optic or Coax Data		Other Services					Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG			Type	Qty	Function	Qty	Size (cm)			Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)
20	18	34	58	FO	144	FLUID LINES	6	2.5		6.2			3	±5			60
4	13					ACS FEED	4	1.0									60
6	3																60

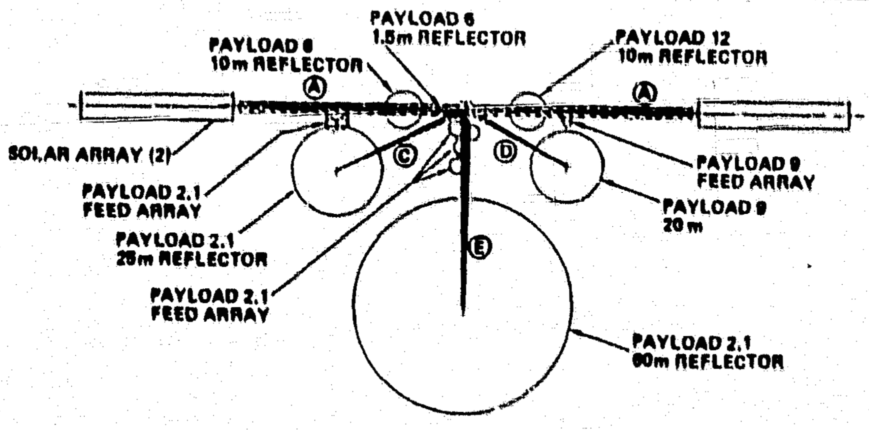


Figure 1-18. Expanding arm "A" utilities accommodation data sheet.

One concept for utilities accommodation across an expandable structure such as element "A" is shown in Figure 1-19. The truss structure itself is in development at General Dynamics Convair. A full-scale 5-bay section has been fabricated and functionally tested through packaging and deployment operations with umbilicals attached, as shown. Where the total cross-sectional area of the utilities to be accommodated on a structural element such as this is great, the diameter of a single umbilical would be approximately 3.5". In actual design, multiple umbilicals would be used to keep the umbilical diameters and bend radii low, to provide the flexibility needed. If the umbilical cross-sectional area exceeds the available space on the packaged beam, an alternative method of handling the umbilicals must be used, or the packaging geometry opened up somewhat to accommodate the utilities.

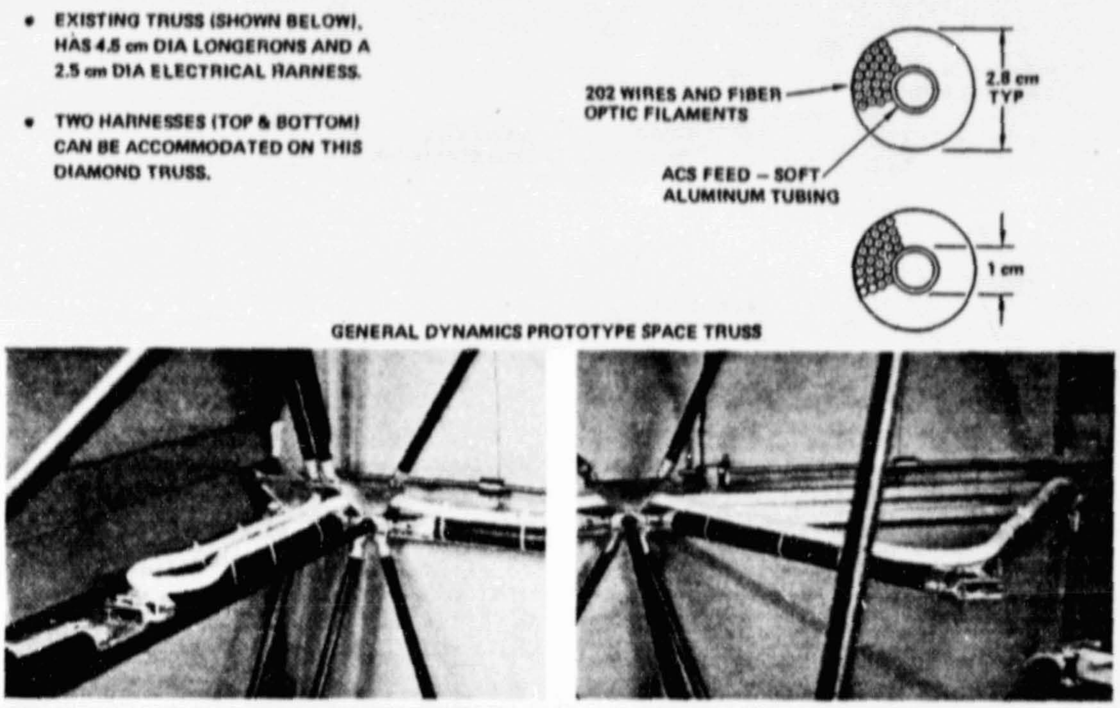
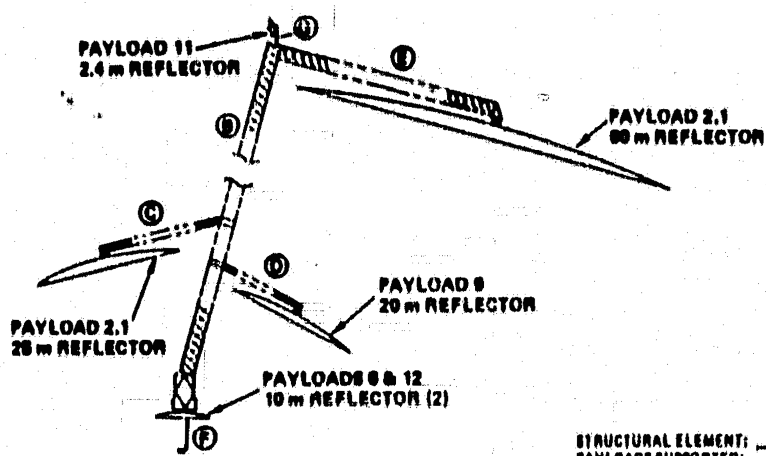


Figure 1-19. Expanding arm "A" utilities accommodation concept.

The utility requirements for central mast "B" and attached structural elements are shown in Figure 1-20. Fiber optic elements are required through element "B" to the Interplatform Link antenna, as shown. Again, this may require relocation of the IPL antenna to a less favorable operating position, if the fiber optics technology to route the lines across the expanding mast and rotating joint proves to be too complex.

Utilities requirements for Alternative #4, Platform Module No. 1, are summarized in Table 1-4. Note here the combined utilities weight of 6.20 kg/meter and the combined utilities cross-sectional area of 62.38 cm^2 on element "A", much higher on this large platform module than shown on any of the smaller Alternative #1 modules.



STRUCTURAL ELEMENT: EXPANDING MASTS B THRU G
PAYLOADS SUPPORTED: 2.1, 6, 9, 12, 11

Structural Element	Utility Requirements: Power Distribution Qty	Power Distribution AWG	Qty of 22 AWG TSP	Qty of 26 AWG TSP	Fiber Optic or Coax Data Type	Fiber Optic or Coax Data Qty	Other Services Function	Other Services Qty	Other Services Size (cm)	Utility Combined Weight (kg/m)	Services Routing: Pivoted Support Qty	Pivoted Support Deg	Rotating Joint Qty	Rotating Joint Deg	Telescoping Strut Qty	Telescoping Strut ΔL(m)	Expand Mast ΔL(m)
Ⓑ	16	18	22	41	–	–	ACS FEED	2	1.0	2.4							90
Ⓒ	4	18	6	8						0.8							45
Ⓓ	4	18	6	24						1.15							30
Ⓔ	4	18	6	24						1.15							53
Ⓕ	4	18	–	8	FO	11				0.61							7
Ⓖ	4	18	4	29	FO	4							1	±180			2

Figure 1-20. Alternative #4 expanding masts utilities data sheet.

Table 1-4. Alternative #4, Platform Module No. 1, utilities summary.

STRUCTURAL ELEMENT	UTILITY REQUIREMENTS (QTY): POWER WIRES	DATA WIRES (TSP)	OPTICAL FIBERS	FLUID LINES	ROUTING REQUIREMENTS (QTY): PIVOT	ROTATE	TELESCOPE	EXPAND ΔL(m)	COMBINED UTILITIES WEIGHT (kg/m)	COMBINED CROSS-SECTION AREA (cm^2)
A	30	92	144	6	–	–	–	90	6.20	62.38
B	16	63	4	–	–	–	–	90	2.40	7.88
C	4	14	–	–	–	–	–	45	0.80	1.02
D	4	30	–	–	–	–	–	30	1.15	2.21
E	4	30	–	–	–	–	–	53	1.15	2.21
F	4	8	11	–	–	–	–	7	0.61	1.51
G	4	33	4	–	–	–	–	2	0.22	1.39

1.4.6 ALTERNATIVES #2 AND #3. Platform Alternatives #2 and #3 were evaluated with respect to Alternatives #1 and #4, respectively, to identify any unique structural requirements for utilities accommodation. None were found. Differences existed only in the quantitative values of specific design details peculiar to each platform module. Alternative concepts #1 and #4 covered the requirements for fully deployed modules, partially deployed and partially assembled modules, half-cargo-bay modules, full-cargo-bay modules, free-flying modules, docked modules, ground mated OTV/platform modules, low-earth-orbit mated OTV/platform modules, and serviced modules. Platform modules of Alternatives #2 and #3 all fall in these categories.

1.5 SUMMARY

Utilities accommodation requirements with respect to number and size of cables, wires, fiber optics, fluid lines, and joint motions are impossible to summarize when evaluating structural concept variations that evolve in this type of study. There has been no single concept selected for the Operational Platform as yet, certainly no hard detailed design. The utilities accommodation requirements can, therefore, only be regarded as typical or representative. Quantitative values on which to base hard requirements will only emerge in later phases of the program. What can be summarized here, however, are the "maximum" requirements encountered in the analysis of the module structural elements with respect to weight and cross-sectional area of the utilities. These are given in Table 1-5, for the most stringent line routing encountered over an expanding mast, a telescoping mast, a rotating joint, and a geniculate or pivoting joint. Detailed requirements for all the structural elements analyzed will be found in the master utilities accommodation charts and individual data sheets in Appendix A.

Table 1-5. Most stringent utility routings.

		Weight	Area
Expanding Mast	Alternative 4 Module No. 1 Element A	6.222 kg/m	62.38 cm^2
Telescoping Mast	Alternative 1 Platform No. 6 Element A_1	3.333 kg/m	41.01 cm^2
Rotating Joint	Alternative 1 Platform No. 1 Element E	4.696 kg/m	31.99 cm^2
Pivoting Joint	Alternative 1 Platform No. 1 Element E	4.696 kg/m	31.99 cm^2

2

INTERFACE REQUIREMENTS

Interface requirements between payload mission equipment and platform subsystems, and for servicing and docking operations, were evaluated for structural impact on the Geostationary Platforms. Since mission equipment and platform subsystem interfaces are existing state-of-the-art in current communications satellites, the major areas of investigation were as follows:

a. Assembly (payload components/platform structure) of platform modules in low earth orbit.

b. OTV/Platform/Orbiter interfaces.

c. Docking of platform modules in geosynchronous orbit.

d. Accommodation of orbital servicing (OTV and TMS) interfaces with the platform.

2.1 ASSEMBLY OF PLATFORM MODULE SEGMENTS IN LOW EARTH ORBIT

Because of the limited Shuttle stay time in orbit, and for reliability and safety reasons, a fully deployable platform is a more attractive concept than a man-assisted assembly concept. The fully deployable configuration appears to be viable for smaller platform modules such as those analyzed in Alternatives #1 and #2. Platform subsystems, deployment mechanisms, mission equipment, etc., can be prechecked on the ground to minimize deployment and checkout operations in low earth orbit.

The larger platforms investigated in concept Alternative #4 require some individual or segmented subassembly items. This approach maximizes the volumetric packaging of the platform in the cargo bay. Although this packaging scheme is more attractive than a fully deployable platform it is apparent that interfaces between the platform segments become a major design requirement. When individual segments are packaged, the airborne support equipment design also becomes more difficult. These interfaces become critical in that they must protect the segments from high launch loads.

Utility accommodations must be provided within structural elements, creating additional interface requirements for utilities during assembly operations. The handling of structural elements during assembly also requires that interfaces be provided to accommodate operations involving the Orbiter Remote Manipulator Systems (RMS), the Manned Maneuvering Unit (MMU), and EVA capability (hand holds, grappling fixtures, etc.).

For large platforms and payloads such as those in Alternative #4, the large feed arrays become an interface of great concern. "Large" in this case applies to arrays that cannot be packaged within the 15-foot diameter of the Orbiter cargo bay, but must be broken up into smaller segments. Although the feed array does not fit the definition of a true interface, the development of a segmented large feed array is critical to the design of a geostationary platform. From a structural requirements standpoint, the segments of the array must be assembled accurately and efficiently, and the array attached accurately to its proper location on the platform without undue difficulty or loss of time. An example of such an array is the one required for payload #2.1, High Volume Trunking, on Alternative #4. This array is approximately 13.2 m × 6.6 m × 1 m when assembled, and consists of four subassemblies for packaging within the Orbiter bay.

2.2 OTV/PLATFORM/ORBITER INTERFACES

2.2.1 ALTERNATIVES #1 AND #2. The "half-cargo-bay" platform configuration used in Alternatives #1 and #2 is mated to an OTV during ground operations, installed in the Orbiter, and delivered to low earth orbit ready for deployment, checkout, and delivery to geostationary orbit. The external platform interfaces here, as shown in Figure 2-1 for Alternative #1, Platform No. 6, are between the platform and the OTV, and between the platform and the Airborne Support Equipment (ASE) cradle.

The OTV and the platform are stowed as a unit payload in the Orbiter cargo bay. The forward end of the OTV will be attached to the aft end of the platform to provide aft support while in the Orbiter, and to provide a thrust face during transfer from LEO to GEO. Platform concepts for Alternatives #1 and #2 require a stowed length of 26 feet within the cargo bay, leaving 34 feet available for the OTV.

The platform/OTV interface consists of a structural thrust ring on the aft end of the platform, compatible with the OTV forward thrust interface ring, and capable of supporting a maximum 6895 kg mass during Orbiter ascent or OTV transfer. Presuming an OTV low-thrust configuration development for a $T/W \leqslant 0.10$, the platform thrust interface will be designed to meet the OTV thrust specification.

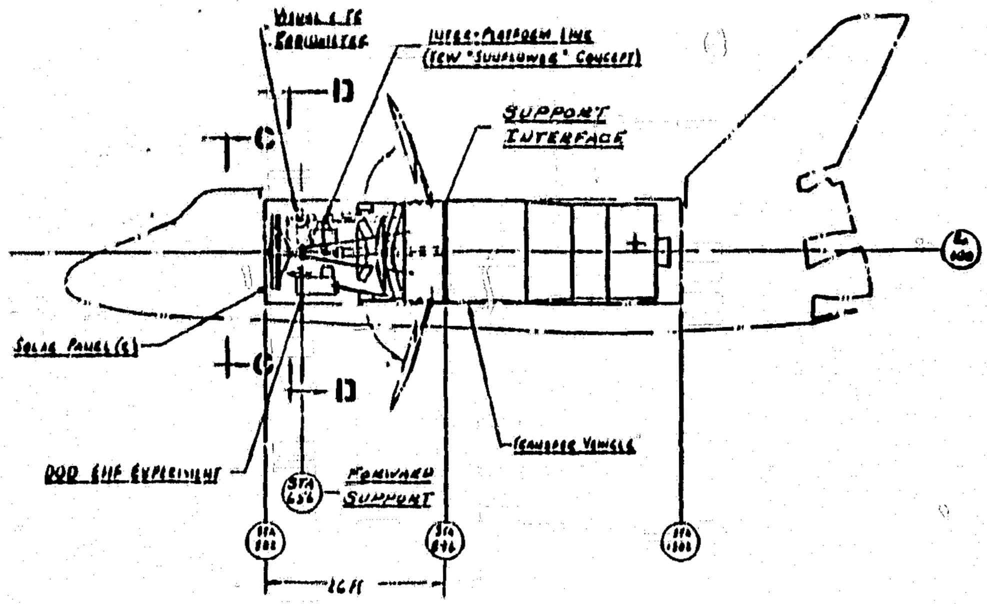


Figure 2-1. Platform/OTV/Orbiter structural interfaces, Alternative #1, Platform No. 6.

In addition to meeting structural load requirements, the OTV/platform interface must also include umbilical disconnects for platform/OTV/Orbiter command and data channels, and power for deployment operations. This type of interface is standard with existing satellites and their propulsion units, and no attempt has been made in this study to quantify the interface since each module will have different deployment modes and power requirements which in themselves have not as yet been quantified.

After deployment of the platform structural elements and payload components in low earth orbit and transfer to geosynchronous orbit, a separation system is required to release the platform module from the OTV with minimum distrubing torques. To minimize the mission-peculiar demands on the OTV interface, the active half of the separation system will be integrated with the platform, sized for the specific needs of the individual platform module configuration. The passive, or reaction half of the system will be standard on the OTV for all platform modules.

The OTV and platform unit will be supported within the Orbiter cargo bay by an ASE cradle. The package is supported at its forward end by Orbiter attach points at Station 656.00. The aft end is supported by the OTV airborne support equipment cradle at Stations 939.2 and 1269.6. Cradle rotation about an aft trunnion may be as high as 75° for some OTV/platform packages to permit deployment of main reflector dishes without interfering with Orbiter observation, restricting RMS operations, or encroaching on Orbiter safety space. Rotation requirements for most platform modules, however, will not exceed 45°.

The airborne support equipment cradle must have a restow capability in case checkout requirements in low earth orbit are not met and the payload must be returned to earth. The final OTV/cradle support system configuration must also assist in ensuring payload compatibility with the Orbiter dynamic environment.

In summary, the OTV/Platform/Orbiter interface requirements for Platform Alternatives #1 and #2 are:

a. Orbiter attach points on the platform module near the platform forward end, vicinity of Orbiter Station 656.00.

b. OTV/Platform interface

   1. Thrust ring for static support, Orbiter ascent to LEO, and OTV transfer to GEO: 6895 kg mass reaction.

   2. Umbilical disconnect for command and data channels, and power.

   3. Low-velocity separation system ($\leq$1 ft/sec), active half on platform, passive on OTV.

c. ASE cradle for OTV support, minimum 45° rotation, maximum 75° rotation for deployment, and restow capability.

d. OTV/Platform/Orbiter support system capable of reacting the Orbiter dynamic environment.

2.2.2 ALTERNATIVES #3 AND #4. Platform modules for Alternative concepts #3 and #4 differ from Alternatives #1 and #2 concepts in that they are full Orbiter-cargo-bay size platform modules. As such, they must be supported by an ASE cradle fore and aft for transfer to low earth orbit, rotated by the cradle for deployment, deployed, separated from the Orbiter and ASE cradle, and mated with an OTV which has been delivered to LEO in a second Shuttle flight.

Platform concepts for Alternatives #3 and #4 require a stowed length of 60 feet within the Orbiter cargo bay, including space for rotation and deployment while still attached to the Orbiter. The platform module will be supported within the Orbiter cargo bay by an ASE cradle capable of reacting the side and end-thrust loads during Orbiter occupancy, ascent, and abort landing. Attach points between cradle and platform will be placed as close as possible to the cradle/Orbiter attach points to minimize cradle structural loading. The cradle will be required to rotate about an aft trunnion axis to a nominal 45°, maximum 75°. The ASE cradle must have a restow capability to permit return of the platform module to earth, should the platform fail to meet checkout requirements in low earth orbit. The Platform/cradle/Orbiter support system must also assist in ensuring payload compatibility with the Orbiter dynamic environment.

After the platform/cradle rotation operation, the platform will be deployed, checked out, and separated from the Orbiter and cradle, preparatory to mating with the OTV coming up on the next Shuttle flight.

For mating with the OTV, the platform must have an aft interface thrust ring compatible with the OTV forward end thrust interface ring, capable of reacting a maximum 37,000 kg mass during orbit transfer from LEO to GEO. The platform itself must be equipped with grappling fixtures compatible with the Orbiter RMS end effectors, to assist in mating the platform module to the OTV.

In addition to the structural load interface requirement, the OTV/Platform interface must also include umbilical disconnects for platform/OTV command and data channels, and for power. The umbilical disconnect panels are to be activated and powered closed only after the platform/OTV structural mating is complete.

After transfer to geosynchronous orbit, a separation system is required to release the platform module from the OTV with minimum disturbing torques. As planned for Alternatives #1 and #2 modules, Alternatives #3 and #4 modules will have an active half of the separation system, sized for the specific needs of the individual platform module configuration. The passive half of the system will be standard on the OTV for all platform modules.

In summary, the OTV/Platform interface requirements for Platform Alternatives #3 and #4 are:

a. ASE cradle attach points on the platform module fore and aft, as close as possible to the cradle/Orbiter attach points.

b. ASE cradle for platform support, minimum 45° rotation, maximum 75° rotation for deployment and restow capability, capable of reacting the Orbiter dynamic environment.

c. OTV/Platform interface

   1. Thrust ring for OTV transfer to GEO: 16,800 kg mass reaction.

   2. Power-closed umbilical disconnect at the structural docking interface, for command and data channels, and power.

   3. Low-velocity separation system ($\leqslant$1 ft/sec), active half on the platform (passive half on the OTV), integral with the structural interface.

   4. Grappling fixtures on the platform central core, compatible with the RMS end effectors.

2.3 PLATFORM MODULE-TO-MODULE DOCKING IN GEO

Previous studies done by Convair have identified a single-point docking system as the optimum method of joining large structures in space because it minimizes both risk and structural loading (obviating the need for a complex damping system) and does not require great technology development. The central core structure, which is a common element in the platform design, becomes an ideal interface for the single-point docking scheme. Figure 2-2 illustrates the basic concept.

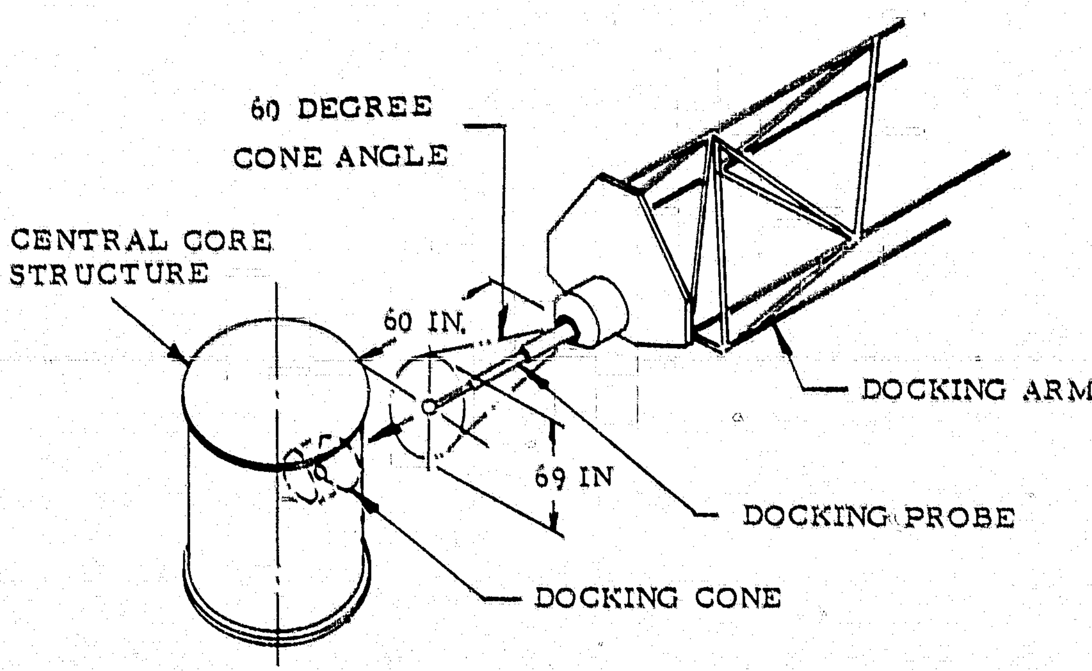


Figure 2-2. Docking system configuration.

Where docking of two large structures is desired in more than one place (two or three mast interfaces) an initial single-point docking can be made, followed by platform rotation and latching of the other two interfaces. Docking of two platforms requires:

a. A structural connection

b. A utilities connection (power, data transmission, command lines, etc.).

The concept investigated for Alternative #4 uses the single-point docking system incorporating a utilities or service panel interface. The basic design philosophy in this scheme is to perform the structural alignment, docking, and latching or lock-up of the platforms before the service panel is engaged.

Figure 2-3 identifies the service utilities that are required across the interfaces for the three modules that make up platform Alternative #4. For simplicity, utilities are combined by function into separate disconnects, as shown by the 52 fiber optic data line disconnects between modules #1 and #2.

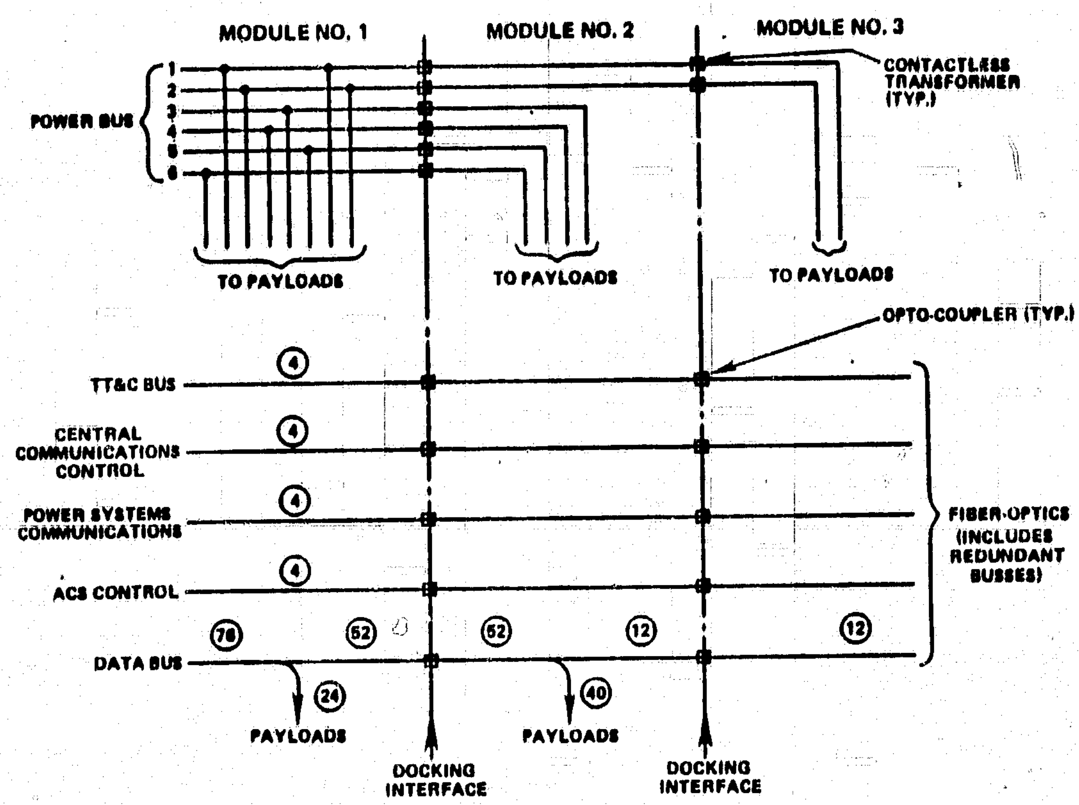
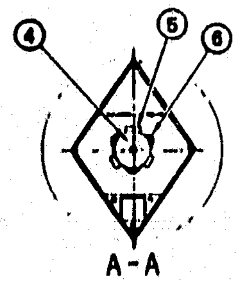
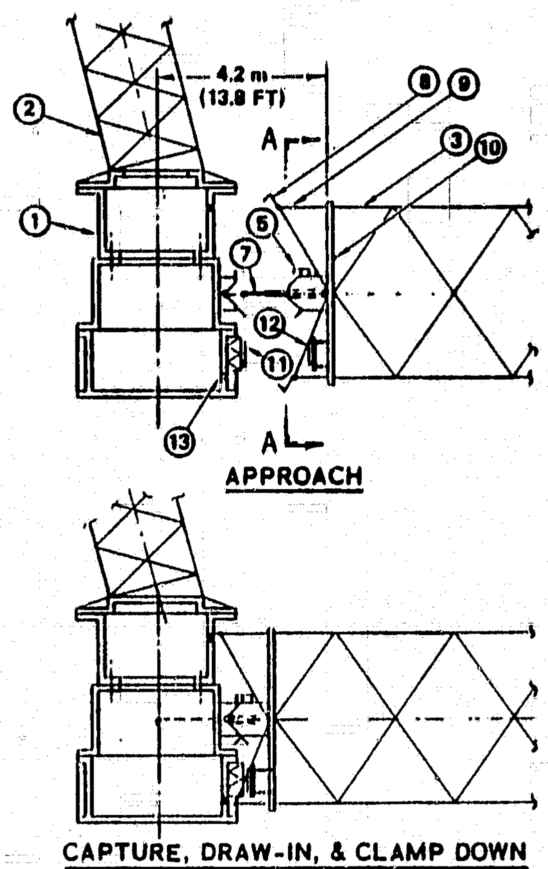


Figure 2-3. Docking interface schematic - support services.

The docking concept for Alternative #4 - platform modules #1 and #2, is shown in Figure 2-4.





1. CENTER CORE STRUCTURE (MODULE NO. 1)
2. PLATFORM NO. 1
3. DOCKING ARM (MODULE NO. 2)
4. DOCKING CONE
5. LATCHING PAWLS (3 PLCS)
6. DOCKING GUIDE
7. DOCKING PROBE WITH CAPTURE MECHANISM
8. LATCHING PAWLS (INTERFACE STRUCTURE) TYP. 4 PLCS
9. INTERFACE STRUCTURE (CORE TO DOCKING ARM)
10. HINGE
11. SERVICES UMBILICAL PANEL (PASSIVE)
12. SERVICES UMBILICAL PANEL (ACTIVE)
13. RETENTION FITTING (TYP. 4 PLCS)

Figure 2-4. Docking concept - Alternative #4, Platform Modules #1 and #2.

Module #2 is the active module and incorporates the steerable probe and docking latches. In the final approach position (approximately 5 feet), the steerable probe is engaged into the passive docking port in module #1. The steerable probe is retracted, drawing the two modules together. Docking guides are provided on the docking port and receptacle that orient or clock the two modules as the draw-in is in progress. Once the draw-in is complete, perimeter latches on the active probe are actuated, structurally joining the two halves of the docking mechanism. Details of the probe mechanism are shown in Figure 2-5.

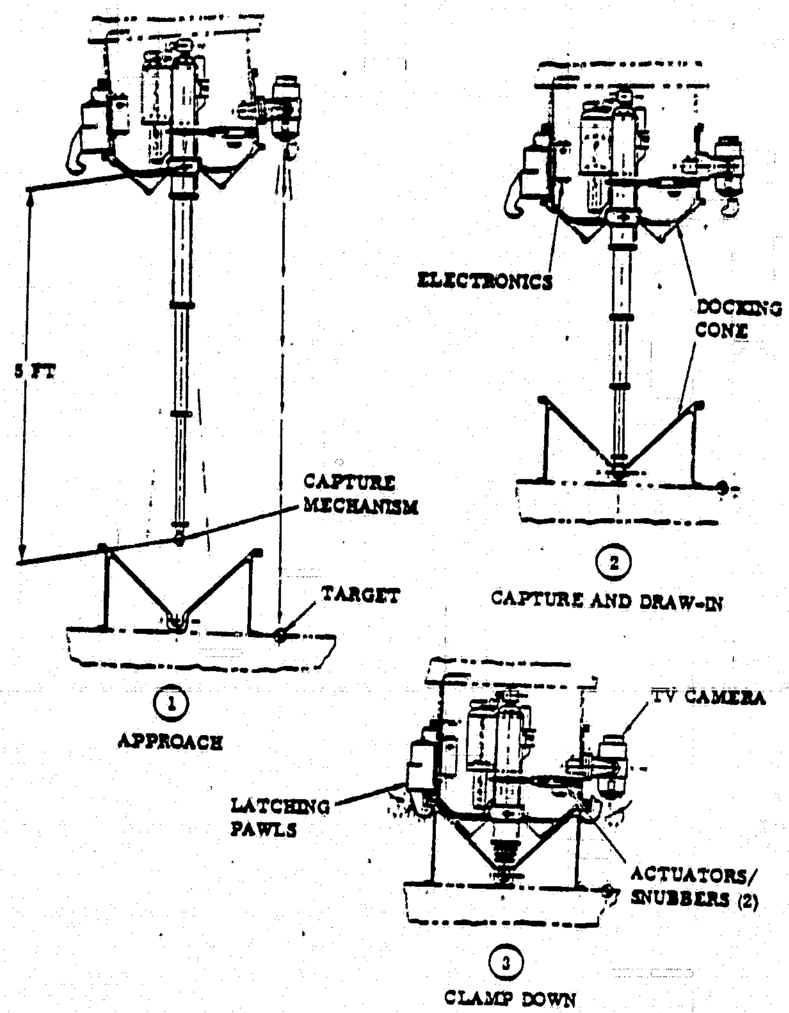


Figure 2-5. Soft docking mechanism.

After the initial docking operation has been completed, four latching pawls on the horizontal longerons of the module #2 docking arm are engaged with the retention fittings in the core structure of module #1, completing the structural tie-in of the two platforms (see Figure 2-4). To accommodate the utilities across the two modules, a service panel approximately 24 inches square is required, Figure 2-6.

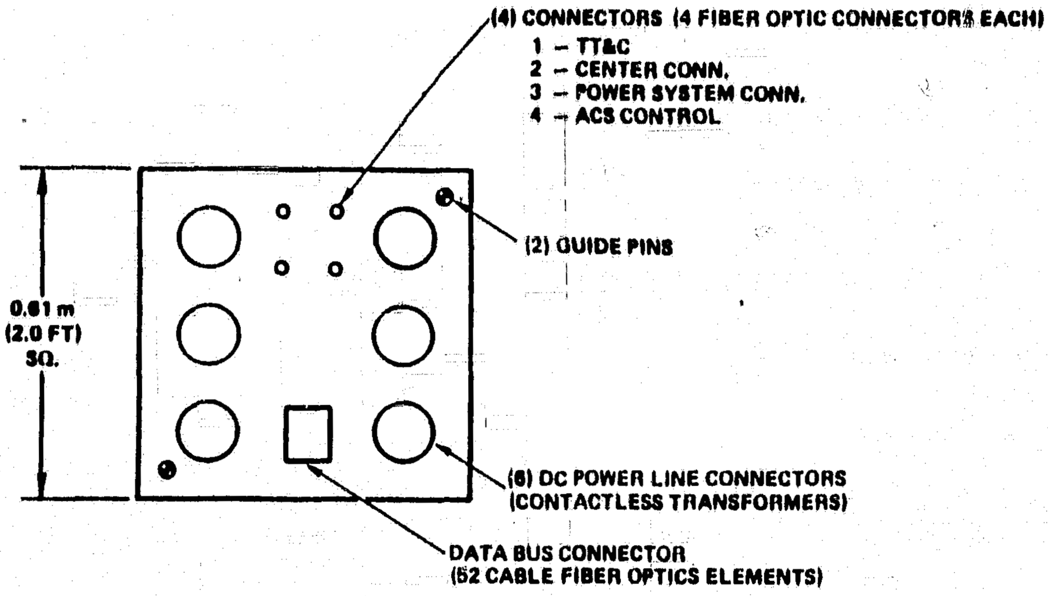


Figure 2-6. Docking interface umbilical panel concept.

The central core structure of module #1 contains a fixed interface for terminating the utilities. The active module contains a floating matching interface. After the structural tie-in is made between platforms, the active panel is actuated until the utilities connectors are mated. Alignment of the DC power connectors does not appear to be as critical as the other utilities since they would employ contactless transformers. Research to date indicates that the fiber optic connectors, especially those that require a large number, will require technology development. It is envisioned that the individual connectors within the floating service panel would also have some degree of float to allow for misalignment and engagement of the connectors.

2.4 ACCOMMODATION OF ORBITAL SERVICING

To extend the useful life of geostationary platforms, servicing in geostationary orbit is needed. Servicing will include resupply of fluids such as hydrazine for the ACS system, replacement of expendables such as batteries, replacement of degraded or failed black boxes, and upgrading of systems hardware with advanced hardware. The major guidelines for on-orbit servicing at GEO are as follows:

a. Considerations

1. Platform/OTV structural interface (thrust ring) is common to all platform modules of all alternative concepts.

2. Support system expendables and replaceable components are concentrated primarily in the platform module core.

3. Interface is available for servicing operations after OTV separation.

b. Design for Servicing

1. Emphasize placement of platform expendables and replaceable components in the core, or near it.

2. Emphasize commonality of expendables and replaceable component configuration and location in all platform modules.

3. Provide service system (e.g., TMS) soft docking and hard latching capability at OTV interface location.

4. Provide powered fluid/electrical umbilical panels at interface.

5. Coordinate replaceable "black box" component design with the NASA Satellite Services Working Group (MTG-3), for compatibility with a dedicated servicer.

c. Structural Interface Requirements

1. Compatibility with OTV interface thrust ring (configuration and thrust load).

2. Compatibility with TMS or other standardized servicer system docking and servicing operations.

Since the platform designs contain a common central structure which contains the major components of the support subsystem, it can serve as the interface for the Teleoperator Maneuvering System (TMS). Advantages of this concept are:

a. A common TMS interface for all platforms,

b. Replaceable components and platform expendables are contained in a centralized location within reach of the TMS manipulator arm,

c. A soft docking technique could be used for the TMS with unobstructed access to the platform during approach and docking.

The central core system can also contain a servicing panel with a matching one on the TMS. The operation of the panels would be similar to that described for the utilities accommodation panel. Figure 2-7 illustrates the TMS on-orbit servicing concept.

A variation of the above servicing concept is shown in Figure 2-8. In this concept, the TMS and OTV interface would be essentially the same (the O.D. of the central structure).

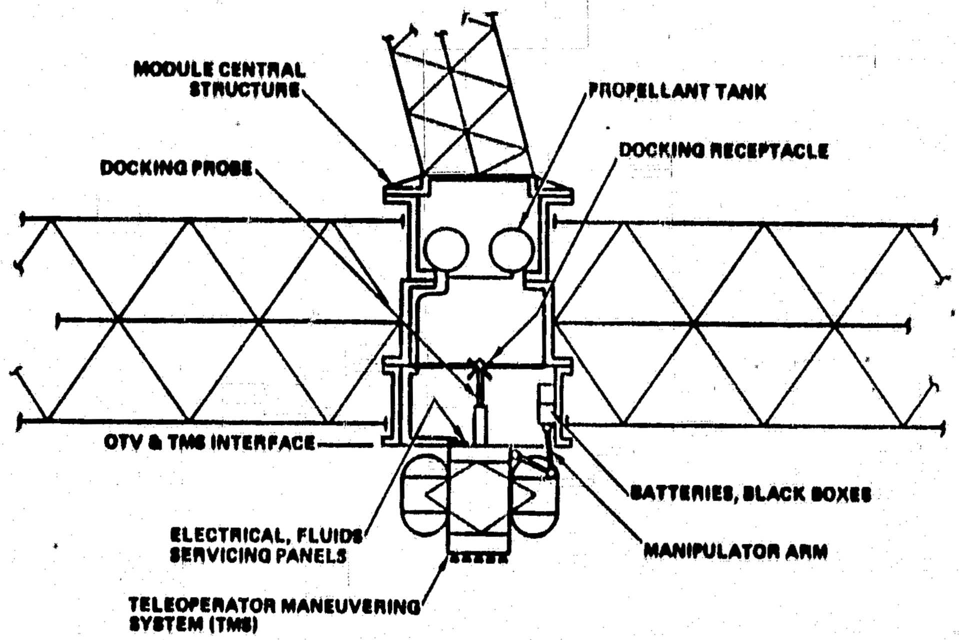


Figure 2-7. TMS on-orbit servicing concept.

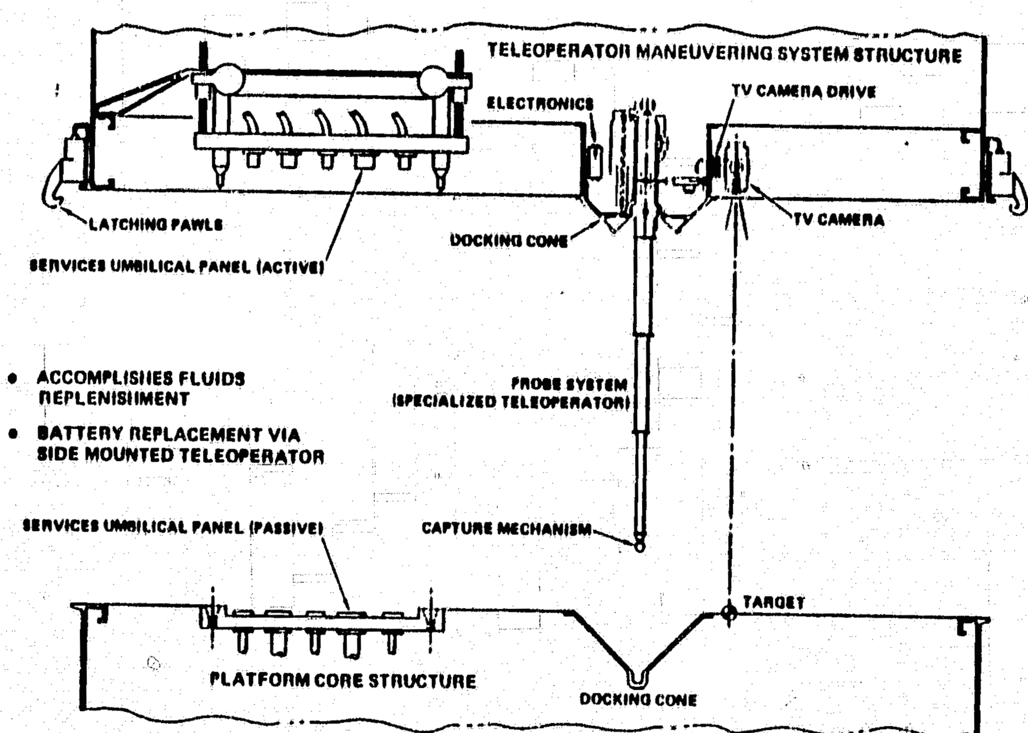


Figure 2-8. Alternative TMS on-orbit servicing concept.

Another concept that offers possibilities yet requires further study, varies from the previously described concept in the manner in which the servicing is accomplished. In this version, the predicted serviceable items such as propellants, batteries, etc., are contained in a cylindrical wafer structure that would interface with the central core structure (OTV ring). The wafer would have the appropriate alignment and latching mechanisms for attachment to the core. The TMS would position the service wafer and through the appropriate connectors the new serviceables (propellants, batteries, etc.) would bypass the original installation in the core structure. This scheme would not require the removal of old propellant tanks, batteries, etc.

3

STRENGTH AND STIFFNESS

The platform configurations considered in this study must all be designed to withstand the following major loading conditions:

a. Shuttle launch and landing loads. These loads can be reacted by a properly designed Orbiter cargo bay cradle.

b. Deployment loads. Deployment rates of various structural elements can be made low enough so that induced loads do not exceed other operational loads.

c. Orbit (LEO to GEO) transfer loads.

d. Docking and/or servicing loads. General Dynamics' soft-docking approach minimizes docking velocities with correspondingly low loads that do not exceed other operational loads.

e. On-orbit ACS loads. These loads can be minimized, consistent with operational requirements, by limiting thruster force and torque.

The orbit transfer loading condition was chosen for preliminary sizing since this loading condition is well defined and is generally the most severe.

Once a preliminary design concept has been sized for strength considerations, other operational requirements must be checked. The structure must be resized and iterated until all requirements are satisfied.

Stiffness requirements of various structural elements will generally be dependent on relative geometric tolerances that various payloads and payload components must maintain under the actions of any given loading. Operational tolerances of each payload (e.g., feed-reflector geometry) must be satisfied during all on-orbit loading conditions. There are two basic on-orbit loading conditions:

a. Docking and/or servicing loads. Resulting loads and distortions can be minimized by use of a soft-docking approach.

b. On-orbit ACS loads.

ACS loads resulting from pointing and stationkeeping at geosynchronous orbit, along with operational tolerances, dictate the stiffness requirements. The structural sizing may again have to be iterated to satisfy overall lower bound structural vibrational frequencies.

A major structural consideration is thermal compatibility with the space environment under all operational attitudes and conditions. There are basically two requirements that must be satisfied in this respect. All structural temperatures must remain within material allowables, and worst-case temperature differential distortions must still permit normal operation of all payloads and payload components. The second condition necessitates well-defined payload-unique requirements. Because of the specific nature of this information with respect to each payload, the thermal analysis structural iteration is not considered practical at this point.

3.1 ALTERNATIVE #1

Platform Nos. 1, 2, and 6 are representative of Alternative #1 and were analyzed in detail with respect to the structural considerations previously discussed.

3.1.1 SIZING FOR STRENGTH. For Alternative #1, the transfer vehicle is an expendable OTV with $T/W = 0.07$. A dynamic factor of 2.0 was used in this analysis. Preliminary analysis indicates that orbital transfer with this OTV is feasible for the fully deployed configurations of Platforms 1, 2, and 6.

Structural elements of the platforms were sized for strength using the weights, geometry, and dimensions of probable mast or beam configurations such as a double or single tube, coilable Astromast, articulated Astromast, or expandable truss, depending on the packaging constraints and the operational load requirements involved. These structural elements are shown in Table 3-1.

For some of the more heavily loaded sections, Astromasts were chosen because of the need for highly efficient packaging. Other types of expandable booms were considered for these applications, but could not be packaged in the space available in the Orbiter cargo bay.

Where coilable Astromasts were selected, the fiberglass "Supermast" configuration was used, with half the bay length of the standard coilable Astromast. The Supermast weighs about 40 to 45% more, has the same bending stiffness, but has four times the bending strength of the standard Astromast. Supermast analysis and data were derived from the standard Astromast data available from the Astro Research Corporation at the time the study was performed, as given in Appendix B. Astro Research Corporation has since published a report for NASA/MSFC on "Current and Projected Performance Characteristics of Deployable Structural Masts", Report No. AR C-TN-1085 dated 15 April 1980.

Table 3-1. Alternative #1 Strength Requirements.

Structural Element	Bending Moment, M (Nm)	Similar To	Diameter	Thickness (cm)	Stiffness Characteristics EI (N m²)	Stiffness Characteristics JG (N m²)	Margin of Safety
PLATFORM NO. 1							
D — IPL MAST	70	SINGLE TUBE (G.E.)*	2.54 cm	0.051	679.	160.	0.00+
A — CENTRAL MAST ([illegible] AXIS)	5,120	ARTICULATED ASTROMAST (G.E.)*	0.22 m	—	3.16×10^5	9.29×10^3	0.05
B — 2[illegible] m WRAP-RIB ANTENNA MAST	6,570	SUPERMAST ASTROMAST**	0.42 m	—	2.80×10^6	8.24×10^4	0.02
C — 16.3 m WRAP-RIB ANTENNA MAST	2,840	SUPERMAST ASTROMAST**	0.32 m	—	9.15×10^5	2.69×10^4	0.02
H — WRAP-RIB ANTENNA FEED SUPPORTS (EACH)	1,900	SINGLE TUBE (G.E.)*	10.2 cm	0.203	1.75×10^5	4.11×10^4	0.07
G — SOLAR ARRAY MASTS (EACH)	2,930	SUPERMAST ASTROMAST**	0.32 m	—	9.15×10^5	2.69×10^4	0.03
PLATFORM NO. 2							
C — IPL MAST	97	SINGLE TUBE (G.E.)*	3.18 cm	0.045	1.18×10^3	276.	0.00+
A — CENTRAL MAST (YAW AXIS)	270	SINGLE TUBE (G.E.)*	4.47 cm	0.062	4.50×10^3	1.06×10^3	0.00+
E — SOLAR ARRAY SUPPORTS (EACH)	1,813	TWO TUBES (G.E.)*	6.68 cm	0.094	4.56×10^4	1.07×10^4	0.00+
B — 6 m WRAP-RIB ANTENNA MASTS (EACH)	371	SINGLE TUBE (G.E.)*	4.97 cm	0.069	6.89×10^3	1.62×10^3	0.00+
D — INTERFEROMETER MASTS (EACH)	3,407	SUPERMAST ASTROMAST**	0.33 m	—	1.23×10^6	3.62×10^4	0.03
PLATFORM NO. 6							
A — IPL MAST	176	SINGLE TUBE (G.E.)*	3.86 cm	0.109	5.10×10^3	1.20×10^3	0.00+
E — SOLAR ARRAY SUPPORTS (EACH)	330	TWO TUBES (G.E.)*	3.78 cm	0.106	9.30×10^3	2.18×10^3	0.00+
B — 4 m WRAP-RIB ANTENNA MASTS (EACH)	46	SINGLE TUBE (G.E.)*	2.47 cm	0.069	845.	198.	0.00+
D — DOD EHF EXPERIMENT SUPPORT	641	TWO TUBES (G.E.)*	4.73 cm	0.133	2.29×10^4	5.37×10^3	0.00+

*(G.E.): GY70/X30 GRAPHITE-EPOXY $(0_2/\pm 24)_s$

** EXISTING FIBERGLASS. NEED G.E. EQUIVALENT CTE.

It should be noted that dimensions and stiffness characteristics of the Supermast structural elements in Table 3-1 are for the fiberglass Supermast. Fiberglass is unsuitable for this application, where thermal distortion must be held to very low values to maintain RF beam geometry between feed assemblies, subreflectors, and antenna reflectors. The fiberglass masts were used for preliminary sizing because they are the only known type of structure with such a high packaging density which are adequately defined. A key technology requirement for this program is a thermally stable (e.g., graphite-epoxy) expandable mast with a packaging efficiency approaching that of the coilable Astromast.

For the articulated Astromast application, initial sizing was done using graphite-epoxy material. The basis for the sizing data analysis is also included in Appendix B.

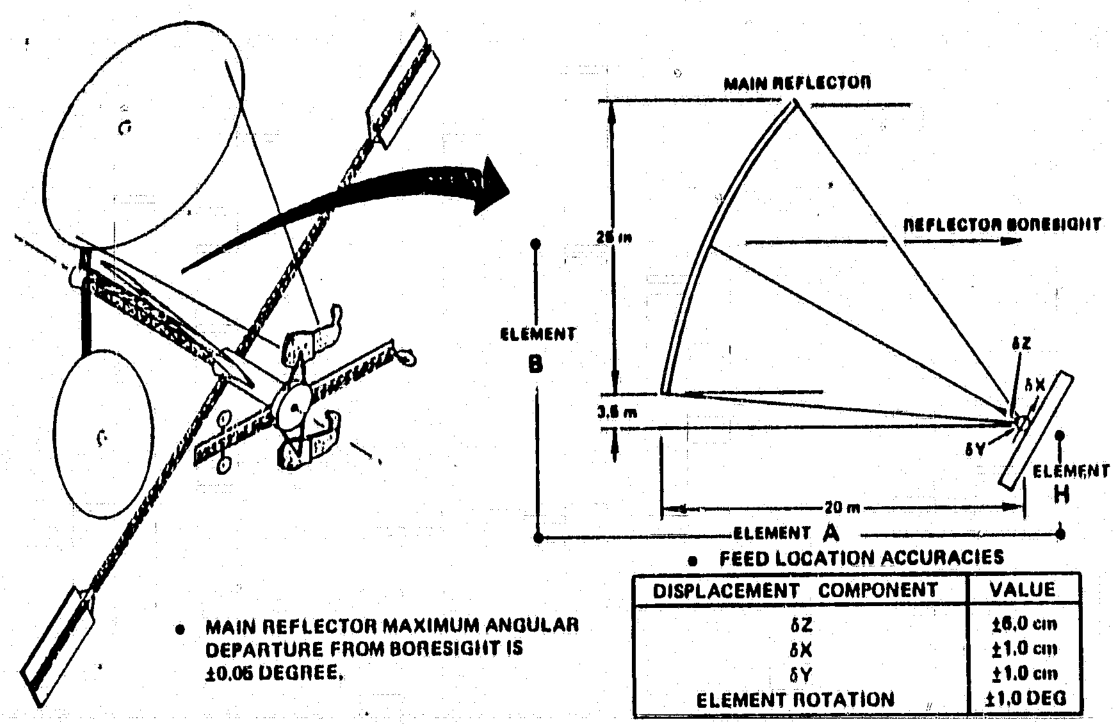
For the expandable truss beam, scaling data for the GDC On-Orbit Assembly (OOA) type of expanding truss was used, based on the relationships given in Appendix B.

From a strength standpoint, it has been determined that the effect of the utility distribution system on the structural mass of the platforms considered is minimal. The weight penalties associated with even the most critical structural supports (i.e., cantilevered subsystem supports) are on the order of 2 to 4% increase in structural mass for each element. It is important to note that this penalty is an upper limit since other performance requirements (e.g., stiffness, packaging, etc.) will no doubt control many aspects of structure size such that stress will not be critical.

3.1.2 RESIZING FOR STIFFNESS. The stiffness requirements are generally dependent on operational geometric tolerances and on-orbit ACS loading. For the platforms of Alternative #1, accelerations produced by ACS firing are approximately 0.01 g in each of the three principal axes. A dynamic factor of 2.0 is applied to these accelerations. Payloads #2.1 (Platform No. 1) and #2.2 (Platform No. 6), both from Alternative #1, were selected and the stiffness requirements determined. These payloads are representative, and results can be generalized to other payloads of Alternative #1.

Figure 3-1 illustrates the transmitter system of Platform No. 1, Payload #2.1, along with the relative feed-reflector location accuracies that must be maintained during normal on-orbit operation. The structural elements that connect the feed and reflector are designated by letters, and are keyed to Table 3-2 which summarizes the strength requirement (orbit transfer) and stiffness requirement (ACS firing) for these elements. In this particular case, two of the three elements must be significantly increased in size to satisfy stiffness requirements.

A similar analysis was performed for Payload #1.2 of Platform No. 6. The feed-reflector location accuracies are shown in Figure 3-2 and the results of the stiffness analysis are summarized in Table 3-3.



- MAIN REFLECTOR MAXIMUM ANGULAR DEPARTURE FROM BORESIGHT IS ±0.05 DEGREE.

- FEED LOCATION ACCURACIES

DISPLACEMENT COMPONENT	VALUE
δZ	±6.0 cm
δX	±1.0 cm
δY	±1.0 cm
ELEMENT ROTATION	±1.0 DEG

Figure 3-1. Platform No. 1, Payload 2.1 displacement tolerances.

Table 3-2. Platform No. 1, Payload 2.1 structural requirements.

ELEMENT NUMBER	REQUIREMENT	TYPE OF SECTION	EI (Nm^2)	JG (Nm^2)
H	STRENGTH (ORBIT TRANSFER)	10.2 cm DIAMETER TUBE, WALL THICKNESS = 0.203 cm, GRAPHITE-EPOXY	1.76×10^5	4.11×10^4
	STIFFNESS (ACS FIRING)	(ABOVE SECTION ADEQUATE)		
A	STRENGTH (ORBIT TRANSFER)	0.22 m DIAMETER ARTICULATED ASTROMAST, GRAPHITE-EPOXY	3.10×10^5	9.29×10^3
	STIFFNESS (ACS FIRING)	1.07 m DIAMETER ARTICULATED ASTROMAST, GRAPHITE-EPOXY	4.36×10^7	3.09×10^7
B	STRENGTH (ORBIT TRANSFER)	0.42 m DIAMETER SUPERMAST ASTROMAST, FIBERGLASS	2.80×10^6	0.24×10^4
	STIFFNESS (ACS FIRING)	0.82 m DIAMETER SUPERMAST ASTROMAST, FIBERGLASS	2.04×10^7	1.18×10^6

- FEED LOCATION ACCURACIES

DISPLACEMENT COMPONENT	VALUE
δZ	±0.2 cm
δX	±0.2 cm
δY	±0.2 cm
ELEMENT ROTATION	±1.0 DEG

- MAIN REFLECTOR MAXIMUM ANGULAR DEPARTURE FROM BORESIGHT IS ±0.05 DEGREE.

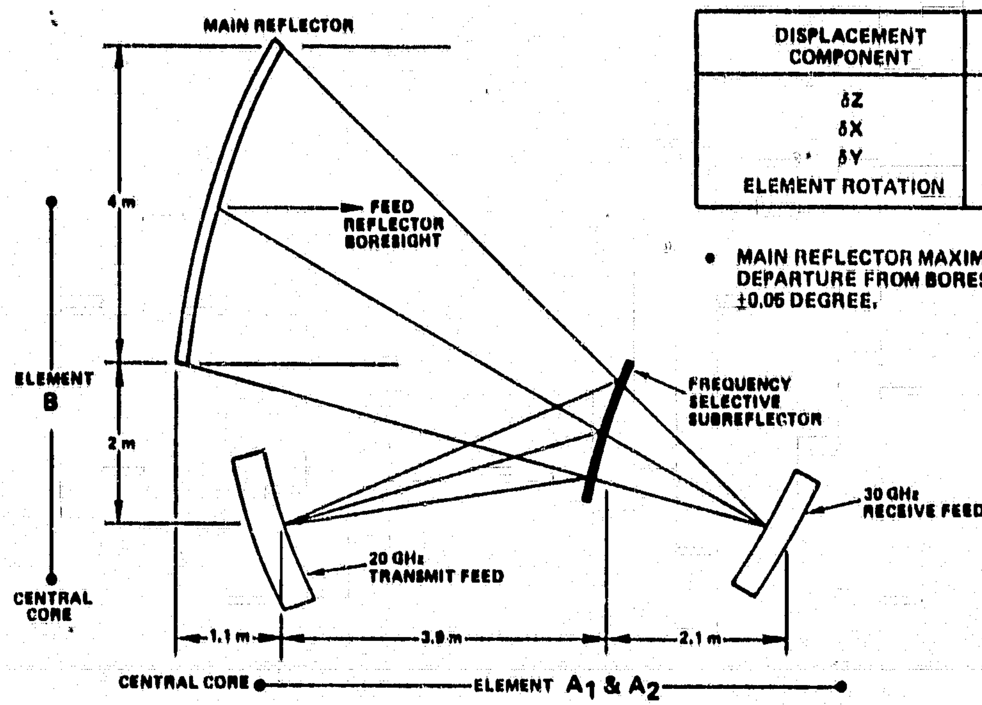


Figure 3-2. Platform No. 6, Payload 1.2 displacement tolerances.

Table 3-3. Platform No. 6, Payload 1.2 structural requirements.

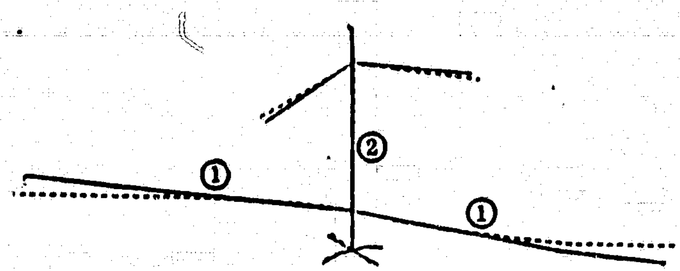
ELEMENT NUMBER	REQUIREMENT	TYPE OF SECTION	EI (N m²)	JG (N m²)
A_1 & A_2	STRENGTH (ORBIT TRANSFER)	3.86 cm DIAMETER TUBE, WALL THICKNESS = 0.109 cm, GRAPHITE-EPOXY	5.10×10^3	1.20×10^3
	STIFFNESS (ACS FIRING)	18.7 cm DIAMETER TUBE, WALL THICKNESS = 0.52 cm, GRAPHITE-EPOXY	2.75×10^6	5.09×10^4
B	STRENGTH (ORBIT TRANSFER)	2.47 cm DIAMETER TUBE, WALL THICKNESS = 0.169 cm, GRAPHITE-EPOXY	8.45×10^2	1.98×10^2
	STIFFNESS (ACS FIRING)	6.48 cm DIAMETER TUBE, WALL THICKNESS = 0.18 cm, GRAPHITE-EPOXY	4.00×10^4	7.59×10^3

The resizing of various structural elements to meet stiffness requirements will effect a weight penalty. The weight penalty associated with meeting these requirements for the Alternative #1 platforms is an average 8% increase in structural weight, or an average 2% increase in total platform weight for each of the platforms considered.

3.1.3 <u>DYNAMIC ANALYSIS.</u> A NASTRAN finite element model was constructed for Platform No. 1. The model had been resized to meet stiffness requirements, and comprised 32 grid points, 30 structural elements, and 192 structural degrees of freedom. An analysis was made to determine natural modes and corresponding natural vibrational frequencies. The fundamental natural frequency of the system was found to be 0.148 Hz, and the results are shown in Table 3-4. These results are typical of what would be expected of the other platforms of Alternative #1.

Table 3-4. Platform No. 1 dynamic analysis summary.

STRUCTURAL VIBRATION MODE 10
NATURAL FREQUENCY: 0.204 HZ



MODE	FREQUENCY	DESCRIPTION OF MODE SHAPES
1-6	—	RIGID BODY MODES
7	.148	① VERTICAL 1ST BENDING
8	.152	① HORIZONTAL 1ST BENDING
9	.172	① + ② COUPLED BENDING + TORSION
10	.204	① + ② COUPLED BENDING + 2ND TORSION
11	.235	① + ② COUPLED BENDING
12	.258	
↓	↓	
22	.875	

Steps must be taken to ensure that the low frequency vibrational modes do not interact with the ACS and cause instability. The General Dynamics modes control technique developed under the DARPA ACOSS program provides control solutions for this new class of Large Space Systems. Thus, low frequency vibrational modes of this nature will not cause difficulty for the control system design.

3.2 ALTERNATIVE #4

Of the four configurations considered in this study, the structure of Alternative #4 is the most divergent from Alternative #1, which was the first to be analyzed in detail. For this reason, Alternative #4 was selected as the next concept for detailed structural analysis.

3.2.1 SIZING FOR STRENGTH. For Alternative #4 platform module transfer to GEO, a 2-stage, standard engine, reusable OTV with T/W = 0.31 was initially considered for sizing structural elements of the three independent modules that comprise the platform. A dynamic factor of 2.0 was used. Preliminary results indicated that the platform modules could not be transferred by this OTV while fully deployed because of structural limitations. This OTV was, therefore, used with a low-thrust engine to provide a more appropriate T/W = 0.035 for estimating the size of structural elements of this platform. Representative structural sections of the Alternative #4 platform are shown in Figure 3-3. These are referenced in Table 3-5, a summary of the minimum structural sections required for strength at the various locations. Graphite-epoxy OOA type trusses are chosen where applicable because of their excellent thermal characteristics.

The effect of the utility distribution system on the structural mass of the platform due to strength considerations is minimal. The magnitude of the effect is on the order of 2 to 4% additional structural mass for each element. This result is essentially identical to that determined for the Alternative #1 platforms.

3.2.2 RESIZING FOR STIFFNESS. Stiffness requirements were determined for the on-orbit ACS loading condition. For Alternative #4, accelerations produced by ACS firing are approximately 0.0003 g in each of the three principal axes. A dynamic factor of 2.0 is applied to these accelerations.

The largest antennas (Payloads #1.1 and #2.1) are representative and were selected for the stiffness analysis since their influence is more likely to have a pronounced effect on the total platform structure than some of the smaller payloads. The dimensions of the three antenna systems along with the respective operational feed-reflector displacement tolerances are given in Figure 3-4. The locations of these antennas and the corresponding supporting structure are shown in Figure 3-3. The strength requirements (orbit transfer) and stiffness requirements (ACS firing) for the supporting structure are summarized in Table 3-6. In most instances, design is governed by orbit transfer strength requirements.

The weight penalty associated with satisfying stiffness requirements over and above strength requirements is 22.0% of structural weight, or 2.7% of total platform weight.

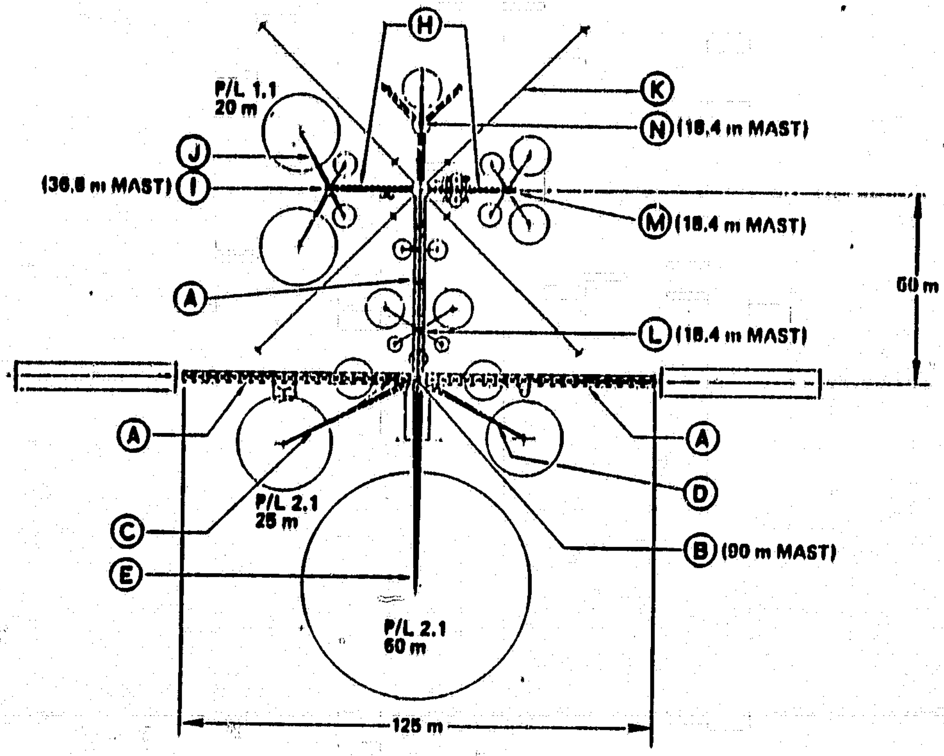
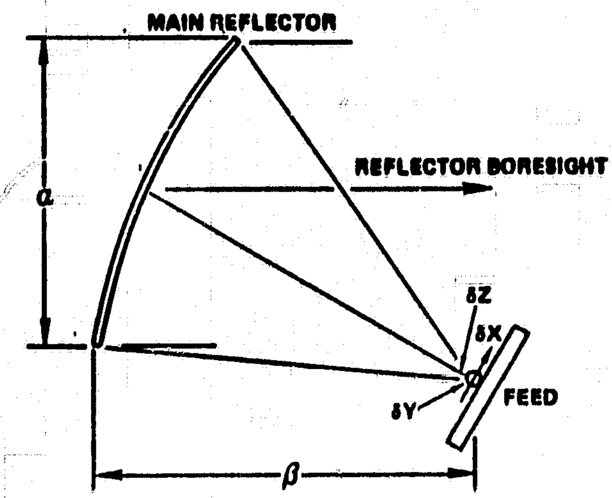


Figure 3-3. Alternative #4 structural elements and payloads.

Table 3-5. Alternative #4 strength requirements.

STRUCTURAL ELEMENT	BENDING MOMENT M (Nm)	SIMILAR TO	DEPTH (m)	STIFFNESS CHARACTERISTICS Elxx (N m^2)	Elyy (N m^2)	JG (N m^2)	MARGIN OF SAFETY
A	40,139	OOA TYPE TRUSS (G.E.)*	5.0[illegible]	7.36 X 10^8	3.67 X 10^8	2.36 X 10^7	0.43
B & E	24,012	OOA TYPE TRUSS (G.E.)*	2.29	5.83 X 10^7	2.91 X 10^7	2.47 X 10^6	0.43
C & D	3,218	OOA TYPE TRUSS (G.E.)*	0.93	3.10 X 10^6	1.56 X 10^6	1.68 X 10^5	0.43
H	101,427	OOA TYPE TRUSS (G.E.)*	2.96	3.10 X 10^8	1.56 X 10^8	8.81 X 10^6	0.43
I	963	OOA TYPE TRUSS (G.E.)*	0.62	6.31 X 10^5	3.16 X 10^5	5.02 X 10^4	0.43
J	1,746	OOA TYPE TRUSS (G.E.)*	0.76	1.36 X 10^6	6.83 X 10^5	9.15 X 10^4	0.43
K	1,704	SUPERMAST ASTROMAST**	0.33 DIA	1.23 X 10^6	1.23 X 10^6	3.62 X 10^4	0.47

*(G.E): GY70/X30 GRAPHITE-EPOXY $(0_2/\pm 24)_s$
** EXISTING FIBERGLASS. NEED G.E. EQUIVALENT CTE.



P/L NO.	DIMENSIONS		FEED LOCATION ACCURACIES			
	α*	β*	δX*	δY*	δZ*	ELEMENT ROTATION
2.1, 60 m	60	90	0.203	0.203	0.203	0.1 DEGREE
2.1, 25 m	25	20	0.010	0.010	0.060	0.05 DEGREE
1.1, 20 m	20	36.8	0.076	0.076	0.076	0.1 DEGREE

*METERS

Figure 3-4. Alternative #4 representative payload geometry tolerances.

Table 3-6. Alternative #4 structural requirements.

ELEMENT NUMBER	REQUIREMENT	DEPTH OF SECTION*	EI_{xx} (Nm^2)	JG (Nm^2)
Ⓑ & Ⓔ	STRENGTH	2.29 m	5.83×10^7	2.47×10^6
	STIFFNESS	3.31 m	2.55×10^8	1.08×10^7
Ⓒ	STRENGTH	0.93 m	3.10×10^6	1.68×10^5
	STIFFNESS	(ABOVE SECTION ADEQUATE)		
Ⓐ	STRENGTH	5.00 m	7.35×10^8	2.36×10^7
	STIFFNESS	(ABOVE SECTION ADEQUATE)		
Ⓘ	STRENGTH	0.62 m	6.31×10^5	5.02×10^4
	STIFFNESS	0.91 m	2.90×10^6	2.31×10^5
Ⓙ	STRENGTH	0.76 m	1.36×10^6	9.15×10^4
	STIFFNESS	(ABOVE SECTION ADEQUATE)		

*ALL SECTIONS ARE GRAPHITE EPOXY OOA TYPE TRUSSES.

3.2.3 DYNAMIC ANALYSIS. A NASTRAN finite element model was generated for the Alternative #4 platform based on the individual module orbit transfer strength requirements. The model was comprised of 65 grid points, 64 structural elements, and 390 structural degrees of freedom. Natural modes and corresponding natural frequencies were determined for the system; the results are given in Figure 3-5. The fundamental natural frequency of the system based on strength requirements is 0.019 Hz. A similar analysis of the Alternative #4 platform resized to comply with stiffness requirements would yield significantly higher natural frequencies. Again, caution must be exercised to ensure that the lower frequency vibrational modes do not interact with the ACS and cause instability. As noted previously, ACOSS control techniques can obviate this possibility.

MODE	FREQUENCY (Hz)	DESCRIPTION OF MODE SHAPES
1-6	—	RIGID BODY MODES
7	0.019	(2) MAST TORSION
8	0.023	(4) ARM TORSION
9	0.030	(8) MAST TORSION
10	0.043	(9) & (10) MASTS, COUPLED TORSION
11	0.044	(1) BEAM TORSION
12	0.046	
↓	↓	
23	0.098	

STRUCTURAL VIBRATION MODE 7
NATURAL FREQUENCY = 0.019 Hz

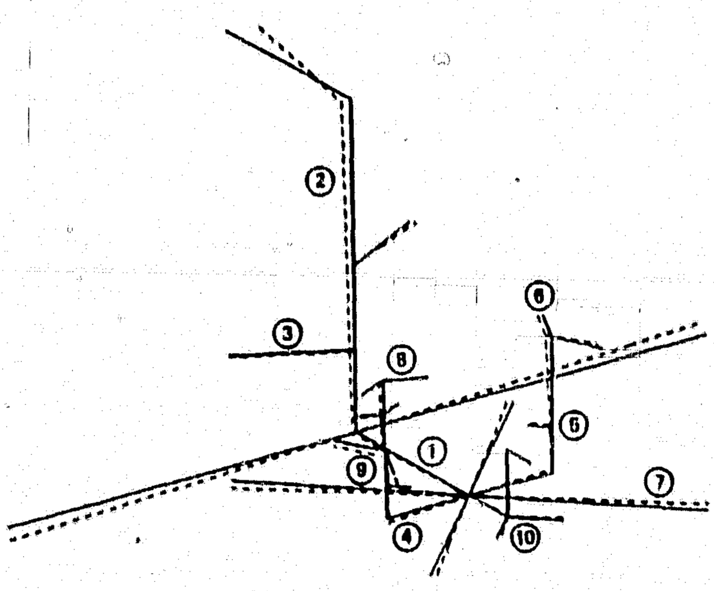


Figure 3-5. Alternative #4 dynamic analysis.

3.3 ALTERNATIVES #2 AND #3

From a structural analysis point of view, Alternatives #2 and #3 are essentially intermediate with respect to Alternatives #1 and #4; i.e., they share important structural characteristics of each.

Alternative #2 is similar in most aspects to Alternative #1. Each consists of a number of 15,000 lb modules, with each module mated to a single-stage expendable OTV and launched in a single Shuttle flight. The principal difference between the two concepts is the buildup option at geosynchronous orbit. The Alternative #2 platform is composed of docked, dependent modules while Alternative #1 consists of a constellation of independent platforms.

The identical maximum packaged sizes and weights of the Alternative #2 and #1 modules imply similar Orbiter cargo-bay cradle designs (ASE) to react Shuttle launch and landing loads. Loads induced by LEO to GEO orbit transfer will be essentially equivalent since the same OTV is used for transfer in either case. Deployment loads, along with docking and/or servicing loads, are not a major consideration in either case since these will be limited by appropriate deployment rates and docking velocities, respectively, such that resulting loads do not exceed other operational loads.

It would be reasonable to expect significant differences in ACS loading and related on-orbit stiffness requirements between Alternatives #2 and #1 because of the difference in buildup option, i.e., docked modules versus independent modules, respectively. The natural vibrational frequencies of a large docked platform would also generally differ from those of smaller, independent platforms. These aspects of Alternative #2 may not be comparable to those of Alternative #1. The buildup option of Alternative #4, however, is the same as that of Alternative #2 and ultimately yields a single large platform. The stiffness requirements and dynamic response of Alternative #2 would be expected to be similar to that of Alternative #4.

The utility distribution systems of Alternatives #2 and #4 are also similar, since each system is initiated by an autonomous module and then is built up with the addition of each successive module until completion. Any influence that the utility distribution system may have on the strength requirements of the Alternative #2 platform would be expected to be similar to that of Alternative #4.

The characteristic structural aspects of Alternative #2, therefore, are common to those of the Alternative #1 and #4 concepts. It is reasonable and appropriate to recognize that the general results and conclusions of corresponding, respective analyses of Alternatives #1 and #4 would not be changed significantly by the additional analysis of Alternative #2. Therefore, the analysis of Alternative #2 is not considered necessary at this time.

Likewise, the Alternative #3 concept shares similar structural characteristics with Alternatives #1 and #4. Alternatives #3 and #4 each consist of a number of 37,000 lb modules launches individually in single Shuttle flights and mated individually in LEO with a two-stage reusable low-thrust OTV brought up in two successive Shuttle flights. The buildup modes of Alternatives #3 and #1 are the same: each yields a constellation of independent platforms.

The analysis of Alternative #3 is not considered necessary because of its similarity to Alternatives #4 and #1. If the analysis were performed for #3, however, it would be expected that the ASE requirements and orbital transfer requirements would be similar to those of Alternative #4, and the stiffness requirements, dynamic response, and utility distribution system influence on strength to be similar to those of Alternative #1.

3.4 SUMMARY

Alternatives #1 and #4 were analyzed in detail with respect to strength requirements, stiffness requirements, and dynamic response. It was determined that Alternatives #2 and #3 are intermediate in nature with respect to structural characteristics, and that the additional analyses of #2 and #3 would only provide similar results. The analyses of Alternatives #2 and #3, therefore, are not considered necessary at this time.

The strength requirements were found to be dependent on LEO to GEO orbital transfer, which is the most severe loading condition encountered. For Alternative #1, the transfer vehicle is an expendable OTV with T/W = 0.07. Orbital transfer is feasible for the fully deployed configurations of the Alternative #1 platforms considered. The two-stage reusable OTV with T/W = 0.31 was initially considered for Alternative #4 orbit transfer. Platform modules could not be transferred fully deployed by this OTV, and a more appropriate T/W = 0.035 was used in the analysis.

The utility distribution systems were found to have only a slight influence on the strength requirements of structural members. The effect represents an increase in structural weight on the order of 2 to 4% for each structural element of Alternatives #1 and #4. Design considerations other than strength are likely to govern the designs of most members, and since this is a conceptual design analysis, the 2 to 4% effect is considered negligible.

The stiffness requirements are dependent on the specific operational geometric tolerances that payloads and payload components must satisfy under any loading condition. The critical on-orbit loading condition is ACS firing for the purposes of pointing and stationkeeping. Accelerations produced by ACS firing are approximately 0.01 g and 0.0003 g along each of the three principal axes for Alternatives #1 and #4, respectively. Nearly all structural elements of the Alternative #1 platforms required significant size increases (above strength requirements) to satisfy stiffness requirements. This produced an 8% increase in structural weight, or a 2% increase in total platform weight for Alternative #1. Approximately half of the Alternative #4 members required resizing to satisfy stiffness requirements. The resulting increase in weight for the Alternative #4 platform is approximately 22% in structural weight, or 3% in total platform weight.

NASTRAN finite element analyses were performed to determine natural modes and corresponding natural vibrational frequencies for Platform No. 1 of Alternative #1, and for Platform Alternative #4. The fundamental natural frequency of the Alternative #1 platform resized for stiffness requirements was found to be 0.148 Hz. The fundamental natural frequency of the Alternative #4 platform sized for strength requirements was 0.019 Hz. For each case, steps must be taken to assure that low frequency modes do not interact with the ACS and cause instability. Presently available modes-control techniques provide control solutions for Large Space Systems such as those investigated in this study.

4

LSST TECHNOLOGY NEEDS

To place Operational Geostationary Platforms in orbit in the 1990s, an advancement in some structures-related platform technologies will be required. In some instances these technologies are already in partial development. Others have surfaced as a result of the conceptual analysis effort in this study. To minimize program funding and schedule risks in this and similar future related missions, and to ensure proper operational program evolution, the more advanced technologies must be identified and defined, and plans developed to verify their operational validity. The purpose of this study is to assist the Large Space Systems Technology management in satisfying these program objectives.

4.1 TASK OBJECTIVE

The objective of this task is to identify structures-related technologies needed to enable successful development of Operational Geostationary Platforms of the 1990s. Accomplishment of this objective requires:

a. Analysis of the design concepts, drawings, tabular data, requirements, and analytical data resulting from the previous tasks, to identify NASA LSST structural technology requirements.

b. Comparison of the technology requirements to existing or currently planned technology developments.

c. Identification of deficiencies or voids.

d. Formulation of a technology recovery plan.

4.2 SCOPE

As noted in the introductory discussion of Task 11 in this report, the four Operational Platform concepts selected by NASA and designated Alternatives #1 through #4 were analyzed in different degrees. Alternative #1 was analyzed in detail, #4 was analyzed for differences from #1, and #2 and #3 were investigated as mid-range derivatives of the other two.

Technology requirements and needs in this analysis are limited to those related to structure only. In most instances the technology needs are common to all concepts. Only the larger, docked platforms have additional technology needs in the areas of assembly and OTV mating in low earth orbit, and platform-to-platform docking in geosynchronous orbit.

4.3 METHODOLOGY

Four areas were looked at in determining the structural technology needs for development of Operational Geostationary Platforms.

a. Utilities Accommodation

b. Interfaces

c. Strength & Stiffness

d. Materials & Structural Components

In each of these areas, Alternative #1 was further defined to provide structural detail in the areas of utilities accommodation and interfaces, particularly with respect to utilities requirements and routings over structural elements and joints. Strength, stiffness, materials, and structural component requirements were also determined to meet payload pointing accuracy requirements. The drawings, sketches, and data resulting from the detailed definitions were then analyzed to identify feasible design configurations to accommodate the utilities and to identify structural technology requirements. Alternative #4 was scrutinized to determine any additional unique technical requirements, and the process repeated for Alternatives #2 and #3.

After all technical requirements were identified, they were listed and the status of each determined with respect to technology voids, existing state-of-the-art, and existing or planned technology development. From this comparison, the recommended technology development requirements were extracted to assist LSST program management in formulating a technology development plan.

4.4 TECHNOLOGY REQUIREMENTS

4.4.1 UTILITIES ACCOMMODATION. Regardless of the size or complexity of the platform configurations considered in this study, interconnection of platform subsystems and mission equipment is a commonality basic to all, as shown in Figure 4-1. Additional interconnection is required between many of the subsystems themselves, such as the power management subsystem, power generation (solar arrays), power storage (batteries), and distribution subsystems. To satisfy these routing and interconnection requirements, the platform structure must support fluid lines, signal and data cables, and power busses across both rigid and deployable structural elements.

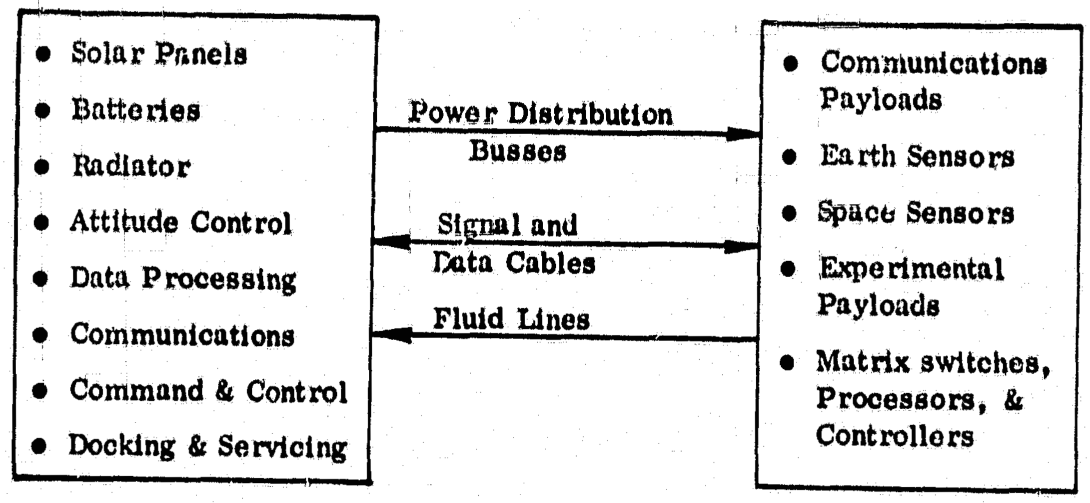


Figure 4-1. Utilities accommodation requirements.

There are no technology requirements for routing utility lines across rigid structural elements; this is an existing satellite state-of-the-art.

There is a technology requirement, however, in routing utility lines across deployable structural members, and across deployment joints. To package the platform within the Shuttle cargo bay, many platform structural elements must be telescopic, expandable, or foldable with rotating and/or geniculate joints. To be compatible with the structural elements, the utilities lines must themselves be capable of extension, contraction, or bending, with storage accommodation in the packaged condition.

Mechanisms and techniques for accomplishing the above is an area of technology requirement which has not as yet been developed adequately for space application. The technology involves mechanisms for extending fluid lines and electrical umbilicals along extensible booms and beams; storage mechanisms such as reels, scissors, and cylinders; integrated and optimized utility line cross-sections for bending and storage; techniques for flaking, lagging, guiding, coiling, and reeling; and reliable transition across rotating joints. In most cases, the technology requirement encompasses both structural and subsystem design considerations. The methodology or technology development must, therefore, be a coordinated effort to obtain standardized, acceptable solutions.

4.4.2 INTERFACE REQUIREMENTS. In analyzing the interface requirements involved in the Operational Geostationary Platform configurations selected by NASA, only those interfaces unique to the platform program were addressed. Internal subsystem/mission equipment interfaces were not considered since they are state-of-the-art as presently utilized in existing communications satellites.

Interfaces which are unique to the platform program are directly related to program-unique operations:

a. Assembly of platform module segments (payload components and platform structure) in low earth orbit.

b. Mating of the orbit transfer vehicle stages to the platform, in low earth orbit.

c. Docking of platform modules in geosynchronous orbit.

d. Docking of a Service System (TMS) with a platform in geosynchronous orbit.

4.4.2.1 Assembly of Platform Module Segments in Low Earth Orbit. Fully deployable cargo-bay size platform modules designed to carry predominantly communications payloads, generally exhibit packaging densities far below the available optimum of 1,083.3 lb per linear ft. of cargo bay. To more efficiently utilize the available weight capability of the Orbiter, full cargo-bay size platform modules must, therefore, be designed to accommodate some separately packaged platform module segments and payload components, carried in space available volumes in the cargo bay. This approach, as used in Alternatives #3 and #4, requires assembly of the separately packaged segments in low earth orbit while the platform module is still attached to the Orbiter. Concept Alternatives #1 and #2, the smaller, fully deployable configurations with attached OTVs, do not require such assembly.

Assembly of platform module segments in low earth orbit requires the use of the Orbiter Remote Manipulator Systems (RMS) and astronaut extravehicular activity (EVA), with or without the Manned Maneuvering Unit (MMU) depending on the complexity and location of the assembly interface. Astronaut EVA capability includes installation and removal of protective covers and tie-downs; operation of tools and equipment; connection of mechanical, fluid, and electrical interfaces and umbilicals; deployment, retraction and positioning of antennas, booms, and solar arrays; override of mechanisms; and cargo transfer.

Structural interface requirements to accomplish the assembly tasks include the following:

a. Structural interfaces designed for EVA assembly with simplicity of task and minimum time requirement as design goals.

b. Incorporation of standard grapple fixtures on segments to accommodate Orbiter RMS standard end effectors.

c. Incorporation of standard STS handrails and handholds on segments as required for EVA use.

The above requirements are within existing state-of-the-art design and do not impose technology development needs on the program.

4.4.2.2 OTV/Platform Mating in Low Earth Orbit. Platform module-to-OTV mating in low earth orbit may or may not prove to be platform-program unique. Platform structural interfaces are required, however, for platform concept Alternatives #3 and #4, to assemble each platform module and its transfer stages in low earth orbit before transfer of the module to geosynchronous orbit as shown in Figure 4-2.

Preliminary operational analysis indicates an advantage in delivering the platform module to low earth orbit in the first Orbiter flight, deploying it, and mating it with the first transfer stage arriving in the second Orbiter flight.

Structural interface requirements to accomplish the mating task include:

a. Airborne Support Equipment cradle attach points on the platform module to accommodate cradle support and rotation for platform deployment, checkout, and separation.

b. Incorporation of a standard OTV mating interface ring on the platform module capable of interfacing with the OTV structure and systems, and capable of sustaining the OTV thrust load.

c. Incorporation of standard grapple fixtures on the platform module to accommodate RMS end effectors.

These requirements are within existing state-of-the-art design and do not impose technology development needs on the program.

4.4.2.3 Docking of Platform Module-to-Platform Module in Geosynchronous Orbit. Orbiter and OTV performance capabilities as now projected for the next two decades place operational and design constraints on large space structures. To establish a single large platform of the 100,000 to 200,000 lb class in geosynchronous orbit, piecemeal delivery of modules to the desired geosynchronous location is required, with subsequent module-to-module docking and synthesis of the platform systems. "Docking" as used here indicates complete structural and system interconnection, as planned for Alternatives #2 and #4.

In-depth analysis of rendezvous and docking techniques and hardware has been the subject of Air Force and IRAD studies at General Dynamics for the past three years. For large flexible space structures such as the geostationary platform, a single-point soft-docking concept has been identified and defined as optimum from a standpoint of minimum operational risk, structural loading, and technology development. A variation of this concept is the initial single-point soft-docking, followed by platform module rotation and latching where the configuration involves two or three structural mast or "arm" interface connections.

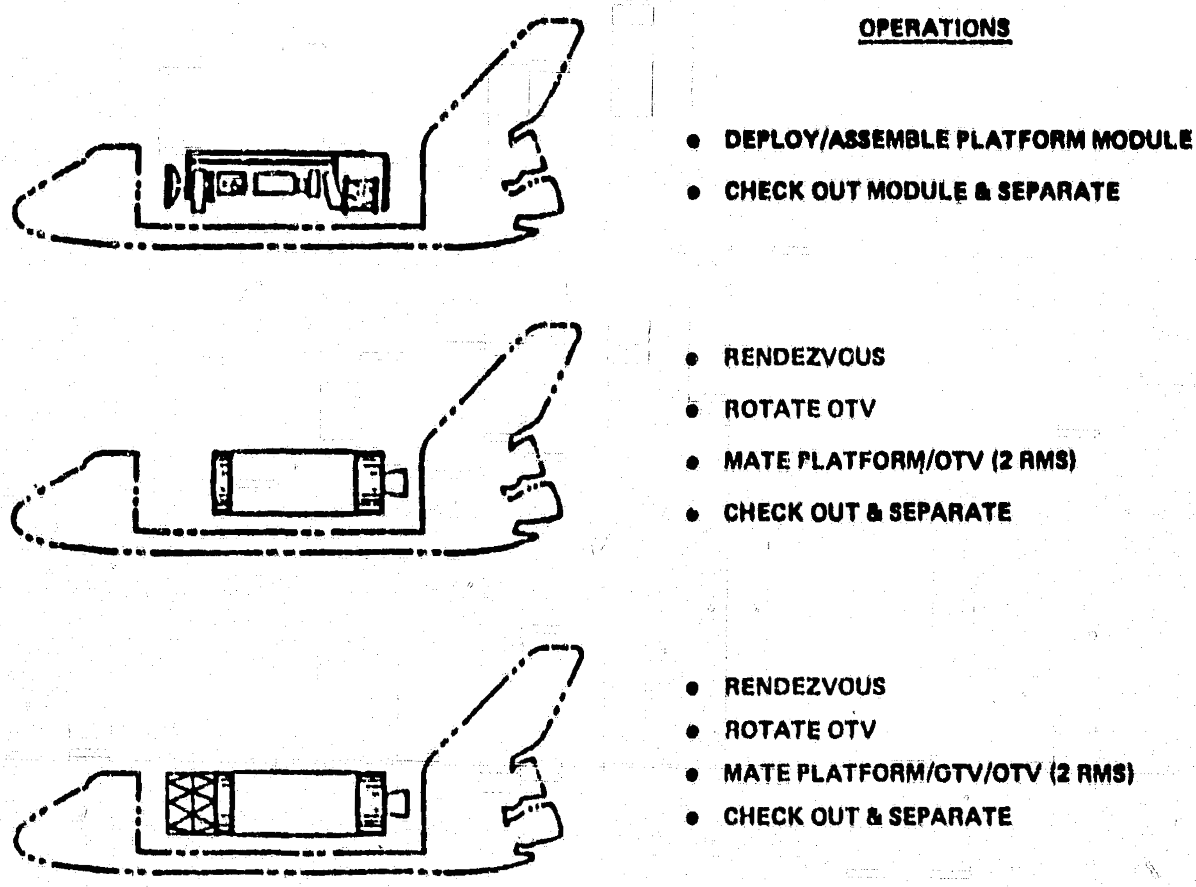


Figure 4-2. OTV/platform module mating in low earth orbit.

The single-point soft-docking concept is shown in Figure 4-3, applied to docking of Platform Modules #1 and #2 of Alternative #4. Details of the probe mechanisms are shown in Figure 4-4.

The active docking mechanism on the approaching or active module incorporates an extendable probe 5 ft. in length that can be steered within a 60 degree cone angle. At a distance of 5 ft. or less between modules (final approach position), the probe is extended and steered until contact is made with the passive module docking port and locked in. Draw-in of the two modules follows, until full contact of the conical surfaces is made and they are latched together. The method minimizes the absorption energy involved, obviating the need for a complex load-damping system. After draw-in, module rotation about the active module roll axis takes place until the yaw axes are aligned, permitting engagement and lock-in of the perimeter latches, as shown in Figure 4-3.

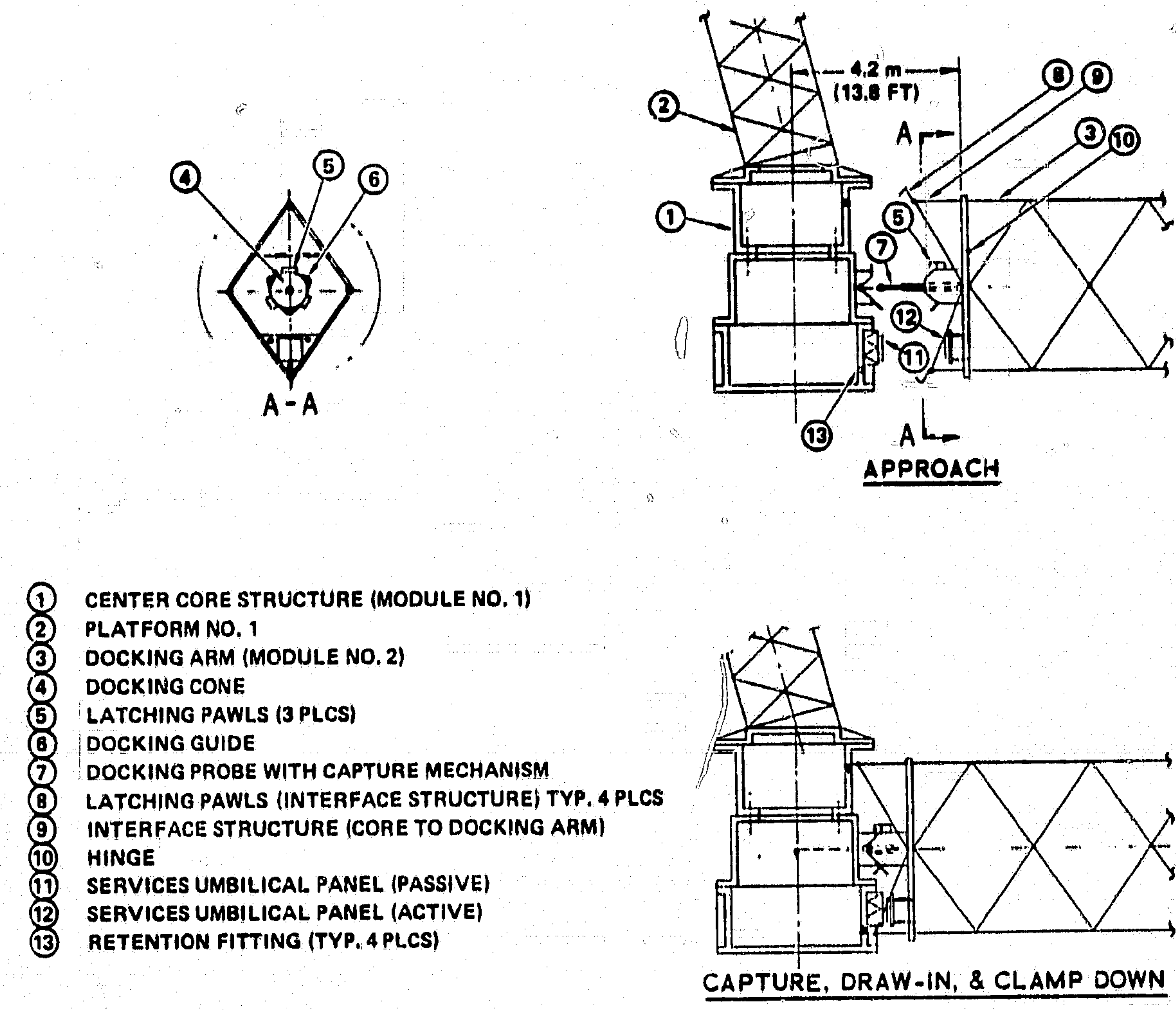


Figure 4-3. Single-point soft-docking concept.

The platform module-to-platform module docking interface requirement leads to two technology development needs for the geostationary platform program:

a. *Soft-docking, hard-latching mechanisms for large flexible space structures.*

b. *Integrated docking/umbilical panel units, soft-docking mechanisms integrated with powered umbilical panels carrying combined electrical, fluid, and fiber optic connectors, which are engaged only after structural alignment and lock-in is complete.*

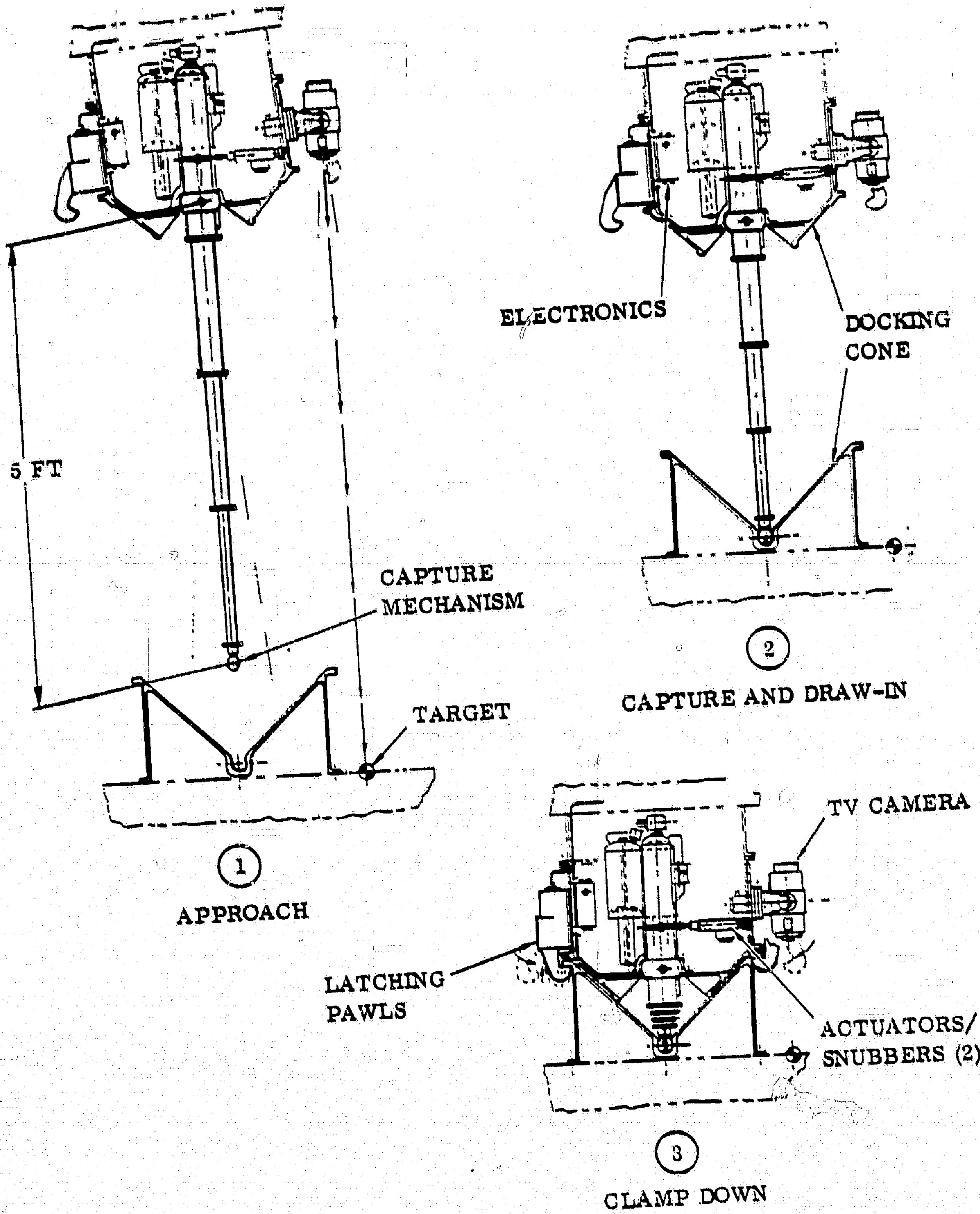


Figure 4-4. Soft-docking mechanism.

4.4.2.4 Servicing in Geosynchronous Orbit. Servicing of Operational Geostationary Platforms is a concept which extends the useful life of the platforms and can be used to upgrade system hardware and communications services if desired. It includes resupply of fluids such as hydrazine by fluid transfer or tank replacement, replacement of expendables such as batteries, and replacement of degraded or failed components such as black boxes. It can also mean replacement of technologically obsolete components with more advanced hardware.

A basic structural concept of the Operational Geostationary Platforms is the central core or hub containing the major components of the support subsystems, support interfaces for the structural arms, masts and booms, and the transfer vehicle interface (thrust ring). A major advantage of the concept is its adaptability to design for on-orbit servicing. Specifically:

a. The OTV interface on the platform is common to all platform modules.

b. Support system expendables and replaceable components are concentrated primarily in the platform module core, immediately adjacent to the interface.

c. The interface is available for servicing operations after the OTV is jettisoned in GEO.

These considerations are exploited in designing for on-orbit servicing. The platform/OTV interface becomes the platform/Servicing System interface, and the following design guidelines are established:

a. Platform expendables and replaceable components are positioned in or near the core, with ready access from the servicing system, assumed to be the Teleoperator Maneuvering System (TMS).

b. Expendables and replaceable components in all platform modules are to have commonality of configuration and location.

c. Soft-docking and hard-latching capability is to be provided at the interface for TMS docking.

d. The docking interface is to include powered fluid/electrical umbilical panels.

e. Replaceable "black box" component design is to be coordinated with the NASA Satellite Services Working Group (MTG-3), for compatibility with a dedicated Servicing System such as the TMS or a dedicated derivative.

The above interface requirements for On-Orbit Servicing indicate a technology need identical to that for the platform module-to-module docking operation identified in the previous discussion. The structural interface and detailed requirements will be somewhat different for the two operations, but the technology remains the same.

Figure 4-5 illustrates a feasible concept of the Service Docking Interface.

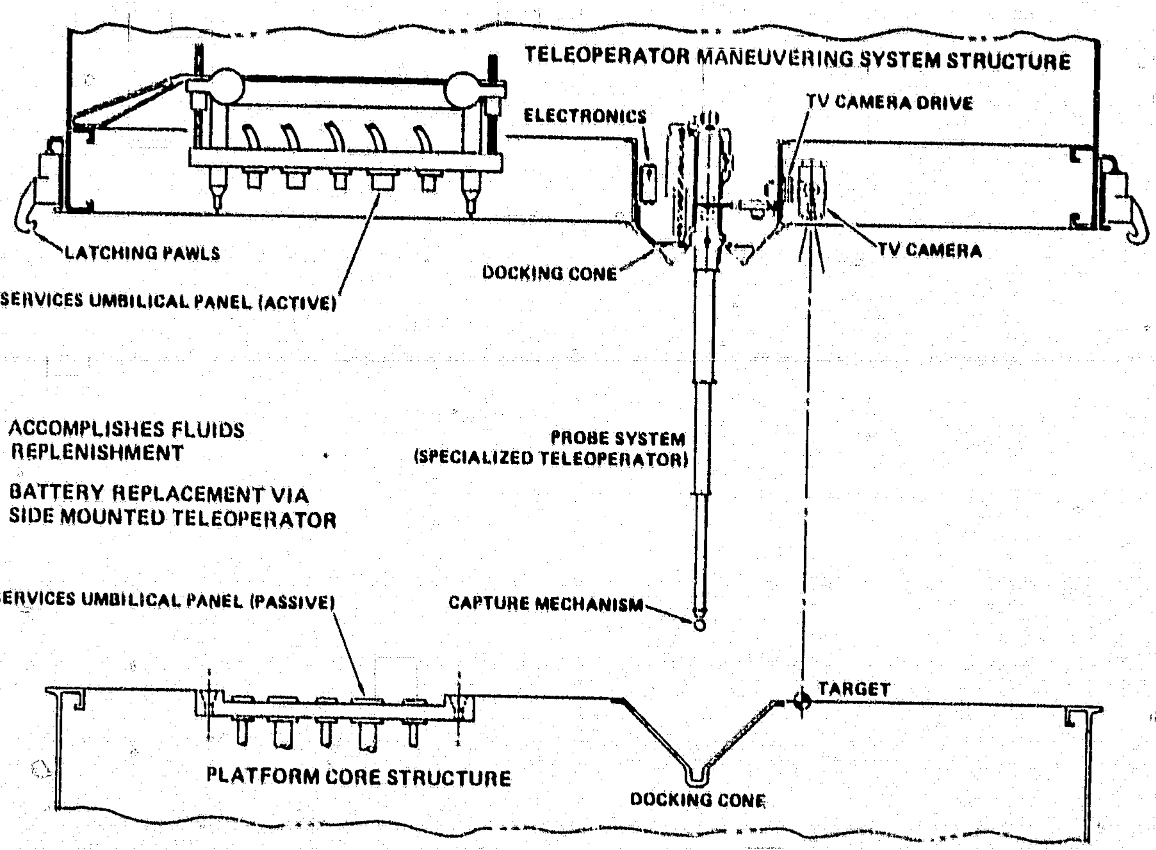


Figure 4-5. On-Orbit Servicing Interface concept.

4.4.3 STRENGTH AND STIFFNESS. In platform design for communications payloads at geosynchronous altitude, stiffness of the structure separating the feed assemblies from the antenna dishes is a critical design requirement to maintain proper beam geometry. Deflection or distortion of the structure is caused by thermal environment and by induced loads resulting from the attitude control system.

To eliminate thermal distortion, graphite-epoxy composite materials are used with the fiber orientation of the layup designed to give a zero coefficient of thermal expansion (CTE). In actual fabrication, the zero CTE is never attained, but the slight positive or negative value of the product is well within the allowable deflection tolerances specified by the beam geometry.

Strength and stiffness required to react loads of all kinds is a matter of design, in most cases, and does not involve technology development of any kind.

For deployable structures, however, special applications are encountered which require technology development. Some of the structural platform elements are carried to low earth orbit in a volume-constrained folded or packaged configuration. Typical of such a configuration is the Astromast built by Astro-Research Corporation of Santa Barbara, California. The packaging density of this mast is excellent, but it is fabricated only in relatively small sizes, and of fiberglass. *There is a high-priority need for a high package density deployable mast fabricated in larger sizes, with the low thermal distortion characteristic of graphite-epoxy composites.* To date, attempts to build such a mast have met with little success.

4.4.4 MATERIALS AND STRUCTURAL COMPONENTS. Closely related to the technology requirements noted in the preceding sections are three areas of technology development which have surfaced during this study:

a. Space-qualified composite structural elements for extended life.

b. Composite end fittings for composite structural elements.

c. Space-qualified deployment mechanisms.

4.4.4.1 Space-Qualified Composite Structural Elements. Structural materials for the geostationary platforms must be insensitive to temperature effects (low CTE), and have a high specific stiffness (high modulus/density ratio). Thermally stable, graphite-reinforced organic matrix composites have proven to be the most likely candidates for this application. For extended 16-year life, however, additional research should be undertaken to optimize the materials and fabrication techniques:

a. Selection of an optimum epoxy matrix consistent with the temperature duty cycle of the platform.

b. Selection of materials, plies, angles, temperature, and cure cycles to minimize microcracking and aging.

c. Minimize outgassing.

d. Evaluate moisture effects and solutions.

e. Minimize radiation effects.

f. Optimize adhesive properties.

4.4.4.2 Composite End Fittings. Existing graphite-epoxy composite fabrication techniques employ aluminum or titanium end fittings to join the composite tubular structural elements, complicating the design to attain zero CTE for the structure.

There is a technology requirement to develop layup type, compression molded composite end fittings to replace the metal end fittings.

4.4.4.3 Space-Qualified Deployment Mechanisms. Deployment mechanisms for extending expandable or telescoping booms and masts employ linkages, levers, latches, motors, gears, bearings, etc., which are state-of-the-art. Reliability of such mechanisms in a space environment is uncertain unless research is undertaken to space-qualify the systems with respect to operating temperatures, thermal cycling, vacuum effects, lubricants, outgassing, friction, wear, etc.

4.5 STRUCTURAL TECHNOLOGY NEEDS

Shown in Figure 4-6 are the major structural technology areas identified as requiring development for the Operational Platforms of the 1990s, and their recommended status.

4.5.1 UMBILICAL STOWAGE AND DEPLOYMENT MECHANISMS. There is no known activity at the present time for development of umbilical stowage and deployment mechanisms for application on large space structures. The development must be a coordinated effort involving both the umbilical design to meet typical utility requirements, and the deployment mechanism design to meet the deployment requirements. A single development agency or contractor is indicated.

4.5.2 SOFT-DOCKING, HARD-LATCHING MECHANISMS. General Dynamics Convair has expended appreciable effort in studying the mechanics, operational requirements, design and hardware associated with docking of large structures in space. The concept described in the preceding section of this report is a feasible solution to the re-requirement. Development should continue, however, for design, fabrication, and testing of a selected concept or concepts. Coordination should be emphasized between the concept developer and the NASA offices responsible for the OTV, TMS, and the Office of Satellite Services.

Structural Technology Need	Coordinate Development With	Existing Effort	Augment	Begin New Studies
Umbilical Stowage & Deployment Mechanisms	Umbilical Technology			✓
Soft-Docking, Hard-Latching Mechanisms	OTV TMS	✓	✓	
Integrated Docking/ Umbilical Panels	OTV TMS			✓
Deployable, High Packaging Density, Low CTE Masts		✓	✓	
Space Qualified, Long-Life Composite Materials		✓	✓	
Composite Structural Element End Fittings				✓
Space Qualified Deployment Mechanisms				✓

Figure 4-6. Technology development needs for the Geostationary Platform program.

4.5.3 INTEGRATED DOCKING/UMBILICAL PANELS. Parallel with the development of soft-docking concepts, umbilical panels need to be developed as an integral part of the docking hardware to provide post-docking system functions. Such umbilicals will be required to interconnect platform module systems in the platform docked configurations and to interconnect the TMS or equivalent servicing system with all platforms in both the docked and constellation configurations.

4.5.4 DEPLOYABLE, HIGH PACKAGED DENSITY, LOW CTE MAST. Until recently, Astro-Research Corporation has had little success in developing such a mast. The need is great. A breakthrough is required either in Astromast technology, or development of a new concept such as the expandable truss. Without such development, efficient design of deployable platform structures will be hampered.

4.5.5 SPACE-QUALIFIED, EXTENDED LIFE COMPOSITE STRUCTURAL MATERIALS. Extensive effort has been applied toward development of composite structural materials. The existing effort needs augmentation if the potential for application to long-life space structures is to be realized.

4.5.6 COMPOSITE END FITTINGS. The development of composite end fittings to replace existing metallic fittings is an advancement in state-of-the-art which would benefit the large space structures programs in terms of decreased weight, more thermally stable structures, and simplification of strut design. The development should be started now to complement the development of the long-life composite materials technology.

4.5.7 SPACE-QUALIFIED DEPLOYMENT MECHANISMS. Deployment mechanisms are being designed to provide deployment capability for large space structures, but as yet there has been no attempt to ensure reliability of such concepts. Fabrication and testing in a space environment needs to be planned before platform structural design proceeds.

4.6 TECHNOLOGY DEVELOPMENT PLAN

If the Geostationary Platform structural technology needs listed in Section 4.5 were to be initiated or augmented as indicated, each item of developed hardware could be ground-tested in a simulated space environment. Serious consideration should be given, however, to integrating the technology developments in a single Orbiter-based space validation test unit, similar to that shown in Figure 4-7. The unit shown is being proposed for validation testing of an expandable truss, adaptable to deployment of an existing 5-bay, 26 ft. section of the truss, or to deployment of a full-length 266 ft. beam. The unit will fly as an additional payload on a Spacelab mission.

An LSST structural technology test mission would consist of two items in the cargo bay, sharing the Orbiter with other payloads. The principal item would be an advanced technology expandable truss similar to that shown in Figure 4-7, incorporating the following technology developments:

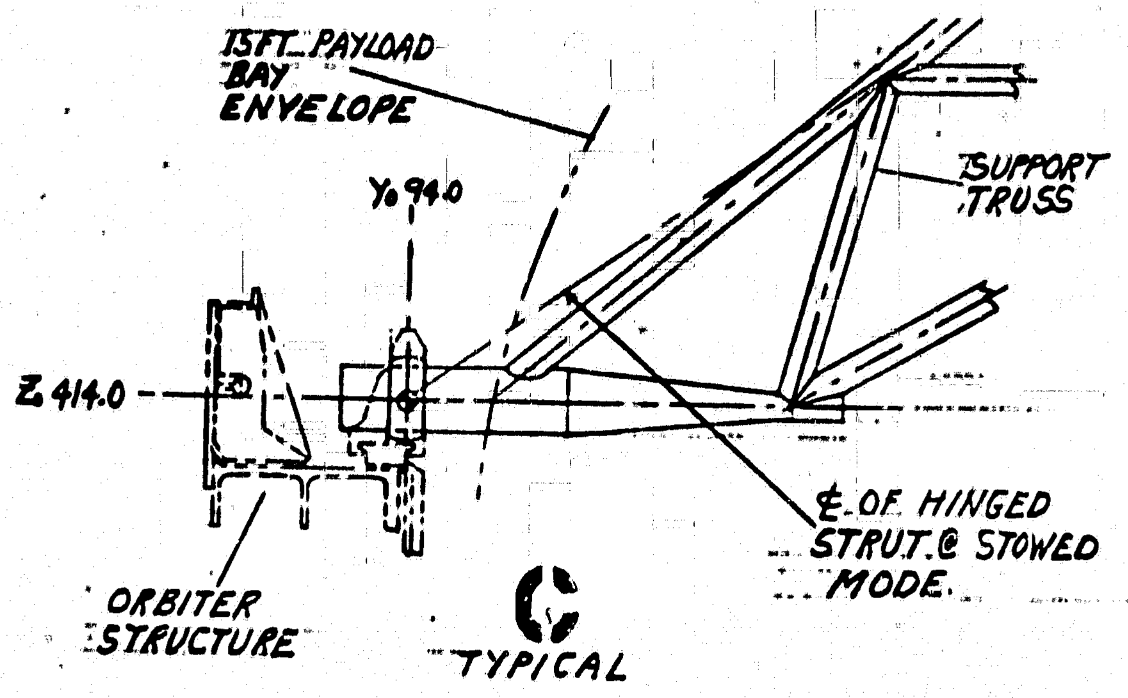
a. Advanced composite material structural elements with composite end fittings.

b. Structural deployment and umbilical stowage/deployment mechanisms designed for space environment.

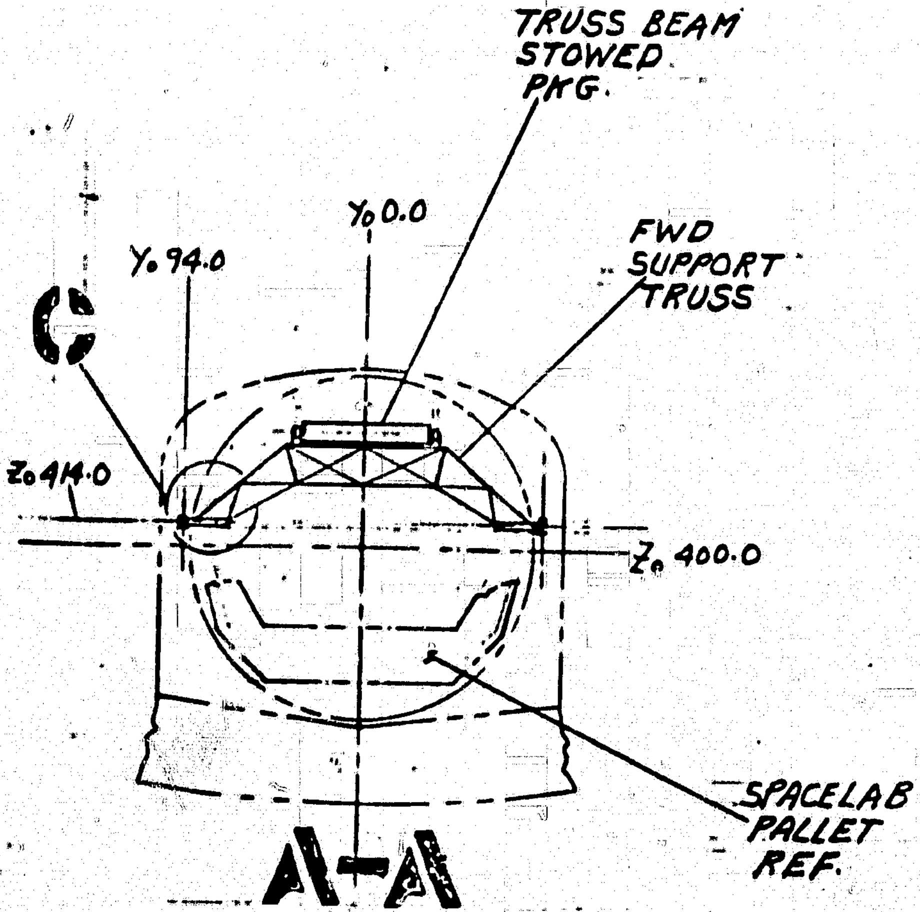
c. An experimental multi-purpose umbilical bundle for deployment with the truss.

d. A passive docking unit with integrated umbilical disconnect panels, on the forward face of the mast.

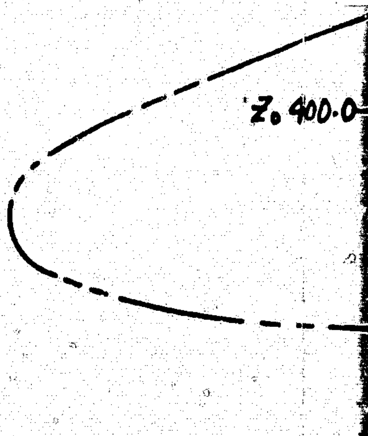
The secondary payload item would be an active docking unit stowed in the forward section of the cargo bay, to be lifted from the cargo bay with the RMS and held in final approach position for docking with the passive unit on the mast until the probe is captured and the active unit proceeds with the draw-in and latch operation, followed by powered closure of the umbilical panels.



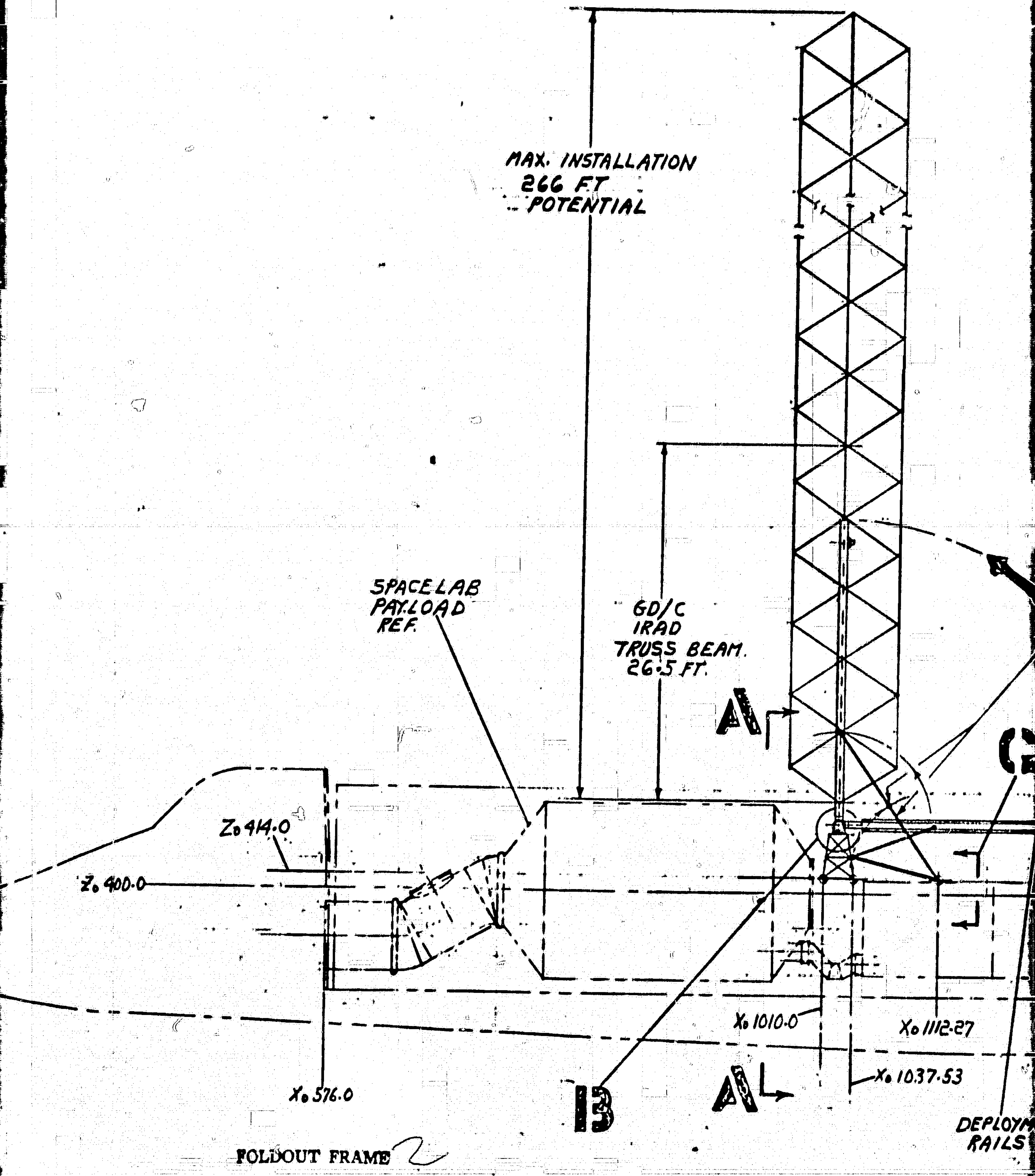
15FT. PAYLOAD BAY ENVELOPE
SUPPORT TRUSS
Y₀ 94.0
Z₀ 414.0
℄ OF HINGED STRUT @ STOWED MODE
ORBITER STRUCTURE
C
TYPICAL



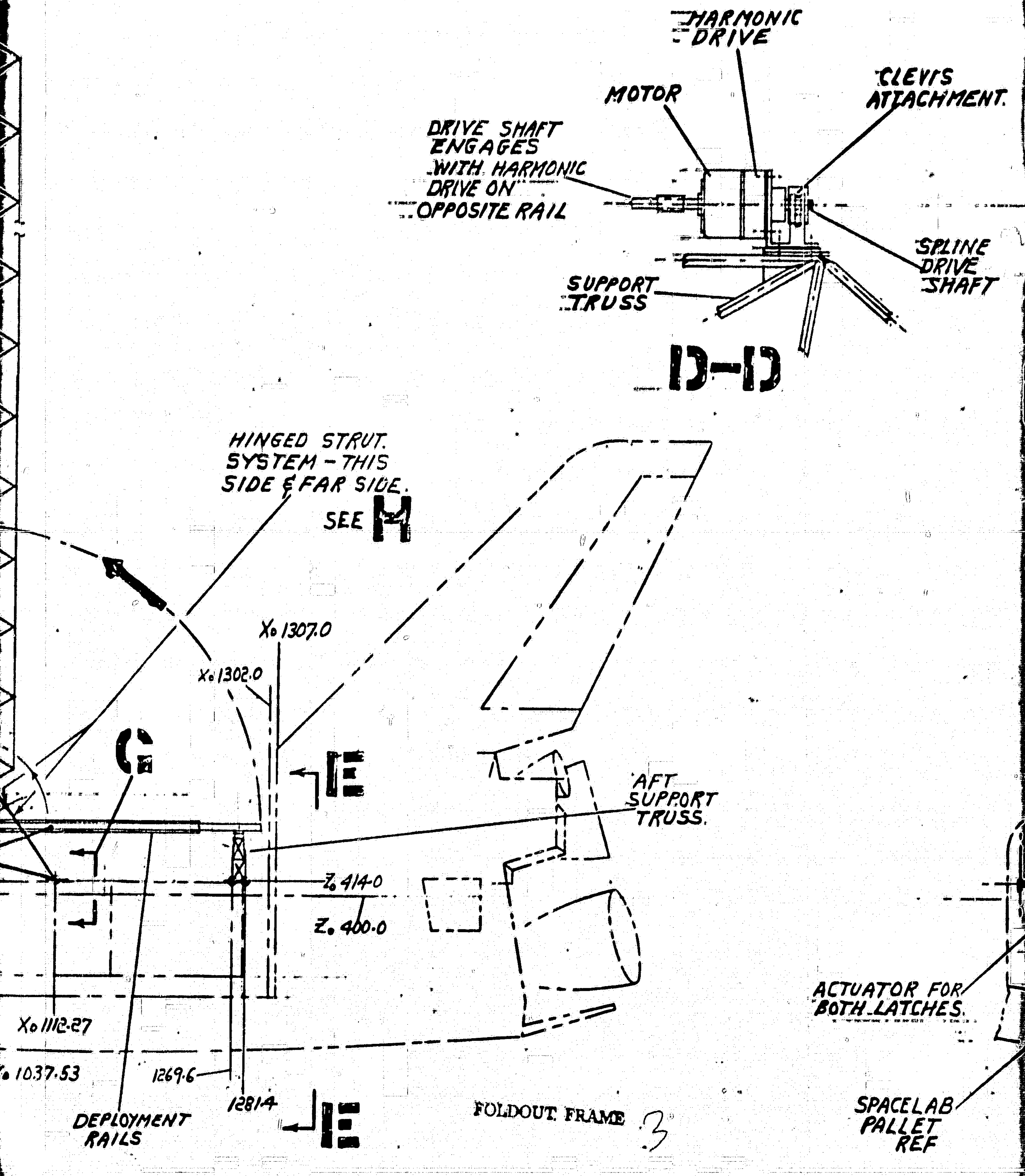
TRUSS BEAM STOWED PKG.
Y₀ 0.0
FWD SUPPORT TRUSS
Y₀ 94.0
C
Z₀ 414.0
Z₀ 400.0
SPACELAB PALLET REF.
A-A



Z₀ 400.0



FOLDOUT FRAME 2



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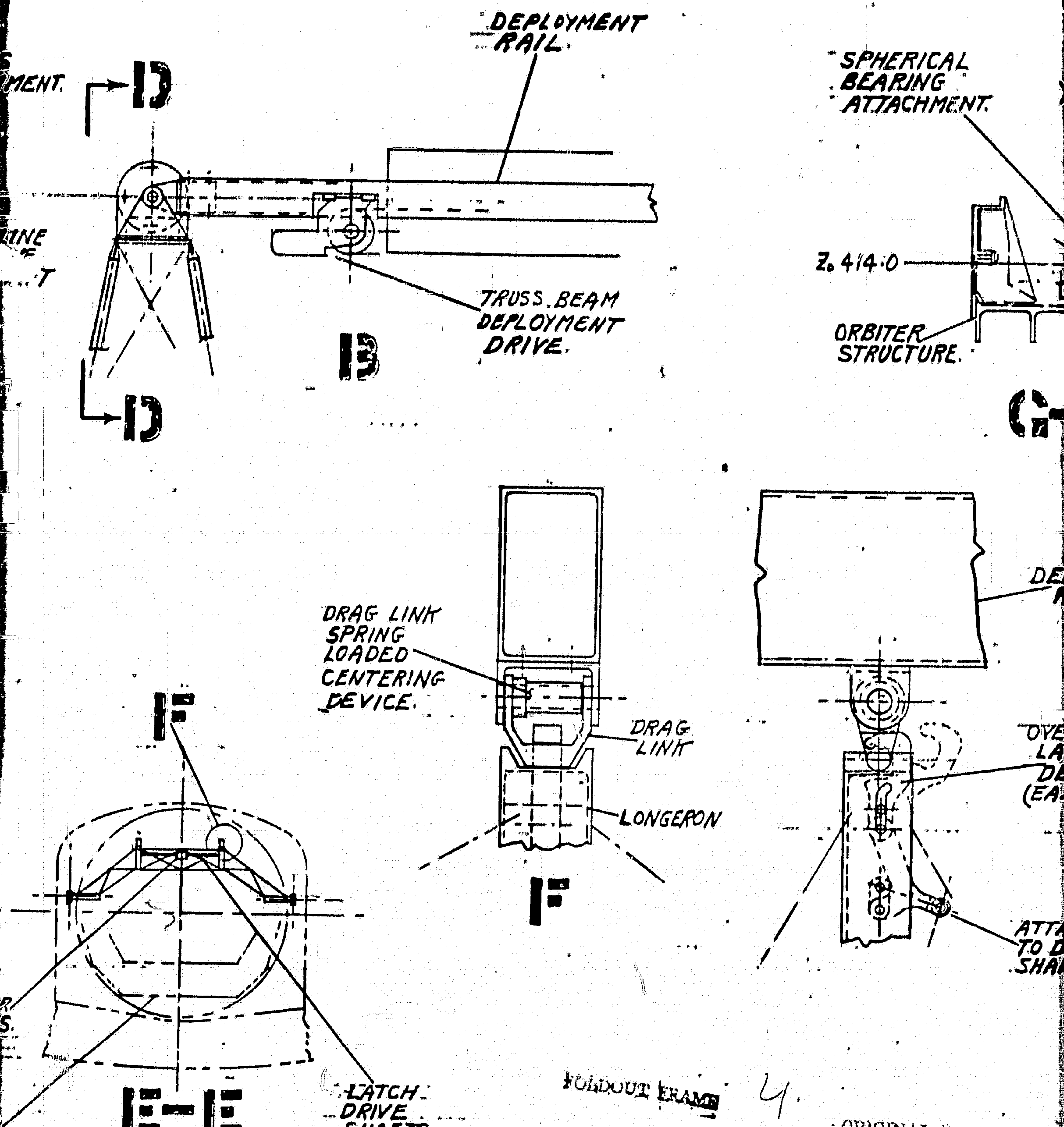

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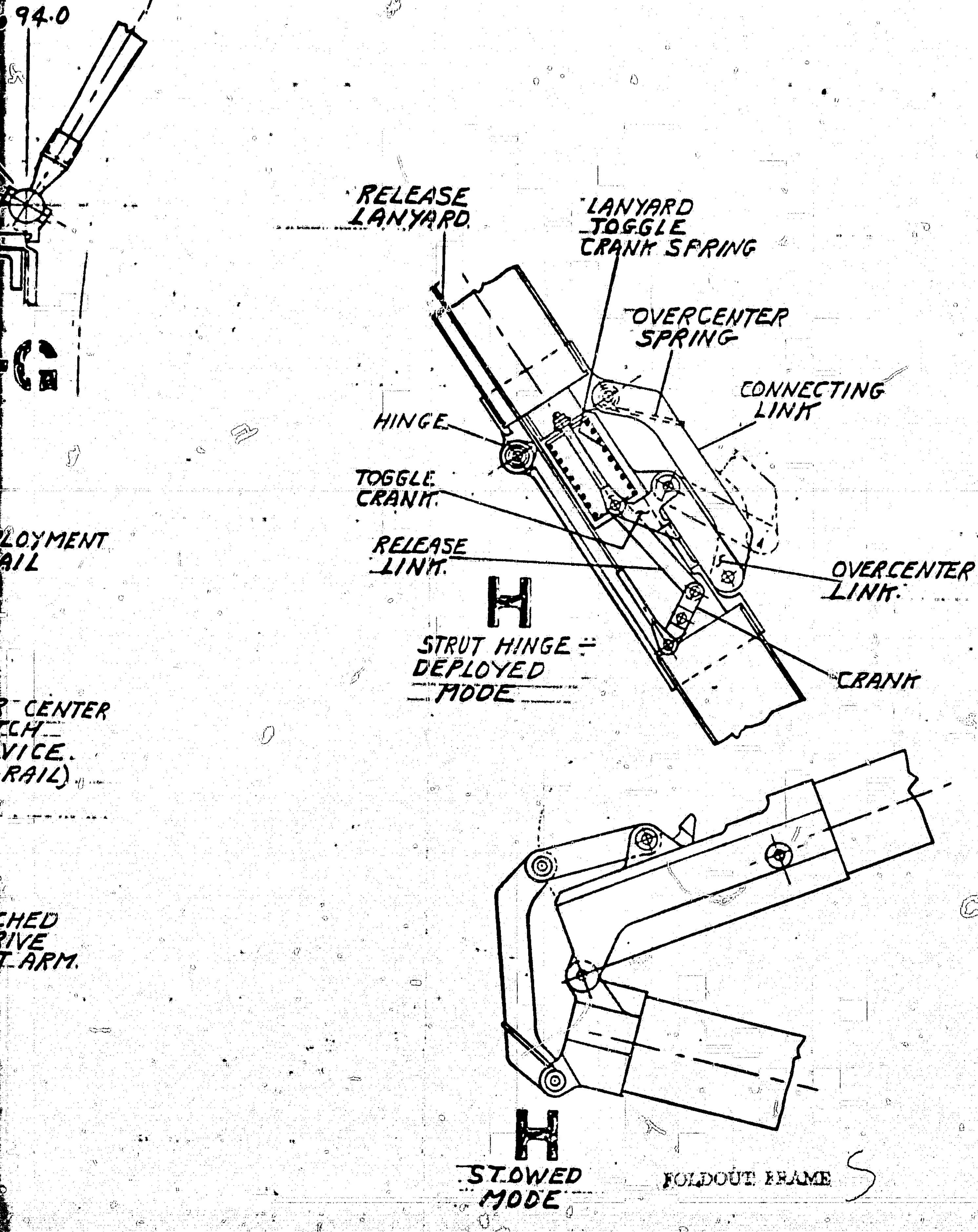


FOLDOUT FRAME

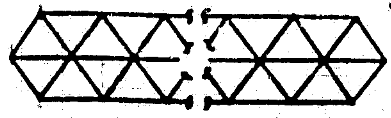
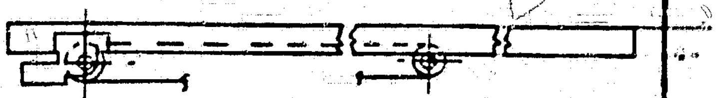
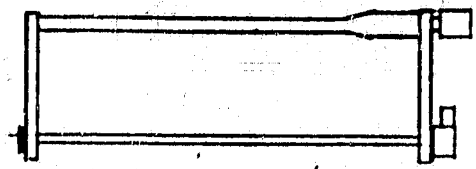
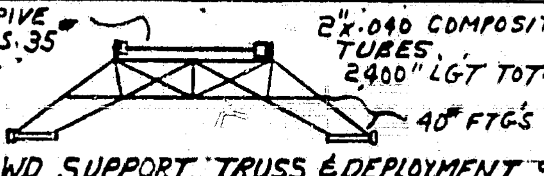
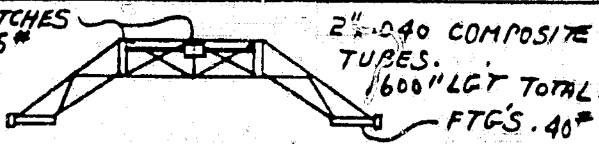
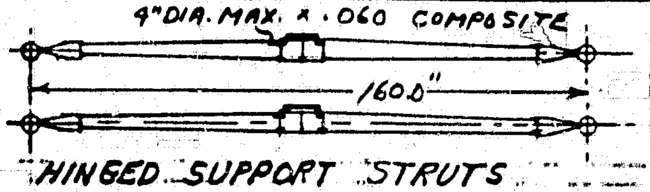
ITEM NO SCALE	WT. LBS.
 3.25 #/FT IRAD 1.44 #/FT OPTIMUM. TRUSS BEAM	383.0 ← FOR OPTIMUM (266 FT)
 DEPLOYMENT SYSTEM/HORIZONTAL DRIVE	
 DEPLOYMENT SYSTEM/VERTICAL LIFT.	30.0
 DRIVE SYS. 35# 2" x .040 COMPOSITE TUBES. 2400" LGT TOTAL 40# FTG'S FWD SUPPORT TRUSS & DEPLOYMENT SYS.	112.0
 LATCHES 25# 2" x .040 COMPOSITE TUBES. 1600" LGT TOTAL FTG'S. 40# AFT SUPPORT TRUSS & LATCH SYS.	90.0
 4" DIA. MAX. x .060 COMPOSITE 160.0" HINGED SUPPORT STRUTS	30.0
15% CONTINGENCIES	
TOTAL	

Figure 4-7. Deployable truss beam installed in the Shuttle with Spacelab manifest.

Testing would include functional validation of the deployable structure and deployment mechanisms, thermal distortion and deflection measurements, and docking hardware validation and operations.

Testing could well include related technology developments:

a. Design of a multi-purpose umbilical bundle, rather than a simulated umbilical for deployment mechanism testing.

b. TMS operations for docking, rahter than the RMS docking simulation.

c. Servicing operations - fluid transfer or component replacement.

d. Sensors for approach and docking operations.

e. Low earth orbit replacement of structural elements or system components by EVA, to validate the Orbiter capability of LEO checkout and repair of large space systems before orbital transfer.

f. Retraction of deployable structures for return to earth.

5

SUMMARY
RESULTS & RECOMMENDATIONS

In summarizing the results of the four Subtasks discussed in the previous sections of this report, both structural requirements and recommended technology developments are covered for the range of Operational Platform configurations selected from the Initial Study. A summary of specific detailed requirements for Platform No. 1 of Alternative #1 is also included, as representative of a typical single platform analysis.

It should be clearly understood that while the technology development requirements stemming from this study are specific, the detailed data and structural requirements can only be accepted as typical and representative of a family of geostationary platform configurations which will evolve from this conceptual study as the program develops.

5.1 UTILITIES ACCOMMODATION

Structural accommodation of the utilities required on the Geostationary Platform modules proved to be less demanding than was originally anticipated:

- Volume accommodation within non-deployable structural elements was no problem.

- Weight of the utilities was insignificant in relation to the overall platform and structural element weights.

By far the most significant result of the analysis was the observed need for innovative approaches and techniques for accommodation of utilities across deployable structures and joints.

The most stringent structural requirements with respect to utilities weight, cross sectional area and deployment accommodation are summarized for the three "worst case" routings analyzed, as follows.

5.1.1 ALTERNATIVE #1, PLATFORM NO. 1. As shown in Figure 5-1, element "E" is a semi-deployable payload-support structural arm carrying power, data, and fluid lines which must pivot down 90°, extend 1.6 meters, and deploy in cross section for rigidity. Packaged payload No. 3 then extends downward on a three-section telescopic mast, rotates 90°, extends the main reflector arms 1.2 meters, and deploys the main reflectors. These are the routing requirements. Representative design solutions to accommodate the deployment movements listed are detailed in Section 1. Utilities accommodations on this particular structural element are:

a. Trunk Umbilicals
   - Power: 4 wires, #10 AWG
     18 wires, #18 AWG
   - Function: 36 TSP, #22 AWG (Actuator power leads)
     50 TSP, #26 AWG (Baseband data and sensors)
     150 Fiber Optics, 1.3 mm (Baseband data and broadband RF)
   - Fluid: 2 lines, 2.5 cm dia (radiator)
   - Combined Umbilical Weight: 4.696 kg/m
   - Combined Umbilical Cross-section: 31.99 cm^2

b. Payload No. 3 Branch Umbilicals
   - Same as the trunk, less 14 wires, #18 AWG and 34 wires, #26 AWG.

5.1.2 ALTERNATIVE #1, PLATFORM NO. 6. Figure 5-2 illustrates the worst case routing for a telescoping mast structural element. As shown, the mast must extend nearly 5 meters overall, 3.6 meters in the lower element A_1. There are numerous techniques for accommodating the utilities umbilicals over such a mast. The one shown here, a traveling utilities reel, uses a flat-ribbon single umbilical; details are shown in Section 1. While not a structural requirement, development of this type of umbilical would run in parallel with the structural element and reel design.

Utilities accommodations on the mast are:

- Power: 8 wires, #18 AWG
- Function: 18 TSP, #22 AWG
  33 TSP, #26 AWG
  583 Fiber Optics, 1.3 mm
- Fluid: 2 lines, 1.0 cm dia.
- Combined Umbilical Weight: 3.333 kg/m
- Combined Umbilical Cross-section: 41.01 cm^2

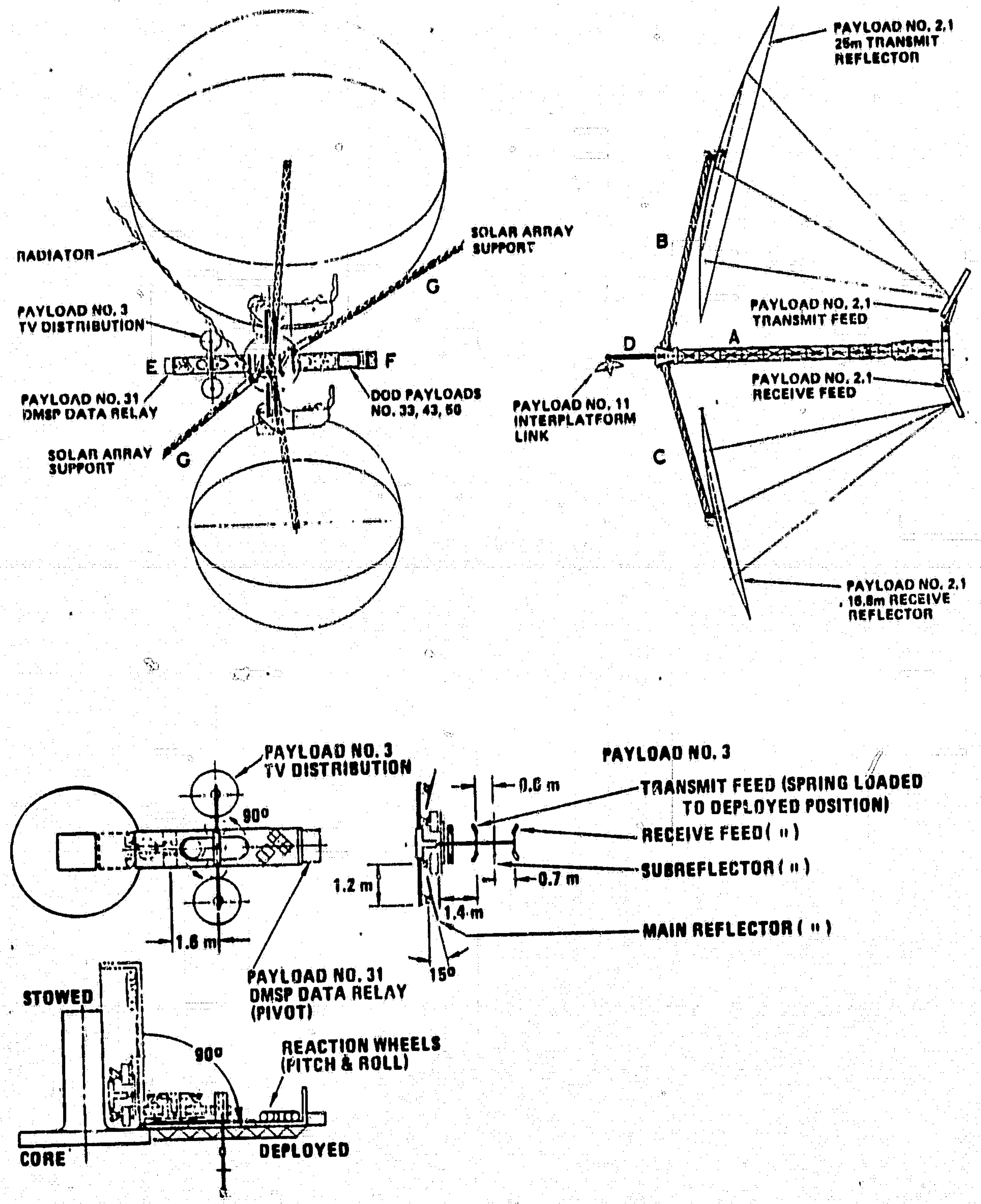


Figure 5-1. Alternative #1, Platform No. 1 utilities routing requirement, Arm E.

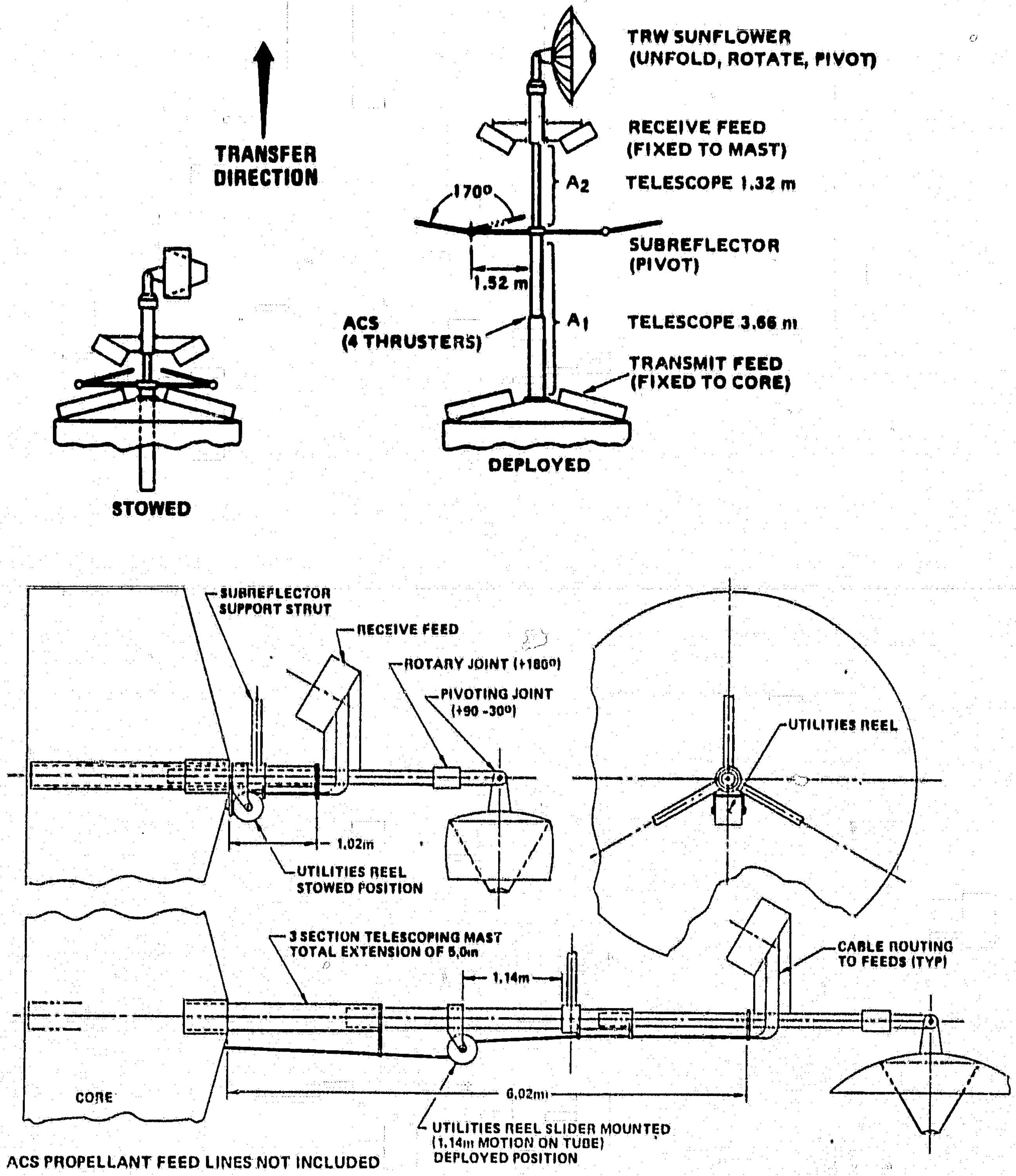


Figure 5-2. Alternative #1, Platform No. 6 utilities accommodation concept on telescoping mast.

5.1.3 ALTERNATIVE #4, PLATFORM NO. 1. This platform module, Figure 5-3, carries the longest expandable masts used in the development of the candidate platform configurations. The truss structure itself, expandable mast "A" in the figure, is in development at General Dynamics Convair; a full-scale 5-bay deployable section (5 ft × 7 ft × 26 ft), Figure 5-4, has been fabricated and functionally tested. The truss is built of both rigid and hinged graphite-epoxy struts, and has been exercised through packaging and deployment operations with umbilicals attached, as shown. Again, umbilical development should be coordinated with structural development as a corollary technology.

Utilities accommodations on the platform mast "A", Figure 5-3, are as follows:

- Power: 6 lay cables, #3 AWG, 19 strand
  4 wires, #13 AWG
  20 wires, #18 AWG

- Function: 34 TSP, #22 AWG
  58 TSP, #26 AWG
  144 Fiber Optics, 1.3 mm

- Fluid: 6 lines, 2.5 cm dia
  4 lines, 1.0 cm dia

- Combined Umbilical Weight: 6.222 kg/m

- Combined Umbilical Cross-section: 62.38 cm^2

5.1.4 GENERAL. Where the total cross-sectional area of the utilities to be accommodated on a structural element is great, as is the case in the three examples summarized above, the diameter of a single umbilical would be in the order of 2.5" to 3.5". In actual design, multiple umbilicals would be used to keep the umbilical diameters and bend radii low, to provide the flexibility needed on the type of structure being used. Multiple umbilicals have the added advantage of routing directly to a payload or support system component (such as a solar panel) without having to branch off a trunk umbilical.

In general, utilities accommodation imposes no particular problems in the structural requirements area. A fallout of the analysis, however, is the requirement for technology development in the umbilical design area.

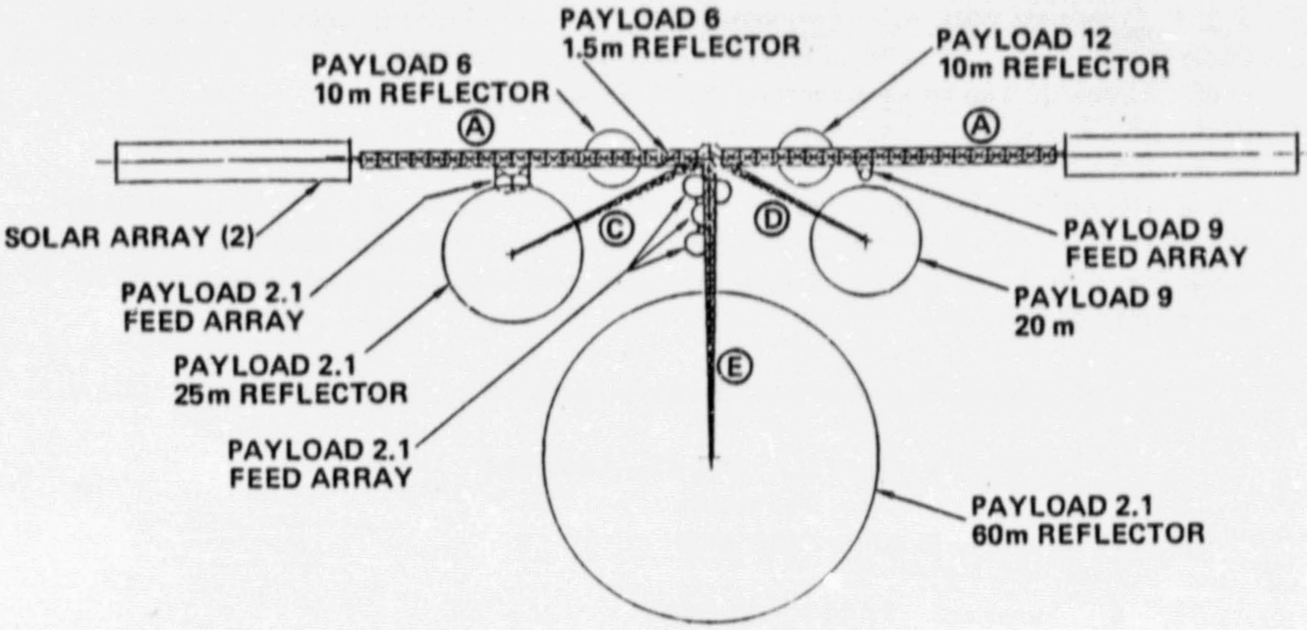


Figure 5-3. Alternative #4, Platform module No. 1.

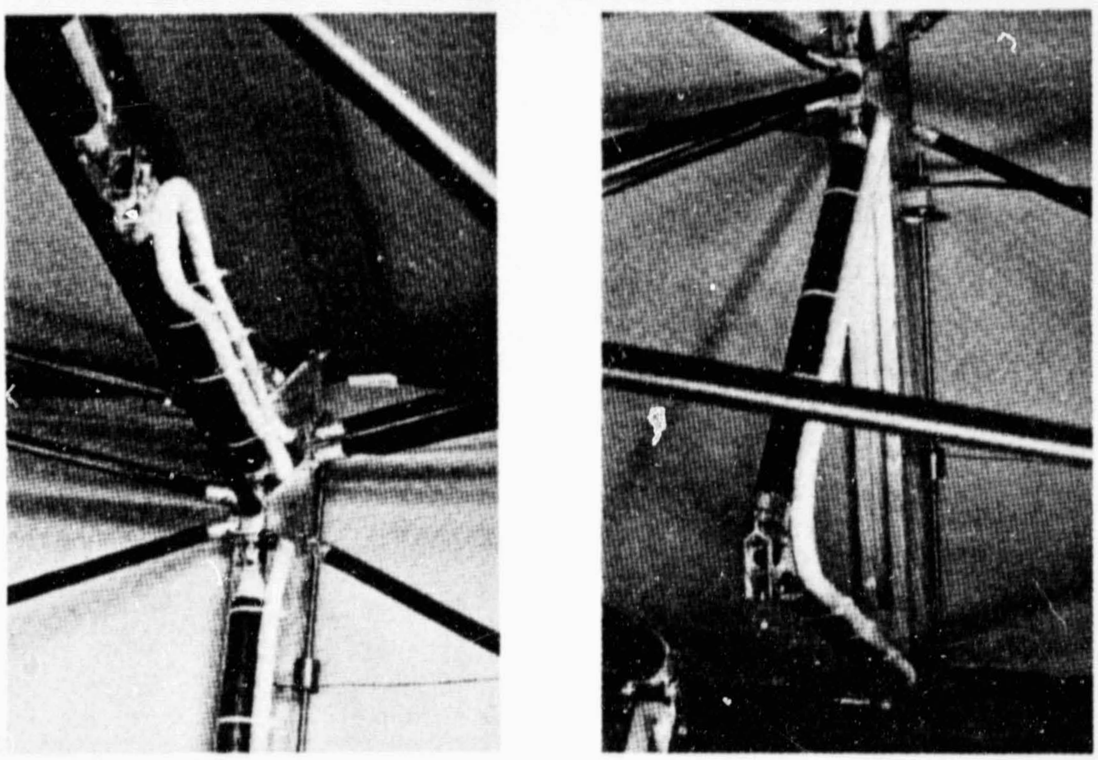


Figure 5-4. General Dynamics prototype space truss.

5.2 INTERFACE REQUIREMENTS

Platform internal subsystem/mission equipment interfaces are existing state-of-the-art as used in present day communications satellites and do not lead to technology development requirements. Platform-unique interface requirements which do lead to technology needs are those involved in platform operations. Such interface requirements are summarized by operation as follows:

a. Platform Module Assembly in LEO

- Simple segment-to-segment interface design for EVA assembly.
- Grapple fixtures on segments for RMS and effectors.
- Handrails and handholds on segments as required for EVA assembly.

b. OTV/Platform Module Mating in LEO

- Platform Module/ASE cradle attach points for boost loads, rotation, deployment, checkout, and separation.
- Platform/OTV interface thrust ring and umbilical panel on the platform to accommodate the OTV.
- Grapple fixtures on the platform modules for RMS end effectors.

c. Module-to-Module Docking in GEO

- Docking loads on the structure less than operational loads during Orbiter ascent or OTV transfer.
- Minimum bumping risk, i.e., positive mechanical draw-in.
- Sequential docking, structural locking, and umbilical connection.

d. On-Orbit Servicing in GEO

- Same interface requirements as module-to-module docking in GEO.
- Structural interface compatibility with the TMS, preferably the same interface as the OTV.

5.3 STRENGTH AND STIFFNESS

5.3.1 STRENGTH. Strength analysis and sizing of platform structural elements were based on LEO-to-GEO transfer in the deployed configurations, the most severe loading condition encountered during the platform mission. Orbit transfer acceleration loads used in the analyses were 0.07 g for Alternative #1 platforms with the expendable OTV, and 0.035 g for Alternative #4 platforms with the 2-stage reusable OTV.

Utility accommodation was found to have only a slight influence on the strength requirements of structural members, increasing the structural element weights by 2 to 4%.

5.3.2 STIFFNESS. Stiffness requirements for the platform structural elements are a function of the specific geometric tolerances that communications payloads and their components must maintain under operational conditions. The critical on-orbit loading condition is ACS firing for pointing and stationkeeping, producing linear accelerations along each of the three principal axes of approximately 0.01 g and 0.0003 g for Alternatives #1 and #4, respectively.

Resizing of structural elements above strength requirements to satisfy stiffness requirements required significant increases in section size and weight: 8% increase in structural weight (2% in total platform weight) for Alternative #1; 22% increase in structural weight (3% in total platform weight) for Alternative #4.

Stiffness requirements outweight strength requirements for the Geostationary Platform configuration in this study, a payload-unique characteristic, possibly, of the communications platform large space system structure.

5.3.3 STRUCTURAL VIBRATION FREQUENCIES. Dynamic model analysis of Alternative #1, Platform No. 1 sized for stiffness, and Alternative 4 Platform sized for strength, both showed fundamental natural frequencies in the seventh mode, at 0.148 Hz (vertical bending, solar array arm) for the Alternative #1 platform, and at 0.019 Hz (torsion, central mast) for Alternative #4. These values are unimportant in themselves, but do show the approximate range of frequencies to be expected with this type and size of structure. As more definitive designs and hardware develop during the program, the finite element analyses will more accurately identify natural modes and frequencies for which modes-control techniques can provide control solutions.

5.4 REQUIREMENTS SUMMARY

Results of the analysis of Geostationary Platform Alternative #1, Platform No. 1, are summarized in Table 5-1, as representative of typical platform utilities interface requirements.

Major structural requirements and parameters for both Alternative #1 and #4 are summarized in Table 5-2.

Table 5-1. Alternative #1, Platform No. 1 utilities interface requirements summary.

Structural Element	UTILITY REQUIREMENTS										ROUTING REQUIREMENTS								Combined Utilities Weight (kg/m)	Combined Cross-Section Area (cm²)
	Power Wires		Data Wires (TSP)		Optical Fibers		Coax Cable		Fluid Lines		Pivot Joints		Rotary Joints		Telescope Mast		Expanded Mast			
	Qty	AWG #	Qty	AWG #	Qty	ϕ (mm)	Qty	Size	Qty	ϕ (cm)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	Qty	ΔL (m)		
A	4	15	32 65	22 26	4	1.3			2	1.0							1	17.3	3.437	12.20
B			6 18	22 26							1	110	1	½			1	14.9	0.707	2.52
C			6 18	22 26							1	110	1	½			1	11.8	0.707	2.52
D	4	15	6 29	22 26	4	1.3					1	120	1	180			1	3.7	1.066	4.31
E	18 4	18 10	36 50	22 26	150	1.3			2	2.5	1 2	90 15	1	90	1 4 2 1 1	1.6 1.2 1.4 0.6 0.7	1	GDC Semi-Deployable	4.696	31.99
F	6 4	6 18	16 40	22 26	1	1.3	8	RG303	4	1.0	1	90					1	GDC Semi.	3.648	14.46
G	6	6	6 10	22 26							1	90	1	Comm			1 1	22.3 10.0	1.592	12.07
Rcv Feed Assy Arm	4	18	10 22	22 26	65	1.3					1 1	110 10	1	90					1.231	16.39
Xmit Fd Assy Arm	4	18	10 22	22 26	65	1.3					1 1	110 2	1	90					1.231	16.39
Radiator Module			4 19	22 26					2	2.5	1 18	90 150							1.349	12.07

Table 5-2. Summary - major platform structural requirements and parameters.

Maximum Platform Module Weight	
Alternative #1:	15,000 lb.
Alternative #4:	37,000 lb.
Orbit Transfer Vehicle	
Alternative #1:	Single-stage, expendable, low thrust OTV.
Alternative #4:	Two-stage, reusable, low thrust OTV.
Orbit Transfer Loads	
Alternative #1:	T/W = 0.07; dynamic factor = 2.0. Largest bending moment = 6,570 Nm.
Alternative #4:	T/W = 0.035; dynamic factor = 2.0. Largest bending moment = 101,427 Nm.
Effect of Utility Distribution on Structural Weight	
Alternative #1:	2 to 4% increase.
Alternative #4:	2 to 4% increase.
Attitude Control System Accelerations	
Alternative #1:	$A_x = A_y = A_z = 0.01$ g; dynamic factor = 2.0.
Alternative #4:	$A_x = A_y = A_z = 0.0003$ g; dynamic factor = 2.0.
Effect of Stiffness Resizing on Structural Weight	
Alternative #1:	8% increase.
Alternative #4:	22% increase.
Fundamental Natural Vibrational Frequency	
Alternative #1:	0.148 Hz (Platform No. 1).
Alternative #4:	0.019 Hz.

5.5 STRUCTURAL TECHNOLOGY NEEDS

The major structural technology needs which have emerged from this study are summarized in Figure 5-5. While all have evolved from the geostationary platform configuration requirements, all are equally applicable to any large space structures based on the deployment concept and missions involving docking and servicing.

Structural Technology Need	Coordinate Development With	Existing Effort	Augment	Begin New Studies
Umbilical Stowage & Deployment Mechanisms	Umbilical Technology			✓
Soft-Docking, Hard-Latching Mechanisms	OTV TMS	✓	✓	
Integrated Docking/ Umbilical Panels	OTV TMS			✓
Deployable, High Packaging Density, Low CTE Masts		✓	✓	
Space Qualified, Long-Life Composite Materials		✓	✓	
Composite Structural Element End Fittings				✓
Space Qualified Deployment Mechanisms				✓

Figure 5-5. Technology development needs for the Geostationary Platform program.

5.6 RECOMMENDATIONS

As a risk reduction step in implementation of the Geostationary Platform program and other related large space structures programs, the structural technology requirements listed in Figure 5-5 above should be initiated early in the program schedule, prior to Phase B. These technologies should be considered a minimum development commitment if the programs are to proceed.

Serious consideration should also be given to integrating the single technology developments into a single Orbiter-based space validation test unit as described in Section 4.6. The test unit would require considerably less than half the cargo bay volume, minimizing the STS cost. Testing would include functional validation of the deployable structure and deployment mechanisms, utilities and utilities deployment mechanisms, docking and umbilical connection hardware, and measurements of thermal distortion, loads, and deflections. Related technologies could also be tested or validated including TMS operations for docking and servicing, sensors for approach and docking, EVA component replacement or repair techniques, EVA-assisted assembly, and solar array deployment.

APPENDIX A

UTILITIES ACCOMMODATION DATA

UTILITIES SIZING DATA

Cable weight data.

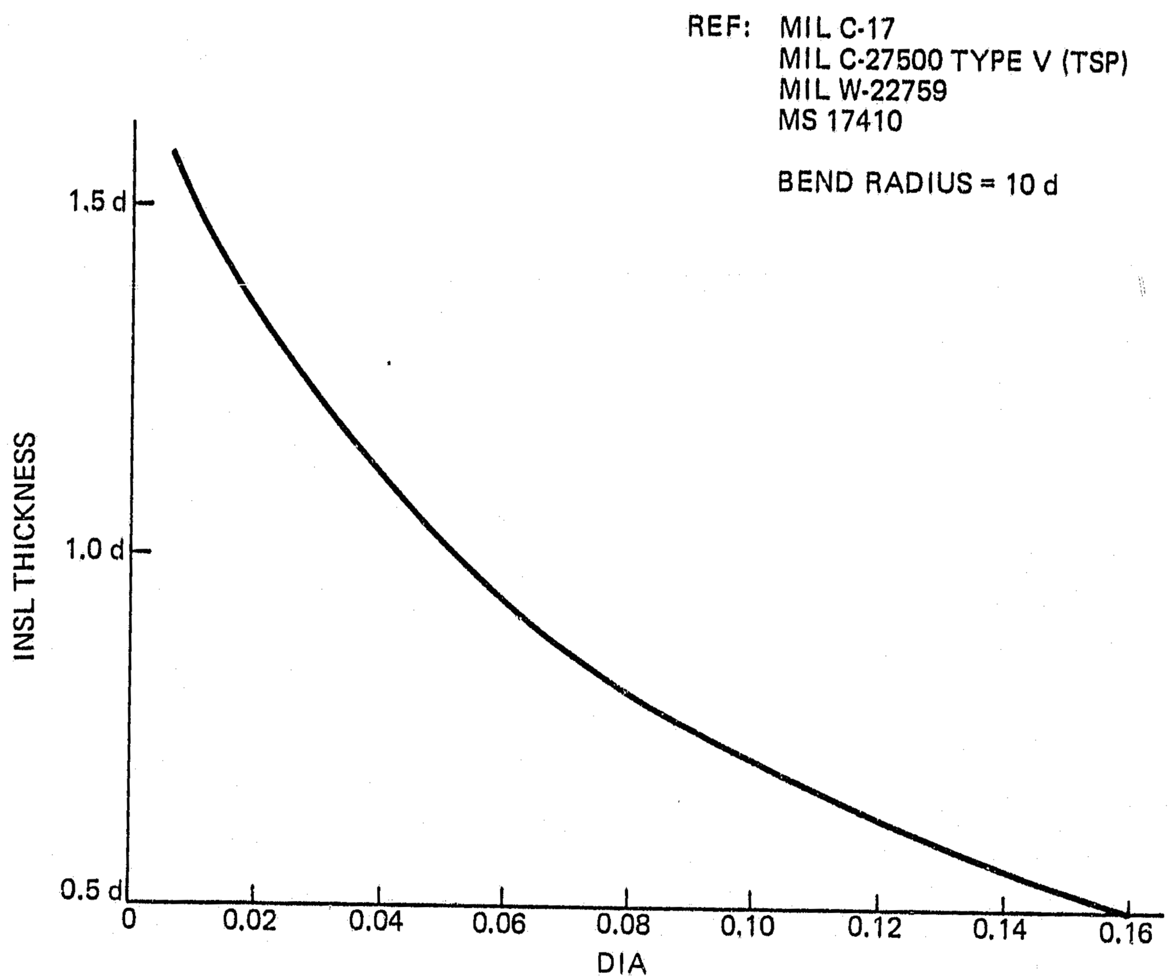
RG 303 COAX CABLE:	0.170 in. Dia.	33 lb/1,000 ft
RG 142 COAX CABLE:	0.206 in. Dia.	45 lb/1,000 ft
GOLITE 5000 Single-Sheathed Optical Filament:	1.3 mm Dia.	1.5 lb/1,000 ft

STANDARD WIRING

AWG	DIA. (in.)	TYPE	Wt/Unit Length*
6	0.1620	Single Copper Conducter Glass Reinforced TFE Cover	118.2 lb/1,000 ft
10	0.1019	Single Copper Conducter Glass Reinforced TFE Cover	46.32 lb/1,000 ft
15	0.05707	Single Copper Conducter Glass Reinforced TFE Cover	19.26 lb/1,000 ft
16	0.05082	Single Copper Conducter Glass Reinforced TFE Cover	17.64 lb/1,000 ft
18	0.04030	Single Copper Conducter Glass Reinforced TFE Cover	13.08 lb/1,000 ft
22	0.02535	Twisted Shielded Pair MIL-C-27500 Type V	36.24 lb/1,000 ft
26	0.01594	Twisted Shielded Pair MIL-C-27500 Type V (Ratioed using bare wire weight)	14.33 lb/1,000 ft

*kg/m = 0.0014882 X lb/1,000 ft

Estimate of conductor insulation thickness for purpose of determining minimum bend radii.



Minimum bend radii for electrical/data services.

1.3 mm Fiber Optic — Jacketed, Single Strand

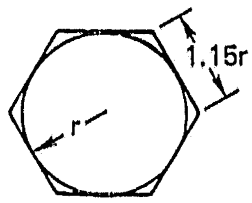
Minimum Radius = 0.31 inches

For the coated copper conductors — assume minimum bend radius of

10 X Outside Jacket Diameter

WIRE TYPE	OUTSIDE DIA. (In.)	MIN BEND RADII (In.)	X-SECTION AREA (in^2)	COMMENTS
RG 303 COAX	0.170	1.70	0.0227	
RG 142 COAX	0.206	2.06	0.0333	
AWG 3	0.370	3.70	0.1070	Woven strap for pivots
AWG 6	0.324	3.24	0.0824	Woven strap for pivots
AWG 10	0.245	2.45	0.0471	
AWG 13	0.203	2.03	0.0320	
AWG 15	0.171	1.71	0.0230	
AWG 16	0.152	1.52	0.0181	
AWG 18	0.129	1.29	0.0131	
AWG 22 TSP	0.177	1.77	0.0246	
AWG 26 TSP	0.121	1.21	0.0115	
1.3 mm O.F.	0.102	0.31	0.0082	

BUNDLE PACKAGING AREA =



$$\left(\frac{A_{HEXAGON}}{A_{CIRCLE}}\right) \cdot N \cdot A_{UTILITY}$$

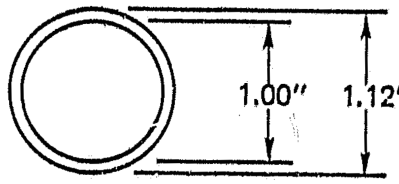
$$\frac{A_{HEXAGON}}{A_{CIRCLE}} = \frac{3.4641\, r^2}{\pi r^2} = \boxed{1.103}$$

Tubing weight data.

2.5 cm DIA TUBE

Aluminum

$\rho = 0.102 \text{ lb/in}^3$



$A = 0.761 \text{ in}^2$

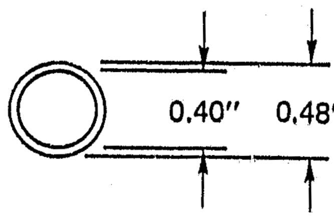
$A = 4.909 \text{ cm}^2$

$$W = (0.102)\frac{\pi}{4}(1.12^2 - 1.0^2) = 0.0204 \text{ lb/in} = 244.6 \text{ lb/1,000 ft}$$

1.0 cm DIA TUBE

Aluminum

$\rho = 0.102 \text{ lb/in}^3$



$A = 0.122 \text{ in}^2$

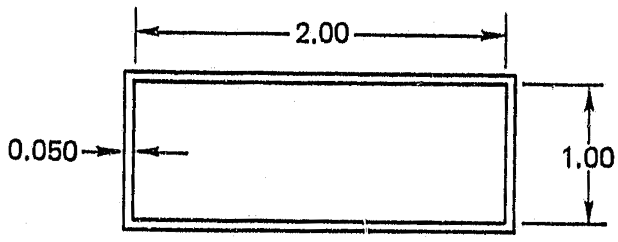
$A = 0.785 \text{ cm}^2$

$$W = (0.102)\frac{\pi}{4}(0.48^2 - 0.40^2) = 0.00564 \text{ lb/in} = 67.7 \text{ lb/1,000 ft}$$

WAVEGUIDE 2.5 X 5 cm

Aluminum

$\rho = 0.102 \text{ lb/in}^3$



$$W = 0.102\,(6)\,(0.050) = 0.0306 \text{ lb/in} = 367.2 \text{ lb/1,000 ft}$$

$$A = 1.938 \text{ in}^2 = 12.5 \text{ cm}^2$$

ALTERNATIVE 1

ALTERNATIVE 1
UTILITY CROSS-SECTION AREA REQUIREMENTS

PLATFORM NO.	STRUCTURAL ELEMENT/WT		Σ WIRE AREAS (in2)	CABLE AREA (in2)	CABLE DIA (in.)	OTHER SERVICE
1	A	2.804	1.4627	1.6134	1.433	
1	B	0.707	0.3546	0.3911	0.706	
1	C	0.707	0.3546	0.3911	0.706	
1	D	1.066	0.6059	0.6683	0.922	
1	Feeds	1.231	1.0844	1.1961	1.234	
1	E	4.696	3.1148	3.4356	2.092 +	(2) 2.5 cm Fluid Lines
1	F	3.547	1.5902	1.7540	1.4944 +	(3) 1.0 cm Fluid Lines
1	G	1.592	0.7570	0.8350	1.031	
1	Radiator		0.3169	0.3495	0.667 +	(2) 2.5 cm Fluid Lines
2	A_3	1.020	0.2649	0.2922	0.610 +	(1) 2.5 X 5 cm Waveguide
2	A_2	1.603	2.7438	3.0264	1.963	
2	A_1	1.818	2.8422	3.1349	1.998	
2	B	0.933	0.4629	0.5106	0.806	
2	C	0.921	0.5171	0.5704	0.852	
2	D	0.212	0.1211	0.1336	0.413	
2	E	0.531	0.3090	0.3408	0.659	
6	A_2	2.485	5.4125	5.9700	2.757	
6	A_1	2.700	5.5109	6.0785	2.782	
6	B	0.718	0.3645	0.4020	0.716	
6	C	1.234	0.7044	0.7770	0.995	
6	D	0.773	0.4137	0.4563	0.762	
6	E	0.531	0.3090	0.3408	0.659	

ALTERNATIVE 1

PLATFORM NO. 1

Alternative 1, Platform No. 1 Wire Sizing

E = 100 VDC; ΔE = 1V

E = IR; Power = EI

Assume drop of 1% is permissible, or ΔE = 2V.

Assume peak power = 2 X average power.

Assume redundant hot/ground wires, i.e., 4 wires/function.

Assume minimum wire size of #18 AWG.

PAYLOAD	P AVG POWER (W)	LENGTH ℓ (ft)	$I = \frac{P}{E}$ (amps)	ALLOW $R = \frac{\Delta E}{I}$ for LENGTH ℓ	R FOR 1,000 FT (ohms)	AWG #
#2.1 XMITTER	320	30	3.2	0.31	10.4	18
#2.1 RECEIVER	130	30	1.3	0.77	25.6	18
#3 XMITTER	1800	40	18.0	0.06	1.4	18
#3 RECEIVER	150	45	1.5	0.67	14.8	18
#11	300	90	3.0	0.33	3.7	18
#31	100	40	1.0	1.00	25.0	18
#33, #43 & #56	100	35	1.0	1.00	28.6	18
SOLAR PANELS (DBL)	2620	90	26.2	0.04	0.42	18

Alternative 1 – Platform No. 1 Services Compilation

STRUCTURAL COMPONENT A (Payload 2.1 Reflectors & Payload 11)

4 (15 AWG), 24 TSP (22 AWG), 65 TSP (26 AWG), 4 (1.3 mm FOS)
(Mast A extend deleted)

TOTAL = 1,884 lb/1,000 ft
= 2.804 kg/m

STRUCTURAL COMPONENTS B & C – See Data Sheet

475 lb/1,000 ft = 0.707 kg/m

STRUCTURAL COMPONENT E (Payloads 3 and 31 plus reaction wheels)

4 (10 AWG), 18 (18 AWG), 36 TSP (22 AWG), 50 TSP (26 AWG),
150 (1.3 mm FOS), 2 (2.5 cm Cooling Lines)

3,156 lb/1,000 ft = 4.696 kg/m

STRUCTURAL COMPONENT F (Payloads 33, 43, & 56 plus batt & prop tanks)

6 (6 AWG), 4 (18 AWG), 16 TSP (22 AWG), 40 TSP (26 AWG),
1 (1.3 mm FOS), 3 (1.0 cm Vent/Feed Lines), 8 (RG 303 COAX)

2,383 lb/1,000 ft = 3.547 kg/m

STRUCTURAL COMPONENT G – See Data Sheet

1,070 lb/1,000 ft = 1.592 kg/m

STRUCTURAL COMPONENT D – See Data Sheet

716 lb/1,000 ft = 1.066 kg/m

PAYLOAD 2.1 FEEDS – See Data Sheet

827.5 lb/1,000 ft = 1.231 kg/m

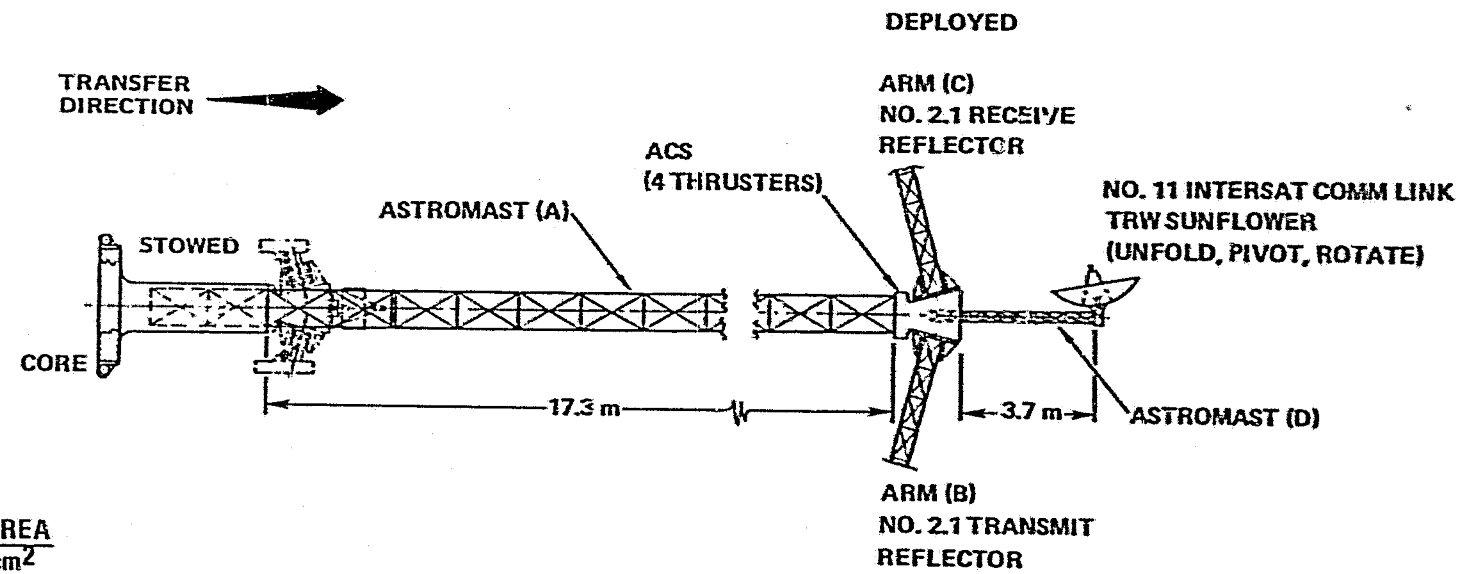
TASK 11 DATA SHEET – LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 1

POWER: 100 VDC

STRUCTURAL ELEMENT: CENTRAL EXTENDABLE MASTS (A & D)
PAYLOADS SUPPORTED: NO. 2.1 REFLECTORS, NO. 11

Utility Requirements									Utility	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services			Combined Weight	Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
4	15	6	29	FO	4				1.066	1	120	1	±180			3.7	(D)
4	15	32	65	FO	4	ACS FEED	2	1.0	3.437							17.3	(A)



CABLE X-SECT AREA
(A) = 10.63 cm^2
(D) = 4.31 cm^2

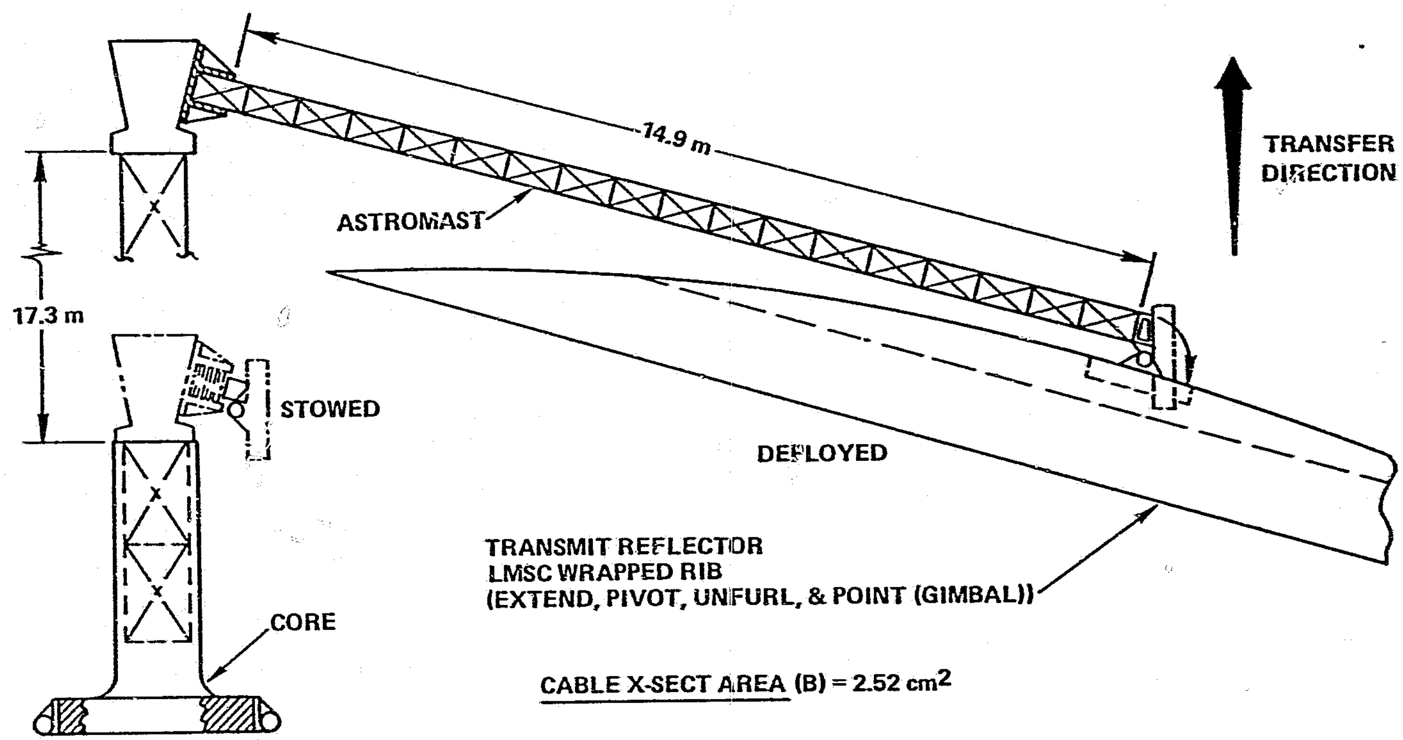
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: EXTENDED ARM (B)
PAYLOADS SUPPORTED: NO. 2.1 TRANSMIT REFLECTOR

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
—	—	6	18	—	—	—	—	—	0.707	1	110 ±0.5	1	±0.5	—	—	14.9



CABLE X-SECT AREA (B) = 2.52 cm^2

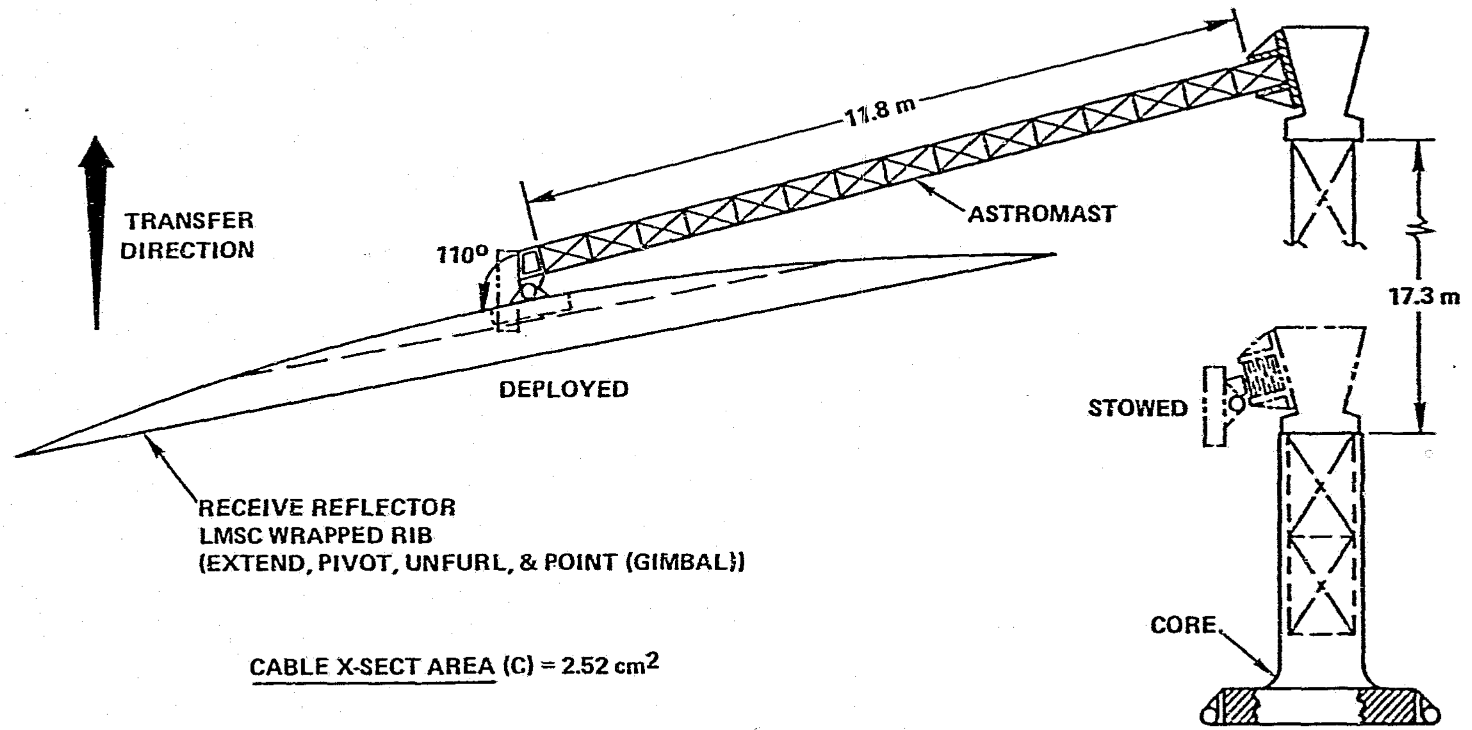
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: EXTENDED ARM (C)
PAYLOADS SUPPORTED: NO. 2.1 RECEIVE REFLECTOR

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
—	—	6	18	—	—	—	—	—	0.707	1	110 ±0.5	1	±0.5	—	—	11.8



CABLE X-SECT AREA (C) = 2.52 cm^2

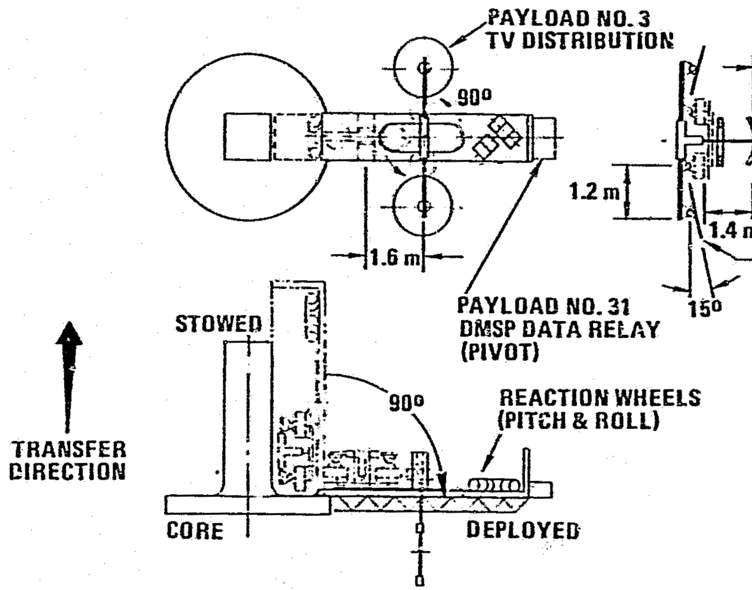
TASK 11 DATA SHEET — LSST UTILITIES

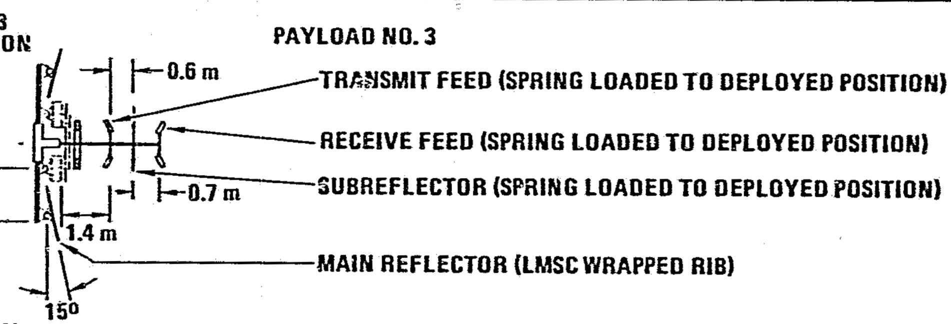
ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: PIVOTING ARM (E)
PAYLOADS SUPPORTED: NO. 3 REFL & FEEDS, NO. 31, P&R WHEELS

Utility Requirements										Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG TSP	Qty of 26 AWG TSP	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG			Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
18 4	18 10	36	50	FO	150	RADIATOR FLUID LINES	2	2.5	4.696	1 2	90 15	1	90	1 4 2 1 1	1.6 1.2 1.4 0.6 0.7	(SEMI-DEPLOY-ABLE)	*





CABLE X-SECTION AREA (E) = 22.17 cm^2

* ALL SERVICES EXCEPT (14) 18 AWG & (34) 26 AWG TSP GO TO PAYLOAD NO. 3

PAYLOAD NO. 3 CABLE X-SECTION AREA = 18.08 cm^2

TASK 11 DATA SHEET — LSST UTILITIES

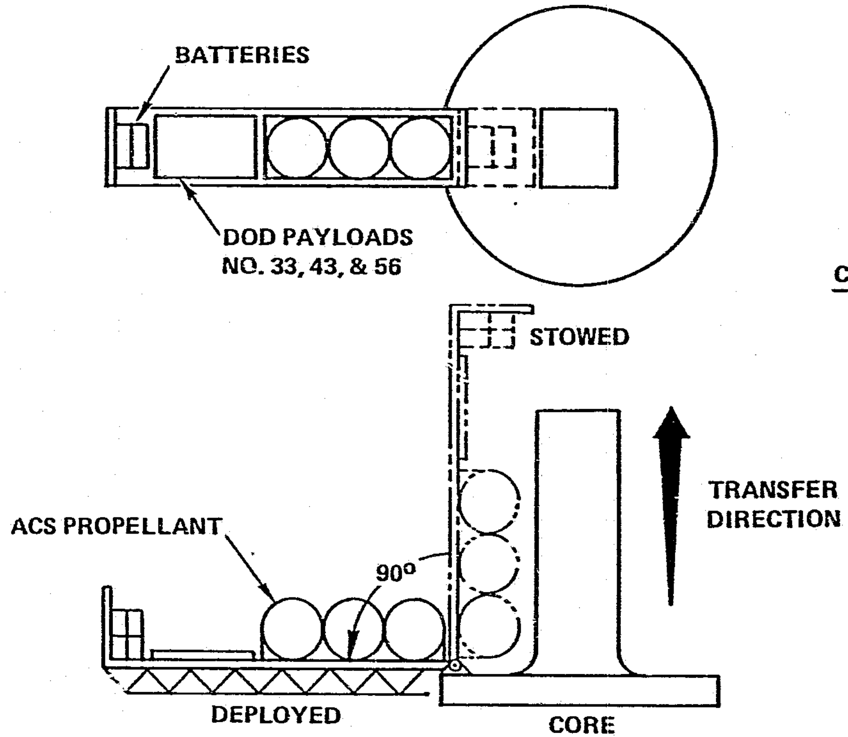
ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: PIVOTING ARM (F)

PAYLOADS SUPPORTED: NO. 33, NO. 43, NO. 56, BATTERIES & ACS PROP

Utility Requirements										Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services					Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)			Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
6	6	16	40	1.3 mm FO	1	BAT VENT	1	1.0		3.648	1	90	—	—	—	—	(POP-UP SUPP. TRUSS)
4	18			RG303 COAX	8	ACS VENT	1	1.0									
						ACS FEED	2	1.0									



CABLE X-SECT AREA (F) = 11.32 cm^2

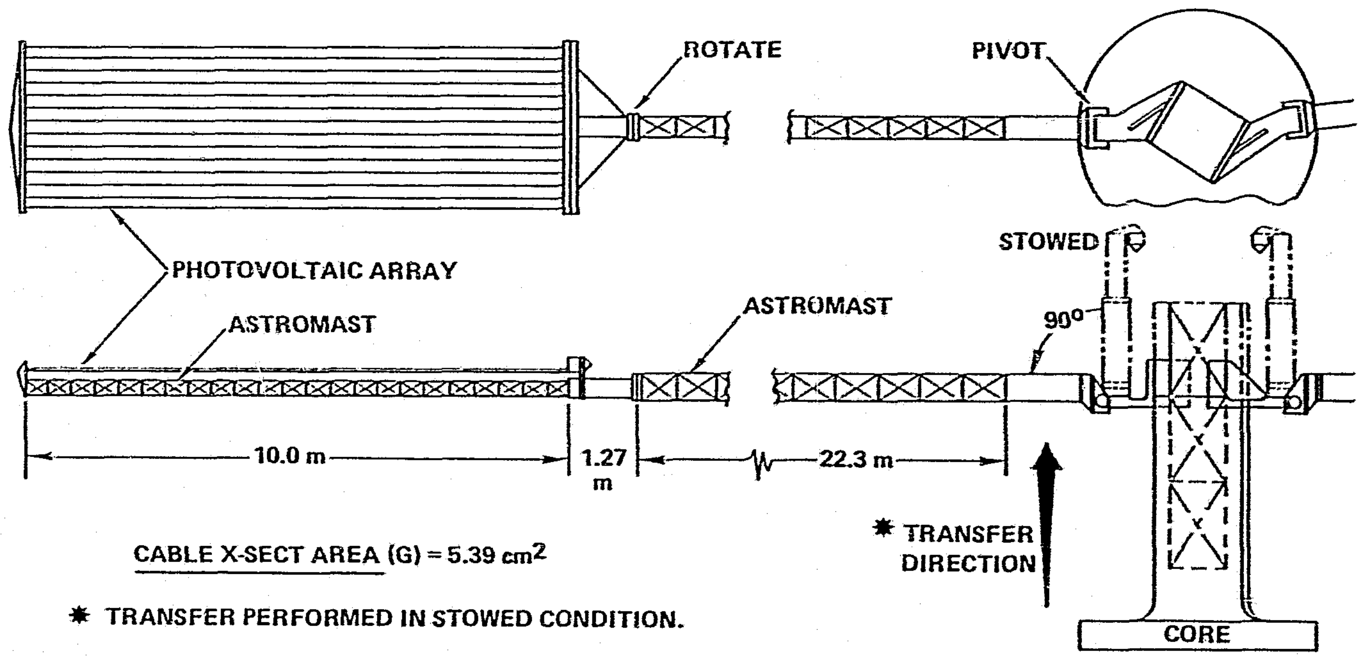
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: PIVOTING EXTENDABLE ARMS (G)
PAYLOADS SUPPORTED: SOLAR ARRAY (PLATFORM POWER)

Utility Requirements									Utility Combined Weight	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
6	6	6	10	—	—	—	—	—	1.592	1	90	1	UNLIM	—	—	22.3 10.0 (SOLAR ARRAY)



CABLE X-SECT AREA (G) = 5.39 cm^2

✱ TRANSFER PERFORMED IN STOWED CONDITION.

TASK 11 DATA SHEET — LSST UTILITIES

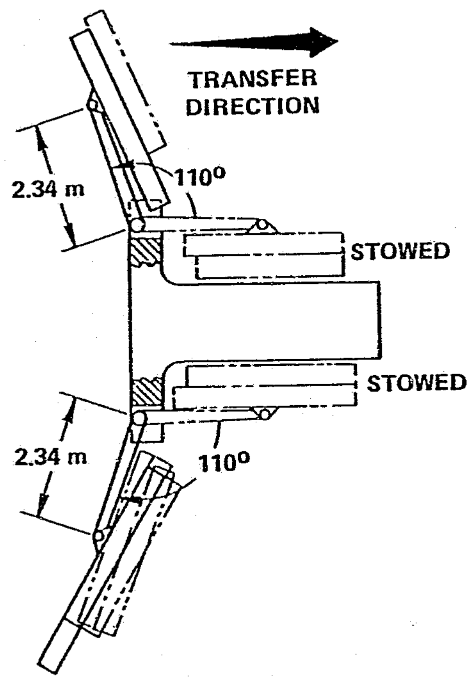
ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

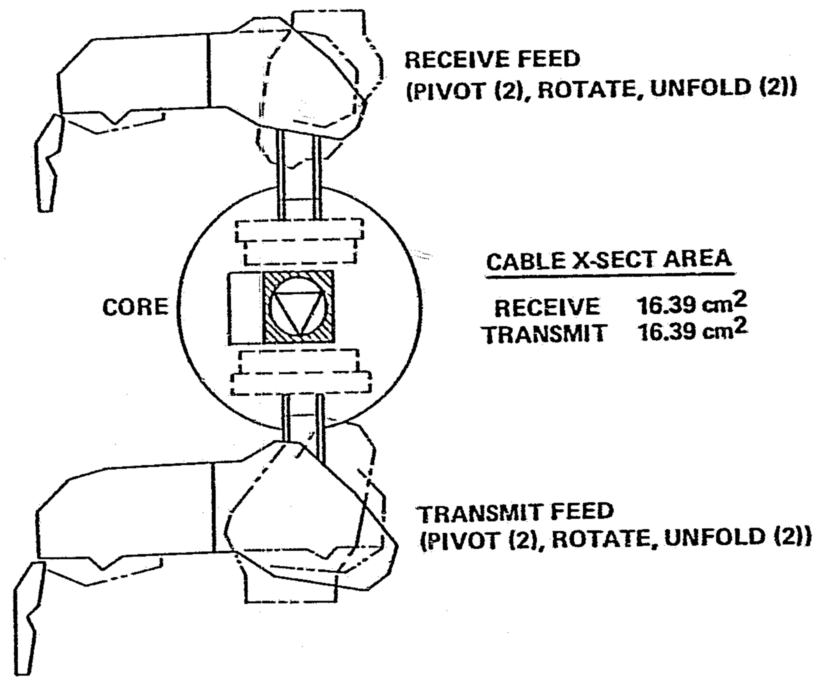
POWER: 100 VDC

TRUCTURAL ELEMENT: PIVOTING ARMS (H)
PAYLOADS SUPPORTED: NO. 2.1 TRANSMIT & RECEIVE EEEDS

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)	
4	18	10	22	FO	65	—	—	—	1.231	{ 1 { 1	110 10±0.5	1	90	—	—	—	*
4	18	10	22	FO	65	—	—	—	1.231	{ 1 { 2	110 2±0.5	1	90	—	—	—	**

* Receive
** Transmit





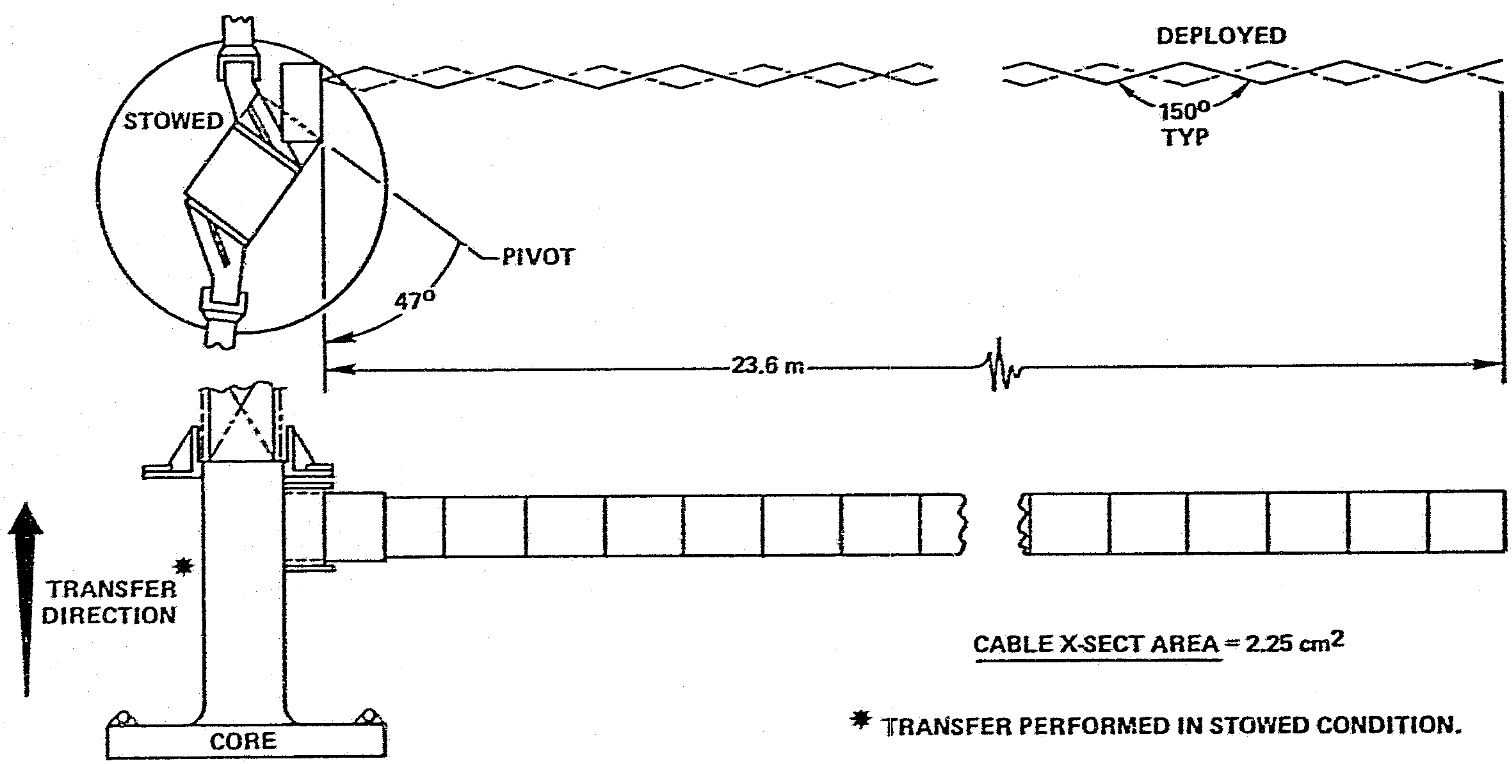
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 1 (Contd)

POWER: 100 VDC

STRUCTURAL ELEMENT: PIVOTING MODULE
PAYLOADS SUPPORTED: RADIATOR (PLATFORM THERMAL CONT.)

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
—	—	4	19	—	—	FLUID LINES	2	2.5	1.349	1	90	—	—	—	—	—
										18	150	(RADIATOR PANELS — 23.6 m)				



CABLE X-SECT AREA = 2.25 cm^2

* TRANSFER PERFORMED IN STOWED CONDITION.

Operational Concept Alternative #1, Platform 1 LSST Utilities Accommodation

PLATFORM PAYLOAD OR FUNCTIONAL SUBSYSTEM		UTILITY REQUIREMENTS													SERVICES ROUTING								NOTES
		Power(1) Distribution		Actuator Commands			Data Transmission		Fiber Optics		Other Utility Services			Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast		(1) 108 VDC
DESCRIPTION	Qty	Bus Qty	AWG	Function	TSP Qty	AWG	TSP Qty	AWG	Qty	Size (mm)	Function	Qty	Size (cm)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)	ID	
PAYLOAD #2.1 – Comm Dom, Reg, Oceanic Trunking • Transmit Reflector	1	—	—	Extend (2) Pivot, Gimbal	6 TSP 18	22 26	—	—	—	—	—	—	—	1	110 ±0.5	(Gimbal) 1	 ±0.5	—	—	17.3 14.9	A B	LMSC wrapped rib Astromasts (2)
• Transmit Feed Assy	1 NA 1 CA 1 SA	4	18	Pivot (2), Rotate, Unfold	10 TSP 18	22 26	4 TSP	26	65	1.3	—	—	—	1 1	110 2 ± 0.5	1	90	—	—	—		Feed – 180° & 97° pivot hinges
• Receive Reflector	1	—	—	Extend (2), Pivot, Gimbal	6 TSP 18	22 26	—	—	—	—	—	—	—	1	118 ±0.5	(Gimbal) 1	 ±0.5	—	—	17.3 11.8	A C	LMSC wrapped rib Astromasts (2)
• Receive Feed Assy	1 NA 1 CA 1 SA	4	18	Pivot (2), Rotate, Unfold	10 TSP 18	22 26	4 TSP	26	65	1.3	—	—	—	1 1	118 18 ± 0.5	1	90	—	—	—		Feed – 186° & 97° pivot hinges
PAYLOAD #3 – TV Distribution Assembly	1	—	—	Pivot, Translate, Rotate	6 TSP	22	—	—	—	—	—	—	—	1	90	1	90	1	1.6	—	E	
• Main Reflector	2	—	—	Telescope (2), Pivot	6 TSP	2	—	—	—	—	—	—	—	1	15	—	—	2	1.2	—	E	
• Transmit Feed	2	4	10	Telescope (2)	4 TSP	22	4 TSP	26	75	1.3	Radiator Fluid Lines	2 (Total)	2.5	—	—	—	—	2	1.4	—	E	
• Subreflector	2	—	—	Telescope, (Ang. Indicat.)	3 TSP	22	—	—	—	—	—	—	—			—	—	1	0.6	—	E	
• Receive Feed	2	4	18	Telescope	2 TSP	22	4 TSP	26	75	1.3	—	—	—	—	—	—	—	1	0.7	—	E	
PAYLOAD #31 – DMSP Data Relay	1	4	18	Pivot	—	—	4 TSP	26	—	—	—	—	—	1	90	—	—	—	—	—	E	Fixed to Arm E
PAYLOAD #11 – Inter-Satellite Comm Link	1	4	15	Extend (2), Pivot, Rotate, Unfurl	6 18	22 26	7 4	26 26	4	1.3	—	—	—	1	120	1	±180	—	—	17.3 3.7	A D	TRW SunflowerAstromasts (2)
PAYLOAD #33 – Materials Exposure, DOD Exp	1			Pivot	2	22	5 Coax 4 TSP	RG 303 26	—	—	—	—	—	1	90	—	—	—	—	—	F	Fixed to Arm F
PAYLOAD #43 – Magnetic Substorm Monitor – DOD	1	4	18	Pivot	—	—	3 Coax 4 TSP	RG 303 26	—	—	—	—	—	1	90	—	—	—	—	—	F	Fixed to Arm F
PAYLOAD #56 – Fiber Optics Demo – DOD Exp	1			Pivot	—	—	4 TSP	26	1	1.3	—	—	—	1	50	—	—	—	—	—	F	Fixed to Arm F
Solar Panels	2	6	6	Pivot, Rotate, Extend	6 6	22 26	4	26	—	—	—	—	—	1	90	1	Unlim	—	—	22.3 10.0*	G	Commutated Rotary Joint. *No services thru 2nd Astromast
Radiator	1			Rotate, Unfold	4	22	19 TSP Analog	26	—	—	Fluid Lines	2	2.5	1	47	—	—	—	—	23.6	Core	
Batteries	4	6	6	Arm/Safe	2	22	4 TSP	26	—	—	Vent	1	1.0	1	90	—	—	—	—	—	F	Fixed to Arm F
Reaction Wheels – Yaw	2	2	18	Speed Control	2 TSP	26	4 TSP	26	—	—	—	—	—	Fixed to Core							Core	
– Pitch & Roll	5	2	18	Speed Control	2 TSP	26	4 TSP	26	—	—	—	—	—	1	90						E	Fixed to Arm E
ACS Propellant Tanks	3	—	—	Shut Off	2 TSP	22	4 TSP	26	—	—	Feed & Vent	2	1.0	1	90						F	Fixed to Arm F
Thruster Clusters	3	—	—	ON/OFF	2 TSP	22	4 TSP	26	—	—	Prop Feed	1	0.5	Fixed to Core							Core	
Disconnect Panel	1	4	18	Disengage from OTV	2 TSP	22	20	26	—	—	Fluid Vent	1	1.0					3	0.1		Core	

ALTERNATIVE 1

PLATFORM NO. 2

Alternative 1, Platform No. 2 Wire Sizing

E = 400 VAC; ΔE = 4V

E = IR; Power = EI

Assume drop of 1% is permissible, or ΔE = 2V.

Assume peak power = 2 X average power.

Assume redundant hot/ground wires, i.e., 4 wires/function.

Assume minimum wire size of #18 AWG.

PAYLOAD	P AVG POWER (W)	LENGTH ℓ (FT)	$I = \frac{2P}{E}$ (AMPS)	$R = \frac{\Delta E}{I}$ (OHMS FOR ℓ)	R FOR 1,000 FT (OHMS)	AWG #
#1.1 XMITTER	500	20	2.50	1.6	80	18
#1.1 RECEIVER	167	40	0.84	4.8	120	18
#7	1200	45	6.00	0.67	14.8	18
#11	300	55	1.50	2.67	48.5	18
#27 MAST	33	180	0.17	24.24	135	18
#27 AXIAL	100	40	—	—	—	18
SOLAR PANELS (DBL)	3915	25	19.6	0.20	8.2	18

Alternative 1 — Platform No. 2 Services Compilation

STRUCTURAL COMPONENT A — Consisting of three telescoping struts and a double pivoting arm

A_3 (8) AWG 19, (8 TSP) AWG 26, (3 COAX) RG 303, 2.5 x 5 Waveguide

685.5 lb/1,000 ft = 1.020 kg/m

A_2 (12) AWG 18, (12 TSP) AWG 26, (6 COAX) RG 303, (4 TSP) AWG 22,

(270) 1.3 mm FO 1,076.9 lb/1,000 ft = 1.603 kg/m

(plus two TSP for A_3 telescoping) (8 TSP) AWG 22

1,221.8 lb/1,000 ft = 1.818 kg/m

A_1 (12) AWG 18, (12 TSP) AWG 26, (6 COAX) RG 303, (14 TSP) AWG 22,

(270) 1.3 mm FOS 1,439.3 lb/1,000 ft = 2.142 kg/m

Assumes that (2 TSP) 22 AWG are required for each telescoping section — may not be necessary. Total deployment may be feasible via cable or belt drive with only 1 drive motor & fully deployed position sensor, i.e., 2 TSP total, which are connected at the telescoping strut base.

(A_1) (12) AWG 18, (12 TSP) AWG 26, (6 COAX) RG 303, (8 TSP) AWG 22,

(270) 1.3 mm FOS 1,221.8 lb/1,000 ft = 1.818 kg/m

STRUCTURAL COMPONENT B — See Data Sheet

627.1 lb/1,000 ft = 0.933 kg/m

STRUCTURAL COMPONENT C — Individual Telescope Drives

BASE STRUT:

(4) 18 AWG, (12 TSP) 22 AWG, (29 TSP) 26 GA, (4) 1.3 mm FOS

908.8 lb/1,000 ft = 1.352 kg/m

FOR CABLE ACTIVATED TELESCOPE — See Data Sheet — Wire Count

618.9 lb/1,000 ft = 0.921 kg/m

STRUCTURAL COMPONENT D — See Data Sheet

142.6 lb/1,000 ft = 0.212 kg/m

STRUCTURAL COMPONENT E — See Data Sheet

356.9 lb/1,000 ft = 0.531 kg/m

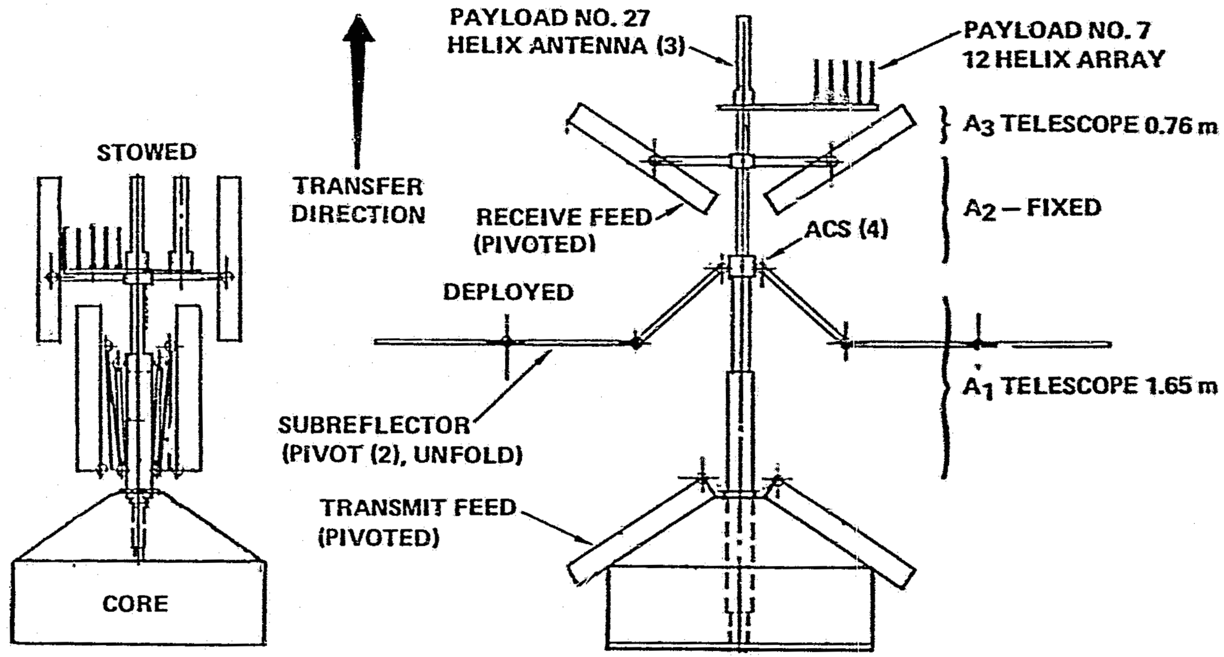
TASK 11 DATA SHEET – LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 2

POWER: 400 VDC

STRUCTURAL ELEMENT: CENTRAL TELESCOPING MAST (A)
PAYLOADS SUPPORTED: NO. 1.1 RECEIVE FEED & SUBREFL, NO. 7, NO. 27

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing							
Power Distribution		Qty of 22 AWG TSP	Qty of 26 AWG TSP	Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG			Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
8	18	—	8	RG303	3	FIBER OPTIC		1.3 mm	1.020					1	0.76		A_3
12	18	4	12	RG303	6	FIBER OPT	270	1.3 mm	1.603	1	56			1			A_2
12	18	16	12	RG303	6	FIBER OPT	270	1.3 mm	2.451	2	50			2	1.65		A_1
						ACS FEED	2	1.0			140						



CABLE X-SECT AREA

$(A_3) = 1.89\ cm^2$
$(A_2) = 19.53\ cm^2$
$(A_1) = 20.45\ cm^2$

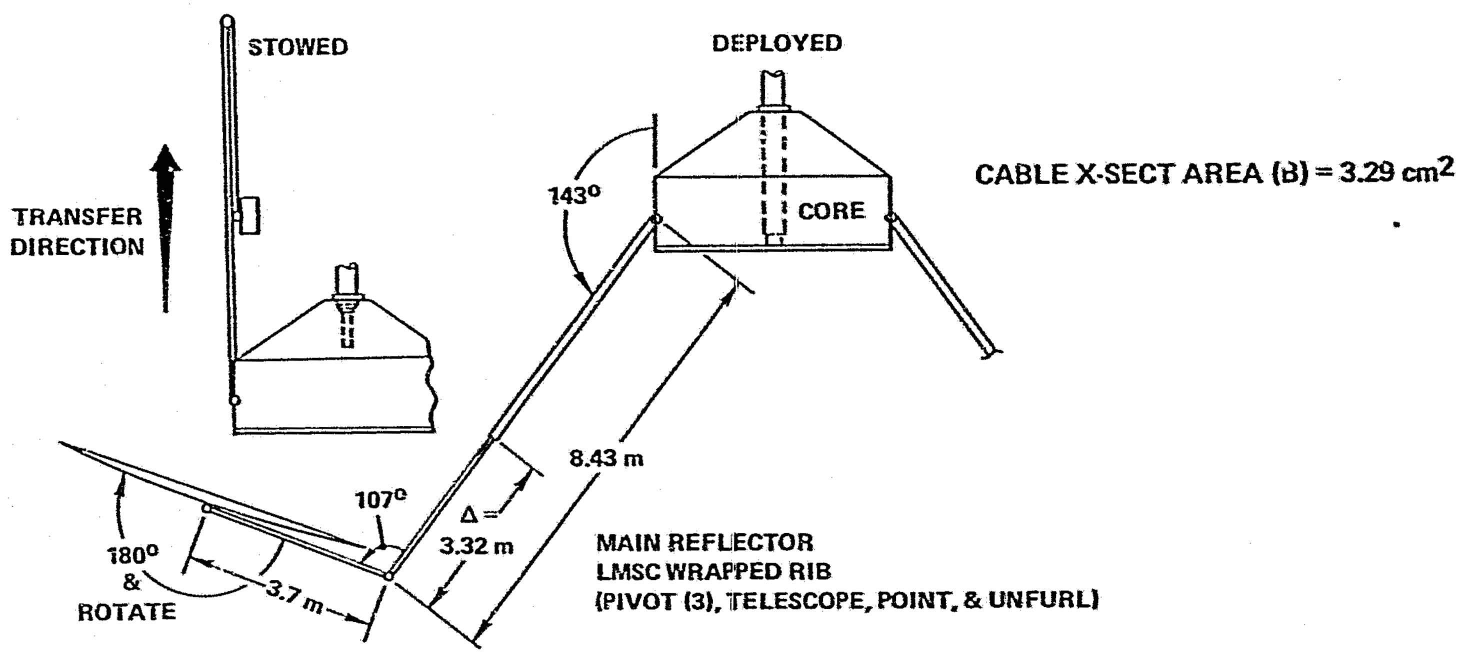
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 2 (Contd)

POWER: 400 VDC

STRUCTURAL ELEMENT: PIVOTING/TELESCOPING ARM (B)
PAYLOADS SUPPORTED: NO. 1.1 MAIN REFLECTOR

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
—	—	9	21	—	—	—	—	—	0.933	1	143			1	3.32	—
										1	107					
										1	180	1	±0.5			



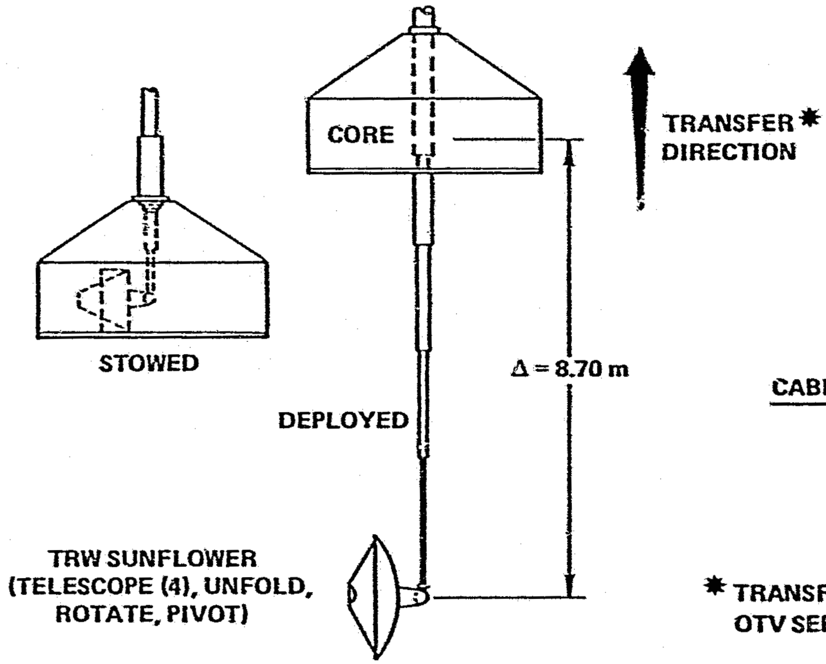
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 2 (Contd)

POWER: 400 VDC

STRUCTURAL ELEMENT: CENTRAL TELESCOPING MAST (C)
PAYLOADS SUPPORTED: NO. 11 INTERSATELLITE COMM LINK

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
4	18	4	29	FO	4	—	—	—	0.921	1	+30 −90	1	±180	4	8.70	



CABLE X-SECT AREA (C) = 3.68 cm²

* TRANSFER PERFORMED IN STOWED CONDITION.
OTV SEPARATION REQUIRED PRIOR TO DEPLOYMENT.

TASK 11 DATA SHEET — LSST UTILITIES

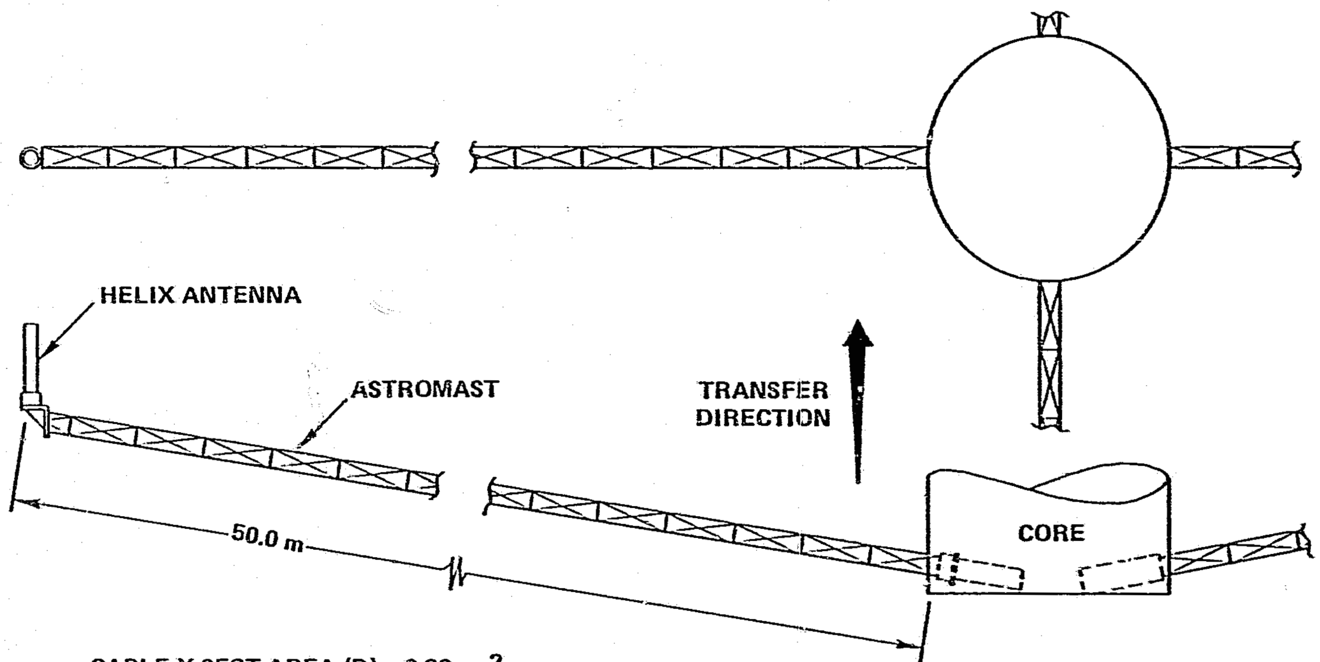
ALTERNATIVE 1, PLATFORM NO. 2 (Contd)

POWER: 400 VDC

STRUCTURAL ELEMENT: EXPANDING MAST (D)

PAYLOADS SUPPORTED: NO. 27 RF INTERFEROMETER

Utility Requirements									Utility Combined Weight	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
4	18	—	4	RG303	1	—	—	—	0.212	—	—	—	—	—	—	50.0



CABLE X-SECT AREA (D) = 0.86 cm^2

TASK 11 DATA SHEET – LSST UTILITIES

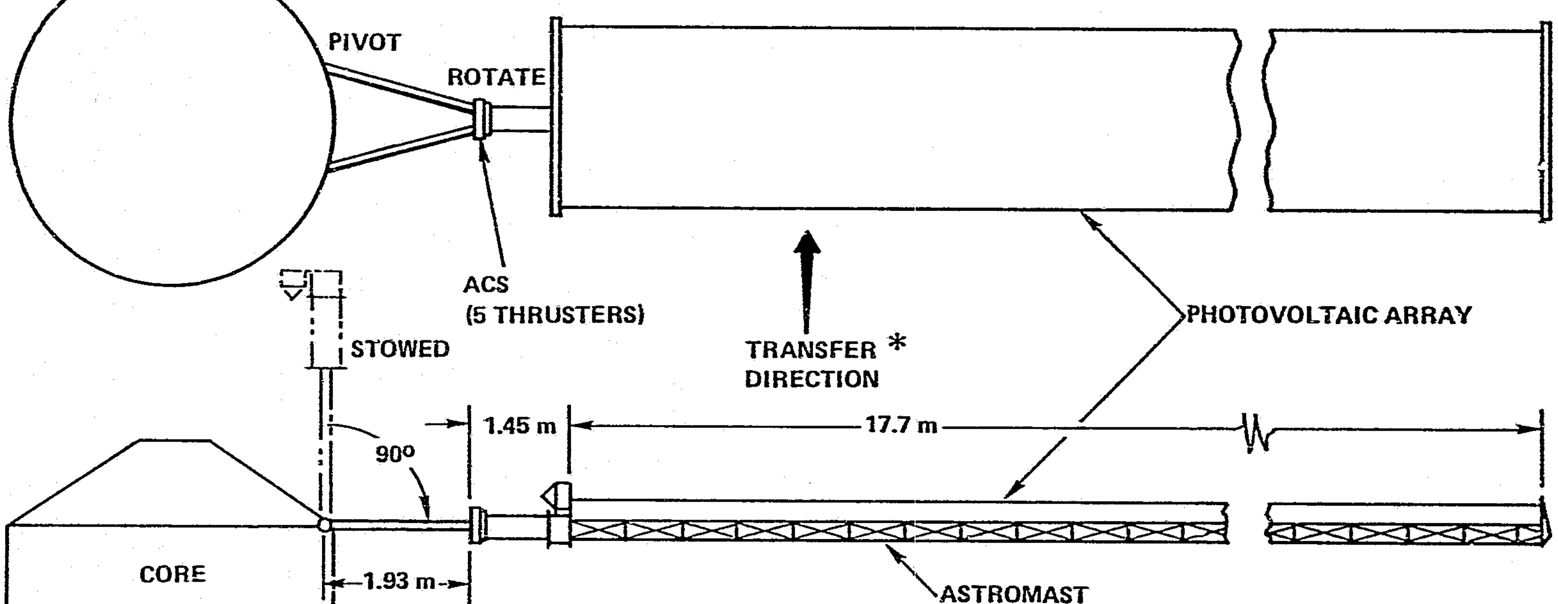
ALTERNATIVE 1, PLATFORM NO. 2 (Contd)

POWER: 400 VDC

STRUCTURAL ELEMENT: PIVOTING ARM (E)
PAYLOADS SUPPORTED: SOLAR ARRAY (PLATFORM POWER)

Utility Requirements									Utility Combined Weight	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)
8	16	12	10			ACS FEED	2	1.0	1.272	1	90	1	UNLIM.			17.7 (SOLAR ARRAY)

CABLE X-SECT AREA (E) = 2.47 cm^2



*TRANSFER PERFORMED IN STOWED CONDITION.

Operational Concept Alternative #1, Platform 2 LSST Utilities Accommodation

PLATFORM PAYLOAD OR FUNCTIONAL SUBSYSTEM		UTILITY REQUIREMENTS													SERVICES ROUTING								NOTES
		Power (1) Distribution		Actuator Commands			Data Transmission		Fiber Optics		Other Utility Services			Formed Support		Rotating Joint		Telescoping Boom		Expand Mast			(1) 400 VAC †Telescoping Act. Wire Count Not Included.
DESCRIPTION	Qty	Sec Qty	AWG	Function	TSP Qty	AWG	Qty	AWG	Qty	Size (mm)	Function	Qty	Size (cm)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)	[illegible]	
PAYLOAD #11 – Direct to User Comm Networks	1 RA 1 CA 1 SA								145 65 68	1.2 1.2 1.2	Radiator Fluid Lines	2	2.5									
• Transmit Array		4	12	Point	2	22	4 TSP	26						1	124	-	—	—	—	—	Core	
• Subreflector	3	-	—	Telescope, Point (2), Unfold	6	22	—	—	—	—	—	-	—	{1 {1	58 148	-	—	1	1.72	—	A1	
• Receive Array	{1 RA {1 CA {1 SA	4	12	Telescope (2), Point†	2	22	4 TSP	26	145 65 68	1.2 1.2 1.2	—	-	—	1	58	-	—	2	2.08	—	A1A2	
• Main Reflector	3	-	—	Tilt, Point (2), Rotate, Unfold	3 21	22 26	—	—	—	—	—	-	—	{1 {1 {1	142 167 123	1	±8.5	1	1.32	—	B	LMSC wrapped rib
PAYLOAD #7 – Air Mobile Communications 12 Helix Array & Mast	1	4	12	Telescope (3) †	—	—	4 TSP 2** Coax	26 RG 142	—	—	Waveguide Upper Tele to Antenna	1	2.5 X.S.B	-	—	-	—	3	2.75	—	A1A2A3	**Lower Telescoping Section
PAYLOAD #11 – Inter-satellite Comm Link	1	4	12	Rotate, Unfold, Tilt (4), Point †	4 16	22 26	4 TSP 7 TSP	26 26	4	1.3	—	-	—	1	{+38 {-16	1	±180		2.75	—	C	TRW Sunflower
PAYLOAD #27 – RF Interferometer																						
• Mast Mtd Sensors	4	4	12	Extend	—	—	4 TSP 1 Coax	26 RG 393	—	—	—	-	—	-	—	-	—	—	—	58	D	Astromast
• Arm Mtd Sensors Cluster of (3)	1	4	12	Telescope (3) †	—	—	3 Coax 4 TSP	RG 393 26	—	—	—	-	—	-	—	-	—	3	2.75		A1A2A3	
Solar Panels	2	8	16	Point, Rotate, Extend	2 6	22 26	4 TSP	26	—	—	—	-	—	1	58	1	Unlim	—	—	17.7*	E	Commercial Rotary Joint. *No Interface thru Astromast.
Radiator	1	—	—	Rotate, Unfold, Pump	4	22	11 TSP Analog	26	—	—	Fluid Lines	2	2.5	1	36	-	—	—	—	11.5	F	
Batteries	4	4	56	Actu/Tube	2	22	4 TSP	26	—	—	Vent	1	1.8	Fixed to Core							Core	
Reaction Wheels	7	2	18	Speed Control	2 TSP	26	4 TSP	26	—	—	—	-	—	Fixed to Core							Core	
Attitude Control System																						
• Propellant Tanks	2	-	—	Shut Off	2 TSP	22	4 TSP	26	—	—	Feed & Vent	2	1.8	Fixed to Core							Core	
• Thruster Clusters	3	-	—	ON/OFF	2 TSP	22	4 TSP	26	—	—	Prop Feed	1	0.5	Fixed to Core							Core	
Switch Matrix	1													Fixed to Core							Core	
Disconnect Panel	1	4	12	Disengage from OTV	2	22	28 TSP	26	—	—	Fluid Vent	1	1.9	-	—	—	—	2	8.1	—	Core	

ALTERNATIVE 1

PLATFORM NO. 6

Alternative 1, Platform No. 6 Wire Sizing.

$E = 400$ VAC; $\Delta E = 4V$

$E = IR$; Power $= EI$

Assume drop of 1% is permissible, or $\Delta E = 2V$.

Assume peak power = 2 X average power.

Assume redundant hot/ground wires, i.e., 4 wires/function.

Assume minimum wire size of #18 AWG.

PAYLOAD	P AVG POWER (W)	LENGTH ℓ (FT)	$I = \frac{2P}{E}$ (AMPS)	$R = \frac{\Delta E}{I}$ (OHMS FOR ℓ)	R FOR 1,000 FT (OHMS)	AWG #
#1.2 XMITTER	2,000	40	10	0.4	10.0	18
#1.2 RECEIVER	167	10	0.85	4.7	471	18
#11	300	50	1.5	2.67	53	18
#19	100	30	0.5	—	—	18
#54	500	30	0.5	—	—	18
SOLAR PANELS (DBL)	2,600	32	13	0.31	9.62	18

Alternative 1 — Platform No. 6 Services Compilation

STRUCTURAL COMPONENT A — Consisting of three telescoping struts

A_2 8 (18 AWG), 6 TSP (22 AWG), 33 TSP (26 AWG), 583 (1.3 mm FOS)

1,669.6 lb/1,000 ft = 2.485 kg/m

A_1 8 (18 AWG), 12 TSP (22 AWG), 33 TSP (26 AWG), 583 (1.3 mm FOS)

1,886.9 lb/1,000 ft = 2.808 kg/m

FOR CABLE ACTUATED TELESCOPE

A_1 8 (18 AWG), 10 TSP (22 AWG), 33 TSP (26 AWG), 583 (1.3 mm FOS)

1814.4 lb/1,000 ft = 2.700 kg/m

STRUCTURAL COMPONENT B — See Data Sheet

482.1 lb/1,000 ft = 0.718 kg/m

STRUCTURAL COMPONENT C — See Data Sheet

829.2 lb/1,000 ft = 1.234 kg/m

STRUCTURAL COMPONENT D — See Data Sheet

519.3 lb/1,000 ft = 0.773 kg/m

STRUCTURAL COMPONENT E — See Data Sheet

356.9 lb/1,000 ft = 0.531 kg/m

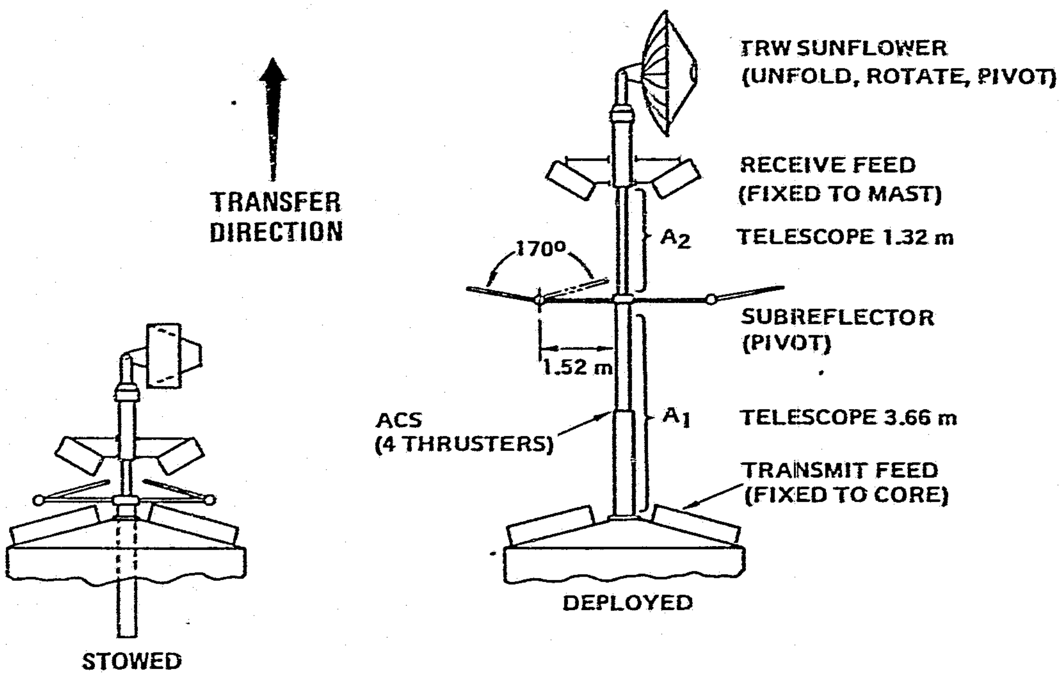
TASK 11 DATA SHEET – LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6

POWER: 400 VAC

STRUCTURAL ELEMENT: CENTRAL TELESCOPING MAST (A)
PAYLOADS SUPPORTED: NO. 1.2 RECEIVE FEED & SUBREFL, NO. 11

Utility Requirements									Utility	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services			Combined Weight	Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast	
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)	
8	18	6	33	FO	583				2.485	1	+90 –30	1	+180	1	1.32		A_2
8	18	18	33	FO	583	ACS FEED	2	1.0	3.333	3	170			2	3.66		A_1



CABLE X-SECT AREA
$(A_2) = 38.52\ cm^2$
$(A_1) = 39.44\ cm^2$

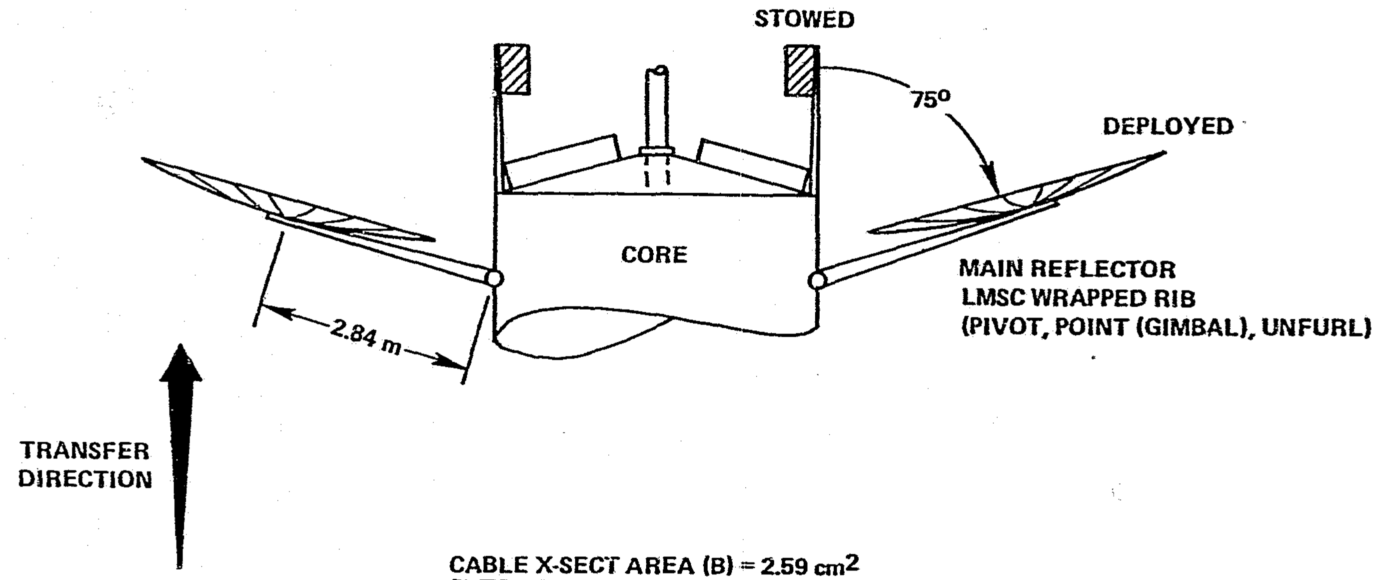
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6 (Contd)

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING ARM (B)
PAYLOADS SUPPORTED: NO. 1.2 MAIN REFLECTOR

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG TSP	Qty of 26 AWG TSP	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG			Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
—	—	5	21	—	—	—	—	—	0.718	1 1	75 ±0.5	1	±0.5	—	—	—



CABLE X-SECT AREA (B) = 2.59 cm^2

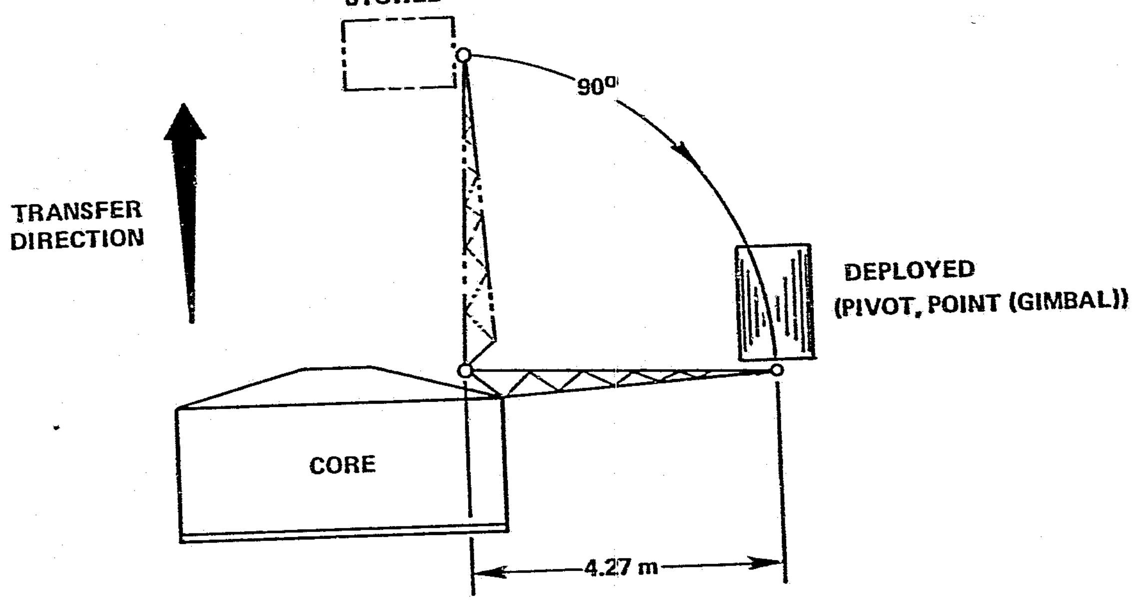
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6 (Contd)

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING ARM (C)
PAYLOADS SUPPORTED: NO. 19 VISUAL & IR RADIOMETER

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing							
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
4	18	3	46	FO	6	—	—	—	1.234	1 1	90 ±0.5	1	±0.5	—	—	—



CABLE X-SECT AREA (C) = 5.01 cm^2

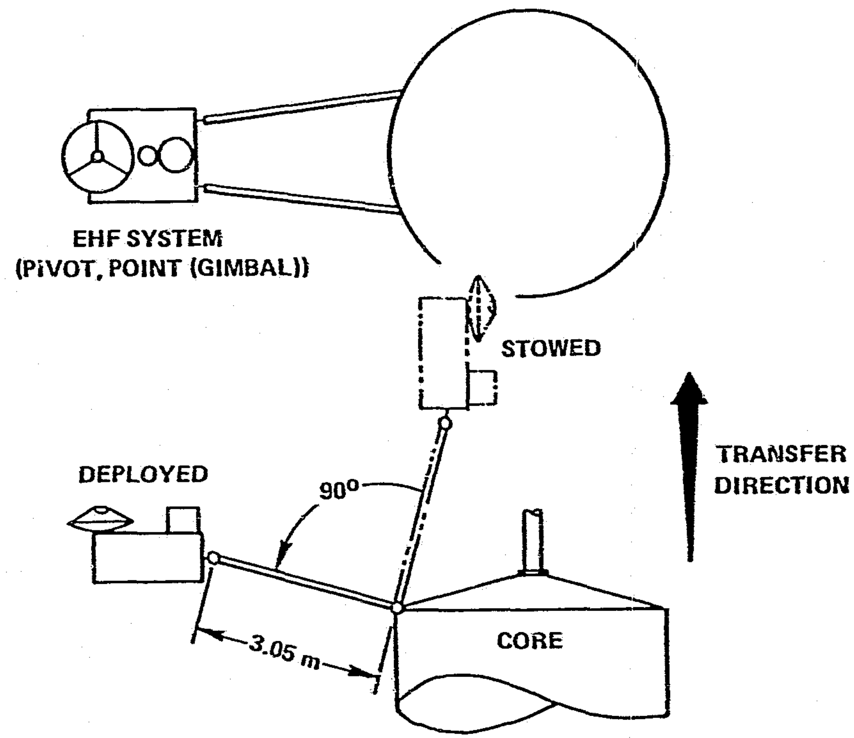
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6 (Contd)

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING ARM (D)
PAYLOADS SUPPORTED: NO. 54 EHF SYSTEM

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
4	18	3	25	—	—	—	—	—	0.773	1 1	90 ±0.5	1	±0.5	—	—	—



CABLE X-SECT AREA (D) = 2.94 cm^2

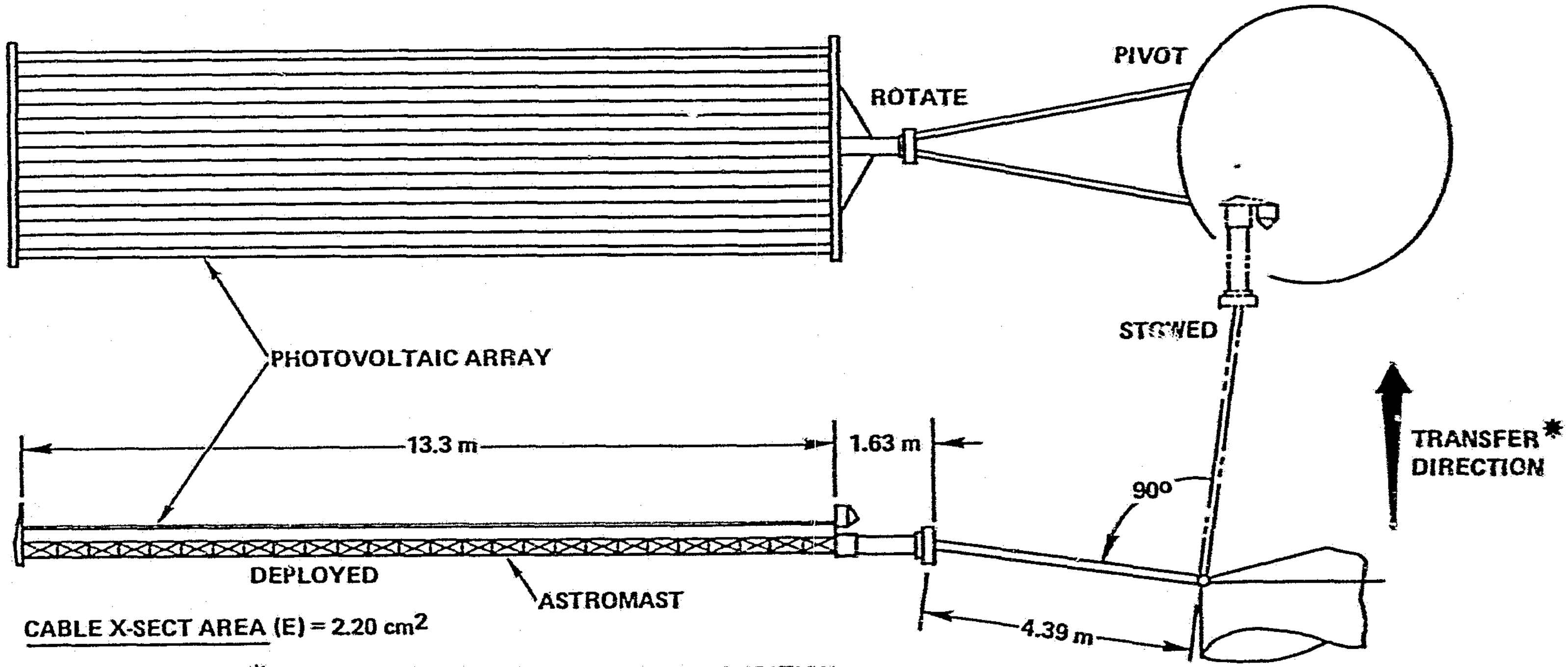
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6 (Contd)

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING ARM (E)
PAYLOADS SUPPORTED: SOLAR ARRAY (PLATFORM POWER)

Utility Requirements									Utility Combined Weight (kg/m)	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)		Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)
8	16	2	10	—	—	—	—	—	0.531	1	90	1	UNLIM	—	—	13.3 (SOLAR ARRAY)



CABLE X-SECT AREA (E) = 2.20 cm^2

* TRANSFER PERFORMED IN STOWED CONDITION.

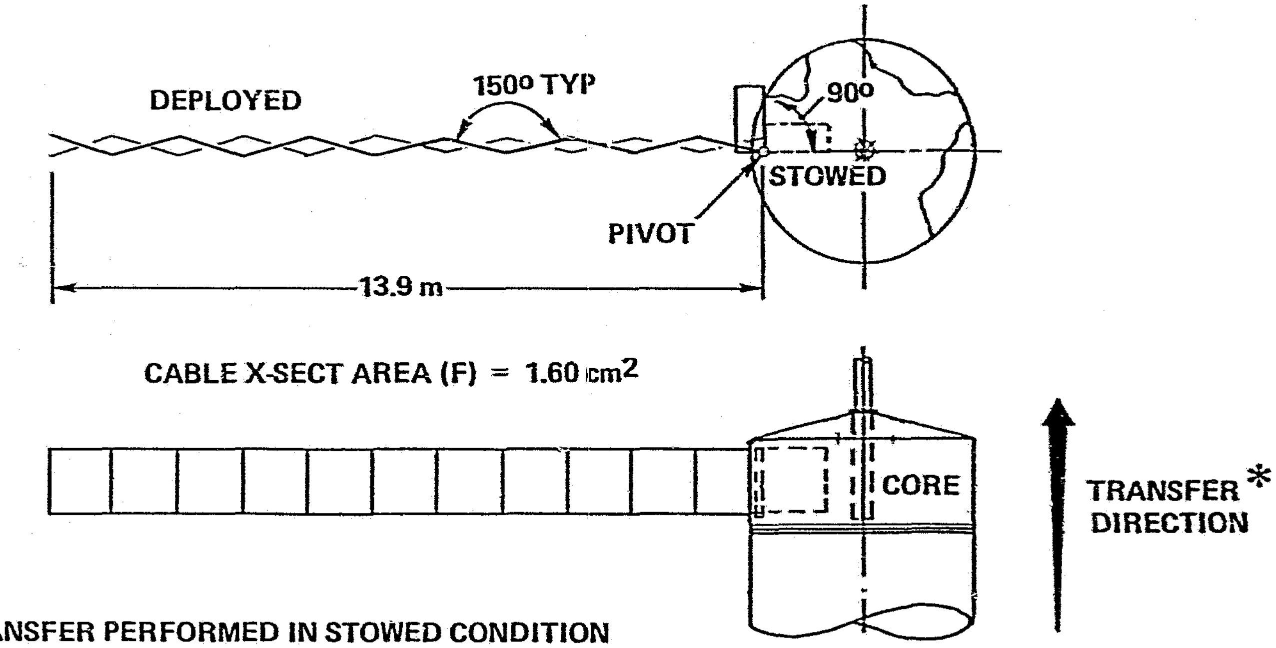
TASK 11 DATA SHEET — LSST UTILITIES

ALTERNATIVE 1, PLATFORM NO. 6 (Contd)

POWER: 400 VAC

STRUCTURAL ELEMENT: PIVOTING MODULE (F)
PAYLOADS SUPPORTED: RADIATOR (PLATFORM THERM. CONT.)

Utility Requirements									Utility Combined Weight	Services Routing						
Power Distribution		Qty of 22 AWG	Qty of 26 AWG	Fiber Optic or Coax Data		Other Services				Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast
Qty	AWG	TSP	TSP	Type	Qty	Function	Qty	Size (cm)	(kg/m)	Qty	Deg	Qty	Deg	Qty	ΔL(m)	ΔL(m)
		4	11			FLUID LINES	2	2.5	1.178	1	90					
										10	150	(RADIATOR PANELS — 13.9 m)				



* TRANSFER PERFORMED IN STOWED CONDITION

Operational Concept Alternative #1, Platform 6 LSST Utilities Accommodation

PLATFORM PAYLOAD OR FUNCTIONAL SUBSYSTEM		UTILITY REQUIREMENTS													SERVICES ROUTING								NOTES
		Power(1) Distribution		Actuator Commands			Data Transmission		Fiber Optics		Other Utility Services			Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast		(1) 400 VAC †Telescoping Act. Wire Count Not Included.
DESCRIPTION	Qty	Bus Qty	AWG	Function	TSP Qty	AWG	Qty	AWG	Qty	Size (mm)	Function	Qty	Size (cm)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)	ID	
PAYLOAD #1.2 – Direct to User Comm Networks • Receive Array	1 NA 1 CA 1 SA	4	18	Telescope (3)	1		4 TSP	26	379 105 95	1.3 1.3 1.3	—	—	—	—	—	—	—	3	4.98	—	A1A2	
• Subreflector	3	—	—	Telescope (2), Pivot†	2	22	—	—	—	—	—	—	—	1	170	—	—	2	3.66	—	A1	
• Transmit Array	1 NA 1 CA 1 SA	4	18	—	—	—	4	26	379 105 95	1.3 1.3 1.3	Radiator Fluid Lines	2	2.5	Fixed to Core				—	—	—	Core	
• Main Reflector	3	—	—	Pivot (2), Rotate, Unfurl	5 21	22 26	—	—	—	—	—	—	—	1 1	75 ±0.5	1	±0.5	—	—	—	B	LMSC wrapped rib
PAYLOAD #11 – Inter-satellite Comm Link	1	4	18	Rotate, Unfurl Tele (3), Pivot †	18 4	26 22	4 TSP 7 TSP	26 26	4	1.3	—	—	—	1	+90 -30	1	±180	3	4.98	—	A1A2	TRW Sunflower
PAYLOAD #19 – Visual and IR Radiometer	1	4	18	Pivot Gimbal	3 42	22 26	4	26	6	1.3	—	—	—	1 1	±0.5 90	1	±0.5	—	—	—	C	
PAYLOAD #54 – EHF System	1	4	18	Pivot Gimbal	3 21	22 26	4	26	—	—	—	—	—	1 1	±0.5 90	1	±0.5	—	—	—	D	
Solar Panels	2	8	16	Pivot, Rotate, Extend	2 6	22 26	4 TSP	26	—	—	—	—	—	1	90	1	Unlim	—	—	13.3*	E	Commutated Rotary Joints. *No services thru Astromast.
Radiator	1	—	—	Rotate, Unfold, Pump	4	22	11 TSP Analog	26	—	—	Fluid Lines	2	2.5	1	90	—	—	—	—	11.5	F	
Batteries	4	4	16	Arm/Safe	2	22	4 TSP	26	—	—	Vent	1	1.0	Fixed to Core							Core	
Reaction Wheels	7	2	18	Speed Control	2 TSP	26	4 TSP	26	—	—	—	—	—	Fixed to Core							Core	
Attitude Control System																						
• Propellant Tanks	3	—	—	Shut Off	2 TSP	22	4 TSP	26	—	—	Feed & Vent	2	1.0	Fixed to Core							Core	
• Thruster Clusters	3	—	—	ON/OFF	2 TSP	22	4 TSP	26	—	—	Prop Feed	1	0.5	Fixed to Core							Core	
Switch Matrix	1													Fixed to Core							Core	
Disconnect Panel	1	4	18	Disengage from OTV	2	22	20 TSP	26	—	—	Fluid Vent	1	1.0	—	—	—	—	3	0.1	—	Core	

Operational Concept Alternative #1, Platform 6 LSST Utilities Accommodation

PLATFORM PAYLOAD OR FUNCTIONAL SUBSYSTEM: DESCRIPTION	Qty	UTILITY REQUIREMENTS: Power(1) Distribution: Bus Qty	AWG	Actuator Commands: Function	TSP Qty	AWG	Data Transmission: Qty	AWG	Fiber Optics: Qty	Size (mm)	Other Utility Services: Function	Qty	Size (cm)	SERVICES ROUTING: Pivoted Support: Qty	Deg	Rotating Joint: Qty	Deg	Telescoping Strut: Qty	ΔL (m)	Expand Mast: ΔL (m)	ID	NOTES (1) 400 VAC †Telescoping Act. Wire Count Not Included.
PAYLOAD #1.2 – Direct to User Comm Networks • Receive Array	1 NA 1 CA 1 SA	4	18	Telescope (3)	1		4 TSP	26	379 105 95	1.3 1.3 1.3	—	—	—	–	—	—	—	3	4.58	—	A1A2	
• Subreflector	3	–	—	Telescope (2), Pivot †	2	22	—	—	—	—	—	–	—	1	178	—	—	2	3.66	—	A1	
• Transmit Array	1 NA 1 CA 1 SA	4	18	—	—	—	4	26	379 105 95	1.3 1.3 1.3	Radiator Fluid Lines	2	2.5	Fixed to Core				—	—	—	Core	
• Main Reflector	3	–	—	Pivot (2), Rotate, Unfurl	5 21	22 26	—	—	—	—	—	–	—	1 1	75 ±0.5	1	±0.5	—	—	—	B	LMSC wrapped rib
PAYLOAD #11 – Inter-satellite Comm Link	1	4	18	Rotate, Unfurl Tele (3), Pivot †	18 4	26 22	4 TSP 7 TSP	26 26	4	1.3	—	–	—	1	+90 -30	1	±180	3	4.58	—	A1A2	TRW Sunflower
PAYLOAD #19 – Visual and IR Radiometer	1	4	18	Pivot Gimbal	3 42	22 26	4	26	6	1.3	—	–	—	1 1	±0.5 90	1	±0.5	—	—	—	C	
PAYLOAD #54 – EHF System	1	4	18	Pivot Gimbal	3 21	22 26	4	26	—	—	—	-	—	1 1	±0.5 90	1	±0.5	—	—	—	D	
Solar Panels	2	8	16	Pivot, Rotate, Extend	2 6	22 26	4 TSP	26	—	—	—	-	—	1	90	1	Unlim	—	—	13.3*	E	Commutated Rotary Joints. *No services thru Astromast.
Radiator	1	—	—	Rotate, Unfold, Pump	4	22	11 TSP Analog	26	—	—	Fluid Lines	2	2.5	1	90	-	—	—	—	11.5	F	
Batteries	4	4	16	Arm/Safe	2	22	4 TSP	26	—	—	Vent	1	1.0	Fixed to Core							Core	
Reaction Wheels	7	2	13	Speed Control	2 TSP	26	4 TSP	26	—	—	—	-	—	Fixed to Core							Core	
Attitude Control System																						
• Propellant Tanks	3	–	—	Shut Off	2 TSP	22	4 TSP	26	—	—	Feed & Vent	2	1.0	Fixed to Core							Core	
• Thruster Clusters	3	–	—	ON/OFF	2 TSP	22	4 TSP	26	—	—	Prop Feed	1	0.5	Fixed to Core							Core	
Switch Matrix	1													Fixed to Core							Core	
Disconnect Panel	1	4	18	Disengage from OTV	2	22	20 TSP	26	—	—	Fluid Vent	1	1.0	–	—	—	—	3	0.1	—	Core	

ALTERNATIVE 4

Alternative 4, Platform No. 1 Wire Sizing

E = 400 VAC; ΔE = 4 V

E = IR; Power = EI

Assume drop of 1% is permissible, or ΔE = 2V.

Assume peak power = 2 X average power.

Assume redundant hot/ground wires, i.e., 4 wires/function.

Assume minimum wire size of #18 AWG.

PAYLOAD	P AVG POWER (W)	LENGTH ℓ (ft)	$I = \frac{P}{E}$ (amps)	$R = \frac{\Delta E}{I}$ (ohms for ℓ)	R FOR 1,000 FT (ohms)	AWG #
#2.1 XMITTER RECEIVER } 60 m	450	40	2.25	1.8	45	18
XMITTER RECEIVER } 25 m	750	125	3.75	1.06	8.48	18
#6 XMITTER RECEIVER	1,250	60	6.25	0.64	10.67	18
#9	4,000	90	20	0.2	2.2	18
SOLAR PANELS	18,000 (6 busses)	225	90	0.04	0.18	18
#11 XMITTER RECEIVER	300	300	1.5	2.67	8.9	18
#12 XMITTER RECEIVER	100	60	3.3	1.2	20	18

Alternative 4 — Platform No. 1 Services Compilation

STRUCTURAL COMPONENT A (Lateral Arms)

- Power = 6 (3 AWG) + 20 (18 AWG) + 4 (13 AWG) = 1,889 lb/1,000 ft
  = **2.81 kg/m**
- Commands & Data Transmission = 34 TSP (22 AWG) + 58 TSP (26 AWG)
  = 2,063 lb/1,000 ft
  = **3.07 kg/m**
- Fiber Optic = 144 (1.3 mm FOS) = 224.6 lb/1,000 ft
  = **0.33 kg/m**

TOTAL FOR COMPONENT A = 2.81 + 3.07 + 0.33
= **6.20 kg/m**

STRUCTURAL COMPONENT B (90 m Mast)

16 (18 AWG) + 22 TSP (22 AWG) + 41 TSP (26 AWG) = 1,574 lb/1,000 ft
= **2.40 kg/m**

STRUCTURAL COMPONENT C (Payload 2.1 Boom, 25 m Reflector)

4 (18 AWG) + 6 TSP (22 AWG) + 8 TSP (26 AWG) = 536 lb/1,000 ft
= **0.80 kg/m**

STRUCTURAL COMPONENT D (Payload 9 Boom)

4 (18 AWG) + 6 TSP (22 AWG) + 24 TSP (26 AWG) = 769 lb/1,000 ft
= **1.15 kg/m**

STRUCTURAL COMPONENT E (Payload 2.1 Boom, 60 m Reflector)

4 (18 AWG) + 6 TSP (22 AWG) + 24 TSP (26 AWG) = 769 lb/1,000 ft
= **1.15 kg/m**

STRUCTURAL COMPONENT F (Payloads 6 & 12 Feed Mast)

4 (18 AWG) + 11 (1.3 mm FOS) + 8 TSP (26 AWG) = 339 lb/1,000 ft
= **0.51 kg/m**

STRUCTURAL COMPONENT G (Payload 11 Mast)

4 (18 AWG), 4 TSP (22 AWG) + 29 TSP (26 AWG) + 4 (1.3 mm FOS)
= 618 lb/1,000 ft
= **0.92 kg/m**

ALTERNATIVE 4
UTILITY CROSS-SECTION AREA REQUIREMENTS

PLATFORM NO. 1 STRUCT. ELEMENT	STRUCT. ELEMENT WT (kg/m)	Σ WIRE AREAS (in^2)	CABLE AREA (in^2)	CABLE DIA (in.)	OTHER SERVICE
A	6.20	3.716	4.099	2.28	(6) 2.5 cm Fluid Lines
B	2.40	1.208	1.3324	1.303	
C	0.80	0.292	0.322	0.641	
D	1.15	0.476	0.525	0.818	
E	1.15	0.476	0.525	0.818	
F	0.51	0.235	0.2588	0.574	
G	0.92	0.5171	0.5704	0.852	

Operational Concept Alternative #4, Platform 1 LSST Utilities Accommodation

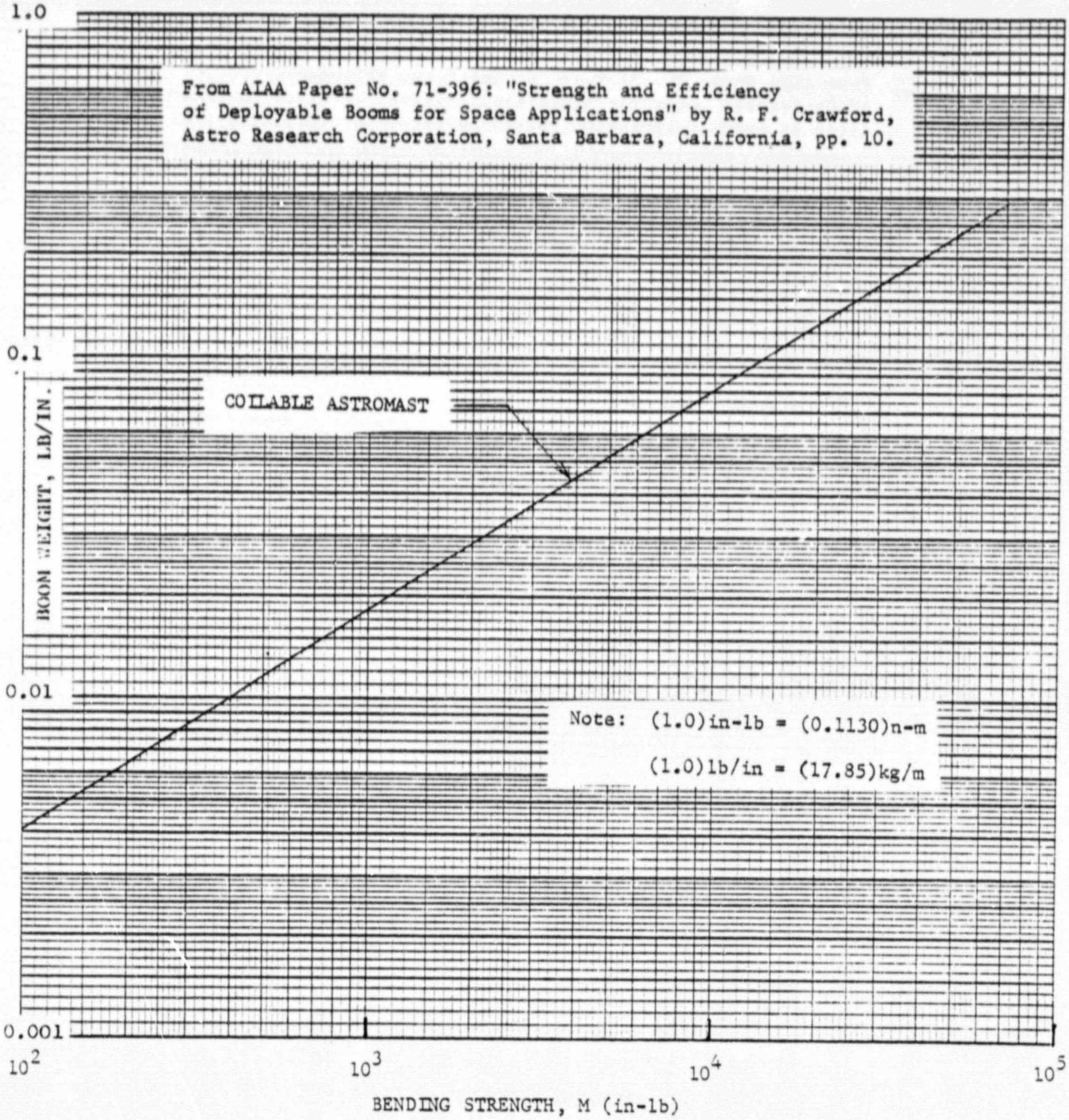
PLATFORM PAYLOAD OR FUNCTIONAL SUBSYSTEM		UTILITY REQUIREMENTS												SERVICES ROUTING								NOTES
		Power(1) Distribution		Actuator Commands			Data Transmission		Fiber Optics		Other Utility Services			Pivoted Support		Rotating Joint		Telescoping Strut		Expand Mast		(1) 400 VAC
DESCRIPTION	Qty	Bus Qty	AWG	Function	TSP Qty	AWG	Qty	AWG	Qty	Size (mm)	Function	Qty	Size (cm)	Qty	Deg	Qty	Deg	Qty	ΔL (m)	ΔL (m)	ID	
PAYLOAD #2.1 – HVT C-Band					20	26										(Gimbal)						
60m Reflector	1	—	—	Extend, Gimbal, Unfurl	6	22	4	26	—	—	—	—	—	—	—	1	±0.5	—	—	138	B,E	OOA Truss wrap rib
60m Feed Assy	1 NA	4	18	Pivot (4)	8	22	4	26	62	1.3	Rad. Line	2	2.5	5	90			—	—	—	A	5 hinged horns
25m Reflector	1	—	—	Extend, Gimbal, Unfurl	6	22	4	26	—	—	—	—	—	—	—	(Gimbal) (1 ± 0.5)		—	—	48	B,C	
25m Feed Assy	1SA, 1CA	4	18	—	—	—	4	26	43	1.3	Rad. Line	2	2.5	—	—	—	—	—	—	—	A	OOA Truss
PAYLOAD #6 – Home TV				Extend	2	22															F	Pantagraph Beam
10m Reflector	1	4	18	Unfurl,	4	22	4	26	—	—	—	—		—	—	Gimbal		—	—	—	—	
(Center Feed)				Gimbal	20	26	4	26	7	1.3	—	—	—	—	—	1 ± 0.5		—	—	7.6	A	OOA Truss
1.5m Reflector	1	4	18	Unfurl, Gimbal	6	22	4	26	7	1.3	—	—	—	—	—			—	—	—	—	
PAYLOAD #9 – Land Mobile					20	26	—	—	—	—	—	—	—	—	—	(Gimbal)						
20m Reflector	1	—	—	Extend, Gimbal, Unfurl	6	22	4	26	—	—	—	—	—	—	—	1 ± 0.5		—	—	53	B,D	OOA Truss
Feed Array	1 NA Alaska Hawaii VI	4	13	—	—	—	—	—	21	1.3	Rad. Line	2	2.5	—	—	—	—	—	—	—	A	OOA Truss
PAYLOAD #12 – Data Collection																						
10m Reflector	1	—	—	Unfurl, Gimbal	6	22	4	26	—	—	—	—	—	—	—	(Gimbal)				7.6	A	OOA Truss
Feed Array	1	4	18	Extend	4	22	4	26	4	1.3	—	—	—	—	—	1 ± 0.5					F	Pantagraph Beam
Batteries	12	6		Arm/Safe	2	22	12	26	—	—	Vent	1	1.0	(Fixed to Core)								
Reaction Wheels (Yaw, Pitch, Roll)	7	2	18	Speed Control	2	26	4	26	—	—	—	—	—	(Fixed to Core)							Core	
ACS Propellant Tanks	3	—	—	Shut Off	2	22	4	26	—	—	Feed & Vent	2	1.0	(Fixed to Core)							Core	
Thruster Clusters	3	—	—	ON/OFF	2	22	4	26	—	—	Prop Feed	1	0.5	(Fixed to Core)							Core	
Disconnect Panel	1	4	18	Disengage from OTV	2	22	2 TSP	26	—	—	Fluid Vent	1	1.0	—	—	—	—	3	0.1	—	Core	
Solar Panels	2	6	3	Extend	4	22																
				Rotate	6	26	4	26	—	—						2	360	—	—	61	A	OOA Truss
PAYLOAD #11 – IPL																						
2.4m Reflector	1																					
Center Feed	1	4	18	Unfurl, Gimbal	4	22	4	26	4	1.3	—	—	—	—	—	1	±180	—	—	90	B	TRW Sunflower
				Pivot	18	26	7	26													F	Pantagraph Beam

APPENDIX B

STRENGTH & STIFFNESS DATA

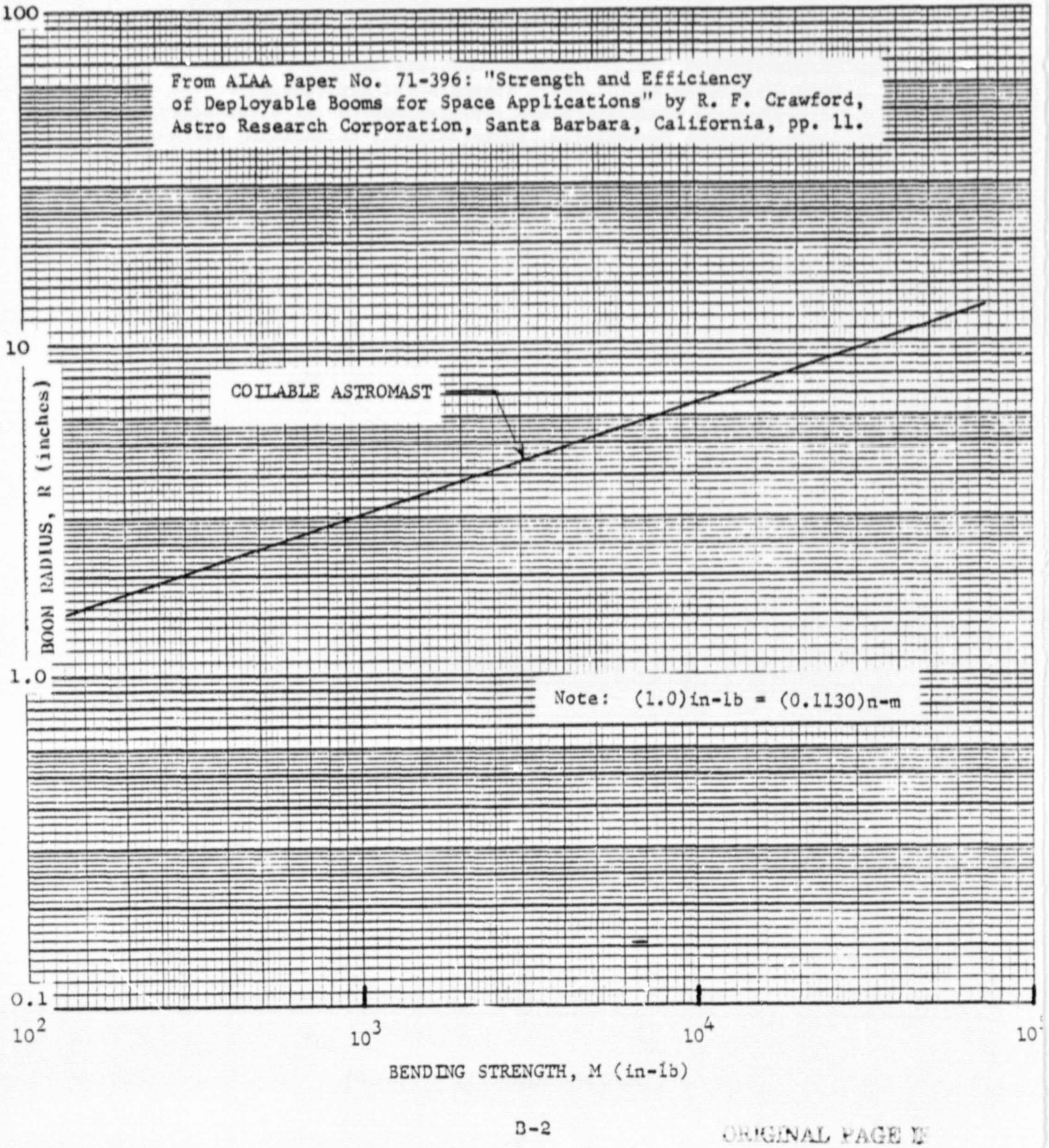
STANDARD COILABLE ASTROMAST

WEIGHT OF BOOM PER INCH OF LENGTH VS BENDING STRENGTH



STANDARD COILABLE ASTROMAST

BOOM RADIUS VERSUS BENDING STRENGTH



ARTICULATED ASTROMAST EQUATIONS

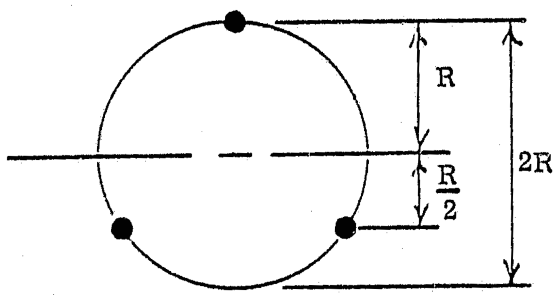
$$w = (7.80)\,\rho\, A_{\ell}$$

$$EI = (1.5)\, E\, A_{\ell} R^2$$

$$P_{CR} = \frac{\pi^2 E I_{\ell}}{3 R^2}; \quad P_{CR} \leqslant \sigma_{ALLOW} A_{\ell}$$

where: w = weight of boom per unit length
ρ = density of boom material
A_{ℓ} = cross-sectional area of one longeron
E = Young's modulus
I = moment of inertia of boom
R = boom radius
P_{CR} = critical axial load of longeron
I_{ℓ} = moment of inertia of longeron
σ_{ALLOW} = allowable stress of boom material

Source: AIAA Paper No. 71-396: "Strength and Efficiency of Deployable Booms for Space Applications" by R. F. Crawford, Astro-Research Corporation, Santa Barbara, California.



$$M = (3.0)\, R\, P_{CR}$$

where: M = bending strength of boom

ARTICULATED ASTROMAST EQUATIONS (Contd)

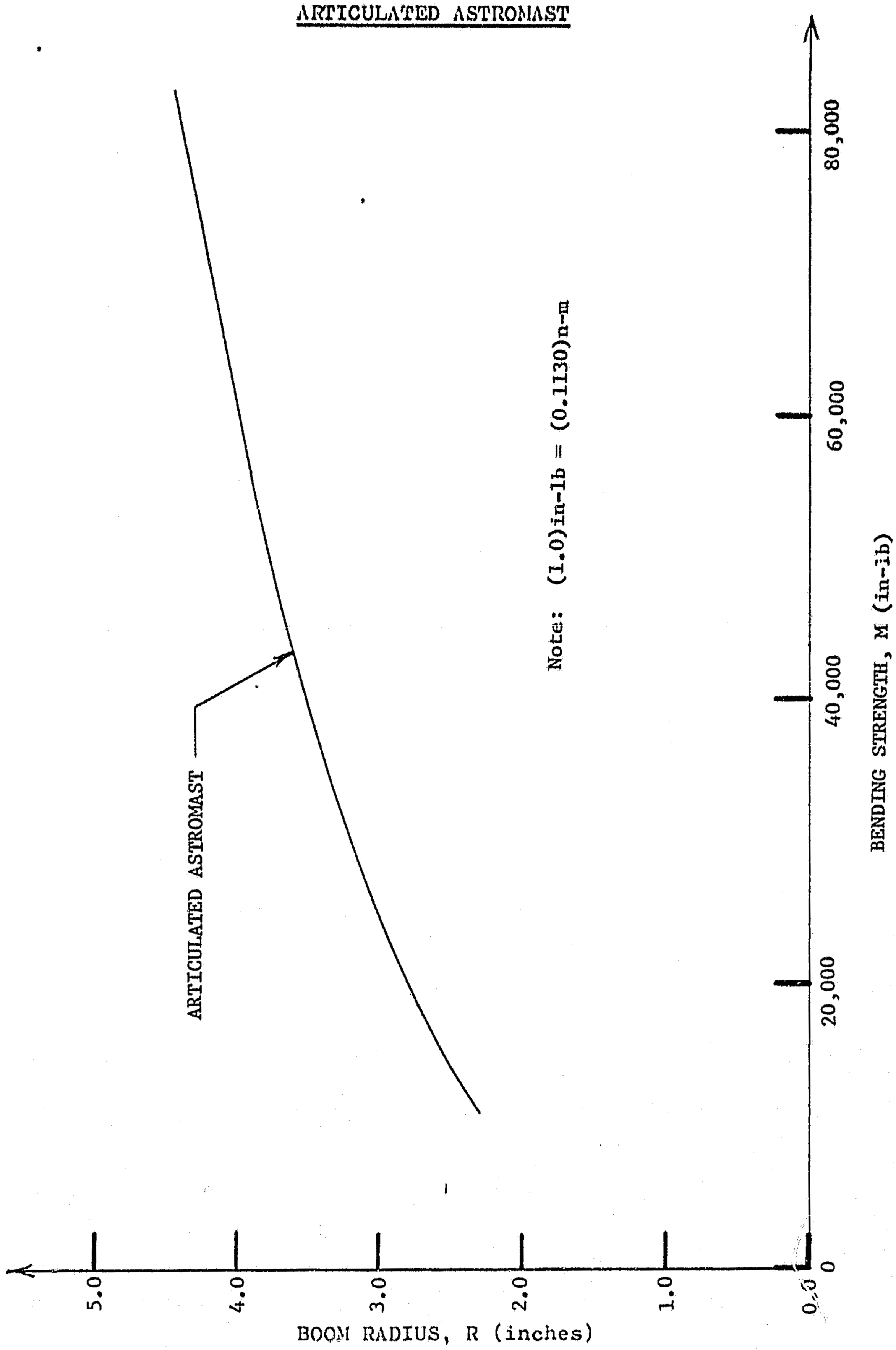
Additional data and assumptions used to formulate properties of articulated astromasts:

a. Use GY70/X30 graphite-epoxy in a $(O_2/\pm 24)_s$ layup.

b. For the articulated Astromast, stiffness and strength are not severely restricted as for the coilable Astromast since elements have no stringent limitations as to size. As a point of reference, the articulated Astromast will be sized such that M and w are coincident with the coilable supermast Astromast over the range of interest.

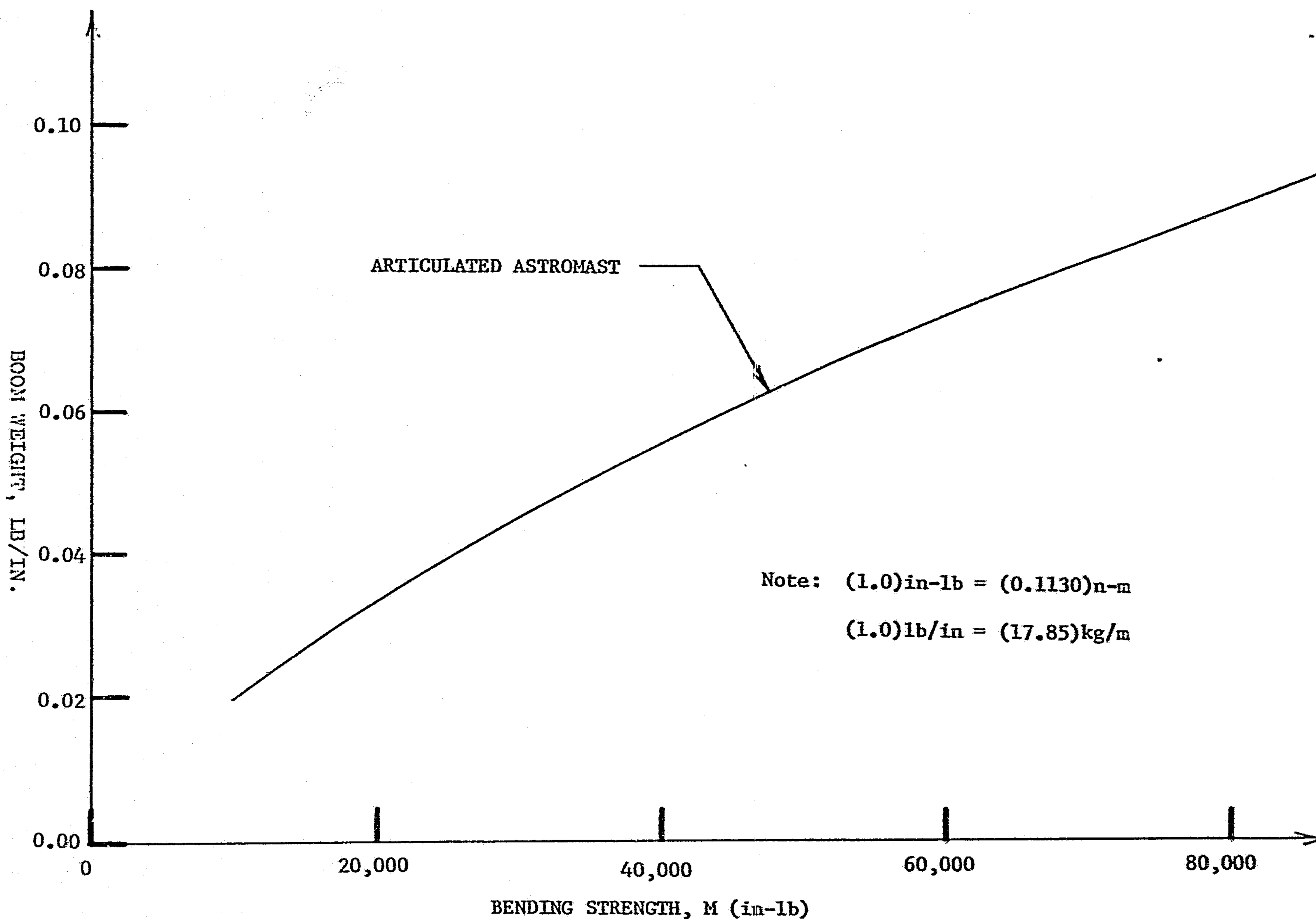
c. An inside diameter of 3/8" will be used for all longitudinal elements.

ARTICULATED ASTROMAST



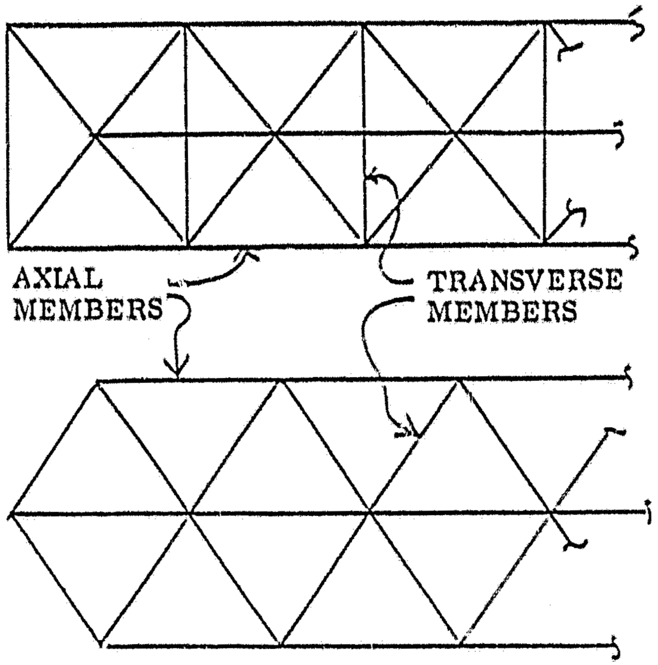
BOOM RADIUS VERSUS BENDING STRENGTH.

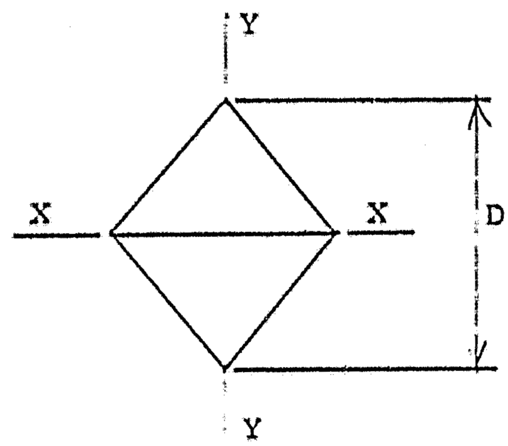
ARTICULATED ASTROMAST



WEIGHT OF BOOM PER INCH OF LENGTH VERSUS BENDING STRENGTH.

OOA TYPE EXPANDABLE TRUSS EQUATIONS





$$EI_{XX} = \frac{E A_A D^2}{2}$$

$$EI_{YY} = \frac{E A_A D^2}{4}$$

$$JG = \frac{E A_T D^2}{8}$$

where: E = Young's modulus
A_A = Cross-sectional area of axial members
A_T = Cross-sectional area of transverse members
D = Depth of truss