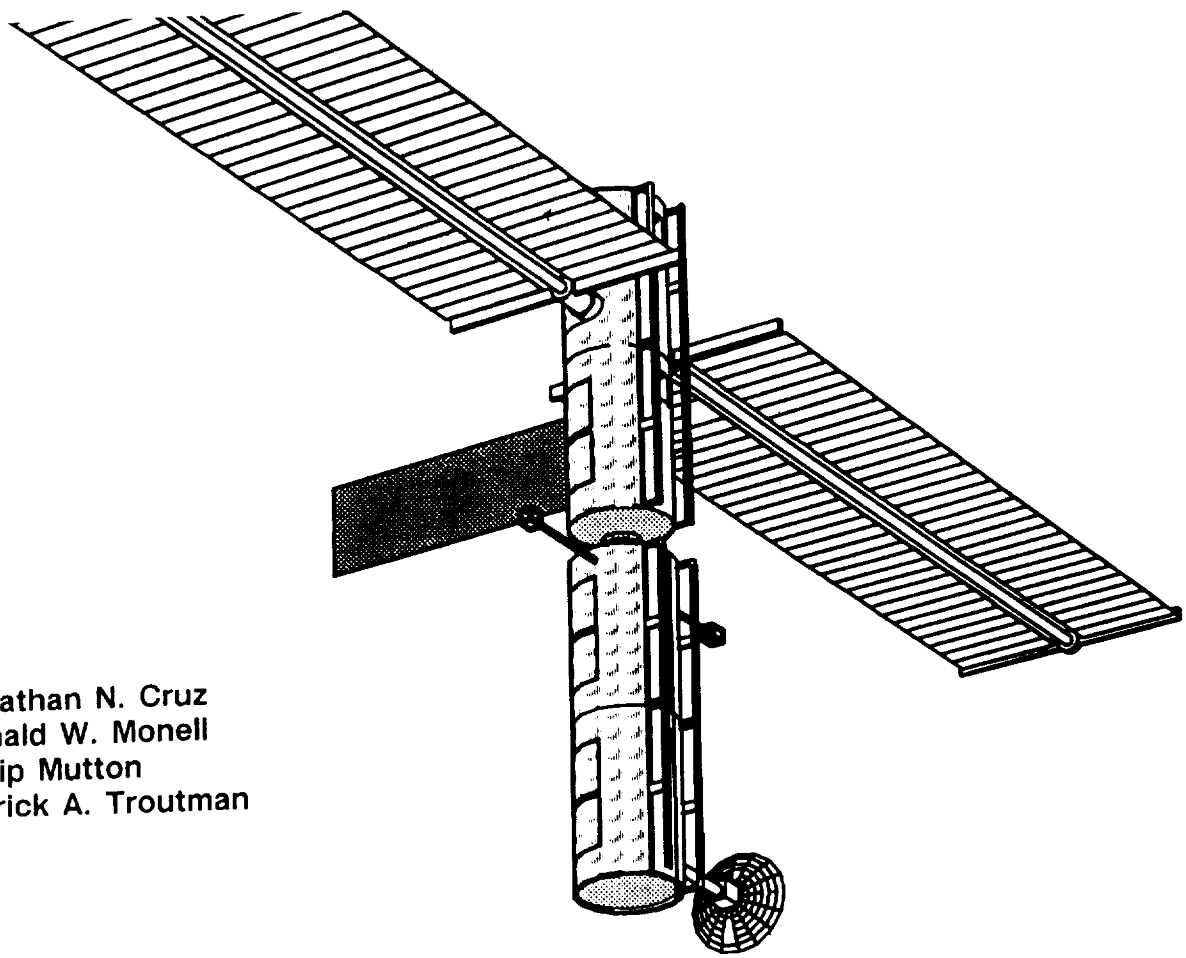
NASA Technical Memorandum 102780

# Pre-Integrated Structures for Space Station Freedom





Jonathan N. Cruz
Donald W. Monell
Philip Mutton
Patrick A. Troutman

February 1991

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23665-5225

# Table of Contents

– This Page Intentionally Left Blank –

# Introduction

– This Page Intentionally Left Blank –

# Introduction

The assembly of Space Station Freedom has always presented a significant challenge to its design engineers. Never before had a spacecraft the size of Freedom been required to be delivered to orbit in such a comparably small launch vehicle (the space shuttle). This size difference dictated numerous shuttle launches and on-orbit assembly. In 1986, one half of Freedom's transverse boom along with a pressurized node was manifested on the shuttle as the first assembly flight. This included 18.75 KW of power, ten bays of erectable five meter truss and its assembly equipment, RCS and fuel, full communications and avionics. By the time the program reached the PDR stage in 1990, the items manifested on the first assembly flight were reduced to one 18.75 Kw PV unit, a few bays of truss and associated assembly devices.

The reduction of station hardware on the first assembly flight is due to many factors. Shuttle performance decreases, station system and support hardware mass increases, a more conservative understanding of shuttle packaging and C.G. constraints, increases in flight support equipment (FSE) and large increases in EVA estimates have made it increasingly difficult to launch and assemble the station with a limited number of shuttle flights. At PDR it took four shuttle flights to launch and assemble what was manifested on the first flight in 1986. The prime benefit on an erectable space structure - the ability to construct a large spacecraft from a small launch package - was no longer being realized for Freedom assembly.

The shuttle with its 60 foot cargo bay is capable of delivering to orbit long pre-integrated sections of truss using only a limited amount of FSE since there would be only one large cargo element in the cargo bay. Based on length alone, three shuttle flights can bring up one half of the transverse boom in pre-integrated sections with the added benefits of ground integration, ground verification and a substantial reduction in EVA as compared to using erectable truss. In July of 1990 the LaRC Space Station Freedom Office (SSFO) began to study the technical feasibility of using pre-integrated structure in the assembly of Freedom with the objective being to maximize ground integration and minimize on-orbit integration/verification functions. The concept was based on utilizing an isogrid tube as part of the pre-integrated structure. The feasibility of the structural concept was evaluated with respect to system/structural interfaces, dynamic and thermal loads, assembly manifesting/operations and station orbital characteristics.

## Ground Rules/Assumptions

The study was based on a given isogrid form which is described in the following section, "Pre-integrated Truss Structural Description." Baseline data were used for the subsystems definitions (number, size, etc. of ORU's) and the STS launch capability. Weights used for manifesting were provided by Level II to be more compatible with the current design status, and a margin of 15% was added to allow for uncertainties.

# Ground Rules/Assumptions

- Erectable truss replaced with isogrid tube structure with 22-inch node spacing
- Assume baseline STS capability
- Baseline subsystems requirements will not change
- Utilize Level II -provided weights
  - -add 15% structural margin

– This Page Intentionally Left Blank –

# Pre-Integrated Truss Structural Descriptions

## Isogrid Structural Features

Isogrid is a lattice of stiffening ribs which intersect to form an array of equilateral triangles. This arrangement creates a structure which exhibits isotropic behavior and has a Poisson's ratio of 1/3. This design is efficient in carrying compression and bending loads, acting similar to a beam–column.

There are several advantages to using isogrid in structural applications. It is easily analyzed by virtue of its isotropic behavior. The method of manufacturing isogrid allows for optimization for a wide range of loading intensities. Isogrid provides a standard pattern (every 22 inches in this case) for attachment. These attachment nodes allow for a wide variety of equipment to be mounted to the structure with minimum impact to the basic isogrid structure. The method of manufacturing and the attachment nodes allow for reinforcement at concentrated load points and around cutouts. Isogrid also provides redundant load paths.

# Isogrid Structural Features

- **A lattice of intersecting ribs forming an array of equilateral triangles**
- **Characteristics:**
  - Isotropic (no directions of instability or weakness)
  - Efficient in compression and bending
- **Advantages:**
  - Easily analyzed
  - Can be optimized for wide range of loading intensities
  - Standard pattern for attachment (nodes accomodate equipment mounting without change)
  - Readily reinforced for concentrated loads and cutouts
  - Redundant load paths

## Integrated Structure Dimension Drivers

The length and diameter of the isogrid structure were driven by numerous factors. The orbiter imposes the most requirements that impact the structure's dimensions. A length of 44 feet was chosen to provide sufficient clearance between the isogrid structure, the aft bulkhead camera and the orbiter to station docking module. This length also allowed the structure to stay within the orbiter C.G. constraints and lift capability. Increasing the length of the structure would improve overall assembly efficiency by reducing the total number of flights. This may require exceeding some orbiter constraints and thus was not considered for this feasibility study. The diameter of the isogrid truss was also driven by orbiter packaging requirements. A maximum diameter of 14.5 feet is allowed in the orbiter bay. A slightly diameter (13.3 feet) was chosen for the isogrid structure so that some external packaging of elements (mobile transporter rails, berthing mechanisms, etc.) was possible.

# Integrated Structure Dimension Drivers

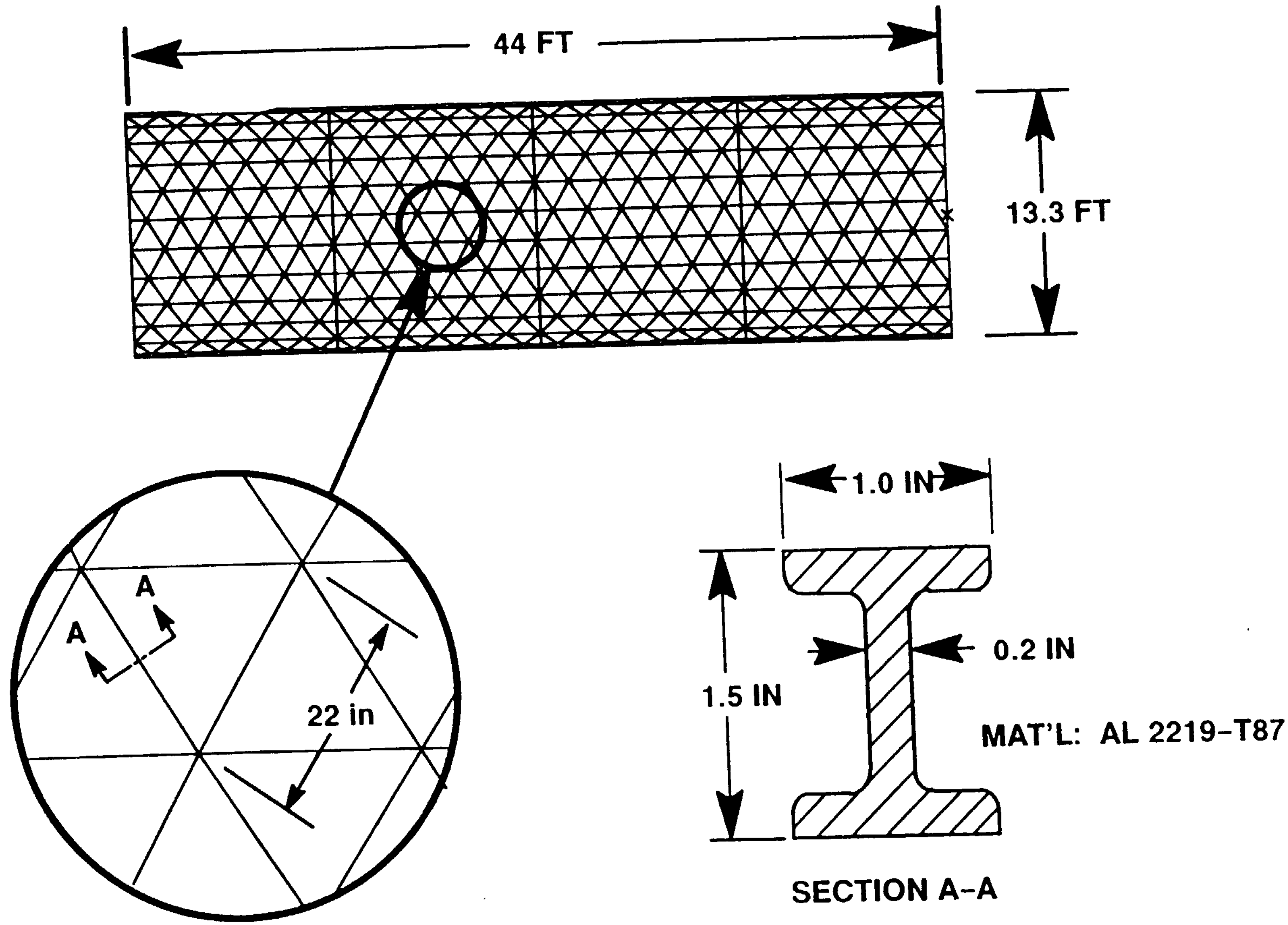
**Length** – Transverse boom clearances, number of assembly flights, orbiter C.G. constraints, orbiter clearances, RMS reach limits, packaging requirements, EVA access and weight.

**Diameter** – Orbiter clearances, internal vs external packaging of some elements, EVA access and weight.

## Isogrid Configuration

The cylindrical structure is constructed in the form of an aluminum isogrid, which is fabricated by using several machined segments welded together along the longeron members. Each grid has a dimension of 22 inches between adjacent nodes.

# Isogrid Configuration

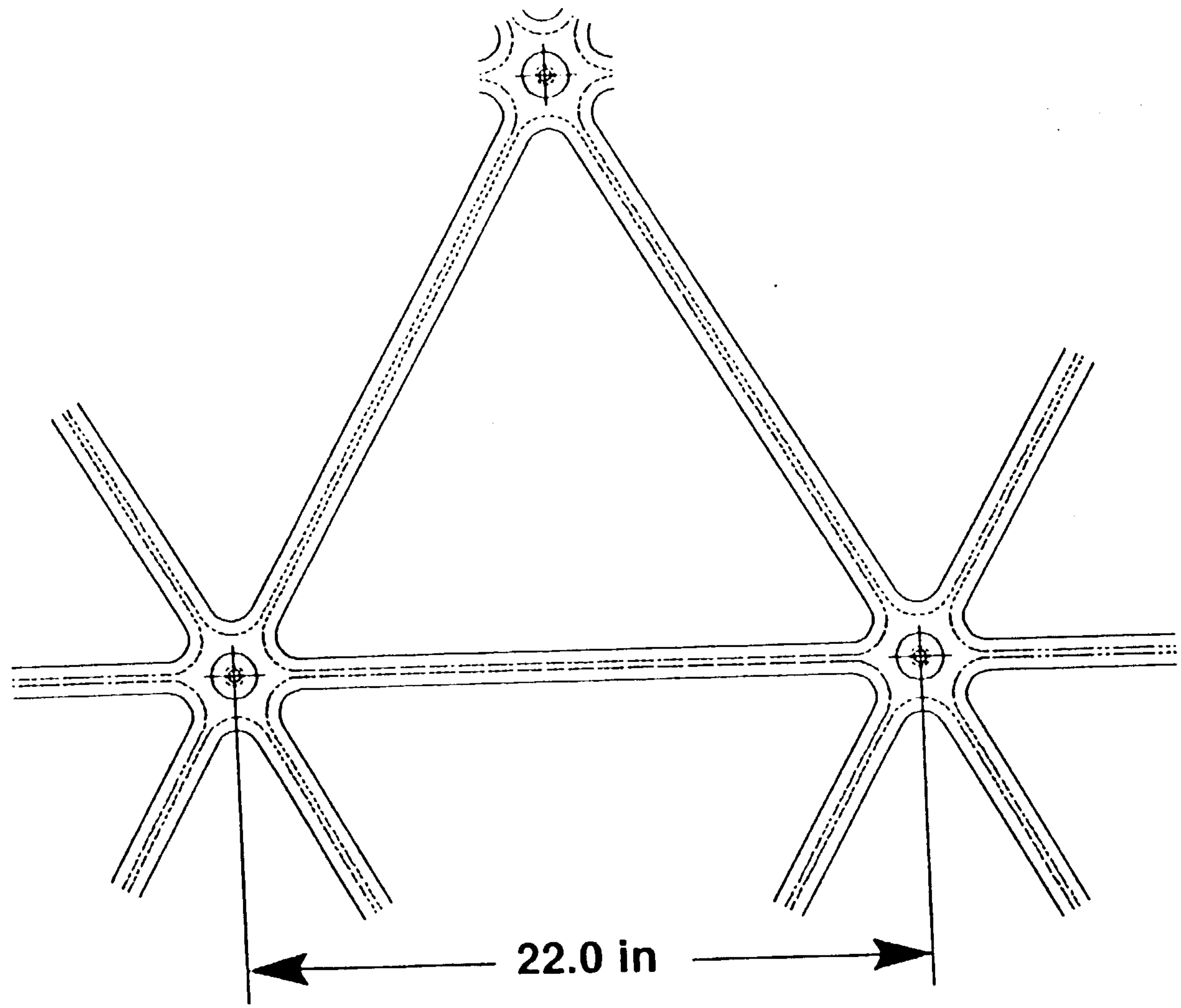



CLOSEUP VIEW OF ISOGRID

## Typical Segment of Isogrid

In a single segment of isogrid the structure can be seen to be very open, hence its light weight. The incorporation of attachment points at each node provides flexibility for the location of system hardware, and shielding materials.

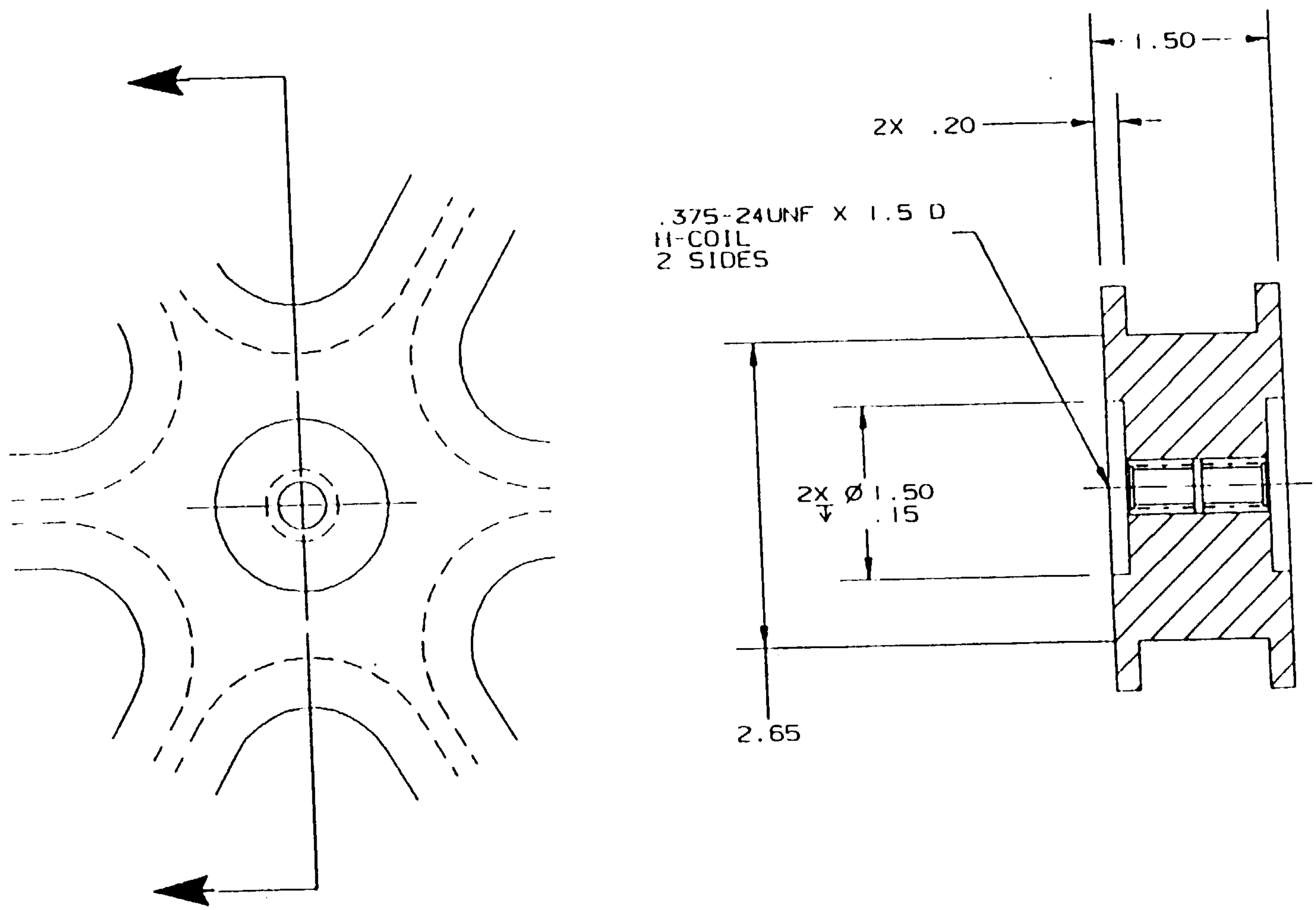
# Typical Segment of Isogrid



## Isogrid Node With Insert(s)

At each node, a threaded insert facilitates attachment of subsystems, utilities, payloads, etc., on either the inside or the outside of the structure. Extremely flexible as systems change or grow.

# Isogrid Node With Inserts








ORIGINAL PAGE IS
OF POOR QUALITY

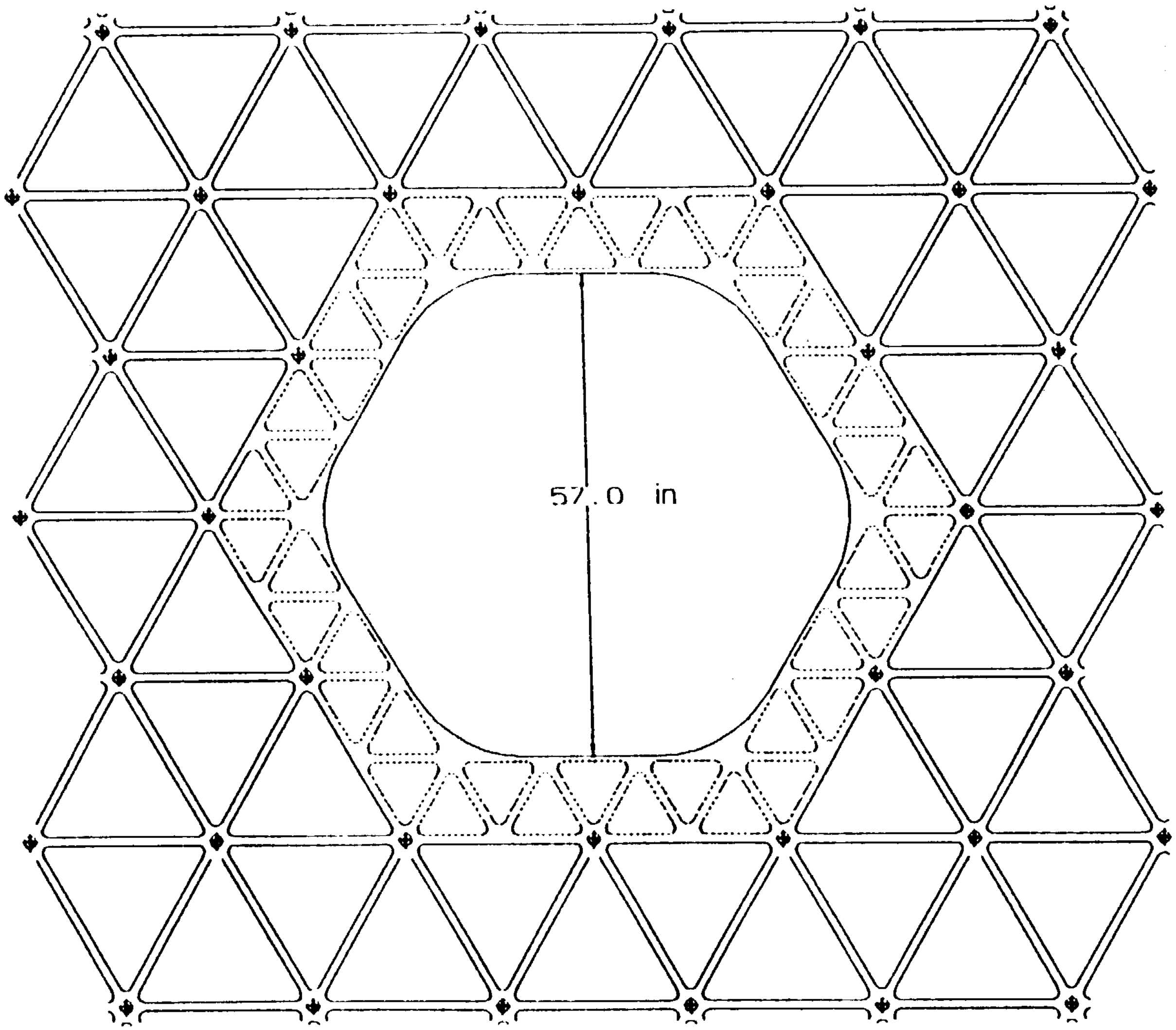
## EVA Access Hole

The access apertures required for EVA and other automated maintenance activities may be reinforced by using longerons on each side of the hole, and/or by locally adding structure as shown.

A similar approach may be used for subsystems/payloads having elements which pass through to the outside and require an aperture greater than a single isogrid element (such as beta joints). The concept shown may be modified for the various apertures sizes required.

NASA — FREEDOM

# EVA Access Hole




LaRC SSFO

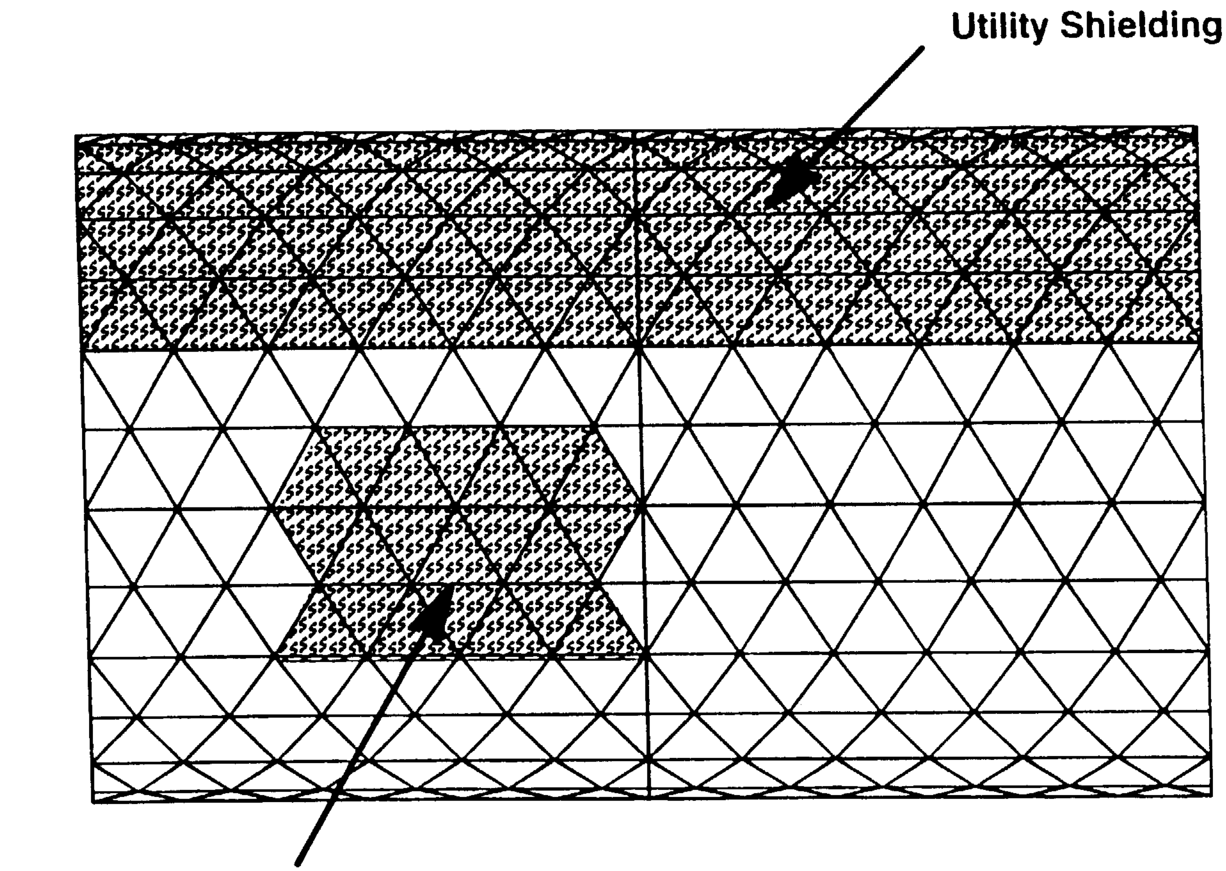
## Shielding Options

Isogrid lends itself to incorporating shielding for debris and micrometeoroid protection.

Large areas can be covered as may be necessary for utility protection, and smaller areas can be selectively shielded for subsystem/payload protection. In addition, shielding may be attached to, or incorporated in, the utility support rail structure.

The isogrid may be fabricated with integral shielding at selected grids, or by attaching separate shielding elements at any of the nodes.

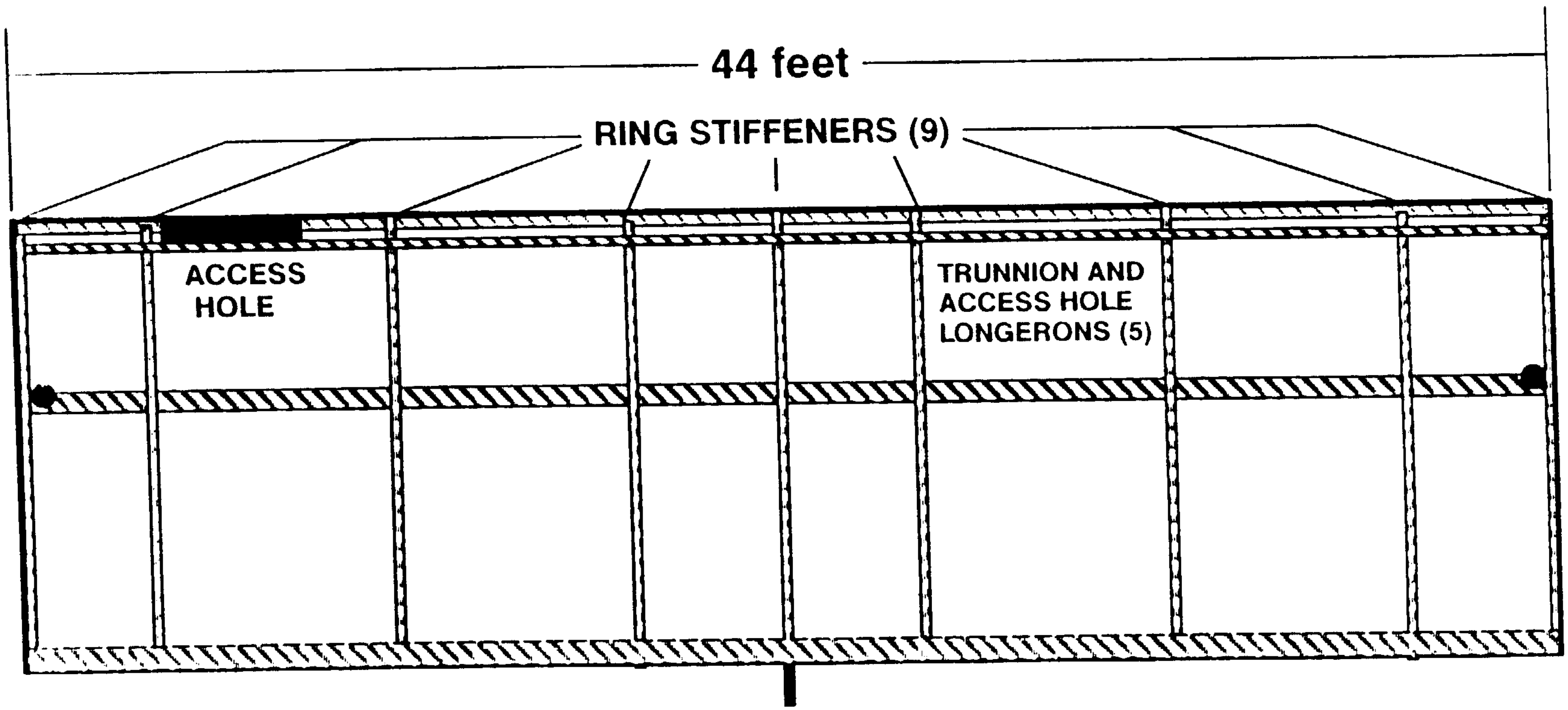
# Shielding Options



## Pre–Integrated Structure Isogrid Skin and Added Support

Hybrid section showing longerons and structural rings as used in the structural analysis.

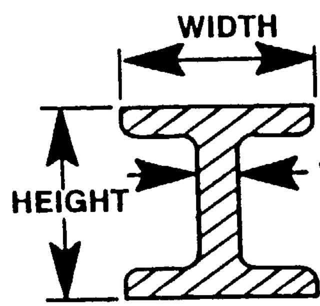
# Pre–Integrated Structure Isogrid Skin and Added Support



## Dimensions of Structural Elements

The cross-sectional dimensions of the isogrid and stiffening structure members are tabulated in the following chart. The material used was aluminum 2219-T87. Both I-beam and C-channel sections were used- the type used is indicated in the chart.

# Dimensions of Structural Elements




MAT'L: AL 2219-T87

| | Height (in) | Width (in) | Web Thickness (in) |
|---|---|---|---|
| Isogrid Element | 1.5 | 1.0 | 0.200 |
| Keel Longeron | 6.0 | 6.0 | 0.313 |
| Trunnion Longeron | 5.0 | 3.0 | 0.125 |
| Top Longeron (C) | 5.0 | 2.0 | 0.156 |
| Ring Stiffeners | | | |
| Primary | 5.0 | 2.5 | 0.125 |
| Secondary (C) | 5.0 | 4.0 | 0.125 |
| End Ring (C) | 5.0 | 4.0 | 0.125 |
| Container Edge Stiffener (C) | 5.0 | 4.0 | 0.125 |

NOTE: (C) indicates C-Channel; all others are I-Beams

– This Page Intentionally Left Blank –

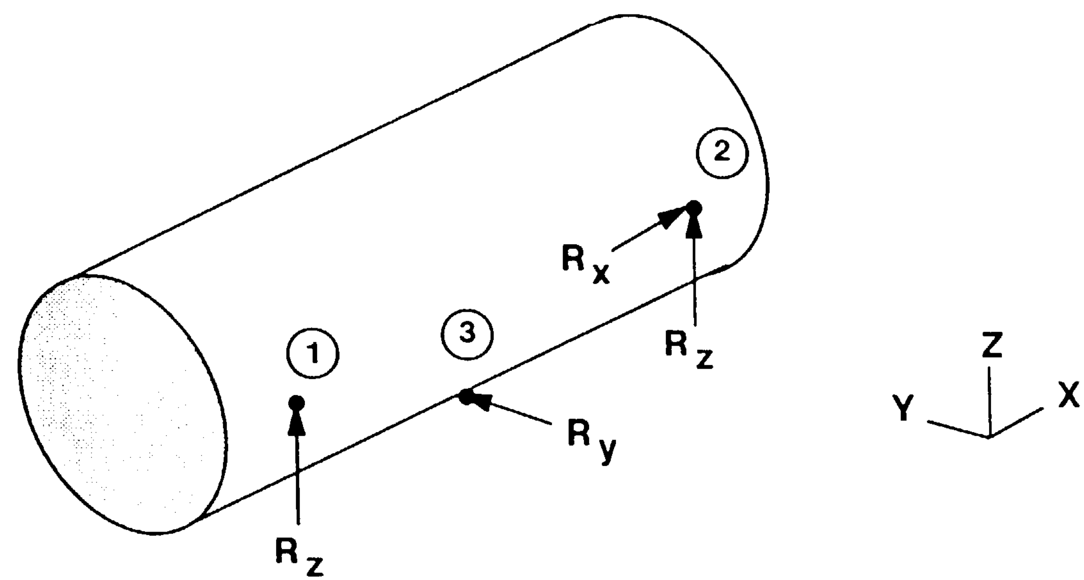
# Orbiter Interfaces

- Four Trunnion Fittings:
  - Forward pair react Z-axis loads only
  - Aft pair react both X-axis and Z-axis loads
- One Keel Fitting:
  - Reacts Y-axis loads only

## Orbiter Interface Design Loads

The maximum reaction loads at the orbiter interface points are summarized below. The load cases from which these were obtained are presented in the Structural Analysis section of this paper.

# Orbiter Interface Design Loads



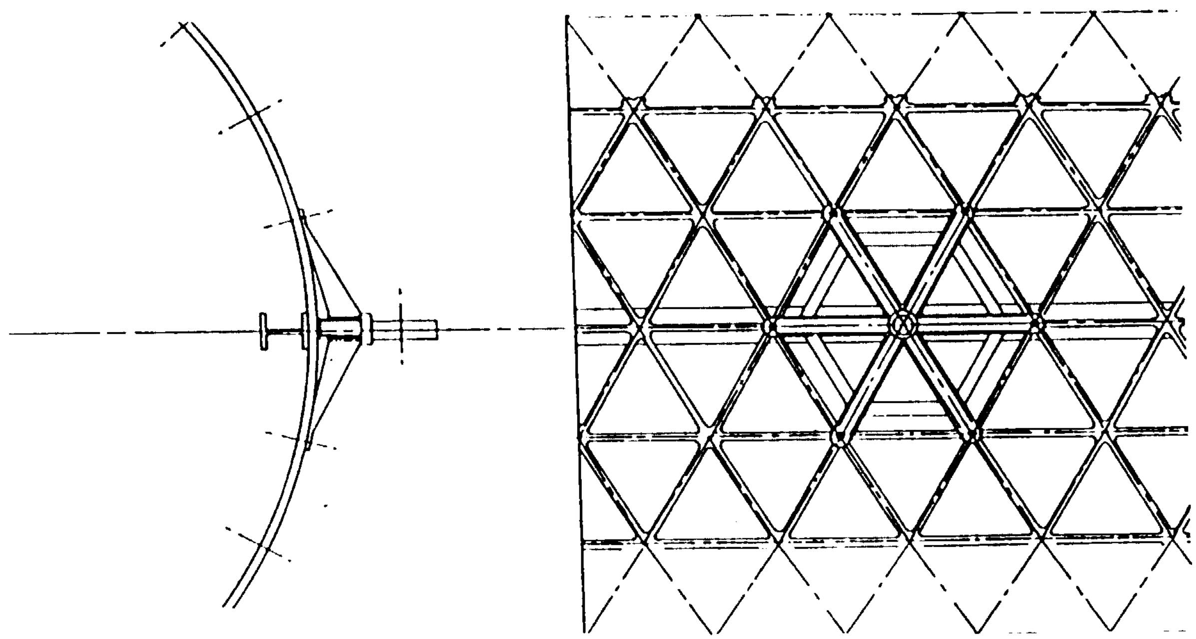

| Attach Point | $R_x$ (lbf) | $R_y$ (lbf) | $R_z$ (lbf) |
|---|---|---|---|
| 1 – Stabilizing | — | — | –27500 |
| 2 – Primary | 41200 | — | –100000 |
| 3 – Keel | — | –50000 | — |

## Trunnion Fitting

Four trunnion fittings support the integrated truss elements in the STS cargo bay. The aft (primary) pair of trunnions provide support in the X and Z axes, and the forward (stabilizing) pair provide support in the Z axis only.

Each trunnion spreads the load through seven nodes of the isogrid, as well as directly into the major longerons. The aft trunnions weigh 100 lbs. each, and the forward trunnions weigh 80 lbs. each.

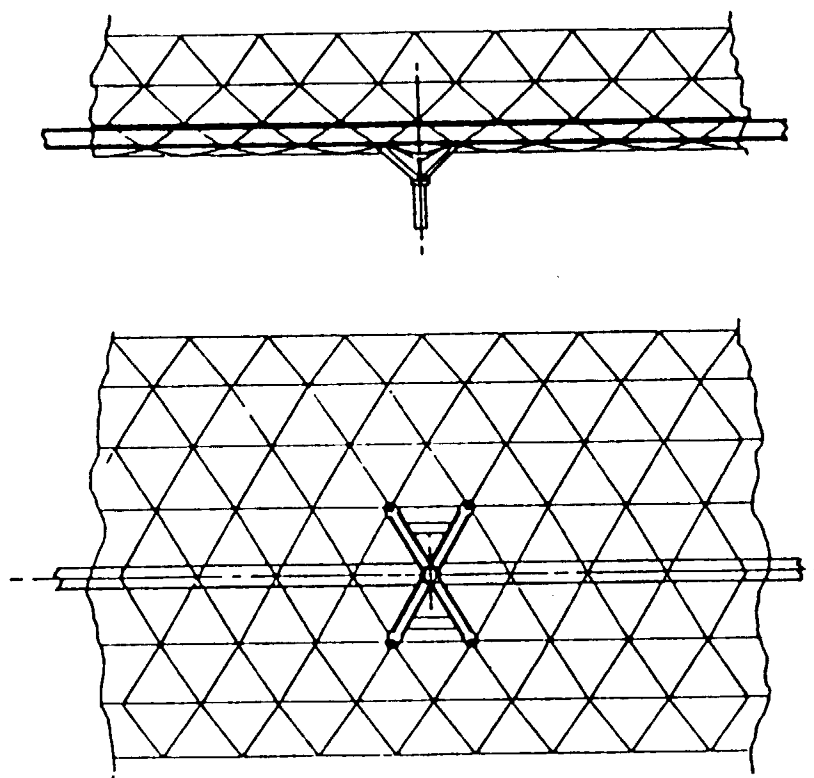
# Trunnion Fitting



## Keel Fitting

The keel fitting provides lateral support and distributes the load through five isogrid nodes, and into the keel longeron. This fitting weighs 80 lbs.

# Keel Fitting



– This Page Intentionally Left Blank –

# Packaging and Mechanisms

## Packaging Options

Several approaches can be taken with respect to packaging of the subsystems in the integrated structure. One approach could be to package the systems on the exterior of the structure. This approach enhances accessibility but requires some systems to be attached to the structure while on orbit which reduces the amount of pre-integration and increases the amount of EVA required. The systems that need attachment on orbit (RCS tanks, N2O2 carriers, etc.) take up valuable payload volume in the orbiter that could be used for additional structure length thus leading to an increase in the number of assembly flights. Another approach is to package all the systems in the interior of the structure. This approach would require all ORUs to removed through small access holes in the structure via small containerized systems. Breaking up the systems into small units requires more interfaces and volume leading to additional weight and increased EVA requirements. An approach to get around these problems is to put the major subsystems in large removable sections of the structure. This approach requires additional structural weight to reinforce areas of the structure where the the container sections can be removed but the advantage of having major subsystems located in one removable section (less distribution, less EVA and SSRMS accessibility) compensate for the weight penalty. The packaging approach used for this study is a hybrid of all of the above. Some equipment such as docking mechanisms and mobile transporter guide rails are mounted on the outside of the structure. Appendages such as thrusters, solar arrays, radiators and antennas are brought up stowed inside of the structure then EVA attached on orbit. Some subsystems, such as data processors and communications electronics, are packaged in small modular containers that are removed through access holes in the structure. Larger subsystems, such as RCS tanks and mechanical joints, are packaged in large removable structural sections.

# Packaging Options

<u>External Packaging</u>

Major ORUs and some systems mounted outside of structure.
- Increases number of assembly flights.
- Requires EVA assembly and on orbit integration.

<u>Internal Packaging</u>

All ORUs and systems mounted inside of structure.
- Requires all ORUs to be removed through small access holes resulting in increased EVA, weight, volume and additional interfaces.
- Limits SSRMS accessibility.

<u>Internal Packaging with Removable Container Sections</u>

Major ORUs mounted inside of removable structural sections.
- Requires additional structural weight to reinforce areas of structure where container sections can be removed.
- Allows SSRMS access of major ORUs (such as hydrazine tanks) without requiring them to be mounted external to the structure.

**The selected packaging concept is a <u>hybrid</u> of all three options.**

## Pre-Integrated Hybrid Isogrid Structure Packaging

### (Large Container Section)

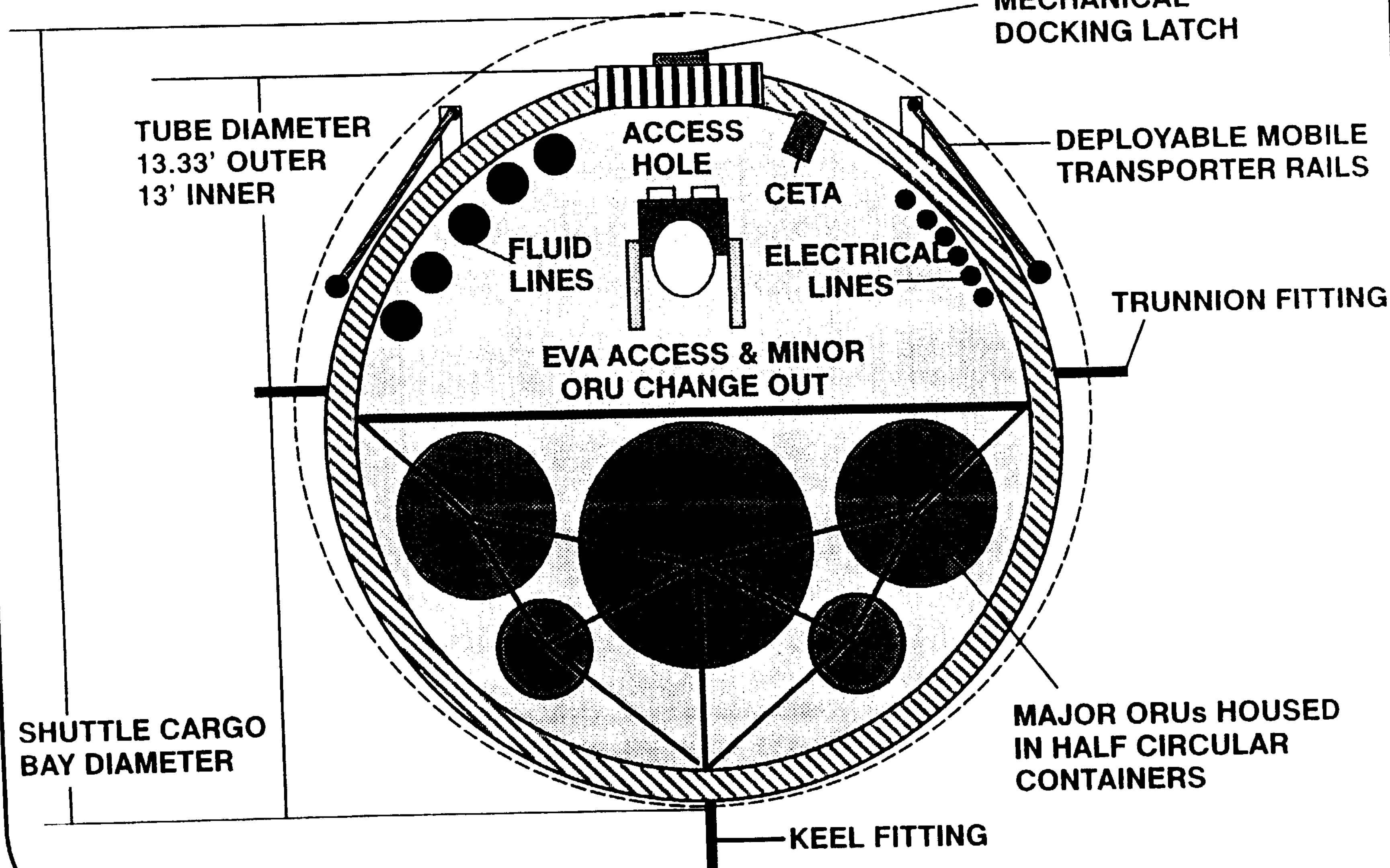
An end view of the integrated structure is shown. The diameter of the structure is 13.33 feet which allows room for the externally mounted rails and docking mechanisms. The bottom half of the structure is a removable container section for housing large subsystems. The upper half of the structure is used as an EVA access corridor and includes utility lines, a CETA device and access holes. Minor ORU access to the subsystem container is done via the EVA corridor.

NASA

FREEDOM

# Pre-Integrated Hybrid Isogrid Structure Packaging

(LARGE CONTAINER SECTION)




LaRC SSFO

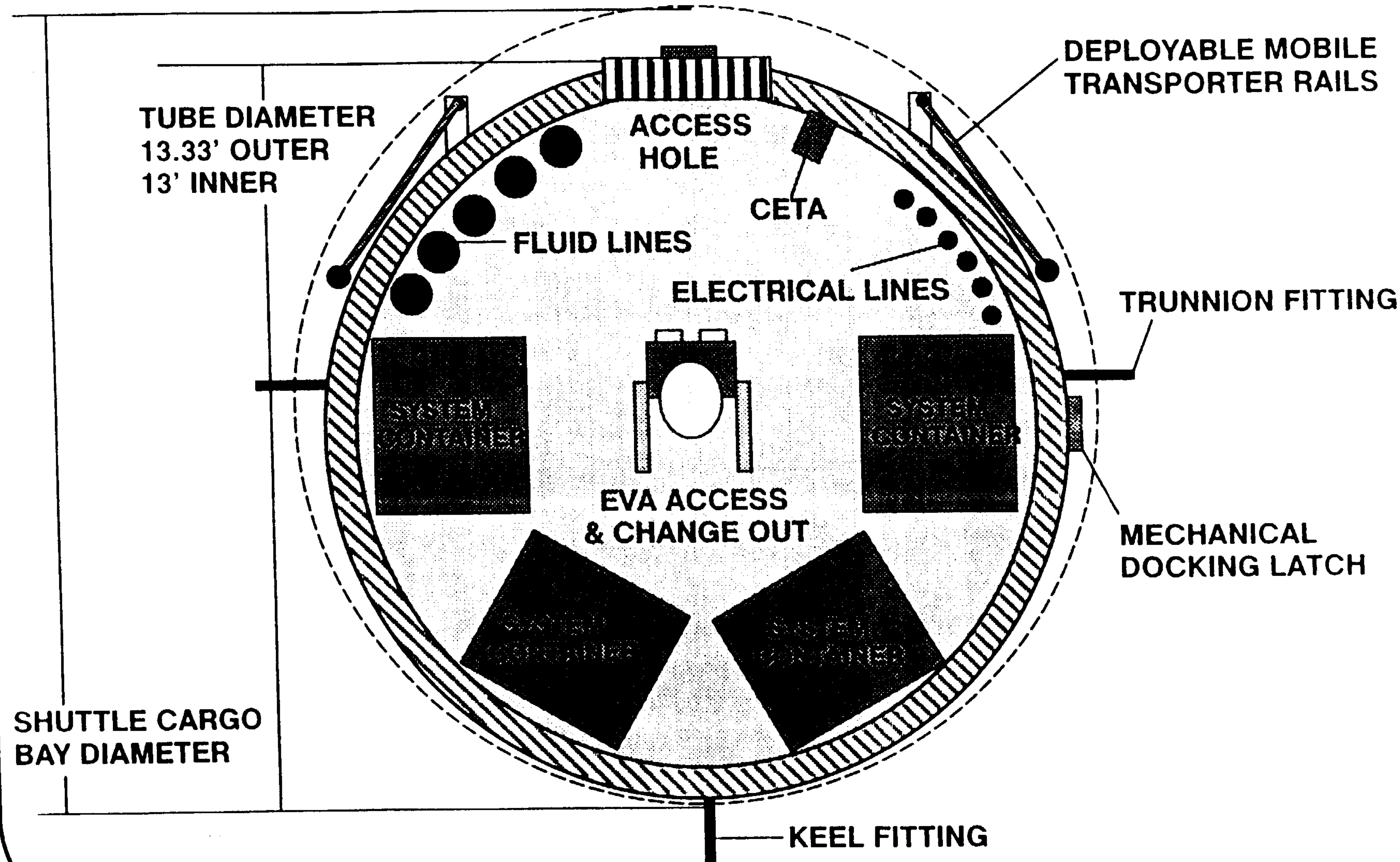
## Pre-Integrated Hybrid Isogrid Structure Packaging
### (Radial Container Section)

An end view of the integrated structure is shown. The diameter of the structure is 13.33 feet which allows room for the externally mounted rails and docking mechanisms. The bottom half of the structure contains radial system containers that can be removed through the access hole in the upper part of the structure. The upper half of the structure is used as an EVA access corridor and includes utility lines and a CETA device.

NASA — FREEDOM

# Pre–Integrated Hybrid Isogrid Structure Packaging

(RADIAL CONTAINER SECTION)



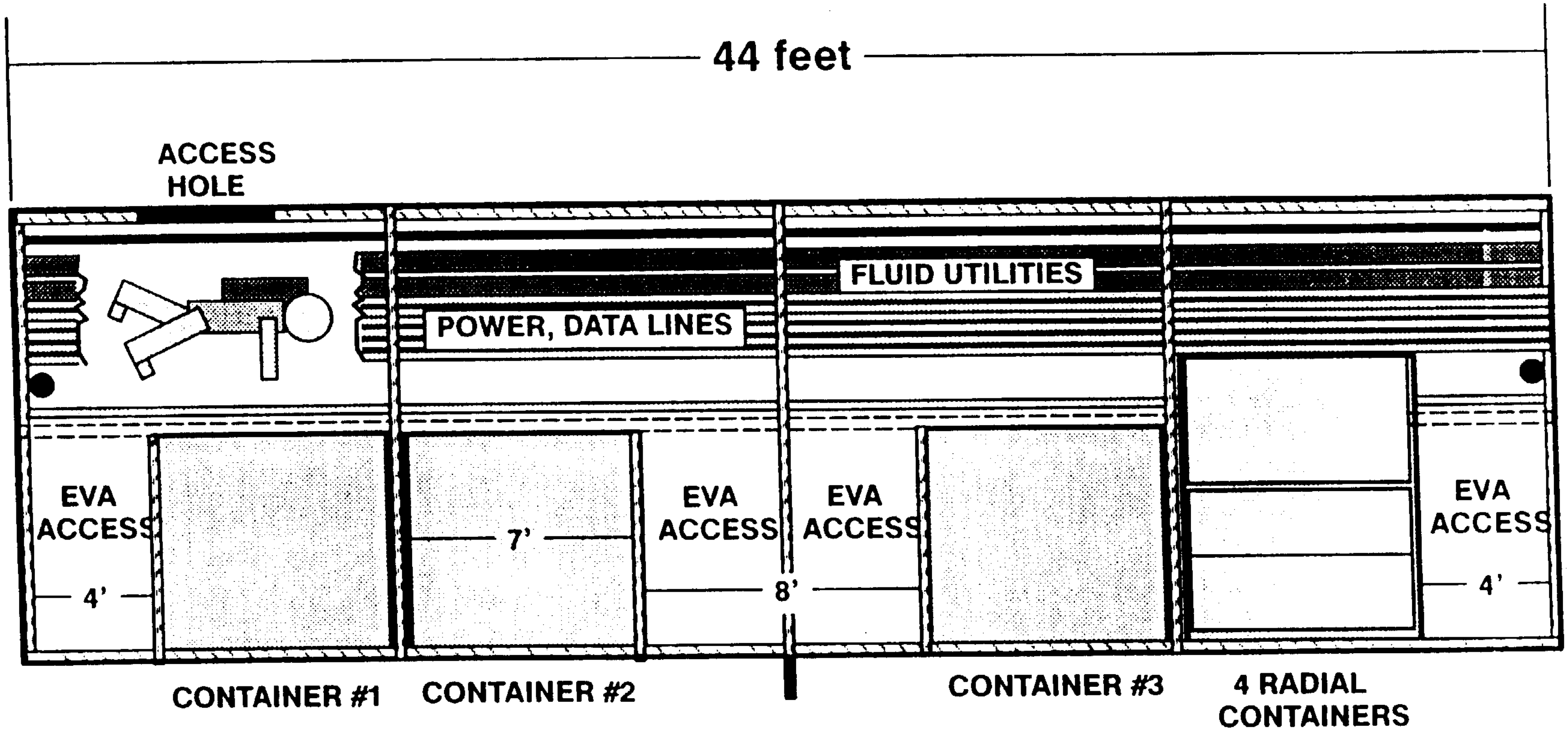

LaRC SSFO

## Pre-Integrated Hybrid Isogrid Structure Packaging

### (SIDE VIEW)

A side view of the integrated structure is shown. The length of the structure is 44 feet which maintains orbiter clearance and center of gravity requirements. A typical section would have several removable container sections and one radial container section. Each section is 7 feet long with 4 feet of EVA access/utility interface space available on one side. The upper half of the structure is used as an EVA access corridor and includes utility lines, a CETA device and an access hole.

# Pre–Integrated Hybrid Isogrid Structure Packaging

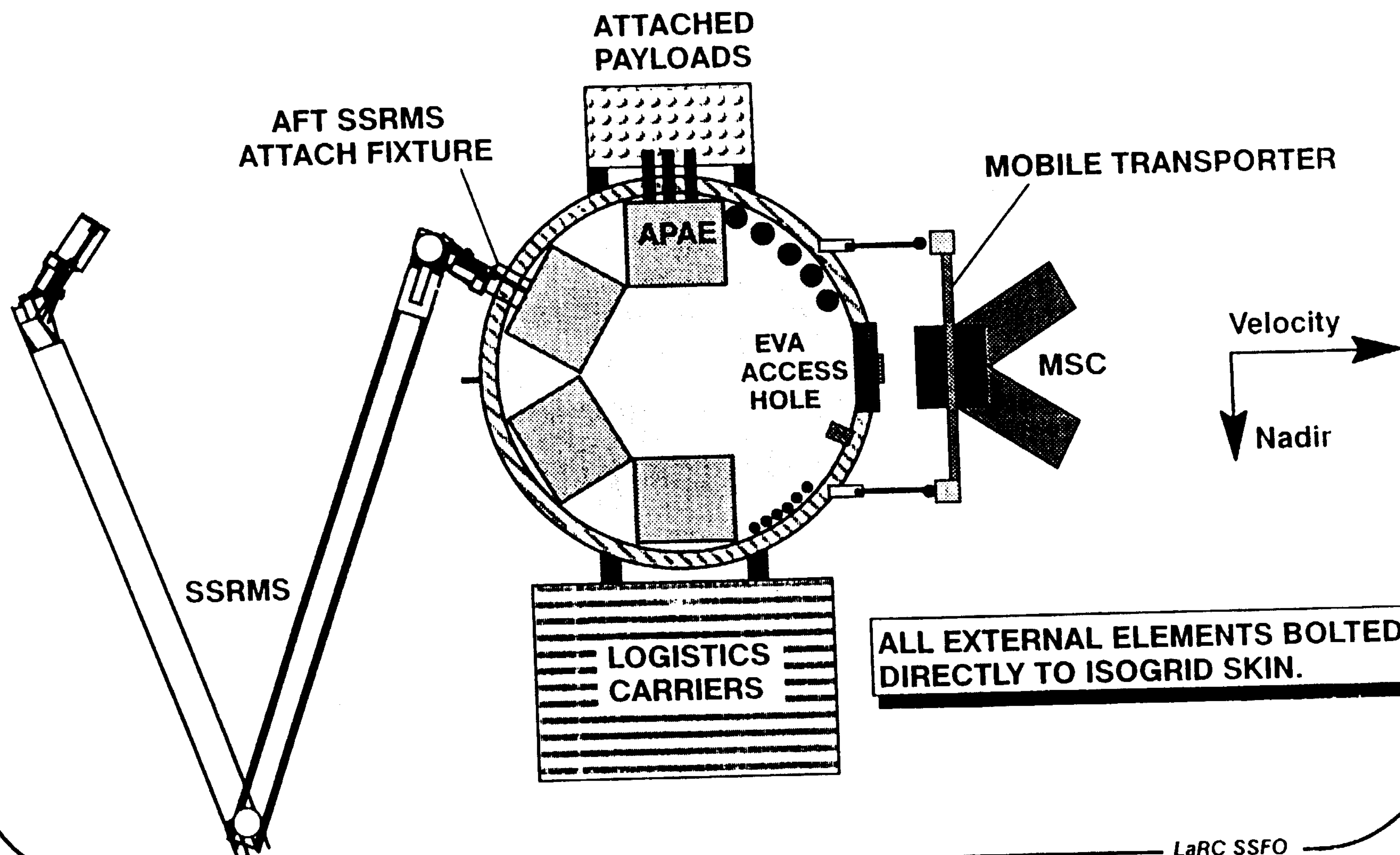



**Additional longerons, ring stiffeners and container structure have been added to the Isogrid skin for added strength.**

## External Attachment Capability

The methods for attaching external elements are shown. The isogrid skin provides a large number of attach points due to the pre-drilled holes located at the intersections of the beam members. Attached payloads can be mounted directly to the isogrid with utility interfaces running through the open triangular sections into the structure. The MSC rails and additional logistics carriers can be mounted in a similar fashion. An aft SSRMS attach fixture will be required on some sections of the station to accommodate reach requirements for items such as radiators and the JEM module

# External Attachment Capability

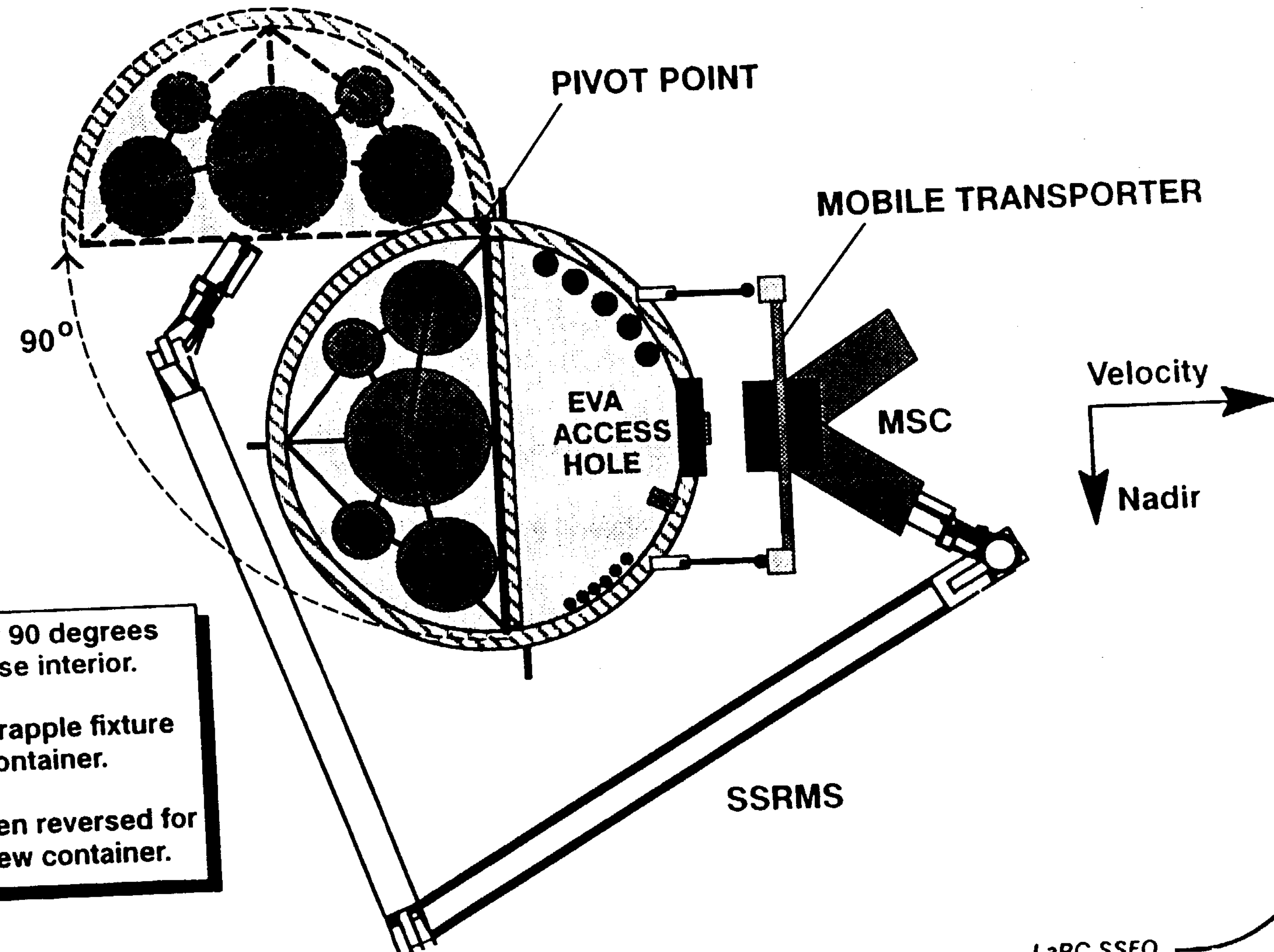



ALL EXTERNAL ELEMENTS BOLTED DIRECTLY TO ISOGRID SKIN.

## Major ORU Container Replacement

Major subsystem ORUs are accessed through the use of removable container sections. The structural container section is rotated 90 degrees outward to expose the interior. The SSRMS grabs a grapple fixture, lifts the section away from the station, then places the section in the orbiter cargo bay. The procedure is reversed with a replacement section (RCS tanks for example). For some applications, removal of the container section may not be necessary since the SSRMS may be able to remove specific subcomponents from container section while in the rotated position.

# Major ORU Container Replacement




Rotate container 90 degrees outward to expose interior.

SSRMS grabs grapple fixture then removes container.

Procedure is then reversed for installation of new container.

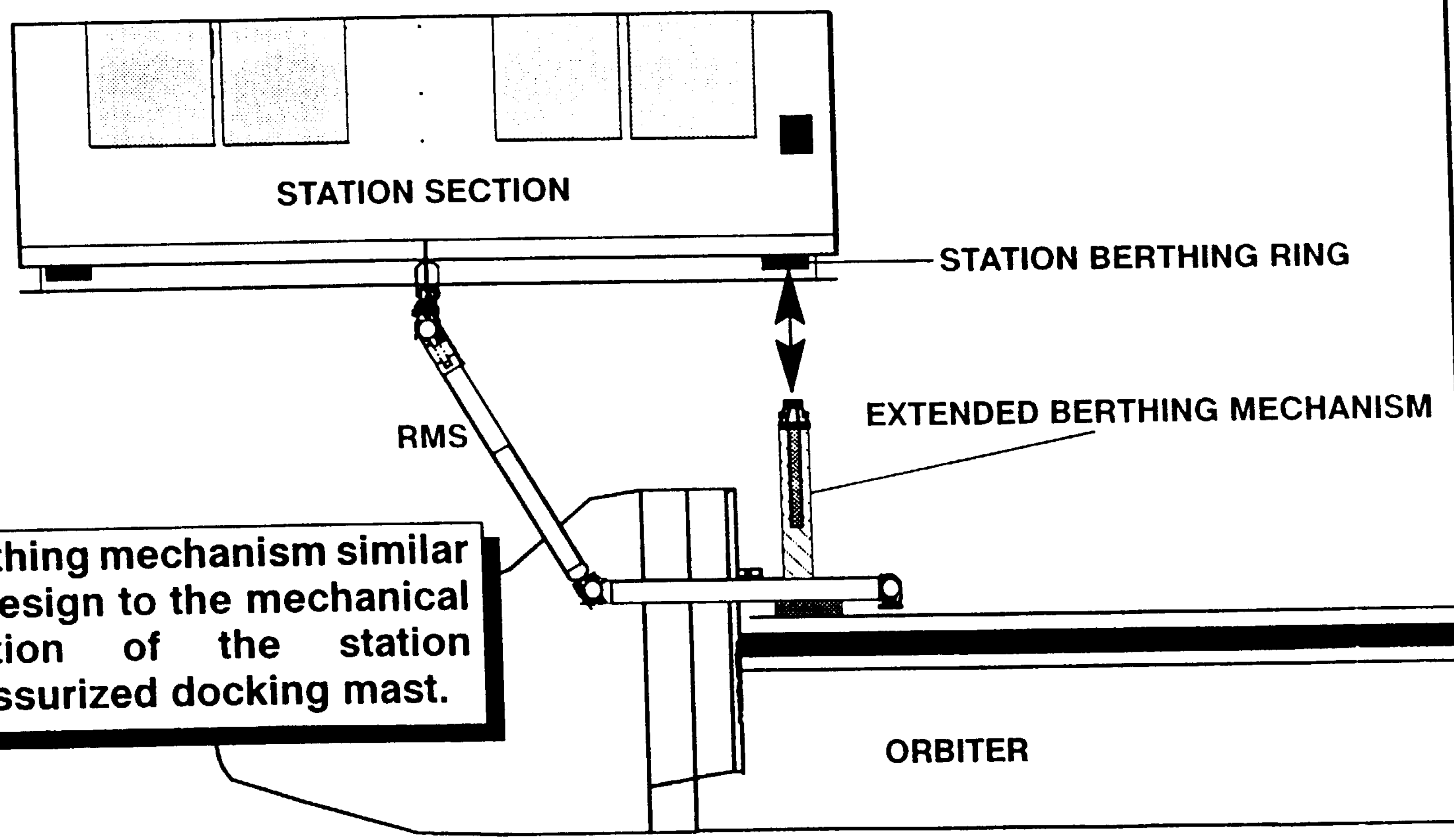
## Station Assembly Mechanisms and Attachment Methods

Each tubular section is assembled to the next by manipulating it with the arm on the STS until it is aligned.

The two sections are brought together, and three guide pins provide the final alignment and accept shear loads across the joint. The first pin to engage is longer than the other two. This allows initial engagement followed by rotation of the tube for final alignment and docking.

At each guide pin location, there is also a latch which automatically secures the two sections together axially in a soft docked condition. After it has been established that this connection is secure, two mechanisms are simultaneously operated (EVA) to provide final alignment and docking. Once final docking is complete, the bolts around the interface are secured (EVA) to accept operational loading.

# Station Assembly Mechanisms and Attachment Methods




Berthing mechanism similar in design to the mechanical portion of the station pressurized docking mast.

## Mechanisms and Attachment Methods

Mechanisms are incorporated in the end of each truss section to assist in the alignment during assembly. Initial engagement of the two sections is made by automatic latches to provide a secure condition (soft docking) prior to EVA.

Final docking is established when the two sections are pulled fully together, and the final attachment is made with bolts to provide structural integrity of the assembled truss.

Once the mechanical assembly is complete the utilities, which are integrated within the tube section are connected to the adjoining tube with quick disconnect (QD) fittings. The pre-integration of the utilities in the tube permits the use of rigid sections of fluid lines with flexible segments at the QD interfaces.

# Mechanisms and Attachment Methods

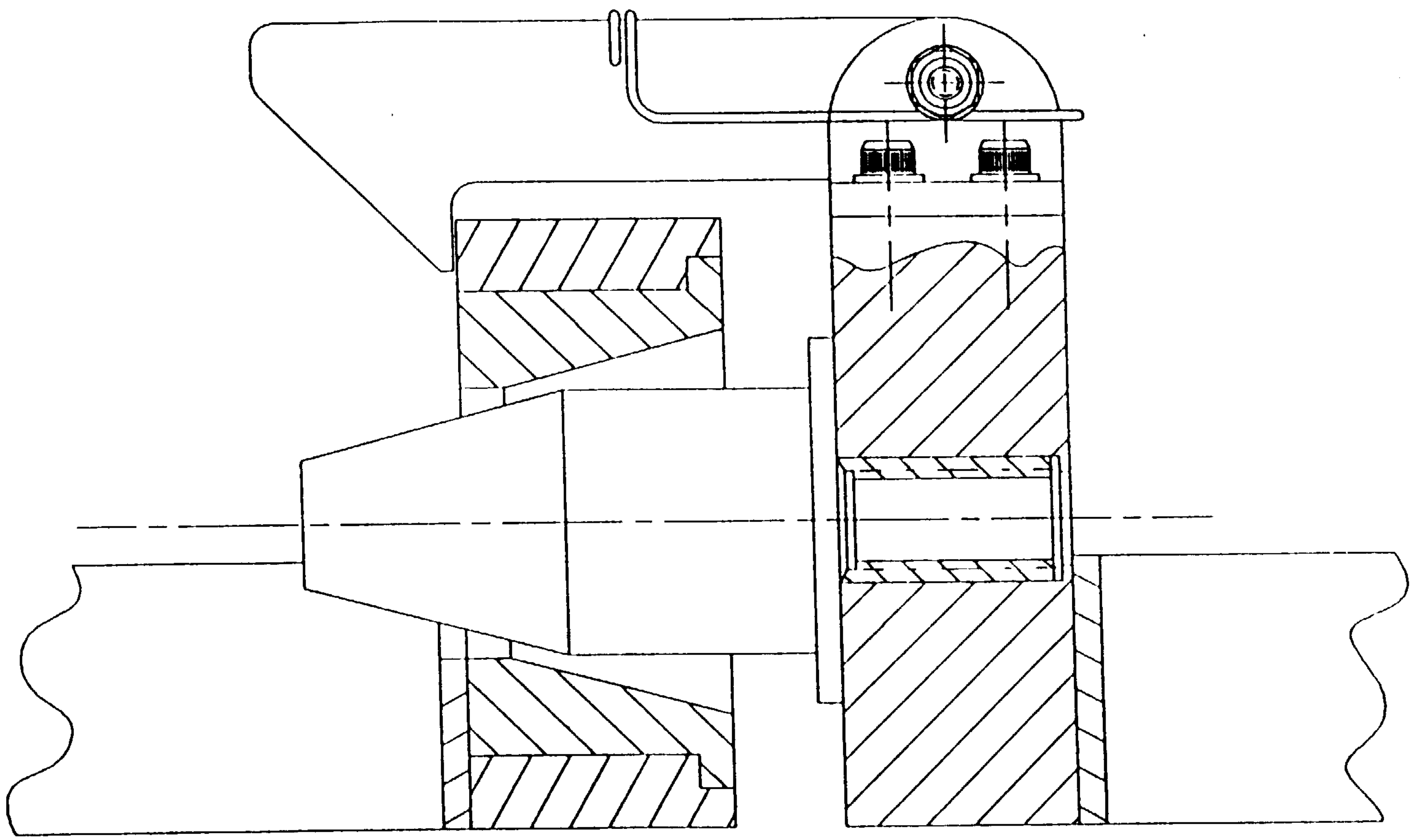
- **Isogrid Section Interface:**
  - Alignment and soft docking
  - Final docking (EVA)
  - Final attachment (EVA)
- **Utilities:**
  - Quick disconnects (EVA)
  - Use of flexible and rigid sections possible
  - Flexibility in choice of support locations
  - Individual and group retainer system to optimize maintenance procedures

## Soft Docking Alignment Pin and Latch

Docking alignment is facilitated by the tapered section of the pins.

The latch is designed with free play along the axis of the tube section during initial engagement to ensure operation of all three latches.

# Soft Docking Alignment Pin and Latch

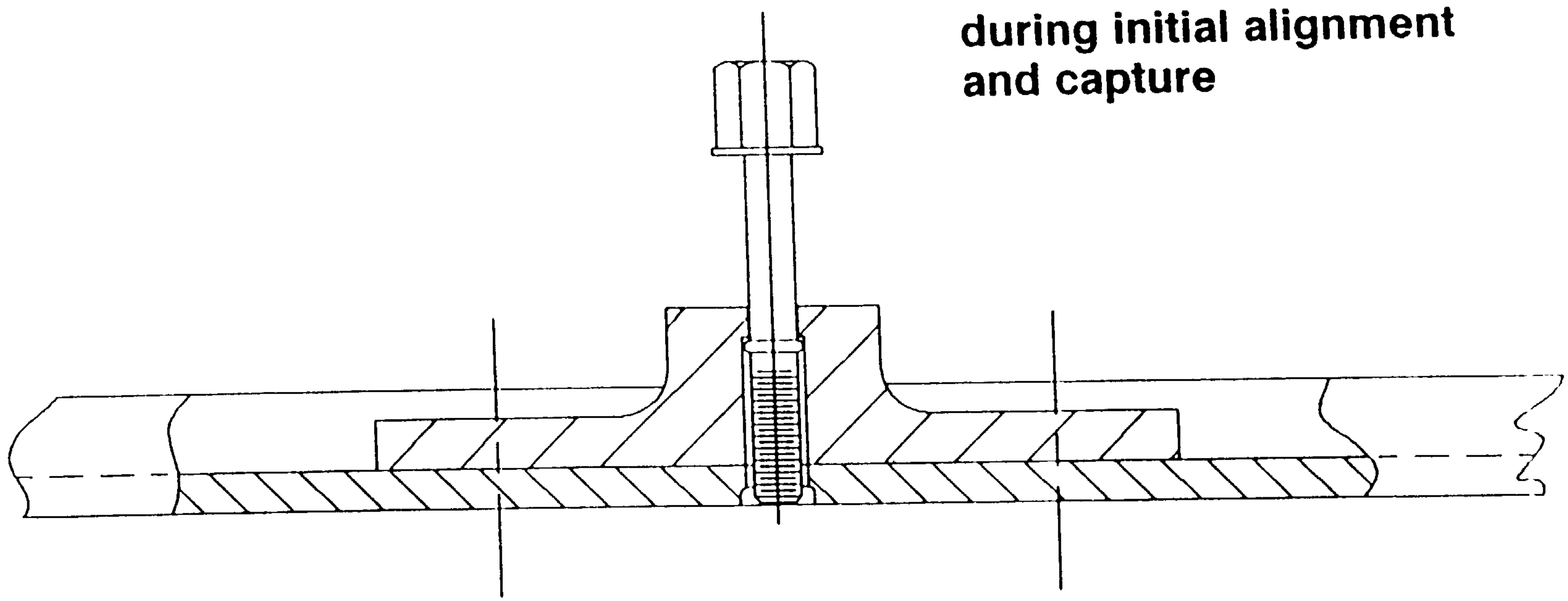


## Attachment Bolt Detail

During the docking/latching sequence, the bolts are retracted to prevent interference. Once latched securely, the bolts are inserted into the adjacent isogrid section and tightened.

# Attachment Bolt Detail

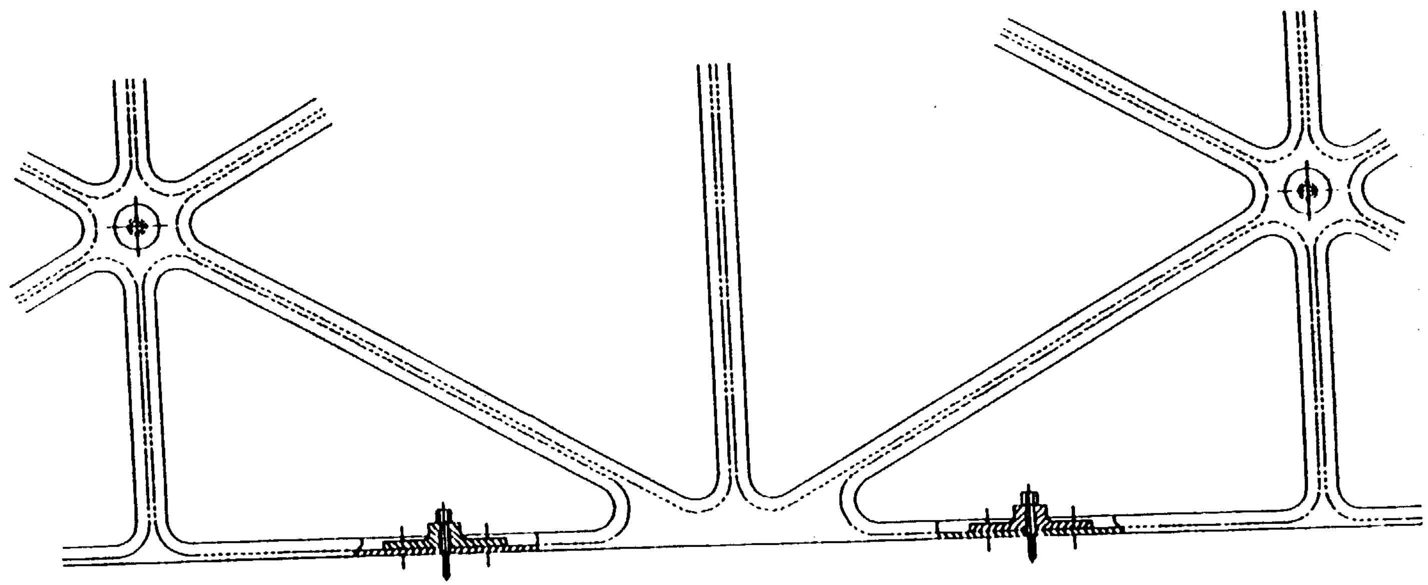
Bolt is retracted
during initial alignment
and capture



## Tube/Tube Attachment Bolt

Final attachment of each tube section is made using retained bolts through the ends of the isogrid.

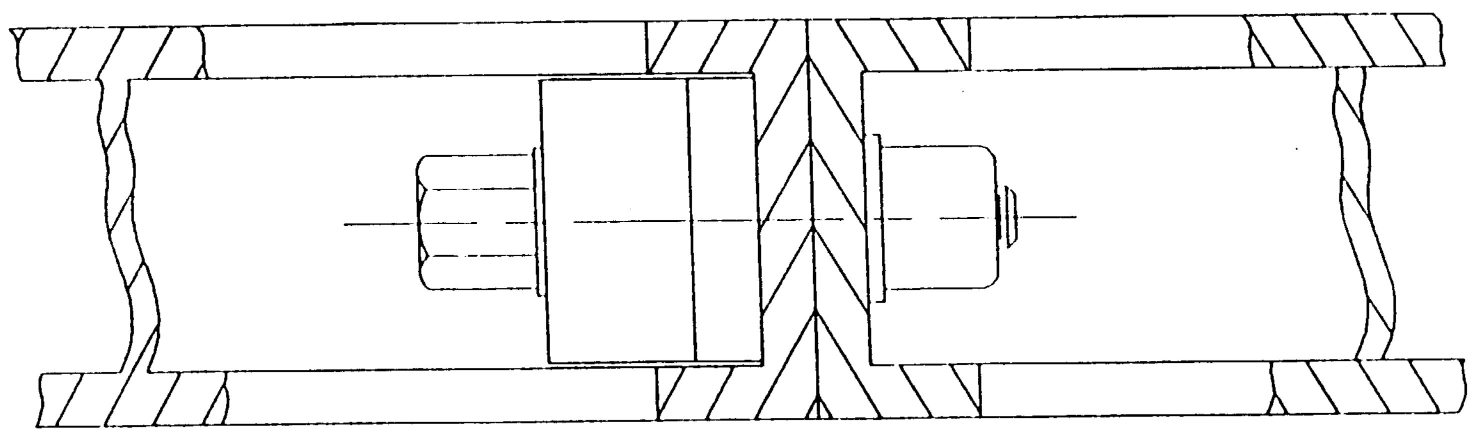
# Tube/Tube Attachment Bolts



## Final Position of Attachment Bolt for Two Mated Sections (Typical)

The bolts are shown within the thickness of the isogrid.

# Final Position of Attachment Bolt For Two Mated Sections (Typical)



## Utility Interconnection

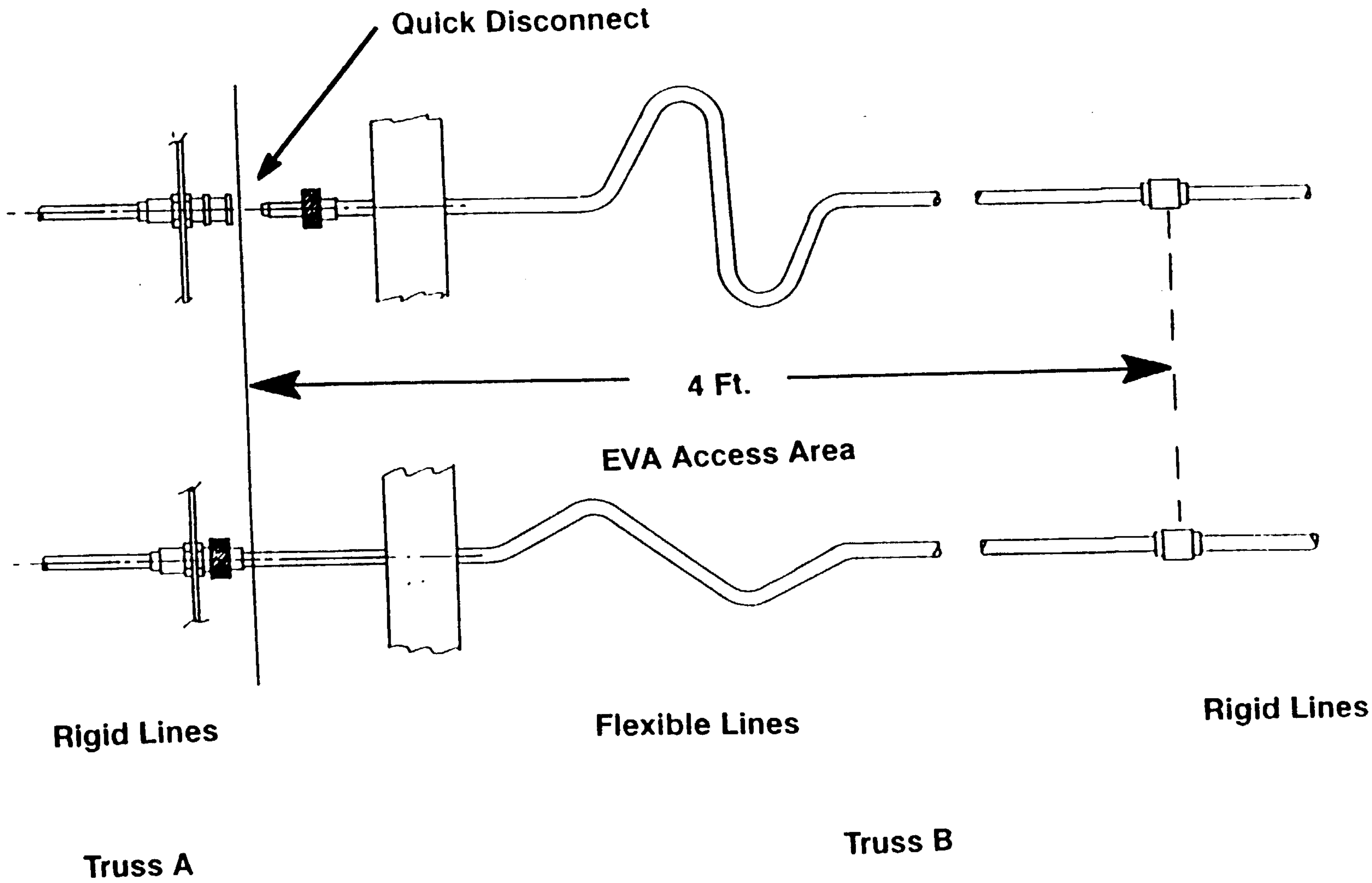
Within the isogrid, utility lines can be rigid or semirigid, to the extent that service replacement will allow.

A section at one end of each truss element will be flexible to allow the lines to be retracted during launch, and extended to connect to the rigid lines in the adjacent truss element during assembly.

The extendable section of the lines can be achieved in several ways including methods/materials used in the current baseline. Each line is equipped with a quick disconnect for ease of assembly. Electrical lines use the same mounting concept.

NASA — FREEDOM

# Utility Interconnection

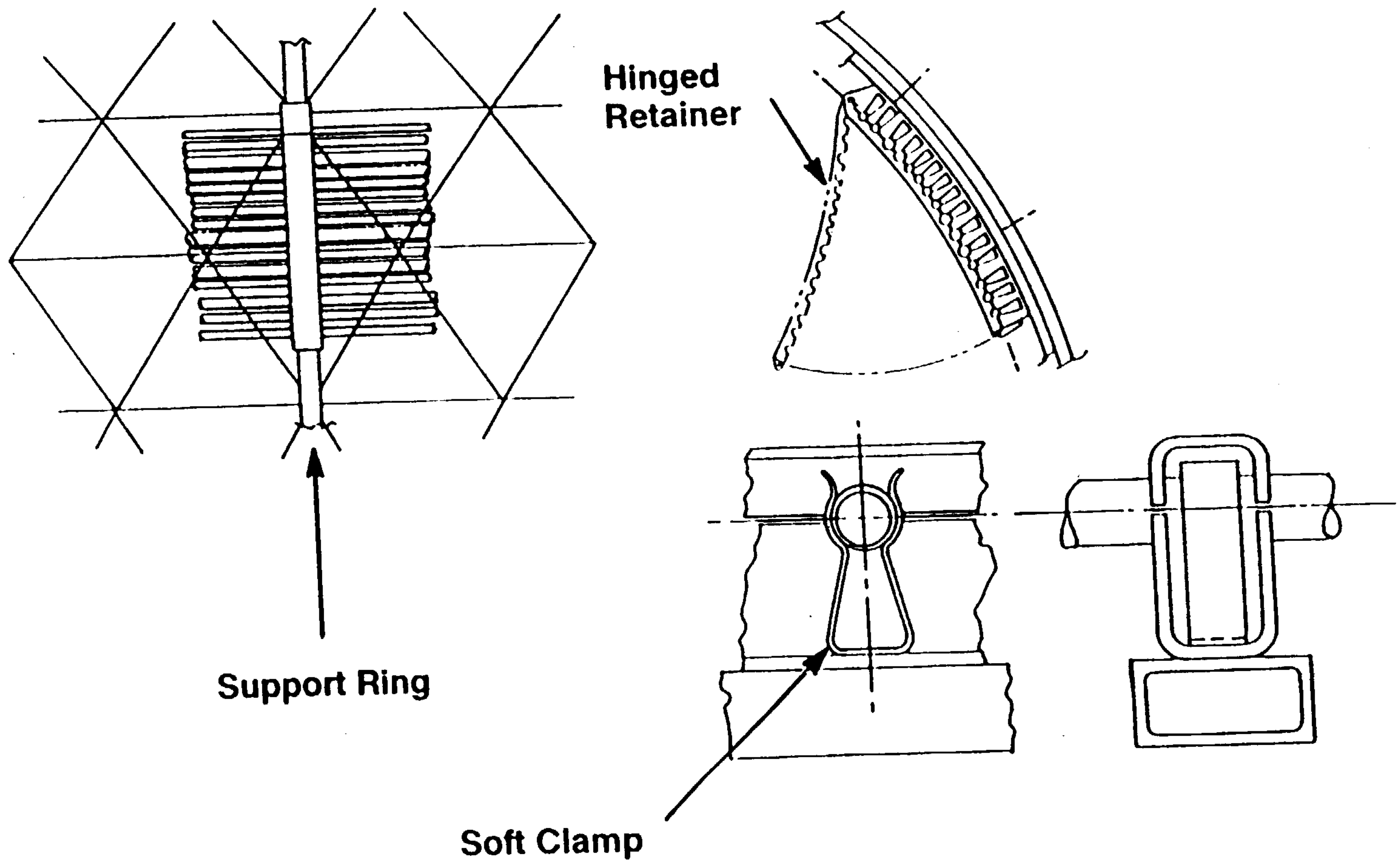



LaRC SSFO

## Utility Line Attachment

Attachment may be with hard clamps applied to each line individually, or with soft clamps with a retainer providing security for a group of lines or cables. The retainer locks the soft clamps and provides structural support during launch loads.

# Utility Line Attachment

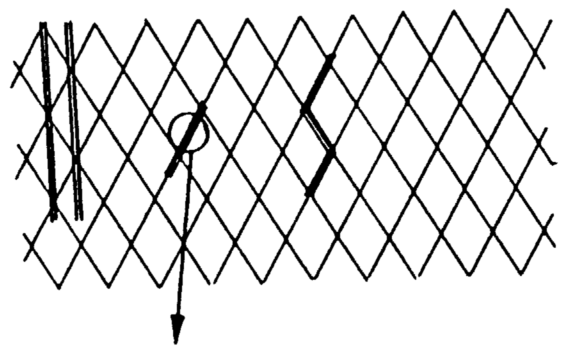


## Utility Support Locations

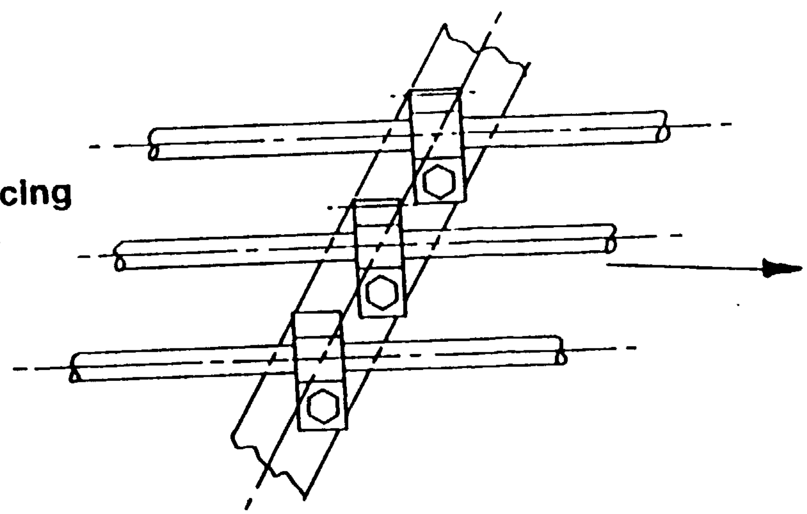
Utilities are supported on rails which offer numerous options for attachment to the isogrid.

A circumferential ring (or partial) can be situated at 11 inch increments, or diagonal rails can be mounted following the contours of the isogrid members. The latter may permit closer spacing of the utility lines, while allowing access to the clamps for maintenance.

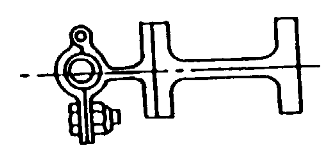
# Utility Support Locations



Support rail mounting options bolted at Isogrid nodes



Reduced spacing possible with angled rail



## Subsystem Mounting Concepts

Internally mounted ORUs may be pre-integrated. Externally mounted ORUs must be stowed inside during launch, and assembled on the exterior of the truss on orbit.

Larger ORUs (such as an RCS tank farm) are in the form of removable semicircular segments of the isogrid structure. Smaller ORUs are mounted on trays and may be removed from the tray and transported through an EVA access hole during service operations. Each type of mounting method may be used exclusively within a particular section of truss, or a combination of both types may be used as required.

External attachments to the isogrid may be single point attachments to an individual node for small items such as UHF antennas, or using a "foot" to distribute the load over several nodes as would be required for a large antenna assembly. Attached payloads may be secured directly to the nodes with similar "feet", or mounted on struts as required. PV arrays and radiators are mounted on beta joints, which are accessible through enlarged openings in the isogrid.

# Subsystem Mounting Concepts

- **Internal Attachments:**
  - Major ORU container replaceable as a unit or serviceable for subsystem element replacements (tanks,etc.)
  - Container is retained as an integral part of the structure during launch and operation
  - Smaller subsystems on trays inside a contiguous tube section
- **External attachments:**
  - Single point attachments to nodes
  - Attached payloads to nodes via struts or load spreading brackets
  - Antennas/radiators to similar mounts or through isogrid to subsystem

## Subsystem Integration Approach

The First Element Launch (FEL) is used as a representative truss section since it was found to be one of the heaviest launch payloads. It also has a relatively small margin for the location of the center of gravity with respect to the orbiter payload requirements.

The configuration of the system/subsystem hardware in this flight is varied in that it incorporates several types of mounting requirements. These include large ORUs in removable containers, smaller ORUs mounted on trays, and some directly mounted to the isogrid, as well as fixed and movable external system elements.

# Subsystem Integration Approach

**Use First Element Launch (FEL) as representative example.**

- **FEL is one of the more critical flights with regard to:**

  a) Total mass to orbit
  b) Center of gravity location within the STS cargo bay

- **FEL feature:**

  a) Mounting of large and small ORU's in containers, on trays, and directly on isogrid
  b) Attachment of external ORU's

# First Element Launch – Flight TR1
## Assembled Configuration

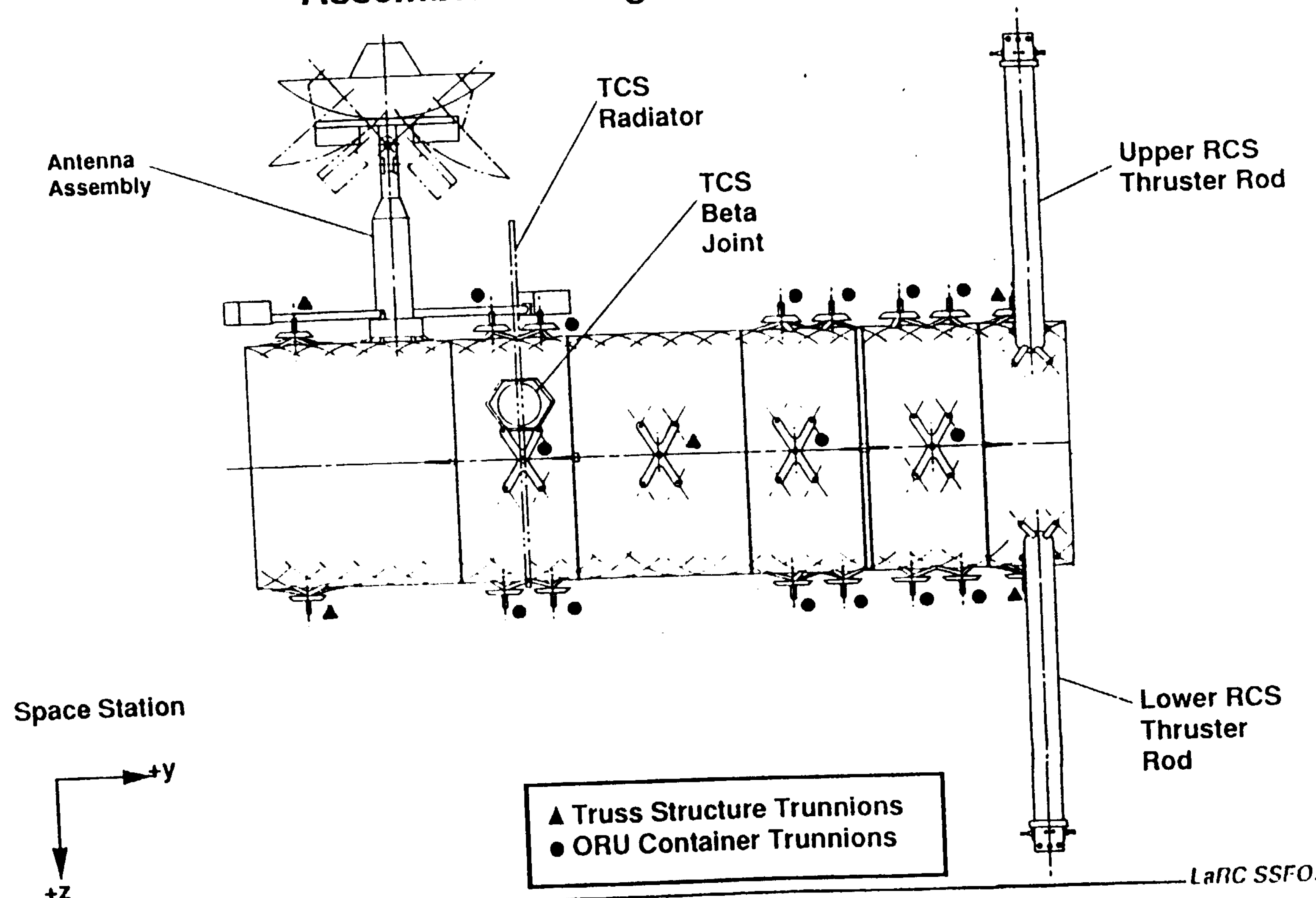
The first element launch was selected for a more detailed evaluation of the structures and mechanisms used in the reinforcement of the isogrid and the mounting of the subsystem elements. This flight was studied because: 1.) It contains both large removable containers (RCS and TCS and smaller ORUs (C&T, DMS, and EPS elements); 2.) The need for mounting external elements is addressed in the case of RCS thruster pods, TCS radiator, and C&T antenna assemblies; 3.) This is one of the more critical flights in regard to payload mass and center of gravity requirements for the NSTS launch vehicle.

The standard cargo interface trunnions are shown for attaching the 44' integrated truss section within the orbiter cargo bay. In addition a set of trunnions is shown on each of the removable containers. These may be in place during initial launch of the integrated section if clearances permit, or attached on orbit in preparation for returning the container to earth. Replacement containers will have trunnions permanently attached for use when launching/returning the container as an independent cargo element.

NASA — FREEDOM

# First Element Launch - Flight TRI

## Assembled Configuration



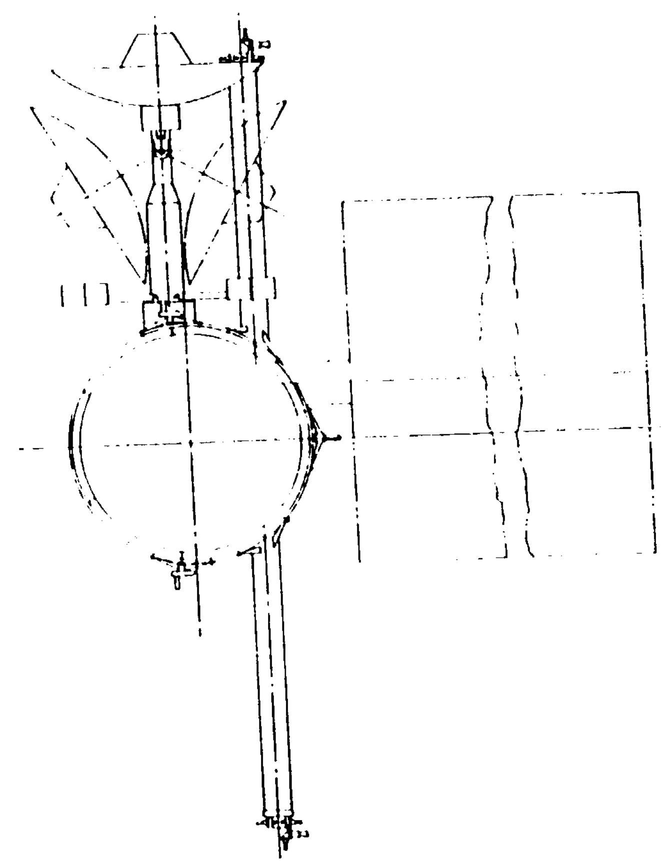

LaRC SSFO

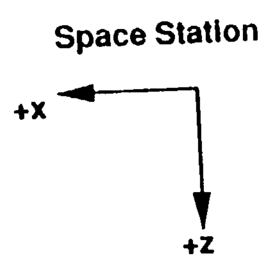
## First Element Launch - Flight TR1
## Assembled Configuration - End View

In this end view the relative locations of the antenna assembly, RCS thrusters, and TCS beta joint can be seen.

# First Element Launch - Flight TRI

## Assembled Configuration - end view





# Packaging – First Element Launch

As far as possible systems are integrated prior to launch. Exceptions to this are externally mounted items which are stowed inside the tube section for launch, and assembled on the exterior of the isogrid during EVA, or by using robotics capabilities.

# Packaging–First Element Launch

## Integrated Items

- RCS Tank Farms
- GN&C Star Trackers & ISA's
- TCS–baseline pallet mounted ORU's
- C&T–baseline pallet mounted ORU's for C&T, DMS, and EPS systems
- Temporary Power System

## Items Stowed for Launch

- RCS Thruster Assemblies
- SGS Ku-Band Antenna and Support Structure
- Antenna mounted C&T ORU's

# First Element Launch - Flight TR1
## Launch Configuration

In the launch configuration, the integrated systems hardware is located in containers (RCS and TCS system elements), directly on the isogrid (GN&C elements and utilities), ORU trays (C&T, DMS and EPS system elements and the temporary power system).

The temporary power system and its associated PV array are also pre-integrated. The electronics and batteries are on an ORU mounting tray, and the solar panel blanket is directly "wrapped" around an available area of the main isogrid tube such as the central EVA access section.

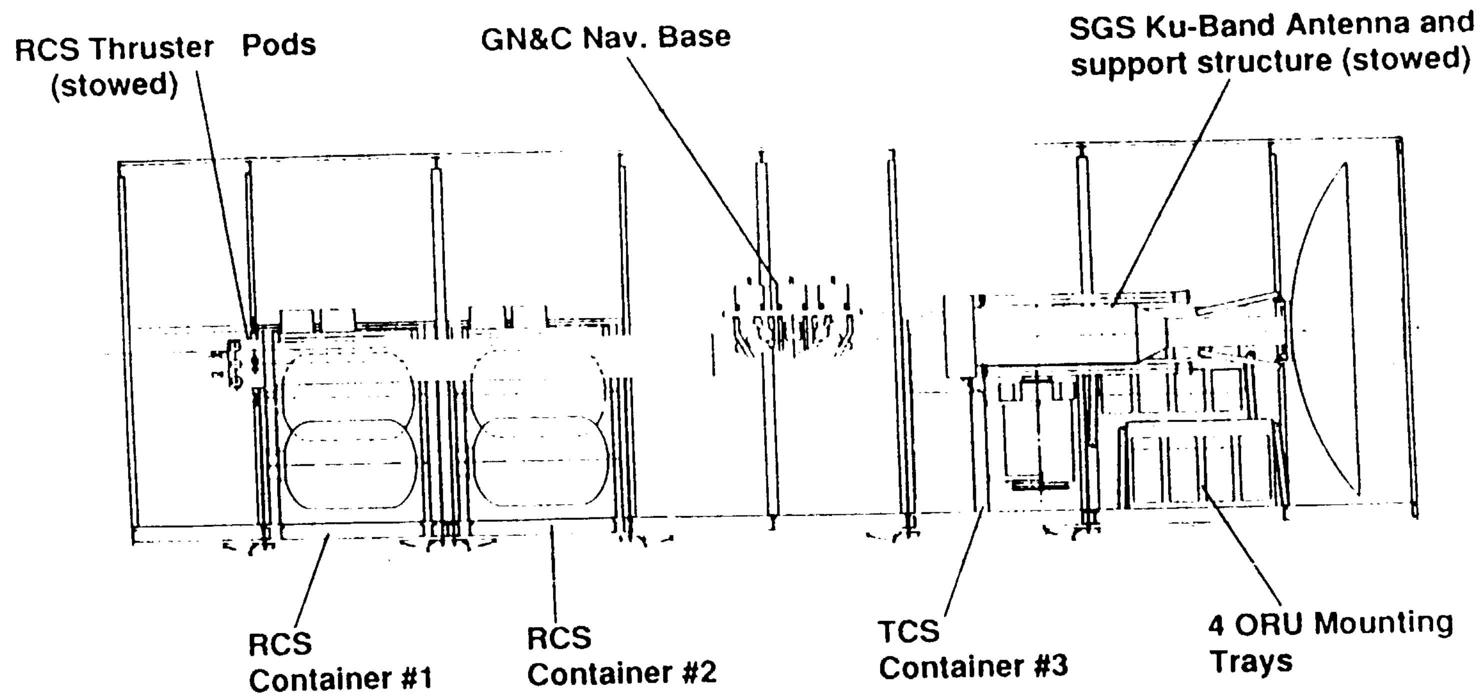
The stowed items are the RCS thruster pods and the Ku-Band antenna with its support structure. Some antenna mounted C&T system elements are also stowed on one of the mounting trays.

The propulsion system conceived for this structural configuration features a tank farm assembly in each removable RCS container. The thruster pod assemblies are on extended booms to provide the necessary reaction torque moments. There are four tanks (type V075) in each RCS container providing a total capacity of 4255 lbs of fuel per container. The RCS tank containers are ORUs for the purpose of refueling, and maintenance, and may be configured as either: One container serving both thruster pods. The other set of tanks is to be used when the first is being replaced/refueled, or one container dedicated to each of the upper and lower thruster assemblies, as in the baseline station.

A special consideration for these configurations is that the fuel lines between the tanks and the thrusters must be connected and disconnected on orbit. Quick disconnect technology (Fairchild poppet valve type) has been developed for on-orbit refueling of the GRO spacecraft, and this may be applied to this concept. Alternatively a ball valve type (Moog design - tested, but not yet qualified) may offer the increased flow rates which may be necessary for this application.

# First Element Launch - Flight TRI

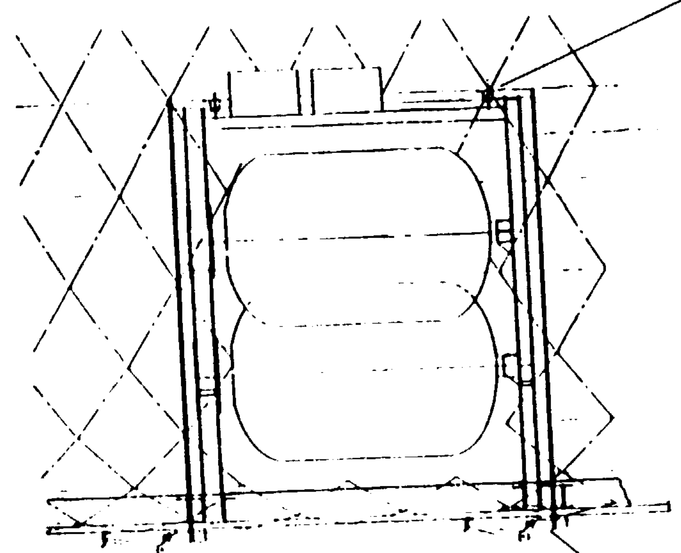
## Launch Configuration

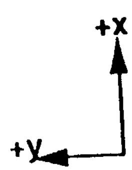


## RCS Container - Side View

This view shows the location of the attachment fittings which retain the container. The keel fittings between the two containers are retractable pin and latch mechanisms which are tapered for alignment purposes, and are capable of reacting loads in the orbiter Y and Z axes. On orbit, the reduced load requirements may permit replacement containers to be secured by a subset of the six attachment fittings described, the balance to be used for alignment purposes only.

# RCS Container - Side View

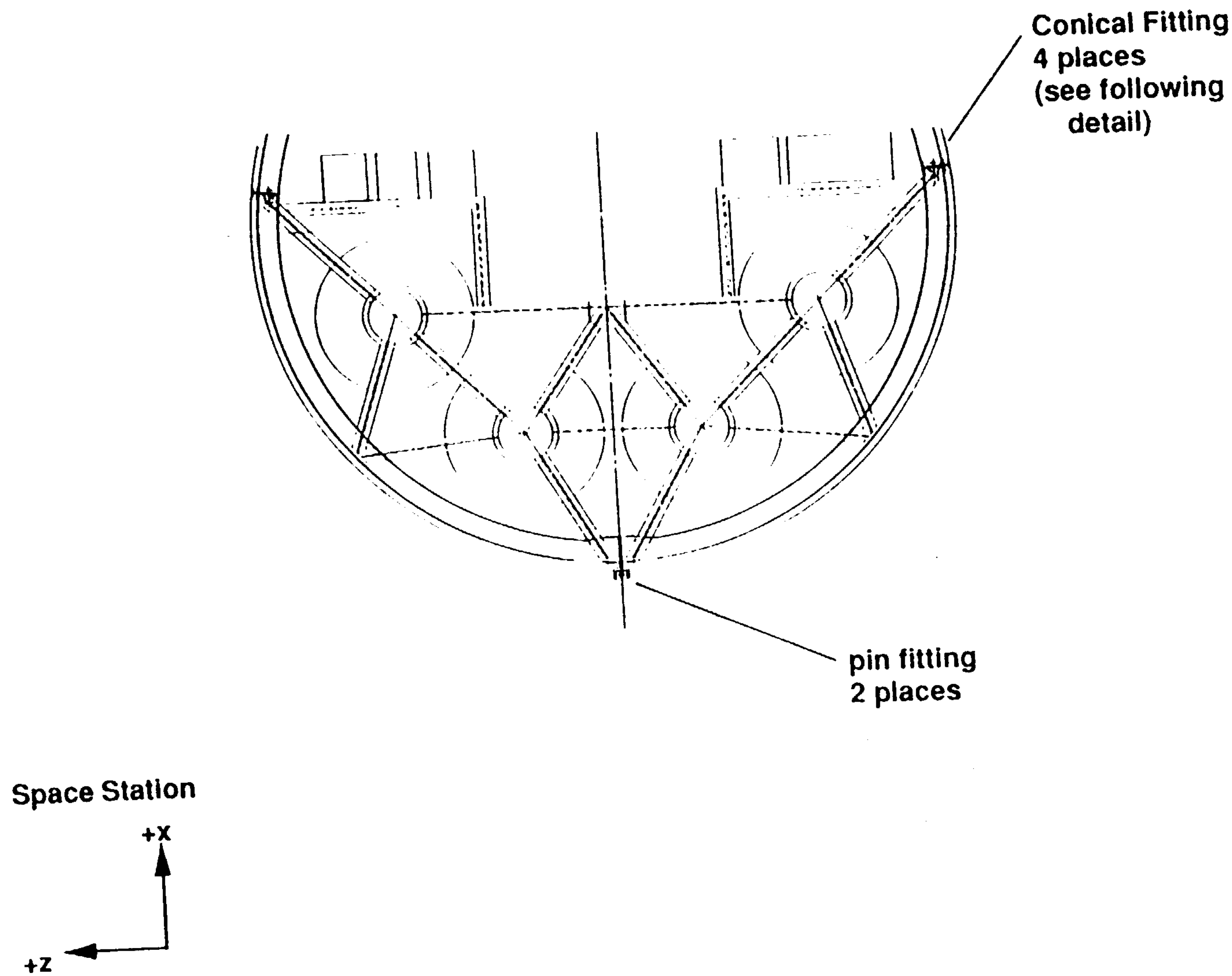


## RCS Container – End View

The fuel tanks are mounted between two end frames in a manner similar to that used in the baseline. The aft frame (launch orientation) provides primary support in three axes, while the forward, somewhat lighter, frame provides secondary support in the Y and Z axes only. The upper extension of these end frames forms a support for a platform used to mount the electronic components.

# RCS Container - End View



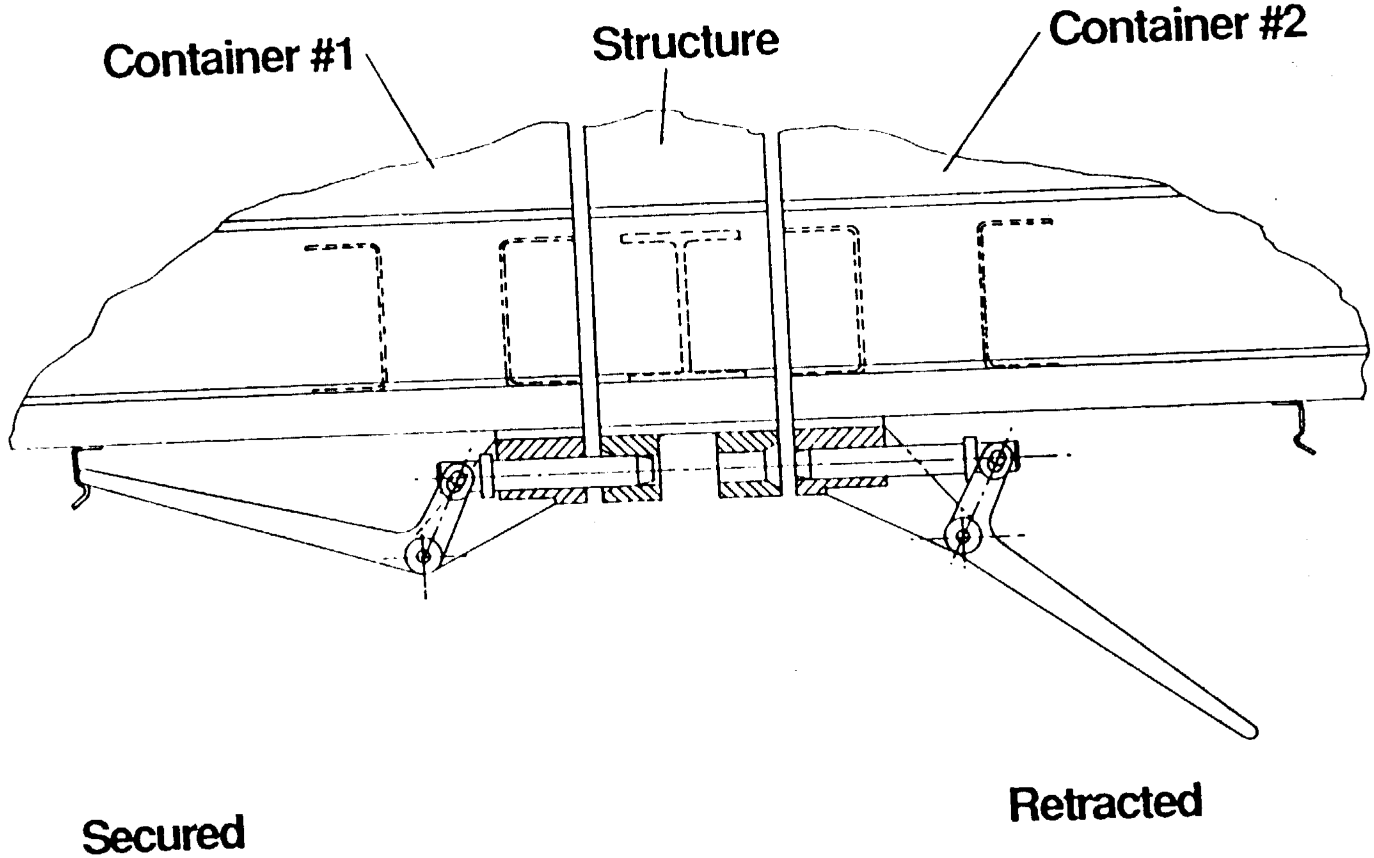
## Container Attachment Fittings at Keel

The two pin fittings at the keel are operated by a cam/lever mechanism. They can react loads in the Y and Z axes, and alone are sufficient to react the reboost loads in these directions.

NASA — FREEDOM

# Container Attachment Fittings at Keel

## Pin Type



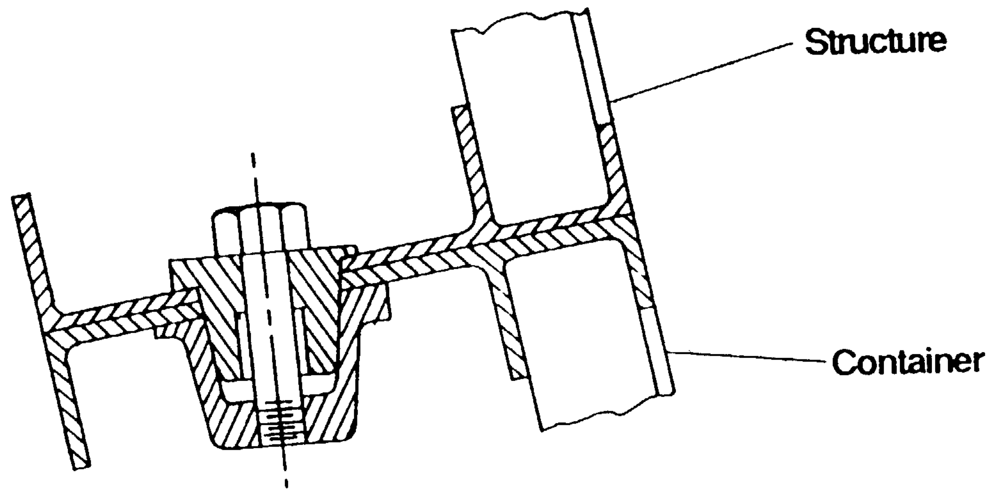

LaRC SSFO

## Container Attachment Fittings
## Conical

The four conical fittings provide alignment and attachment of the container into the main tube structure. These are designed to react loads in the orbiter X and Y axes through the main longerons to the orbiter attachment trunnions. The bolts provide the mechanism for pulling the container fully into the load carrying attachment as well as carrying Z axis loads in tension. The bolts may not be required for the lighter on–orbit loads, and may be left undone after the first service replacement of the container. A simple (light) latch may be attached to the exterior to facilitate installation of replacement containers. Further study is required to determine the feasibility of these details, and the specifics of connecting the fuel lines feeding the thrusters.

# Container Attachment Fittings

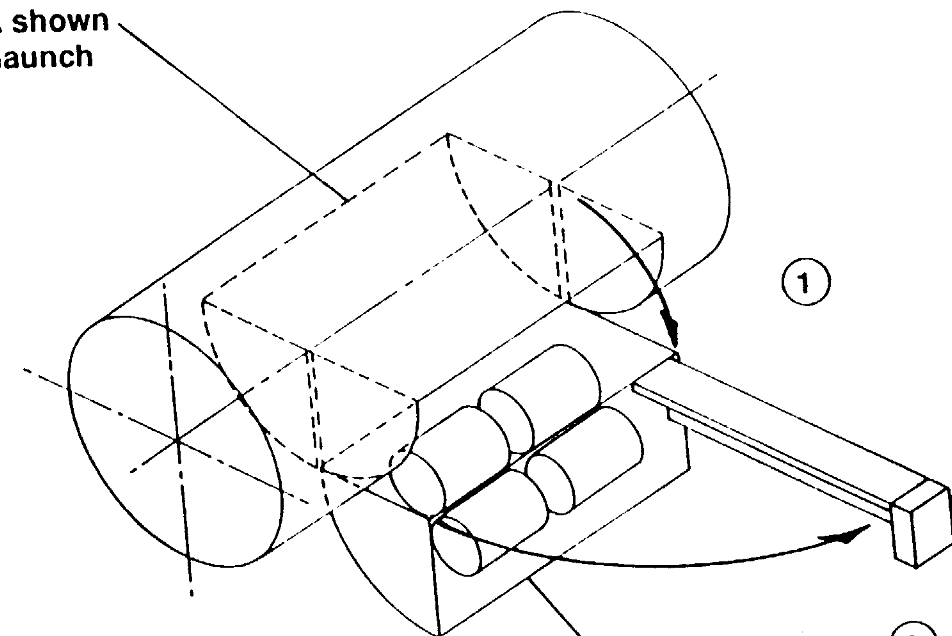
## Conical



## Alternate Propulsion System Configuration

Alternate configurations have been considered to eliminate the on orbit hypergolic connections. However, no detailed study has yet been made of the structures and mechanisms for these options. In this scheme, the complete propulsion system is a single ORU (as in the baseline). The container in this case is a quarter section of isogrid and is twice the length of the semicircular containers. It is hinged at the keel, and stabilized by struts between it and the main isogrid structure. The thruster pod assemblies fold out from the container after it has been rotated outward to its operating position. A structural feature of this scheme is that the integrity of the keel longeron can be retained between the two RCS containers.

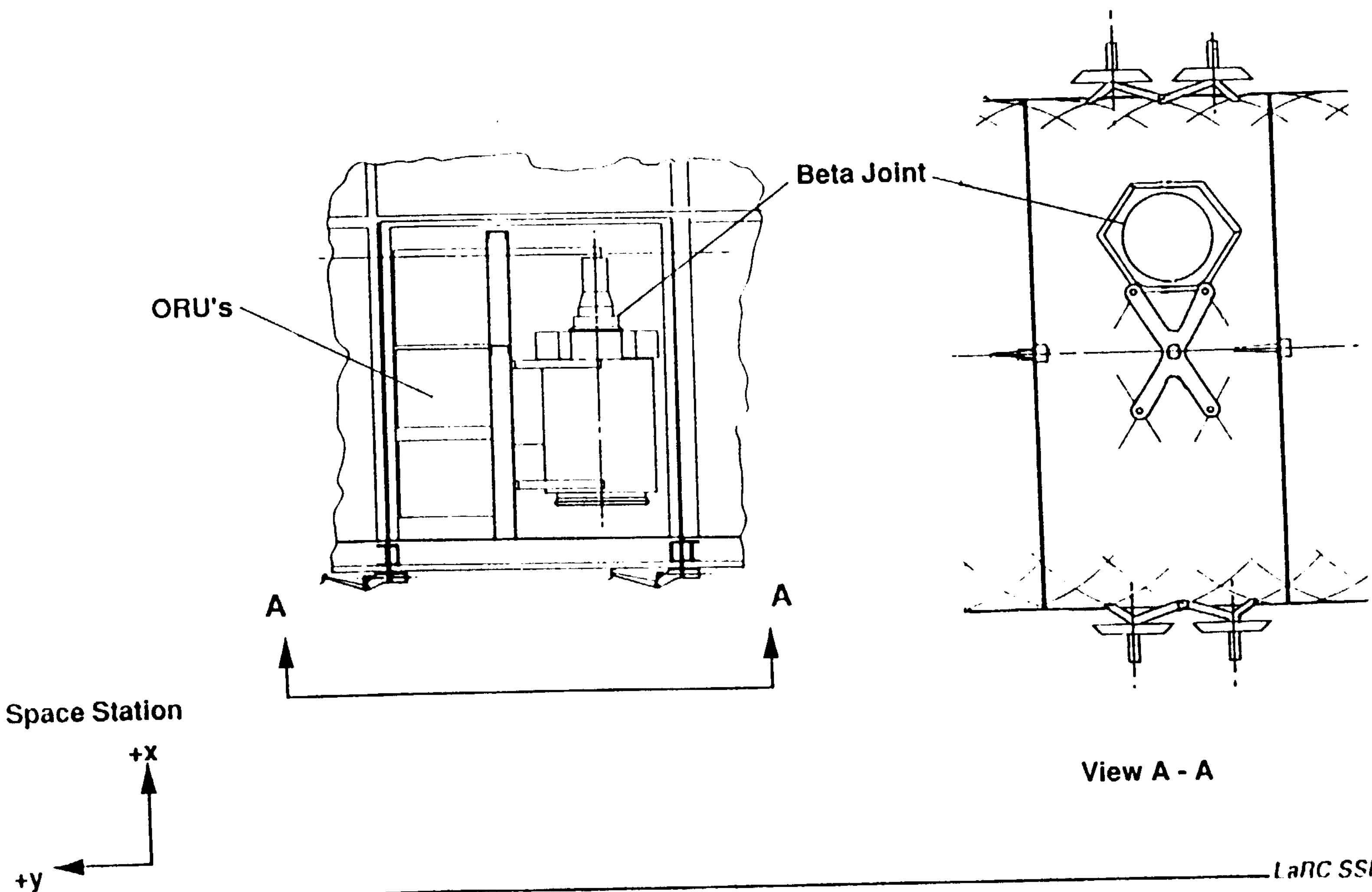
# Alternate Propulsion System Configuration



## TCS Container – Side View

The Beta joint is located with its axis coincident with an isogrid node point. The isogrid node itself and adjacent members are removed and the opening reinforced in a similar manner to that used for the EVA access aperture (view A–A). Other TCS and distributed systems ORUs are mounted on both sides of the central framework, which also supports the beta joint. The radiator is delivered to the station, installed, and deployed on a subsequent flight.

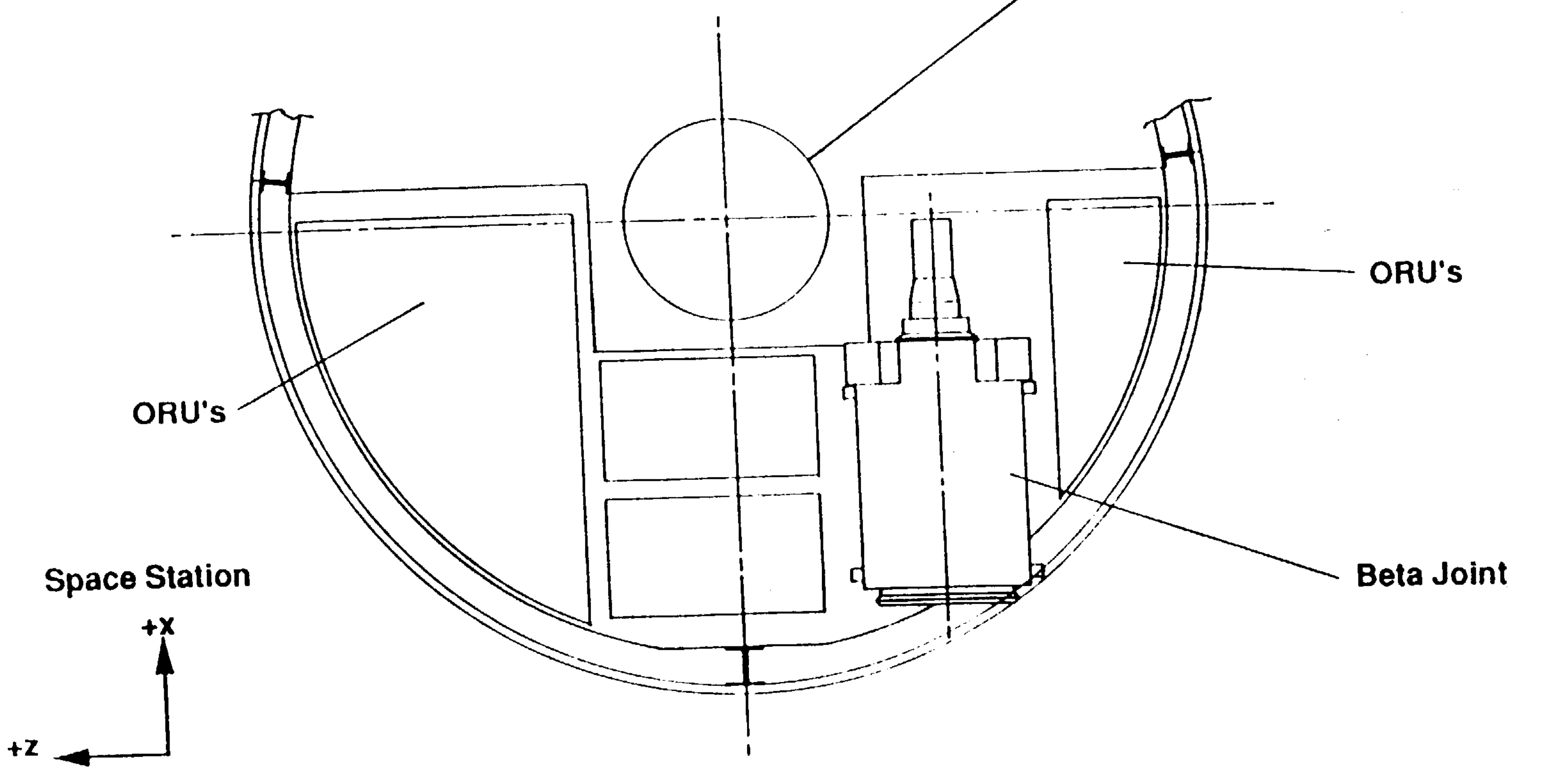
# TCS Container - Side View



## TCS Container – End View

The Beta joint and other ORUs are mounted on a pallet–like framework, which is integral to the container. The aft end (launch orientation) of the antenna support structure is attached to this framework when it is in the stowed position.

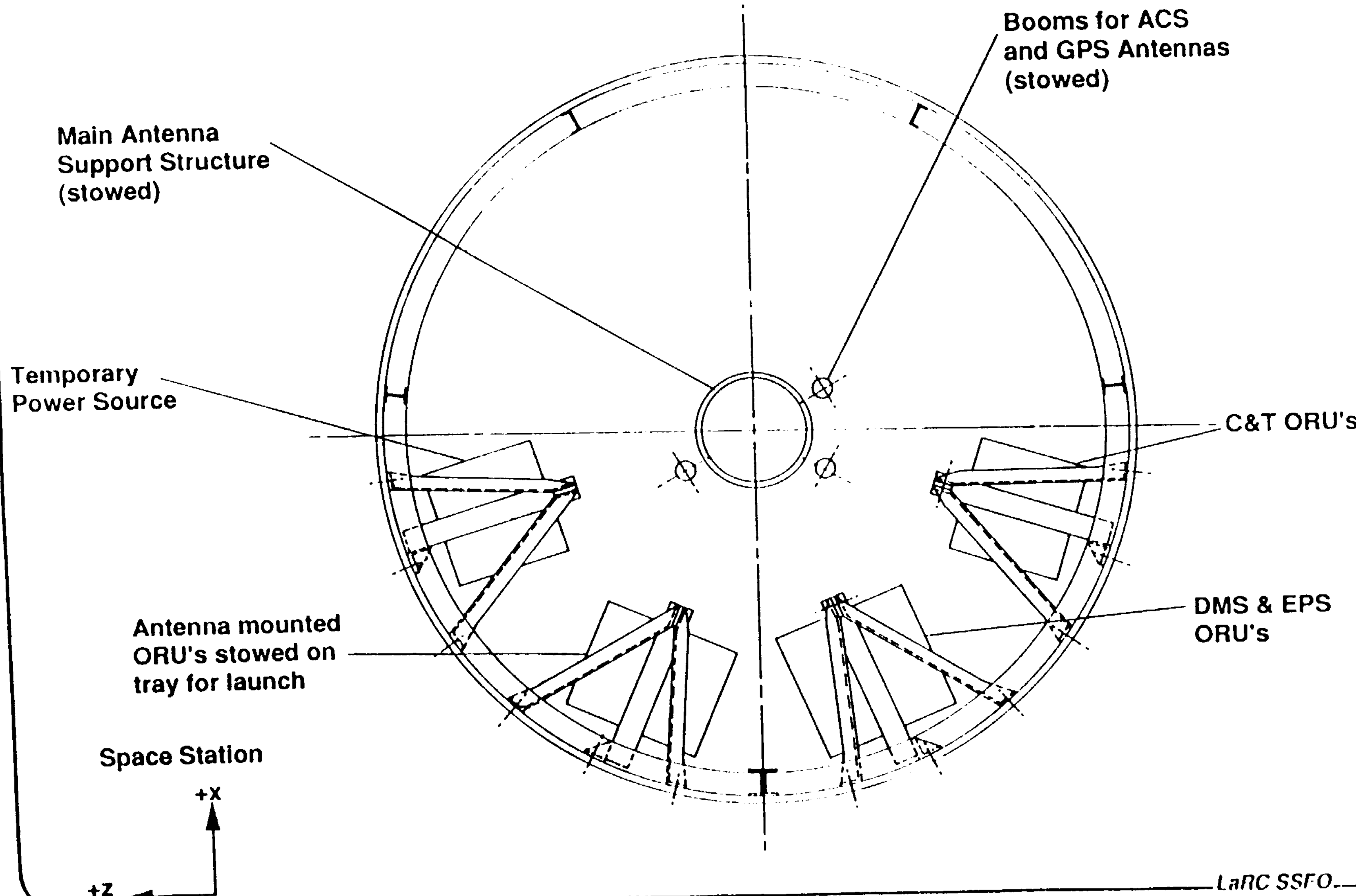
# TCS Container - End View



## Subsystem Trays

Smaller subsystems and/or ORUs are mounted on both sides of trays which are positioned radially in a non-removable section of the tube structure. The subsystem elements which were on the baseline C&T pallet are located on two of the trays (except for the antenna mounted and GN&C components). The first tray, immediately below the antenna assembly, contains the C&T system elements. The second, adjacent to the first contains distributed system elements of the DMS and EPS systems.

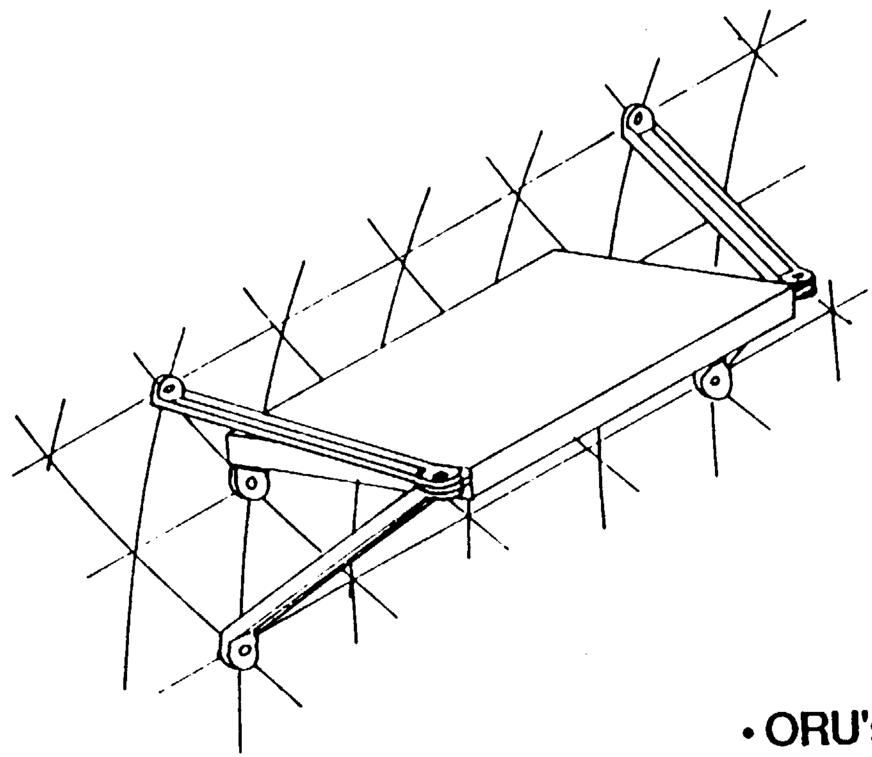
# Subsystem Trays



## Subsystem Tray Attachment

Tray mounting brackets and support struts are attached directly to the isogrid nodes. The tray may be fixed, or utilize sliding and/or hinged rails to orient the ORUs for easier access for servicing.

# Subsystem Tray Attachment



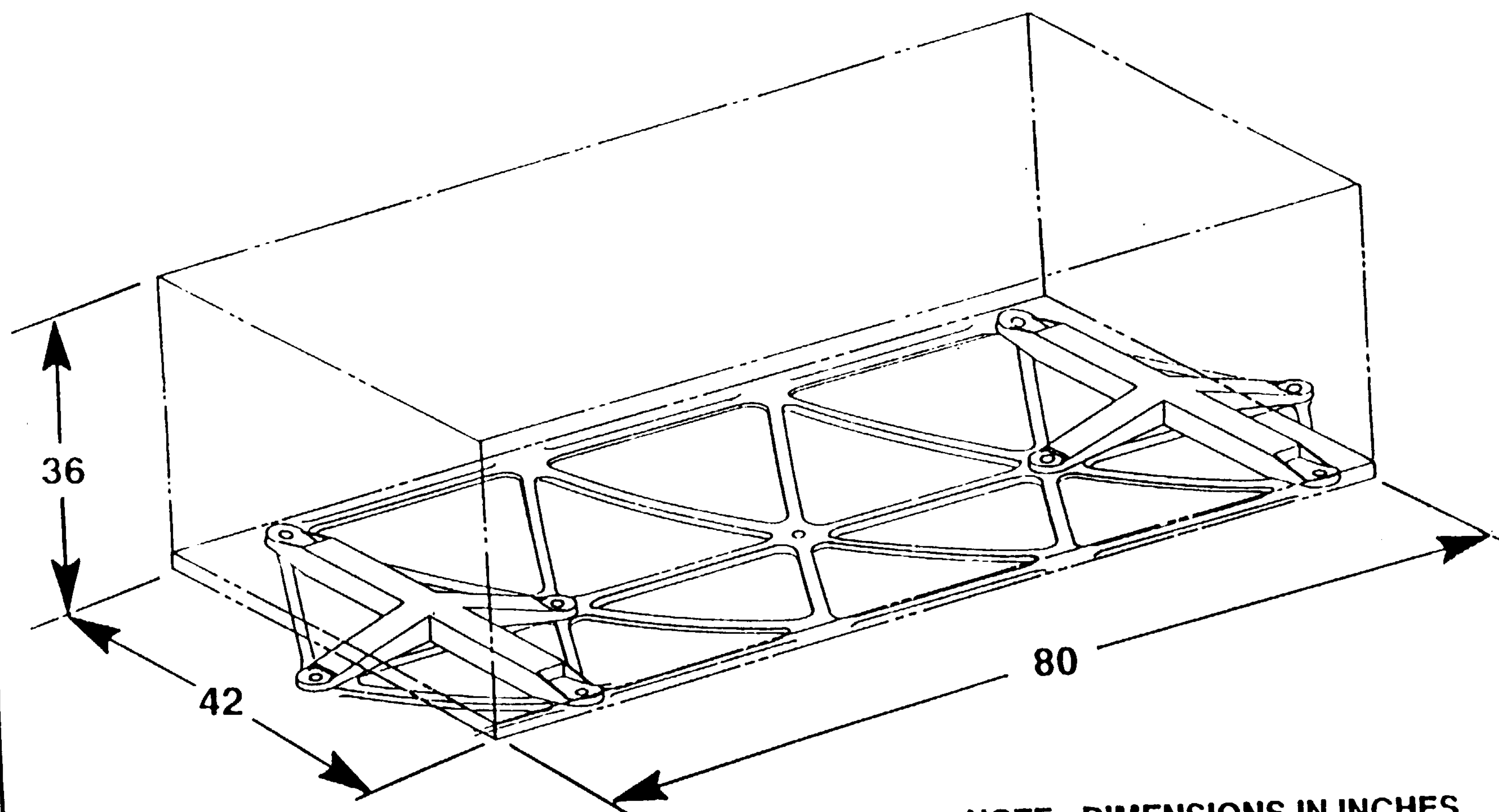
- ORU's mount on both sides of tray

## Alternate Subsystem Mounting Assembly

ORU's which are too large for the previous subsystem tray mounting method, but not large enough to require a complete container, may be mounted on this type of tray. It is suitable for system elements up to 80"x36"x41.5" and weighing up to 1000 lbs.

The system element is mounted on a tray (depending on specific requirements), which is supported on the isogrid via a pair of mounting brackets. The load is thereby distributed over eight isogrid nodes. The mounting assembly weighs 65 lbs.

# Alternate Subsystem Mounting Assembly

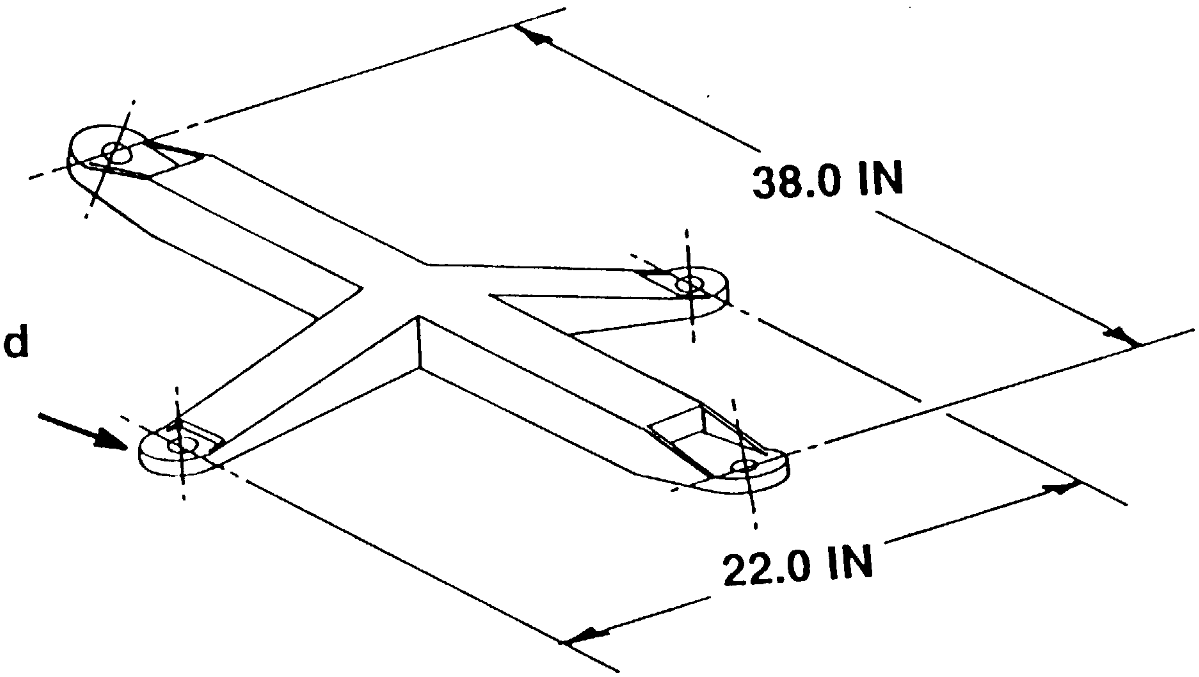



NOTE: DIMENSIONS IN INCHES

## Subsystem Mounting Bracket

A typical mounting bracket to support the alternate subsystem tray spans 22" (between adjacent node points) by 38" (twice the height of a single isogrid segment) to spread its load over four nodes.

# Subsystem Mounting Bracket




Attaches to isogrid nodes at 4 points

2 per subsystem (typical)

# GN&C ORUs

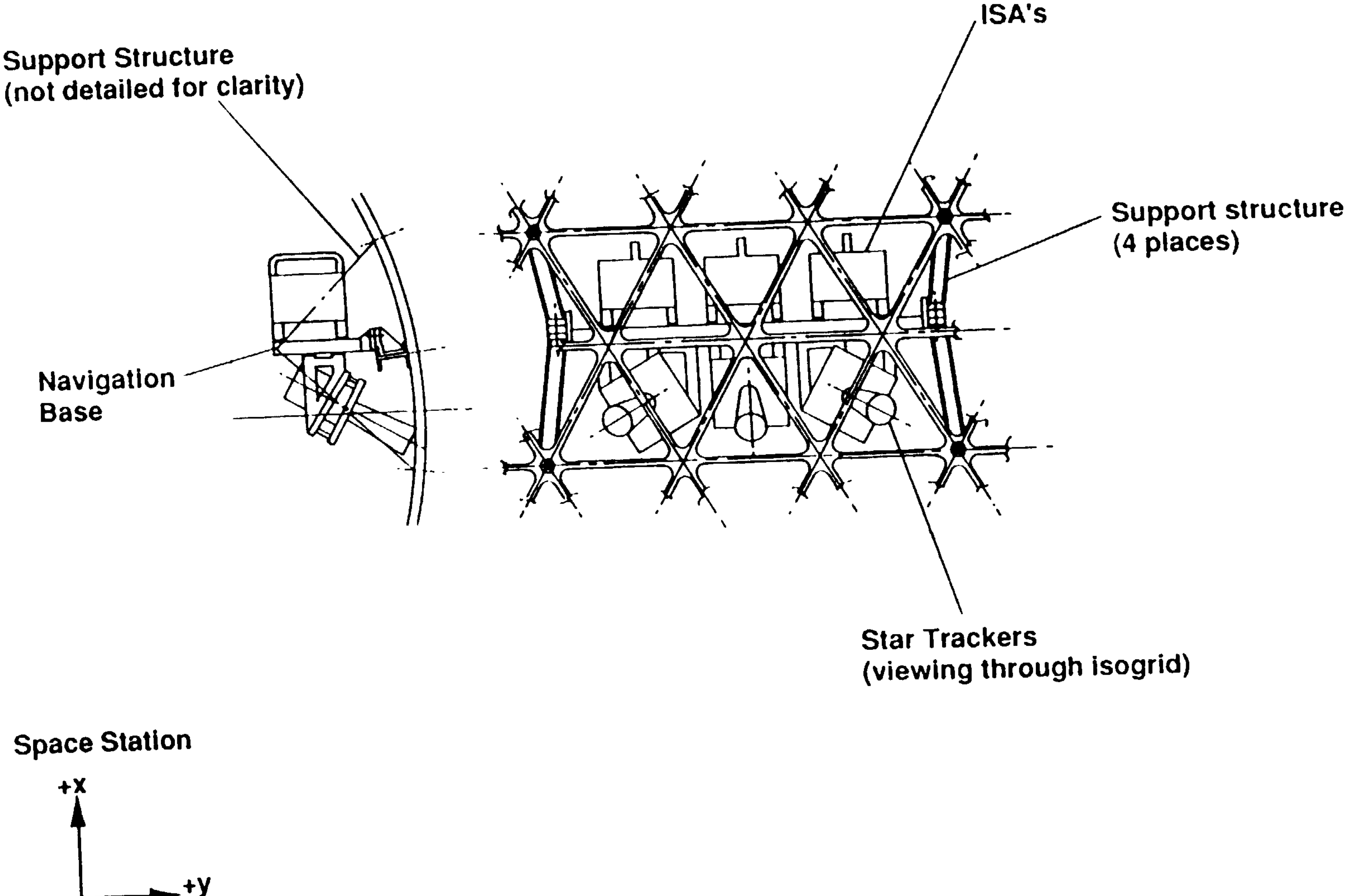
The navigation base is attached to the isogrid within the central EVA access area. this location permits viewing angles which avoid obstruction by the Ku–Band antenna. The star tracker's view is through the isogrid openings. The collocation of star trackers and ISAs on a single navigation base is retained, but they are mounted on opposite sides for ease of replacement and to minimize incursion into the EVA access volume.





C-2

# GN&C ORU s

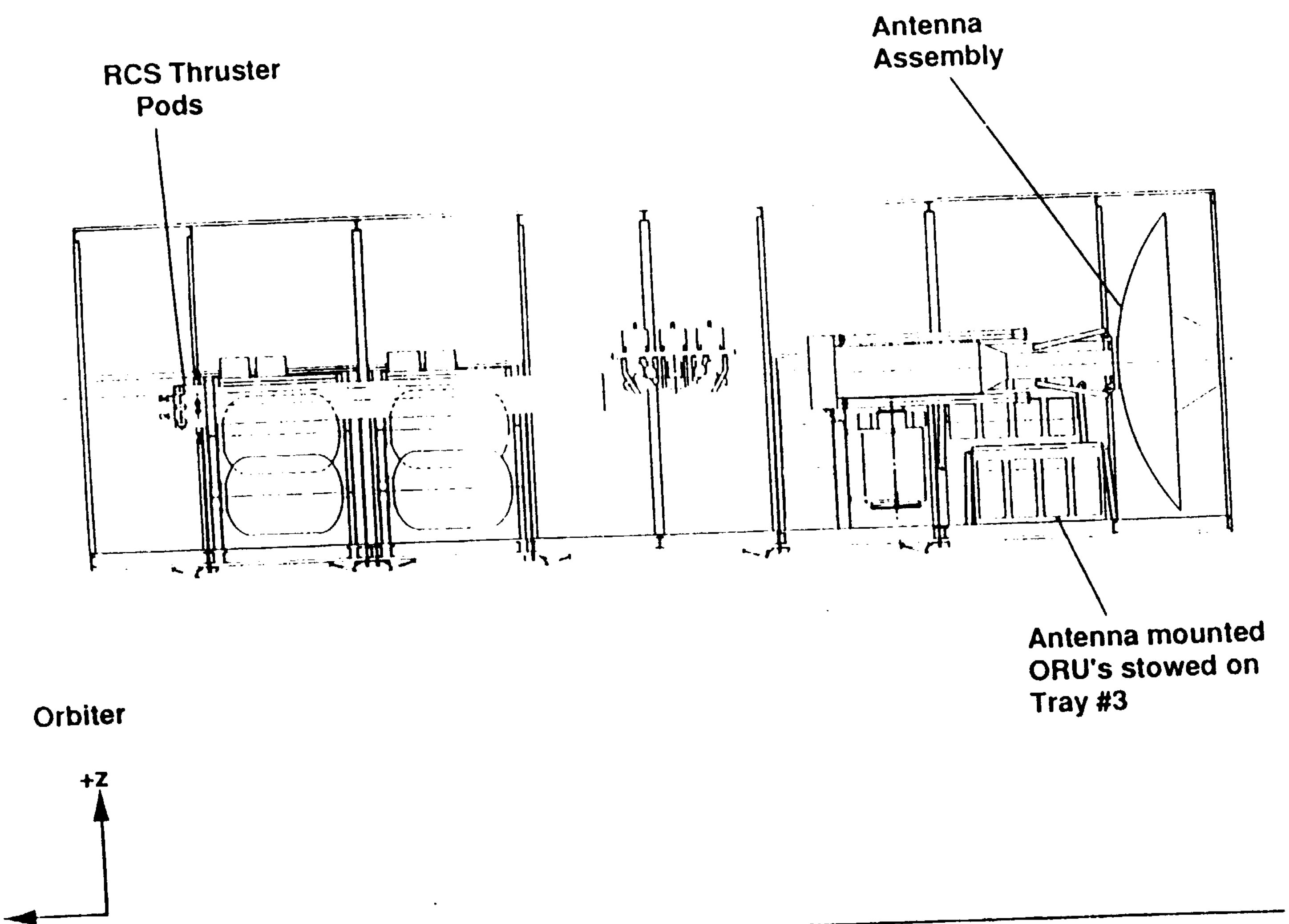

Support Structure
(not detailed for clarity)
Navigation
Base
ISA's
Support structure
(4 places)
Star Trackers
(viewing through isogrid)
Space Station
+x
+y

## First Element Launch - Flight TR1
## Stowed Items

The RCS thruster pods are stowed on top of the RCS containers one on each side of the center line of the main tube structure. The thrusters themselves, being within the EVA access area placing their mass toward the aft end of the orbiter payload. The Ku-Band antenna assembly is mounted axially within the tube at the forward end with the deployable booms folded along its length.

# First Element Launch - Flight TRI

## Stowed Items

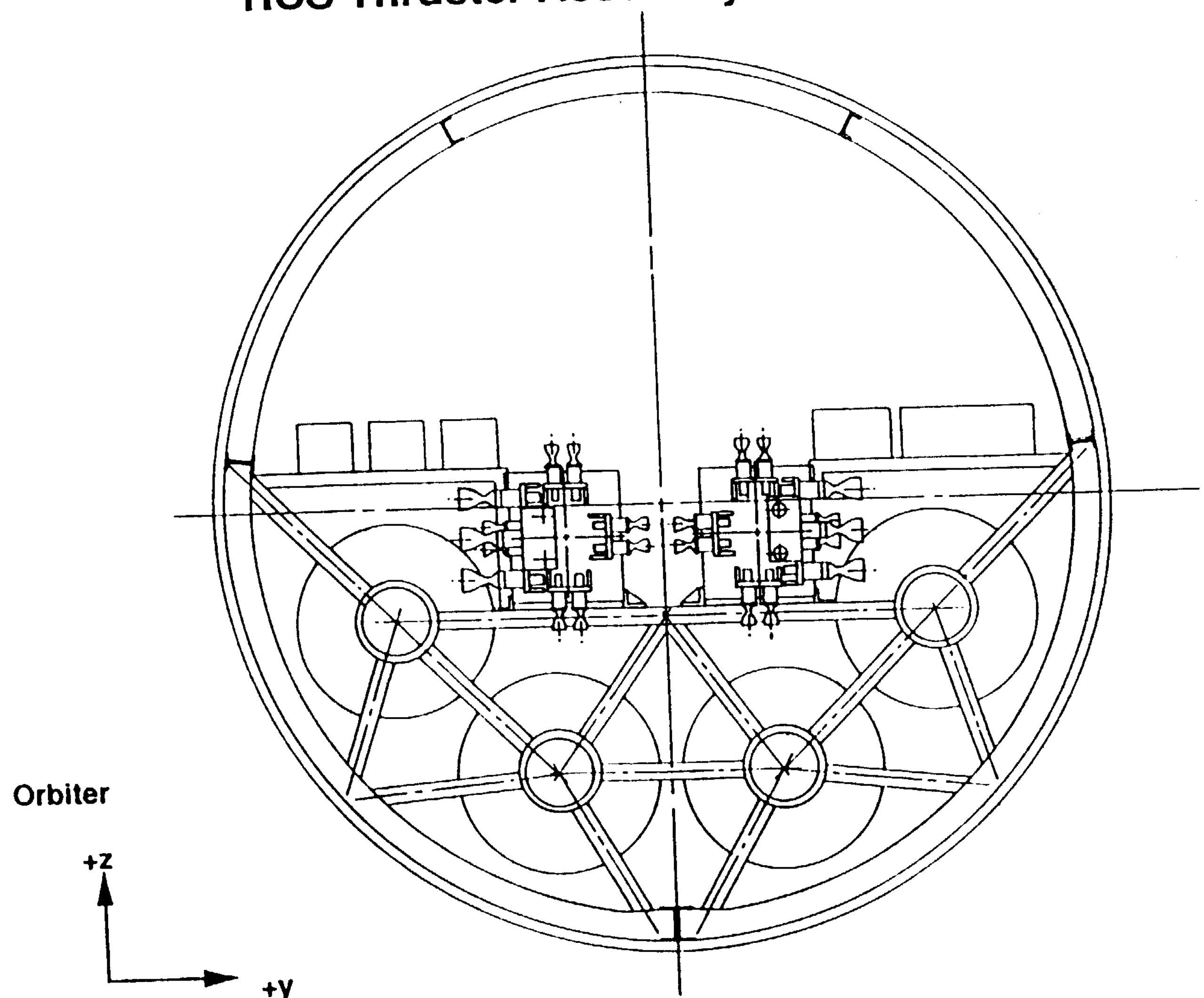


## Stowed Items
## RCS Thruster Assembly – Stowed

This figure shows the thruster assemblies stowed for launch. They are attached to the RCS container tank support structure by means of brackets and latches (FSE). In operation the booms are attached to the outside of the isogrid (after on-orbit assembly), and the thruster pods at the ends of the booms may be separate ORUs.

# Stowed Items

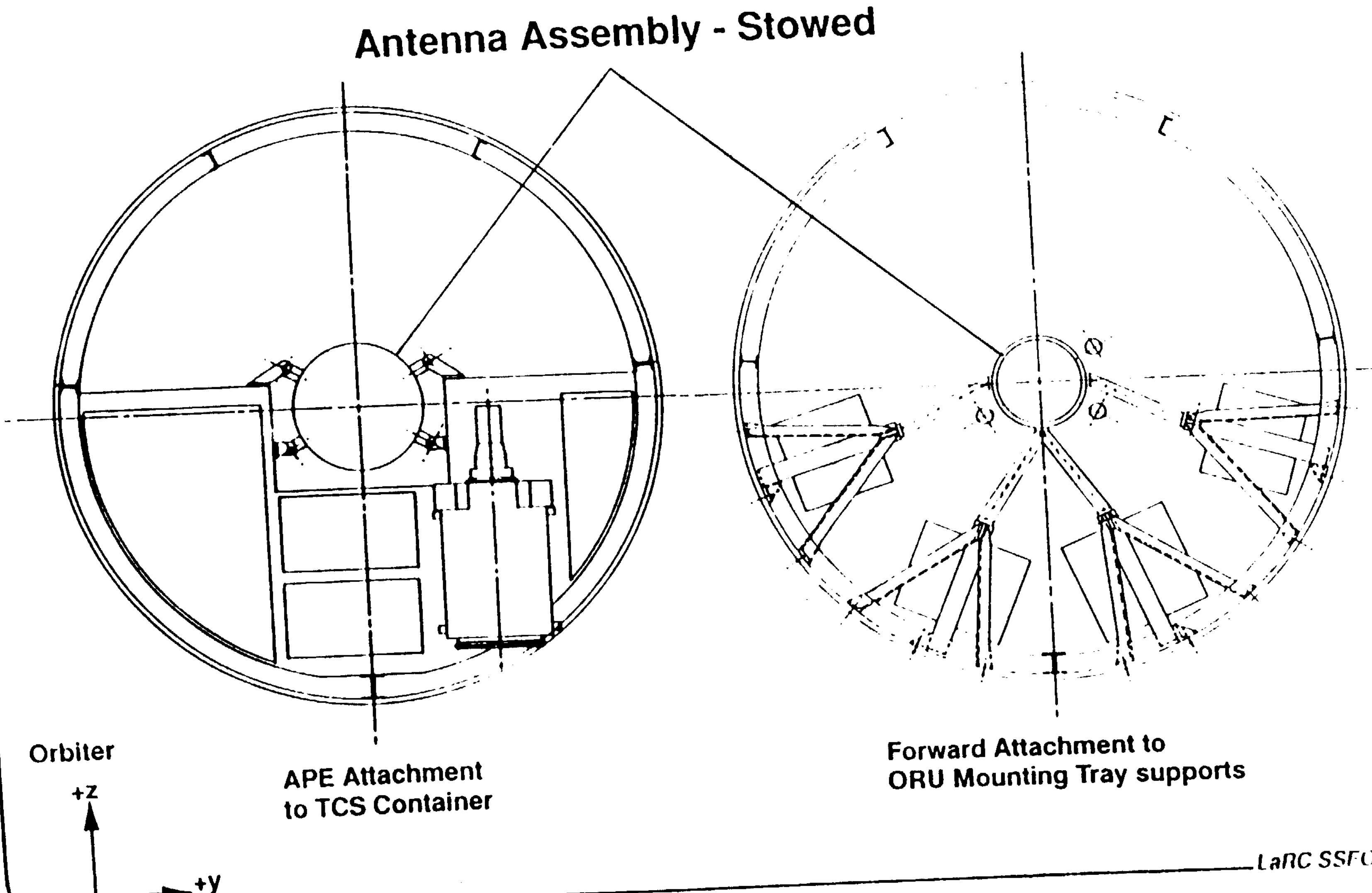
## RCS Thruster Assembly - Stowed



## Stowed Items
## Antenna Assembly - Stowed

The base of the stowed antenna assembly is secured to central framework of the TCS Container by four brackets brackets and latches (FSE). The forward end is similarly secured on four struts attached to the ORU mounting tray supports.

# Stowed Items



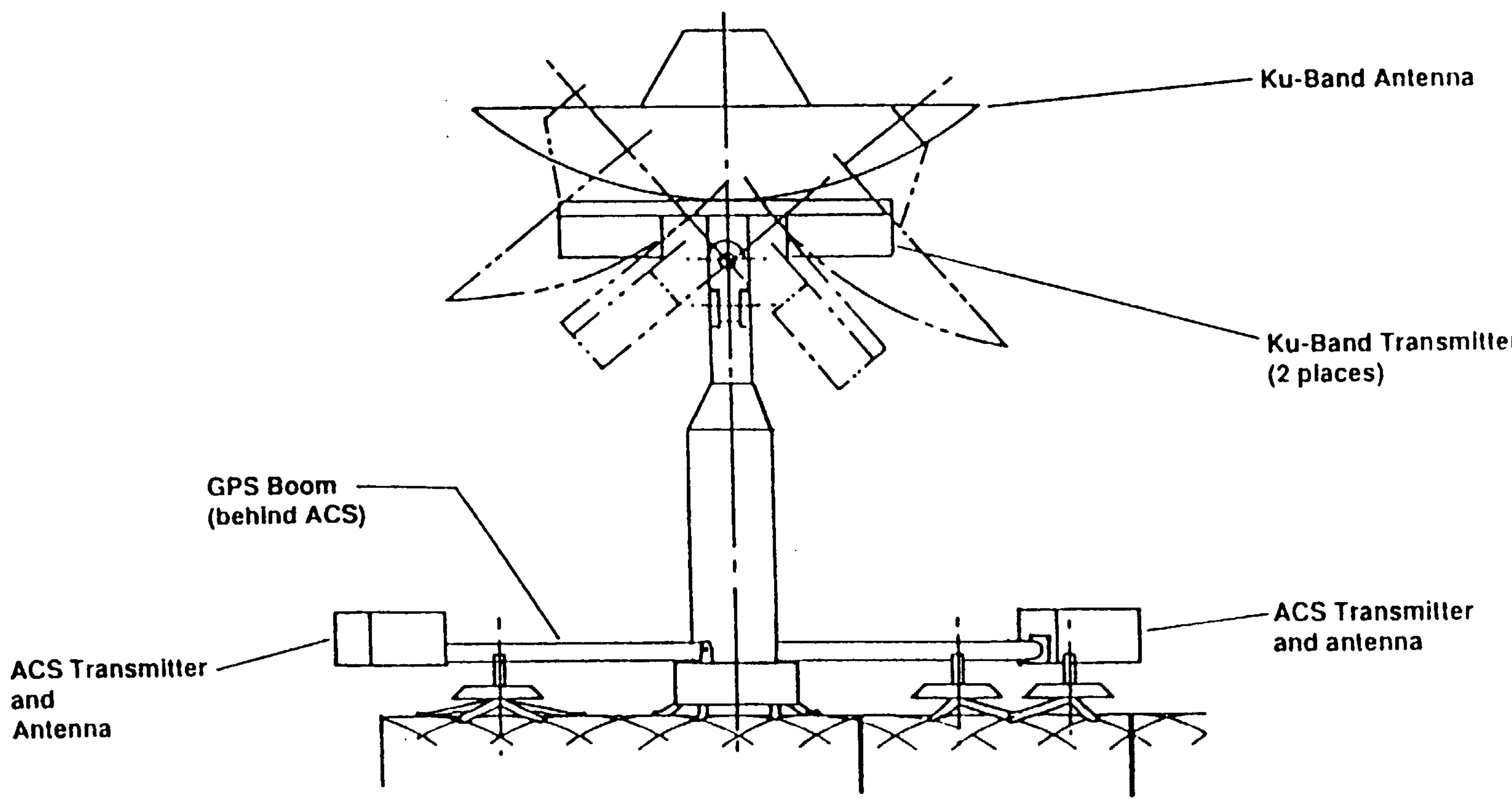
## Stowed Items
## Antenna Assembly - Operational

The base of the antenna assembly is attached at six isogrid nodes. The antenna support structure includes a main tubular member (possibly an isogrid structure) to support the Ku-Band parabolic antenna with five deployable booms incorporated in the assembly. The two upper booms accommodate the Ku-Band Space to Ground System (SGS) transmit/receive units. Two of the three lower booms provide attachment points for the S-Band Assembly Contingency System (ACS) transmit/receive units. The third is an accommodation for the Global Positioning System components to be installed on a later flight. Each of the booms is secured and deployed using a system of latches and hinges similar to the baseline system.

The above mentioned antenna mounted ORUs are attached to an unused subsystem tray during the launch phase. These are the same ORUs as are antenna mounted in the baseline station with one exception. The SGS antenna controllers are mounted on the antenna structure in the baseline, but in this design, are integrated on a subsystem tray located at the base of the antenna support structure along with the other C&T ORUs.

# Stowed Items

## Antenna Assembly - Operational



# Packaging Mechanisms for FEL
## Summary

This study of system configurations and mounting methods demonstrates the following advantages and disadvantages.

Advantages:

i) Many options exist for methods of mounting system hardware.
ii) A degree of modularity is possible for the mounting methods creating the opportunity to design common elements.
iii) The numerous attachment points (one at every isogrid node), permit flexibility in the location of subsystem hardware.
iv) Micrometeoroid/debris shielding may readily be attached over the isogrid, or integrated into the structure itself.

Disadvantages:

i) The precise location of attachment points is fixed at the grid nodes. Optimization of the grid size and reinforcing structure could minimize this effect.
ii) The system hardware generally appears as concentrated loads, which during launch (the highest load condition), are reacted at the fixed orbiter attachment points. The distribution of these loads requires significant reinforcement of the isogrid structure.

# Packaging Mechanisms for FEL

## Summary

**Advantages**

- Flexibility of attachment methods
- Numerous attachment points
- Ease of attaching micrometeroid/debris shielding

**Disadvantages**

- Isogrid restricts precise location of attachment points for subsystems to predefined nodes
- Relies heavily on reinforcement rings and longerons to distribute concentrated launch loads

**Comments**

- Further studies are required to fully optimize this concept, particularly the grid size relative to the various ORU's, trunnion locations, etc.
- A "strongback" truss structure is also worthy of further study

# Further Study

## Isogrid Optimization

The isogrid structure offers flexibility of attachment methods, which may be applied to many types of ORUs and/or payloads. It provides numerous attachment points for subsystem elements, although the fixed spacing of the isogrid does predefine the precise attachment locations.

The optimum isogrid spacing may be other than 22 inches, and may result in better load distribution and/or improved ORU attachments. For example, it may be advantageous for the isogrid used for the container shells to be a different grid size than that of the main truss section, or for the section above the main longerons to be other than that for the sections between the longerons and the keel.

## Strongback Approach

This study has focused on the isogrid as a primary structure, and has shown that significant reinforcement is required to handle launch loads, which are concentrated at the orbiter attachment trunnions. A strongback truss structure comprised of longerons at the trunnion locations may provide the basis of an optimal structure for reacting launch loads, as well as more readily utilizing existing hardware mounting configurations.

The isogrid may be viewed as a secondary structure, and incorporated as required to provide torsional rigidity and to carry distributed loads. This approach may result in a lighter isogrid form, which could be applied in selected areas. These areas would benefit from the addition of a torsional stiffening structure, and/or from the positive attributes of the isogrid for mounting items such as utilities and micrometeoroid shielding.

# Further Study

- Optimization of grid size relative to the various ORU's, trunnion locations, etc.

- A "strongback" truss structure is also worthy of further study.

– This Page Intentionally Left Blank –

NASA

FREEDOM

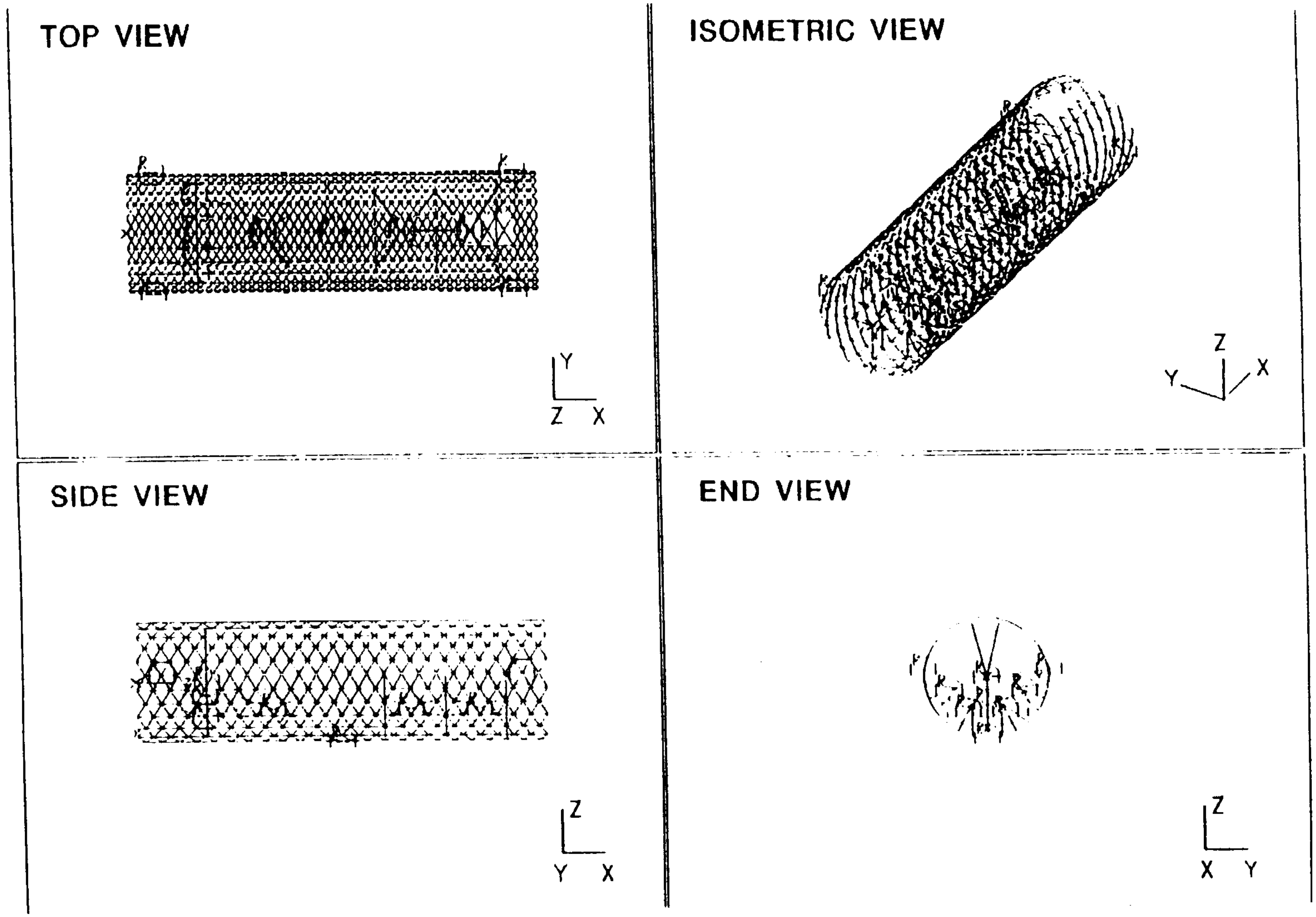
# Structural Analysis

LaRC SSFO

## Isogrid Truss Finite Element Model

Here are three orthographic views and an isometric view of the finite element model created to represent the analysis case.
The model contains 919 nodes and 2489 beam elements and rigid body elements. All internal subsystems are included as
rigid body elements, but are connected to the structure with flexible beam elements. The TCS and RCS systems are
included in removable containers that will simplify changeout on-orbit. The container attachments to the rest of the truss
are modeled here by rigid body elements that are constrained only in selected directions to simulate the actual attachment
devices that are presented in the Packing and Mechanisms section of this addendum. Utilities are included as
non-structural mass, so they provide no structural rigidity to the model though their mass effects are included. Trunnion
fittings used for the interface with the orbiter are modeled as rigid bodies to simulate a stiff plate used to distribute the
loads through several elements of the isogrid.

# ISOGRID TRUSS FINITE ELEMENT MODEL



## Primary Structural Mass Breakdown

The total structure required to support the payloads and withstand the expected loads has been divided into two classes- primary structure and secondary structure. The primary structure, which includes the isogrid itself as well as additional major structure needed to stiffen the isogrid, is itemized in the following table.

# Primary Structural Mass Breakdown

| | | |
|---|---|---|
| **Isogrid** (44 ft section) | 2768 (lbm) | 2768 (lbm) |
| **Primary Stiffening Structure** | | |
| Trunnion longeron (2) | 208 | |
| Keel longeron | 382 | |
| Top longeron (2) | 80 | |
| End Ring (2) | 181 | |
| Isogrid stiffening ring (adjacent to containers) (4) | 362 | |
| Center ring (3) | 294 | |
| EVA access stiffener (4) | 13 | |
| Isogrid trunnions (5) | 440 | |
| Connecting hardware | 200 | |
| ***Total primary stiffening structure*** | 2160 | 2160 |

***Total primary structural mass 4928 lbm***

## Secondary Structural Mass Breakdown

The total structure required to support the payloads and withstand the expected loads has been divided into two classes-primary structure and secondary structure. The secondary structure, which is used to attach the payloads to the isogrid, is itemized in the following table.

# Secondary Structural Mass Breakdown

| | | | |
|---|---|---|---|
| **Propulsion System (2 units)** | | | |
| Container stiffener | | 420 | |
| Tank support (fore) | | 200 | |
| Tank support (aft) | | 100 | |
| Trunnions (10) | | 460 | |
| | ***Subtotal*** | 1180 | 1180 |
| **Thermal Control System** | | | |
| Aperture reinforcement | | 10 | |
| Container stiffener | | 210 | |
| ORU support | | 425 | |
| Trunnions (5) | | 230 | |
| | ***Subtotal*** | 875 | 875 |
| **C&T System** | | | |
| Rack structure | | 180 | 180 |
| **Temporary Power System** | | | |
| Rack structure | | 60 | 60 |

***Total secondary structural mass*** *2295 lbm*

## Structural Analysis Summary

Three static load cases and a normal modes analysis were used in the structural analysis. The first two cases shown were obtained from MSFC, and represent the worst case loads they expected for module-sized payloads in the orbiter during liftoff and landing, respectively. A factor of safety of 1.4 was applied to the loads received from MSFC to make them ultimate loads. The third loadcase used was the worst case presented in Attachment 1 (ICD-2-19001) (also known as Volume 14). This worst case load was found in Table 4.1.3-4: Landing of Non-Returnable Cargo. A factor of safety of 1.4 was also applied to this case in order to use ultimate loads. A normal modes analysis was performed to determine the minimum natural frequency of the entire model (this was done to ensure that the requirement that the minimum natural frequency for FEL must be greater than or equal to 8 Hz was met).

# Structural Analysis Summary

| Loadcase | Load Factors (Ultimate) (g's) | | | Max Princ Stress (psi) | Max Disp (in) |
|---|---|---|---|---|---|
| | Nx | Ny | Nz | | |
| 1 * | -6.2 | -1.8 | -2.7 | -24410 | 1.430 |
| 2 * | +4.1 | +0.5 | +1.4 | +11670 | 0.709 |
| 3 # | -1.7 | +0.8 | +3.0 | -12360 | 0.764 |
| 4 | **Normal Modes Analysis** (within orbiter PLB) | | | **Min. Freq. = 14.17 Hz** | |

- Note: The load factors above include a 1.4 factor of safety.

* *MSFC Liftoff/Landing loads*

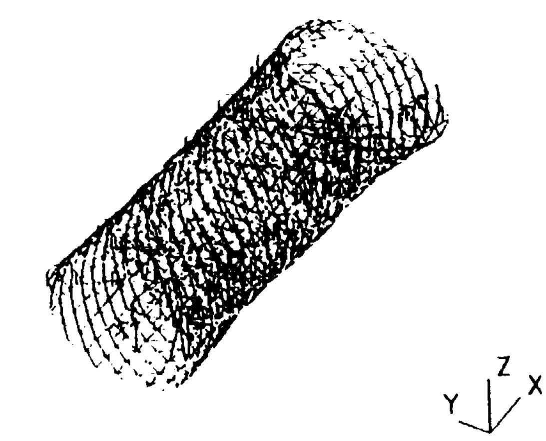
\# *Attachment 1 (ICD-2-19001) Table 4.1.3-4 Landing of Non-Returnable Cargo*

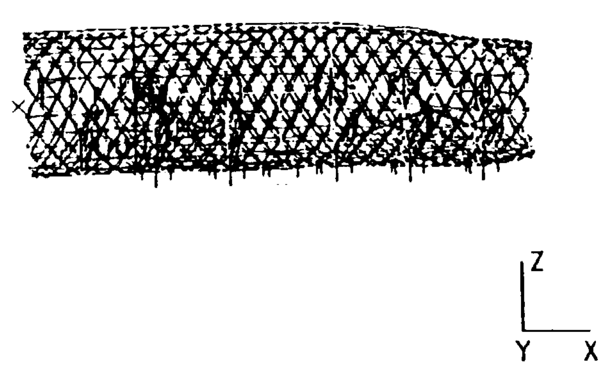
## Deformed Structure– Launch Loads

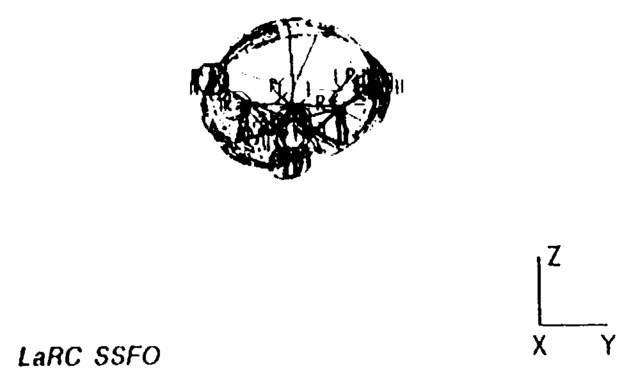
This is the deformed shape of the structure when it is exposed to the launch loads listed as Case 1 on the previous chart. The deformations have been magnified by a factor of 25 to be able to see them. The actual maximum deflection, which occurs in the isogrid along the stiffening ring between the two removable pallets, is only 1.43 inches. The maximum stress within the structure is –24410 psi, which, when considering an ultimate strength of 69000 psi, provides a factor of safety of 2.8.

# DEFORMED STRUCTURE - LAUNCH LOADS

- Ultimate Load Factors:
  - $N_x = -6.2$ g
  - $N_y = -1.8$ g
  - $N_z = -2.7$ g
- Max. Principal Stress = -24410 psi
- Max. Displacement = 1.43 in
- Note: Scale of Deformation = 25:1



## Deformed Structure- Landing Loads

Here is the deformed shape of the structure when the landing loads listed as Case 2 on the summary sheet are applied to it. The deformations have been magnified by a factor of 25 to be able to see them. The actual maximum deflection, which occurs along the keel between the two removable pallets, is only 0.709 inches. The maximum stress within the structure is 11670 psi, which provides a factor of safety of 5.9.

# DEFORMED STRUCTURE - LANDING LOADS

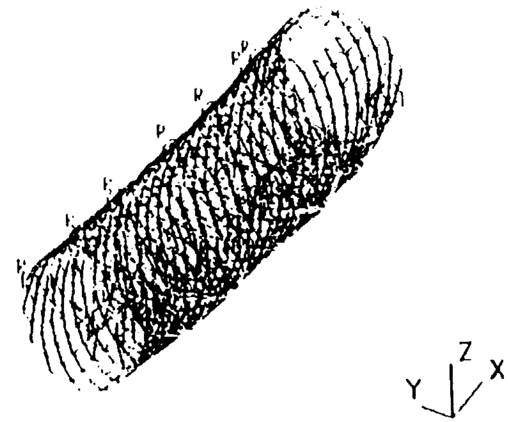
- Ultimate Load Factors:

  Nx = +4.1 g

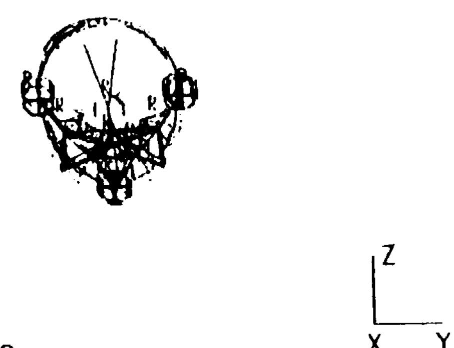
  Ny = +0.5 g

  Nz = +1.4 g

- Max. Principal Stress = +11670 psi
- Max. Displacement = 0.709 in
- Note: Scale of Deformation = 25:1








LaRC SSFO



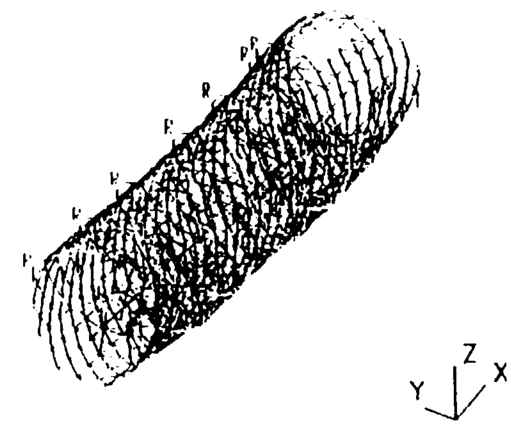
ORIGINAL PAGE IS
OF POOR QUALITY

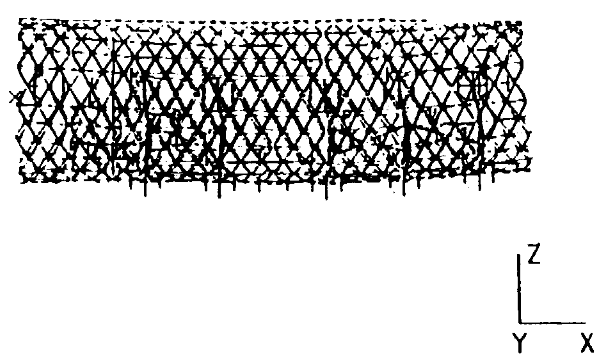
## Deformed Structure– Abort Landing Loads

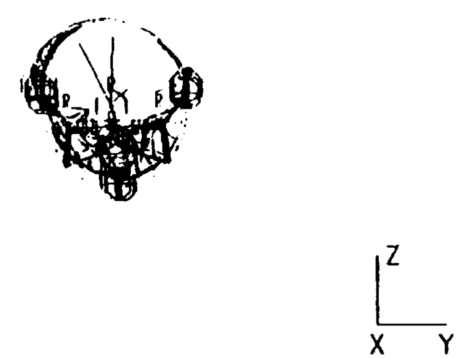
The deformed shape shown here occurs when the loads listed as Case 3 are applied to the structure. The deformation have been magnified by a factor of 25 to be able to see them. The actual maximum deflection, which occurs along the keel between the two removable pallets, is only 0.764 inches. The maximum stress within the structure is 12360 psi, which provides a factor of safety of 5.6.

# DEFORMED STRUCTURE - ABORT LANDING LOADS

- Ultimate Load Factors:
  - Nx = -1.7 g
  - Ny = +0.8 g
  - Nz = +3.0 g
- Max. Principal Stress = -12360 psi
- Max. Displacement = 0.764 in
- Note: Scale of Deformation = 25:1




LaRC SSFO



ORIGINAL PAGE IS
OF POOR QUALITY

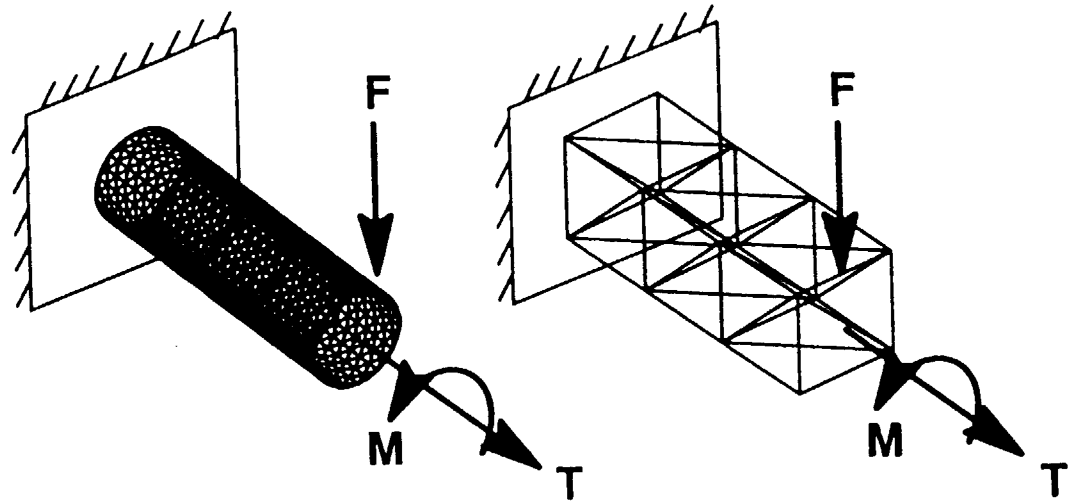
## Stiffness of Isogrid vs. SSF Box Truss

A stiffness comparison analysis was performed between the isogrid truss structure and three bays of 5–meter SSF box truss. The lengths were similar– the box truss was slightly longer. Both ends of each truss section were rigidized, and one end was fixed in place to cantilever the truss sections. Three different loads were then separately applied to the free end of each truss section: a tensile force (T), a bending force (F), and a torsional moment (M). The deflections at the ends of the two truss sections were then compared, with the deflections being normalized to the SSF box truss.

The isogrid truss was considerably stiffer in all respects to the SSF box truss. When stiffeners were added to the isogrid truss, overall stiffness was more than doubled when compared to isogrid alone.

The stiffness of the isogrid is, in some respects, less than that of the isogrid in the original study due to the fact that three removable container sections have been created in the model used for the study in this addendum.

# Stiffness of Isogrid vs. SSF Box Truss




| | Ratios of stiffness in: | | |
|---|---|---|---|
| | Tension (T) | Torsion (M) | Bending (F) |
| Isogrid only | 5.0 | 2.6 | 3.4 |
| Isogrid with stiffeners | 13.2 | 5.7 | 7.3 |
| SSF Box Truss | 1 | 1 | 1 |

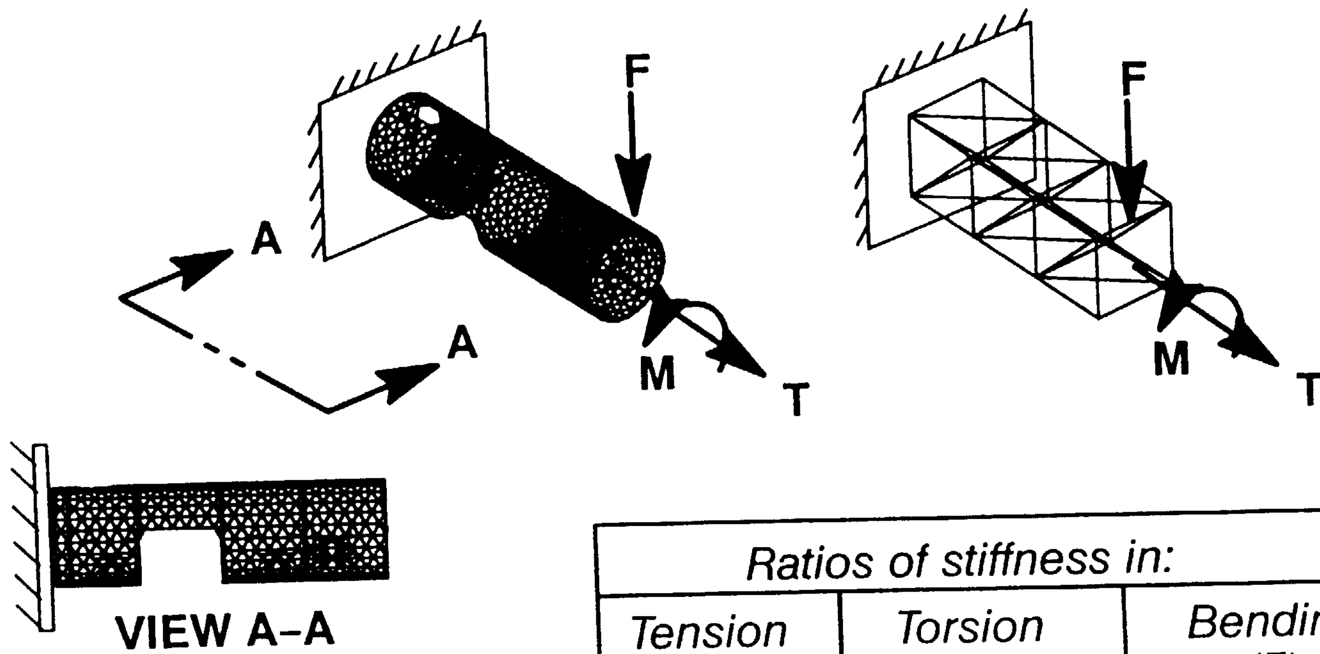
## Stiffness of Isogrid with Container Section Removed vs. SSF Box Truss

A stiffness comparison analysis was performed between the isogrid truss structure with a container section removed and three bays of 5-meter SSF box truss. The container section removed was seven feet long and slightly over half the cylinder's diameter high.

The end conditions and loadings used were identical to those used on the previous chart with the container section in place. The removal of the container section makes a big difference in the stiffness of the isogrid truss, but it still remains more stiff than the SSF box truss. The model used in the analysis was originally created without the removable container concept in mind, so the strongest stiffener is running along the bottom of the cylinder, which is the part that is removed. If stronger stiffeners are used in areas remaining when the container is removed, the stiffness of the structure should increase.

NASA — FREEDOM

# Stiffness of Isogrid with Container Section Removed vs. SSF Box Truss




| | Ratios of stiffness in: Tension (T) | Torsion (M) | Bending (F) |
|---|---|---|---|
| Isogrid with 7 ft. Container Section Removed | 5.6 | 1.3 | 5.3 |
| SSF Box Truss | 1 | 1 | 1 |

LaRC SSFO

nopalletstiff

## Structural Analysis Conclusions

From this analysis of the feasibility of using isogrid as the primary truss of the space station, it appears that isogrid with additional stiffening structure would provide a good framework for the space station. The isogrid is stronger, stiffer, and undergoes smaller deflections and stresses under given loads than the current baseline truss.

# Structural Analysis Conclusions

- Isogrid has a greater axial, torsional, and bending stiffness than the current baseline truss
- Additional stiffening structure (ie. longerons, ring stiffeners, etc.) is needed to carry launch and abort landing loads
- The load cases analyzed produce small deflections and principal stresses
- Based upon this preliminary analysis, the use of isogrid as truss appears to be a viable option

- This Page Intentionally Left Blank -

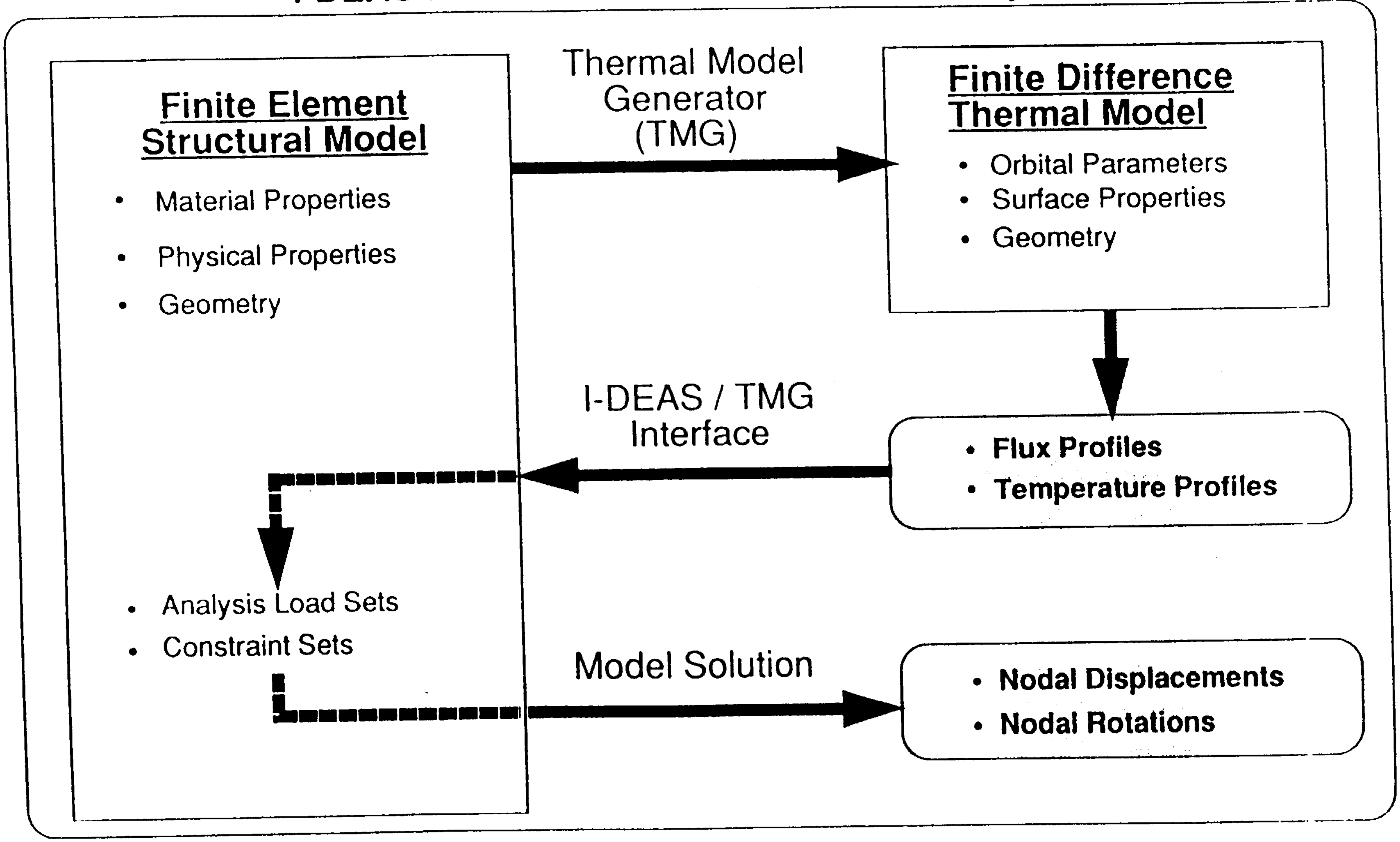
# Thermal Analysis

## Analysis Approach

The objective was to perform a thermal distortion analysis of the preintegrated truss structure. To do so, the **finite element structural model** (MB1-806), created using the I-DEAS (Interactive Design and Evaluation of Advanced Spacecraft) CAE analysis package, was first converted to a finite-difference thermal model using the **Thermal Model Generator** (TMG) analysis package. Analysis of the thermal model determined the temperature profiles for all of the thermal nodes, which in turn serve as input load sets for the linear-static distortion analysis. The results of the distortion analysis are nodal displacements and rotations. This diagram illustrates the described analysis approach.

# Thermal Distortion Analysis Approach

## I-DEAS Finite Element Modeller And Analyzer

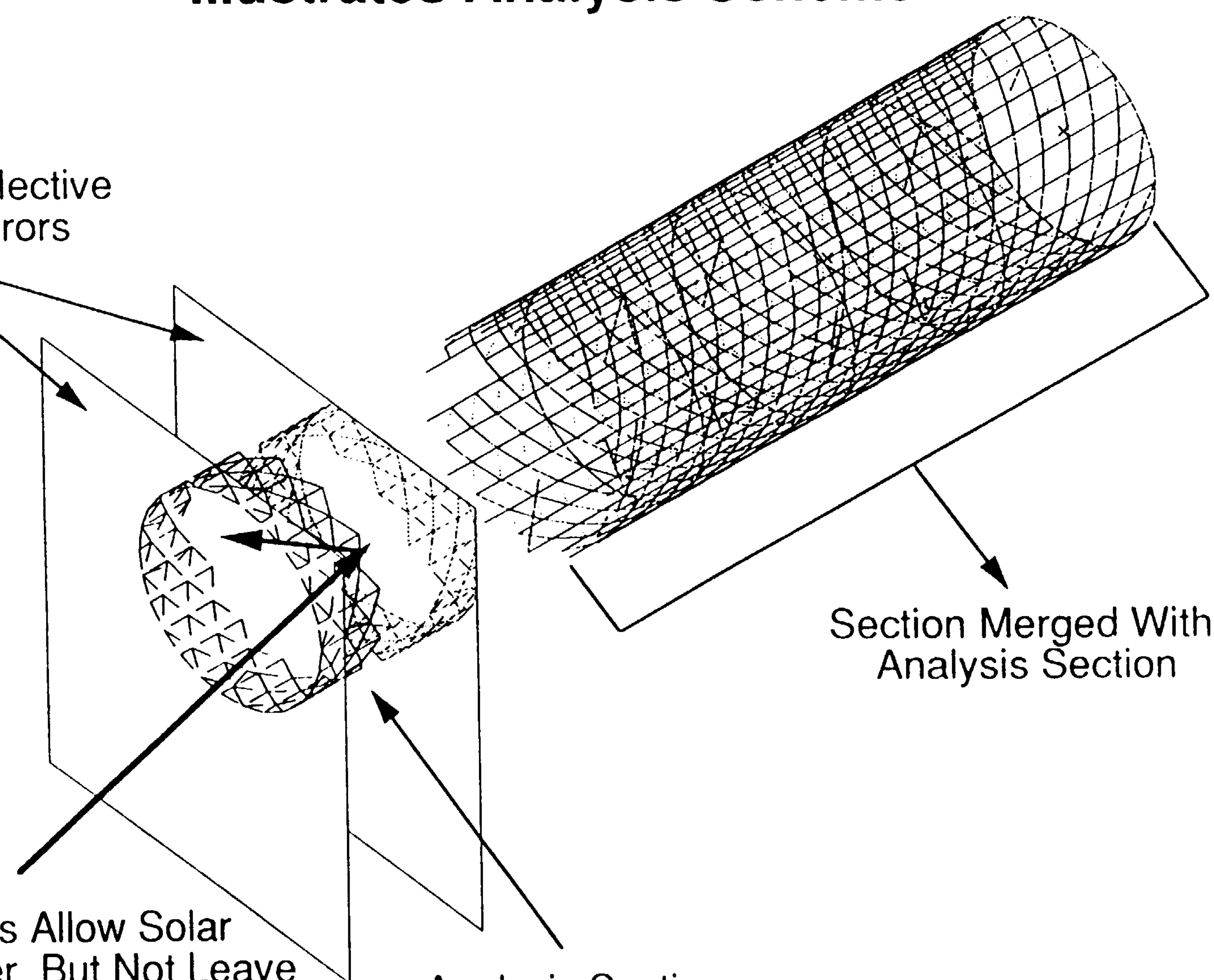


## Thermal Analysis Scheme

This exploded view illustrates an analysis scheme driven by the excessive computational times typically required by complex thermal models. This issue dictated an analysis scheme that both simplified the thermal model and exploited the occurrence of symmetry in the structure. The analysis approach chosen selects a small subsection of the complete thermal model and closes it between planar, inward reflecting surfaces. Once an incident flux is reflected at these surfaces, any reflected flux can: (1) impinge on other isogrid members, (2) escape through openings in the side of the structure, or (3) be reflected again by the opposing mirror. This achieves an approximation of an infinite length of the structure.

Performing a thermal analysis on the subsection determines the temperature profiles of all thermal nodes in the subsection. To exploit the symmetry of the truss structure, it is assumed that all identically oriented thermal nodes with identical material and physical properties will have essentially the same net heat flux and temperature profiles. All isogrid members outside of the analyzed subsection are assigned temperature profiles identical to their like-oriented counterpart in the analyzed subsection. The results of the analysis are considered to be worst case for the orbital orientations studied.

# Exploded View Of Thermal Model Illustrates Analysis Scheme



## Assumptions

Several characteristics representative of the isogrid truss structure and its orbital environment serve as assumptions for the analysis process.

# Thermal Analysis Assumptions

- Only the thermal mass in the isogrid members and longerons modelled
- $\alpha_{solar} / \varepsilon_{thermal}$ = 0.3/0.2 with no degredation (LDEF analogy)
- Orbit inclination = 28.5°
- Orbit altitude = 380 km (205-n miles)
- Orbit beta angle = 0°
- Earth declination = 0° (Equinox)
- Earth albedo = 0.35
- No subsystems mounted internal to isogrid section
- Structural members modelled as hexagonal tubes
- At time t=0, model is fully deployed and isothermal at 0 °C

# Orbital Configurations

Two orbital configurations were studied. The **Gravity Gradient** configuration is applicable during the early assembly stages, while the **Assembly Complete** orientation represents the LVLH attitude of the structure during later assembly stages through **Assembly Complete.** The analysis results are characterized in three parts:

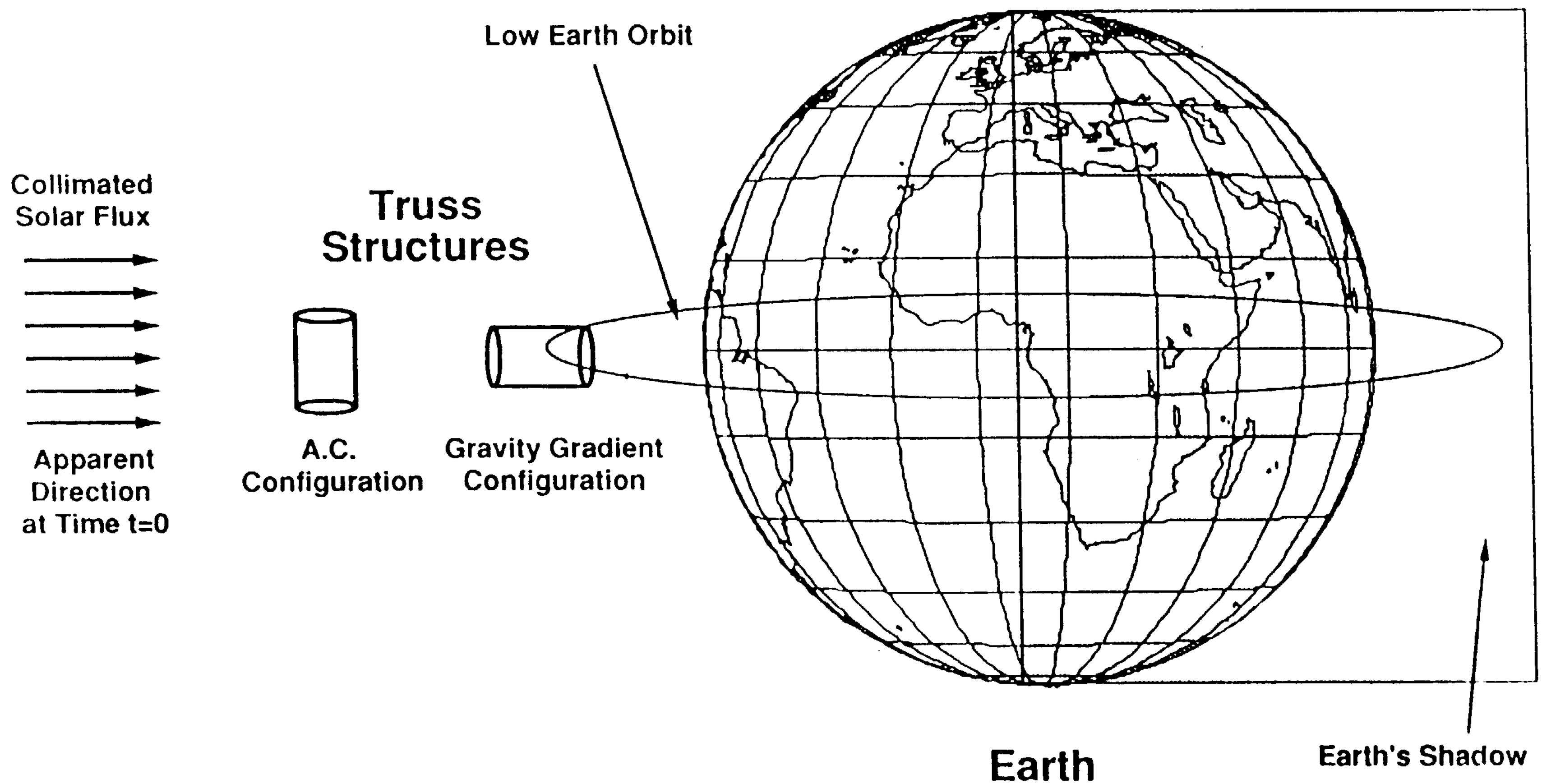
(1) Net flux on representative elements,

(2) Temperature profiles for selected representative elements,

(3) Maximum thermal distortions for an end ring of the isogrid structure.

These results are presented for both orbital configurations.

# Relative Orientation Of Pre-integrated Truss Structure In Two Orbital Configurations




Note: The orientation of the configurations are shown for illustration, and are not shown to scale. Both orientations were analyzed with identical orbit parameters.

## Incident Flux Profiles (GG)

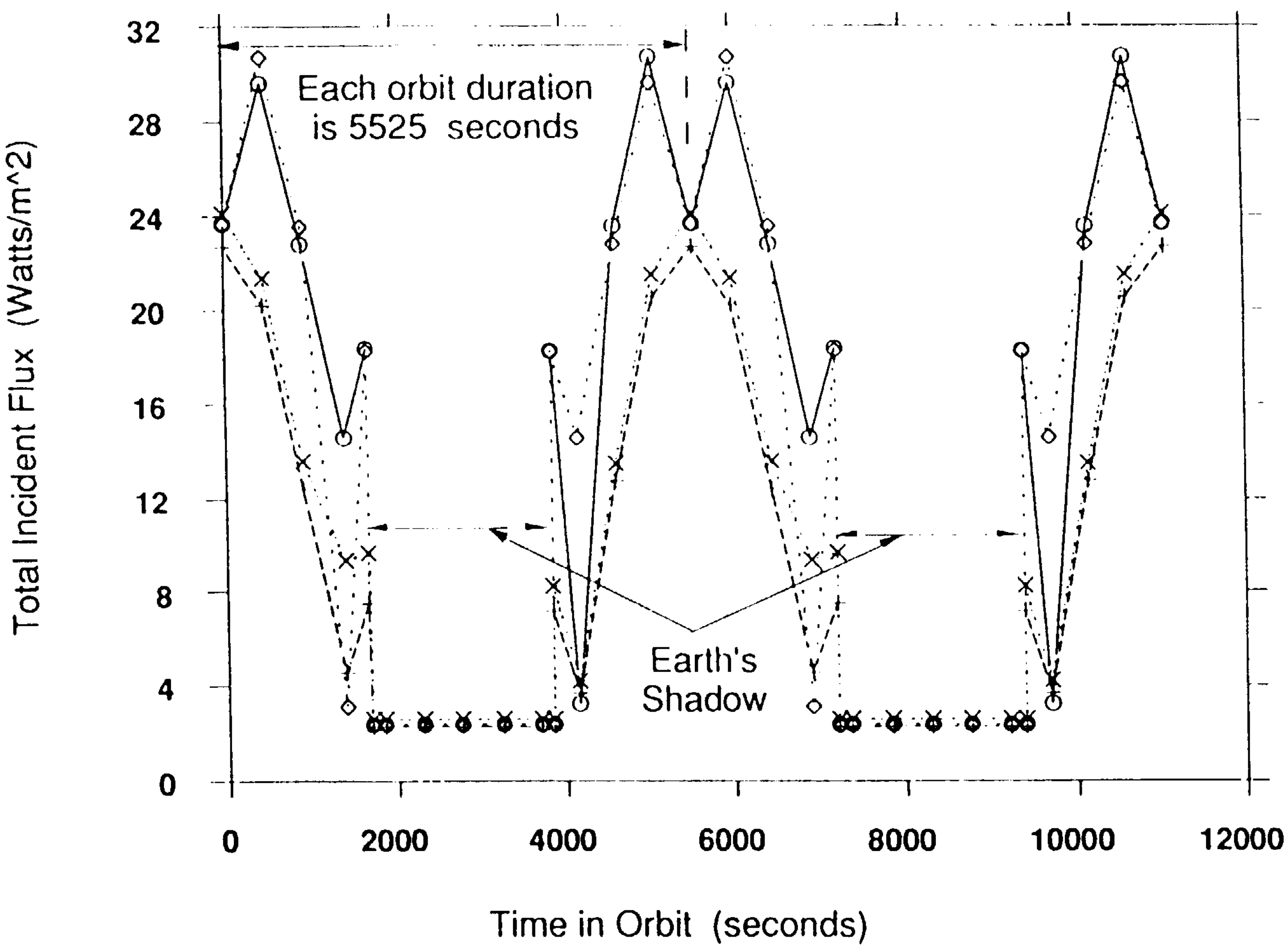
The similar plots illustrated in this and the next chart depict the total incident flux on representative elements as a function of time in orbit. The representative elements were chosen based on their relative orientations, and are spaced approximately 90 degrees apart around the isogrid tube. This chart relates to the **Gravity Gradient** configuration and the next to the **Assembly Complete** configuration.

(1) Both configurations have constant low flux periods lasting approximately 2000 (2K) seconds. This correlates to the period of time these low earth orbit (LEO) configurations spend traversing Earth's shadow during each orbital period.

(2) The flux profiles exhibit sharp changes in magnitudes that correlate with points on the orbit where sunward isogrid members cast brief episodes of shadowing on others behind them as orbit-relative solar angles change.

(3) Flux profiles are symmetrical and repetitive.

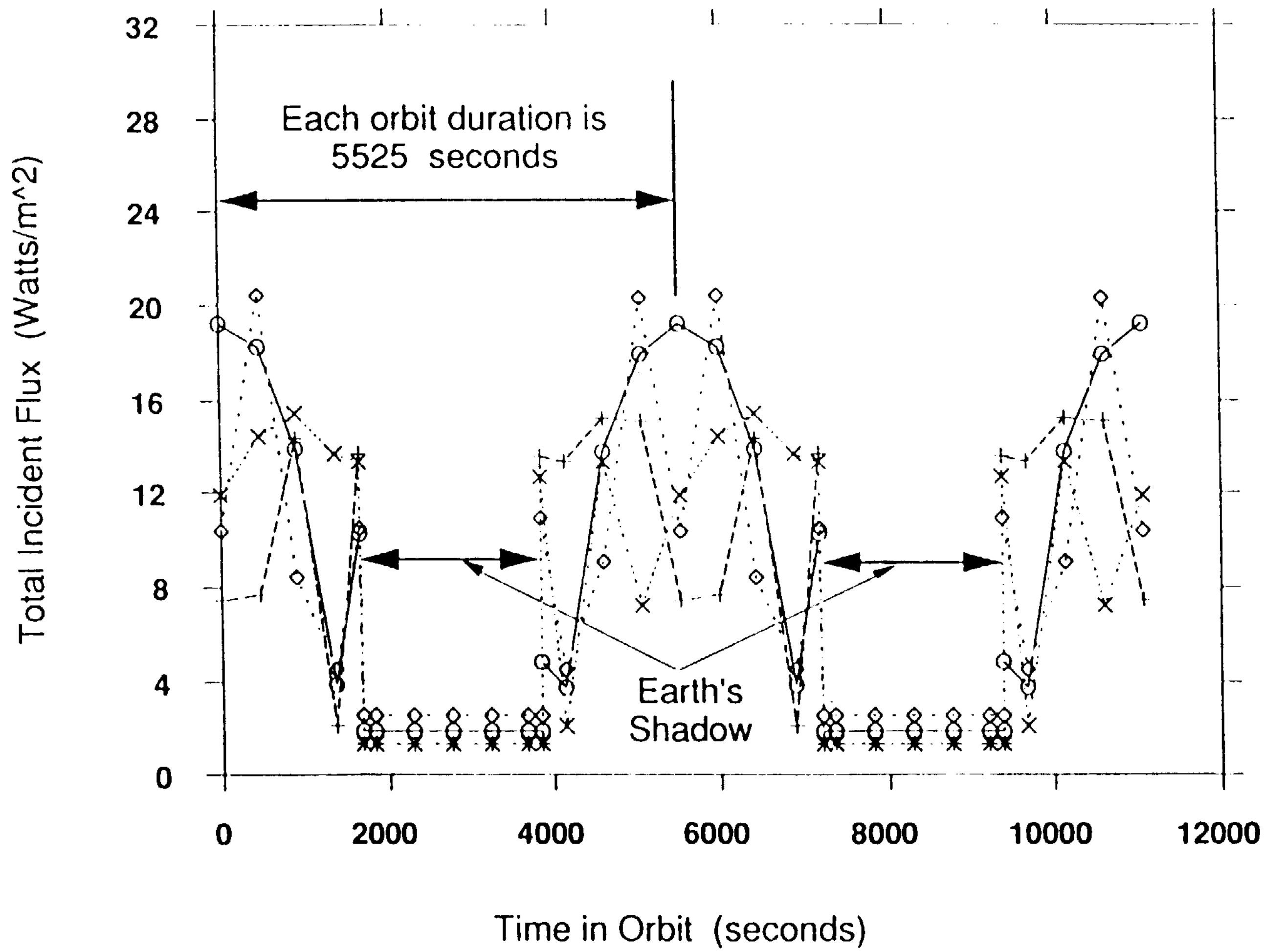
# Incident Flux Profile
# Gravity Gradient Configuration



## Incident Flux Profiles (AC)

In comparing the two configurations as they are represented in these two charts, it can be seen that incident flux for the **Gravity Gradient** configuration is higher than for the **Assembly Complete** configuration. Orbital flux profiles determine temperature profiles for the analysis section.

# Incident Flux Profile
# Assembly Complete Configuration

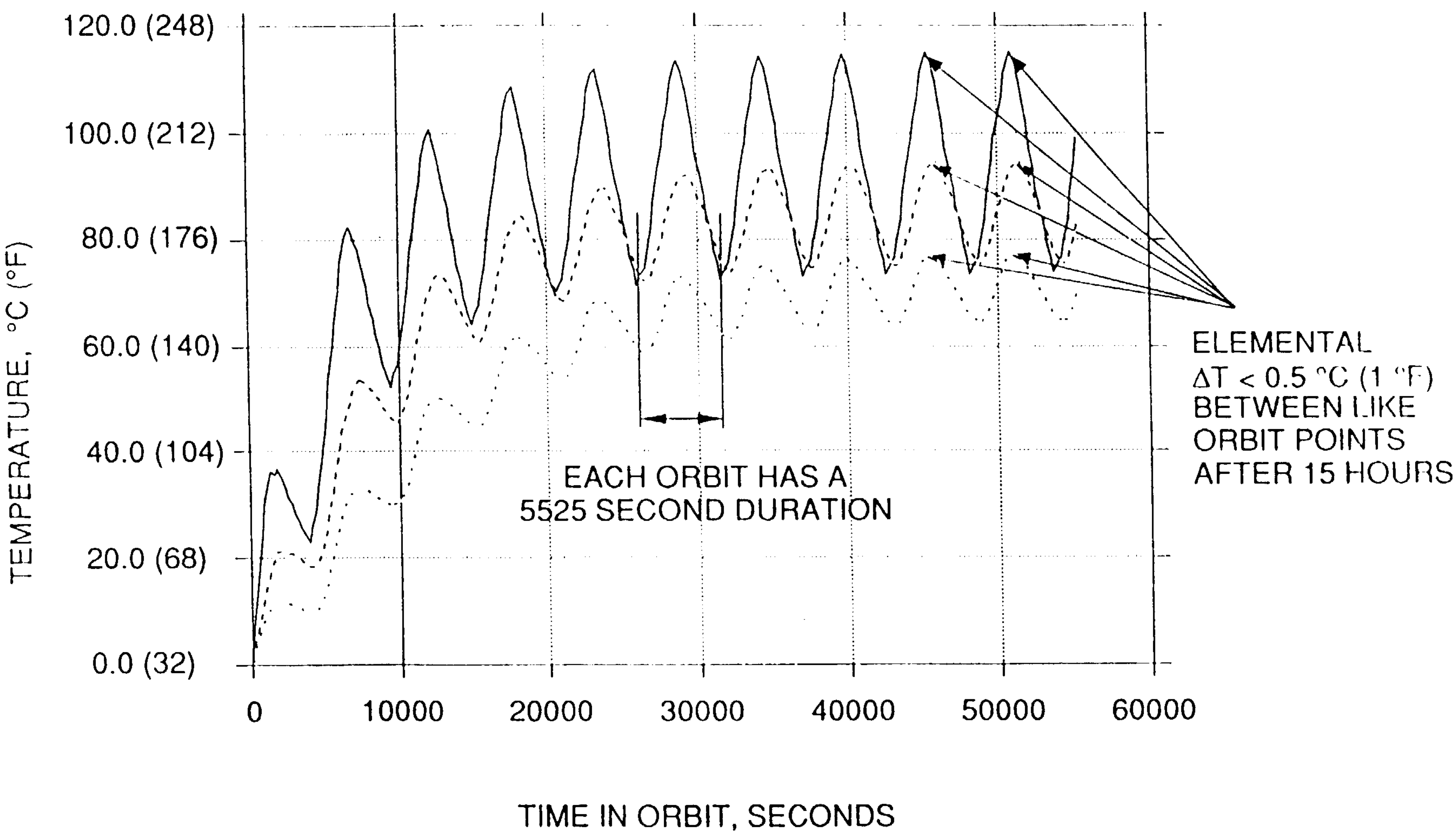


## Temperature Profiles (GG)

In this and the next chart, temperature profiles are depicted for three thermal nodes, representing the maximum, intermediate and minimum temperatures of the structure for each of the analyzed configurations. The first presents the profile as given for the **Gravity Gradient** configuration and the second represents the same for the **Assembly Complete** configuration.

Both configurations achieve a steady-state orbital temperature profile in approximately ten (10) orbits, as illustrated by the recurring maxima and minima on the curves. The time required to reach a steady-state profile is within the time frame anticipated for proposed deployment scenarios.

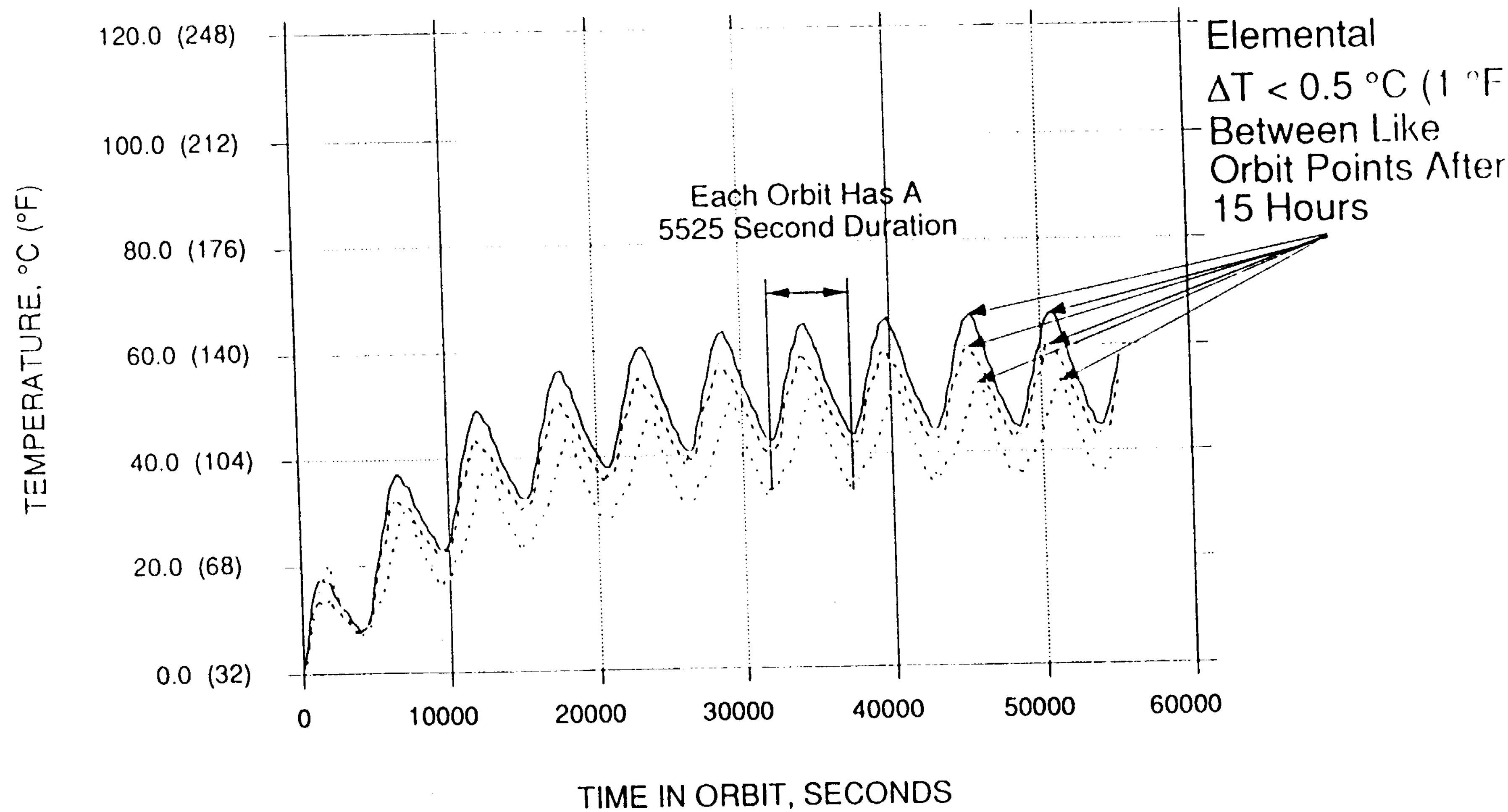
# Temperature Profile
# Gravity Gradient Configuration



## Temperature Profiles (AC)

Note that temperatures for the **Gravity Gradient** configuration are considerably higher than those for the **Assembly Complete** configuration. This corresponds with the higher fluxes noted previously for the **Gravity Gradient** configuration. Temperatures serve as load sets for the linear-static distortion analysis.

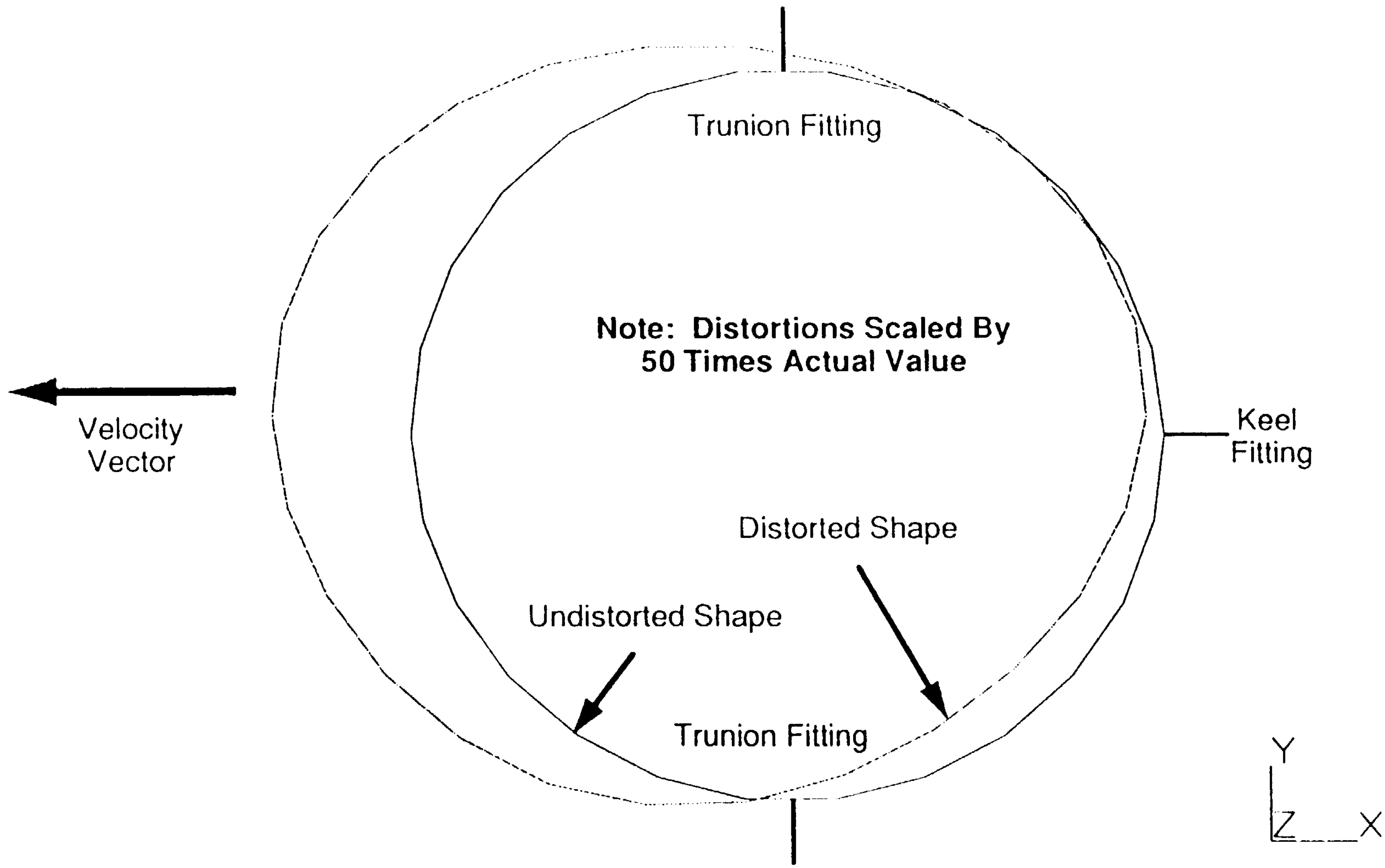
# Temperature Profile
## Assembly Complete Configuration



## Nodal Distortions (GG)

The worst case end ring nodal distortions for both configurations were in the X direction. The curves shown in this and the following chart reveal that the end-ring distortion is in the X-Y plane, which best illustrates the X-direction distortions. As illustrated in this first chart depicting the **Gravity Gradient** configuration, the worst case distortion was found in the X direction where the differential displacement between opposing nodes was 1.0 cm.

# Typical Distorted Isogrid End Ring Gravity Gradient Configuration

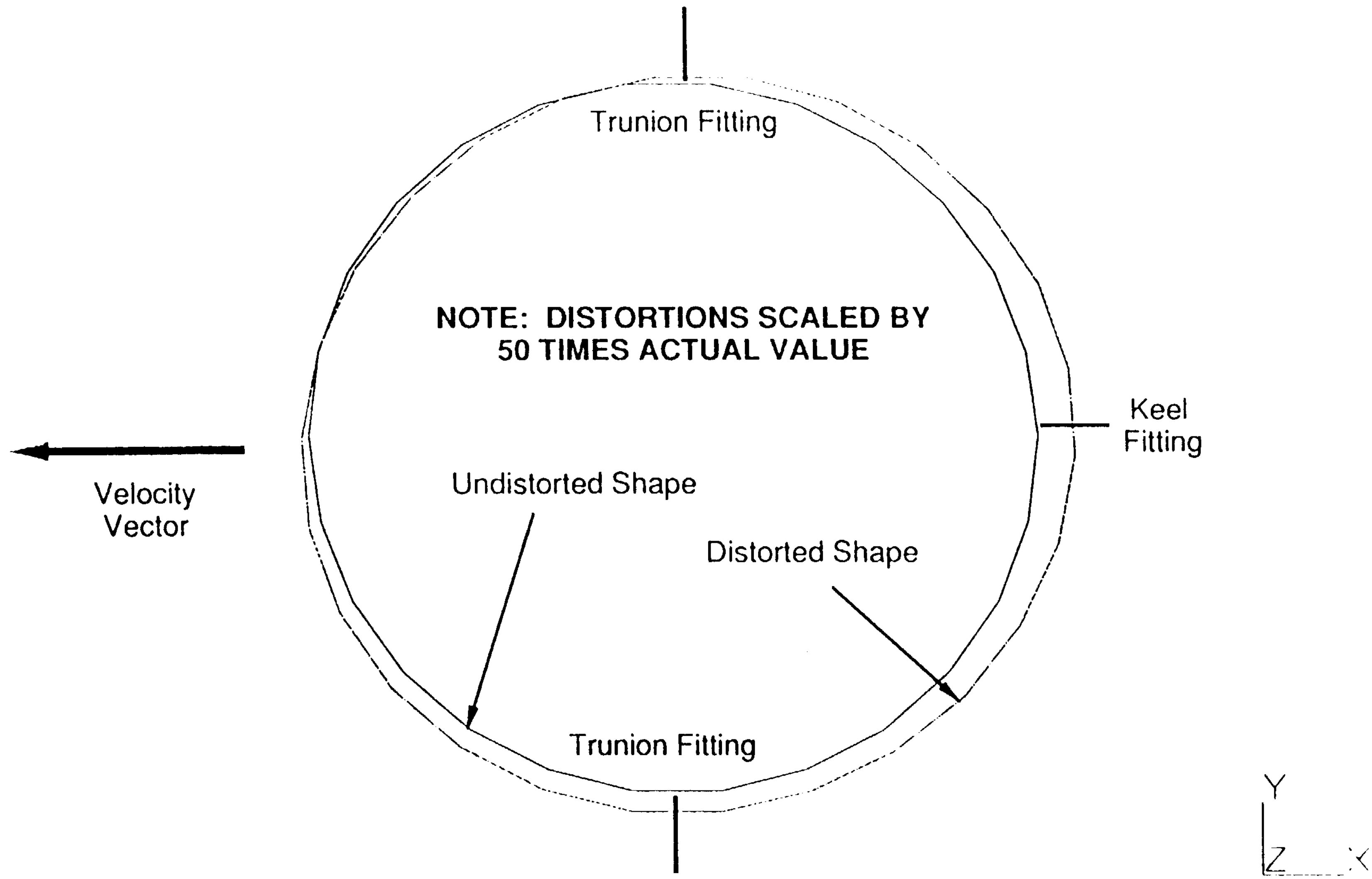



Maximum Nodal Distortion Is ~ 1.0 cm In X-direction

## Nodal Distortions (AC)

In the **Assembly Complete** configuration depicted in this chart, the greatest distortion was in the X direction just as it was for the **Gravity Gradient** configuration, but was only 0.5 cm.

# Typical Distorted Isogrid End Ring Assembly Complete Configuration




Maximum Nodal Distortion Is ~ 0.5 cm In X-direction

## Conclusions

This preliminary thermal analysis indicates that the isogrid truss has a maximum thermal distortion in the end ring of approximately 1.0 cm. This distortion is not considered excessive and should allow soft-docking to occur in a very few orbits after rendezvous. To obtain the thermal profile, it was conservatively assumed that the model would initially be isothermal at O°C (32°F) and that the starting time would correlate to an isogrid structure deployed from the orbiter payload bay. This results in a time of approximately 15 hours to reach the steady-state temperature profile, which should allow hard-docking to be performed during the second day on orbit. It is anticipated that once the soft-docked condition has been achieved, thermal coupling between the mating surfaces of the two sections will accelerate the change toward steady-state conditions.

The calculated maximum temperatures of 112°C (234°F) and maximum temperature gradient of 38°C (67°F) are higher than desired. However, as further analysis can verify, the temperatures can be substantially reduced by optimizing the material surface properties, such as decreasing the $\alpha/\varepsilon$ ratio. In addition, any further analysis should be more detailed so as to include the thermal mass and shadowing effects of the internally mounted subsystems.

# Thermal Analysis Conclusions

- The calculated maximum thermal distortion in the isogrid structure end ring is not anticipated to preclude soft-docking under possible deployment time frames.

- The time to reach steady-state orbital temperature profile is compatible with hard-docking during second day on orbit.

- The calculated maximum temperatures and maximum gradients of the structure can be substantially decreased by optimizing the radiative properties (i.e., decreased $\alpha/\varepsilon$).

- Any further analysis should include the thermal mass and added shadowing of internal systems.

– This Page Intentionally Left Blank –

NASA FREEDOM

# Integrated Assembly

LaRC SSFO

# Manifesting Assumptions

Manifesting was performed to see how many flights it would take to build the integrated space station and to assess its functionality at each stage of the build up. PDRD target weights were assumed for all manifesting factors in order to maintain a direct comparison with the baseline assembly sequence. On flights involving the integrated truss portions of the transverse boom (designated as "truss" flights), a fifteen percent managers reserve was added as compared to the baseline sequence's five percent to account for uncertainties associated with the new packaging philosophy. Universal pallet and debris protection weights were not deleted from cargo element weights thus providing some additional margin for design growth since the hybrid isogrid structure will act as secondary support structure (universal pallet) and debris protection. An additional weight reserve of twenty percent was placed on the basic integrated structure to account for design uncertainties. The weight conservatism was implemented knowing that actual weight estimates for assembly cargo elements are significantly higher than PDRD target weights. This built in conservatism should make the integrated assembly sequence less sensitive to weight growth as compared to the baseline assembly sequence

# Manifesting Assumptions

- Cargo element weights ground ruled as PDRD target weights.
- All comparisons and assumptions based on December 1989 baseline assembly sequence.
- Manager's reserve was increased to 15% to account for packaging and hardware modification uncertainties on truss structure flights.
- Universal pallet and debris protection weights were not deleted from cargo element weights resulting in additional potential weight reserve.
- An additional weight reserve of 20% was placed on the basic integrated structure to account for design uncertainties.

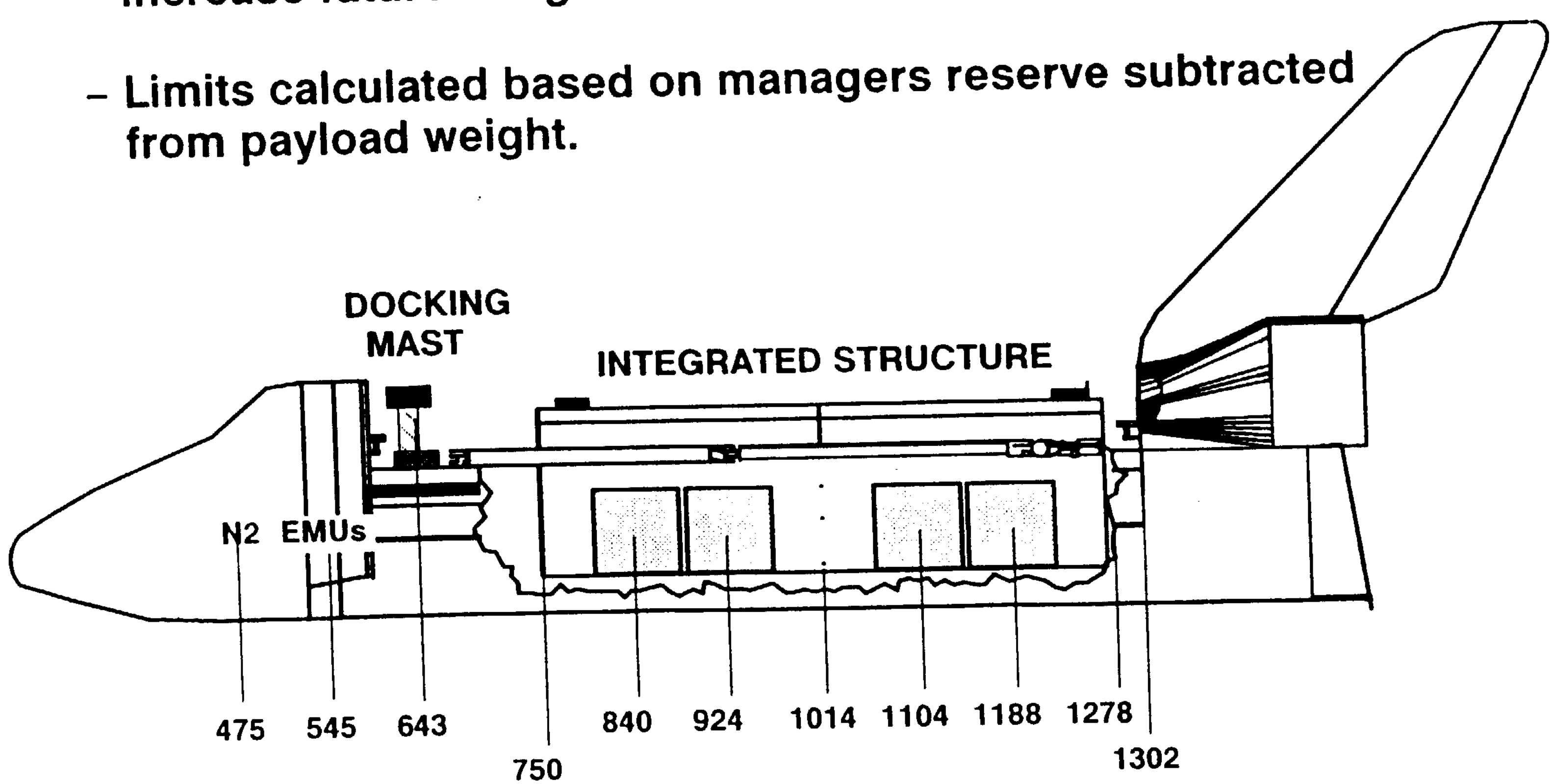
**Although PDRD target weights were used in the manifest, there should be sufficient weight margin available to accommodate current weight estimates.**

## Locations and Assumptions for C.G. Calculations

Center of Gravity (C.G.) calculations were done in accordance with shuttle specifications that were the same as used for the baseline assembly sequence. The 44' structural section was assumed to be located with its end at the 1278 inch position in the orbiter payload bay. This allows two feet of clearance from the end of the structure to the aft bulkhead. The aft bulkhead camera was assumed not to be a problem since the structural section was only 13.3' in diameter. Since the SPDS was not used in the baseline assembly sequence its use was not assumed for the integrated assembly sequence although it could provide an additional 12 inches of C.G. margin. All C.G. calculations were based on actual payload weight and did not add in managers reserve.

# Locations and Assumptions for C.G. Calculations

- C.G. limits based on Kohrs memo, NSTS-JSC TD-88-035.
- Use of SPDS not factored into calculations, reserved to increase future margins.
- Limits calculated based on managers reserve subtracted from payload weight.



## Integrated Assembly Sequence Features

The primary feature of the integrated assembly sequence relates to the great reduction in EVA and on orbit integration required to assemble the station. The ability to reduce theses factors also eliminates the need for some support equipment such as the Assembly Work Platform (AWP). A direct benefit is realized on the first assembly flight since payload space and weight that is normally required for the support equipment is made available for station system elements. As a result, everything required for an active spacecraft can be brought up on the first assembly flight.

The assembly sequence assumes that 44' structural elements are used for constructing the transverse boom. Only appendages such as RCS thrusters, the Mobile Transporter (MT), the Mobile Servicing Center (MSC), PV arrays, radiators and antennas are attached external to the structural sections. The RCS fuel tanks were assumed to be in removable container sections. A module pattern consisting of six identical "common" modules was assumed in this sequence as a place holder for the station's pressurized volume with the primary focus being to complete the transverse boom from alpha joint to alpha joint before any modules were brought up. This focus could be adjusted depending on the priorities involved with early utilization of station.

# Integrated Assembly Sequence Features

- "Active" first assembly flight.
- Maximizes interior packaging by using system containers.
  - Only RCS thrusters, MT/MSC, PV arrays, radiators and antennas external.
  - Fuel tanks are in removable containers.
- Uses 44 foot length hybrid Isogrid structural section.

# EVA Tasks for the Integrated Assembly Sequence

Although most of the station systems and elements are pre-integrated on the ground in the 44' structural section, there are still some components such as antennas and radiators that must either deploy from or be attached to the structure. Deployable mechanisms or robotic assembly can be used to erect these appendages but for the purpose of this study EVA with RMS assistance was assumed for connection and check out of external appendages. EVA with RMS assistance was also assumed to be required for all structural and utility connections between each 44' structural element.

# EVA Tasks for the Integrated Assembly Sequence

- EVA is assumed for all structural and utility connections between two 44 foot integrated elements.

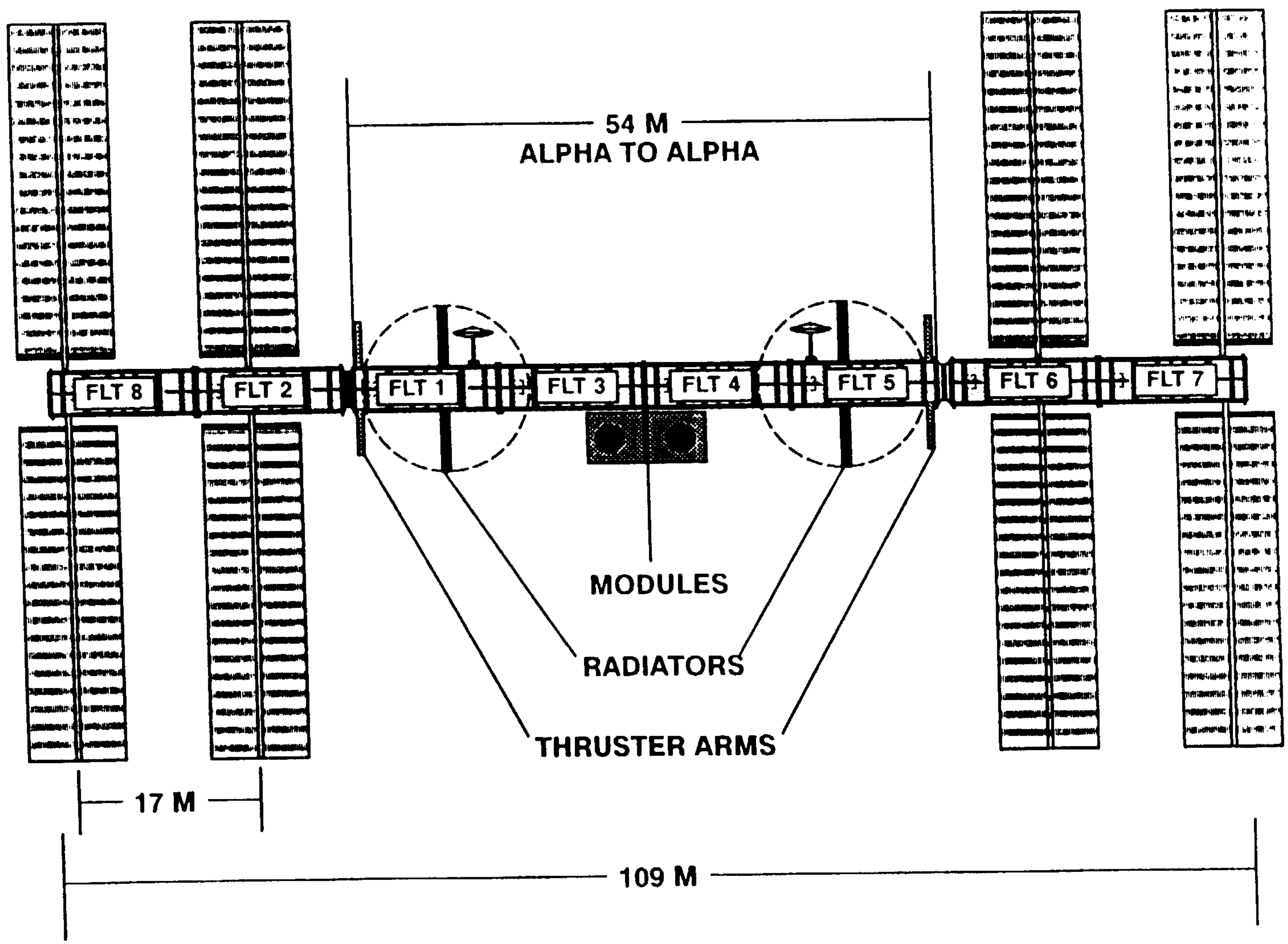
- Additional EVA is assumed for connection and check out of external attached components such as antennas and solar arrays.

## Integrated Configuration

The integrated configuration is assembled using eight NSTS launches for the transverse boom with the remaining assembly flights used for the pressurized modules. Four pre-integrated sections make up the portion of the transverse boom between the alpha joints (54 meters) and one pre-integrated section is used for each of the four PV power units. Proper separation (17 meters) is maintained between the solar arrays to prevent shadowing.

NASA — FREEDOM

# Integrated Configuration




LaRC SSFO

OPTIONA2CONFIG

## Integrated Assembly Sequence Summary

Eighteen NSTS flights are needed to assemble the integrated Space Station equivalent of Freedom. The first six flights bring up all but two sections of the transverse boom. These flights are designated as "TR#." The U.S. modules are then brought up (module flights are designated by "MD#") along with a combination flight, MT1, that brings up the airlock, the mobile transporter and the MSC. The last two PV power units are then delivered followed by the international modules.

# Integrated Assembly Sequence Summary

| | FLT | | |
|---|---|---|---|
| FEL | 1 | TR1 – | Stbd TCS Equipment, two RCS tank containers, RCS thruster arms, antenna assembly, GN&C subcontainer, EPS subcontainer, temporary power unit, utilities and structure. |
| | 2 | TR2 – | IEA, solar arrays, beta gimbals, radiator, alpha joint, utilities and structure. |
| | 3 | TR3 – | CMGs (6), Stbd TCS panels and condensers, upper APAE, PMAD container, FMAD container, module interface, utilities and structure. |
| | 4 | TR4 – | Module support truss, N2O2 repressure tanks, port TCS panels and condenser, FTS with shelter, MMD with SPDM, upper APAE, module interface, utilities and structure. |
| | 5 | TR5 – | Port TCS equipment, two RCS tank containers, RCS thruster arms, antenna assembly, DMS/antenna subcontainer, EPS subcontainer, lower APAE, utilities and structure. |
| | 6 | TR6 – | IEA, solar arrays, beta gimbals, radiator, alpha joint, utilities and structure. |
| MTC | 7 | MD1 – | U.S. Lab Module (17 racks), Pressurized Docking Module |
| | 8 | MT1 – | Airlock, Mobile Transporter, MSC phase 1, Cupola |
| | 9 | MD2 – | U.S. CHCS Module (18 racks) |
| | 10 | MD3 – | U.S. Lab Module (17 racks), Pressurized Docking Module |
| | 11 | MD4 – | U.S. Galley Module (18 racks) |
| | 12 | MD5 – | U.S. Hab Module (18 racks) |
| | 13 | MD6 – | U.S. Hab Module ( 15 racks), Cupola |
| PMC | | L1 – | Logistics Module |
| | 14 | TR7 – | IEA, solar arrays, beta gimbals, radiator, utilities and structure. |
| | 15 | TR8 – | IEA, solar arrays, beta gimbals, radiator, utilities and structure. |
| | 16 | MD7 – | JEM Module |
| | 17 | MD8 – | Columbus Module |
| AC | 18 | MD9 – | JEM ELM PS, JEM ELM ES, Exposed Facility #1 & #2 |

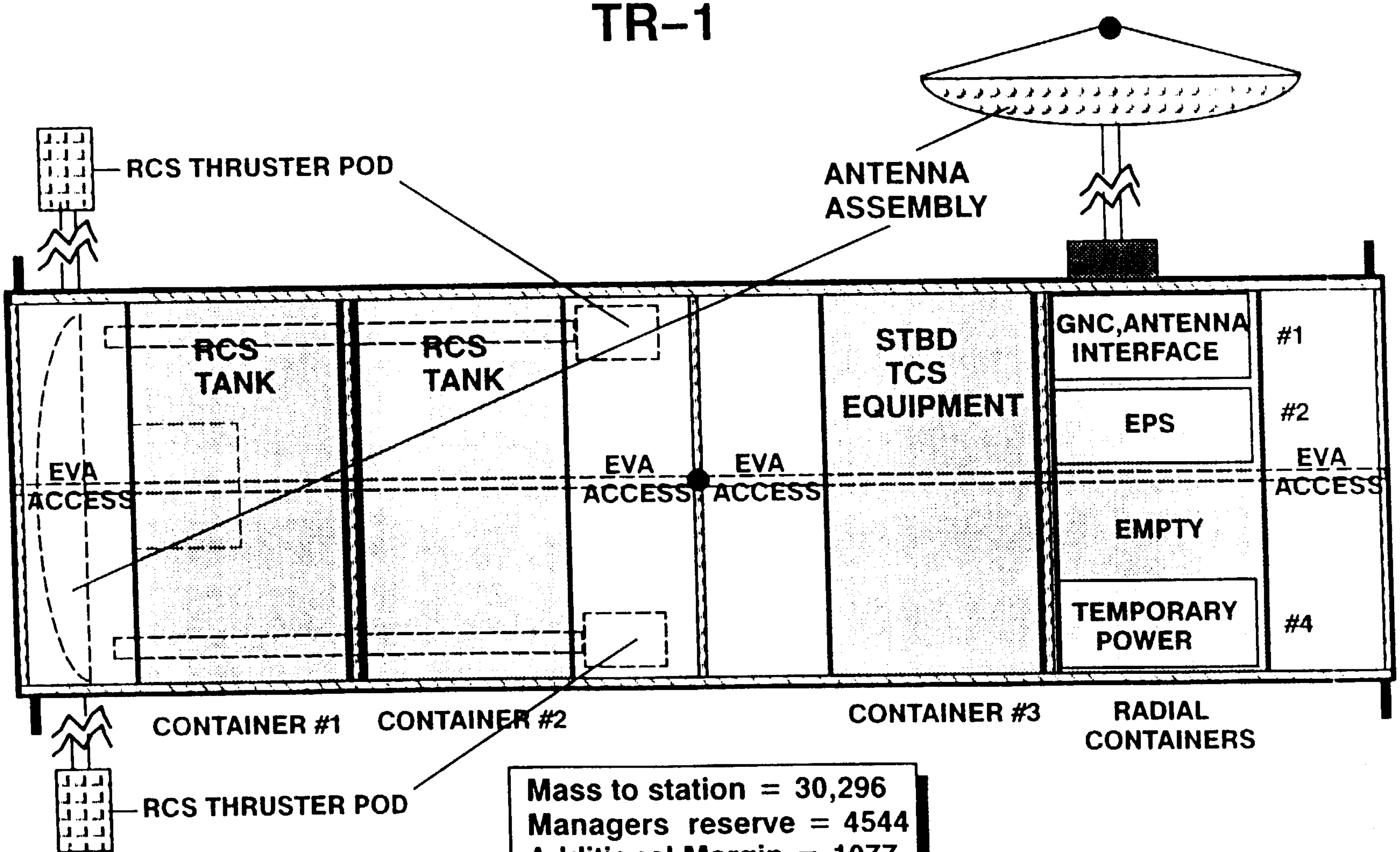
## TR1 Packaging

The first assembly flight brings up the elements that are located just inside the starboard alpha joint. All elements required to enable a minimally active/reboostable spacecraft are included on this flight. Hydrazine fuel tanks loaded with a total of 9000 pounds of fuel are located at one end of the integrated structure in removable container sections. The starboard TCS equipment (including the starboard radiator beta joint) is located in container section three. Radial containers at the other end of the structure contain systems for communications, GN&C, power conditioning and power storage. Packaged internally are two thruster pods with extension arms and the antenna assembly. The exterior of the integrated structure is covered with a sufficient amount of solar cells to power the spacecraft once the structure is deployed. This configuration differs in some ways from the detailed structural analysis discussed earlier, but total weight and functionality are essentially the same.

NASA — FREEDOM

# Pre-Integrated Structure Packaging

## TR-1




Mass to station = 30,296
Managers reserve = 4544
Additional Margin = 1077

LaRC SSFO

MB1PACK

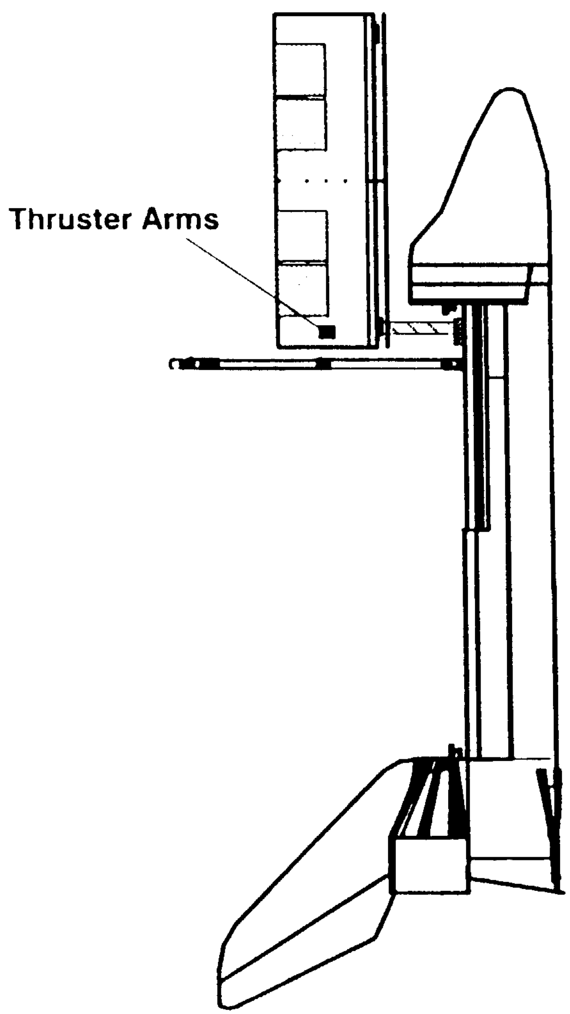


ORIGINAL PAGE IS OF POOR QUALITY

## Truss Flight One Operations

The general sequence is shown for the assembly operations. No detailed study of EVA vs robotics has been attempted.

# Truss Flight One Operations




STEPS 1 AND 2

1) Remove TR1 structure from bay with RMS and berth to docking mast.

2) Remove thruster arms from structure with the RMS and attach to near end.

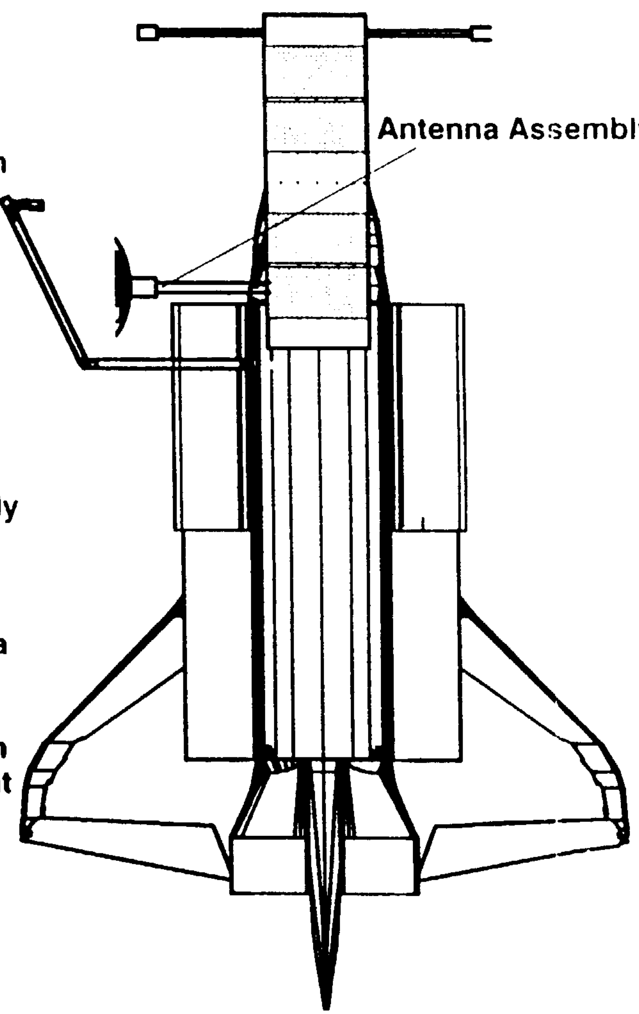
3) Rotate TR1 and berth at opposite end.

4) Remove antenna assembly from structure with the RMS and attach to near end.

5) Deploy booms on antenna support structure.

6) Remove transmitters from tray 3 in structure and mount on antenna assembly.

7) Check out systems and separate.



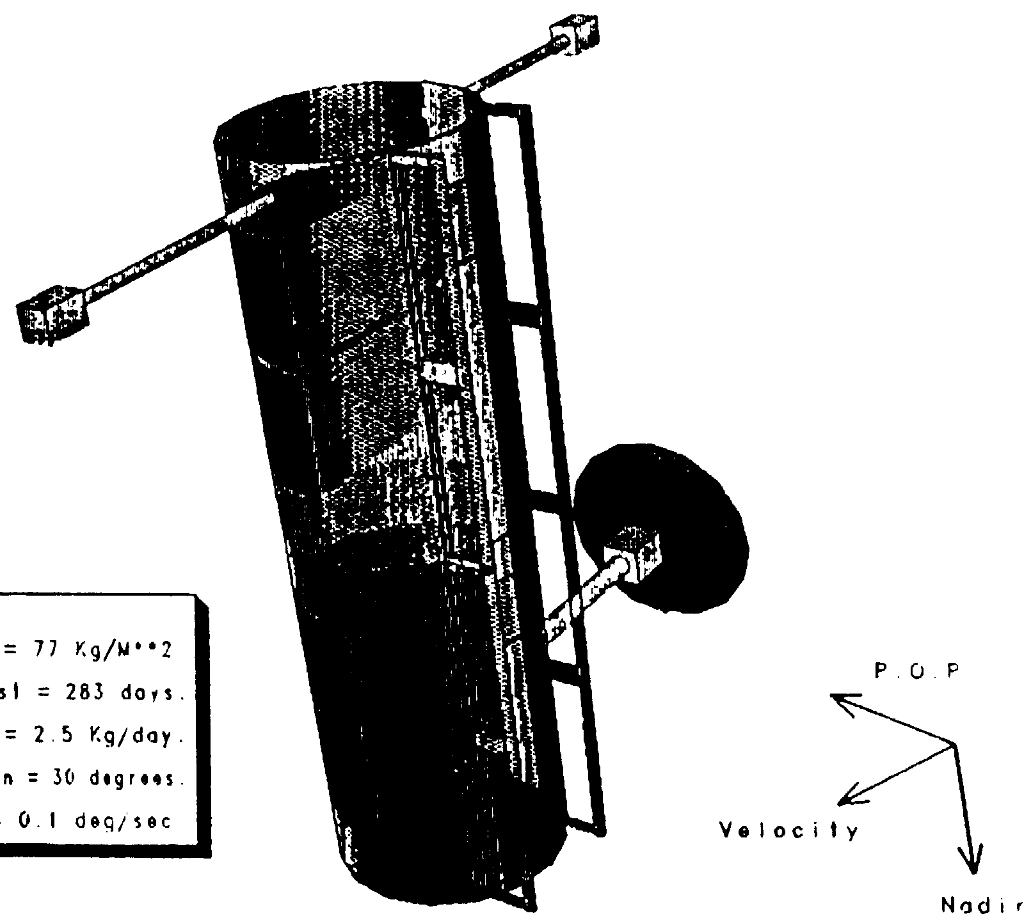

STEPS 3 TO 7

TRIOPSPHIL

## Active First Element Launch

A flight characteristics analysis was performed on the first element launch configuration. The station has all the necessary functionality at this point to be an active spacecraft. The flight mode is gravity gradient stable with antennas and thruster arms aligned along the velocity vector and the longitudinal axis of the structure aligned along nadir. Stability simulations showed this configuration to oscillate at most + 45 degrees per axis with no RCS attitude control. Using RCS thrusters to hold the configuration to within a maximum deviation of 30 degrees required 2.5 kilograms of fuel a day at 190 nmi assuming a design atmosphere of Ap=400 and a flux of 230. The average ballistic coefficient was 77 kg/m**2 which would give the station an orbit lifetime of 282 days if the reboost thrusters were to fail. There is sufficient reboost fuel on board to maintain altitude for many years should the orbiter be grounded for some reason.

# Active First Element Launch




Mass = 13,930 Kg
Ballistic coefficient = 77 Kg/M**2
Lifetime with no reboost = 283 days.
Attitude control fuel = 2.5 Kg/day.
Maximum attitude deviation = 30 degrees.
Maximum angular rate = 0.1 deg/sec

*LaRC SSFO 8/15/90*

## TR1 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the first assembly flight are listed. The overall C.G. location for the combined payload is 13.6 inches within allowable limits. There is 1077 pounds of unused STS lift capability and 4544 pounds of managers reserve available. The numbers used in this list are based on PDRD target weights and secondary structural weight estimates.

Later in the study, a more detailed analysis was done on this flight with actual system weights and structural weights derived from finite element analysis. The resulting detailed mass breakdown and center of gravity calculations are presented in the following four charts.

# Integrated Assembly Sequence Manifest

FLIGHT 1
TR-1
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| STBD TCS EQUIPMENT | 3018 | | | CON#3 | 924 |
| RCS PODS (2) WITH ARMS | 2000 | 200 | | TUBE | 1104 |
| RCS TANK (WITH 4500# OF FUEL) | 6500 | | | CON#1 | 1188 |
| RCS TANK (WITH 4500# OF FUEL) | 6500 | | | CON#2 | 1104 |
| ANTENNA ASSEMBLY | 608 | 60 | | TUBE | 1254 |
| GN&C,DMS/ANTENNA INTERFACE | 399 | 100 | | RC#1 | 840 |
| EPS SYSTEMS | 811 | 100 | | RC#2 | 840 |
| SOLAR CELLS/BATTERIES | 1000 | 100 | | RC#4 | 840 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 1200 | | | | 1014 |
| | 30296 | 560 | 1100 | | |
| HARDWARE | 30296 | | | | |
| 15% RESERVE | 4544 | | | | |
| FSE | 560 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| STRUCTURAL DOCKING MAST | 1550 | | | | |
| EVA RESERVE | 2873 | | | | |
| SUBTOTAL | 40923 | | | CG LOCATION | 1023.1 |
| MARGIN | 1077 | | | CG MARGIN | 13.6 |
| STS CAPABILITY TO 190 NMI | 42000 | | | ALLOWABLE CG LIMIT | 1009.5 |

## Mass Breakdown Flight TR1

The mass data used for subsystems is from the Distributed Systems Deliverable listing date 05/04/90. and is the center requested PDRD weight rather than the target weight. In cases where a breakdown to smaller ORUs has been made, data from the subsystem PDR package was used. The summary mass breakdown shows a total mass to orbit of 38460 lbs. Assuming 42000 lbs load capacity for a 190 nmi orbit, this results in a margin of 3540 lbs.

Detailed mass breakdown is shown following the chart entitled "Center of Gravity Flight TR1".

# Mass Breakdown Flight TRI

| COMPONENT OF MASS | MASS | FSE | CG |
|---|---|---|---|
| ISOGRID TUBE STRUCTURE | 4928 | | 1015.8 |
| PROPULSION SYSTEM | 15380 | 200 | 1146.4 |
| THERMAL CONTROL SYSTEM | 3315 | | 920.8 |
| COMM. AND TRACKING SYSTEM (incl. DMS, and EPS elements) | 2144 | 160 | 848.7 |
| GUIDANCE NAVIGATION AND CONTROL | 241 | | 1003.0 |
| TEMPORARY POWER SYSTEM | 1120 | | 849.0 |
| UTILITIES | 1200 | | 1014.0 |
| TOTALS | 28328 | 360 | 1055.6 |

| FLIGHT 1 MASS TOTALS | |
|---|---|
| Hardware | 28328 |
| 15% Reserve | 4249 |
| FSE | 360 |
| Attach Fittings | 1100 |
| Structural Docking Mast | 1550 |
| EVA Reserve | 2873 |
| FLIGHT TOTAL | 38460 |
| MARGIN | 3540 |
| STS Capability to 190 NMI | 42000 |

## Center of Gravity Flight TR1

The center of gravity summary shows a margin of 13.5 inches from the STS forward limit of 1005 inches. This corresponds to the total mass of 32338 used for the center of gravity calculation. It should be noted that the 15% reserve and part of the EVA reserve are not included in the total mass for calculation of the center of gravity.

# Center of Gravity Flight TRI

## Summary

| | Mass | CG |
|---|---|---|
| Hardware + FSE | 28688 | 1055.6 |
| Attach Fittings | 1100 | 1014.0 |
| Structural Docking Mast | 1550 | 643.0 |
| EVA Res (part) | 900 | 545.0 |
| EVA Res (part) | 100 | 475.0 |
| TOTAL MASS for CG | 32338 | |
| CG LOCATION (see notes) | | 1018.4 |
| CG MARGIN | | 13.5 |
| STS CG LIMIT | | 1005.0 |

| NOTES: | incl. | not incl. |
|---|---|---|
| * 15% reserve: not in CG calc. | | 4249 |
| ** EVA Reserve: | | |
| EMU 3x300# | 900 | |
| Nitrogen | 100 | |
| Crew 2x500# (not in CG calc.) | | 1000 |
| +1 day mission (not in CG calc.) | | 873 |

## Detailed Mass Breakdown and Center of Gravity Table

This table provides a detailed tabulation of the preceding summary charts.

# Detailed Mass Breakdown and Center of Gravity Table

SPACE STATION INTEGRATED TRUSS ASSEMBLY CG TABLE

Code: P = Preintegrated  I = Internally mounted  S = Stowed for launch  E = Externally mounted during assembly

| Flight Element | Code | MASS | FSE | ATTACH | CG |
|---|---|---|---|---|---|
| ISOGRID TUBE STRUCTURE | | | | see below | |
| Isogrid (44ft) | P | 2768 | | | 1014 |
| (w/o segments incl. in 3 containers) | | | | | |
| Longerons (trunnion) (2) | P | 208 | | | 1014 |
| Longeron (keel) (1) | P | 382 | | | 1014 |
| Longerons (forward) | P | 80 | | | 1014 |
| Ring (end & container) (6) | P | 543 | | | 1014 |
| Ring (center) (3) | P | 294 | | | 1014 |
| EVA Access Stiffener (1) | P | 13 | | | 986 |
| Trunnions (5) | P | 440 | | | 1035 |
| Connecting Hardware | P | 200 | | | 1014 |
| Total Tube Structure Mass | | 4928 | | | 1015.8 |
| OTHER STRUCTURE | | | | | |
| Total Other Structure | | 0 | | | |
| TOTAL STRUCTURE | | 4928 | | | 1015.8 |
| PROPULSION SYSTEM | | | | | |
| RCS Container #1 | | | | | |
| Tanks ( 4ea VOTS ) | P,I | 580 | | | 1185 |
| Structure | | | | | |
| Isogrid | P,I | n/a | incl. in structure | | n/a |
| Perimeter | P,I | 210 | | | 1185 |
| Tank Support (fore) | P,I | 100 | | | 1218 |
| Tank support (aft) | P,I | 50 | | | 1154 |
| Trunnions | P,I | 230 | | | 1109 |
| Lines, Sensors, Valves etc. | P,I | 337 | | | 1185 |
| Micrometeoroid Protection | P | 835 | | | 1185 |
| Electrical Harnesses | P,I | 525 | | | 1185 |
| HDHe | P,I | 158 | | | 1200 |
| DC-DC load Conv. (RCA) | P,I | 45 | | | 1200 |
| DRY Mass Container #1 | | 3070 | | | 1180.9 |
| FUEL Container #1 | P,I | 4255 | | | 1185 |
| Total Mass RCS Container #1 | | 7325 | | | 1183.3 |
| RCS Container #2 | | | | | |
| DRY Mass Container #2 | P,I | 3070 | | | 1104 |
| see detail above | | | | | |
| FUEL Container #2 | P,I | 4255 | | | 1109 |
| Total Mass Container #2 | | 7325 | | | 1106.1 |
| RCS Thruster Assy #1 | | | | | |
| Thruster Assemblies | S,E | 155 | | | 1228 |
| Lines etc. (incl. in container) | | | | | |
| Thruster Pod Structure | S,E | 25 | | | 1220 |
| Boom | S,E | 65 | | | 1121 |
| Lines + extra Elect Harnes | S,E | 120 | | | 1118 |
| Flight Support Structure | | | 100 | | 1144 |
| Total Mass Thruster Pod #1 | | 365 | 100 | | 1172.2 |
| RCS Thruster Assy #2 | | | | | |
| see detail above | S,E | 365 | | | |
| Total Mass Thruster Pod #2 | | 365 | 100 | | 1172.2 |
| TOTAL MASS RCS ELEMENTS | | 15380 | 200 | | 1165.4 |
| THERMAL CONTROL SYSTEM | | | | | |
| TCS Container | | | | | |
| Structure | | | | | |
| Isogrid | P,I | n/a | incl. in structure | | n/a |
| Aperture reinforcement | P,I | 10 | | | 901 |
| Perimeter | P,I | 210 | | | 921 |
| ORU Support | P,I | 425 | | | 928 |
| Trunnions | P,I | 210 | | | 917 |
| Universal Pallet | n/a | 0 | | | |
| Secondary Structure | P,I | 54 | | | 915 |
| Gimbal Support | P,I | 41 | | | 915 |
| TCS Rad Rotary Joint | P,I | 164 | | | 904 |
| Micrometeoroid Protection | P,I | 86 | | | 922 |
| Supply Tank | P,I | 190 | | | 918 |
| Dump Tank | P,I | 190 | | | 918 |
| NH3 Fluid | | 736 | | | 918 |
| FMAD Umbilical | P,I | 91 | | | 929 |
| MDM | P,I | 105 | | | 940 |
| Other TCS pallet components | P,I | 581 | | | 929 |
| TOTAL THERMAL CONTROL SYSTEM | | 3115 | | | 920.8 |

## Detailed Mass Breakdown and Center of Gravity Table (Continued)

This table provides a detailed tabulation of the preceding summary charts.

# Detailed Mass Breakdown and Center of Gravity Table (Continued)

SPACE STATION INTEGRATED TRUSS ASSEMBLY CG TABLE cont'd

| Flight Element | Code | MASS | FSE | ATTACH | CG |
|---|---|---|---|---|---|
| COMM. AND TRACKING SYSTEM | | | | | |
| ANTENNA ASSEMBLY | | | | | |
| S-Band Ant Assy(2) | S,R | 80 | | | 886 |
| (boom + attachments) | | | | | |
| Ku-Band Para Ant Assy(1) | S,R | 151 | | | 792 |
| Flight Support Structure | | | 100 | | 886 |
| Upper Ant Support(1) | S,R | 200 | | | 883 |
| (incl joints & Ku T-R booms) | | | | | |
| Upper UHF Omni Ant(1) | S,R | 1 | | | 860 |
| GPS Boom & Attachments | | 40 | | | 886 |
| Total Mass Antenna Assembly | | 472 | 100 | | 860.1 |
| RACK 1 (C&T ORUs) | | | | | |
| Rack Structure | P,I | 60 | | | 849 |
| ACS Baseband Sig Proc.(2) | P,I | 80 | | | 864 |
| Std TDRSS Transponder | P,I | 76 | | | 864 |
| SGS Antenna Controller(2) | P,I | 72 | | | 838 |
| Total Mass Rack 1 | | 288 | | | 851.4 |
| RACK 3 (Antenna mounted ORU's) | | | | | |
| Rack Structure | P,I | | 60 | | 838 |
| ACS T Rs w/antennas | S,R | 98 | | | 853 |
| SGS Ku-Band T-Rs | S,R | 138 | | | 824 |
| Ext TV Camera Assy | S,R | 83 | | | 853 |
| Upper MMD Protection | S,R | 22 | | | 824 |
| Total Mass Rack 3 | | 341 | 60 | | 839.2 |
| GN&C SYSTEM | | | | | |
| Mounted on Longrid | | | | | |
| Star Tracker (3) | P,I | 65 | | | 1003 |
| Upper Nav Base | P,I | 15 | | | 1003 |
| Inertial Sensor Assy (3) | P,I | 130 | | | 1003 |
| Structure | P,I | 31 | | | 1003 |
| Total Mass Nav. Base. Assy | | 241 | | | 1003.0 |

| Flight Element | Code | MASS | FSE | ATTACH | CG |
|---|---|---|---|---|---|
| EPS SYSTEM | | | | | |
| RACK 2 | | | | | |
| Rack structure | P,I | 60 | | | 838 |
| DDCU (2) | P,I | 391 | | | 853 |
| RPC Module 130A (14) | P,I | 162 | | | 834 |
| RPC Module 10A (23) | P,I | 213 | | | 838 |
| SPDA(1) | P,I | 45 | | | 853 |
| EPS Mass Rack 2 | | 871 | | | 843.8 |
| DMS SYSTEM | | | | | |
| RACK 2 | | | | | |
| Data Lines and Conns. | P,I | 34 | | | 838 |
| Upper MDM | P,I | 138 | | | 853 |
| DMS Mass Rack 2 | | 172 | | | 850.0 |
| Total Mass Rack 2 | | 1043 | | | 844.8 |
| TOT. MASS C&T "PALLET FUNCTIONS" | | 2385 | 160 | | 851.3 |
| TEMPORARY POWER SYSTEM (1500W) | | | | | |
| RACK 4 | | | | | |
| Rack Structure | P,I | 60 | | | 842 |
| Power System | P,I | 1000 | | | 842 |
| Incl elect, batt, PV Blanket | | | | | |
| Base and Fittings | P,I | 60 | | | 842 |
| TOTAL MASS TEMP. PWR. SYST. | | 1120 | | | 842.0 |
| UTILITIES | | | | | |
| TOTAL MASS FOR 44' | P,I | 1200 | | | 1014 |
| FLIGHT TOTAL | | 28328 | 160 | | 1025.6 |

LaRC SSFO



ORIGINAL PAGE IS OF POOR QUALITY

## TR2 Packaging

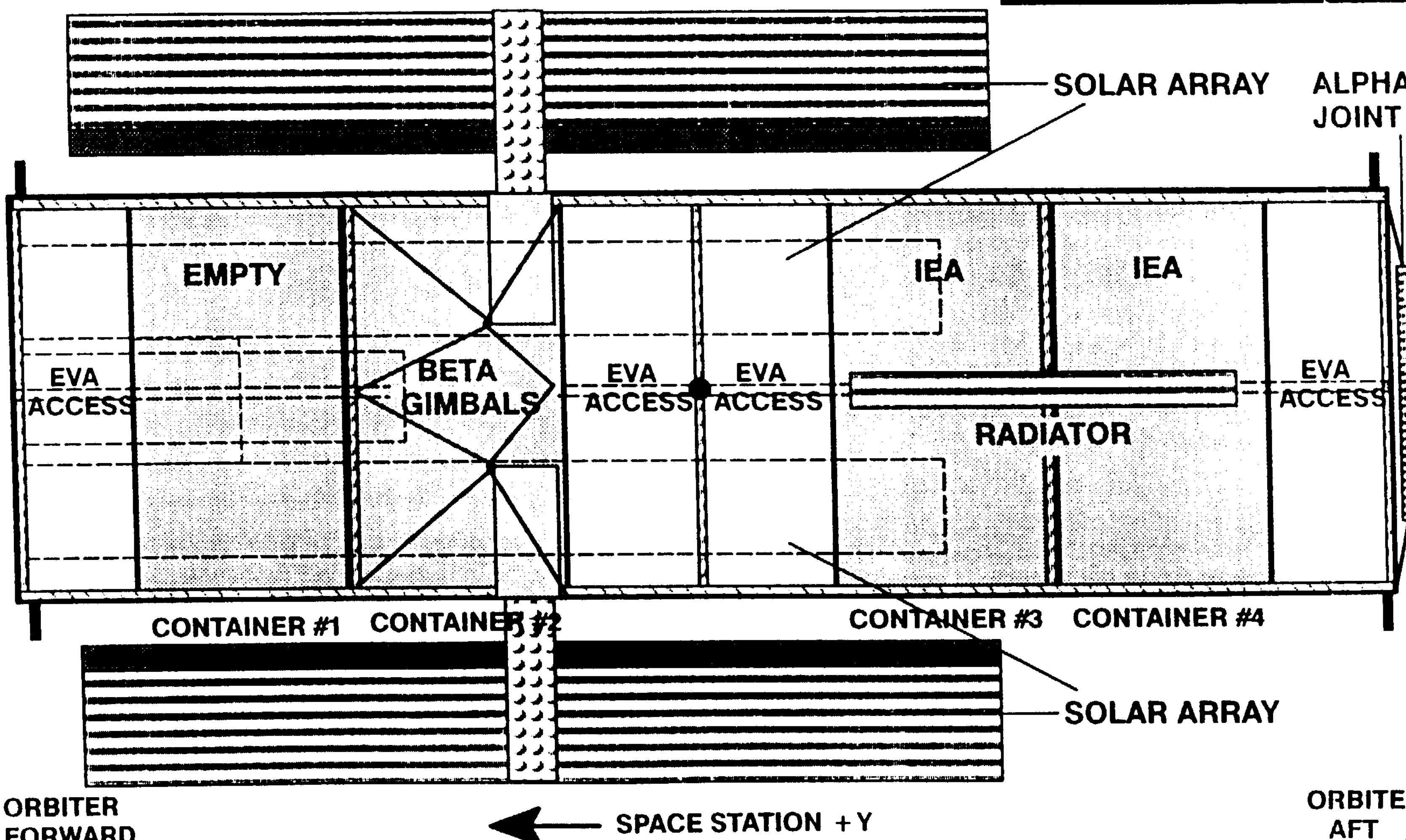
The second assembly flight brings up the power system elements that are located just outside the starboard alpha joint. All elements required to produce 18.75 KW of power are included on this flight. The Integrated Equipment Assembly (IEA) is packaged in two container sections at one end of the integrated structure. The PV array beta gimbals are located in container section two. Packaged internally are two PV arrays and the deployable radiator. An alpha joint is located at the IEA end of the integrated structure.

NASA — FREEDOM

# Pre–Integrated Structure Packaging

## TR–2

Mass to station = 27,572
Managers reserve = 4136
Additional Margin = 4270



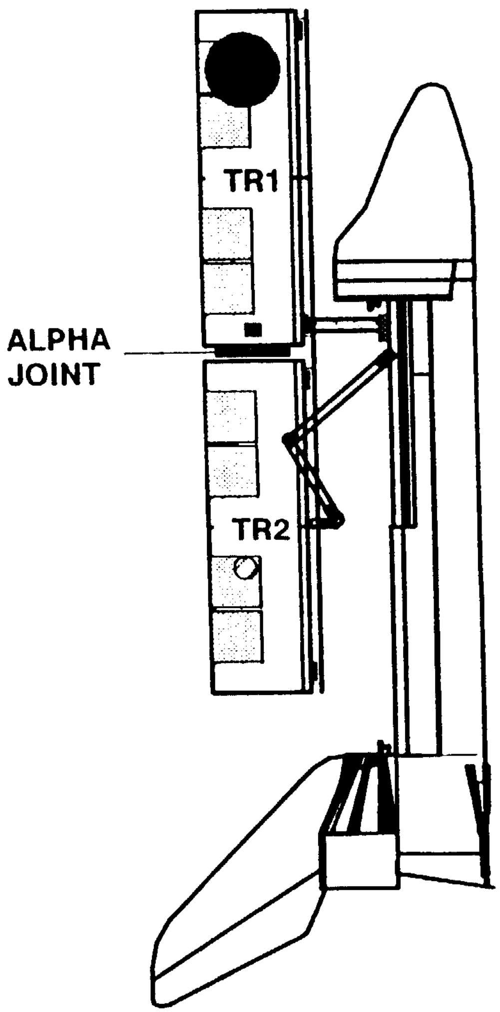

LaRC SSFO

MB2PACK

## TR2 Operations

The operations involved in deploying and assembling the second integrated structural element of the space station result in an addition of 10 KW of power while the arrays operate in a feathered mode. The orbiter must first attach to the TR1 station element. The TR2 integrated structure is then removed from the orbiter cargo bay with the RMS and attached to TR1. The orbiter then detaches from TR1 and attaches to TR2. From this position the RMS removes and attaches internally stored appendages with EVA assistance. After all assembly and check out is complete, the orbiter detaches from the structure but remains in close proximity until all systems are verified operational. A malfunction would require the orbiter to berth to the structure and facilitate repairs.

# Truss Flight Two Operations




STEPS 1 TO 4

1) Berth to TR1.

2) Remove TR2 from cargo bay and rotate.

3) Release alpha joint mechanism.

4) Berth TR2 to TR1. EVA secure TR1 to alpha joint.

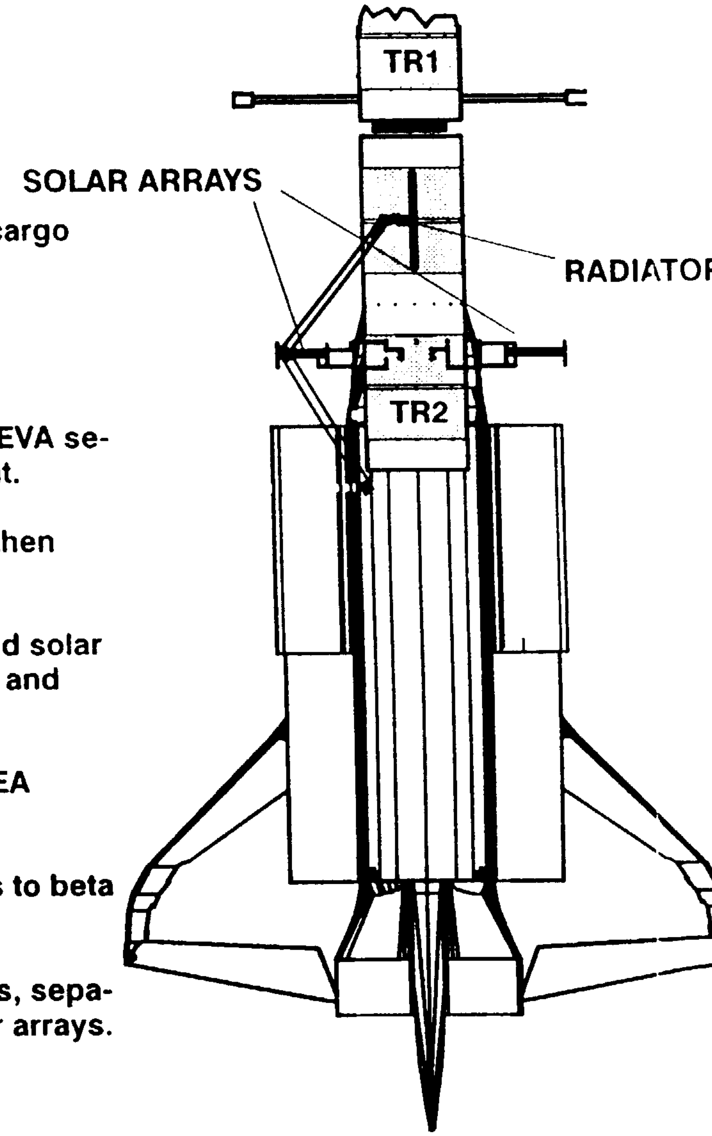
5) Release from TR1 then berth to end of TR2

6)Remove radiator and solar arrays from structure and place in cargo bay.

7)Attach radiator to IEA manifold and deploy.

8) Attach solar arrays to beta joints.

9) Check out systems, separate and deploy solar arrays.



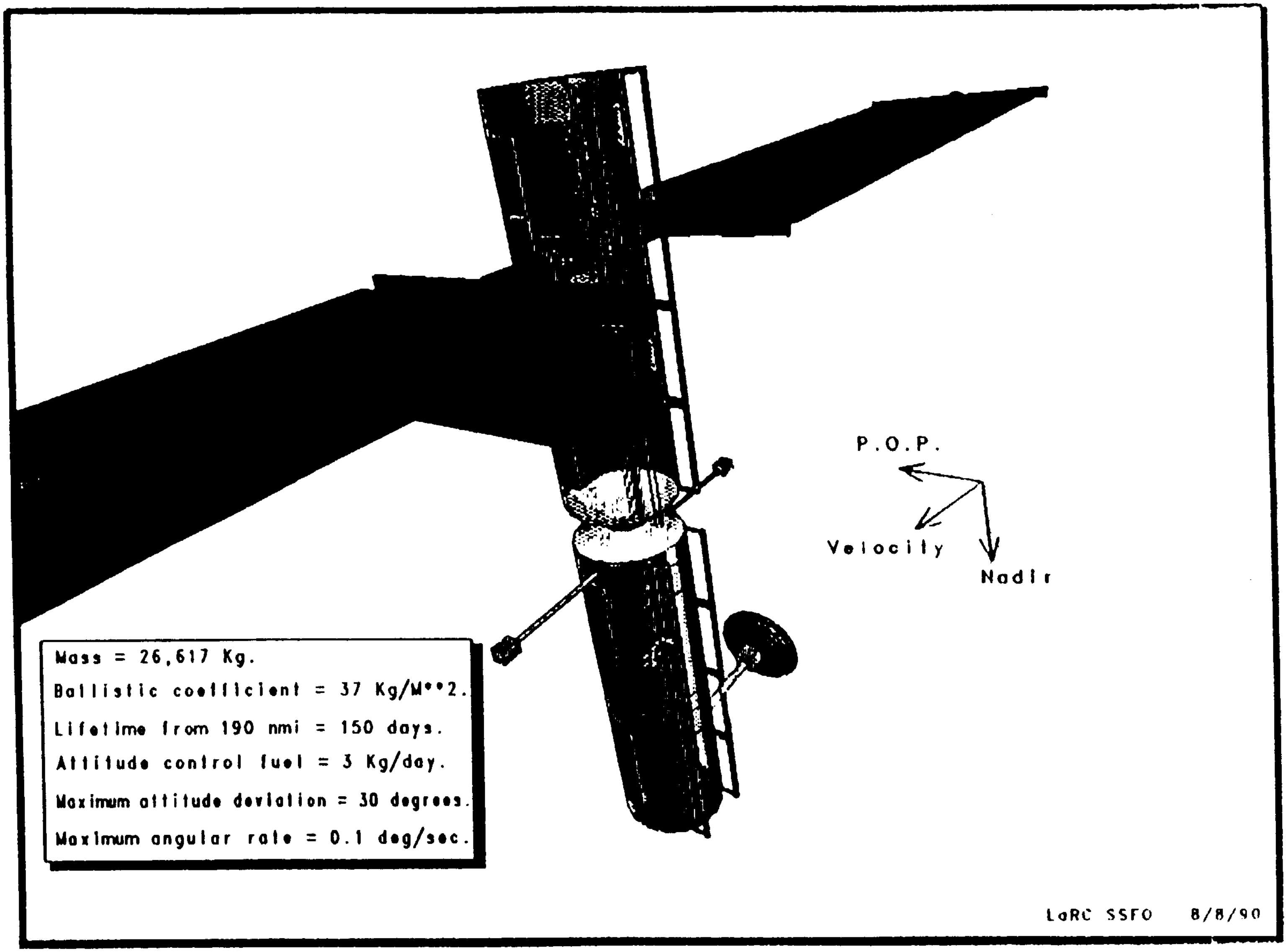

STEPS 5 TO 9

TRUSS2OPS

## Second Assembly Flight Configuration

A flight characteristics analysis was performed on the second assembly flight configuration. The flight mode is gravity gradient stable with the deployed solar arrays, antennas and thruster arms aligned along the velocity vector and the longitudinal axis of the structure aligned along nadir. Stability simulations showed this configuration to yaw 360 degrees once every 5 orbits with no RCS attitude control. Using RCS thrusters to hold the configuration to within a maximum deviation of 30 degrees required 3 kilograms of fuel per day at 190 nmi assuming a design atmosphere of Ap = 400 and a flux of 230. The average ballistic coefficient was 37 kg/m**2 which would give the station an orbit lifetime of 150 days from 190 nmi if the reboost thrusters were to fail. There is sufficient reboost fuel on board to maintain altitude for many years should the orbiter be grounded for some reason.

# Second Assembly Flight Configuration






ORIGINAL PAGE IS
OF POOR QUALITY

## TR2 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the second assembly flight are listed. The overall C.G. location for the combined payload is 10.6 inches within allowable limits. There is 4270 pounds of unused STS lift capability and 4135 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 2
TR-2
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| IEA | 12144 | | | CON#3&4 | 1146 |
| SOLAR ARRAYS | 3636 | 363 | | TUBE | 882 |
| BETA GIMBALS | 882 | | | CON#2 | 954 |
| RADIATOR (DEPLOYABLE) | 1104 | 136 | | TUBE | 840 |
| ALPHA JOINT | 946 | | | TUBE END | 1278 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 600 | | | | 1014 |
| | 27572 | 499 | 1100 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 27572 | | |
| 15% RESERVE | 4136 | | |
| FSE | 499 | | |
| ATTACH FITTINGS | 1100 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 37730 | CG LOCATION | 1014.1 |
| MARGIN | 4270 | CG MARGIN | 10.6 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1003.6 |

## TR3 Packaging

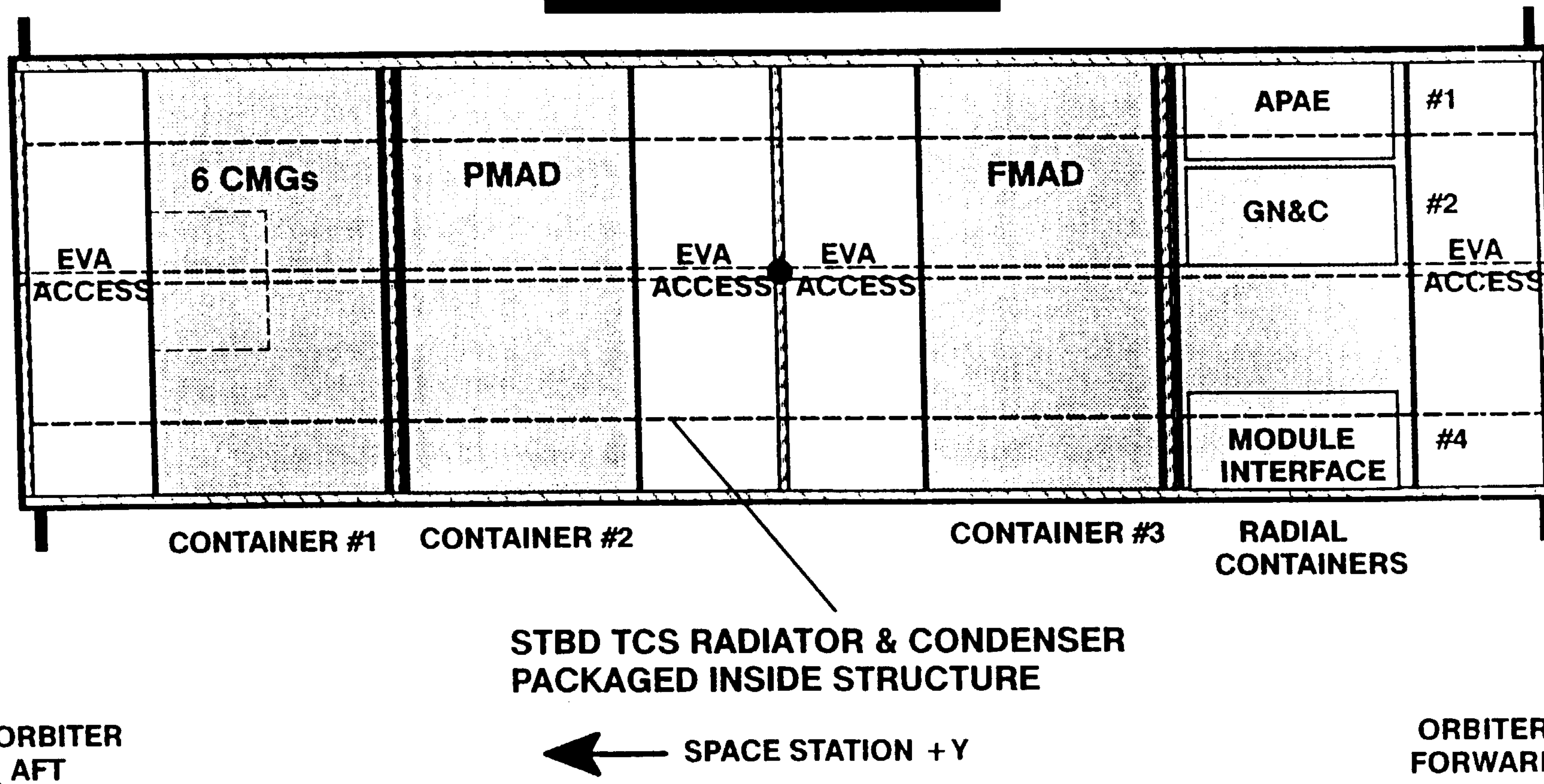
The third truss section flight brings up the CMGs, PMAD, FMAD, one APAE and a pressurized module interface. The CMGs are in container #1, the PMAD equipment is in container #2, the FMAD equipment is in container #3 and the radial containers house the attached payload and pressurized module interfaces along with some GN&C electronics. Packaged internally are the starboard TCS radiator panels and condenser that will be attached to the beta joint on TR1.

NASA — FREEDOM

# Pre–Integrated Structure Packaging

## TR–3

Mass to station = 29,338
Managers reserve = 4401
Additional Margin = 2011



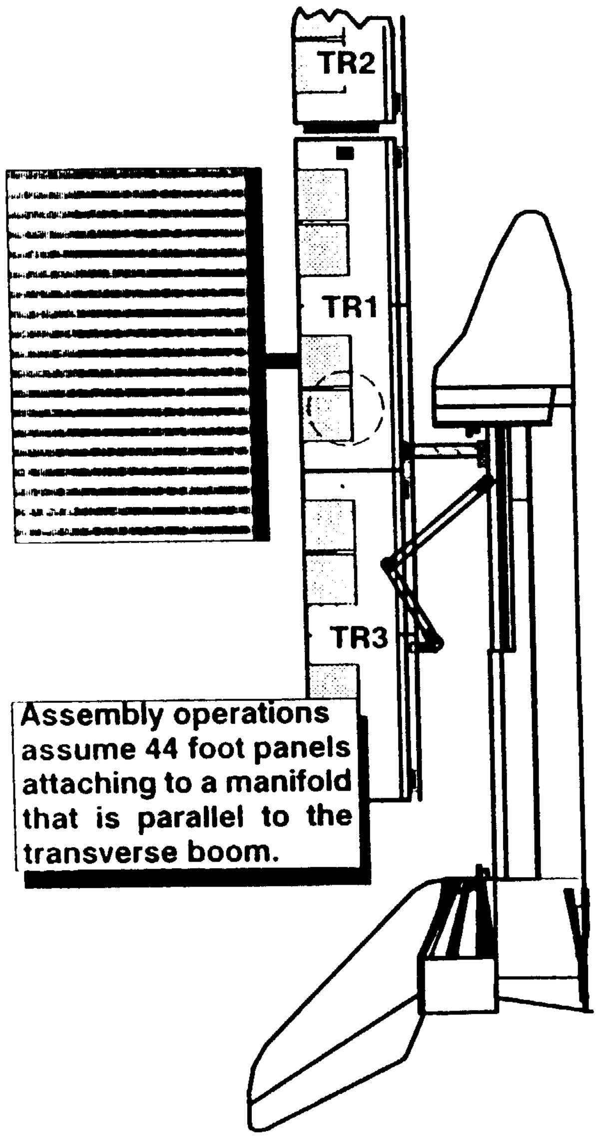

LaRC SSFO

MB3PACK

## TR3 Operations

The operations involved in deploying and assembling the third integrated structural element of the space station are listed. The orbiter must first attach to the TR1 station element. The TR3 integrated structure is then removed from the orbiter cargo bay with the RMS and EVA secured to TR1. The orbiter then detaches from TR1 and attaches to TR3. From this position the radiator panels are removed and placed in the cargo bay. The orbiter then re-attaches to TR1 and the RMS assembles/attaches the radiator to the beta joint on TR1 with EVA assistance. After all assembly and check out is complete, the orbiter detaches from the structure but remains in close proximity until all systems are verified to be operational. A malfunction would require the orbiter to berth to the structure and facilitate repairs.

# Truss Flight Three Operations




1) Berth to TR1.

2) Remove TR3 from cargo bay and rotate.

3) Berth TR3 to TR1. EVA secure TR1 to TR3

4) Release from TR1 then berth to end of TR3.

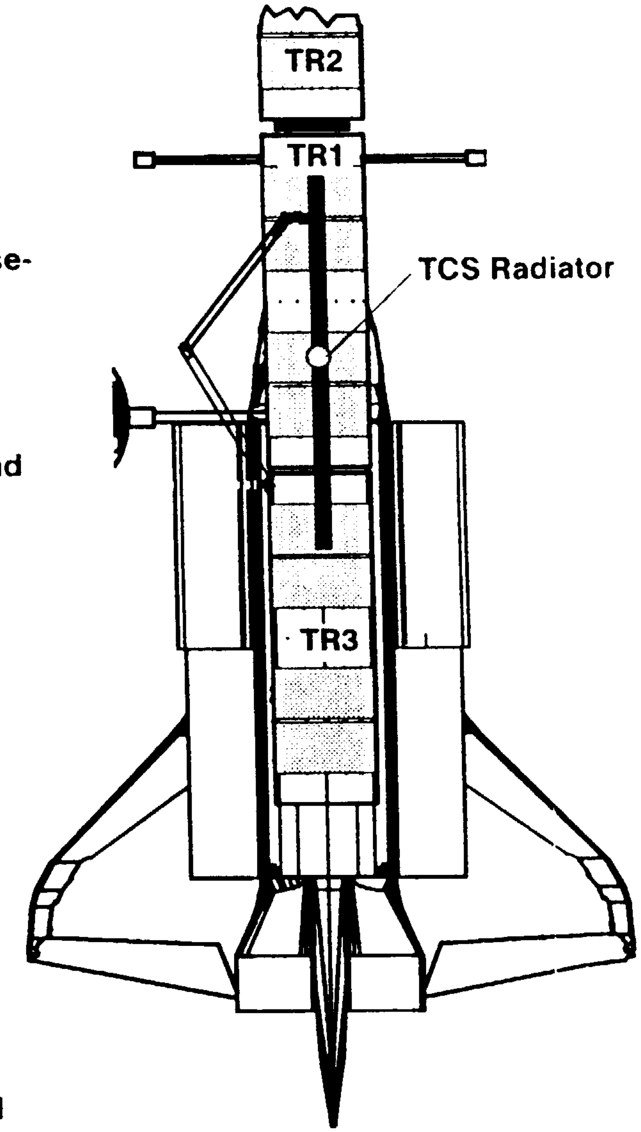
5) Remove TCS radiator and condenser from TR3 and place in cargo bay.

6)Re-berth to end of TR1.

7)Use RMS to install starboard TCS radiator rotating beta joint 180 degrees half way through construction.

8) Check out systems and separate.

STEPS 4 & 5 NOT SHOWN




truss3ops

## TR3 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the third truss section flight are listed. The overall C.G. location for the combined payload is 0.5 inches within allowable limits. There is 2011 pounds of unused STS lift capability and 4401 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 3
TR-3

| STS ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| UPPER APAE | 600 | 100 | | RC#1 | 840 |
| MODULE INTERFACE | 600 | 100 | | RC#4 | 840 |
| STBD TCS PANELS & CONDENSER | 4271 | 427 | | TUBE | 1014 |
| CMG'S (6) | 5130 | | | CON#1 | 1188 |
| GN&C | 777 | 100 | | RC#2 | 840 |
| PMAD | 5069 | | | CON#2 | 1104 |
| FMAD(WET) | 2831 | | | CON#3 | 924 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 1200 | | | | 1014 |
| BALLAST | 600 | | | | 1280 |
| | 29338 | 727 | 1100 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 29338 | | |
| 15% RESERVE | 4401 | | |
| FSE | 727 | | |
| ATTACH FITTINGS | 1100 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 39989 | CG LOCATION | 1008.4 |
| MARGIN | 2011 | CG MARGIN | 0.5 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1007.9 |

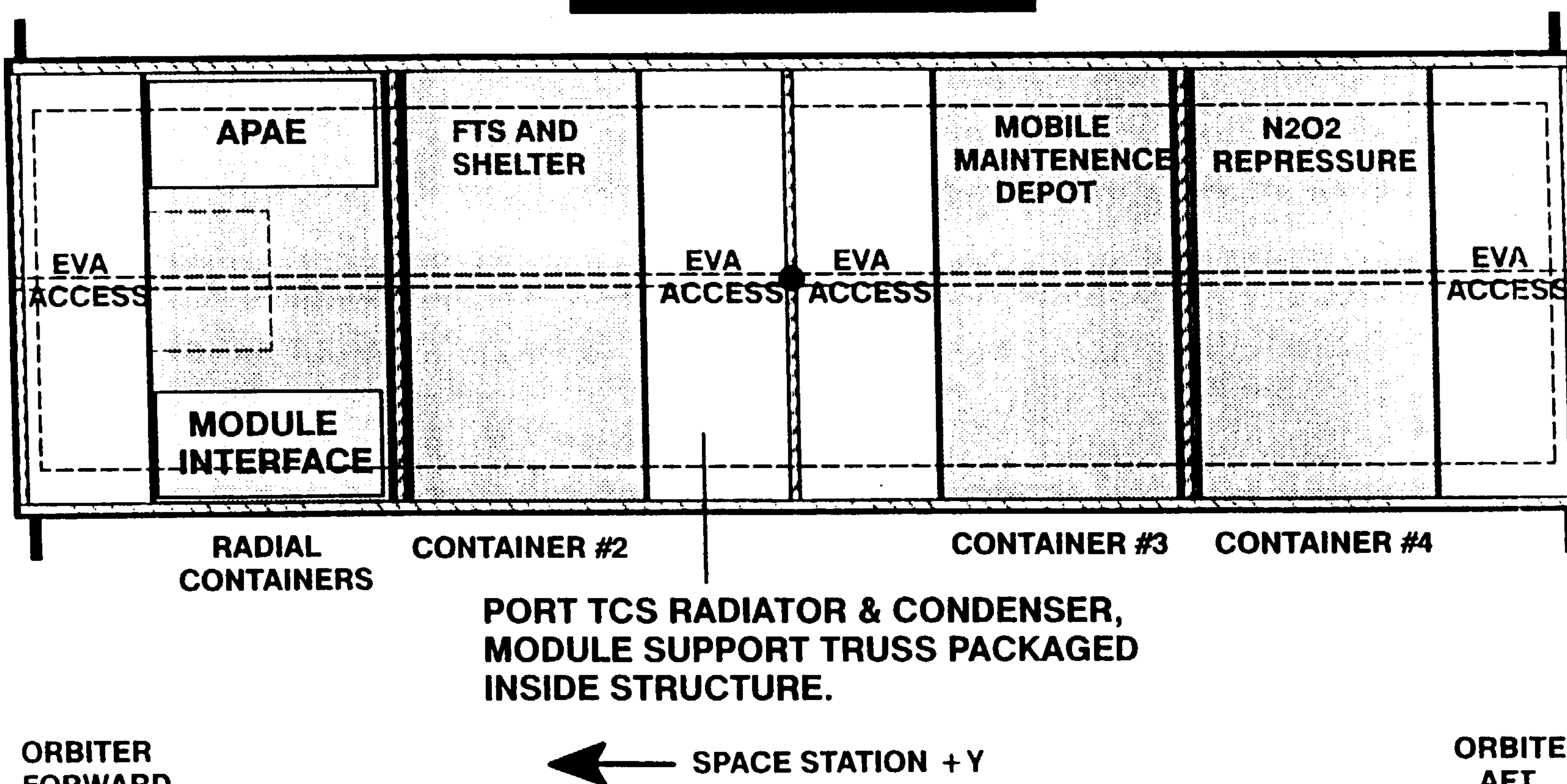
# TR4 Packaging

The fourth truss section flight brings up the $N_2O_2$ repressurization tanks, Mobile Maintenance Depot (MMD), FTS and shelter, an APAE and a pressurized module interface. The FTS and shelter are in container #2, the MMD is in container #3, the repressurization tanks are in container #4 and the radial containers house the attached payload and pressurized module interfaces. Packaged internally are the port TCS radiator panels and condenser that will be attached to the beta joint on the following flight.

# Pre–Integrated Structure Packaging

## TR–4

Mass to station = 30,206
Managers reserve = 4531
Additional Margin = 999



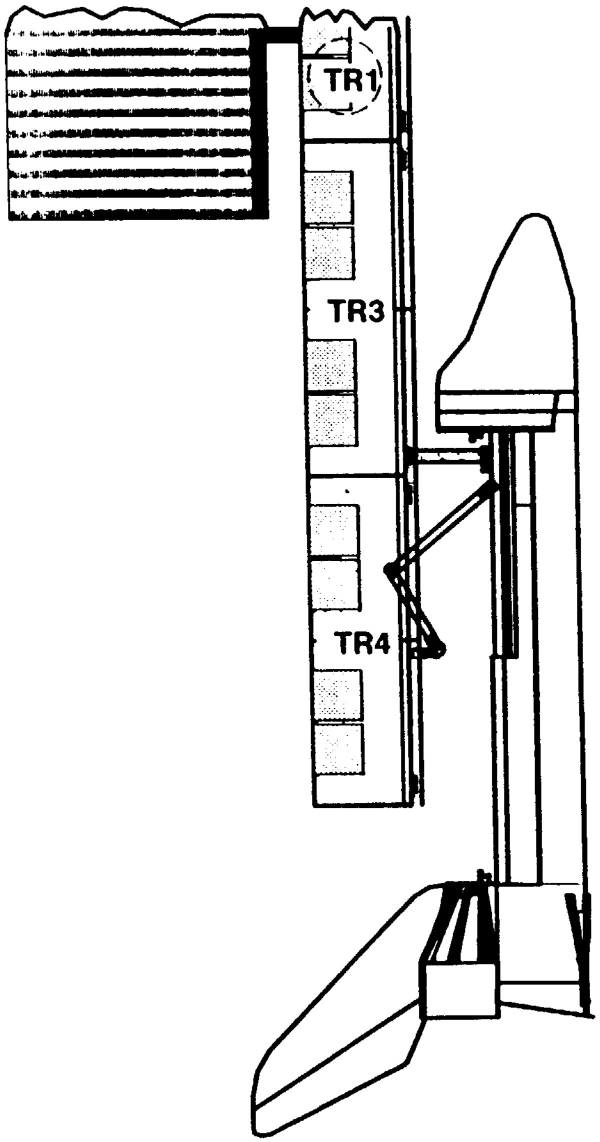

LaRC SSFO

MB4PACK

## TR4 Operations

The operations involved in deploying and assembling the fourth integrated structural element of the space station are listed. The orbiter must first attach to the TR3 station element. The TR4 integrated structure is then removed from the orbiter cargo bay with the RMS and EVA secured to TR3. The orbiter then detaches from TR3 and attaches to TR4. From this position the RMS removes the radiator panels and stows them on TR4. After all assembly and check out is complete, the orbiter detaches from the structure but remains in close proximity until all systems are verified to be operational. A malfunction would require the orbiter to berth to the structure and facilitate repairs.

# Truss Flight Four Operations




STEPS 1 TO 3

1) Berth to TR3.

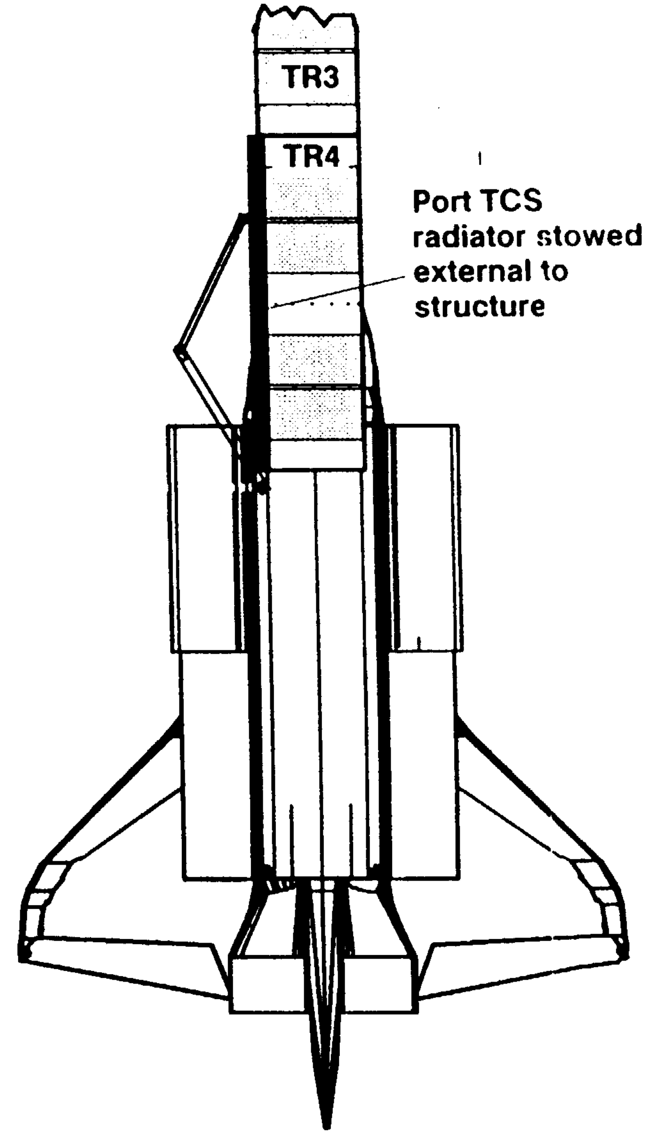
2) Remove TR4 from cargo bay and rotate.

3) Berth TR4 to TR3. EVA secure TR4 to TR3.

4) Release from TR3 then berth to end of TR4.

5) Remove TCS radiator and condenser from TR4 and store on exterior of TR4.

6) Check out systems and separate.




STEPS 4 TO 6

truss4ops

## TR4 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the fourth truss section flight are listed. The overall C.G. location for the combined payload is 14 inches within allowable limits. There is 999 pounds of unused STS lift capability and 4531 pounds of managers reserve available.

NASA — FREEDOM

# Integrated Assembly Sequence Manifest

FLIGHT 4
TR-4
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| MODULE SUPPORT TRUSS | 531 | 114 | | TUBE | 1014 |
| N2O2 REPRESSURIZATION TANKS | 8400 | | | CON#4 | 1188 |
| PORT TCS PANELS & CONDENSER | 4271 | 427 | | TUBE | 1014 |
| FTS/SHELTER | 2232 | | | CON#2 | 924 |
| MMD WITH SPDM | 4112 | | | CON#3 | 1104 |
| MODULE INTERFACE | 600 | 100 | | RC#4 | 840 |
| UPPER APAE | 600 | 100 | | RC#1 | 840 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 1200 | | | | 1014 |
| | 30206 | 741 | 1100 | | |

| | MASS | | |
|---|---|---|---|
| HARDWARE | 30206 | | |
| 15% RESERVE | 4531 | | |
| FSE | 741 | | |
| ATTACH FITTINGS | 1100 | | |
| EVA RESERVE | 2873 | | |
| PRESS. DOCKING MECH. | 1550 | | |
| SUBTOTAL | 41001 | CG LOCATION | 1023.7 |
| MARGIN | 999 | CG MARGIN | 14.0 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1009.6 |

LaRC SSFO

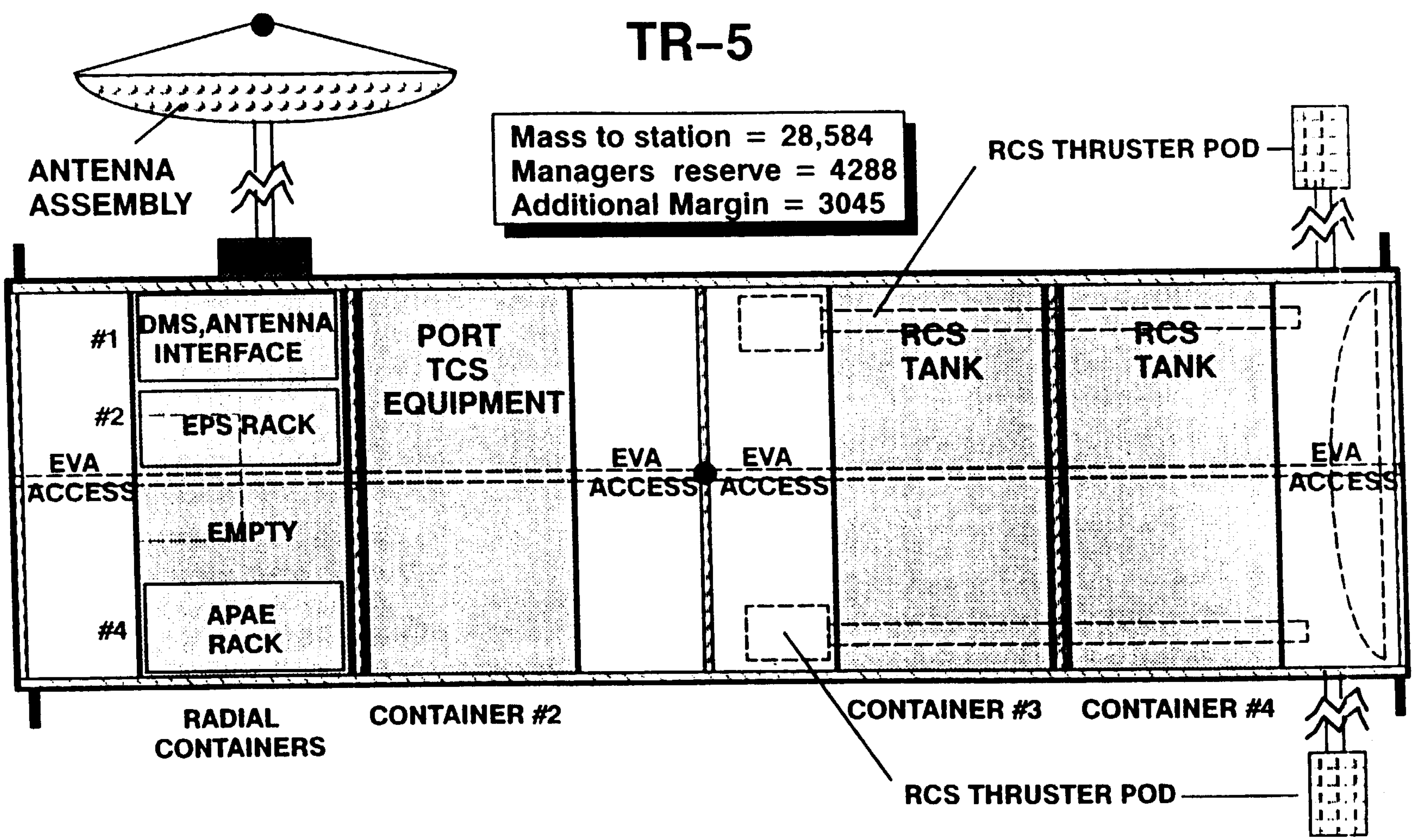
## TR5 Packaging

The fifth truss structure flight is essentially a mirror image of TR1 without the independent power system. Hydrazine fuel tanks loaded with a total of 9000 pounds of fuel are located at one end of the integrated structure in removable container sections. The port TCS equipment (including the port radiator beta joint) is located in container section two. Radial containers at the other end of the structure contain systems for communications and power conditioning. Packaged internally are two thruster pods with extension arms and the antenna assembly. This is identical to TR2.

# Pre-Integrated Structure Packaging

## TR-5

Mass to station = 28,584
Managers reserve = 4288
Additional Margin = 3045



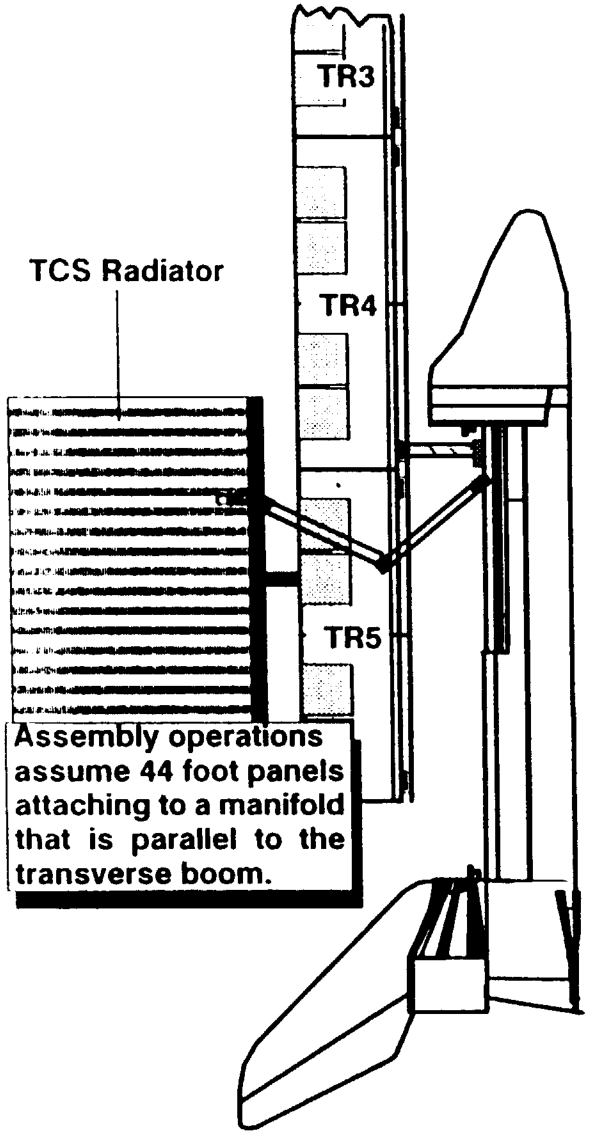


MB5PACKNEW

## TR5 Operations

The operations involved in deploying and assembling the fifth integrated structural element of the space station are listed. The orbiter must first attach to the TR4 station element. The TR5 integrated structure is then removed from the orbiter cargo bay with the RMS and EVA secured to TR4. From this position the RMS removes the radiator panels stowed on TR4 and assembles them on TR5. The orbiter then attaches to the end of TR5, where the RMS removes and attaches the antenna assembly and thruster arms. After all assembly and check out is complete, the orbiter detaches from the structure but remains in close proximity until all systems are verified to be operational. A malfunction would require the orbiter to berth to the structure and facilitate repairs.

# Truss Flight Five Operations




STEPS 1 TO 5

1) Berth to TR4.

2) Remove TR5 from cargo bay and rotate.

3) Berth TR5 to TR4. EVA secure TR5 to TR4

4) Remove stowed port TCS radiator and condenser from TR4 exterior and place in cargo bay.

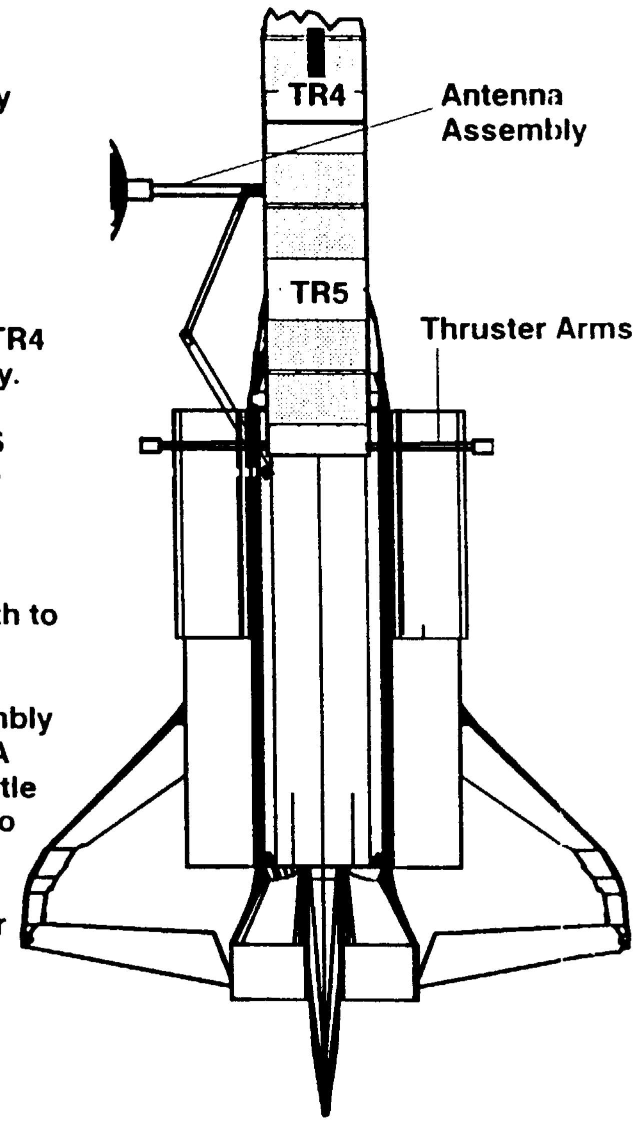
5) Use RMS to install port TCS radiator rotating beta joint 180 degrees half way through construction.

6) Release from TR4 then berth to end of TR5.

7) Remove the antenna assembly from TR5 using RMS then EVA erect the antennas in the shuttle cargo bay. Attach assembly to TR5 with RMS.

8) Remove and install thruster arms to end of TR5.

9) Check out systems and separate.




STEPS 6 TO 9

truss5ops

# TR5 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the fifth truss section flight are listed. The overall C.G. location for the combined payload is 26.2 inches within allowable limits. There is 3045 pounds of unused STS lift capability and 4288 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 5
TR-5
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| PORT TCS EQUIPMENT(WET) | 1706 | | | CON#2 | 924 |
| RCS PODS (2) WITH ARMS | 2000 | 200 | | TUBE | 1146 |
| RCS TANK (WITH 5000# OF FUEL) | 6500 | | | CON#3 | 1104 |
| RCS TANK (WITH 5000# OF FUEL) | 6500 | | | CON#4 | 1188 |
| ANTENNA ASSEMBLY | 608 | 60 | | TUBE | 1254 |
| DMS ANTENNA INTERFACE | 399 | 100 | | RC#1 | 840 |
| EPS SYSTEMS | 811 | 100 | | RC#2 | 840 |
| LOWER APAE | 600 | 100 | | RC#4 | 840 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 1200 | | | | 1014 |
| | 28584 | 560 | 1100 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 28584 | | |
| 15% RESERVE | 4288 | | |
| FSE | 560 | | |
| ATTACH FITTINGS | 1100 | | |
| STRUCTURAL DOCKING MAST | 1550 | | |
| EVA RESERVE | 2873 | | |
| SUBTOTAL | 38955 | CG LOCATION | 1032.1 |
| MARGIN | 3045 | CG MARGIN | 26.2 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1006.0 |

## TR6 Packaging

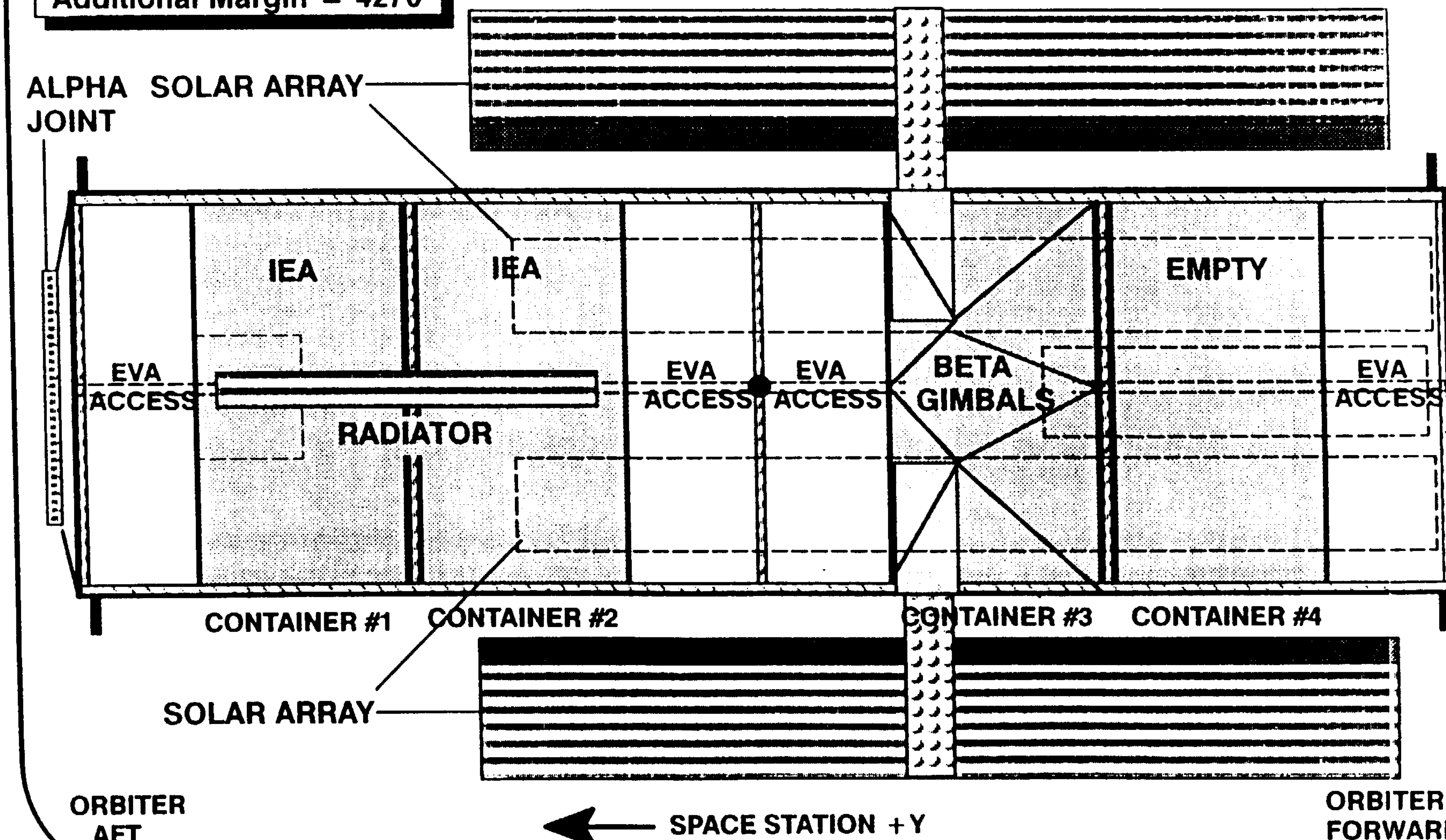
The sixth truss structure flight brings up the power system elements that are located just outside the port alpha joint. All elements required to produce 18.75 KW of power are included on this flight. The Integrated Equipment Assembly (IEA) is packaged in two container sections at one end of the integrated structure. The PV array beta gimbals are located in container section three. Packaged internally are two PV arrays and the deployable radiator. An alpha joint is located at the IEA end of the integrated structure.

NASA — FREEDOM

# Pre-Integrated Structure Packaging

## TR-6

Mass to station = 27,572
Managers reserve = 4136
Additional Margin = 4270



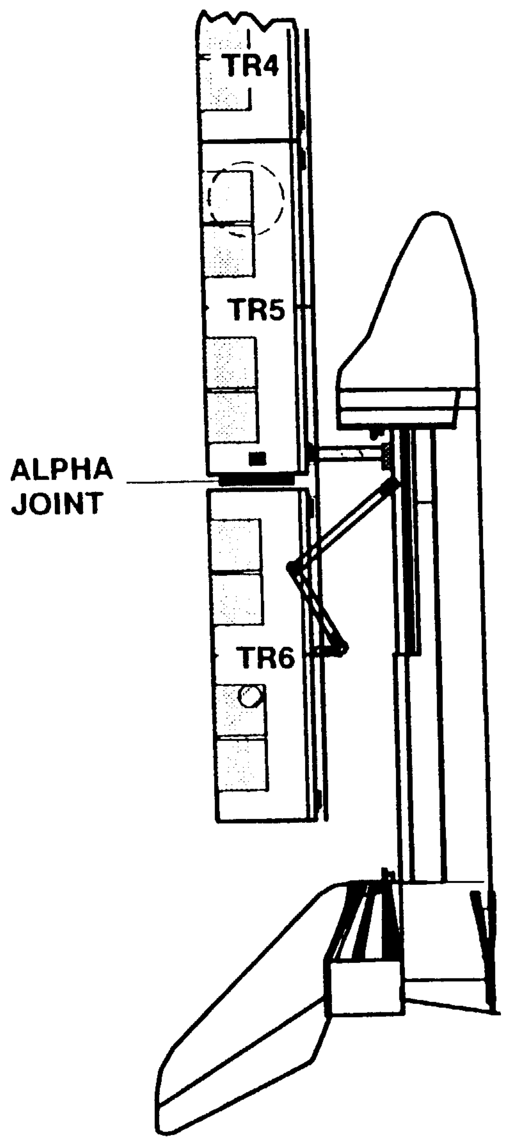

LaRC SSFO

MB6PACKNEW

## TR6 Operations

The operations involved in deploying and assembling the sixth integrated structural element of the space station result in a total power capability of 37.5 KW while flying in a LVLH sun tracking mode. The orbiter must first attach to the TR5 station element. The TR6 integrated structure is then removed from the orbiter cargo bay with the RMS and EVA secured to TR5. The orbiter then detaches from TR5 and attaches to TR6. From this position the RMS removes and attaches internally stored appendages with EVA assistance. After all assembly and check out is complete, the orbiter detaches from the structure but remains in close proximity until all systems are verified operational. A malfunction would require the orbiter to berth to the structure and facilitate repairs.

# Truss Flight Six Operations




STEPS 1 TO 4

1) Berth to TR5.

2) Remove TR6 from cargo bay and rotate.

3) Release alpha joint mechanism.

4) Berth TR6 to TR5. EVA secure TR5 to alpha joint.

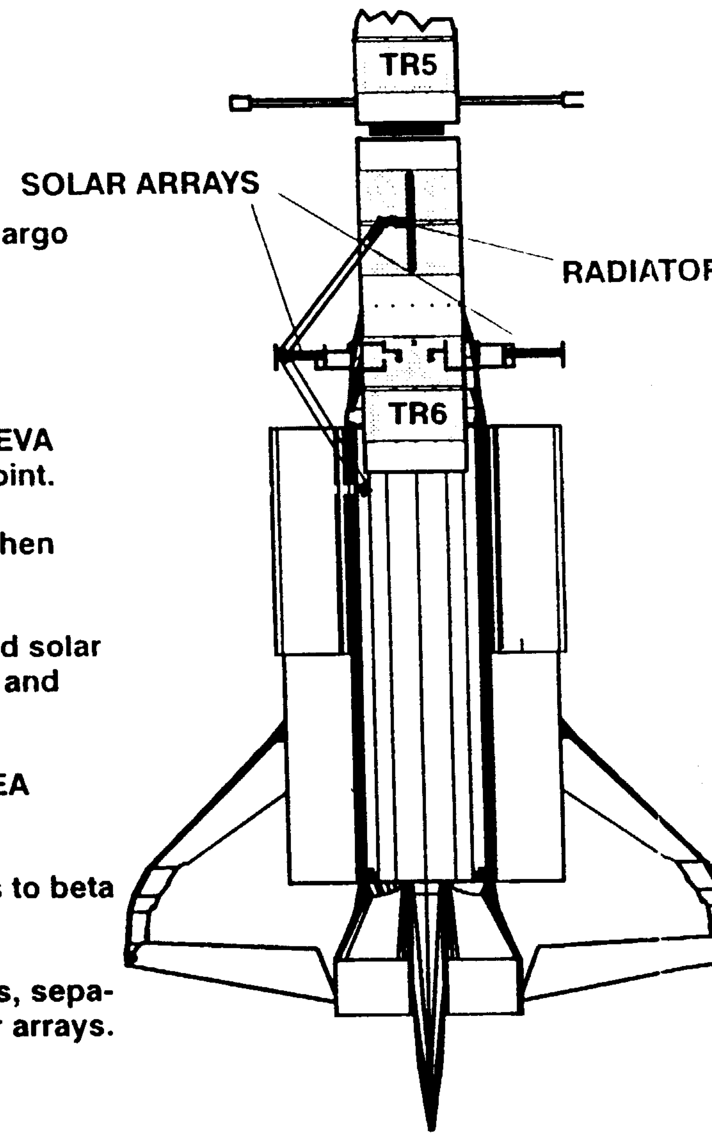
5) Release from TR5 then berth to end of TR6

6)Remove radiator and solar arrays from structure and place in cargo bay.

7)Attach radiator to IEA manifold and deploy.

8) Attach solar arrays to beta joints.

9) Check out systems, separate and deploy solar arrays.




STEPS 5 TO 9

truss6ops

## TR6 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the sixth truss section flight are listed. The overall C.G. location for the combined payload is 10.6 inches within allowable limits. There is 4270 pounds of unused STS lift capability and 4136 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 6
TR-6
STS

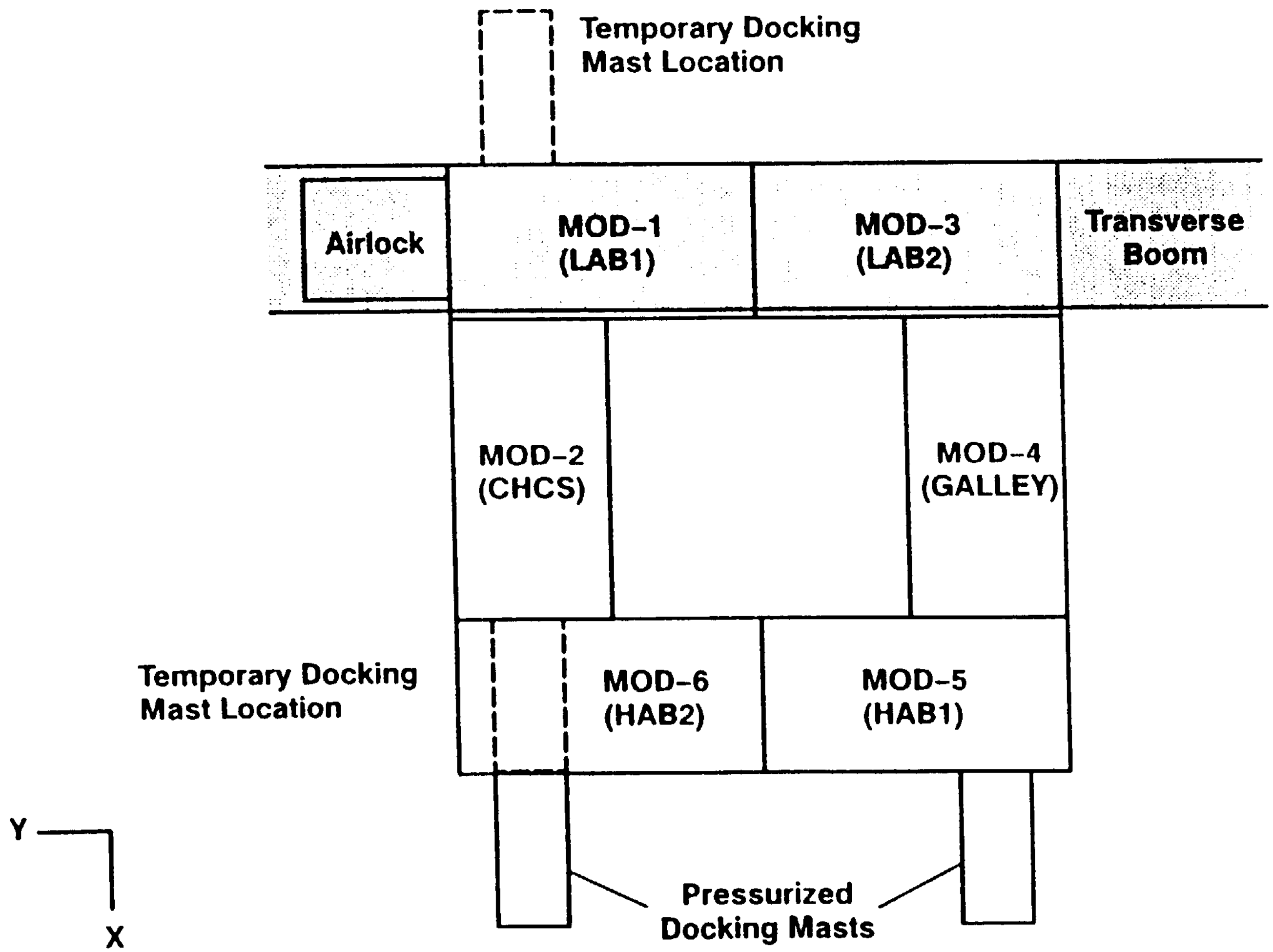
| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| IEA | 12144 | | | CON#1&2 | 1146 |
| SOLAR ARRAYS | 3636 | 363 | | TUBE | 882 |
| BETA GIMBALS | 882 | | | CON#3 | 954 |
| RADIATOR (DEPLOYABLE) | 1104 | 136 | | TUBE | 840 |
| ALPHA JOINT | 946 | | | TUBE END | 1278 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 600 | | | | 1014 |
| | 27572 | 499 | 1100 | | |

| | MASS | | |
|---|---|---|---|
| HARDWARE | 27572 | | |
| 15% RESERVE | 4136 | | |
| FSE | 499 | | |
| ATTACH FITTINGS | 1100 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 37730 | CG LOCATION | 1014.1 |
| MARGIN | 4270 | CG MARGIN | 10.6 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1003.6 |

## Module Pattern Assembly

Once the transverse boom has been completed from starboard to port alpha joints, the module pattern is constructed. The first module brought up is a laboratory module located towards starboard directly under the transverse boom.. A pressurized docking module is manifested along with the lab and is temporarily placed on the aft side of the lab module in the –X direction. The following assembly flight brings up the airlock, mobile transporter, MSC, and a cupola which is stored on the transverse boom. The next flight brings up the CHCS module followed by a flight that brings up the second lab module and another pressurized docking adapter. The galley and both habitation modules are then brought up along with the second cupola on subsequent flights. The pressurized docking modules and cupolas are then placed in their final positions.

# Module Pattern Assembly



## MOD1 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the first module flight are listed. The overall C.G. location for the combined payload is 40.5 inches within allowable limits. There is 134 pounds of unused STS lift capability and 1677 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 7
MOD-1
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| U.S. MODULE 1 (LAB 17 RACKS) | 30916 | 250 | 1100 | | 1110 |
| PRESSURIZED DOCKING MODULE | 2343 | | 880 | | 878 |
| FLUIDS | 277 | | | | 1110 |
| | 33536 | 250 | 1980 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 33536 | | |
| 5% RESERVE | 1677 | | |
| FSE | 250 | | |
| ATTACH FITTINGS | 1980 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 41866 | CG LOCATION | 1056.6 |
| MARGIN | 134 | CG MARGIN | 40.5 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1016.2 |

## Module/Truss (MT) Manifest

The assembly elements, weights, associated FSE and C.G. locations for a combination module pattern (airlock, cupola) / truss structure (mobile transporter, MSC) flight are listed. The overall C.G. location for the combined payload is 0.2 inches within allowable limits. There is 768 pounds of unused STS lift capability and 1547 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 8
MT-1

| STS ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| AIRLOCK | 12339 | 250 | 1100 | | 1178 |
| MSC PHASE 1 | 7176 | | 660 | | 1000 |
| MOBILE TRANSPORTER | 5399 | | 880 | | 880 |
| CUPOLA | 3317 | 700 | 660 | | 776 |
| BALLAST | 2700 | | | | 1280 |
| | 30932 | 950 | 3300 | | |
| HARDWARE | 30932 | | | | |
| 5% RESERVE | 1547 | | | | |
| FSE | 950 | | | | |
| ATTACH FITTINGS | 3300 | | | | 570 |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | 642.7 |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 41232 | | CG LOCATION | | 1015.5 |
| MARGIN | 768 | | CG MARGIN | | 0.2 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1015.3 |

LaRC SSFO

## MOD 2 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the second module flight are listed. The overall C.G. location for the combined payload is 41.6 inches within allowable limits. There are 54 pounds of unused STS lift capability and 1677 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 9
MOD-2
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| U.S. MODULE 2 (HAB 17 RACKS) | 30916 | 250 | 1100 | | 1110 |
| PRESSURIZED DOCKING MODULE | 2343 | | 880 | | 878 |
| FLUIDS | 277 | | | | 1110 |
| | 33536 | 250 | 1980 | | |
| HARDWARE | 33536 | | | | |
| 5% RESERVE | 1677 | | | | |
| FSE | 250 | | | | |
| ATTACH FITTINGS | 1980 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 41946 | | CG LOCATION | | 1057.8 |
| MARGIN | 54 | | CG MARGIN | | 41.6 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1016.3 |

## MOD 3 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the third module flight are listed. The overall C.G. location for the combined payload is 63.1 inches within allowable limits. There are 2773 pounds of unused STS lift capability and 1589 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 10
MOD-3
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| U.S. MODULE 3 (GALLEY 18 RACKS) | 31508 | 250 | 1100 | | 1110 |
| FLUIDS | 277 | | | | 1110 |
| | 31785 | 250 | 1100 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 31785 | | |
| 5% RESERVE | 1589 | | |
| FSE | 250 | | |
| ATTACH FITTINGS | 1100 | | |
| MSC WORKSTATION | 80 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 39227 | CG LOCATION | 1074.9 |
| MARGIN | 2773 | CG MARGIN | 63.1 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1011.8 |

## MOD 4 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the fourth module flight are listed. The overall C.G. location for the combined payload is 60.8 inches within allowable limits. There are 2773 pounds of unused STS lift capability and 1589 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 11
MOD-4
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| US MODULE 4 (CHCS 18 RACKS) | 31508 | 250 | 1100 | | 1110 |
| FLUIDS | 277 | | | | 1110 |
| | 31785 | 250 | 1100 | | |
| HARDWARE | 31785 | | | | |
| 5% RESERVE | 1589 | | | | |
| FSE | 250 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 39227 | | CG LOCATION | | 1074.9 |
| MARGIN | 2773 | | CG MARGIN | | 60.8 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1014.2 |

LaRC SSFO

## MOD 5 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the fifth module flight are listed. The overall C.G. location for the combined payload is 63.1 inches within allowable limits. There is 2773 pounds of unused STS lift capability and 1589 pounds of managers reserve available.

NASA FREEDOM

# Integrated Assembly Sequence Manifest

FLIGHT 12
MOD-5
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| U.S. MODULE 5 (HAB 18 RACKS) | 31508 | 250 | 1100 | | 1110 |
| FLUIDS | 277 | | | | 1110 |
| | 31785 | 250 | 1100 | | |
| HARDWARE | 31785 | | | | |
| 5% RESERVE | 1589 | | | | |
| FSE | 250 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 39227 | | CG LOCATION | | 1074.9 |
| MARGIN | 2773 | | CG MARGIN | | 63.1 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1011.8 |

LaRC SSFO

title

## MOD 6 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the sixth module flight are listed. The overall C.G. location for the combined payload is 32.7 inches within allowable limits. There are 106 pounds of unused STS lift capability and 1652 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 13
MOD-6
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| U.S. MODULE 6 (LAB 15 RACKS) | 29436 | 250 | 1100 | | 1110 |
| CUPOLA | 3317 | 700 | 660 | | 878 |
| FLUIDS | 277 | | | | 1110 |
| | 33030 | 950 | 1760 | | |
| HARDWARE | 33030 | | | | |
| 5% RESERVE | 1652 | | | | |
| FSE | 950 | | | | |
| ATTACH FITTINGS | 1760 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 41895 | | CG LOCATION | | 1049.0 |
| MARGIN | 106 | | CG MARGIN | | 32.7 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1016.2 |

## Logistics Manifest

The assembly elements, weights, associated FSE and C.G. locations for a sample logistics flight are listed. The logistics brought up at this time will be driven by actual outfitting requirements in the hab and lab modules . There is sufficient room in the module flights for the required PMC logistics if full user utilization of the modules at PMC is not assumed. This may eliminate the need for a dedicated logistics flight at this point in the assembly sequence.

# Integrated Assembly Sequence Manifest

| L-1 STS ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| PRESSURIZED LOGISTICS MODULE | 20616 | | 1100 | | 1125.5 |
| UNPRESSURIZED LOG. CARRIER | 13284 | | 1100 | | 906.9 |
| | 33900 | 0 | 2200 | | |
| HARDWARE | 33900 | | | | |
| MANAGER'S RESERVE | 1477 | | | | |
| FSE | 0 | | | | |
| ATTACH FITTINGS | 2200 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 42000 | | CG LOCATION | | 1009.6 |
| MARGIN | 0 | | CG MARGIN | | -7.1 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1016.7 |

## TR7 Packaging

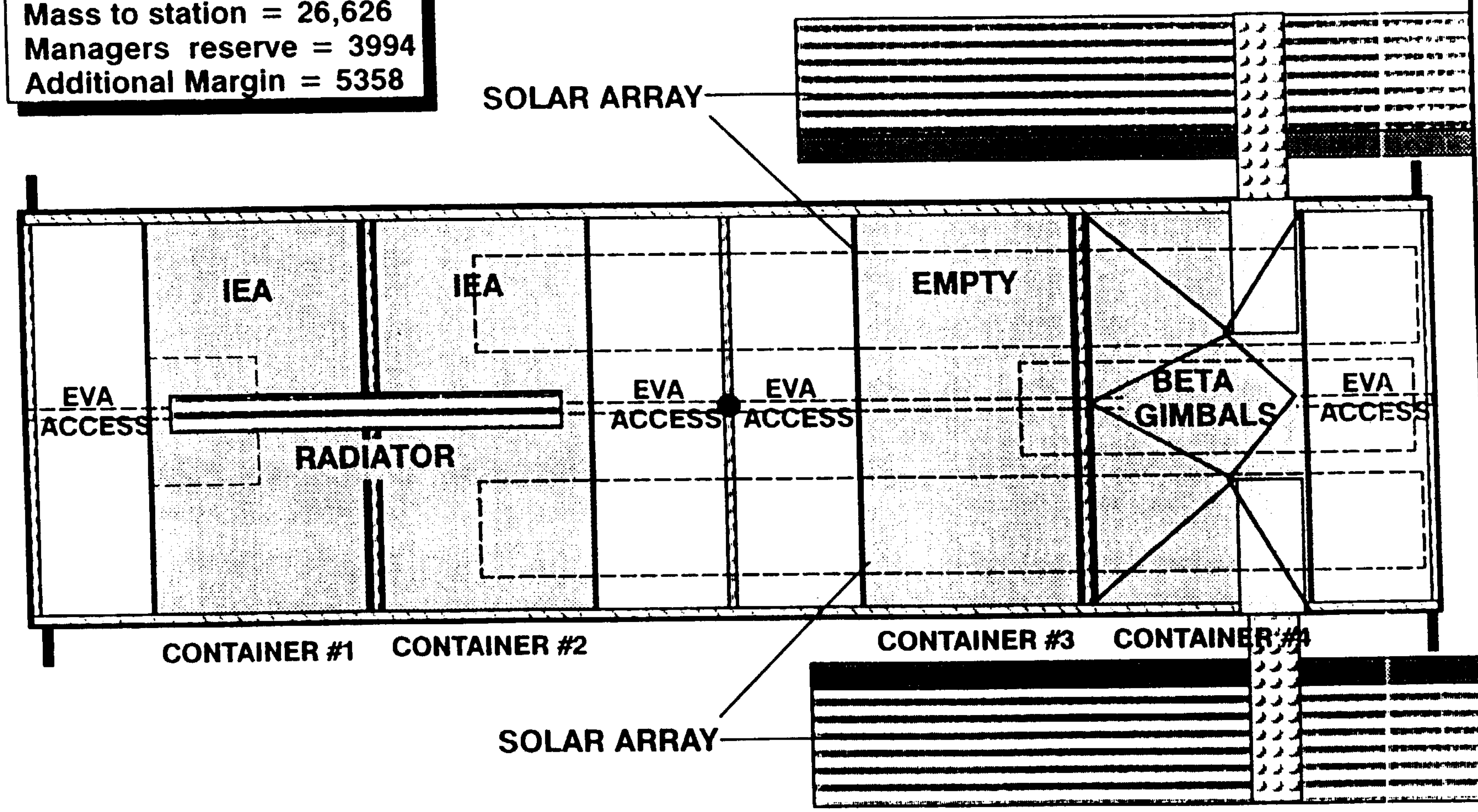
The seventh truss structure flight brings up the outer port power system elements. All elements required to produce 18.75 KW of power are included on this flight. The Integrated Equipment Assembly (IEA) is packaged in two container sections at one end of the integrated structure. The PV array beta gimbals are located in container section four. Packaged internally are two PV arrays and the deployable radiator. .

NASA — FREEDOM

# Pre–Integrated Structure Packaging

## TR–7

Mass to station = 26,626
Managers reserve = 3994
Additional Margin = 5358



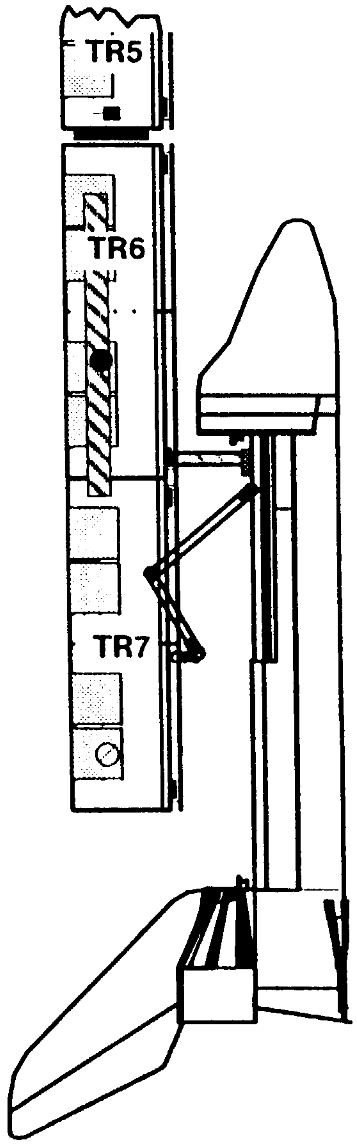

LaRC SSFO

M87PACKNEW

## TR7 Operations

The operations involved in deploying and assembling the seventh integrated structural element of the space station can be approached from two directions. The first approach would involve using the station MT and MSC to translate the new section of integrated truss out to where it will be attached . The second approach involves flying the station in a gravity gradient mode and attaching the orbiter to the TR6 station element. The TR7 integrated structure is then removed from the orbiter cargo bay with the RMS and attached to TR6. The orbiter then detaches from TR6 and attaches to TR7. From this position the RMS removes and attaches internally stored appendages with EVA assistance.

# Truss Flight Seven Operations




STEPS 1 TO 3

1) Berth to TR6.

2) Remove TR7 from cargo bay and rotate.

3) Berth TR7 to TR6. EVA secure TR7 to TR6.

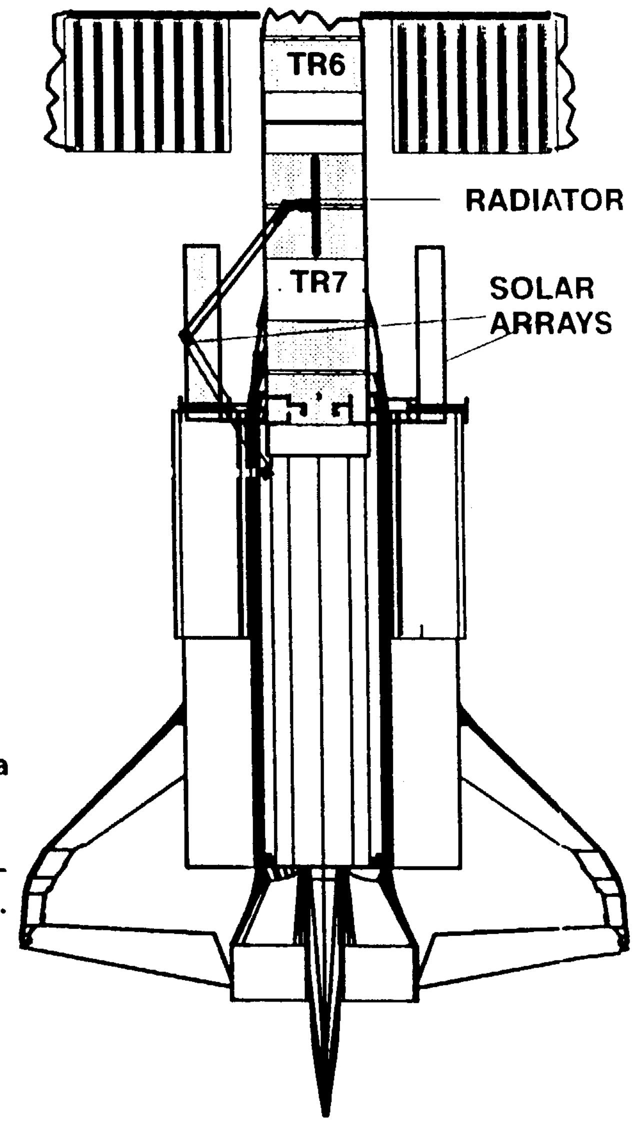
4) Release from TR6 then berth to end of TR7

5)Remove radiator and solar arrays from structure and place in cargo bay.

6)Attach radiator to IEA manifold and deploy.

7) Attach solar arrays to beta joints.

8) Check out systems, separate and deploy solar arrays.




STEPS 4 TO 8

truss7ops

## TR7 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the seventh truss section flight are listed. The overall C.G. location for the combined payload is 0.6 inches within allowable limits. There is 5358 pounds of unused STS lift capability and 3994 pounds of managers reserve available.

NASA — FREEDOM

# Integrated Assembly Sequence Manifest

FLIGHT 14
TR-7
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| IEA | 12144 | | | CON#1&2 | 1146 |
| SOLAR ARRAYS | 3636 | 363 | | TUBE | 882 |
| BETA GIMBALS | 882 | | | CON#4 | 810 |
| RADIATOR (DEPLOYABLE) | 1104 | 136 | | TUBE | 840 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 600 | | | | 1014 |
| | 26626 | 499 | 1100 | | |
| HARDWARE | 26626 | | | | |
| 15% RESERVE | 3994 | | | | |
| FSE | 499 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 36642 | | | CG LOCATION | 1001.9 |
| MARGIN | 5358 | | | CG MARGIN | 0.6 |
| STS CAPABILITY TO 190 NMI | 42000 | | | ALLOWABLE CG LIMIT | 1001.3 |

LaRC SSFO

## TR8 Packaging

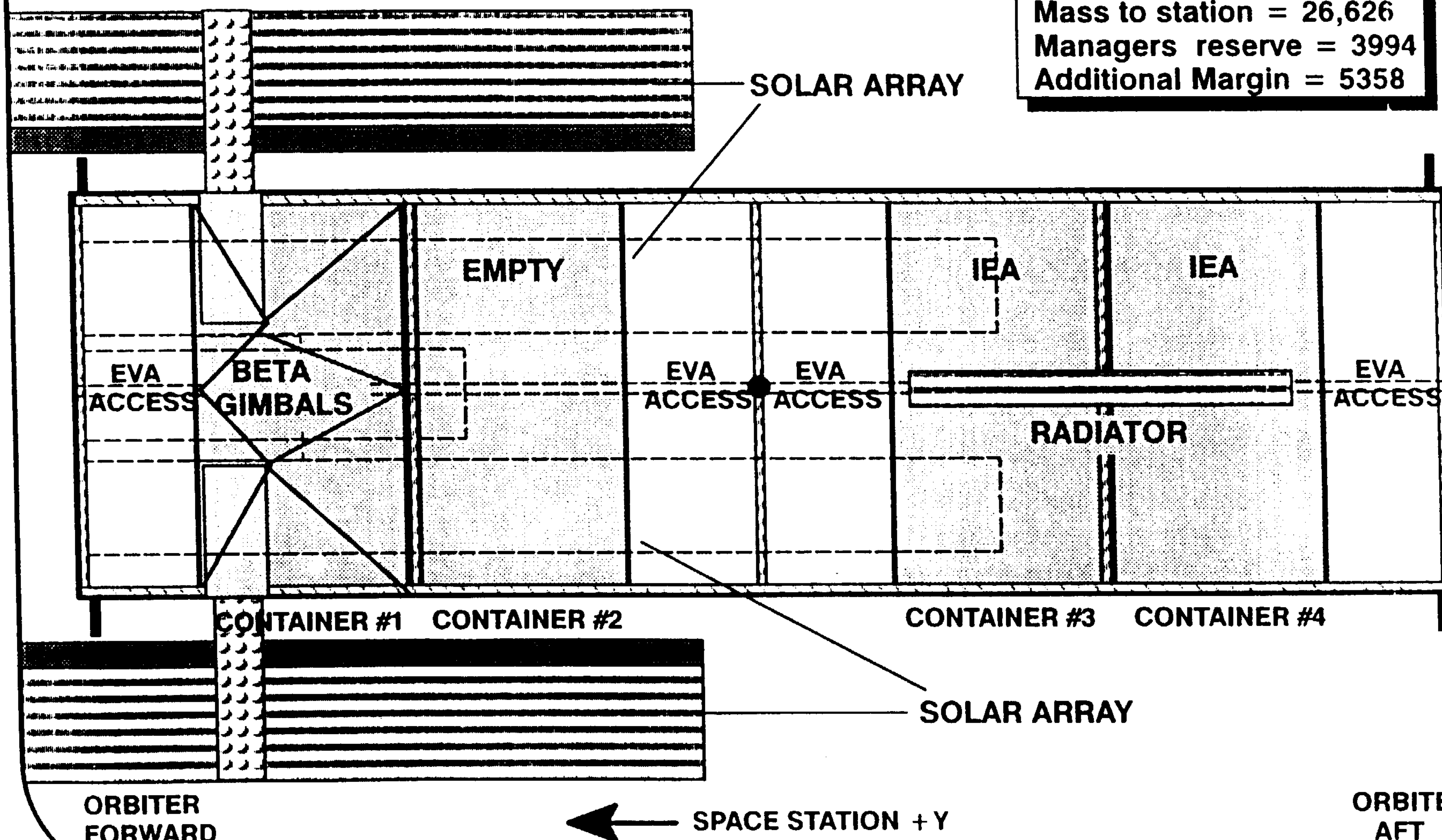
The eighth truss structure flight brings up the outer starboard power system elements. All elements required to produce 18.75 KW of power are included on this flight. The Integrated Equipment Assembly (IEA) is packaged in two container sections at one end of the integrated structure. The PV array beta gimbals are located in container section one. Packaged internally are two PV arrays and the deployable radiator.

NASA — FREEDOM

# Pre-Integrated Structure Packaging

## TR-8

Mass to station = 26,626
Managers reserve = 3994
Additional Margin = 5358



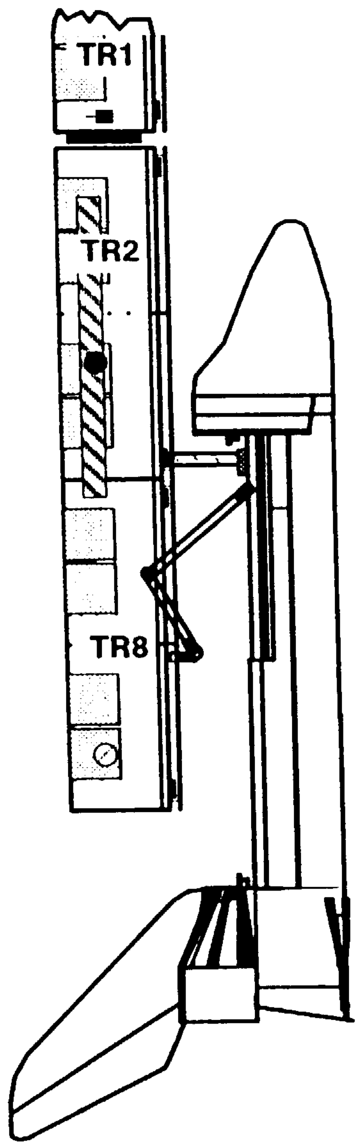

LaRC SSFO

MB8PACKNEW

## TR8 Operations

The operations involved in deploying and assembling the eighth integrated structural element of the space station can be approached from two directions. The first approach would involve using the station MT and MSC to translate the new section of integrated truss out to where it will be attached . The second approach involves flying the station in a gravity gradient mode and attaching the orbiter to the TR2 station element. The TR8 integrated structure is then removed from the orbiter cargo bay with the RMS and attached to TR2. The orbiter then detaches from TR2 and attaches to TR8. From this position the RMS removes and attaches internally stored appendages with EVA assistance.

# Truss Flight Eight Operations




STEPS 1 TO 3

1) Berth to TR2.

2) Remove TR8 from cargo bay and rotate.

3) Berth TR8 to TR2. EVA secure TR8 to TR2.

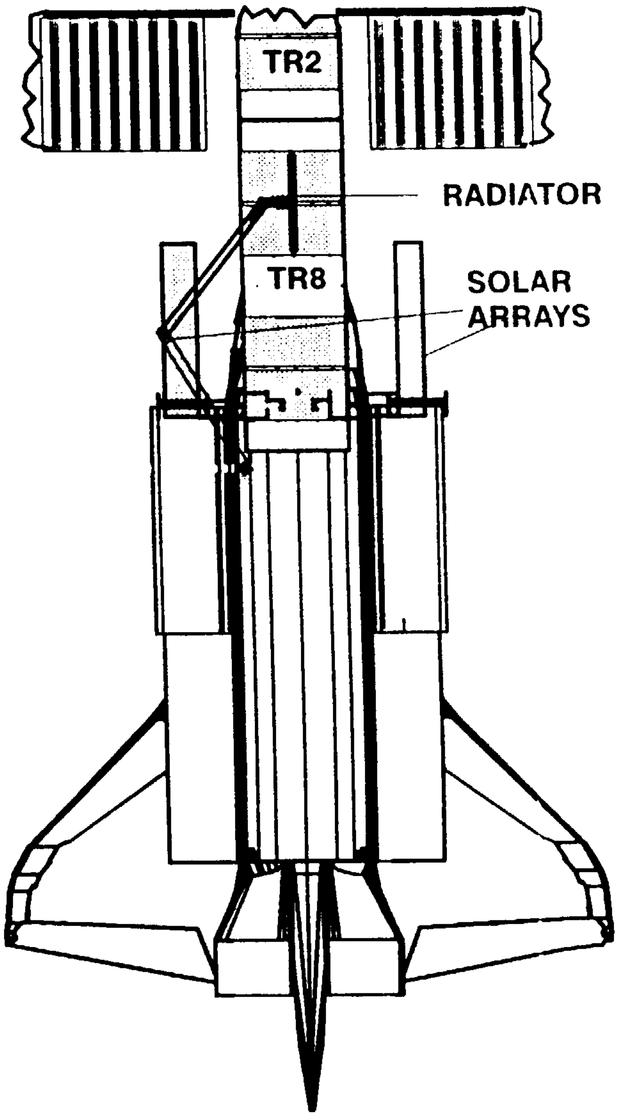
4) Release from TR2 then berth to end of TR8

5)Remove radiator and solar arrays from structure and place in cargo bay.

6)Attach radiator to IEA manifold and deploy.

7) Attach solar arrays to beta joints.

8) Check out systems, separate and deploy solar arrays.




STEPS 4 TO 8

truss8ops

## TR8 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the eighth truss section flight are listed. The overall C.G. location for the combined payload is 0.6 inches within allowable limits. There is 5358 pounds of unused STS lift capability and 3994 pounds of managers reserve available.

NASA — FREEDOM

# Integrated Assembly Sequence Manifest

FLIGHT 15
TR-8
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| IEA | 12144 | | | CON#3&4 | 1146 |
| SOLAR ARRAYS | 3636 | 363 | | TUBE | 882 |
| BETA GIMBALS | 882 | | | CON#1 | 810 |
| RADIATOR (DEPLOYABLE) | 1104 | 136 | | TUBE | 840 |
| STRUCTURE | 8260 | | 1100 | | 1014 |
| UTILITIES | 600 | | | | 1014 |
| | 26626 | 499 | 1100 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 26626 | | |
| 15% RESERVE | 3994 | | |
| FSE | 499 | | |
| ATTACH FITTINGS | 1100 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 36642 | CG LOCATION | 1001.9 |
| MARGIN | 5358 | CG MARGIN | 0.6 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 1001.3 |

LaRC SSFO

## MOD 7 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the seventh module flight are listed. The overall C.G. location for the combined payload is 3.1 inches within allowable limits. All STS lift capability is used but 1716 pounds of managers reserve is available.

NASA FREEDOM

# Integrated Assembly Sequence Manifest

FLIGHT 16
MOD-7
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| JEM MODULE | 33240 | 435 | 1100 | | 1042.1 |
| DDCU'S & HT | 1086 | | | | 1234.9 |
| | 34326 | 435 | 1100 | | |
| HARDWARE | 34326 | | | | |
| 5% RESERVE | 1716 | | | | |
| FSE | 435 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 42080 | | CG LOCATION | | 1019.5 |
| MARGIN | -80 | | CG MARGIN | | 3.1 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1016.4 |

LaRC SSFO

## MOD 8 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the eighth module flight are listed. The overall C.G. location for the combined payload is 3.1 inches within allowable limits. All STS lift capability is used but 1716 pounds of managers reserve is available.

# Integrated Assembly Sequence Manifest

FLIGHT 17
MOD-8
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| ESA MODULE | 33240 | 435 | 1100 | | 1042 |
| DDCU'S & HT | 1086 | | | | 1239.5 |
| | 34326 | 435 | 1100 | | |
| HARDWARE | 34326 | | | | |
| 5% RESERVE | 1716 | | | | |
| FSE | 435 | | | | |
| ATTACH FITTINGS | 1100 | | | | |
| MSC WORKSTATION | 80 | | | | |
| EVA RESERVE | 2873 | | | | |
| DOCKING FIXTURE | 1550 | | | | |
| SUBTOTAL | 42080 | | CG LOCATION | | 1019.5 |
| MARGIN | -80 | | CG MARGIN | | 3.1 |
| STS CAPABILITY TO 190 NMI | 42000 | | ALLOWABLE CG LIMIT | | 1016.4 |

## MOD 9 Manifest

The assembly elements, weights, associated FSE and C.G. locations for the ninth module flight are listed. The overall C.G. location for the combined payload is 2.1 inches within allowable limits. There are 11611 pounds of unused STS lift capability and 1034 pounds of managers reserve available.

# Integrated Assembly Sequence Manifest

FLIGHT 18
MOD-9
STS

| ELEMENT | MASS | FSE | ATTACH | LOCATION | CG |
|---|---|---|---|---|---|
| JEM ELM PS | 10194 | | 1100 | | 1186.7 |
| JEM ELM ES | 1686 | | 880 | | 1049.9 |
| EXPOSED FACILITY #1 | 4989 | | 1100 | | 916.4 |
| EXPOSED FACILITY #2 | 3803 | | 1100 | | 814.1 |
| | 20672 | 0 | 4180 | | |

| | | | |
|---|---|---|---|
| HARDWARE | 20672 | | |
| 5% RESERVE | 1034 | | |
| FSE | 0 | | |
| ATTACH FITTINGS | 4180 | | |
| MSC WORKSTATION | 80 | | |
| EVA RESERVE | 2873 | | |
| DOCKING FIXTURE | 1550 | | |
| SUBTOTAL | 30389 | CG LOCATION | 994.4 |
| MARGIN | 11611 | CG MARGIN | 2.1 |
| STS CAPABILITY TO 190 NMI | 42000 | ALLOWABLE CG LIMIT | 992.3 |

## Assembly Sequence Weight Comparison

A weight comparison between the baseline space station assembly sequence and the integrated space station assembly sequence is given. The weight given for the transverse boom structure for the baseline includes all the truss work and station interface adapters for a total of 11,700 pounds. The equivalent transverse boom structure for the integrated station is made up of eight 44' hybrid isogrid sections yielding a weight of 66,000 pounds. The total spacecraft weight for the baseline station including all systems, structure and modules is 490,200 pounds. The equivalent weight for the integrated station is 537,600 pounds with the increase in weight coming from the additional structural weight of the transverse boom. Total Flight Support Equipment (FSE) and attach fittings for the baseline assembly sequence totals 107,050 pounds over the 18 assembly flights. This includes four outfitting flights using 10,000 pound logistics modules as module rack carriers. The integrated assembly sequence requires 37,900 pounds of FSE/attach fittings for the equivalent on orbit functionality. The ratio of on orbit station mass to FSE/attach fittings for the baseline sequence is 4.5 while the corresponding ration for the integrated sequence is 14.1 indicating a gain in efficiency in manifesting and packaging. Total weight to orbit for the 18 assembly flights is 597,250 for the baseline sequence and 575,500 for the integrated sequence with the difference in weight corresponding to extra weight margin for the integrated sequence.

# Assembly Sequence Weight Comparison

| | BASELINE | INTEGRATED ASSEMBLY |
|---|---|---|
| Transverse Boom Structure | 11,700 | 66,000 |
| Total Spacecraft | 490,200 | 537,600 |
| FSE / Attach Fittings | 107,050 | 37,900 |
| Total Weight to Orbit (excludes EVA reserve, manager reserve, docking module & FTS workstation) | 597,250 | 575,500 |

**A 70,000 pound reduction in flight support equipment and attach fittings enables more weight to be allocated to on orbit station weight thus increasing the efficiency of the assembly sequence.**

**All totals and weights based on 18 module/truss assembly flights. No logistics flights are included. Weights are in pounds.**

## Assembly Sequence Margin Comparison

A comparison of Center of Gravity (C.G.), weight, reserve, EVA and volume margins between the baseline and integrated assembly sequences was made. Both sequences had positive C.G. margins but on average the integrated sequence had a larger C.G. margin. The weight margin (unused STS lift capability) on the baseline sequence is negative on two flights with a total 18 flight margin of 36,026 pounds. The integrated sequence has no negative margins allowing a total 18 flight margin of 47,460 pounds. The baseline sequence consistently used a five percent managers reserve on each flight resulting in an 18 flight total of 26,359 pounds. The integrated sequence used a fifteen percent reserve on truss flights and a five percent reserve on module flights resulting in an 18 flight total of 49,810 pounds. The baseline sequence has several flights where EVA and volume limits are exceeded while the integrated sequence always stays within EVA and volume margins by virtue of being pre-integrated in a fixed volume.

# Assembly Sequence Margin Comparison

| Flight Number | C.G. Margin (in) | | Weight Margin | | Mngrs Reserve | | EVA Margin | | Volume Margin | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | I | B | I | B | I | B | I | B | I |
| 1 | 8 | 14 | 1731 | 1077 | 1482 | 4544 | - | + | + | + |
| 2 | 2 | 11 | 2189 | 4270 | 878 | 4136 | - | + | - | + |
| 3 | 8 | 1 | 3160 | 2011 | 1335 | 4401 | - | + | - | + |
| 4 | 8 | 14 | 399 | 999 | 1480 | 4531 | + | + | - | + |
| 5 | 8 | 26 | 956 | 3045 | 1113 | 4288 | - | + | - | + |
| 6 | 8 | 11 | 250 | 4270 | 1371 | 4136 | + | + | - | + |
| 7 | 2 | 41 | 999 | 134 | 1665 | 1677 | + | + | + | + |
| 8 | 40 | 1 | 5508 | 768 | 1492 | 1547 | + | + | - | + |
| 9 | 2 | 42 | 2291 | 54 | 1556 | 1677 | + | + | + | + |
| 10 | 2 | 63 | -1403 | 2773 | 1779 | 1589 | + | + | + | + |
| 11 | 2 | 61 | -915 | 2773 | 1625 | 1589 | + | + | - | + |
| 12 | 2 | 63 | 702 | 2773 | 1595 | 1589 | + | + | - | + |
| 13 | 2 | 33 | 0 | 106 | 1685 | 1652 | - | + | + | + |
| 14 | 2 | 1 | 0 | 5358 | 1716 | 3994 | + | + | + | + |
| 15 | 2 | 1 | 0 | 5358 | 1716 | 3994 | + | + | + | + |
| 16 | 2 | 3 | 11691 | 0 | 1034 | 1716 | + | + | + | + |
| 17 | 8 | 3 | 3182 | 0 | 1446 | 1716 | - | + | - | + |
| 18 | 8 | 2 | 5286 | 11691 | 1391 | 1034 | - | + | - | + |
| Totals | | | 36,026 | 47,460 | 26,359 | 49,810 | | | | |

B = Baseline, I = Integrated Assembly, Weights in pounds.

## Potential Available Margin for Weight Growth

The preliminary nature of this study dictated that conservative estimates be used in planning and manifesting the assembly sequence. There is potentially over 125,000 pounds of weight margin built into the assembly sequence to accommodate weight growth due to design maturity and overlooked hardware. 47,460 pounds of this margin is available via unused orbiter lift capability. Another 49,810 pounds was set aside as "managers reserve" in the manifests. The manifest used an 8260 pound weight for the isogrid structure when in fact the actual estimate was just under 6000 pounds resulting in 18,336 pounds of isogrid structure margin over eight assembly flights. The weight estimates for the integrated subsystems did not exclude structure such as universal pallets designed to absorb orbiter loads. Since the isogrid structure will be used to carry the orbiter loads, about 12,000 pounds of secondary structure can be deleted from the subsystem weights.

# Potential Available Margin for Weight Growth

| | | |
|---|---|---|
| Flight Margin | = | 47,460 |
| Managers Reserve | = | 49,810 |
| Structure Margin | = | 18,336 |
| Universal Pallets | = | 12,000 |
| Total Potential Margin | = | 127,606 |

# Assembly Sequence Comparison

Additional comparisons of the two sequences are given. Both sequences have the same number of flights to MTC and AC. As was stated earlier, the 14 flights it takes to achieve PMC for the integrated sequence could be reduced by one flight if the additional module rack volume is initially utilized for logistics instead of payloads. The baseline requires one less "truss" flight and one more "module" flight to AC as compared to the integrated sequence for a total of 18 flights. The length of the transverse boom is reduced by about 21 meters for the integrated station and would require an additional "truss" flight to get closer to the baseline dimension. The integrated sequence has 104 module racks on orbit by PMC where the baseline sequence has just 80 modules racks at AC. These extra racks can be used to eliminate the first logistics flight as described earlier. Both sequences achieve 37.5 KW capability at flight 6 while 75 KW is achieved at flight 14 for the baseline and flight 15 for the integrated sequence.

NASA FREEDOM

# Assembly Sequence Comparison

| | BASELINE | INTEGRATED ASSEMBLY |
|---|---|---|
| Flights to MTC | 7 | 7 |
| Flights to PMC | 13 | 14 |
| Flights to AC | 18 | 18 |
| “Truss” Flights | 7.5 | 8.5 |
| “Module” Flights | 10.5 | 9.5 |
| “Alpha to Alpha” | 75 m | 54 m |
| U.S. Racks at AC | 80 | 104 |
| 37.5 kW Power | 6 | 6 |
| 75 kW Power | 14 | 15 |

LaRC SSFO

comparison

## Assembly Sequence Summary

The primary purpose of looking at the design and assembly of a pre-integrated space station was to reduce the amount of on orbit integration and EVA as compared to current baseline space station concept. The number of assembly flights and weight of the station were of secondary importance but it appears that the integrated approach can maintain the baseline number of flights to assembly complete while improving EVA, weight, volume and C.G. margins. The large reduction in FSE and attach fittings yield extra weight margin that can be used for future system weight growth. The integrated approach allows an active spacecraft after the first assembly flight while the baseline design does not go active till the third assembly flight.

# Assembly Sequence Summary

- The integrated approach can maintain the baseline number of flights to assembly complete while improving EVA, weight and C.G. margins.

- The integrated approach reduces the sensitivity of the assembly sequence to weight variations.

## Growth Issues

Several issues associated with growing the integrated space station have been identified. The ability of the alpha joint to handle the extra weight associated with the integrated structure and growth power systems must be evaluated. The interfaces between the isogrid structure and growth structure must be developed. Growing the radiators in the +X direction is complicated by the pre-integrated nature of the beta joint and possible interference with the growth module pattern.. Addition of new utilities and where they will go is another growth issue that needs to be addressed. Some equipment initially located on the transverse boom (such as the C&T system) will be required to be moved to the upper boom. The relocation of these pre-integrated systems requires further study.

# Growth Issues

- SARJ structural and power load limitations
- Isogrid / 5M Erectable Truss structural interfaces
- Restriction of forward TCS radiator growth in 6 module +/–Y option
- Augmentation of subsystem lines on orbit vs. AC growth scars
- Distribution of utilities to growth modules
- Relocation of C&T pallet to upper keel

– This Page Intentionally Left Blank –

# Summary and Recommendations

– This Page Intentionally Left Blank –

## Summary and Recommendations

The pre-integrated isogrid structural concept that was evaluated appears to be technically feasible. Although heavier than erectable truss, the isogrid structure is sized to withstand launch loads fully integrated, thus eliminating or reducing on-orbit integration and EVA requirements. However, additional detailed studies in the areas of structural design and configurations (including non-isogrid structures), assembly, and on-orbit operations must be conducted prior to a finalization of technical results and recommendations.

# Acknowledgments

The authors would like to acknowledge the input, guidance, and direction offered by the SSFO Systems Engineering Analysis Office manager Richard Russell. The authors also wish to acknowledge the help of the following people in the preparation of this report: Pat Cosgrove of Lockheed Engineering & Sciences Co. for his work in the thermal analysis section of this report, Ed Swanson, also of Lockheed, for his help in structural design concepts, and Laura Brewer of Analytical Mechanics Associates, Inc., for her help in the manifesting of the assembly flights.

NASA
National Aeronautics and Space Administration

# Report Documentation Page

| | | |
|---|---|---|
| 1. Report No. NASA TM-102780 | 2. Government Accession No. | 3. Recipient's Catalog No. |

4. Title and Subtitle

Pre-Integrated Structures for Space Station Freedom

5. Report Date

February 1991

6. Performing Organization Code

7. Author(s)


Jonathan N. Cruz, Donald W. Monell, Philip Mutton,
Patrick A. Troutman


8. Performing Organization Report No.

10. Work Unit No.

476-14-15-01

9. Performing Organization Name and Address

NASA Langley Research Center
Hampton, Virginia 23665-5225

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes


Jonathan N. Cruz, Langley Research Center, Hampton, Virginia
Donald W. Monell, Langley Research Center, Hampton, Virginia
Philip Mutton, Lockheed Engineering & Sciences Company, Hampton, Virginia
Patrick A. Troutman, Langley Research Center, Hampton, Virginia


16. Abstract


An in-space construction (erectable) approach to assembling Freedom is planned but the increasing complexity of the station's design along with a decrease in shuttle capability over the past several years has led to an assembly sequence that requires more resources (EVA, lift, volume, etc.) than the shuttle can provide given a fixed number of flights. One way to address these issues is to adopt a "pre-integrated" approach to assembling Freedom. A pre-integrated approach combines station primary structure and distributed systems into discreet sections that are assembled and checked out on the ground. The section is then launched as a single structural entity on the shuttle and attached to the orbiting station with a minimun of EVA. This report discusses the feasibility of a pre-integrated approach to assembling Freedom. The structural configuration, packaging and shuttle integration of discreet pre-integrated elements for Freedom assembly are discussed. It is shown that the pre-integrated approach to assembly reduces EVA and increases shuttle margin with respect to mass, volume and center of gravity limits when compared to the baseline Freedom assembly sequence.


17. Key Words (Suggested by Author(s))

Pre-Integrated Structure
Isogrid

18. Distribution Statement

Unclassified - Unlimited

Subject Category 18

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 277 | A13 |