Definition of Technology Development Missions for Early Space Stations

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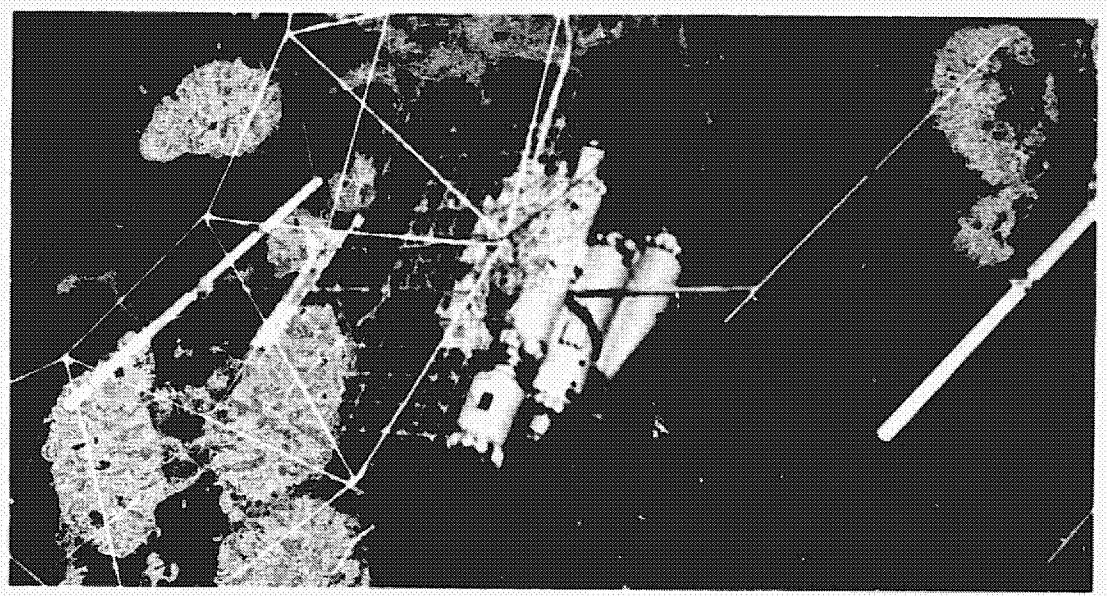
Large Space Structures
Phase II

MSFC
NAS8-35043

Midterm Review

22 March 1984



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TDM-202

Definition of Technology Development Missions for Early Space Stations

- Large Space Structures -

NAS8-35043
Phase II
Midterm Review

Presented to

George C. Marshall Space Flight Center, Alabama

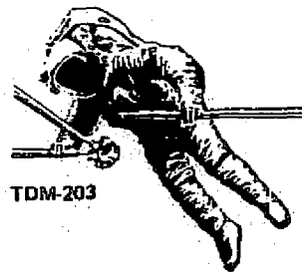
BY
BOEING AEROSPACE COMPANY
KENT, WASHINGTON

22 March 1984

PROGRAM OBJECTIVES

The objectives of this study are to expand and conceptually define the large space structures technology development missions to be performed on an early manned space station and determine the resources needed and the design implications to an early space station to carry out these large space structures technology development missions. Emphasis is being placed on more detail in mission designs and space station resource requirements.

Phase II Program Objectives



TDM-203

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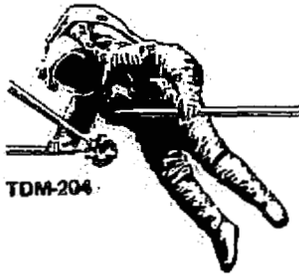
- Expand and refine TDM's
- Determine design implications to an early space station

STUDY APPROACH

The study is being conducted in the five primary tasks specified in the statement fo work. In Task 1 we selected for further study three LSS missions to be accomplished on an early space station and determined the development activities and tests which will lead to these space station missions. The conceptual design of the LSS missions through trade studies, operations analysis, and development of design details occurs in Task 2. Space station resource requirements will be defined in Task 3. Task 4 determined the degree to which current space station concepts can accommodate LSS missions. Programmatic analysis of Task 5 will develop technology development mission (TDM) plans and schedules and perform cost trades.

Study Approach



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- Task 1.0 – Mission Selection
- Task 2.0 – Mission Definition
- Task 3.0 – Space Station Resources Required
- Task 4.0 – Initial Space Station Capability
- Task 5.0 – Programmatic Analysis

STUDY SCHEDULE

The detailed study schedule which identifies study milestones, tasks, study reviews and documentation outputs is shown on the facing page. The schedule will be the yardstick against which study progress will be measured.

This is the second of three formal interim reviews to be held at MSFC at approximately four month intervals.

Because of reduced funding available, the scope of the effort in Subtask 3.2 was reduced and Subtasks 3.5 and 4.2 were eliminated.

Study Schedule

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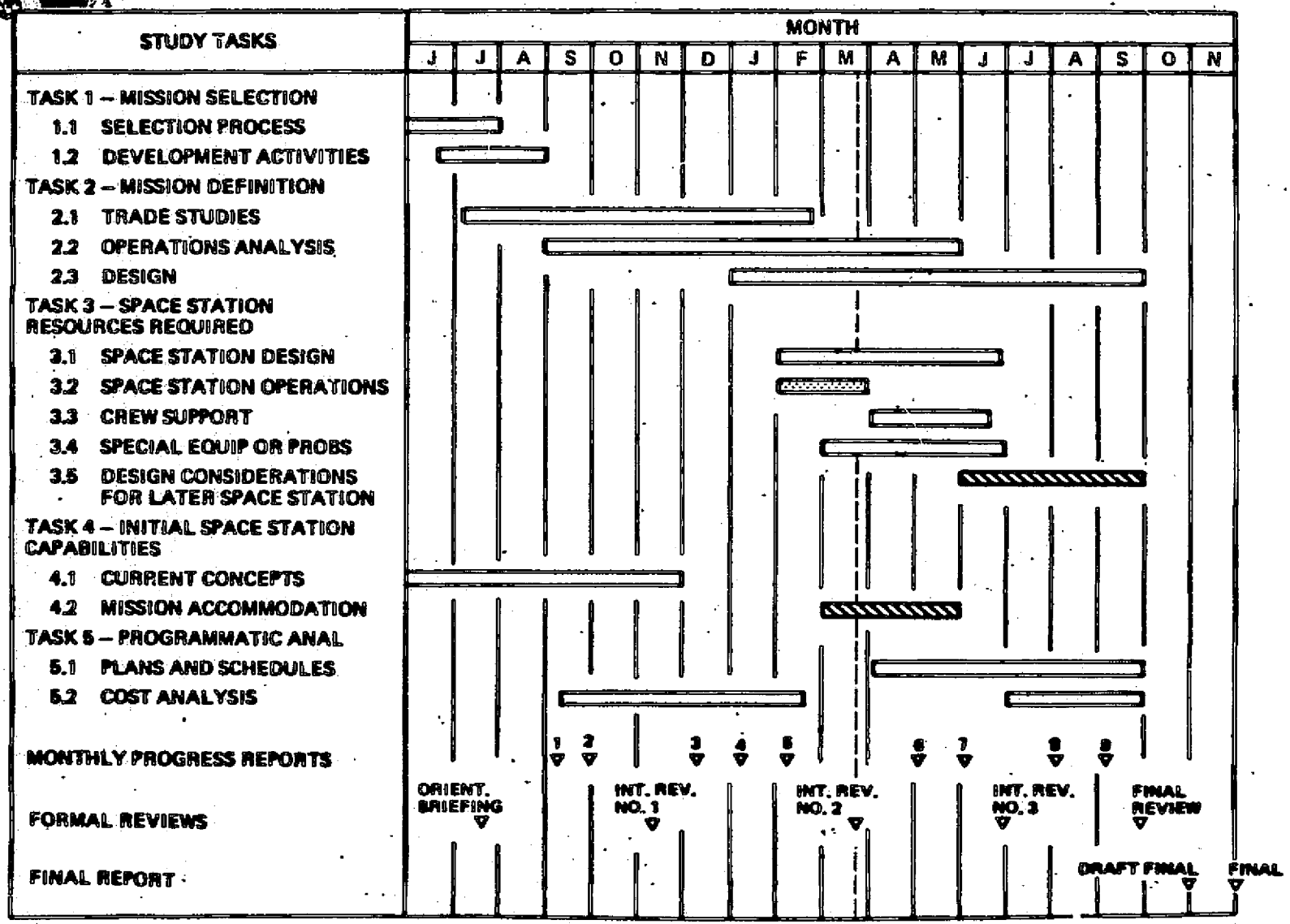
TDM-205



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Second Quarter Progress

This chart lists the Tasks and Subtasks which will be discussed in the midterm review. The definition of potential TDM development activities was completed.

The TDMs have been conceptually defined through design, operations and cost trade studies and detailed design has been initiated. Operations analysis of the TDMs is well underway with the updating of the functional flows and timelines. Space Station resource requirements, both physical and operational, for large space structures construction are being defined.

Second Quarter Progress

TDM-206

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Task 1.0 – Mission Selection

- Subtask 1.2 – Development Activities

Task 2.0 – Mission Definition

- Subtask 2.1 – Design Trade Studies
- Subtask 2.2 – Operations Analysis and Trade Studies
- Subtask 2.3 – Mission Design

Task 3.0 – Space Station Resources Required

- Subtask 3.1 – Space Station Design
- Subtask 3.2 – Space Station Operations
- Subtask 3.4 – Special Equipment or Problems

Task 5.0 – Programmatic Analysis

- Subtask 5.2 – Cost Analysis and Trades

Large Space Structures Technology Development Missions

LSS-1 consists of a deployable truss platform attached to a transfer tunnel located at a docking/berthing port on a space station module. It would become a permanent Space Station facility following its use as a TDM. Compartments installed within the truss members provide storage for small items such as tools, hold down mechanisms, auxiliary lights, etc. Segments of the platform will have floor panels installed to provide storage areas for small modules. A lightweight protective hangar is designed to protect EVA astronauts while performing such tasks as OTV servicing and small satellite refurbishment.

LSS-3 is a large parabolic antenna system which will demonstrate several mission objectives. To provide maximum benefit, it is envisioned as a complete antenna system which can be used to advance Earth sensing technology. The antenna is a version of the microwave radiometer spacecraft (MRS) and, although a higher orbit would be more desirable, could demonstrate the technologies necessary for earth sensing objectives. This structure could also serve as a testbed for different reflector and surface control ideas and various microwave sensing techniques.

LSS-4 is a precision optical system which will be assembled using segmented mirrors supported by a high-stiffness precision truss structure. This optical system could be operated using space station power while attached to a gimbal system to provide inertial pointing or as a free-flyer if a control system/power/data handling module is attached.

Large Space Structures Technology Development Missions

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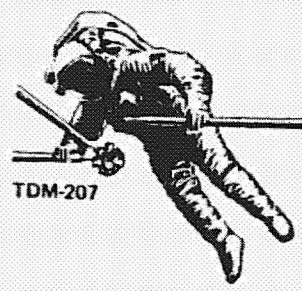
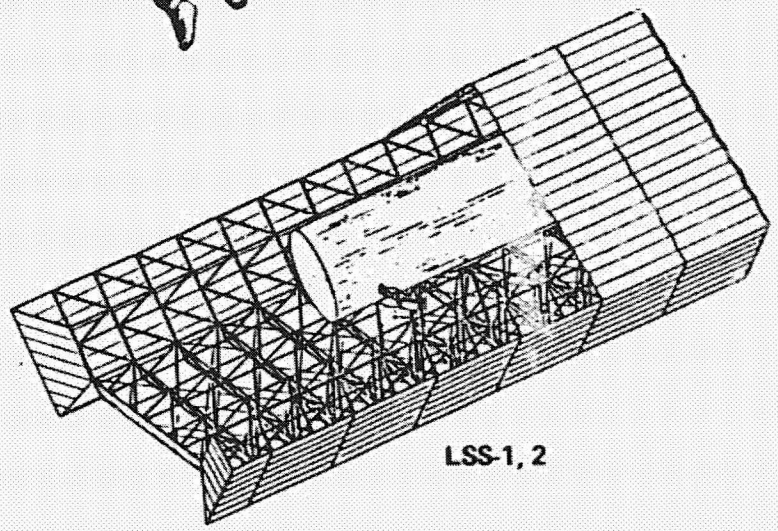
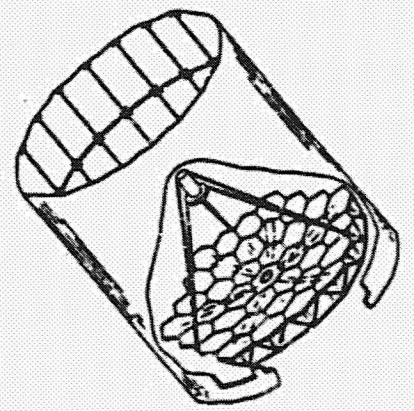


TDM-207



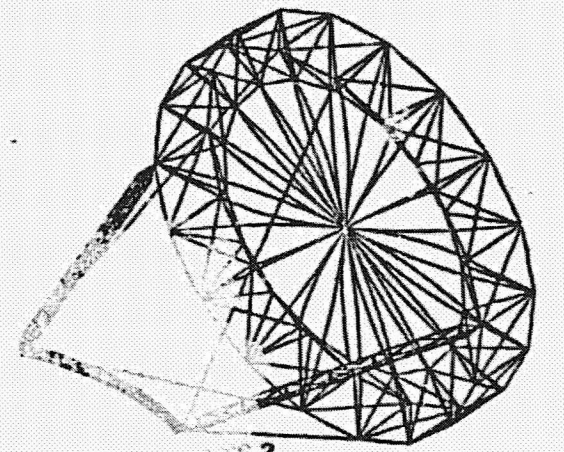
LSS-1, 2

CONSTRUCTION/STORAGE/
HANGAR FACILITY



LSS-4

HIGH PRECISION
OPTICAL SYSTEM



LSS-3

PASSIVE MICROWAVE RADIOMETER

Development Activities

The three technology development missions (TDMs) currently defined will demonstrate the ability to construct large space structures on an early space station. Precursor developments are required to advance the necessary technology and operational procedures required for on-orbit assembly or construction. These precursor activities involve the design, manufacture and test of structural components for the TDMs and the development of detailed procedures for their construction in space. Several arenas can be used to perform these development tests: ground tests in the laboratory, neutral buoyancy tests in a water tank and in-space tests using the Space Shuttle.

Summarized on the following three pages are candidate development activities for each TDM which would provide a logical progression of technology development for the on-orbit construction of large space structures.

Development Activities

LSS-1: Construction/Storage/Hangar Facility

TDM-208

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ACTIVITY	GROUND	NBF	SHUTTLE
DEPLOYMENT	X	X	X
ACCURACY MEASUREMENTS	X		X
THERMAL DEFORMATION MEASUREMENTS	X		X
STATIC TESTS	X		
DYNAMIC TESTS	X		X
INSTALL UTILITIES, RADIATION SHIELD, FLOOR	X	X	X
SIMULATE MODULE ATTACHMENT	X	X	X
REPLACE STRUCTURAL MEMBER (REPAIR)	X	X	X

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Development Activities

LSS-3: Passive Microwave Radiometer

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TDM-209

ACTIVITY	GROUND	NBF	SHUTTLE
PACKAGING (RING TRUSS AND BEAMS)	F		
ASSEMBLY (RING TRUSS)	F,S	S	S
DEPLOYMENT (BEAMS)	F	F	F
ACCURACY MEASUREMENTS	F,S		F,S
THERMAL DEFORMATION MEASUREMENTS	F		F,S
STATIC TEST	F,S		
DYNAMIC TESTS	F,S		F,S
INSTALL UTILITIES, MODULES	F	F	F
INSTALL REFLECTOR AND CONTROLS	S	S	S

F = FULL SCALE (PARTIAL STRUCTURE)

S = SCALE MODEL (1/5 TO 1/10 SCALE)

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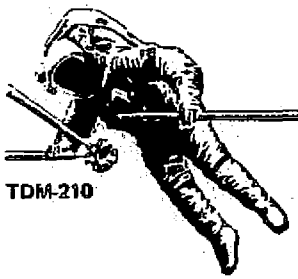
Development Activities

LSS-4: Precision Optical System



TDM-210

BOEING

ACTIVITY	GROUND	NBF	SHUTTLE
PACKAGING	X		
DEPLOY AND ASSEMBLE	X	X	X
ACCURACY MEASUREMENTS	X		X
SATIC TESTS	X		
DYNAMIC TESTS	X		X
THERMAL DEFORMATION MEASUREMENTS	X		X
MIRROR ALIGNMENT MEASUREMENTS	X		X
MIRROR ADJUSTMENT	X		X
REMOVE AND REPLACE MIRROR	X	X	X

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Design Trade LSS-1.1a
Truss Configuration

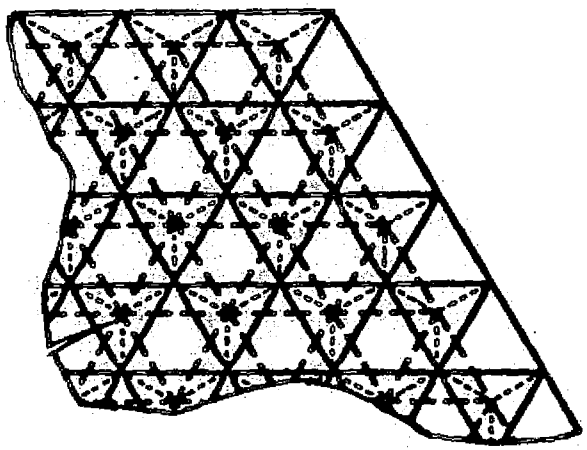
Three options for the deployable platform truss are shown in this chart. The tetrahedral truss consists of a repeating pattern of pyramids whose base is triangular in shape. The repeating pattern for the pentahedral truss is also a pyramid, but with a square base. The hexahedral truss is made up of a series of cubes.

Design Trade LSS-1.1a

LSS-1 Construction/Storage/Hangar Facility Truss Configuration

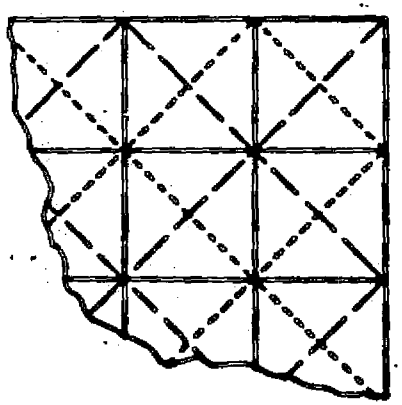
BOEING

TDM-211



PRIMARY SURFACE MEMBER
SECONDARY SURFACE MEMBER
INTERSURFACE MEMBER

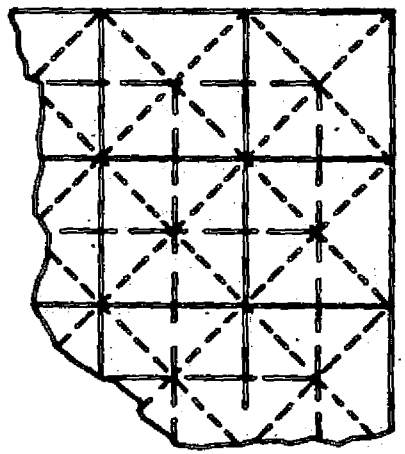
TETRAHEDRAL TRUSS



SURFACE PRIMARY MEMBER AND INTERSURFACE MEMBER
PRIMARY SURFACE DIAGONAL MEMBER
SECONDARY SURFACE DIAGONAL MEMBER

HEXAHEDRAL TRUSS

CHOSEN



PRIMARY SURFACE MEMBER
SECONDARY SURFACE MEMBER
INTERSURFACE MEMBER

PENTAHEDRAL TRUSS

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Design Trade LSS-1.1a
Truss Configuration

This table summarizes quantitative and qualitative results of the trade study which contributed to the selection of the pentahedral truss for LSS-1. Although its flexural rigidity is the lowest, its light weight and small number of members and joints give it a slight preference in the quantitative categories. The triangular repeating pattern of the tetrahedral truss cause it to be unacceptable for the desired shape of the platform. The cubic repeating pattern of the hexahedral truss requires shear diagonals in each of the square faces and therefore impair the accessibility to the volume inside the truss. Its complexity is also judged to be high for the same reasoning. The pentahedral truss was therefore selected for LSS-1.

Design Trade LSS-1.1a

Truss Configuration

TDM-212

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TRADE ITEMS	TETRAHEDRAL TRUSS	PENTAHEDRAL TRUSS (CHOSEN)	HEXAHEDRAL TRUSS
MASS PER UNIT AREA, M (KG/M^2)	1.21	1.22	1.31
FLEXURAL RIGIDITY, D (M-N)	1.15×10^7	1.04×10^7	1.17×10^7
FREQUENCY PARAMETER, $\sqrt{D/M}$	3083.	2920.	2988.
NUMBER OF ELEMENTS PER M^2	2.5	2.4	3.9
NUMBER OF CLUSTER JOINTS PER M^2	.66	.57	.63
NUMBER OF KNEE JOINTS PER M^2	1.66	1.44	1.62
OTHER CONSIDERATIONS:			
SHAPE OF REPEATING PATTERN	TRIANGLE	SQUARE	SQUARE
ACCESSIBILITY OF INTERIOR VOLUME	FAIR	GOOD	POOR
COMPLEXITY	LOW	MEDIUM	HIGH

Design Trade LSS-1.1b
Truss Configuration

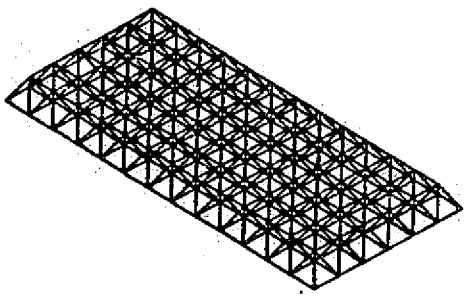
The choice between a planar configuration and a "winged" configuration is primarily based on qualitative reasoning. Although the planar configuration is somewhat simpler and provides a large flat surface, the storage of modules or equipment on its surface may impair its ability to support construction of large space structures unless the construction fixture was high enough so that stored items were out of the way. The winged configuration reduces this problem by providing a raised attachment point for LSS construction projects. This configuration also has higher overall stiffness and provides a variety of attachment opportunities.

Design Trade LSS-1.1

Truss Configuration

BOEING

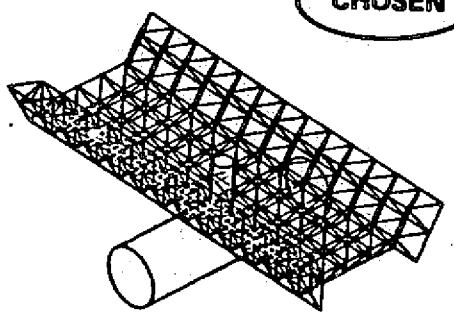
TDM-213



PLANAR

- SIMPLE, NO ARTICULATION
- LARGE PLANAR SURFACE
- STORAGE MAY INTERFERE WITH LSS CONSTRUCTION

CHOSEN



WINGED

- HIGHER STIFFNESS
- WIDER WARIETY OF ATTACHMENTS
- INDEPENDENT STORAGE AND CONSTRUCTION LOCATIONS

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Design Trade LSS-1.3
Space Station Interface

The options identified for the attachment of LSS-1 to the Space Station include three methods of berthing port attachment and one for attachment to a Space Station module. The latter is the preferred method of attachment since the platform loads induced by disturbances such as orbiter docking are distributed to many attachment points. This method also results in higher stiffness. Attaching to two or more berthing ports helps to distribute the loads. Single berthing port attachment schemes result in the highest loads unless additional bracing is provided.

Since the Space Station is in its design infancy, we will continue to develop the center mounted concept with auxiliary bracing as required. This design could easily be modified to the preferred modular attachment concept at a latter date.

Design Trade LSS-1.3

Space Station Interface

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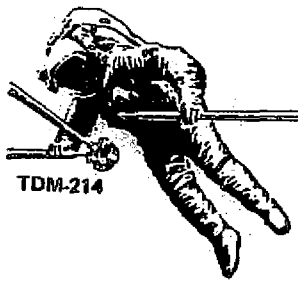

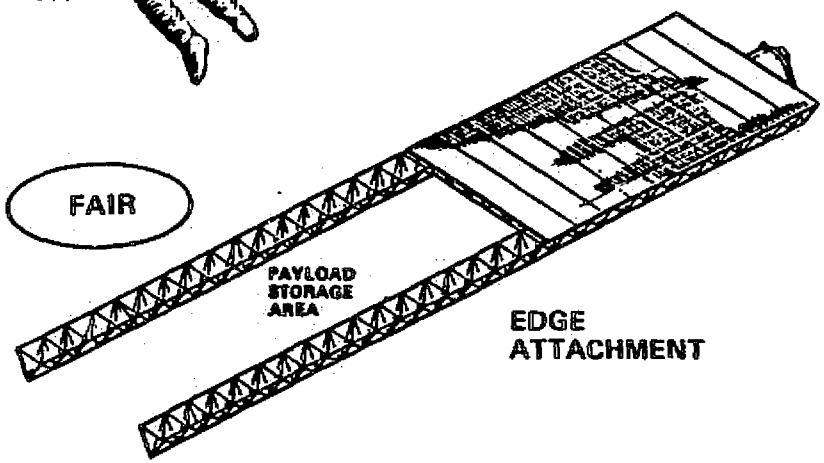

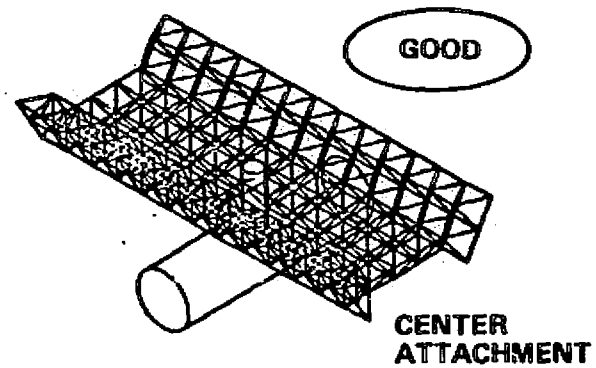

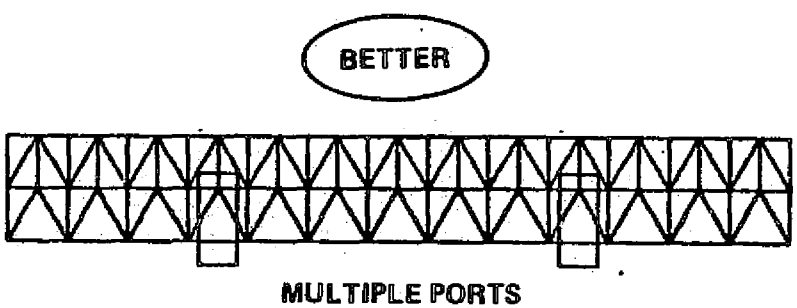

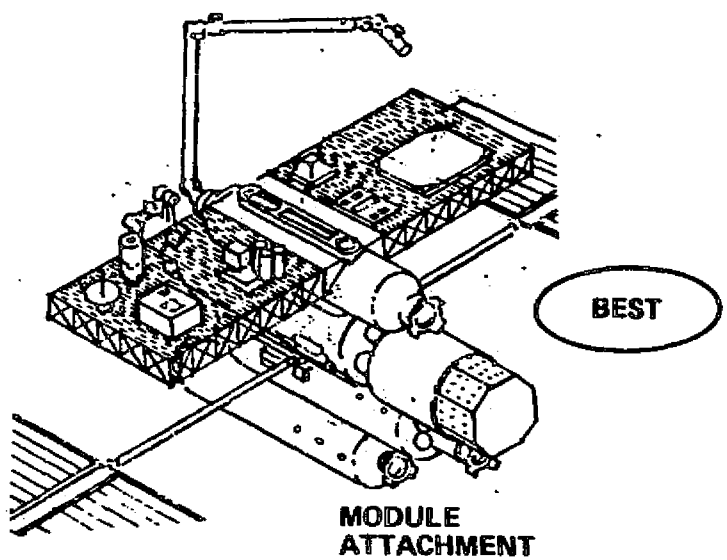

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Design Trade LSS-3.1
Reflector Support Structure

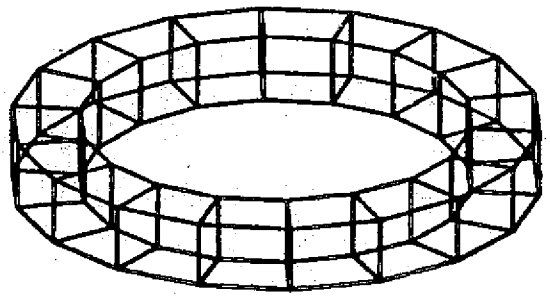
Three reflector support structure concepts are shown in this chart. The ring made of trapezoidal elements is essentially a circular box beam 18 meters deep and 136 meters in diameter. The pentahedral ring truss is 103 meters in diameter, 18 meters deep and has a triangular cross-section. The tetrahedral truss is a parabolic shaped truss whose maximum dimension is 115 meters. Its depth is a function of the length of its members and was varied in the course of the study.

Design Trade LSS-3.1

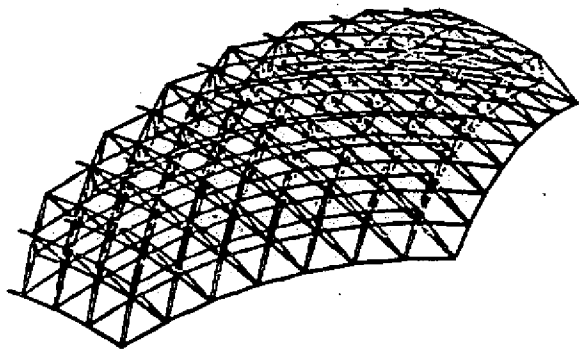
LSS-3 Passive Microwave Radiometer Reflector Support Structure

BOEING

TDM-215

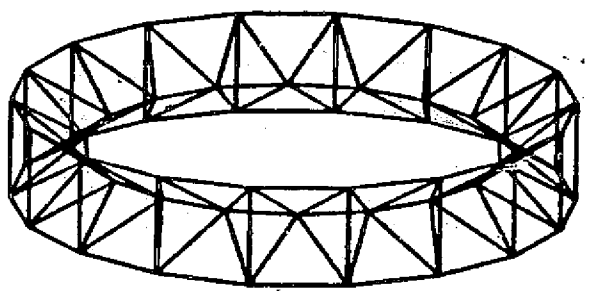


TRAPEZOIDAL ELEMENTS



TETRAHEDRAL TRUSS

CHOSEN



PENTAHEDRAL ELEMENTS

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Design Trade LSS-3.1
Reflector Support Structure

This table summarizes the results of the trade study. Under the assumption that the tetrahedral truss is a deployable concept, the length and diameter of the members was varied to arrive at a baseline configuration. Packaging dimensions and the requirement for a sufficiently large number of "hard points" for proper reflector control led to the 12 ring baseline configuration. The resulting weight and complexity (no. of elements and joints) quickly eliminated it from further consideration.

The two ring configurations are comparable in mass, stiffness and complexity. The pentahedral truss is smaller in overall diameter since the reflector can be attached at the outside diameter while it must be attached to the inside diameter of the box ring truss. The biggest advantage of the pentahedral truss, however, is in the ease of construction. It is significantly easier to construct a pyramid truss module (after fixing its base) than it is to construct a cubic module. The tip of the pyramid aligns itself while shear ties must be added and adjusted to stabilize and align a cube. For this reason, the pentahedral ring truss is selected for LSS-3.

Design Trade LSS-3.1

Reflector Support Structure

TDM-216

BOEING

TRADE ITEMS	OPTIONS: BOX RING TRUSS	PENTAHEDRAL RING	TETRAHEDRAL TRUSS (12 RINGS)
MASS (KG)	887.	774.	3486.
STIFFNESS (1ST MODE FREQ., HZ)	1.08	.85	2.25
NUMBER OF ELEMENTS	144	144	3852
NUMBER OF JOINTS	72	54	901 CLUSTER 2556 KNEE
DIAMETER (M)	136.	103.	115.
OTHER CONSIDERATIONS			
EASE OF CONSTRUCTION	FAIR	GOOD	COMPLEX
		CHOSEN	

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Design Trade LSS-3.2
Truss Member End Joints

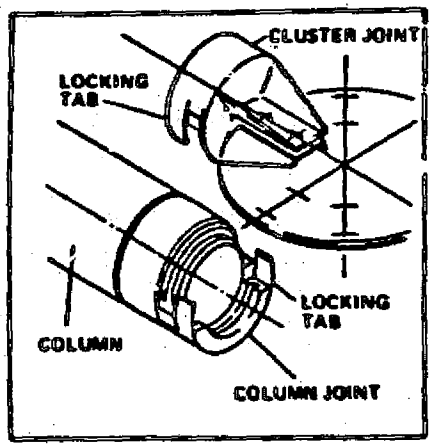
This chart shows the end joint concepts evaluated for the ring truss elements. Truss assembly requires the use of "side entry" joints for both assembly and for potential replacement of members. Although this selection of joints is a very small sampling of proposed truss joint concepts, it represents several classes of joints which can be compared and evaluated.

Design Trade LSS-3.2

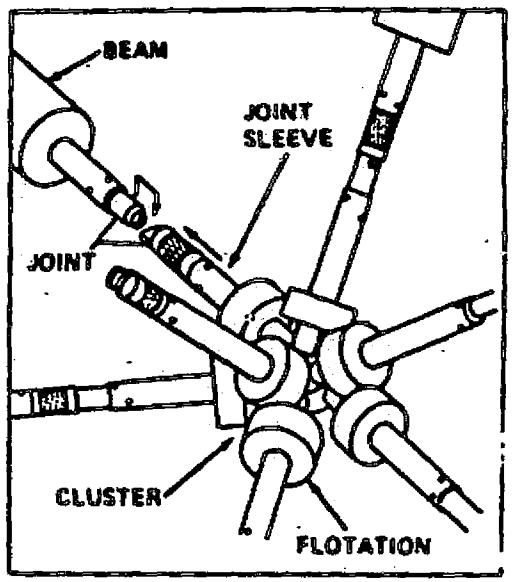
Truss Member End Joints

BOEING

TDM-217

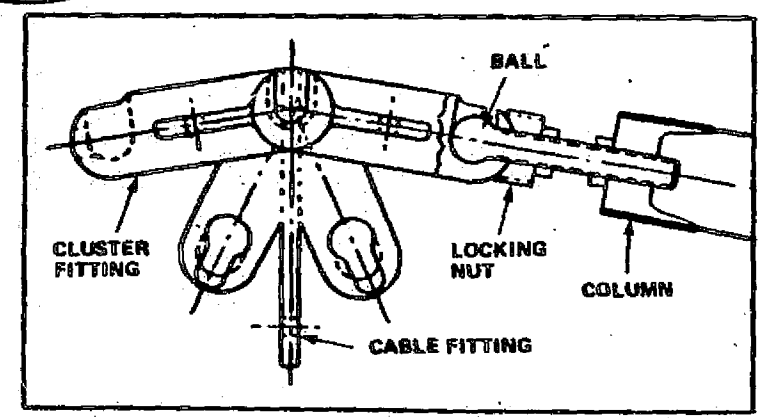


LaRC SNAP–JOINT UNION

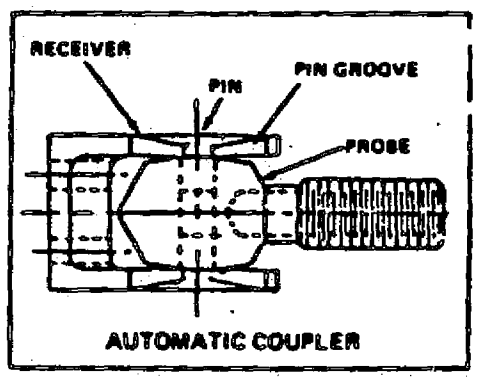


MIT CLUSTER SLIP–JOINT

CHOSEN



BAC BALL AND SOCKET



VOUGHT QUICK–CONNECT COUPLER

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Design Trade LSS-3.2
Truss Member End Joints

This chart lists some of the characteristics of each joint type which led to the selection of the ball and socket joint for LSS-3. Any of these joints could be used in this application, however the properties of the ball and socket joint which cause it to be selected are its ability to eliminate all joint "slop", its tolerance to slight strut misalignment for initial latching, and its potential for being manufactured from low CTE (coefficient of thermal expansion) materials: invar or graphite/epoxy. The ball ends of the struts also eliminate the necessity to index the strut torsionally before latching. The biggest deterrent is the necessity for a tool (wrench) to lock the joint.

Design Trade LSS-3.2

Truss Member End Joints

TDM-218

BOEING

<u>Snap-joint union</u>

- Side-latching joint
- Complex and accurate machining required to minimize joint "slop"
- Accurate strut alignment required for latching
- Opposite ends to strut must be accurately aligned

<u>Cluster slip-joint</u>

- Side-latching joint
- Accurate strut alignment required for latching
- High machining tolerances required to minimize joint "slop"
- Opposite ends of strut must be accurately aligned

<u>Quick-connect coupler</u>

- Side - or end - latching joint
- Good joint "slop" accommodation
- Opposite ends of strut must be accurately aligned

<u>Ball and socket</u> ← Chosen

- Side-latching joint
- Accurate strut alignment not required for initial latching
- Joint "slop" eliminated by locking nut (extra operation)
- Alignment of opposite ends of strut not required
- Cable attachment integrated with cluster fitting

Design Trade LSS-3.3
Truss Member Center Joints

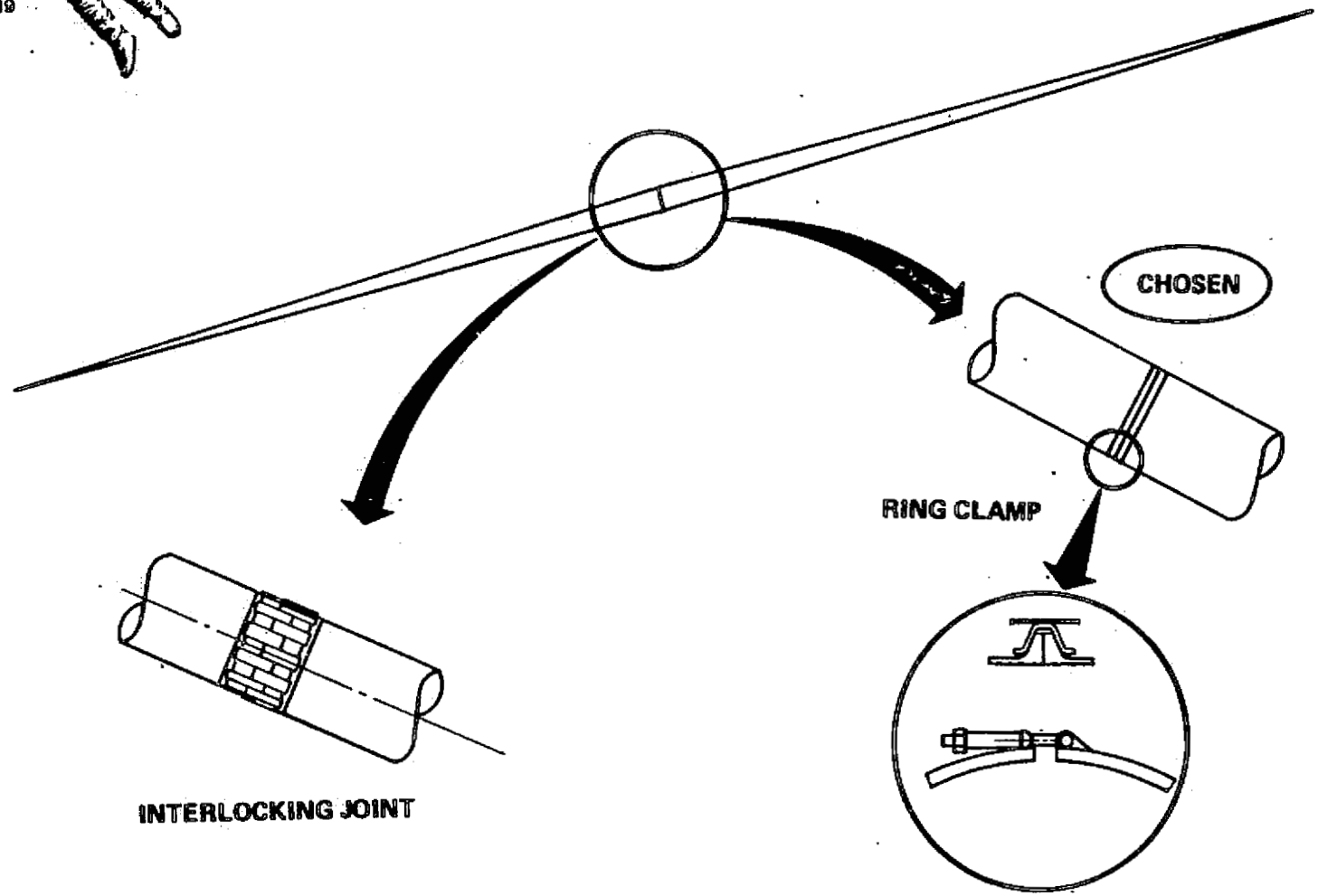
To achieve high packaging density, the use of nestable structs is proposed for the truss members. The center joint which joins the halves is the subject of this trade study. The two concepts shown are the interlocking joint which consists of interlocking fingers on each half of the strut and the ring clamps joint similar to those commonly used in the aerospace industry to join cylindrical structures.

Design Trade LSS-3.3

Truss Member Center Joint

BOEING

TDM-219



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Design Trade LSS-3.3
Truss Member Center Joints

Itemized on this chart are the positive and negative points of each center joint concept. The interlocking joint is operationally simpler since there are no extra parts required. It does, however require proper alignment and an axial force to latch. The manufacturing process is fairly complex and requires accurate machining to assure proper fit and minimum joint slop. Although the ring clamp is an extra part to contend with, the manufacturing simplicity, off-the-shelf technology, self-aligning ability, joint slop elimination and ease of disassembly make it our choice for LSS-3.

Design Trade LSS-3.3

Truss Member Center Joint

TDM-220

BOEING

Interlocking joint

- High precision machining required
- Torsional indexing required prior to latching
- Axial force required for latching
- Disassembly difficult
- No extra parts required
- Automated latching possible

Ring clamp ← Chosen

- High precision machining not required
- Off-the-shelf technology
- Easily disassembled
- No axial force required for latching
- Ring clamp is separate part
- Torsional indexing not required
- Automated latching difficult

Design Trade LSS-3.4
Feed Array Supports

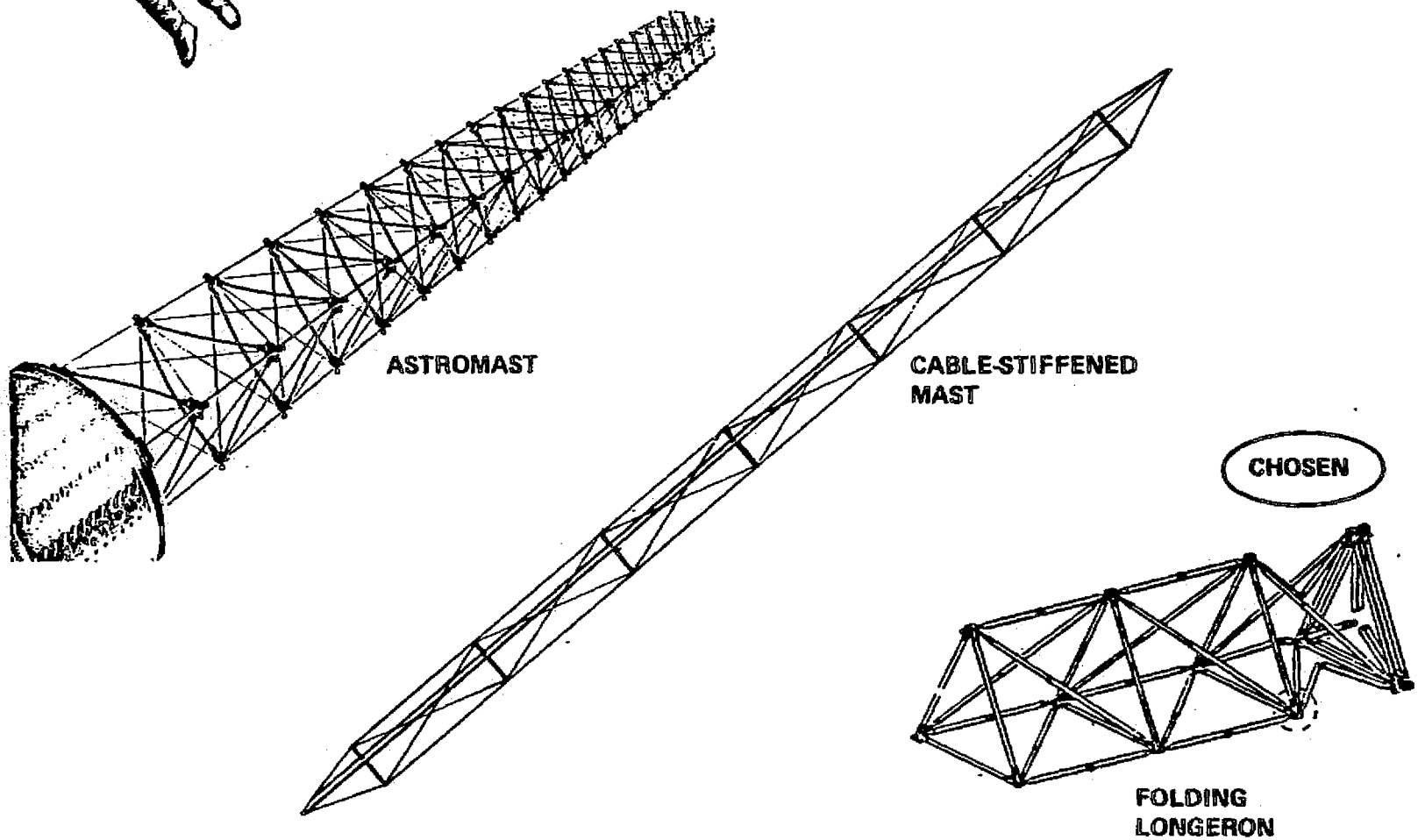
Three types of masts were considered for this trade study: the coilable longeron (Astromast-type) deployable mast, a cable-stiffened mast (consisting of a structural central tube, which carries axial loads, and outrigger cables which provide increased bending stiffness), and a deployable mast with folding longerons (the one shown is a typical example of many similar configurations).

Design Trade LSS-3.4

Feed Array Supports

BOEING

TDM-221



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Design Trade LSS-3.4
Feed Array Supports

This table gives a quantitative and qualitative comparison of the three types of masts shown on the previous chart. The Astromast-type mast has high packaging efficiency, but is the heaviest of the three and has the lowest bending frequency. The cable stiffened mast is somewhat less complex than the other two but has poor packaging efficiency since it consists of seven hinged sections which fold into a 11.5 meter long bundle after the cable spreaders are folded along the central tube. Its bending stiffness depends upon the cable parameters and spreader length. The folding longeron mast (Graphite/Epoxy) is the lightest weight, has good frequency characteristics and is efficiently packaged. This type of mast will, therefore, be used for the feed array supports.

Design Trade LSS-3.4

Feed Array Supports

TDM-222

BOEING

TRADE ITEM	ASTROMAST	TENSION-STIFFENED MAST	CHOSEN FOLDING LONGERON MAST
MASS, KG	320.	150.	56.
BENDING FREQUENCY (PIN-PIN), HZ	.14	.25 - .40	.32
PACKAGING EFFICIENCY	HIGH	LOW	HIGH
COMPLEXITY	HIGH	LOW	HIGH

Design Trade LSS-3.5
Feed Array Truss Beam

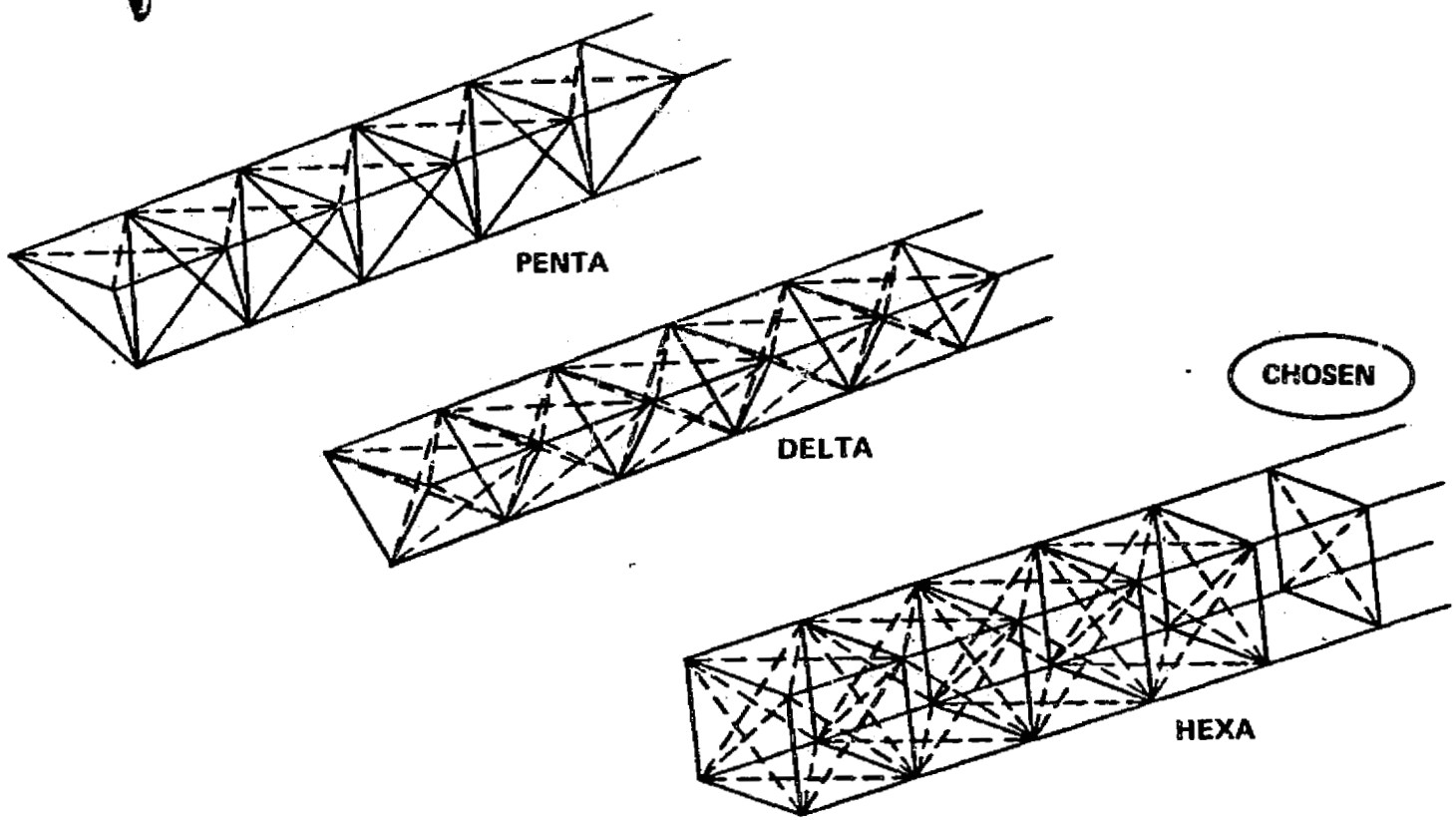
The three types of deployable truss beams considered for the feed array truss beam are shown in this chart. There are several variations of each type reported in the literature, but these three generic types were evaluated in this trade study.

Design Trade LSS-3.5

Feed Array Truss Beam

BOEING

TDM-223



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Design Trade LSS-3.5
Feed Array Truss Beam

This chart compares the characteristics of the three deployable truss beam types. Mathematical expressions were derived for the unit weight and the stiffness-to-weight ratio in terms of dimensional parameters, material properties and member cross sectional areas. Although the hex truss beam is the heaviest, it has the highest stiffness-to-weight ratio (a measure of its bending frequency). Its square modular shape also provides good accommodation for the feed horn assemblies, while the triangular cross-section of the other two truss beams would require the feed assemblies to be mounted externally. This causes the mass to be offset from the elastic axis of the beam and would result in undesirable lateral/torsional coupling. Therefore the hex truss beam was selected for this application.

Design Trade LSS-3.5

Feed Array Truss Beam

BOEING

TDM-224

	PENTA	DELTA	HEXA (CHOSEN)
NUMBER OF ELEMENTS PER BAY			
W/O DIAGONALS	9	6	8
W/ DIAGONALS (1)	10	9	13
NUMBER OF JOINTS PER BAY	3	3	4
STIFFNESS/WEIGHT PARAMETER			
$h = \ell$			
W/O DIAGONALS	.0749	.1069	.125
W/ DIAGONALS	.0646	.0626	.0664
WEIGHT/UNIT LENGTH			
W/O DIAGONALS	8.90	6.24AS	8AS
W/ DIAGONALS	10.32 AS	10.65 AS	15.07 AS
FEED HORN ASSEMBLY ACCOMMODATION	POOR	POOR	GOOD

Design Trade LSS-4.1
Mirror Support Truss

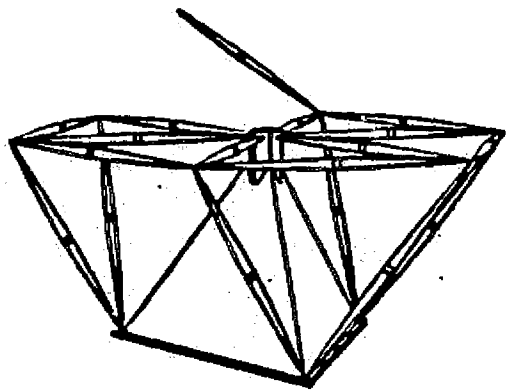
This chart shows three candidate construction techniques for the precision optical system mirror support truss. The assemblable concept relies on in-space assembly while the deployable concept requires on-Earth assembly and checkout with little human intervention on-orbit. The modular concept combines these two methods by high precision manufacture of the mirror support frame with mirrors attached on the ground. The backin truss is semi-deployable for efficient packaging in the Orbiter. Each module is then assembled at the space station and connected to the adjacent module to form the mirror array.

Design Trade LSS-4.1

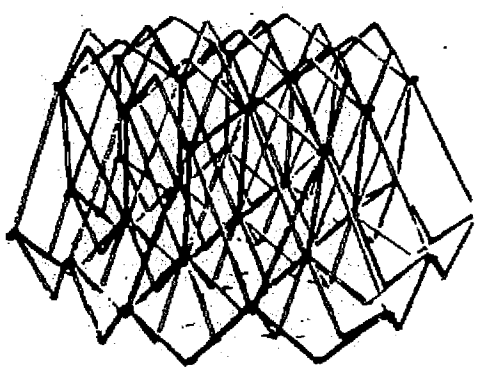
Mirror Support Truss

BOEING

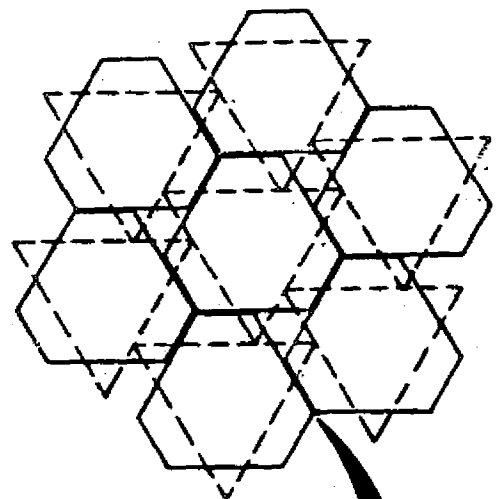
TDM-225



ASSEMBLABLE

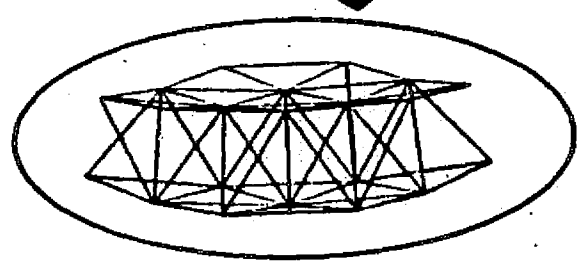


DEPLOYABLE



MODULAR

CHOSEN



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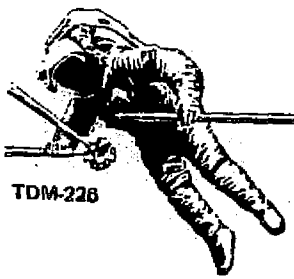
Design Trade LSS-4.1
Mirror Support Truss

This table shows the results of dynamic analyses and weight comparisons for the three trusses. Although the mass of the trusses are nearly identical the first mode frequency of the modular truss concept (with mirror mass included) is somewhat lower than the other two. This is caused by the fact that each module is connected to its adjacent module at three points. Since much of the assembly and adjustment work for the modular concept is accomplished on the ground, the amount of assembly time on-orbit is low, and the as-built accuracy is judged to be higher than the other concepts. The results of the asemblable vs. deployable vs. modular cost trade (reported in more detail later) are also summarized in this chart. This shows that the modular concept is the best choice for LSS-4.

Design Trade LSS-4.1

Mirror Support Truss



TDM-226

BOEING

TRADE ITEM	ASSEMBLABLE TRUSS	DEPLOYABLE TRUSS	MODULAR TRUSS (CHOSEN)
PRIMARY FREQUENCY (TRUSS + MIRRORS) (Hz)	15.0	15.0	9.5
TRUSS MASS (Kg)	159.0	159.0	161.0
EVA ASSEMBLY TIME (TRUSS + MIRRORS)	HIGH	MEDIUM	LOW
ACCURACY (AS ASSEMBLED)	MEDIUM	MEDIUM	HIGH
JOINT REQUIREMENTS	• SIDE LATCH • SELF ALIGNING • ZERO SLOP	• DEPLOYABLE (AUTO) • LOCK-ABLE	• SOME DEPLOYABLE (MANUAL) • SELF ALIGNING • ZERO SLOP
COST ON-ORBIT ($M)	39.3	36.5	27.8

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Design Trade LSS-4.2
Mirror Size

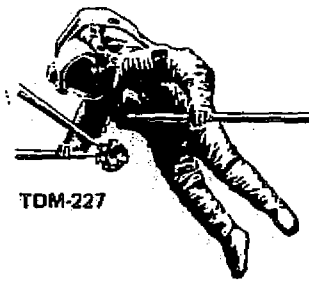
The size of the segmented mirrors on the precision optical system were determined by both mirror manufacturing technology and cost. Large mirrors are more difficult to manufacture, but the smaller mirrors will require more position control mechanisms which will add to the total cost.

Based on the design goal of 15 to 25 kg/m^2 for lightweight mirrors, large (4.0m) diameter mirrors would be too fragile to withstand the boost environment and may not retain their proper shape. A report on mirror technology applicable to the Large Deployable Reflector (LDR)* concludes that the "optimal size for the reflector panels is between 1.5 to 2.0 meters". Therefore the 1.5 meter mirrors will be used for LSS-4.

*ref: M. Krim and J. Russo, NASA CR 166493, LDR Segmented Mirror Technology Assessment Study, Perkin-Elmer Corp., March 1983.

Design Trade LSS-4.2

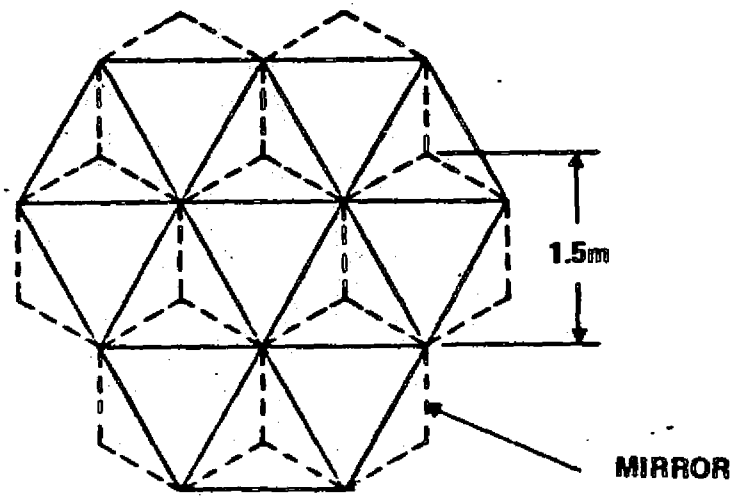
Mirror Size

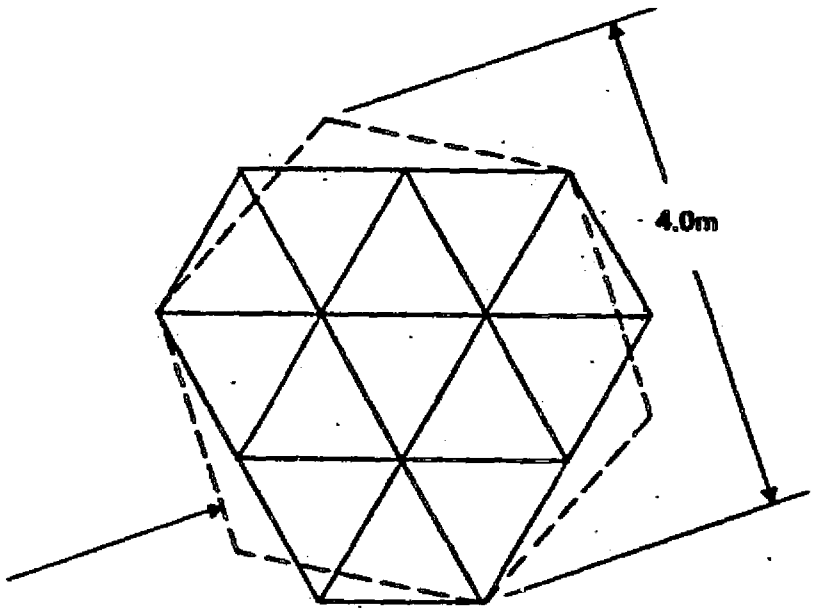


TDM-227

BOEING

CHOSEN





- "....OPTIMAL SIZE FOR THE REFLECTOR PANELS IS BETWEEN 1.5 AND 2.0 METERS" PERKIN-ELMER CORPORATION
- DESIGN GOAL OF 15-25 KG/M^2 ATTAINABLE
- FEWER MANUFACTURING PROBLEMS

- LIGHT WEIGHT MIRROS THIS SIZE ARE TOO FRAGILE
- MAY NOT MAINTAIN PROPER SHAPE
- MISTAKES ARE TOO COSTLY

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Design Trade LSS-4.3
Secondary Mirror Supports and Light Shield

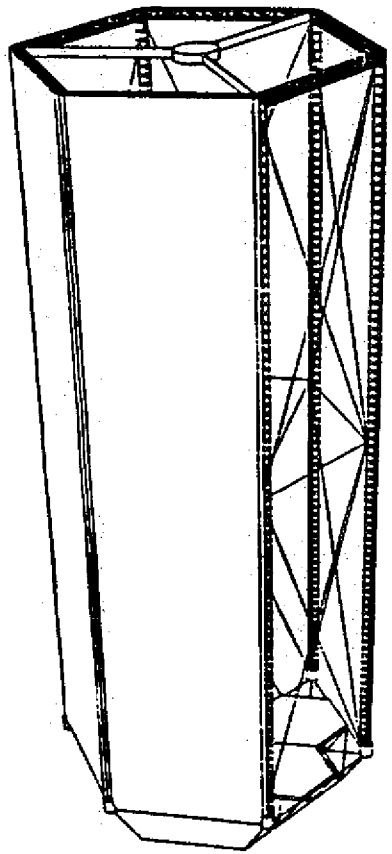
Two candidate secondary mirror support concepts are shown in this chart. One significant factor which contributed to the decision is the support system stiffness. The secondary mirror must retain accurate alignment with respect to the primary mirror. The original LSS-4 concept supports the secondary mirror by a truss ring supported by six extendable masts. These masts also support the light shield panels. A tripod structure is used to support the secondary mirror in the strawman LDR concept, and the light shield is separate from the tripod supports.

Design Trade LSS-4.3

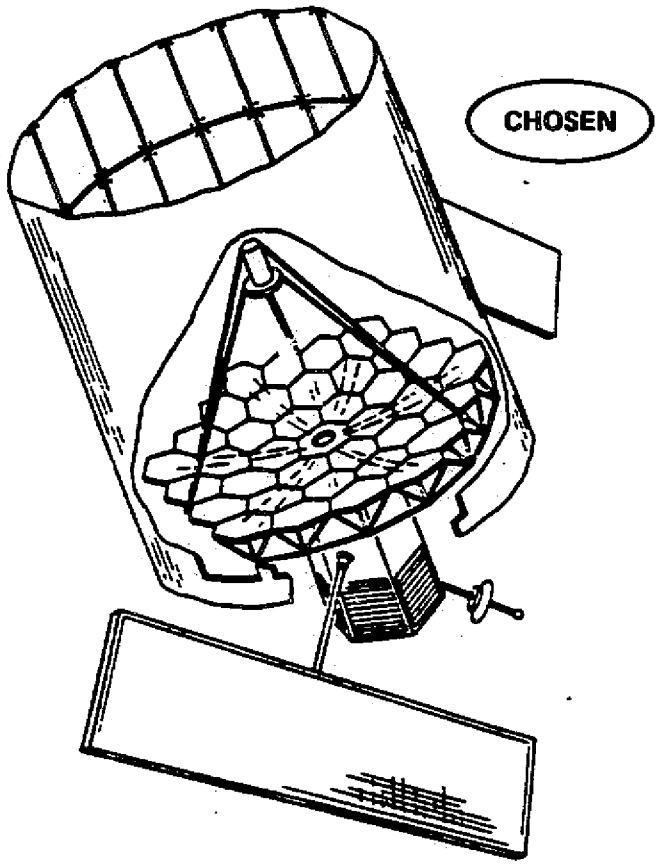
Secondary Mirror Supports and Light Shield

BOEING

TDM-175



LSS-4



NASA/ARC STRAWMAN LDR

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Design Trade LSS-4.3
Secondary Mirror Supports and Light Shield

The tripod support for the secondary mirror was selected for LSS-4 because of its increased stiffness and reduced weight. The separate light shield also was chosen because it is structurally uncoupled from the secondary mirror. Disturbances which may affect the light shield will not be transmitted directly to the secondary mirror.

Design Trade LSS-4.3

Secondary Mirror Supports and Light Shield

TDM-229

BOEING

<u>Original LSS-4 configuration</u>

- Parallel mirror supports require x-braces for stability
- High mechanical complexity
- Light shield attached to secondary mirror supports
- Light shield should extend beyond secondary mirror

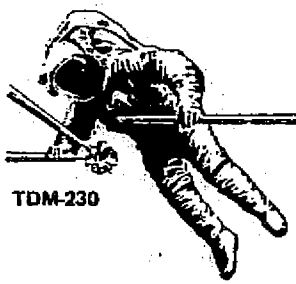
<u>Strawman LDR configuration</u> ← Chosen

- Stiff tripod secondary mirror support
- Light shield is uncoupled from mirror
- Reduced structural weight

Detail Design of TDMS

The design, operations and cost trades have identified the design concepts which are being designed in detail. Detail design of each of the three TDMs has been initiated. Work has concentrated on the passive microwave radiometer (LSS-3). It is approximately 80% complete. Layout drawings of some of the major components of the other two TDMs have been completed.

Detailed Design of TDM's



BOEING

LSS-1: Construction/storage/hangar facility
- 2 layout drawings (deployable truss)
- Design 5% complete

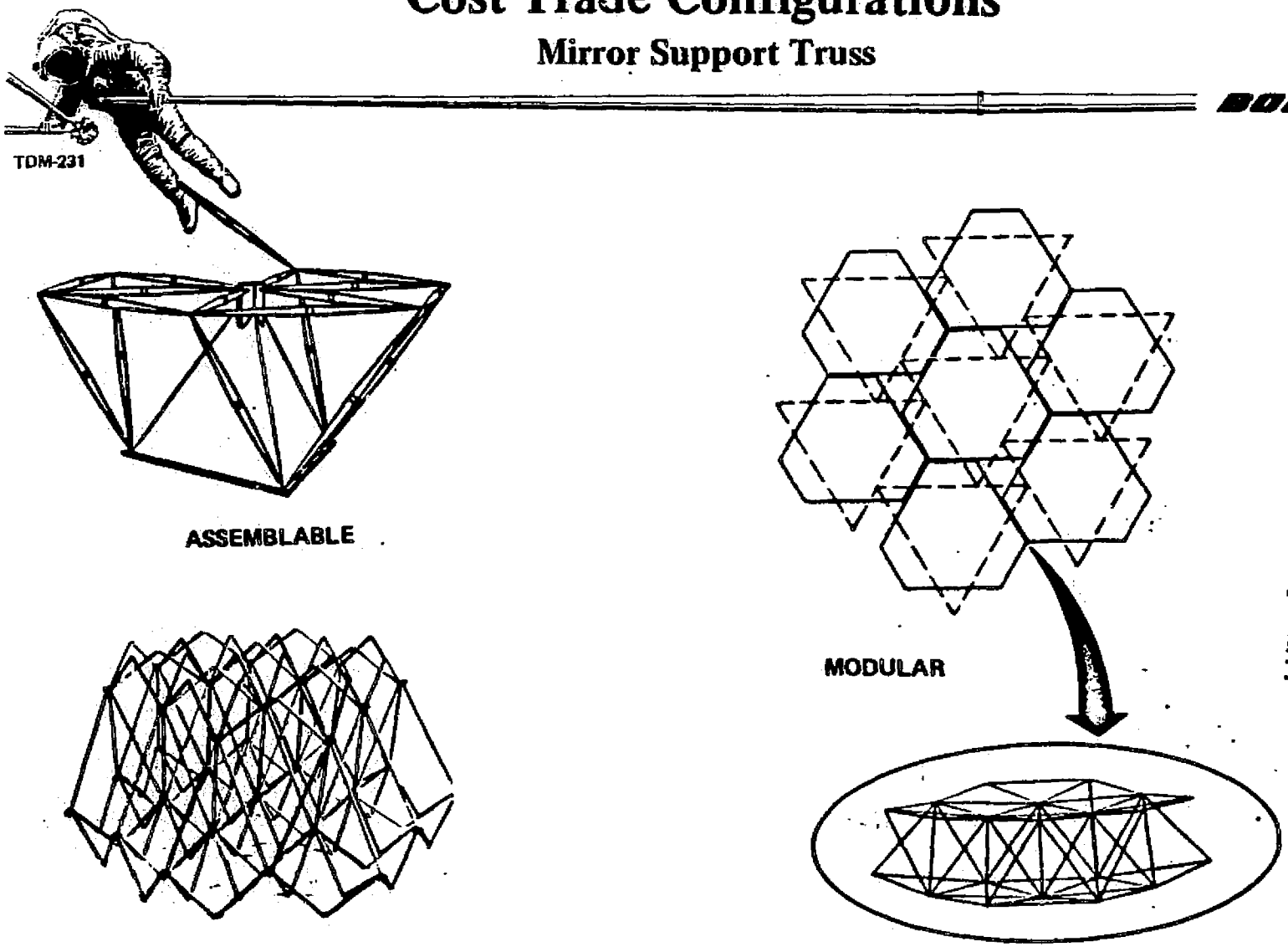
LSS-3: Passive microwave radiometer
- 16 drawings
- Design 80% complete

LSS-4: Precision optical system
- 2 layout drawings (modular truss)
- Design 5% complete

Cost Trade Configurations

Mirror Support Truss

BOEING



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Cost Trade Study Results Assemblable Vs. Deployable Vs. Modular Structural

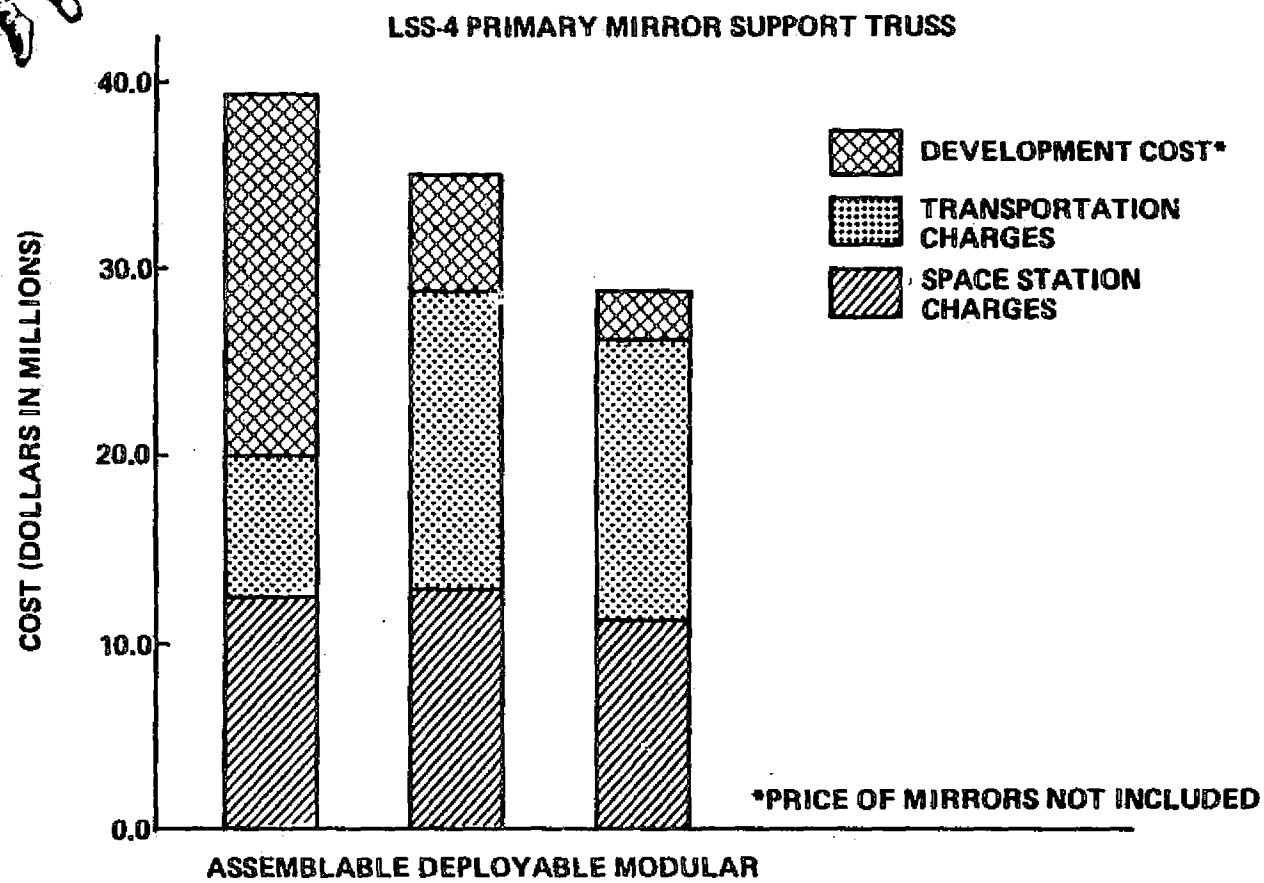
The costs associated with the development, transportation and on-orbit assembly for each of the three concepts are compared in this chart. The development costs are nearly equal. The cost of the mirrors is not included in the total cost of the system. However, mirror costs do influence system integration costs, therefore, are included for that calculation. The high packaging efficiency of the assemblable concept results in the lowest transportation charges. Transportation charges for the other two concepts are nearly equal. The largest differences in cost between the three concepts comes from the charges associated with on-orbit construction. The modular concept requires significantly less assembly since the structure is modularized and the mirrors are integrated with the structure on the ground. These results were a major contributor to the decision to use the modular concept for LSS-4.

Cost Trade Study Results

Assemblable Vs. Deployable Vs. Modular Structure

TDM-232

BOEING



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MISSION OPERATIONS TRADES
LSS CONSTRUCTION SCHEDULE

With the anticipated exposure to specific EVA construction tasks on a day-after day basis, shifts that seem to be suitable at the beginning of a LSS mission may become long after a period of several weeks or months. The duration of the shifts should be limited to a figure that will preclude the development of task-specific fatigue or boredom, with a resulting decrement in performance.

The operators will need to maintain a fairly high level of alertness in case an emergency arises that requires their maximum capabilities.

Day to day long duration usage of the space station EVA suit with any problems (i.e. pressure points, roughness) would become intolerable. With longer shifts, minor problems could turn into major irritants or even a health hazard, causing major decrements in operator performance.

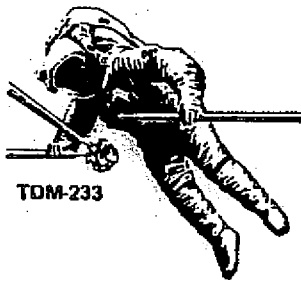
Three operators per shift will be required, full time, during LSS construction activities. The ability to operate more than 1 shift per day will be dependent on the space station crew size and other scheduled space station activities. Two or three shift operation could result in conflicts in the use of facilities and high noise levels while other crew members are trying to sleep.

In earth bound shift work, it has been found that an impairment in performance occurs during the night shift. Performance has been found to be slower, less accurate, and accidents are likely to be more frequent.

Operators are accustomed to working five days a week with short bursts of six or seven day activity. Requiring this type of schedule on a sustained basis will result in fatigue and a loss of efficiency.

Mission Operations Trades

LSS Construction Schedule



BOEING

4, 6, 8 or 10 hours/shift

- Suit comfort
- High efficiency
- Safety

1, 2, or 3 shifts/day

- Dependent on crew size, number of suits
- Sleep/rest cycle
- Eliminates multi-purpose facility conflicts
- Eases adaptation and task scheduling problems

5, 6 or 7 days/week

- Normal earth work schedule
- Other duties
- Independent research

MISSION OPERATIONS TRADES
CONSTRUCTION LOCATION

LSS construction requires a large stable volume or area which will not interfere with space station appendages such as solar arrays and will not compromise the ability of the orbiter to dock with the station.

The platform needs to be large enough to handle construction of TDM LSS-3 microwave radiometer. This also includes the requirement of space for storage of tools, components, and equipment required for the construction tasks. The platform will have to be adaptable to a variety of LSS construction projects and be able to support other space station missions and experiments. It will also need to provide access to space station utilities needed for LSS TDM construction such as power, lighting, remote TV, communications and data lines.

The Docking/Berthing port option would only be adequate for a limited number of LSS TDM's. The limited construction and storage space would make construction of even moderate sized large space structures impossible.

Mission Operations Trades

Construction Location

TDM -234

BOEING

Space station platform ← Chosen

- Large stable construction area
- Ample storage for components/tools
- Potential site for space station RMS/Cherry picker
- Adaptable to a variety of construction projects
- Space station supplies utilities (power, lighting, communications data)
- Potential high drag, shadowing, interference

Docking/berthing port

- Adequate for a limited class of LSS (i. e. deployable)
- Limited storage area for components/tools
- Space station supplies utilities
- Limited construction area

MISSION OPERATIONS TRADES
CONSTRUCTION LOCATION

The use of special construction fixtures (i.e. piers, truss beams, etc.) would also be inadequate for the construction of large space structures.

The linear work area would require a lot of operator translation during construction activities and the size of the work area would limit the size of the LSS TDMs that could be constructed.

The free flyer construction platform would need to provide power, oxygen etc. for construction activities. Solar arrays, fuel cells, or batteries would need to be provided for power.

The use of a co-orbiting platform for LSS construction would require the use of the shuttle vehicle or the design and construction of a special vehicle to carry the workers, tools, components, and equipment back and forth between the two work sites.

Astronaut safety is of prime importance and provision of a safe haven or rescue vehicle on the co-orbiting platform in case of medical emergencies, injuries or other difficulties would be necessary.

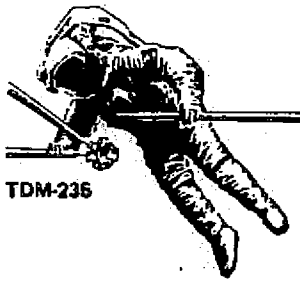
The use of a tethered LSS construction platform could cause flight dynamics problems for the space station. The reaction of the tethered platform and the space station if the tether broke would also be of concern.

Transfer of the crew, tools, components, and equipment from the space station to the tethered platform would be difficult.

Astronaut safety during a medical emergency, injury or other difficulty and transportation back to the space station would be a difficulty.

Mission Operations Trade (Continued)

Construction Location



BOEING

Special construction fixtures (piers, truss beams, etc.)

- Adequate for a limited class of LSS
- Storage area for components/tools
- Space station supplies utilities
- Potential site for space station RMS/Cherrypicker

Free Flyer

- Must supply own power and other utilities
- Transport of crew/tools/components difficult
- Crew safety
- Separate attitude control required

Tether

- Dynamic interaction with space station
- Crew, equipment transfer difficult
- Crew safety
- Utilities through Tether or self-supplied?

Mission Operations Trades

Construction Method

Of the three assembly methods chosen, deployment takes the least operator involvement but incurs high engineering and manufacturing costs. Manual assembly of large space structures is labor intensive, driving the on-orbit costs up while not reducing engineering costs significantly. Prefabrication and assembly of modules can minimize on-orbit assembly costs, however transportation size, weight and packaging must be considered. All three method of construction are being planned for use during the LSS TDMs as each has distinct advantages.

Mission Operations Trades

Construction Method

TDM-236

BOEING

Prefabricate (modules) ← Chosen

- LSS-4 truss and mirrors
- Rapid assembly
- Moderate EVA required

Deploy ← Chosen

- LSS-1 platform
- Expensive design and fabrication
- Minimum EVA required
- Fastest assembly

Assemble ← Chosen

- LSS-3 truss
- Maximum EVA
- Minimum design and fabrication costs
- Longest assembly time

MISSION OPERATIONS TRADES
TOOLS AND SMALL EQUIPMENT RESTRAINTS

Restraints need to be provided that will aid in the optimization of operator efficiency during the LSS TDM construction tasks.

The use of tethers provides a positive restraint for the tools and equipment the operator needs during his EVA tasks. If several items are tethered to the same location, operator movement will tend to tangle the tethers and make retrieval of individual items difficult. During translation or while moving his arms, items tethered to his wrists will tend to swing and could damage other equipment or the EVA suit.

Velcro is easy to attach to most tools and surfaces including the EVA suit. This provides versatile attach points in the work area. Tools can inadvertently get attached to unlikely spots and multiple tools can get attached to the same spot so that it would be hard to grasp individual items. Tools or equipment could accidentally get brushed off or get hooked on something, come loose and drift away. During usage, velcro hooks break off. These particles and outgassing of the adhesive could cause contamination problems.

The use of nets over tool boxes or boxes of loose items will provide adequate restraint and facilitate construction activities. Slits in the net would reduce the problems of removing and replacing items in the boxes.

Clips used to restrain tools, components, and equipment during shipping will also be used to hold these items during construction tasks.

Mission Operations Trade

Tools and Small Equipment Restraint

BOEING

TDM-237

Tethers ← Chosen

- Positive restraint at all times
- Easily available
- Tethers from separate items can become tangled
- Items tend to bang around when operator moves

Velcro ← Chosen

- Easy to attach tools and equipment to suit or work area
- Easy to add attach points
- Degrades with age and usage
- Tools and equipment can come loose

Net ← Chosen

- Positive restraint for loose items
- Difficult to remove and replace tools and equipment

Clips ← Chosen

- Positive restraint of specific tools and equipment
- Hard to grasp and remove tools and equipment
- Good for shipping restraint

Elastic

- Not adequate for restraint

MISSION OPERATIONS TRADES
EVA RESTRAINTS (PERSONNEL)

The space station EVA operators need adequate restraints to enable them to maintain their position, counteract torque, and aid in translation while accomplishing LSS TDM assembly, deployment, and operation. Currently on STS missions, in addition to the tethers used, the EVA operators hang on with one hand or try to wedge themselves into position with their feet.

Tethers are simple and fairly inexpensive but do not provide rigid attachment to aid in the application of torque. Tethers also tend to flop around and could be a hazard if they get tangled in equipment.

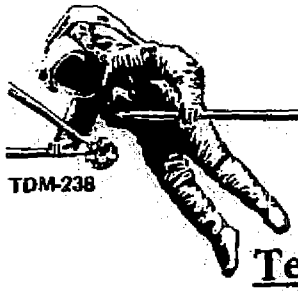
Enclosing work areas with nets would be inexpensive but would require deployment for each task on large structures and would not provide aid for the application of torque. It would stop loose tools from drifting off but, with no other restraint, would require lots of time chasing loose tools. They could be deployed on large space structures. They may tend to get tangled up when trying to deploy or store. Operators may get tangled in net depending on mesh size. They would need to be stowed in a storage area when not in use.

The use of lots of velcro creates a problem in that if there is a lot on the suit the crewmembers would get inadvertently secured when bumping into the matching velcro.

Shoe restraints are fairly expensive and complex. They would require some type of mating gridwork at all assembly locations. They need an emergency breakaway provision in case they hangup. However they would provide one of the best methods of counteracting torque. A problem in the use of foot restraints is that EVA astronauts cannot see their feet to position them into foot restraints.

Mission Operations Trades

EVA Restraints (Personnel)



TDM-238

BOEING

Tethers ← Chosen

- Positive restraint
- Allows large reach and vision envelopes
- Limited torque capability
- Hard to maintain specific work position

Net

- Large volume enclosed by a net eliminates need for safety restraint
- Could get stuck in mesh
- Must use other method to maintain specific work position

Velcro

- Easy to engage
- Operator's motion loosens
- Degrades with age and usage

Foot restraints ← Chosen

- Needed to counteract large torques
- Positive positioning at task site
- Limited reach and vision envelopes
- Difficult to get into
- Limited portability unless attached to RMS or movable platform

MISSION OPERATIONS TRADES
EVA MOBILITY

The ability to translate long distances between work locations rapidly and being able to transfer tools equipment and assemblies quickly and accurately will have a large impact on LSS TDM's assembly timelines.

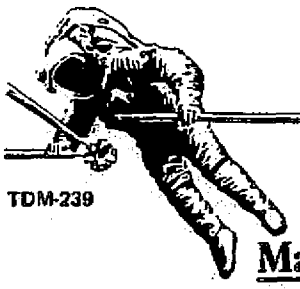
Manual translation for the long distances required along with the requirement of moving equipment will be tiring and time consuming.

The use of the RMS with a manrated work platform will speed up movement of personnel and equipment within the RMS reach envelope.

The MMU will provide flexibility and speed in movement of personnel and equipment. The bulk of the MMU will restrict the operator from working in close quarters. Additional time will be required for fueling and checkout of the MMU system.

Mission Operations Trades

EVA Mobility



TDM-239

BOEING

Manual ← Chosen

- Good for short distances
- Minimum profile for small spaces
- Requires safety line
- Increases operator workload

MMU ← Chosen

- Good for long translations
- Bulky, limits access
- Hard to counteract torque
- Donning and checkout time

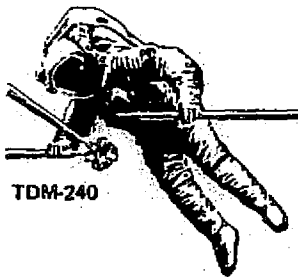
RMS with platform ← Chosen

- Provides mobile torquing platform
- Rapid translation over short distances
- Limited access to work areas
- Limited to reach of RMS

Manned OMV

Not applicable for space station LSS construction activities

LSS TDM Construction Times



BOEING

MISSION	CONSTRUCTION TIME*				
	ELAPSED HOURS	25% CONTINGENCY	TOTAL HOURS	MAN-HOURS	SHIFTS
LSS - 1 **	87.54	21.89	109.43	328.26	18.24
LSS - 3	162	40.50	202.50	607.50	33.75
LSS - 4					
ASSEMBLY	229.33	57.33	286.66	859.98	47.78
DEPLOYMENT	191.78	47.95	239.73	719.18	39.96
MODULAR	169.63	42.41	212.04	636.12	35.34

*CONSTRUCTION ON THE SPACE STATION

**LSS - 1 AND LSS - 2 COMBINED

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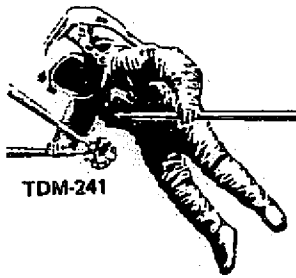
Space Station Design Requirements



BOEING

- Large throat clearances
- Construction platform or attachment provisions
- Air lock near construction area
- RMS capability
  - Fixed (good)
  - Mobile (better)
  - Tracked (best)
- Capability to mount and operate other experiments

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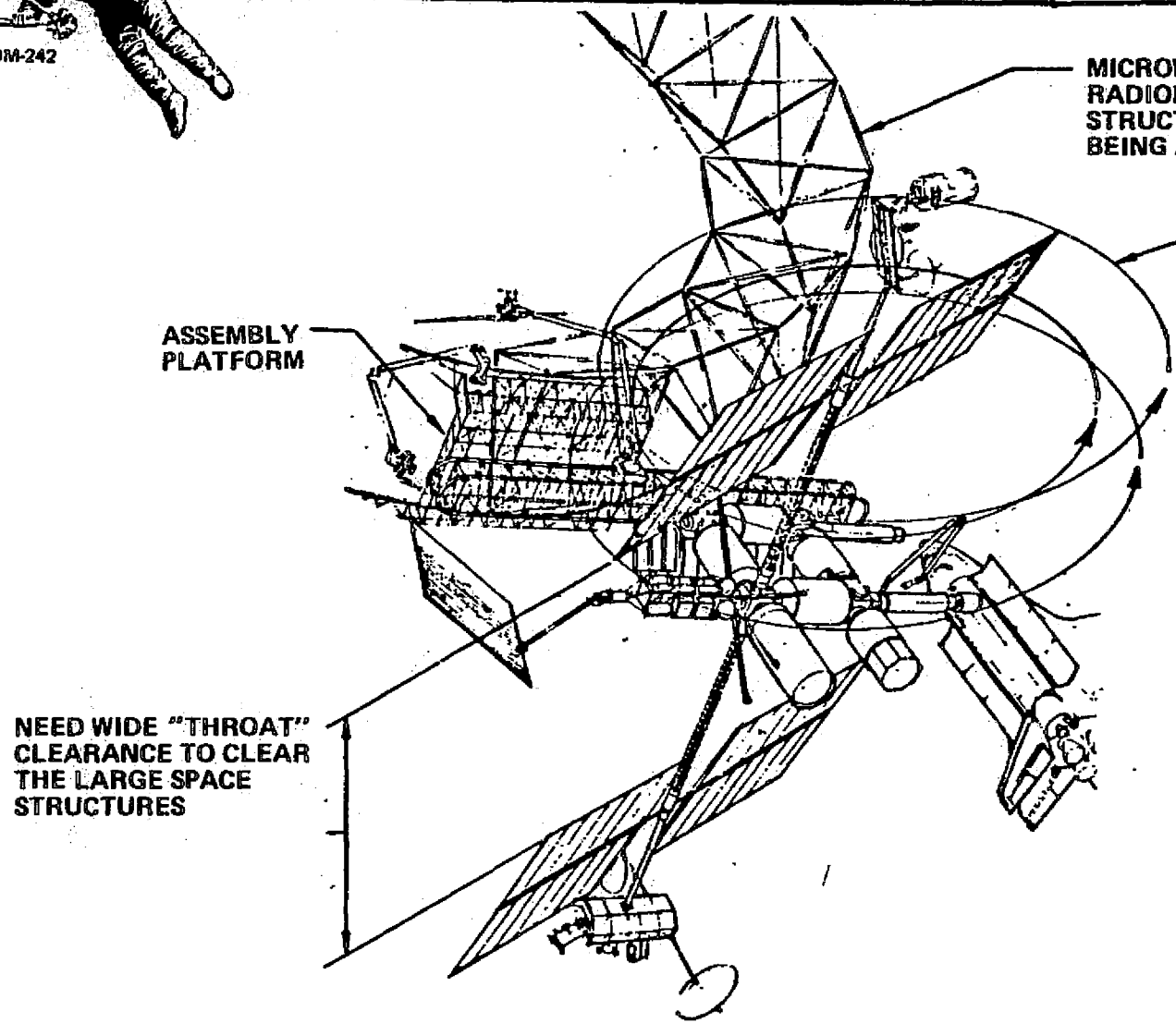
Large Space Structures Impact on Space Station Configurations

This chart demonstrates the neeed to allow sufficient area for construction of the LSS TDMs without interference with the solar arrays or other spare station appendages. The construction area must also be oriented so that drag of both the platform and the construction project is minimized.

Large Space Structures Impact on Space Station Configurations

BOEING

TDM-242



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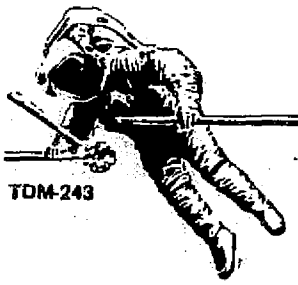
Space Station Operations

During this phase of the study the space station operation analysis is being updated to reflect operations trades and TDM design alterations. Scheduling of space station personnel, facilities and activities will be of prime important to minimize conflicts in all phases of space station operations. LSS testing (accuracy, dynamic response and thermal deformation measurements) must be conducted in an environment where the only disturbance is that which is required in the test. Therefore, some space station operations, (i.e. thruster firings, docking, etc.) must be curtailed during LSS testing.

Space Station Operations



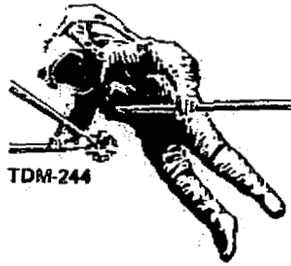
BOEING

- No orbital adjustments allowed during LSS testing
- 3 crew members required during LSS construction
- Scheduling of space station
  - Communications (intercomm)
  - TV (remote)
  - Data handling
  - Data processing
- Scheduling of other experiments
  - RMS operations
  - Platform access
  - Facilities (briefing areas, computers, data links, communications, etc.)
  - Zero-G requirements
- Scheduling of:
  - Shuttle docking
  - OMV and OTV operations

Special Problems

The construction of large space structures attached to the space station may cause some concerns due to additional mass, increased moments of inertia, increased orbital drag, and interface with communications. In addition, make-up air will need to be provided during the construction phase of each TDM due to airlock losses. Contamination around the station will also increase due to the additional air loss, TDM composite materials outgassing, adhesive outgassing etc. The flexibility of LSS construction projects must also be considered so that undesirable interaction with space station stability and control can be prevented.

Special Problems



BOEING

- Mass properties
- Structural dynamics
- Drag
- Shadowing
- Airlock air loss
- Contamination

Dynamics of Large Space Structures

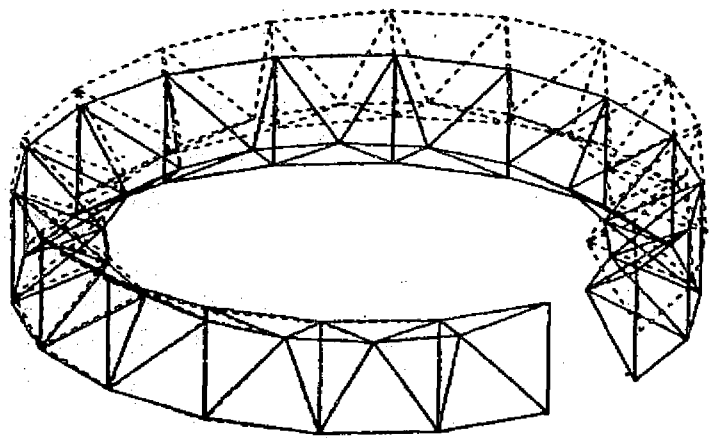
During the construction of large space structures on the space station, care must be exercised to assure that structural dynamics do not impair the stability and/or controllability of the space station. This chart shows the results of a NASTRAN analysis of the LSS-3 truss ring during its assembiy. With the ring attached to the space station at the four points indicated, it has the lowest natural frequency just before the last structural members are installed (frequency = 0.08 Hz). Upon completion, the first mode frequency increases to 0.26 Hz. Installation of the reflector surface and feed system will again tend to reduce the frequency. Analysis of those effects is currently underway.

Dynamics of Large Space Structures

TDM-245

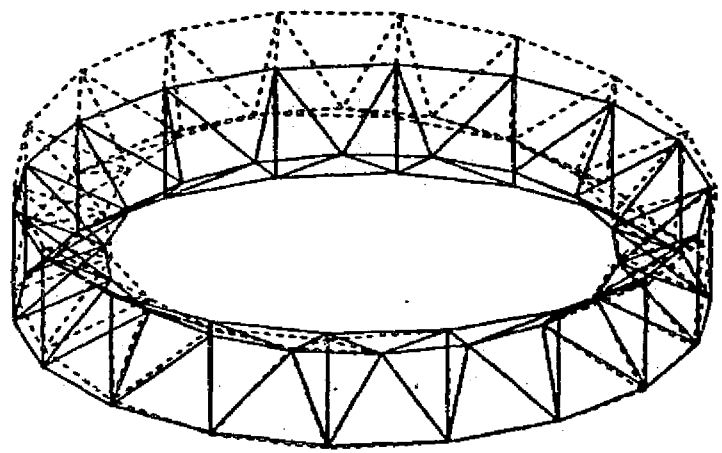
BOEING

f = .08 Hz



95% COMPLETE

f = .26 Hz



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Real Time Space Station Simulation

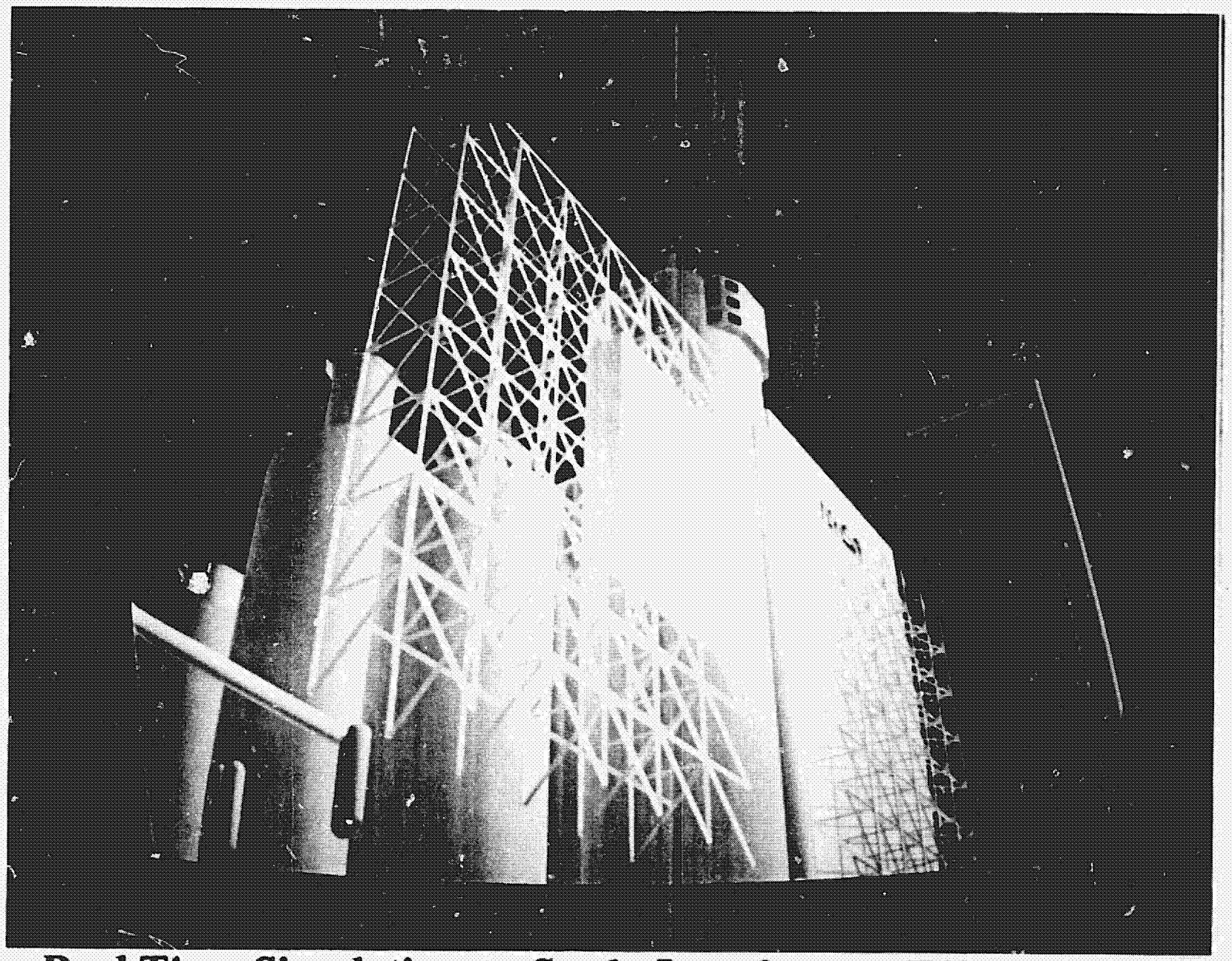
As an IR&D task, a demonstration model of a Boeing space station concept has been implemented on the Evans & Sutherland (E&S) CT5 CIG system installed at the Renton Flight Simulation Center (RFSC). The intent was to provide a vehicle to help assess the feasibility of the CT5 as a space station design tool.

The photo gives an idea as to what is possible with the CT5. The real horsepower of the system lies in its ability to realistically simulate a dynamic visual environment. An artists conception is a snapshot in time of an idea. The real time capability of the CT5 adds the dimensions of time, motion, and dynamic lighting and color effects to concept portrayal.

Visual representation of certain non-visual parameters is possible through the use of semi-transparent surfaces or strings of light points. Sweep areas of solar arrays and thermal radiators could be shown. Docking corridors could be displayed to assess clearances or regions of marginal visibility. Maximum reaches of the remote manipulator could also be shown.

A limited amount of structures deployment could be represented, such as telescoping trussworks and perhaps unfolding solar arrays.

Structures buildup and assembly could be shown.



Real Time Simulation to Study Interference Effects

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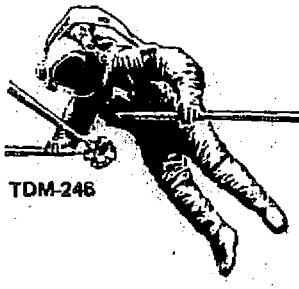
EVA MAKEUP AIR

In reviewing the LSS TDM construction tasks it was determined that airlock usage during EVA would create an extra burden on the space station.

Analysis indicates that, on the average, the airlock will be cycled twice for each construction day. Hamilton Standard data indicates that each airlock cycle loses 1.3 pounds of air. In addition to this air loss, 1.5 pounds of tankage is required for every 1 pound of air delivered to the space station. The table indicates the makeup air required for each LSS TDM.



TDM-246

EVA Makeup Air

BOEING

AIR LOSS DUE TO AIRLOCK OPERATION

MISSION	DAYS	POUNDS		
	CONSTRUCTION	AIR/AIRLOCK* CYCLE	MAKE UP AIR	AIR & TANKAGE DELIVERED TO SPACE STATION**
LSS -1	18	1.3	46.8	117
LSS - 3	34	1.3	88.4	221
LSS - 4	48	1.2	124.8	312

* ASSUMES 2 CYCLES PER CONSTRUCTION DAY

** TANKAGE IS 1.5 LB PER 1 LB OF AIR

Special Equipment

The proposed technology development missions require common tools and equipment which will be part of the space station's equipment list. This equipment could include test equipment such as laser measurement systems, dynamic excitation, response measuring and analyzing equipment and thermal measurement and analysis equipment. Data obtained from these test would be processed by the space stations computer and transmitted to the ground via the space station communications link. Common positioning fixtures, hold-down equipment and construction tools could also be used for several construction projects.

This chart lists the special equipment envisioned to remain on the space station for use during LSS construction projects.

Special Equipment

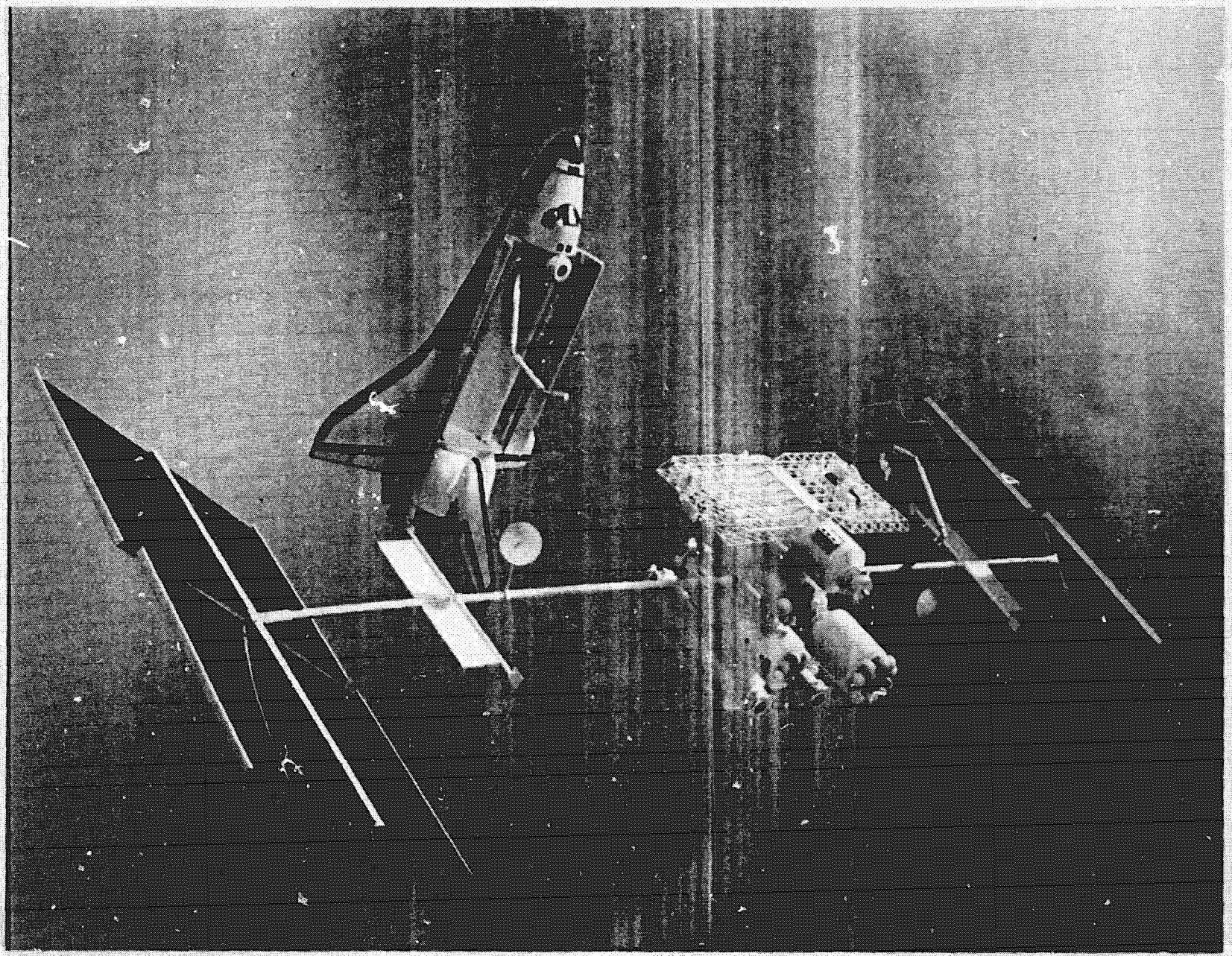
TDM-247

BOEING

- Support fixtures
  - Storage facility
  - Construction fixtures
  - Miscellaneous constraints and hold-downs
  - S/C orientation fixture
  - Articulated holding fixture (laser measurements)
  - Strut alignment and assembly fixture
- Instrumentation
  - Structural dynamics (acceleration, strain, loads, etc.)
  - Thermal response (thermocouples)
  - Position/deflection (precision laser ranging, corner reflectors)
- Data systems
  - Recording
  - Storage & Retrieval
  - Manipulation (EDP)
  - Transmission (uplink and downlink)
- Small tools
  - Maintenance
  - Construction

Space Station Concept

This chart shows a photograph of a model of a Boeing space station raft concept. This model is being used to investigate space station and LSS TDM build-up sequences, interference problems, shadowing, shuttle docking, and experiment mounting and pointing, location of platforms, clearance envelopes, RMS mounting concepts, etc.



Space Station Concept

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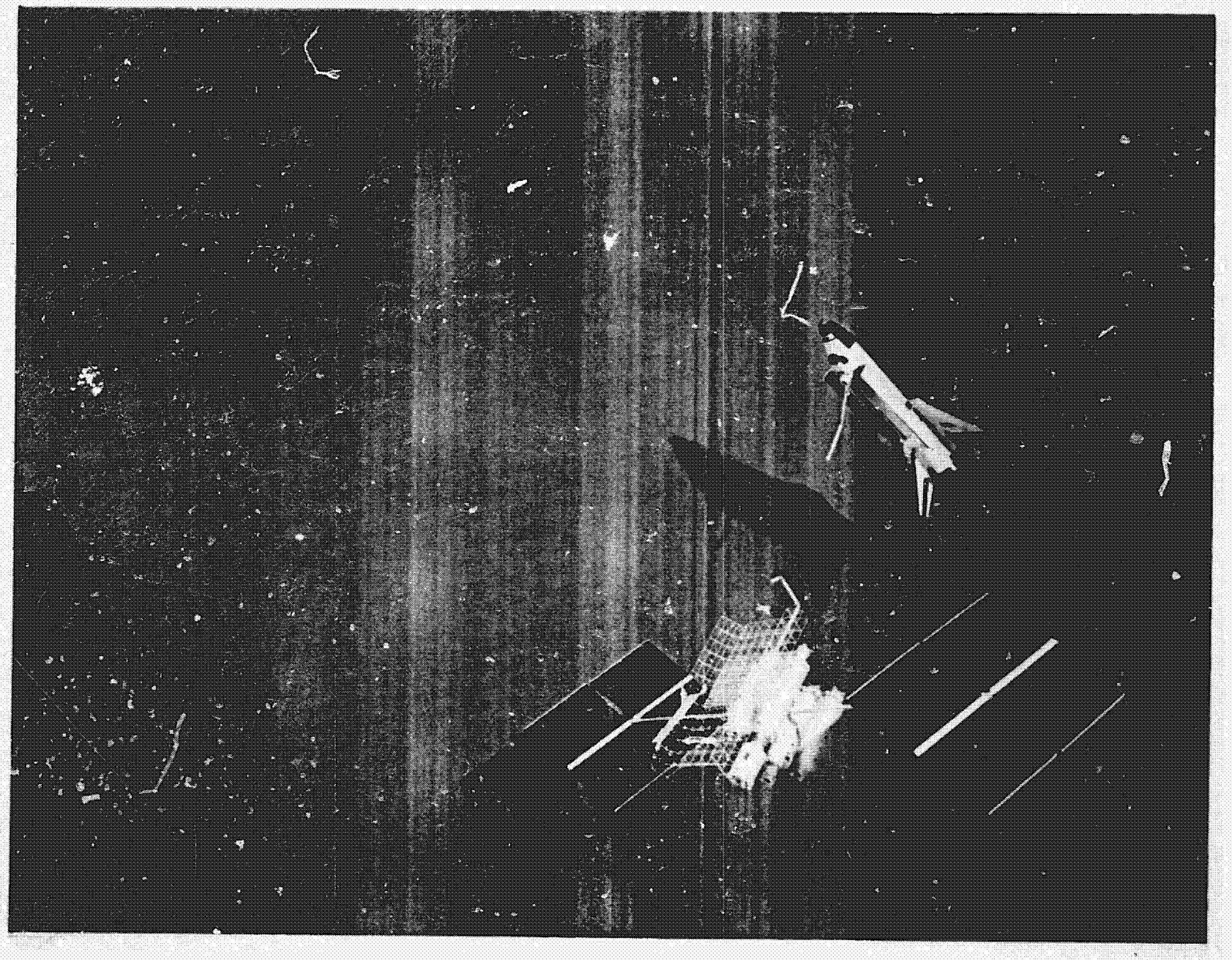
LSS-1 Platform

This sequence shows the LSS-1 TDM platform located on the raft configuration space station. A docking/berthing port mounted RMS is also shown. This starts to give us an indication of the size and area required for the LSS TDMs.



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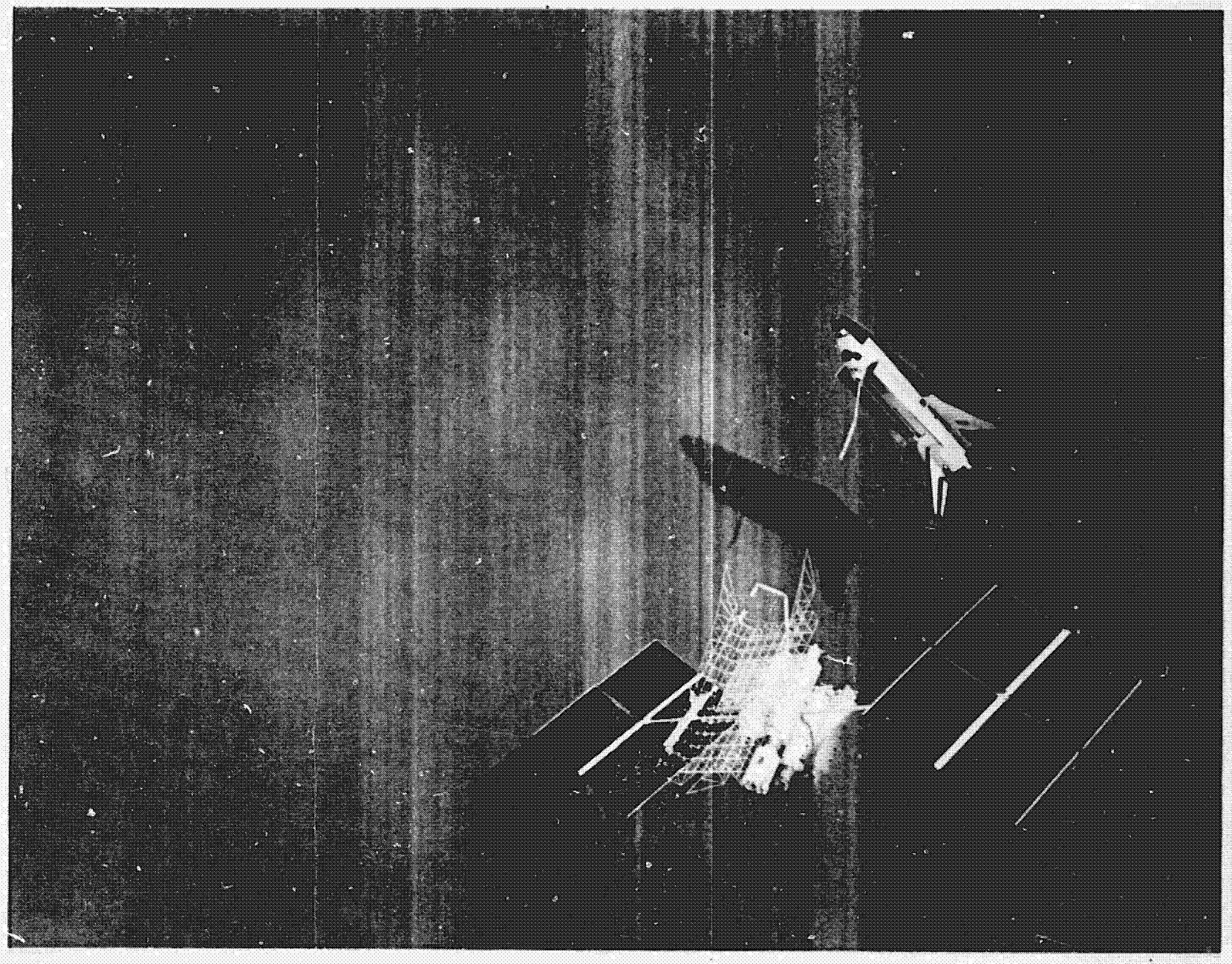
LSS-1 Platform

Platform and LSS-3 Construction Fixture

The LSS-3 construction fixture extends the platform envelope and illustrates the construction base required for this TDM.



Platform and LSS-3 Construction Fixture

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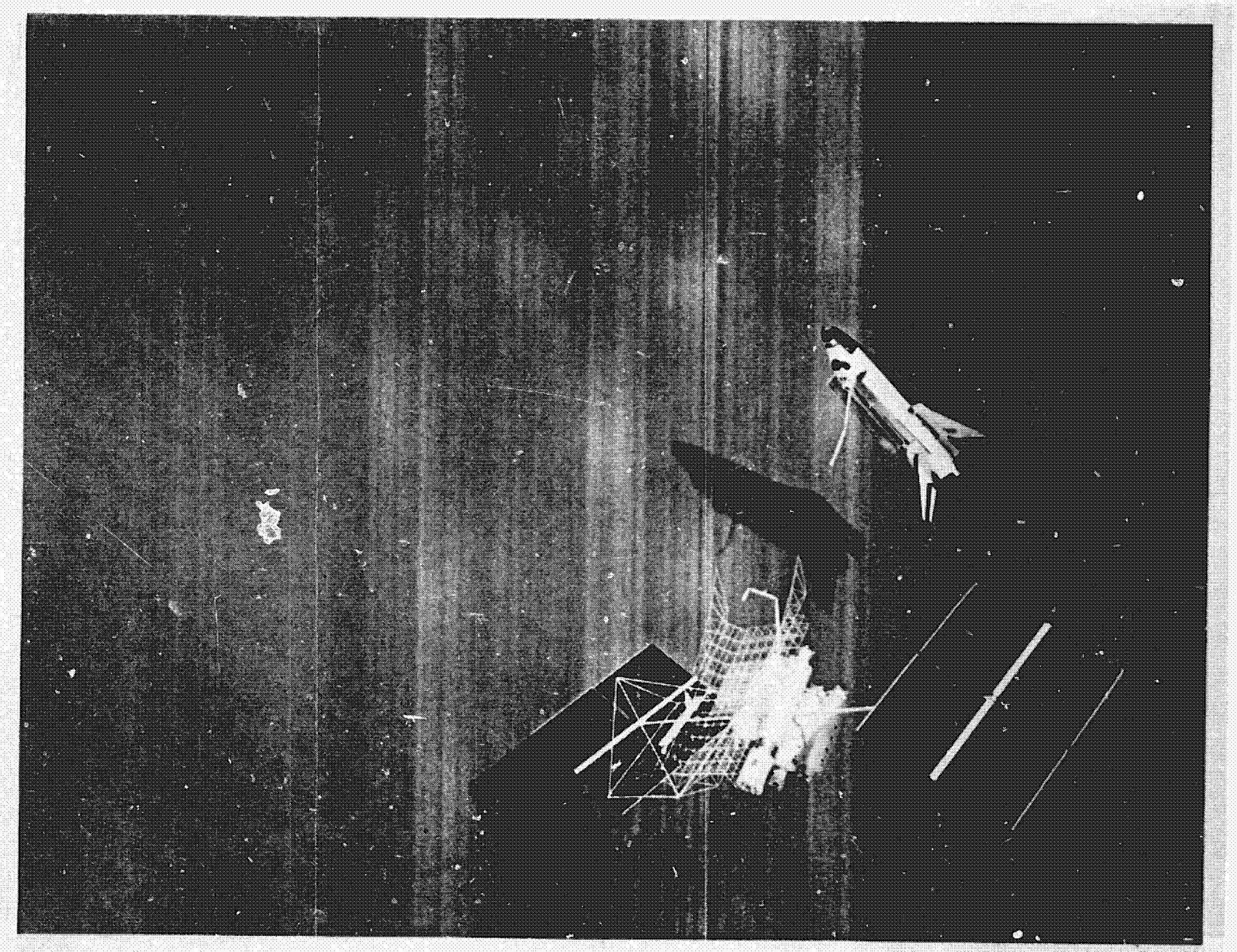
1 Section of LSS-3 Truss

With only one section of the LSS-3 truss completed, interference with other space station operations is at a minimum.



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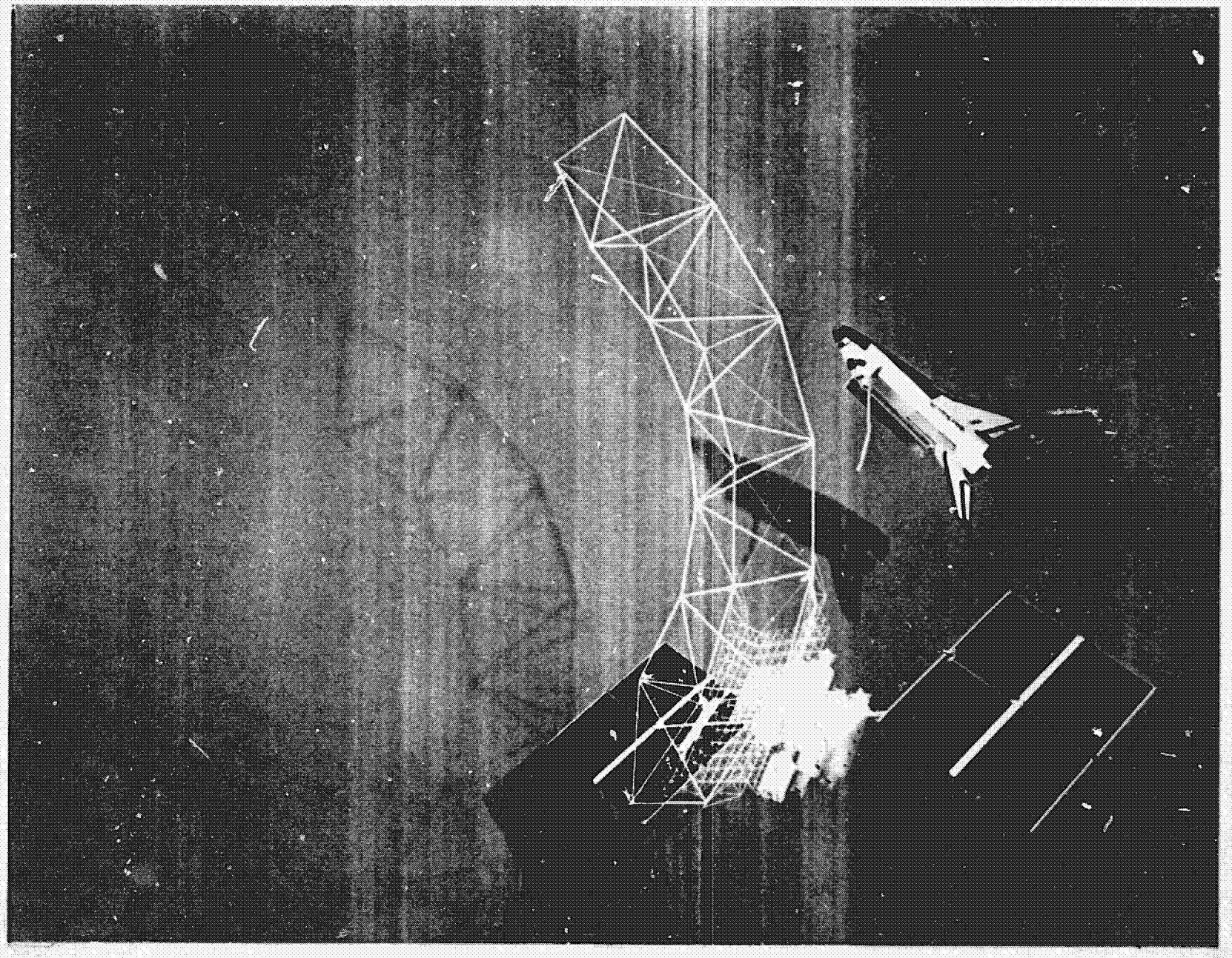
1 Section of LSS-3 Truss

1/3 of Truss Ring Assembled

The growing size of the truss ring starts to indicate the interference problems that the completed microwave radiometer will cause. Structural dynamics of the construction project may start to become significant at this point.



1/3 of Truss Ring Assembled

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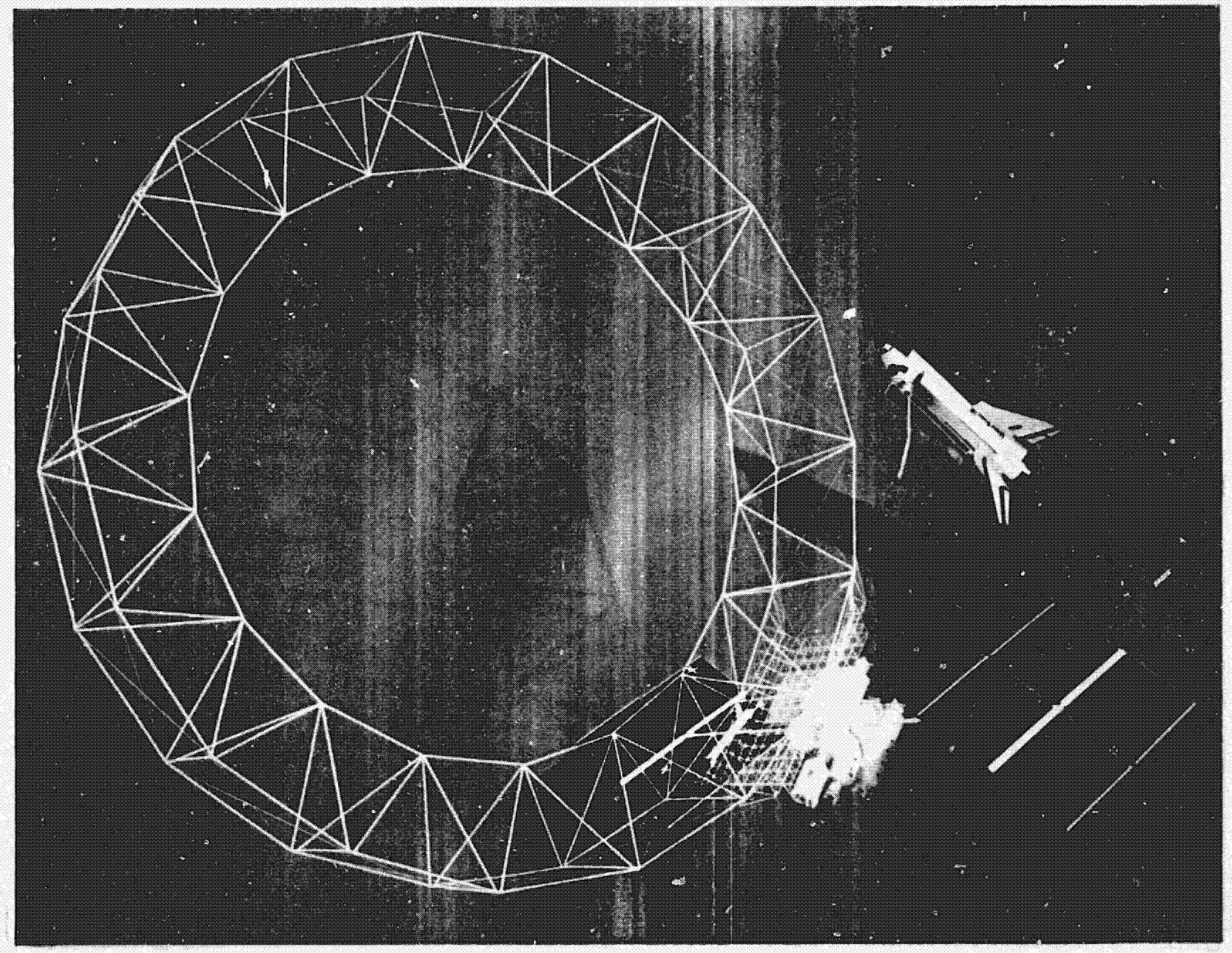
Truss Ring Completed

This photograph gives the first indication of the size of the LSS-3 microwave radiometer in relation to the space station modules and the shuttle. Mass properties and structural dynamic effects must be accounted for.



Truss Ring Completed

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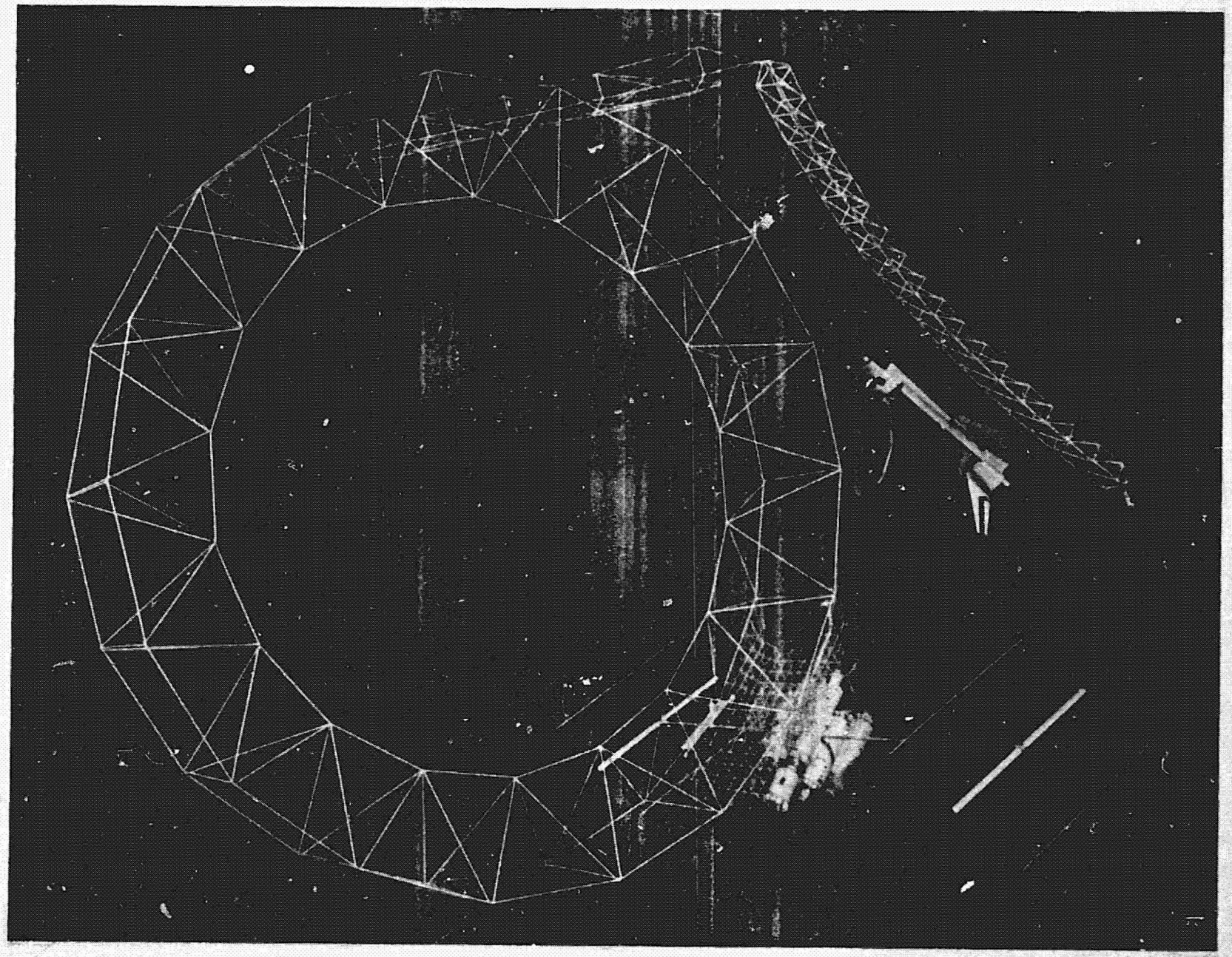
Truss Ring With Feed Truss and Supports

The length and size of the feed supports and feed truss are indicated in this picture. This gives a feeling for the operator and equipment translation distances required during the feed truss mounting sequence.



Truss Ring With Feed Truss and Supports

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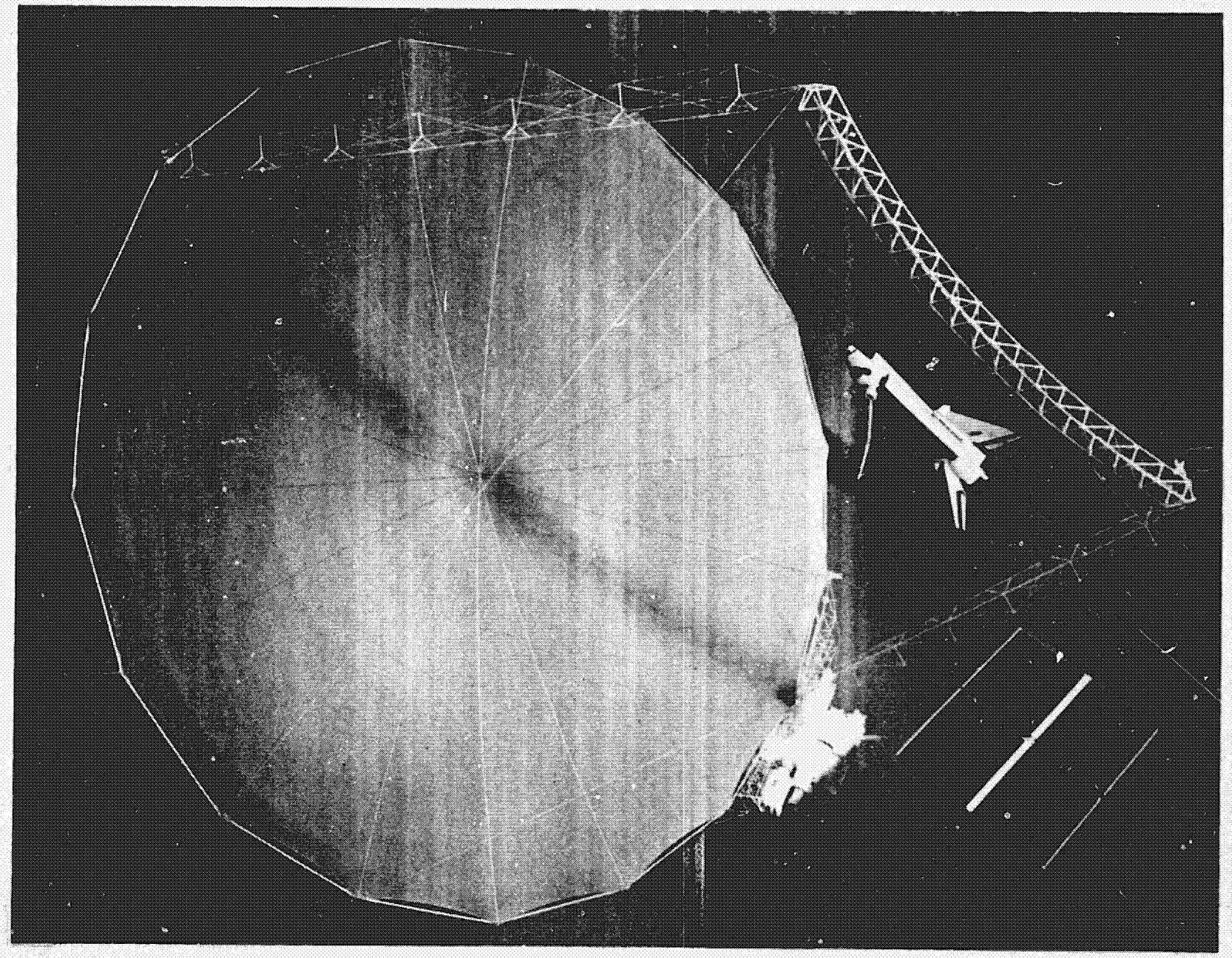
Reflective Mesh Installed

Attaching the reflective mesh dramatically increases the visual size of the microwave radiometer as well as increasing the weight and drag. This photo also graphically shows the potential shadowing problem and the possible influence on other operations in the vicinity of the space station.



Reflective Mesh Installed

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