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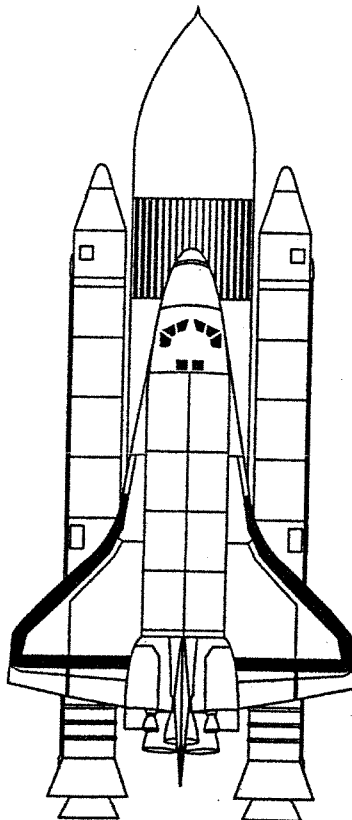
Space Shuttle External Tank

DECEMBER 1997

Configuration and
Operation

Volume I

System Definition Handbook SLWT



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**Configuration and Operation
Volume I**

**System
Definition
Handbook
SLWT**

December 1997

Space Shuttle External Tank

**Lockheed Martin
Michoud Space Systems
New Orleans, Louisiana**

FOREWARD

This document revision is prepared and submitted in accordance with Data Requirement SE61 of the Space Shuttle External Tank Information Requirements Document Production - Increment III, DPD #660 dated March 31, 1989 incorporated in Contract NAS8-36200.

This Handbook presents a compilation of system configuration and operations. The information contained in this Handbook is based on design information, drawings, and analyses completed prior to December 1997. This Handbook is not intended to form requirements or criteria nor place any constraints or restrictions upon design.

Glossary

ACRONYMS AND ABBREVIATIONS

AOA	Abort-Once-Around	MLP	Mobile Launch Platform
ATO	Abort-to-Orbit	MST	Mobile Service Tower
BSTRA	Ball-Strut-Tie-Rod-Assembly	NASA	National Aeronautics and Space Administration
CDF	Confined Detonating Fuse	n mi	Nautical Mile (s)
CE	Contingency Equipment	NPSP	Net Positive Suction Pressure
CRES	Corrosion Resistance Steel	NSI	NASA Standard Initiator
CSE	Common Support Equipment	NSTS	National Space Transportation System
EB	External Tank/Solid Rocket Booster	OD	Outside Diameter
ECO	Engine Cut-Off	OI	Operational Instrumentation
ECS	Environmental Conditioning System	OMS	Orbital Maneuvering System
EMC	Electromagnetic Compatibility	OPF	Orbiter Processing Facility
EMI	Electromagnetic Interference	Orb	Orbiter
EO	External Tank/Orbiter	PCF	Pounds per Cubic Foot
ET	External Tank	PETN	Pentaerythrite
ETCA	External Tank Carrier Assembly	PIC	Pyro Initiator Controller
ETR	Eastern Test Range	PSI	Pounds per Square Inch
FEP	Fluorinated Ethylene Propylene	PSIA	Pounds per Square Inch (Ambient)
FRL	Flame Retardant Latex	PSIG	Pounds per Square Inch (Gauge)
Fwd	Forward	RCS	Reaction Control System
GFP	Government Furnished Property	RDX	Cyclotrimethylene Trinitramine
GH2	Gaseous Hydrogen	RSE	Rotational Support Equipment
GHe	Gaseous Helium	RSS	Range Safety System
GN2	Gaseous Nitrogen	RTLS	Return-to-Launch-Site
GO2	Gaseous Oxygen	S&A	Safe and Arm
GPM	Gallons Per Minute	SAB	Shuttle Assembly Building
GSE	Ground Support Equipment	SCIM	standard cubic inches per minute
GUCA	Ground Umbilical Carrier Assembly	SDH	System Definition Handbook
GUCP	Ground Umbilical Carrier Plate	SE	Support Equipment
He	Helium	SLA	Super Light Ablator
HGDS	Hazardous Gas Detection System	SOFI	Spray-On Foam Insulation
HMX	Cyclotetramethylene Tetranitramine	SRB	Solid Rocket Booster
HNS	Hexanitrostilbene	Sta	Station
ID	Inside Diameter	STA	Structural Test Article
ISS	International Space Station	STE	Special Test Equipment
I/T	Intertank	STS	Space Transportation System
KSC	Kennedy Space Center	TAL	Trans Oceanic Abort Landing
LSC	Linear Shaped Charge	TFE	Tetrafluorethylene
LH2	Liquid Hydrogen	Ti	Titanium
LN2	Liquid Nitrogen	TPS	Thermal Protection System
LO2	Liquid Oxygen	TSE	Transportation and Support Equipment
LPS	Launch Processing System	VAB	Vertical Assembly Building
LWT	Light Weight Tank	VDC	Volts, Direct Current
MA	Martin Ablator	WBS	Work Breakdown Structure
MAF	Michoud Assembly Facility		
MECO	Main Engine Cut-Off		

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1.0 INTRODUCTION

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1. INTRODUCTION

This handbook provides a configuration description and an operations overview of the Space Shuttle External Tank.

1.1 GENERAL

The System Definition Handbook (SDH) provides a technical description of the configuration, layout drawings, and a production overview for the Space Shuttle External Tank (ET). This SDH covers only the ET configuration and does not contain any coverage of other configurations.

1.2 ARRANGEMENT

This SDH has been arranged in two volumes to enhance its usability. Volume I provides a configuration description of the ET. Volume I makes maximum use of illustrations, integrated into the text, to portray the ET and its associated interfaces and equipment. Volume I is standard 8-1/2 x 11 inch size. Volume II provides a compilation of layout drawings depicting the ET design from a system level breakdown. Volume II has been prepared in an 11 x 17 inch size to enhance utilization of the layout drawings.

The cover page of each volume contains a section level index. The first page of each section contains a listing of the primary and secondary level paragraphs contained in that section.

1.2.1 Volume I Contents

Volume I contains 14 sections organized on functional/system basis as listed below. In addition to providing configuration, this volume also briefly describes the transportation, handling, launch site (Kennedy Space Center) and includes a cross reference index of Shuttle/ET performance data.

Section I, Introduction - Briefly describes the arrangement and contents of the SDH.

Section II, Space Shuttle Overview - Provides an overview of the Space Shuttle flight vehicle and its mission.

Section III, External Tank Operations - Describes the ET assembly and delivery, launch sequence, and mission events.

Section IV, External Tank Description - Provides an overall description of the ET and its systems and makes specific reference to appropriate sections for detailed coverage.

Section V, Structures System - Provides a general description of the breakdown of the structures system.

Section VI, LO2 Tank Structure -
Provides a description of the major structural elements and component details of the LO2 Tank.

Section VII, Intertank Structure -
Provides a description of the major structural elements and component details of the Intertank.

Section VIII, LH2 Tank Structure -
Provides a description of the major structural elements and component details of the LH2 Tank.

Section IX, Propulsion System -
Describes the LO2 and LH2 feed system, pressurization, vent system, and the environmental control system.

Section X, Electrical System -
Provides a description of the electrical functions of the operational instrumentation, cabling, electromagnetic compatibility, and lightning protection.

Section XI, Thermal Protection System - Describes the TPS materials, configuration, and launch site closeouts.

Section XII, Interface Hardware -
Describes the ET/Orbiter and ET/SRB interfaces and the transportation, handling, and ground facility interfaces.

Section XIII, Launch Site Facilities/ Equipment - Provides a brief overview of the ET processing flow through transportation and handling.

Section XIV, Production - Provides a brief description of the manufacturing, sequence and handling flow.

1.2.2 Acronyms and Abbreviations

The acronyms and abbreviations used in this SDH are defined in the front of this volume.

2. SPACE SHUTTLE OVERVIEW

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2. SPACE SHUTTLE OVERVIEW

The Space Shuttle is America's Space Transportation System (STS) developed by the National Aeronautics and Space Administration (NASA) to conduct space missions in response to currently projected national and international space program activities. The primary mission of the Space Shuttle is the delivery of payloads to and from Earth's orbit and the deployment of the International Space Station Alpha (ISSA).

2.1 SPACE SHUTTLE VEHICLE

The Space Shuttle is America's most versatile maneuver spacecraft and provides a flexibility never before achieved in space operations. The spacecraft's large cargo capacity and relatively mild launch environment enables it to carry into Earth orbit a variety of payloads, including some which could not be launched before because of size, weight, shape, or sensitivity to launch force limitations.

The Space Shuttle flight vehicle consists of three major elements: a reusable manned Orbiter, an expendable External Tank (ET) containing Orbiter propellant, and two reusable Solid Rocket Boosters (SRBs). The External Tank, the subject of this document, is the largest element of the Space Shuttle. It serves as the backbone structure for attachment of the Orbiter and SRBs and also contains and delivers propellants for the three Orbiter main engines. The External Tank must accommodate the complex stresses created by its own weight and that of the Orbiter prior to launch, then the thrust generated by the Orbiter and the SRBs during launch.

The Space Shuttle is launched in a vertical position using the Orbiter's three main engines and the two SRBs. When the SRBs are expended they are separated from the External Tank, fall into the ocean, and are recovered for reuse. Just prior to orbital insertion, the External Tank is separated, breaks up during reentry, and is not recovered. Two smaller liquid rocket engines place the Orbiter into Earth orbit. After reentry, the unpowered Orbiter lands on a runway like an airplane.

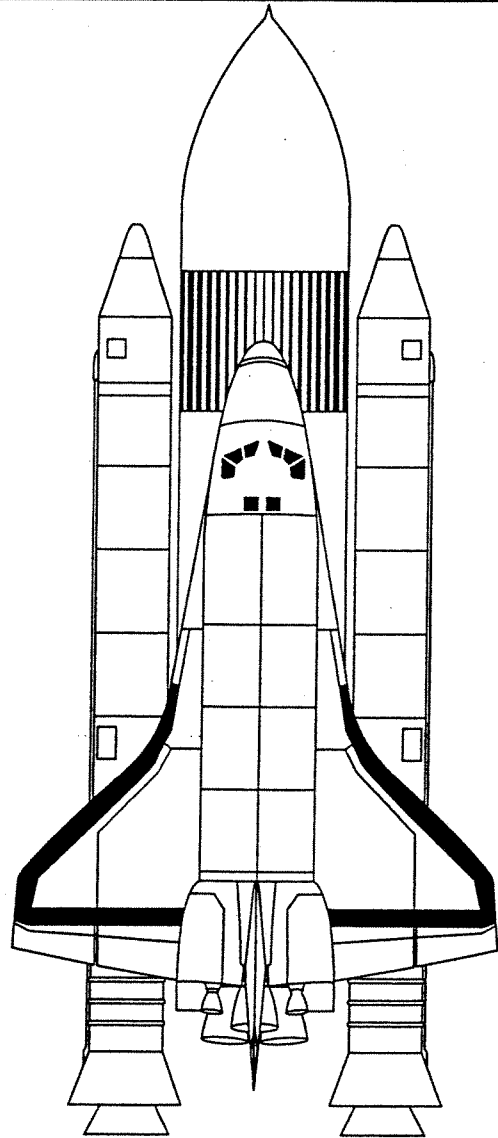


Figure 2-1: Space Shuttle Vehicle

Table 2-1: Space Shuttle Characteristics

	Overall Shuttle	Orbiter
• Length	• 184.2 feet	• 122.2 feet
• Height	• 76.6 feet	• 56.67 feet
• Wingspan	• ---	• 78.06 feet
• Approx. gross lift-off weight (max. payload)	• 4.5 million pounds	• 267,000 pounds
• Landing with max. payload	• ---	• 212,000 pounds

2.1.1 SPACE SHUTTLE ORBITER

The Orbiter can transport into near Earth orbit a three member flight crew, four additional scientific and technical personnel, and a payload. The Orbiter can deliver to orbit single or multi-unit payloads up to 65,000 pounds in its huge 15 by 60 foot cargo bay. It can bring back from Earth orbit payloads weighing up to 32,000 pounds. The Orbiter is 122.2 feet long and has a wingspan of 78.06 feet.

The Orbiter's three main liquid-propellant engines will develop a maximum 375,000 pounds of thrust each at launch. Fuel can be supplied from the External Tank to the three main engines at the rate of 45,283 gallons of liquid hydrogen (LH2) per minute and 16,800 gallons of liquid oxygen (LO2) per minute. Engine thrust, however, can be varied throughout the flight from minimum to full power levels depending on mission needs.

Two Orbital Maneuvering System (OMS) engines in external pods on the aft fuselage provide thrust for orbit insertion, orbit changes, rendezvous, and return to Earth. Reaction control thrusters in the two orbital maneuvering system pods and in a module in the nose section of the forward fuselage provide attitude control in space and precision velocity changes for the final phases of rendezvous and docking or orbit modification. The reaction control thrusters, in conjunction with the Orbiter's aerodynamic control surfaces, also provide attitude control of the Orbiter during reentry. The Reaction Control System (RCS) controls the Orbiter at high altitude and velocity and the aerodynamic control surfaces provide control of the Orbiter at speeds less than Mach 2.

The Orbiter, piloted by the crew but also equipped with an automatic landing system, will land at speeds of between 208 and 226 mph, similar to current high performance aircraft.

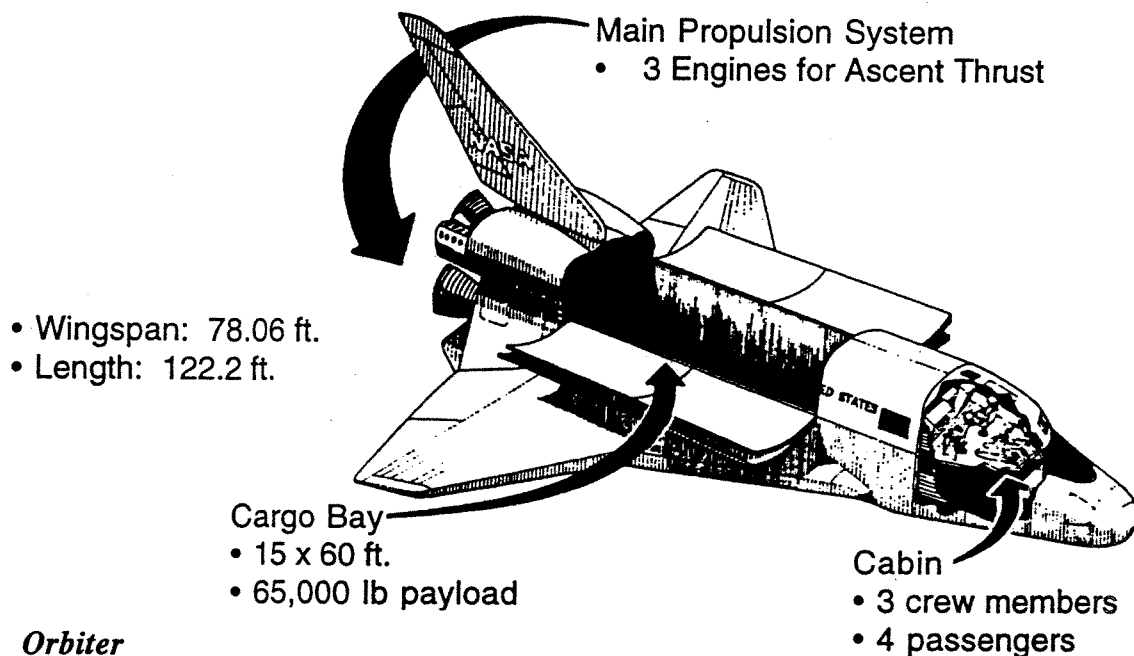


Figure 2-2: Orbiter

2.1.2 SOLID ROCKET BOOSTERS

Two Solid Rocket Boosters (SRBs) will be used for each Space Shuttle flight to provide, along with the Orbiter main engines, the initial ascent thrust to lift the Space Shuttle with its payload from the launch pad to an altitude of about 27.5 miles. Prior to launch, the entire Space Shuttle weight will be supported by the two boosters.

The Solid Rocket Booster is made up of six subsystems: the solid rocket motor, structures, thrust vector control, separation, recovery and electrical and instrumentation subsystems. The overall length of the Solid Rocket Booster is 149.2 feet, and the diameter is 12.2 feet.

The heart of each booster is the motor, the largest solid rocket motor ever flown and the first designed for reuse. It is made up of 11 segments joined together to make four loading segments which will be filled with propellant at the manufacturer's site. The segmented design will permit ease of fabrication, handling and transportation. The segments will be shipped from the manufacturer's site to the launch sites by rail in specially built canisters carried on a flat

rail car. There they will be assembled to make up a complete motor. Each motor, when assembled, will contain about 1.1 million pounds of propellant and at launch, will develop a thrust of 2.9 million pounds.

At burnout, the two Solid Rocket Boosters will be separated from the External Tank by pyrotechnic (explosive) devices and moved away from the Space Shuttle by eight separation motors, four housed in the forward nose frustum and four on the aft skirt. Each of the eight separation motors, fired at solid rocket motor burnout, will develop a thrust of 22,000 pounds for a duration of a little more than one-half second, just enough to move the boosters away from the still accelerating Orbiter and External Tank. Also a part of the system is a device for separating electrical interconnection with the External Tank.

The recovery subsystem consists of parachutes and location aids mounted in the forward section of each booster. The parachutes control the booster's final descent velocity and attitude after separation. The location aids help in the search and retrieval operations for each expended booster and its parachutes.

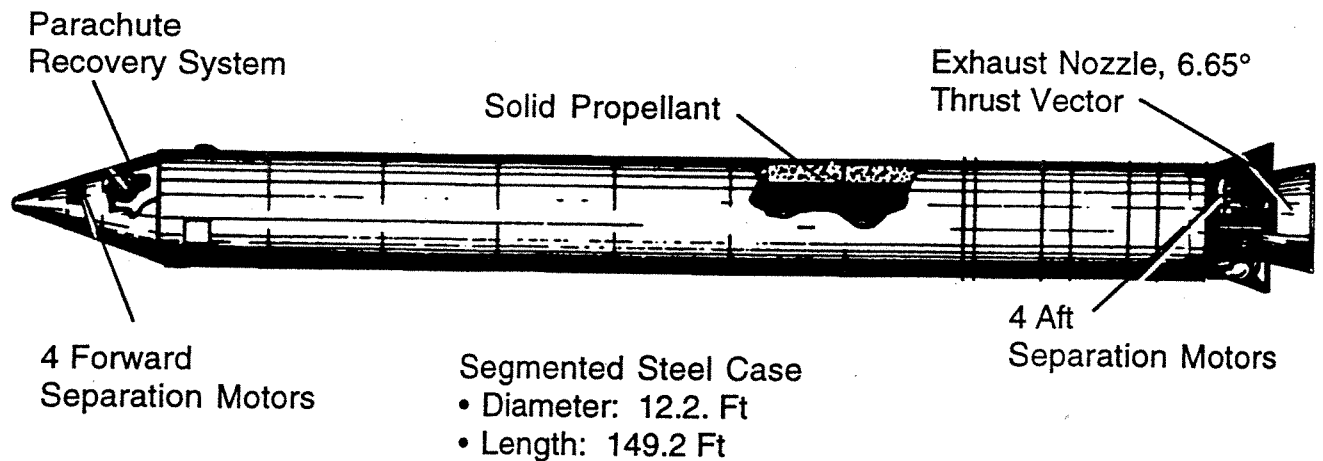


Figure 2-3: Solid Rocket Booster

2.1.3 EXTERNAL TANK

The External Tank (ET) serves a dual role: to provide the structural backbone of the Space Shuttle during launch operations and to contain and deliver liquid hydrogen (LH2) and liquid oxygen (LO2) Propellants for the Orbiter's three main engines. The External Tank is 153.8 feet long and 27.6 feet in diameter. It weighs approximately 57,800 pounds empty and when loaded with propellants at launch weighs approximately 1,674,000 pounds.

The External Tank is separated from the Orbiter just short of orbital velocity at Orbiter's main engine cut-off (MECO). The External Tank pitches away from the Orbiter, tumbles, and breaks up upon reentry and falls within the designated ocean impact area. The External Tank is the only expendable element of the Space Shuttle vehicle. A further discussion of the External Tank is provided in subsequent sections of this handbook.

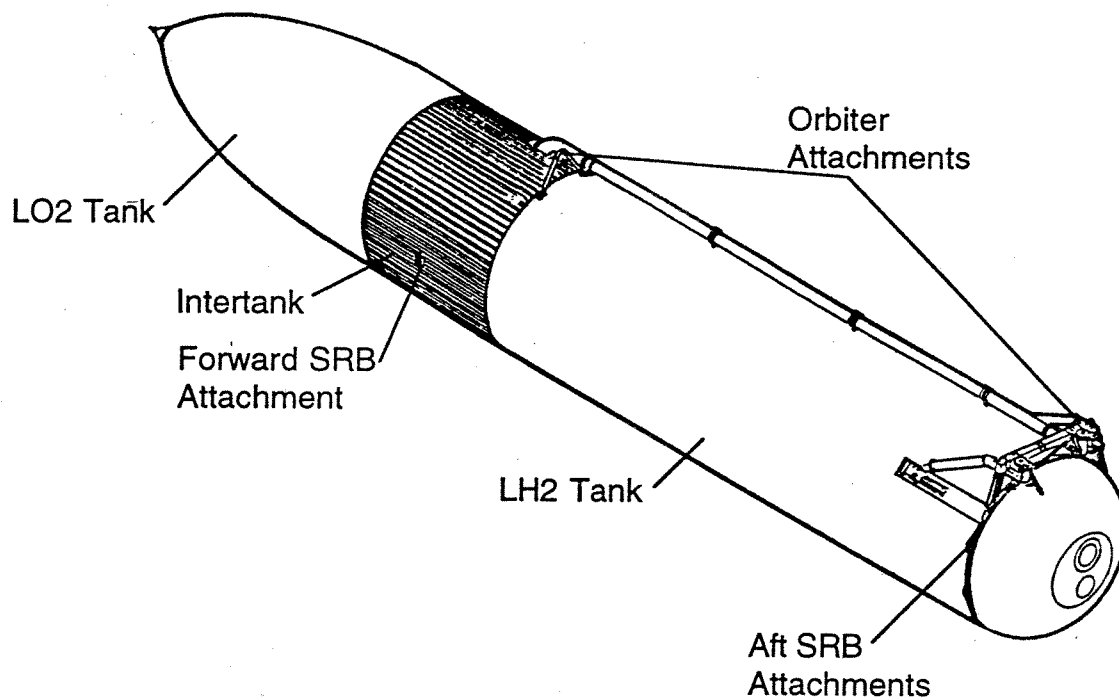


Figure 2-4: External Tank

2.1.4 THRUST MODULATION

The Space Shuttle vehicle is designed to minimize thrust acceleration forces imposed on the flight crew, passengers, and payloads. This is accomplished by the use of variable thrust of the Orbiter's main engines and by selective propellant loading of the Solid Rocket Boosters (SRBs).

Each engine will have three primary levels of thrust or power - minimum, rated and full power. Engine thrust, however, can be varied throughout the range from minimum to full power level depending upon mission needs. Most Space Shuttle flights will be launched at rated power level with each engine developing 375,000 pounds of thrust at sea level. On some Space Shuttle flights where heavy payloads dictate an extra measure of power, up to full power level thrust can be commanded. This level equals 109 percent of rated power. During the latter part of ascent, engine thrust will be reduced to ensure that an acceleration force of no more than three times that of Earth's gravity is reached. This acceleration level, permitted by the throttleable engines, is well under the physical stress limits of non-astronaut scientists who will fly aboard the Space Shuttle. The lowest thrust throttle setting, the minimum power level, equals 65 percent of rated power.

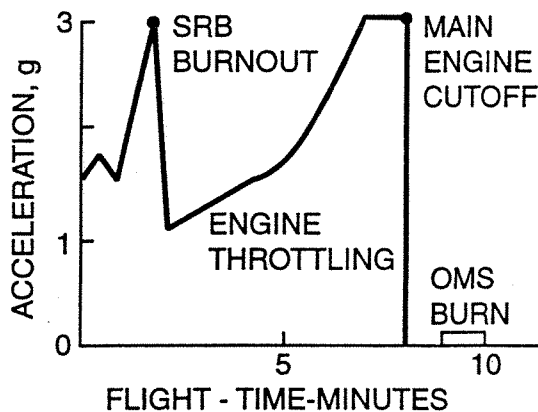


Figure 2-5: Space Shuttle Acceleration Profile (Typical)

Propellant loading of the SRB motor segments is completed in pairs from batches of propellant ingredients to minimize any thrust imbalances between boosters used for a single Space Shuttle flight. The motor segment core shape is designed to cause a regressive thrust 55 seconds into the Space Shuttle flight to prevent overstressing the Space Shuttle vehicle during the critical phase of flight called the period of maximum dynamic pressure.

2.2 SPACE SHUTTLE MISSION

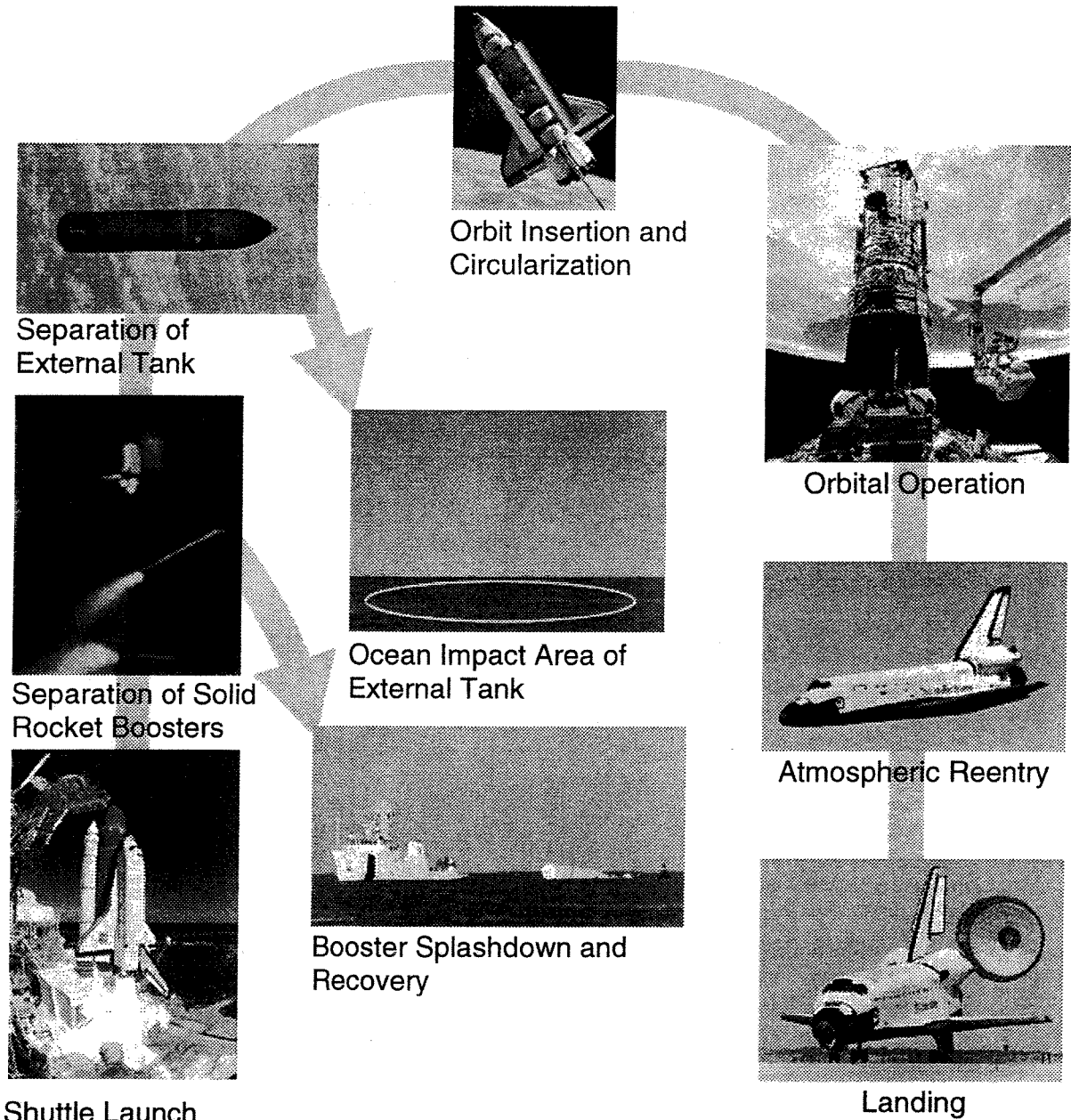
The Space Shuttle systems will be based at the nation's major launch facility to provide access to orbit inclinations required for projected payloads and requirements. Kennedy Space Center (KSC) will be used to launch payloads into orbits of 28.5 to 57 degrees inclination with respect to the equator. (A due east launch from KSC would yield an orbit of about 28.5 degrees.) Range safety criteria restrict the launch directions (azimuths) from the launch site to preclude a released tank or booster from impacting a land area.

The direction of Earth rotation also has a significant bearing on the payload launch capabilities of the Space Shuttle. A due east launch from KSC, using the Earth's easterly rotation as a launch assist, will permit a payload weighing up to 47,000 pounds to be launched. Using recently implemented performance enhancement and the Super Light Weight External Tank (SLWT) permits the Space Shuttle to place ISS payloads up to 36,200 pounds in a 51.6 degree inclination orbit.

2.2.1 MISSION PROFILE

In the launch configuration, the Orbiter and two Solid Rocket Boosters are attached to the External Tank and all are in a vertical position on the launch pad. Each Solid Rocket Booster is attached at its aft skirt to the mobile

At launch, the Orbiter's three main engines, fed liquid hydrogen fuel and liquid oxygen oxidizer from the External Tank, are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the Solid Rocket Boosters. At the proper thrust-to-weight ratio,



launch platform by explosive bolts.

initiators at the holddown bolts are fired to release the Space Shuttle for lift-off.

Figure 2-6: Space Shuttle Mission Sequence

The two Solid Rocket Boosters are jettisoned after burnout, approximately two minutes after lift-off and about 27.5 miles high, and are recovered by means of a parachute recovery system. A homing device on each booster guides recovery craft to it for towing back to shore. The boosters are then refurbished, refueled and made ready for another Space Shuttle flight. The Orbiter main engines continue to burn for approximately six to seven more minutes (eight to nine minutes from liftoff) until the Orbiter is just short of orbital velocity, at which time the engines are shut down and the External Tank jettisoned. During its plunge through the atmosphere, the tank tumbles, breaks up and falls into a predetermined ocean area.

The orbital maneuvering system (OMS) is used to attain the desired orbit, between 100 and 600 nautical miles, and to make any subsequent maneuvers that may be needed during the mission. The crew then begins their payload operations by performing a multitude of assigned tasks, depending upon the purpose of the mission, such as assembly of the ISS, retrieving satellites from Earth orbit, servicing orbiting satellites, conducting experiments in space that cannot be duplicated on Earth, and studying the Earth and deep space from their unique vantage point high above the atmosphere.

After orbital operations are completed, from one to thirty days, deorbiting maneuvers are initiated. The Orbiter will begin to reenter the Earth's atmosphere at a high angle of attack. During reentry, portions of the Orbiter exterior reaches temperatures up to 2,300 degrees Fahrenheit. The Orbiter then levels into horizontal flight at low altitude from an unpowered aircraft-type approach and landing at a speed of between 208 and 226 mph.

The primary Orbiter landing facility is KSC with several alternate landing sites for contingencies. After landing, the Orbiter is towed to ground facilities where any returned payloads are removed. Orbiter refurbishment operations make it ready for another mission in about two weeks.

2.2.2 MISSION DESIGN

The Space Shuttle has the capability to conduct space missions in response to currently projected national and worldwide needs. The primary mission for the Space Shuttle is delivery of payloads to and from Earth orbit. The Space Shuttle system can place payloads up to 65,000 pounds into orbit and return payloads up to 32,000 pounds. Payloads with propulsion stages can place satellites into high Earth orbit or into lunar or planetary trajectories.

Among the multifaceted uses of Space Shuttle during its operational life will be a wide range of applications of the environment of space and space platforms.

The Space Shuttle's uses go far beyond the original plan - improving weather forecasting and communications and Earth-observation satellites that permit a continuous inventory of the world's natural resources and allow for them to be applied more effectively to meeting human needs. The Space Shuttle is also the key element in construction of an ISS. Other Space Shuttle payloads will continue to obtain information on the chemistry and physics of the Sun, stars, planets, and the space through which the Earth is traveling. Still others will extend into space man's earthbound research in such areas as medicine, biology, chemistry, physics, and material manufacturing processes.

Major activity also includes geosynchronous orbits, deep-space missions, elliptical orbits and higher circular orbits. Payloads with such destinations require a propulsion stage in addition to the Space Shuttle. The Space Shuttle will deliver the payload with a propulsion stage to low Earth orbit and will stand by until a successful on-orbit launch is effected. Spinning Solid Upper Stages and Inertial Upper Stages have been developed for this on-orbit launch capability.

The Space Shuttle will not be limited to uses that can be forecast today. Some of these uses could be the key to understanding the physical processes that will allow man to develop unlimited pollution-free power, and to attain knowledge that will lead to new products and industries.

3.0 EXTERNAL TANK OPERATIONS

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3. EXTERNAL TANK OPERATIONS

The flow of operations for the External Tank, because of its function as an integrating element, requires the precise accomplishment of delivery and launch readiness events in unison with other Space Shuttle element.

3.1 ASSEMBLY AND DELIVERY

The External Tank (ET) is provided environmental protection to assure that it is ready for prelaunch activity upon arrival at a launch facility. The ET is manufactured, assembled and given final acceptance testing at the NASA Michoud Assembly Facility in New Orleans, Louisiana. This necessitates a reliable delivery-transportation capability to move assembled ETs to KSC and environmental management to maintain their condition during delivery.

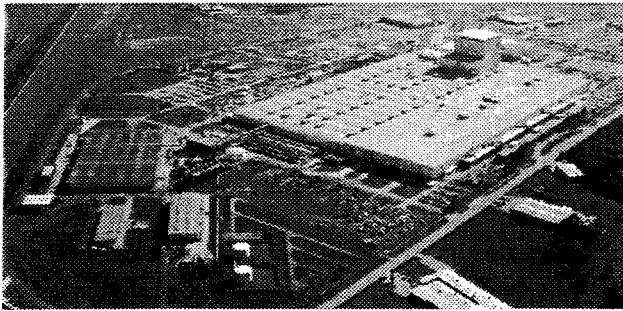


Figure 3-1: Michoud Assembly Facility

3.1.1 DELIVERY EQUIPMENT AND INSTRUMENTATION

ET Assembly Transporter - The ET is mounted on an eight-wheeled ET assembly transporter. The transporter serves as the means of moving the ET system to and from various points of activity during delivery, and remains

with the system until it is moved into the checkout cell in the VAB at KSC.

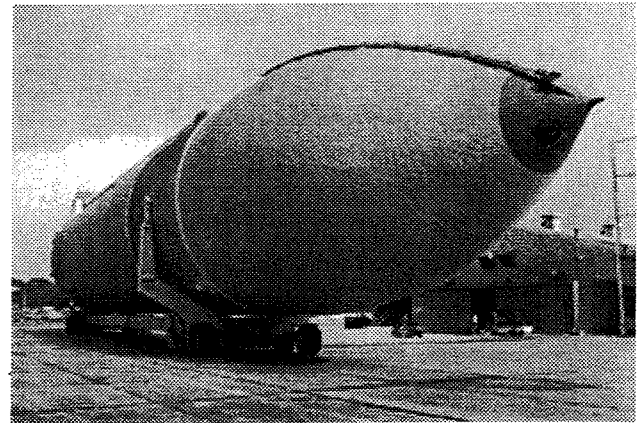


Figure 3-2: External Tank Mounted on Transporter

Environmental Control and Monitoring - External tanks are pressurized at 6 psi with dry GN₂ prior to delivery and maintained through transportation to the VAB at KSC.

Barge Transportation to KSC - The barge transportation system was developed to deliver NASA's Saturn stages to KSC, and both the technique and the barges (modified for the ET system) are used for the delivery of the ETs. A barge requires approximately five days to move an ET system from the Michoud dock to the KSC dock via the Intracoastal Waterway and the Gulf of Mexico around the southern tip of Florida.

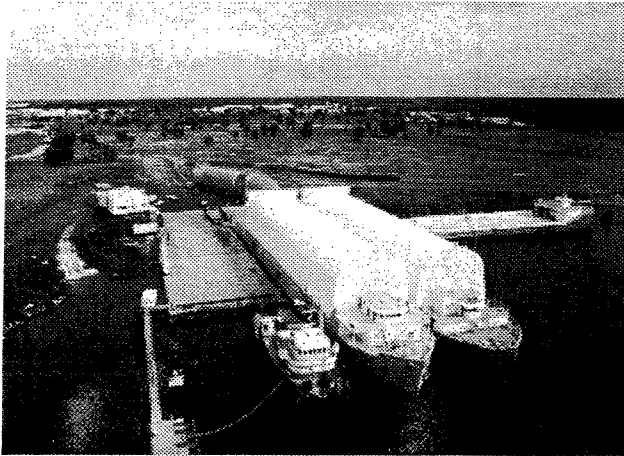


Figure 3-3: Barge Transport of ET to Launch Site

Upon arrival at KSC, the ET system is offloaded and towed on its transporter to the transfer aisle of the Vehicle Assembly Building (VAB). ETs are then rotated vertical in the VAB and placed in the checkout cell for a post move receiving inspection and performance of some of the launch site processing/planned work. Upon completion of this work the ET is moved to the integration cell (HB 1-3) for mate with the SRBs and subsequently the Orbiter.

Recycle of Transportation Equipment - At KSC, the ET transportation equipment and instrumentation are removed and returned to MAF via NASA barge after verification of ET integrity and the ET has been hoisted for installation in the VAB storage or checkout cells.

3.1.2 POST-DELIVERY OPERATIONS AT KSC

The ET is off-loaded using two overhead cranes, one with a capacity of 250 tons and another with a capacity of 175 tons. The ET is raised from its transporter into a vertical position. At that point the 175-ton crane is disconnected and the 250-ton crane moves the ET into a storage or checkout cell where it is attached to wall-mounted supports.

In the checkout cell, a post move receiving inspection is made of the ET. The Ground Umbilical Carrier Plate (GUCP) is installed and the aft hardpoint TPS closeout is performed. Propulsion system leak checks, LO₂/LH₂ umbilical flapper angle and tip load measurements are made along with limited electrical checks. Umbilical TPS closeouts are performed.

Functional checks verify the operation of the propulsion system components, including the LO₂ and LH₂ vent valves, the LO₂ and LH₂ tank closures, electrical feed throughs, and propulsion lines and components. An optical alignment check of the ET is made to establish the precise location of the SRB attachment points and TPS insulation closeouts are performed.

While the ET is awaiting launch, pressure in both tanks is maintained at 6.0±1.0 psig blanket pressure unless test operations require other pressures.

3.2 LAUNCH INTEGRATION AND COUNTDOWN

The External Tank is the central Space Shuttle structure in so far as accommodation of attachment stresses are concerned, and must sustain a variety of stresses at the Orbiter and SRB attachment points depending upon which phase of integration, launch and flight is being experienced.

3.2.1 KSC OPERATIONS

Prior to the ET system's arrival for integration, the SRBs have completed assembly, buildup (segment stacking), and checkout in the integration cell on the mobile launch platform (MLP) in the VAB. During the SRB buildup, the ET attachment-point location data are used to properly space, shim and align the SRBs. Upon verification of alignment and stacking-height data, the SRBs are ready for mating with the ET.

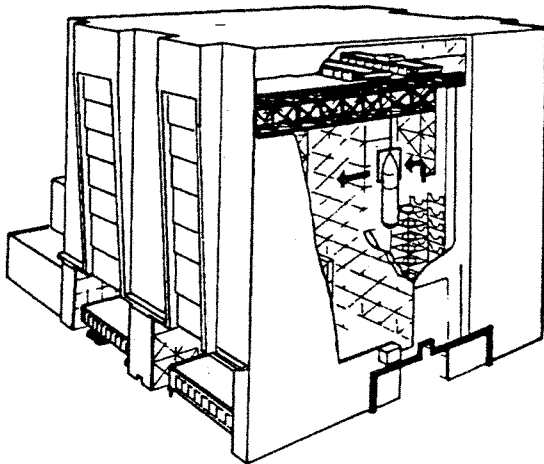


Figure 3-4: ET Leaving Checkout Cell

Mating External Tank to SRBs - The ET system is lowered into position for securing the ET/SRB forward support fittings. When the forward fittings are secured, the aft fittings are mated and secured. The required ET/SRB interface system connections are then made.

Mating Orbiter to External Tank - The Orbiter system completes a safing operation

in the landing area following its return from a previous mission, and is then moved to the Orbiter Processing Facility (OPF) for refurbishment, servicing and checkout for its next flight. Orbiter is then towed to the VAB transfer aisle, lifted and rotated to a vertical position, and is moved (using erection slings) from the transfer aisle to the integration cell prior to mating with the ET/SRBs stack.

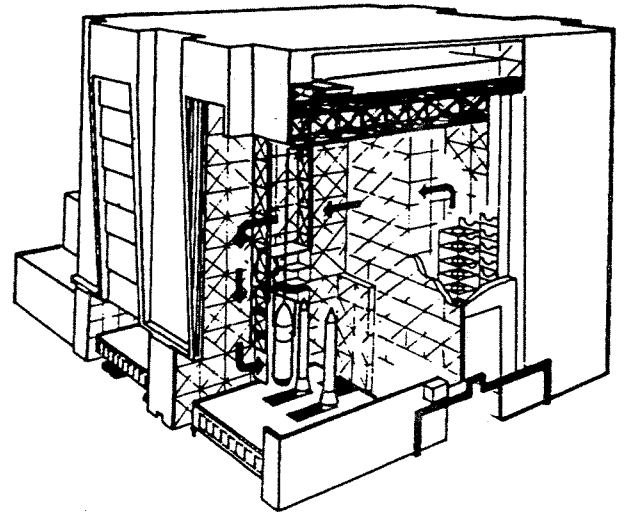


Figure 3-5: ET Mating Operation

The mating operation begins by attaching the Orbiter to the aft ET fittings. The Orbiter is then rotated forward and jacked into final position for attachment to the ET bipod. The assembly torquing operation is completed, propulsion (liquid and gas) and electrical umbilicals between the Orbiter and ET are connected, and a final verification of interfaces is performed before the complete Space Shuttle vehicle is moved from the VAB to the launch pad on the mobile launch platform.

The mobile launch platform is connected to the launch pad and its interfaces are verified. Concurrently, facility servicing lines are mated through the ET intertank carrier plate assembly. The facility LO₂ and LH₂ systems are purged and sampled for two hours. Both ET tanks are purged with helium to assure an inert atmosphere for propellant loading.

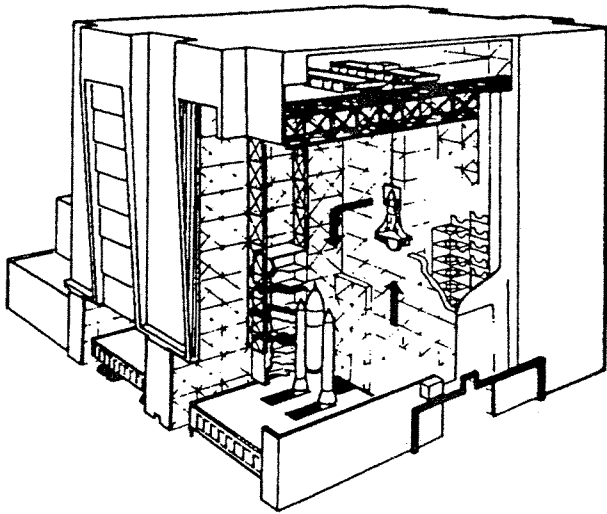


Figure 3-6: Orbiter Mating Operation

3.2.2 FINAL COUNTDOWN

The Space Shuttle terminal countdown sequence begins at T-6 hours. Propellant loading is accomplished from the facility through the Orbiter into the ET. Both LO₂ and LH₂ are loaded simultaneously, starting with a slow flow rate to precondition the lines, tanks and engines. The slow flow rate is continued until the 2% level is reached, at which time the flow rates are increased to the fast fill flow rate until each of the tanks contains 98% of its capacity. The flow rates are then reduced to provide a topping flow rate to 100% capacity, followed by a still slower replenish flow rate to maintain 100% propellant levels. The replenish flow continues until the automatic sequence starts at T-9 minutes.

The LO₂ vapors generated during the loading and conditioning process are vented through vent louvers in the nose cone and a facility vent hood system carrying GO₂ to the umbilical tower. LH₂ vapors are vented directly to

flare stacks through a ET/facility vent system via the intertank ground umbilical carrier assembly. This assembly also provides connections to the pneumatic lines for monitoring the hazardous gas detection system, and for the actuation of the vent valves and helium injection into the LO₂ tank. The LO₂ and LH₂ tanks are then pressurized, with pressurization occurring for the LO₂ tank at T-155 seconds and at T-106 seconds for the LH₂ tank.

3.3 MISSION EVENTS

The ET remains attached to the Orbiter after the SRB boost phase of flight, providing 62,300 gallons of propellants per minute to the Orbiter main engines until separation occurs just prior to achieving orbital velocity.

3.3.1 LAUNCH/ORBIT SEQUENCE

The Orbiter's three main engines are ignited first and after they have achieved steady thrust conditions, the SRBs are ignited. The holddown and the T-Zero umbilical explosive bolts are then blown upon command from the four flight computers and mission elapsed time resets to zero. The vehicle clears the tower at T+7 seconds and initiates pitch and roll maneuvers. The Orbiter monitors and records ET functions and conditions during countdown, liftoff and flight, and initiates all commands to the ET system during flight. The Orbiter-to-SRB cables are structurally carried by the ET from the aft ET/Orbiter umbilicals to the aft ET/SRB structure.

SRB Staging - The two SRB's will be jettisoned after burnout at approximately T+110 seconds and at an altitude of about 27.5 miles. The SRB's will be separated from the ET by pyrotechnic (explosive) devices and moved away from the Space Shuttle by eight separation motors. The ET is protected from separation motor plume impingement by thermal protection material.

External Tank Separation - The Orbiter/ET reach a nominal MECO target altitude of 52 nautical miles at suborbital velocity at approximately 500 seconds after liftoff. The mission-required fuel in the ET has been consumed and the main engines shut-off. The Orbiter side of the Orbiter/ET umbilical disconnect plate assemblies are mechanically retracted and stowed. Each fluid line contains a shutoff valve on both sides of the separation plane to prevent propellant loss after separation. The ET system is structurally separated from the Orbiter system

by means of pyrotechnic devices that fracture attachment hardware links. The separation occurs in a manner that assures no recontact between Orbiter and ET.

ET Venting - A GO2 venting system is incorporated into the ET which enhances the separation safety feature. The vent system relieves if LO2 tank pressure increases to 30-32 psig, but its nearly non-propulsive design limits thrust to less than 50 pounds. The LH2 tank may vent after separation if the tank reaches a pressure of 35-37 psig.

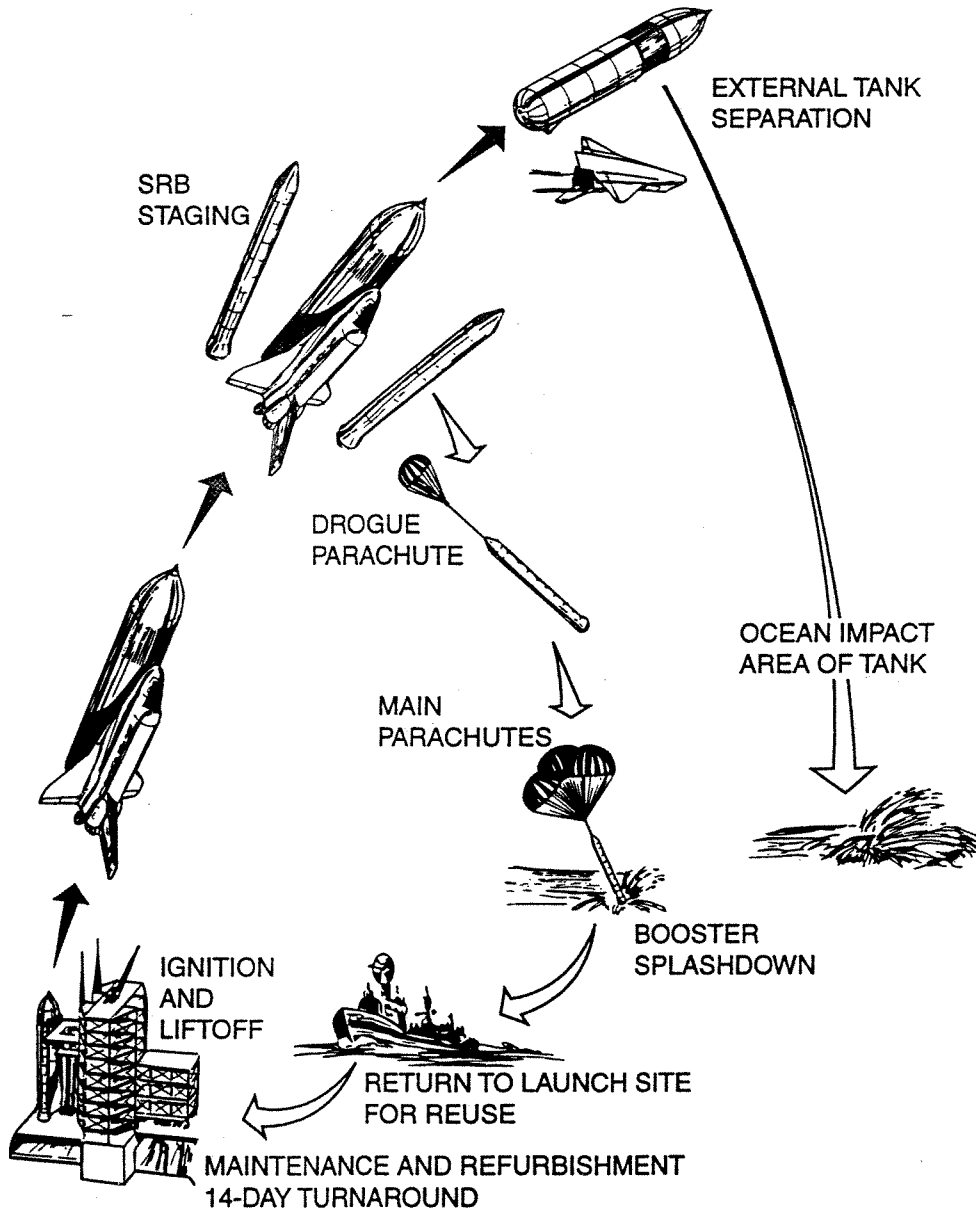


Figure 3-7: Mission Sequence Through ET Separation

4. EXTERNAL TANK DESCRIPTION

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4. EXTERNAL TANK DESCRIPTION

The External Tank contains all of the systems and components necessary to provide fuel and oxidizer for the Orbiter's main engines, and as the Space Shuttle's structural backbone it must be environmentally secure to accomplish its function and able to accommodate the complex variety of imposed on it in a manner to allow large scale production.

4.1 DESCRIPTION

The External Tank (ET) contains and delivers propellants for the Orbiter's three main engines during the launch phase and serves as the structural backbone for the Orbiter and two Solid Rocket Boosters (SRBs) to make up the Space Shuttle flight vehicle. The liquid oxygen (LO2) tank volume is 19,463 cubic feet and contains approximately 1,385,000 pounds of oxidizer. The liquid hydrogen (LH2) tank volume is 52,371 cubic feet and contains approximately 231,000 pounds of propellant fuel. These volumes include a 3% ullage provision.

The ET structure must accommodate complex load paths in that the SRB thrust loads will be induced forward at the intertank while the Orbiter thrust loads will be induced at aft ET/Orbiter attachment points. The SRB thrust will be as high as 2.9 million pounds each at sea level and the three Orbiter's main engines will develop as much as 375,000 pounds thrust each at sea level.

Three primary structures make up the ET; a LO2 tank, an intertank, and a LH2 tank. Since the ET is the only expendable element of the Space Shuttle, design philosophy has been to minimize active or moving parts. All power, pressure, and purges are received from either the Orbiter or ground facility. The only active components on the ET are the vent/relief valves. All operational instrumentation is hardwired to the Orbiter. The separation is pyrotechnically actuated. Slosh baffles are mounted in the LO2 tank and the LH2 tank has a vortex baffle to dampen fluid motion and minimize liquid residuals. Both tanks contain liquid level sensors for propellant loading control.

Both tanks are constructed of aluminum alloy skins with support or stability frames as required, and their skins are welded to provide reliable sealed joints. The sidewalls and end domes require the largest available width of plate stock. The intertank structure utilizes skin stringers with stabilizing frames. The primary structural attachment to the Orbiter consists of one forward and two aft connections, and the primary structural attachment to each of the two SRBs also consists of one forward and three aft connections.

4.1.1 STRUCTURES SYSTEM

Structural design of the ET is complicated by the fact that interactive load effects emanating from internal propellants and pressures, and external aerodynamic pressures and heating must be accommodated. Additional loads associated with the attached Orbiter and SRBs must also be provided for structurally. Structures, in terms of the design configuration and functions, significant design features, and the materials and processes used in fabrication, are discussed separately in Section V, *Structures System*, Section VI, *LO2 Tank Structure*, Section VII, *Intertank Structure*, and Section VIII, *LH2 Tank Structures*.

4.1.2 PROPULSION SYSTEM

The ET contains all the LH2 and LO2 for the Orbiter's main engines. The propulsion system serves the primary function of delivering this oxidizer and fuel to and from the propellant tanks and Orbiter interface through 17 inch feedline disconnects. Delivery rates to the Orbiter are typically 45,300 gpm for LH2 and 17,000 gpm for LO2.

The propulsion subsystems designed to accomplish this and other required functions are the LO2 feedline subsystem, LO2 and LH2 pressurization, and vent/relief subsystems, and the intertank and tank environmental control subsystems.

All controls and valves for the main propulsion system's operation - except for the

LO2 and LH2 vent/relief valves, check valves in the helium inject line, and those valves integral to the interface disconnects - are located in the Orbiter and, during pre-launch operations, in the Facility. Propellants are loaded (and off-loaded, if required) through the Orbiter. Loading rates can reach 12,000 gpm for the LH2 and up to 5,000 gpm for LO2. The propulsion system is discussed in Section IX, *Propulsion System*.

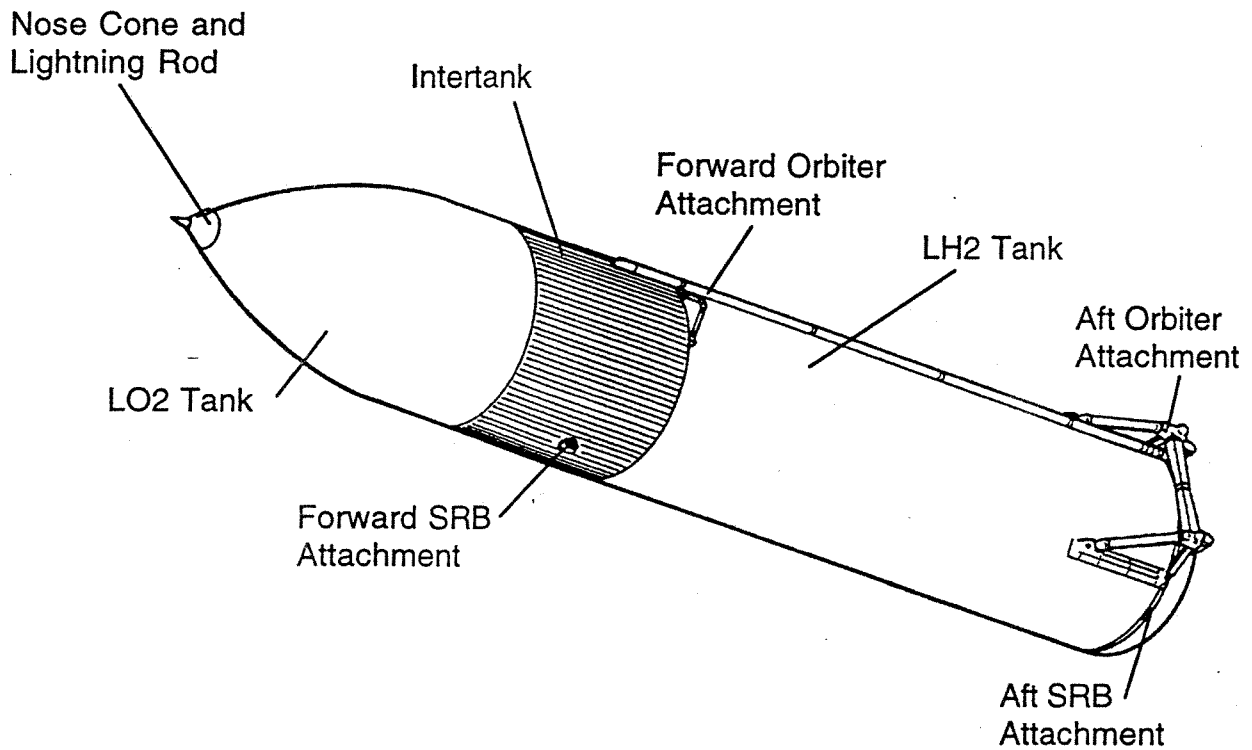


Figure 4-1: External Tank Configuration

4.1.3 ELECTRICAL SYSTEM

The electrical system provides instrumentation sensors, heaters, lightning protection, and associated cabling. All electrical power is derived from the Orbiter except for heater power which is provided by the ground facilities. The electrical system is discussed in Section X, *Electrical System*.

4.1.4 THERMAL PROTECTION SYSTEM

The ET thermal protection system (TPS) is applied to the external surfaces to maintain the cryogenic propellant quality, to protect the structure from ascent and plume heating, and to minimize ice/frost formation. TPS is applied to 16,750 square feet and accounts for approximately 4,000 pounds of the ET weight. Three primary materials are used on the ET. SS-1171, NCFI 24-57, and NCFI 24-124 Spray-On Foam Insulation (SOFI) are the primary cryogenic insulations; and SLA 561 is the primary ablator. Minor quantities of other foams are used for closeouts and MA25S ablator is used for a highly heated local areas. The TPS is discussed in Section XI, *Thermal Protection System*.

4.1.5 INTERFACE HARDWARE

The ET interfaces with the two SRBs, the Orbiter, and with the launch facility. SRB interfaces are six flight-separable structural attach points and electrical connections to allow Orbiter-to-SRB communication and control. Orbiter interfaces include three flight separable structural attachments - electrical, propellant and pressurization umbilicals. A ground facility umbilical interface located at the intertank provides ground services to purge the intertank and to actuate vent valves for prelaunch operations. Section XII, *Interface Hardware*, includes a general description of the

ET/SRB/Orbiter interfaces, their operational functions, and component details.

4.1.6 LAUNCH SITE FACILITIES/EQUIPMENT

The launch site facilities/equipment required to support the ET are located at Kennedy Space Center (KSC). These facilities, and associated transportation and handling equipment are discussed in Section XIII, *Launch Site Facilities/Equipment*.

4.1.7 PRODUCTION

The achievement of the ET production rates required by the Space Transportation System Mission Model presents a significant challenge. The sheer physical size of the ET presents problems in material handling and staging, tooling and fixturing, and facilities to support production requirements. The massive size and quantities of ETs require a restructuring and reorientation to the manufacturing processes to achieve rate production. The ETs are assembled at Michoud Assembly Facility in New Orleans where the basic facility is in a 42 acre building. Additionally, ancillary facilities such as the High Bay Building where the Thermal Protection System is applied, the proof test facilities for pressure testing of the LO2 and LH2 Tanks, and administrative offices are provided.

To meet the production requirements, automated systems have been instituted from master planning against the mission model to the floor parts scheduling and tracking status. Due to the large amounts of aluminum required, annual lot buys are utilized. To maintain configuration control and stability of the work effort, a block build concept is used. The manufacturing processes and sequences required to produce the ET are discussed in Section XIV, *Production*.

4.2 EXTERNAL TANK COORDINATE CONVENTIONS

Standardized coordinate reference planes, data point origins and directional conventions have been established for the ET and are used throughout this handbook.

The forward designation is related to the direction of flight. The ET Y-reference plane intersects the ET (and attached Orbiter) longitudinal centerlines. The Z-reference plane is parallel to the longitudinal centerlines of the ET and the attached SRBs, and is arbitrarily located 400 inches from the ET longitudinal centerline in a direction opposite the attached Orbiter. The X-reference plane is normal to Y and Z planes and is arbitrarily located 2,058 inches forward of the

center of the two aft ET-to-Orbiter structural attach points. Fore and aft distances along the longitudinal ET axis are designated ET Stations, and are measured as positive (+) distances from the X-reference plane.

RIGHT and LEFT designations are in the +Y and -Y directions, respectively, coinciding with the Orbiter pilot's right and left perspective when the ET is assembled to the Orbiter. Angular measurements around the circumference of the ET (without an X plane) are referenced to 0 degrees in the + Z direction (toward the attached Orbiter); positive angles are clockwise looking forward. Clockwise and counter-clockwise used herein will always be in the forward looking perspective.

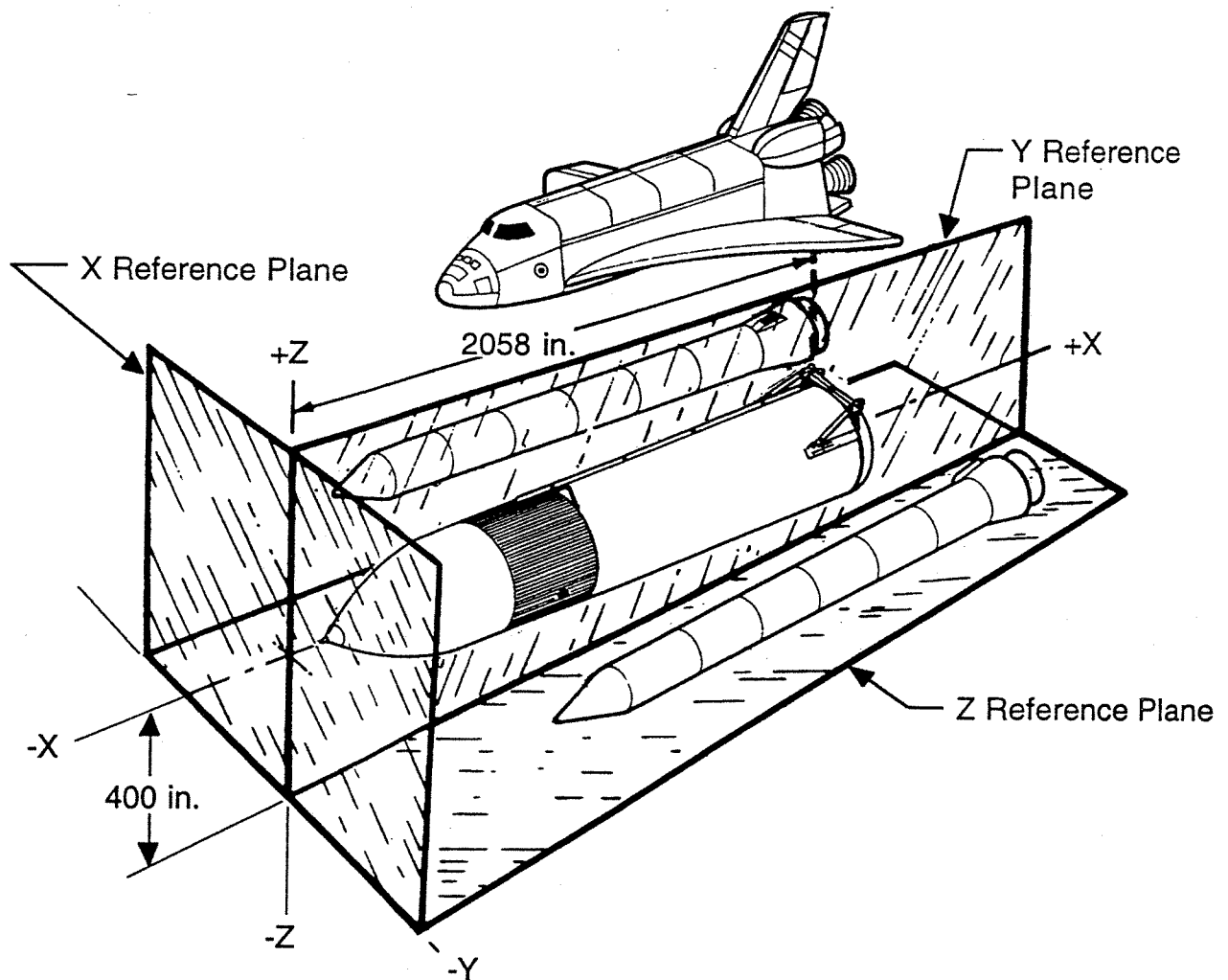


Figure 4-2: ET Coordinate System

5. STRUCTURES SYSTEM

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5. STRUCTURES SYSTEM

The External Tank structure, in addition to providing propellant tanks for the Orbiter receives and distributes stress loads from and to the Orbiter and SRBs, providing load path continuity for the total Space Shuttle flight configuration.

5.1 STRUCTURAL DESCRIPTION

Three primary structural elements comprise the external tank structures system: the LO2 tank, the intertank, and the LH2 tank. The basic structure is made of 2024, 2195, 2219 and 7075 aluminum alloys. The LO2 tank is a welded assembly of machined and formed panels and rings. Chemical milling satisfies the machining function in many areas. Incorporated into the ET as the LO2 forward most element, the LO2 tank is of ogive shape to reduce aerodynamic drag and aerothermodynamic heating. The ogive shape is joined at its aft edge by a tee ring whose aft end is joined to a short cylindrical section, which in turn is joined to a modified 0.75 ellipsoidal dome. A ring frame at the junction of the dome and cylindrical section contains an integral flange for joining the LO2 tank to the intertank.

An 0.75 ellipsoid is one where the ellipse of revolution has a height (x) to radius (y) ratio of 0.75.

The intertank is a skin/stringer/frame structure of cylindrical shape with external stringers and internal frames. It includes a beam which spans the intertank. The ends of the beam contain the SRB thrust fittings which are the

ET/SRB forward interface points. Flanges on the forward and aft ends of the intertank provide structural continuity with the LO2 and LH2 tank assemblies.

The LH2 tank is a welded assembly of barrel sections, I-Ring frames, and dome sections. It is of cylindrical shape, capped on both ends by modified 0.75 ellipsoidal domes. A frame at the juncture of the forward dome and forward barrel contains an integral flange for joining the LH2 tank to the intertank. This frame also provides the structure for the Orbiter forward attach point.

A frame at the juncture of the aft dome and the aft barrel contains the structure for the aft SRB attachment. This frame, together with longerons in the aft barrel, also contains the structure for the aft orbiter attachment.

5.2 MAJOR STRUCTURAL SUBSYSTEMS

The major structural subsystems are described in the following three sections. An overall view of the entire ET structural system is presented here as a visual introduction to these three tank structures.

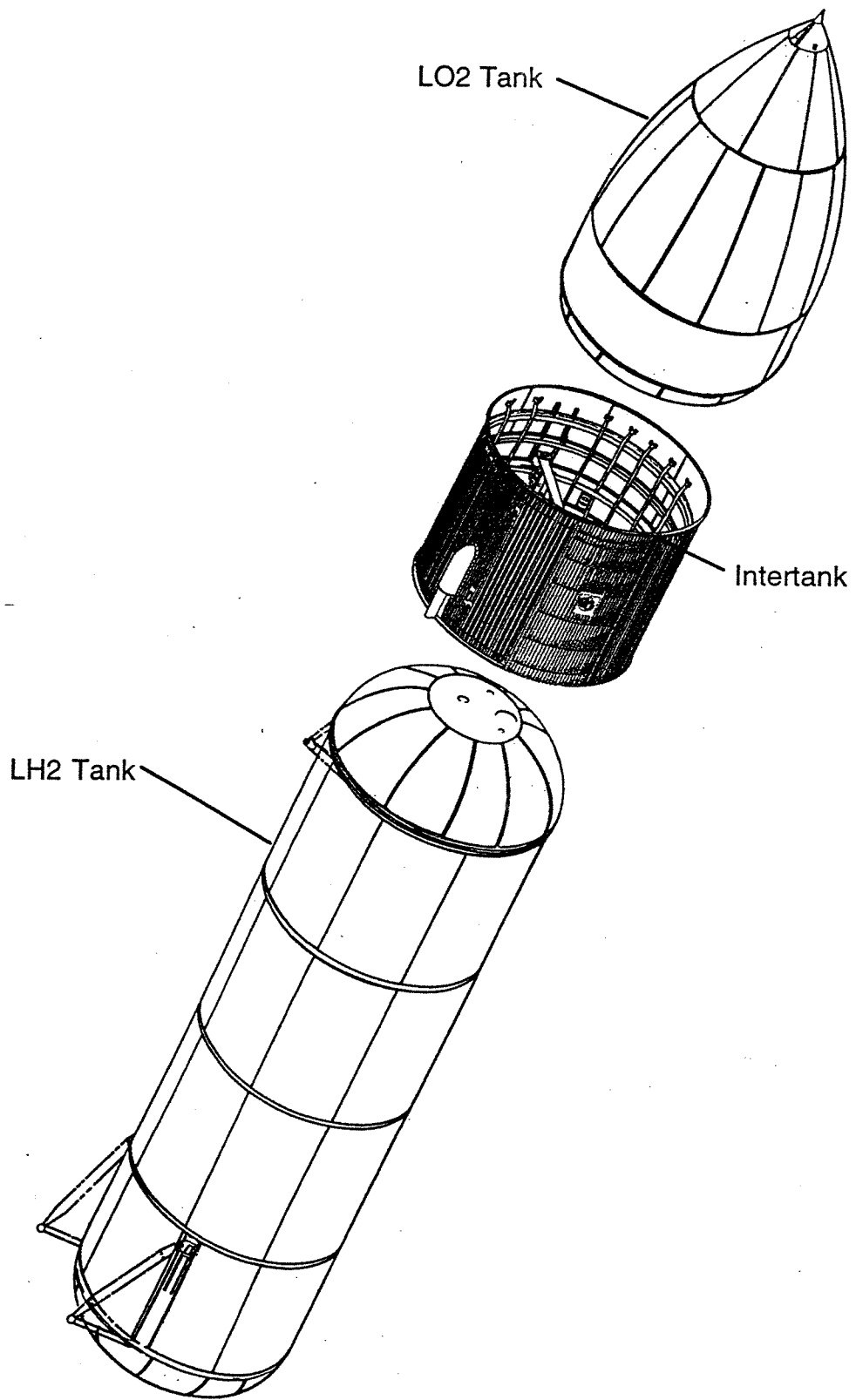


Figure 5-1: External Tank Structure

6. LO2 TANK STRUCTURE

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6. LO2 TANK STRUCTURE

The liquid oxygen (LO2) tank is a thin-wall monocoque shell structure designed to contain 1,384,884 pounds of oxidizer; it measures 655.5 inches long with an outside diameter of 331 inches, has a volume of 20,065 cubic feet and its empty weight is approximately 10,300 pounds.

6.1 DESCRIPTION

The LO2 tank is a welded assembly of preformed, chem-milled gores and panels, and machined fittings and ring chords.

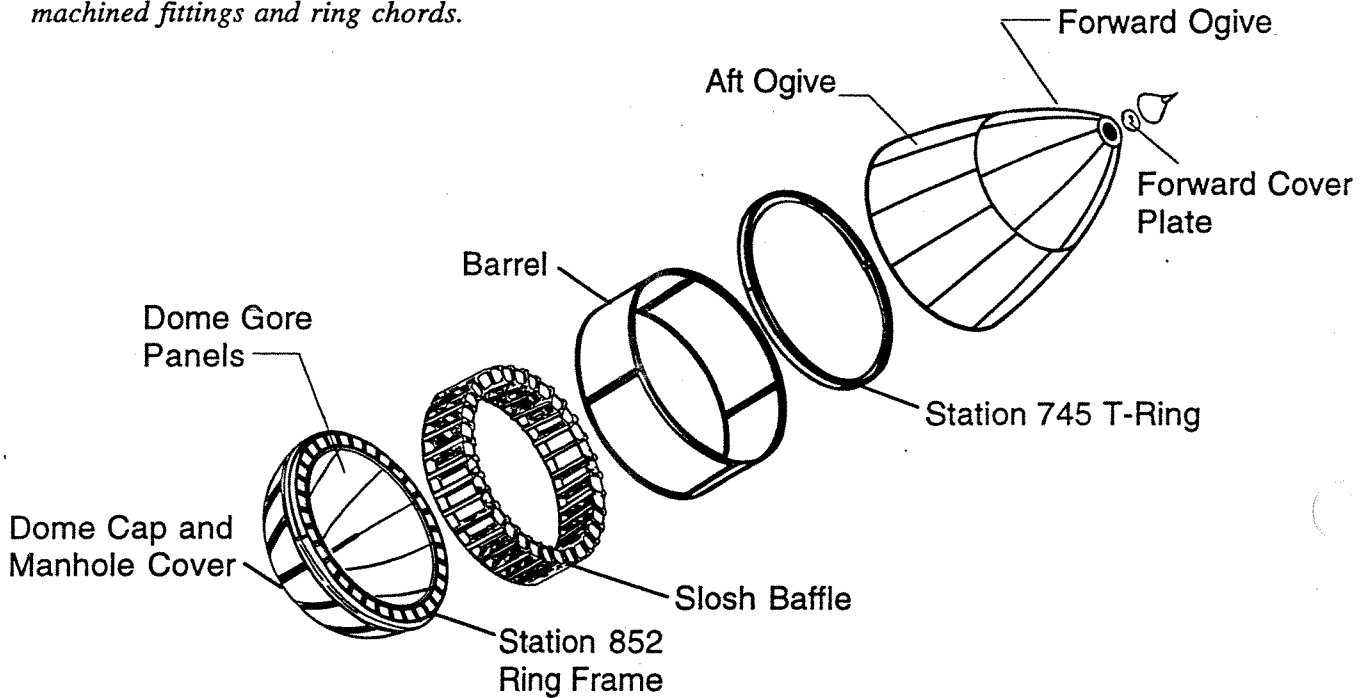


Figure 6-1: LO2 Tank Structure

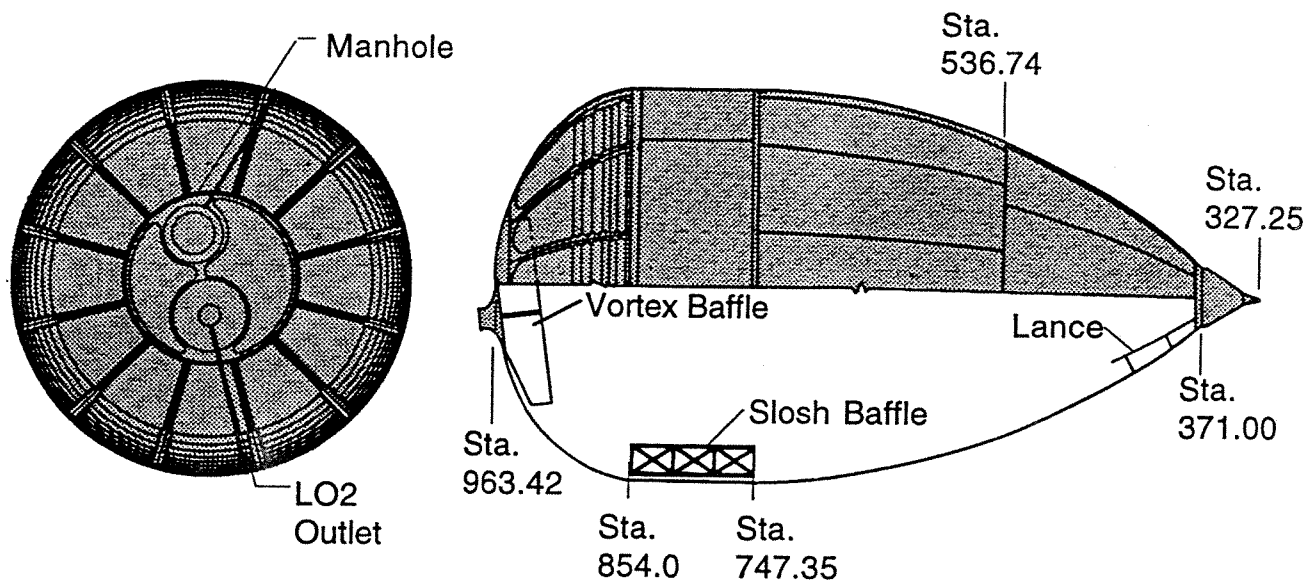


Figure 6-2: LO2 Tank Profile

The ogive nose section is capped by a flat removable cover plate and a nose cone. The aft sections include a short cylindrical barrel and a modified 0.75 ellipsoidal dome. The basic dome shape is also used for the two LH2 tank domes.

A contoured LO2 outlet is located in the dome cap such that its centerline nearly coincides with the launch vehicle acceleration axis at nominal MECO, thus assuring full LO2 availability at that time. Other significant elements of the LO2 tank include an internal slosh baffle to preclude detrimental fluid slosh, a manhole in the dome cap for tank access, a vortex baffle at the LO2 outlet, and provisions for external mounting of pressure line and cable-tray supports. The forward part of the nose cap functions as a lightning rod. LO2 level sensors are mounted on a mast in the forward segment of the tank. The LO2 manhole design is similar to that of the LH2 tank, which permits common drill tooling and seals.

All loads except aerodynamic loads are transferred from and to the LO2 tank at a bolted, flange joint interface with the intertank. The forward ogive and parts of the aft ogive are sized for loads that will be induced during LO2 tank fill and drain operations. Additional areas of the aft ogive and parts of the barrel section are sized for loads resulting from launch release dynamics and

maximum SRB acceleration. The remainder of the aft ogive and barrel section are designed to proof-pressure test loads. The portion of the dome section aft of Sta 856 (to Sta 882) is sized to accommodate hoop compression loads during maximum acceleration at Orbiter end burn. The aft part of the dome, Sta 882 to Sta 928, is configured to accommodate hoop compression loads which occur during LO2 loading. The dome is designed for ullage and head pressure aft of Sta 928. Proof loads exceed flight loads in some areas because of the impracticality of simulating LO2 dynamic head. The forward portion of the ogive nose-section skin is sized at a minimum of 0.08 inches in thickness to avoid penetration by lightning.

Aluminum alloys are used exclusively in the fabrication and assembly of the LO2 tank structure.

The SLWT weld lands were increased in thickness compared with the LWT design. Known as robust weld lands, the following SLWT weld lands were increased by up to 0.25 in. to compensate for Al 2195 weld repair allowables:

- Ogive to Ogive
- Barrel panel to barrel panel
- Dome gore to dome gore
- Dome cap to dome body

Table 6-1: SLWT LO2 Tank Materials

ELEMENT	MATERIAL	CONDITION
Nose Cone		
• Lightning Rod	A356.0 Casting	T61
• Major Cone		
- Skin	Composite Epoxy Graphite	--
- Mounting Brackets	Ti-6-4V (Titanium Bar)	A
Ogive		
• Gores	2195 Plate	T8A4
• Cover Plate	2219 Plate	T87
• Forward Fitting	2219 Forging	T87
T-Ring	2219 Extrusion	T8511
Barrel Panels	2219 Plate	T87
Interior and Exterior Lugs	2219 Sheet/Plate	T87
Dome		
• Cap	2219 Plate	T87
• Gores	2195 Plate	T8A4
• Manhole Cover and Fitting	2219 Plate	T87
• Suction Fitting	2219 Forging	T87
• Ring Frame (Chords)	2219 Extrusion	T8511
Slosh Baffle		
• Webs	2024 Sheet	T62
• Web Stiffeners; Tension Strap	2024 Sheet	T81
• Chord Angle	2024 Sheet	T8511
• Stiffener Angle	2024 Sheet	T8511
• Stringer	2024 Extrusion	T8511
Vortex Baffle		
• Splice; Caps and Stiffeners	2024 Extrusion	T8511
• Web; Splash Plate and Straps	2024 Sheet	T81

6.2 MAJOR ASSEMBLIES

The major assemblies which comprise the LO2 tank are the nose cone and cover plate, forward and aft ogive sections, cylindrical barrel section, slosh baffle, and LO2 aft dome. These are discussed here in detail.

6.2.1 NOSE CONE AND COVER PLATE

The nose cone, mounted on the truncated tip of the ogive, consists of a removable conical composite epoxy graphite assembly that serves as an aerodynamic fairing for propulsion and electrical system components mounted on the ogive forward fitting and cover plate. Its forward most element is a cast aluminum lightning rod. The triple cone shape minimizes shock reattachment on the ogive, reducing thermal protection requirements.

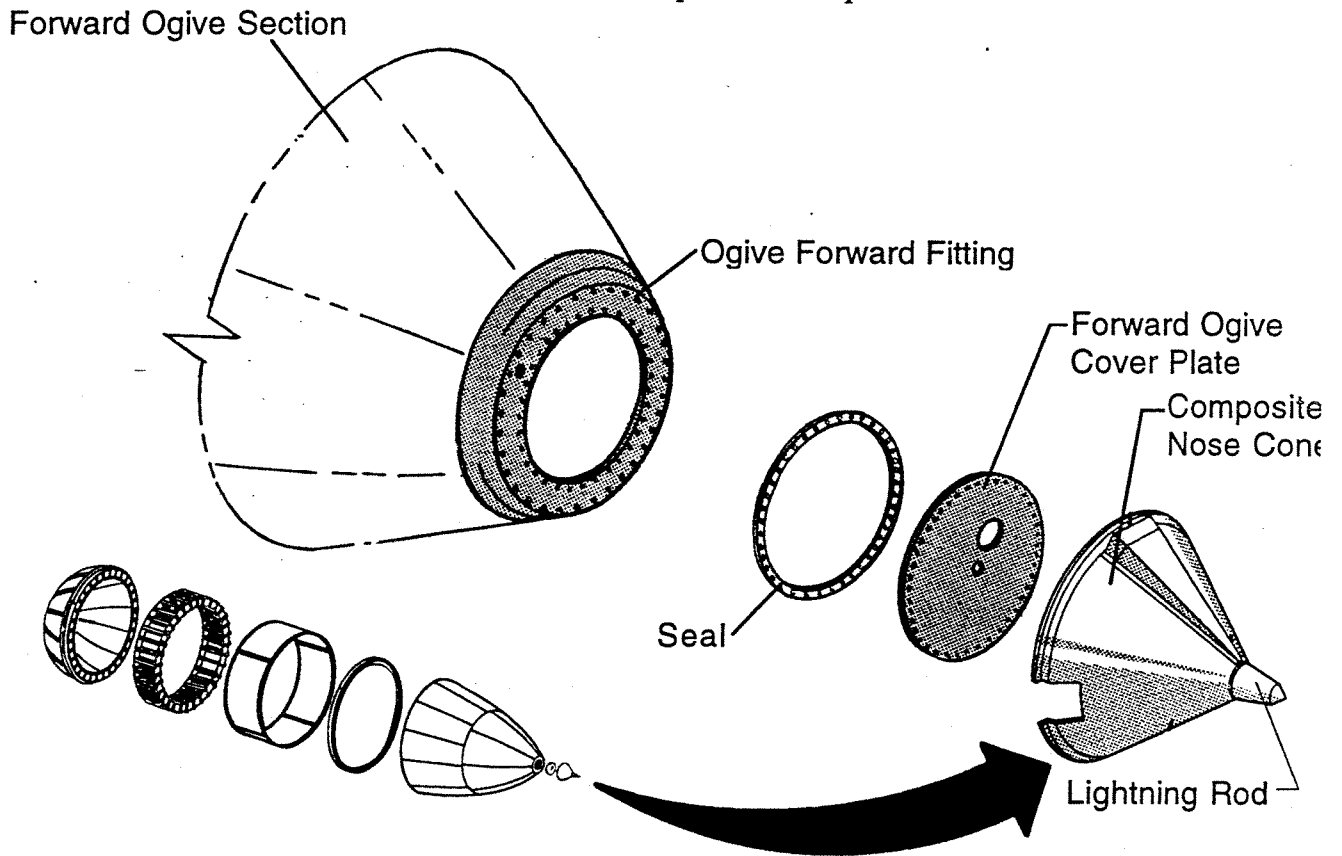


Figure 6-3: Nose Cone and Forward Ogive Cover Plate

The lightning rod is a double conic casting 13.34 inches long, and is bolted to the major conical section by six 1/4-inch diameter mounting bolts through the base of the casting. The tip is rounded to a 0.16-inch radius to avoid the high recovery temperature on a sharp spike. Two handling holes are provided as an aid for removal/replacement of the entire nose cone.

The major conical section is 30.51 inches long, and is constructed of 0.252 to 0.336-inch thick epoxy graphite composite. The cone includes provisions for two stainless steel louvers on opposite sides that are part of the LO2 vent system and are mounted to the forward LO2 tank ring. An aerodynamically faired penetration for the electrical cable tray and the LO2 pressurization line are also provided. The nose cone is attached to the nose cone brackets by 29 3/8-inch diameter bolts.

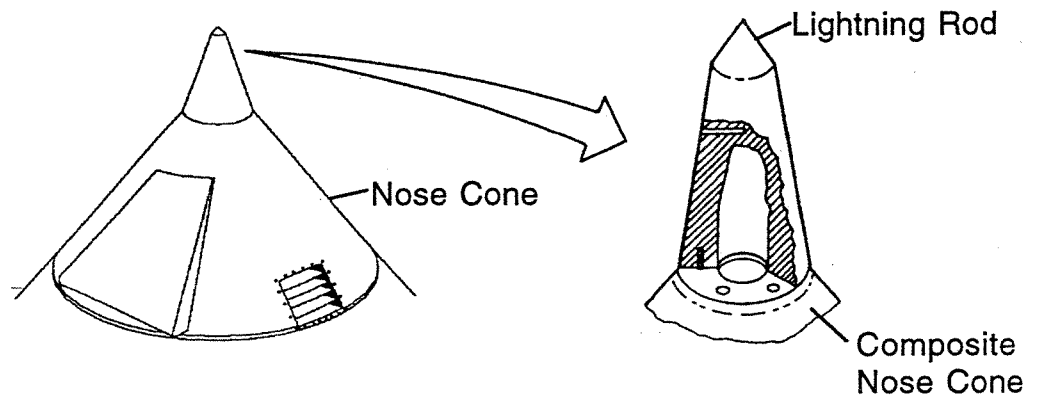


Figure 6-4: Nose Cone and Lightning Rod

The cover plate serves as a removable pressure bulkhead for the LO2 tank and provides a location for mounting propulsion system components described in Section IX, *Propulsion System*. The plate is 39 inches in diameter with a basic thickness of 0.35 inches. The plate incorporates integrally machined stiffeners, having a nominal depth of 1.50 inches. All machining for stiffeners and mounting bosses is internal, leaving the external surface of the plate unobstructed for component mounting. The cover plate is joined to the ogive forward ring by 92 5/16 inch bolts. A Naflex pressure seal provides a gastight joint. This metallic seal, which has a redundant sealing feature is common for all cover plates on the LO2 and LH2 tanks. Removal

of the plate provides a 36-inch diameter access opening to the LO2 tank.

6.2.2 OGI VE SECTION

The ogive section consists of the forward fitting, eight forward gores and twelve aft gores. These are welded to form an ogive section with a 612-inch radius.

The forward fitting is a one-piece, machined forging that includes the cover plate mating-and-sealing surface; it is butt welded to the forward ogive gore assembly. The ring contains a 1.4-inch penetration for the electrical feed-through connector.

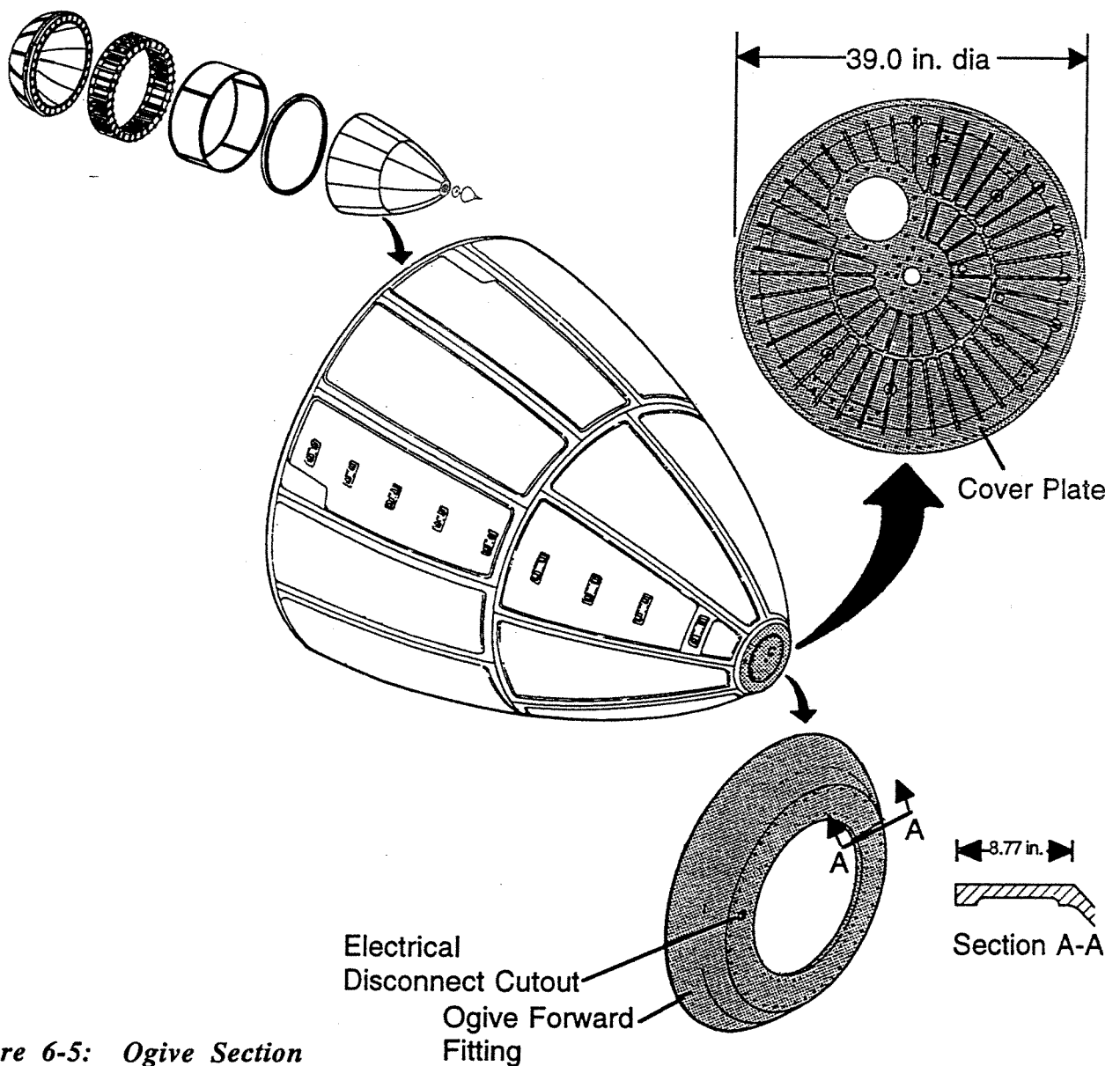


Figure 6-5: Ogive Section

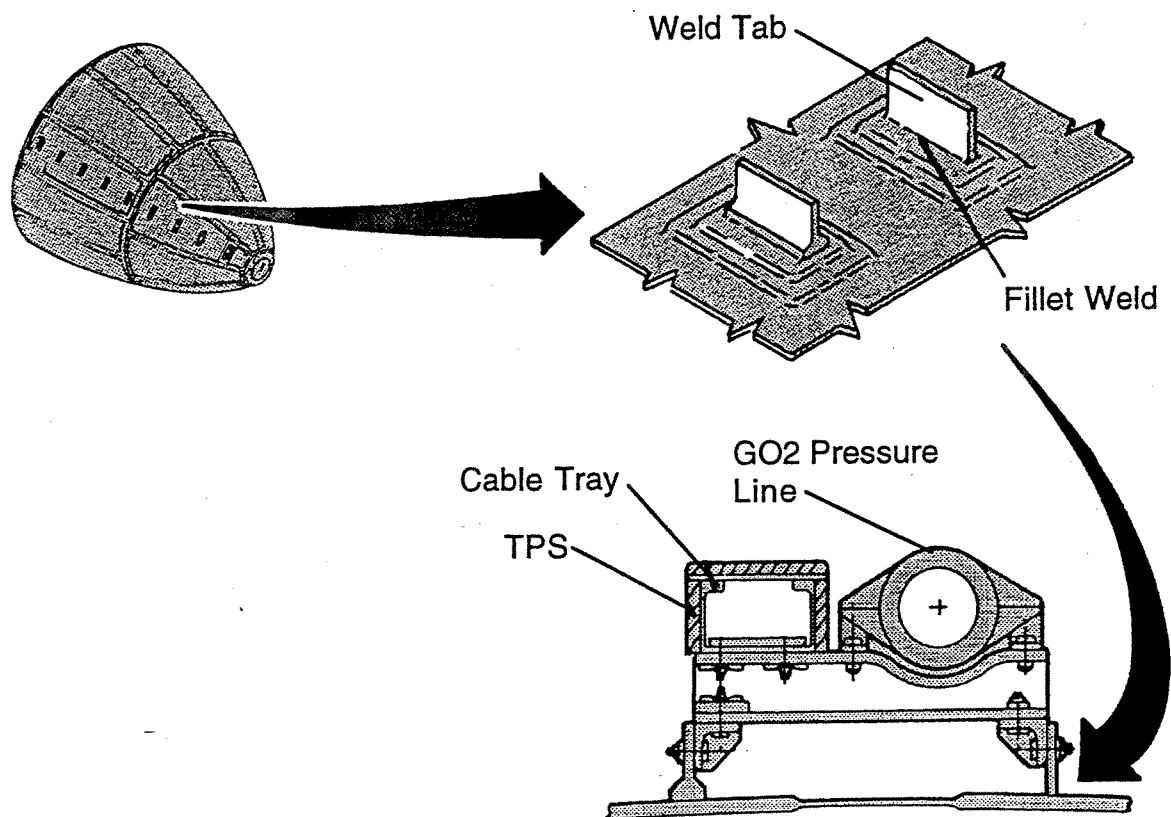


Figure 6-6: Weld Tabs

One forward and one aft ogive section have locally thickened skin pads and weld tabs for the attachment of support brackets for the LO2 pressurization line and electrical cable tray traversing the upper right quadrant of the tank. These elements are further described in Section IX, *Propulsion System*, and Section X, *Electrical System*.

The skin pads and weld tabs continue over the adjoining barrel section. The forward two mounting pads on the forward ogive gore also include internal tabs to provide support for the sensor lance (described later in this section).

All ogive gore panels are formed to the required curvatures and chem-milled on both sides to the correct pattern. They are edge trimmed and butt welded in weld fixtures during assembly to form the ogive section. Gore membrane thicknesses are chem-milled in grid panels to accommodate tank stabilization and SRB acceleration loads.

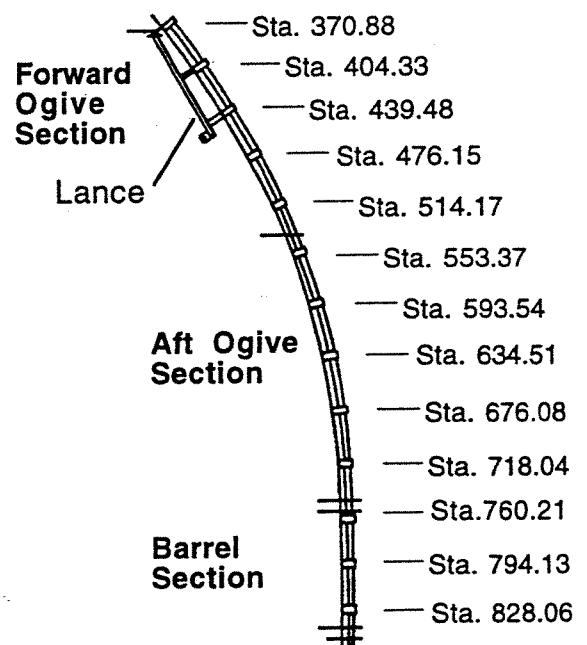


Figure 6-7: Support Locations

The forward ogive section has a gore commonality of 2/2/2/1/1; the aft ogive section has a gore commonality of 2/2/2/1/1/4; the differences being caused by circumferential differences in load distributions from the SRB attach points in the intertank, and by the single gore panel having weld tab provisions. Increased material thickness, tapered longitudinally with the heavier gauges toward the aft end, are provided along the edges of all gore panels to compensate for reduced physical properties in the heat-affected zones of the edge welded areas. These symmetrical double-stepped weld lands are configured to minimize bending stresses in the weld areas without excessive weight.



Figure 6-8: Weld Lands (Typical)

An extruded "T" ring frame is butt welded to the aft edge of the ogive section and to the forward edge of the barrel section of the LO2 tank. This frame provides for the forward attachment of the slosh baffle and contributes to LO2 tank stability. It is pre-formed to a circular shape in four 90 degree segments, and machined to its final cross-section. The four segments are butt welded together to complete the frame.

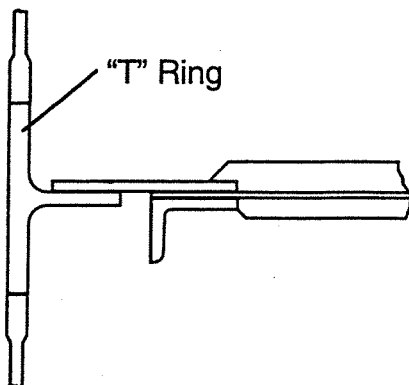


Figure 6-9: Forward Baffle Support

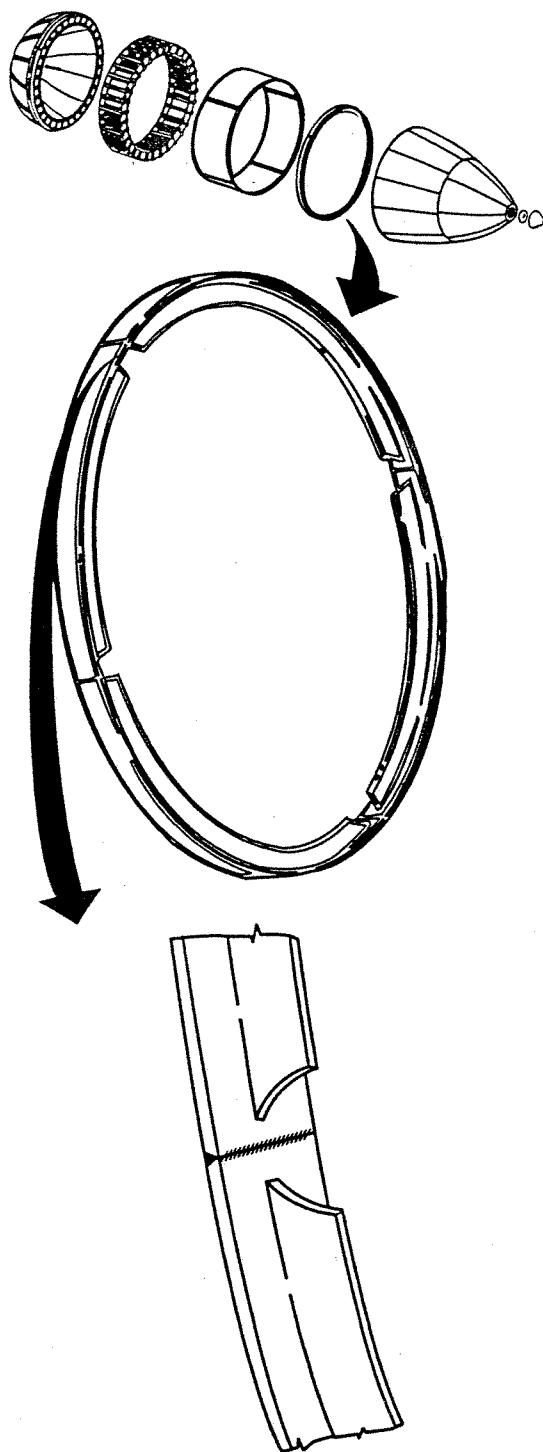


Figure 6-10: T-Ring Frame (Station 744)

6.2.3 CYLINDRICAL BARREL SECTION

The 98.2-inch-long barrel section is fabricated from four chem-milled and formed panels welded together. Skin thickness on the two side panels are tailored in grid fashion to accommodate SRB thrust loads. The other two panels are identical except for three thickened skin pads and weld tabs on one panel. These tabs support the cable tray and GO2 pressure line extending over the barrel. The barrel section skin is also tapered in a manner similar to the ogive gores.

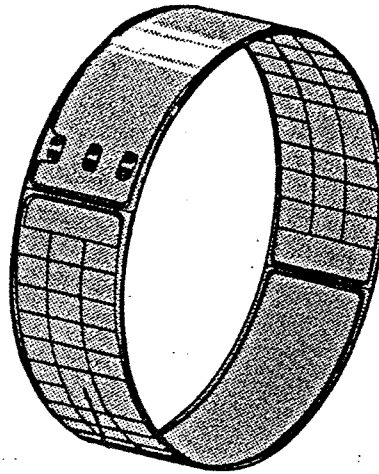


Figure 6-11: LO2 Cylindrical Barrel Section

6.2.4 SLOSH BAFFLE ASSEMBLY

The LO2 slosh baffle assembly is designed to provide a minimum of 0.5% damping when the slosh mass is greater than 10% of the total weight of the ET plus remaining LO2. The slosh baffle consists of rings tied together with longitudinal stringers and tension straps. The webs of the frames, web stiffeners, and stringers are riveted. Tension straps are pin joined.

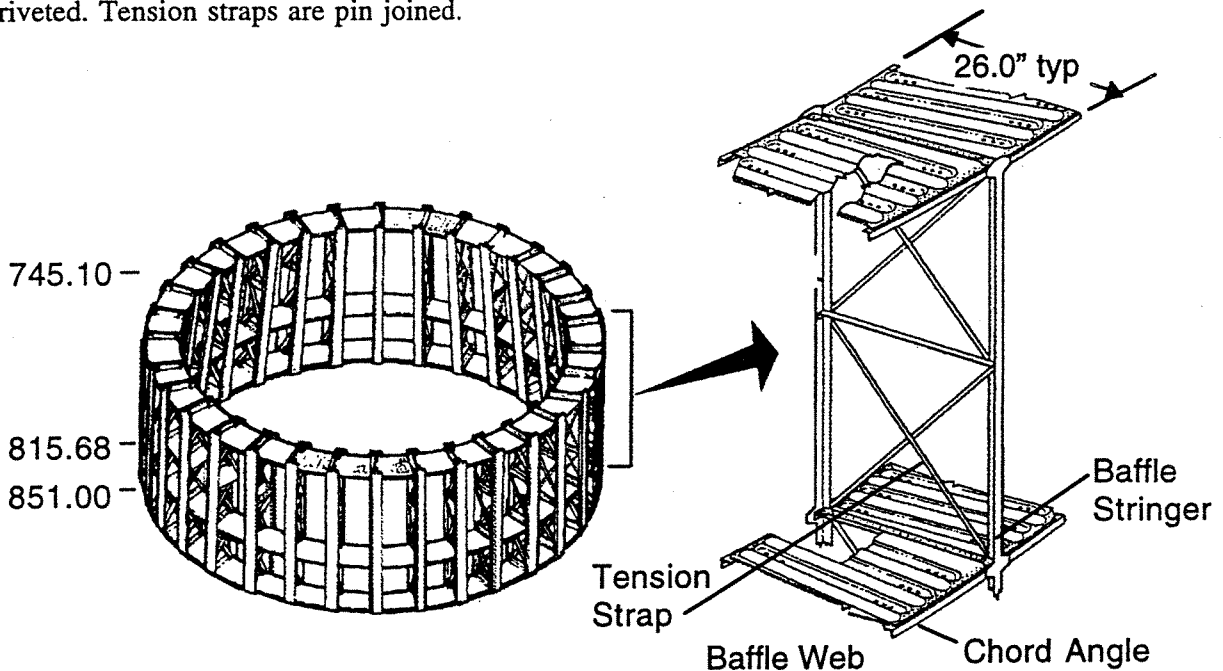


Figure 6-12: Slosh Baffle Structural Configuration

6.2.5 LO2 AFT DOME SECTION

The LO2 aft dome section consists of the aft (dome-to-barrel) ring frame, twelve identical gore segments and a 140-inch diameter dome end-cap. The end-cap includes the LO2 contoured feed outlet, a 36 inch diameter manhole access, and a 1.28-inch diameter penetration for the aft LO2 low-level sensor electrical feed-through connector.

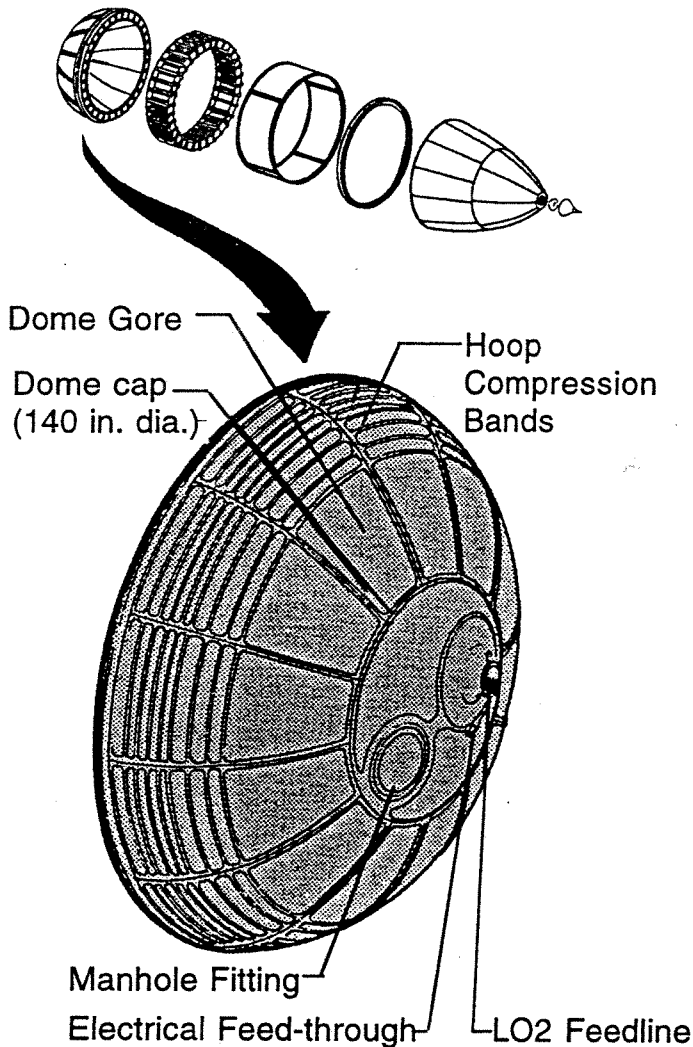


Figure 6-13: LO2 Aft Dome Section

The dome is assembled by welding together three pre-formed and chem-milled gore skins and a quarter section of the extruded ring frame that has been stretch-formed and machined. This assembly constitutes a dome quarter panel. The quarter panels are welded together, after which the dome end-cap is welded onto the assembly. The four dome ring chord flanges are cut away

locally at the flange ends to facilitate welding. Mechanical splices are incorporated to bridge those discontinuities.

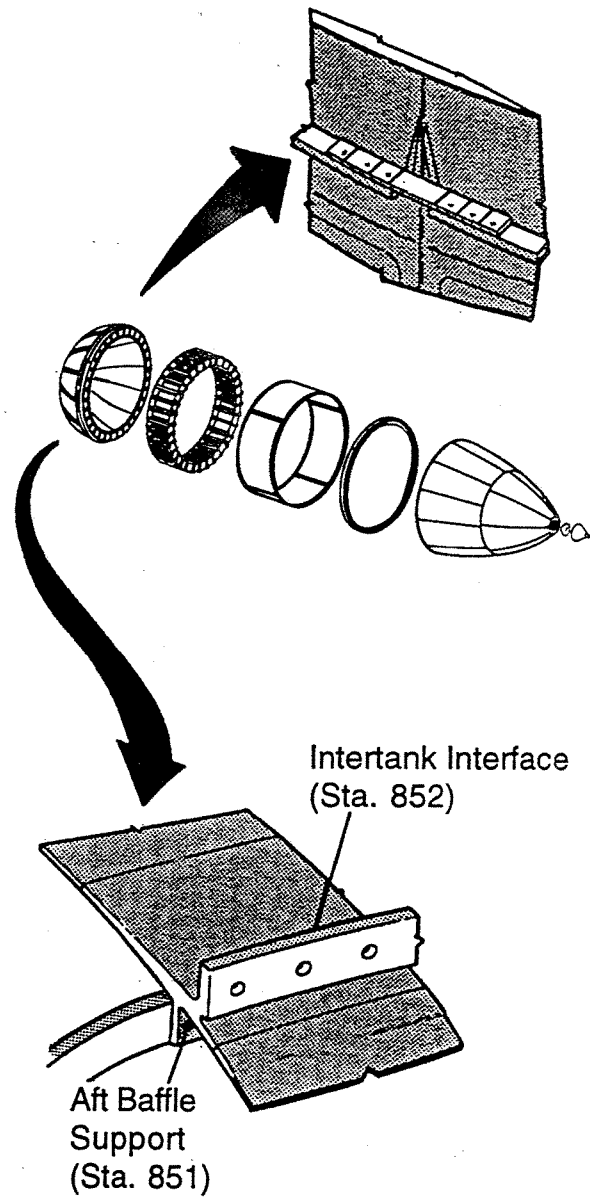


Figure 6-14: Dome Ring Splice/Chord

The aft ring frame serves as the weld juncture between the barrel section and the dome. The outer flange, which is mated to the intertank with 194 9/16-inch bolts. The center-to-center dimensions of the hole pattern vary around the frame from 3.6 to 7.2 inches. This pattern is dictated by the intertank design and load distributions.

The dome gore panels are tapered by chem-milling in steps to tailor the skin thickness to the increased loads toward the tank bottom. Panel membrane and weld lands are tapered longitudinally. The membranes are reinforced by a series of circumferential chem-milled bands. Symmetrical triple-stepped weld lands are configured to minimize bending stresses. Gore panels are contoured to form a 0.75 height-to-radius ellipsoid.

The spherical dome cap is 140 inches in diameter and is spun formed and then chem-milled on both sides. The cap consists of a constant thickness membrane with symmetrical triple-stepped weld lands around the periphery, cutouts for LO2 outlet/inlet fitting and the manhole fitting, and for an electrical feed-through connector.

The contoured LO2 outlet/inlet fitting is a machined part having a 64-inch overall diameter, and an inside diameter at the outlet of 17 inches. The fitting is welded to the cap eight degrees off center, with respect to the centerline of the tank, to approximately coincide with the vehicle acceleration axis at nominal MECO. This assures full propellant availability at the burnout attitude.

Provisions are made for attaching the vortex baffle and the 800-micron screen internally. A flange is provided at the outlet side for attachment to the LO2 line, as further defined in Section IX, *Propulsion System*. There are 44 slotted holes (0.75 x 0.472 inches) equally spaced on an 18.870-inch diameter for 7/16-inch attachment bolts.

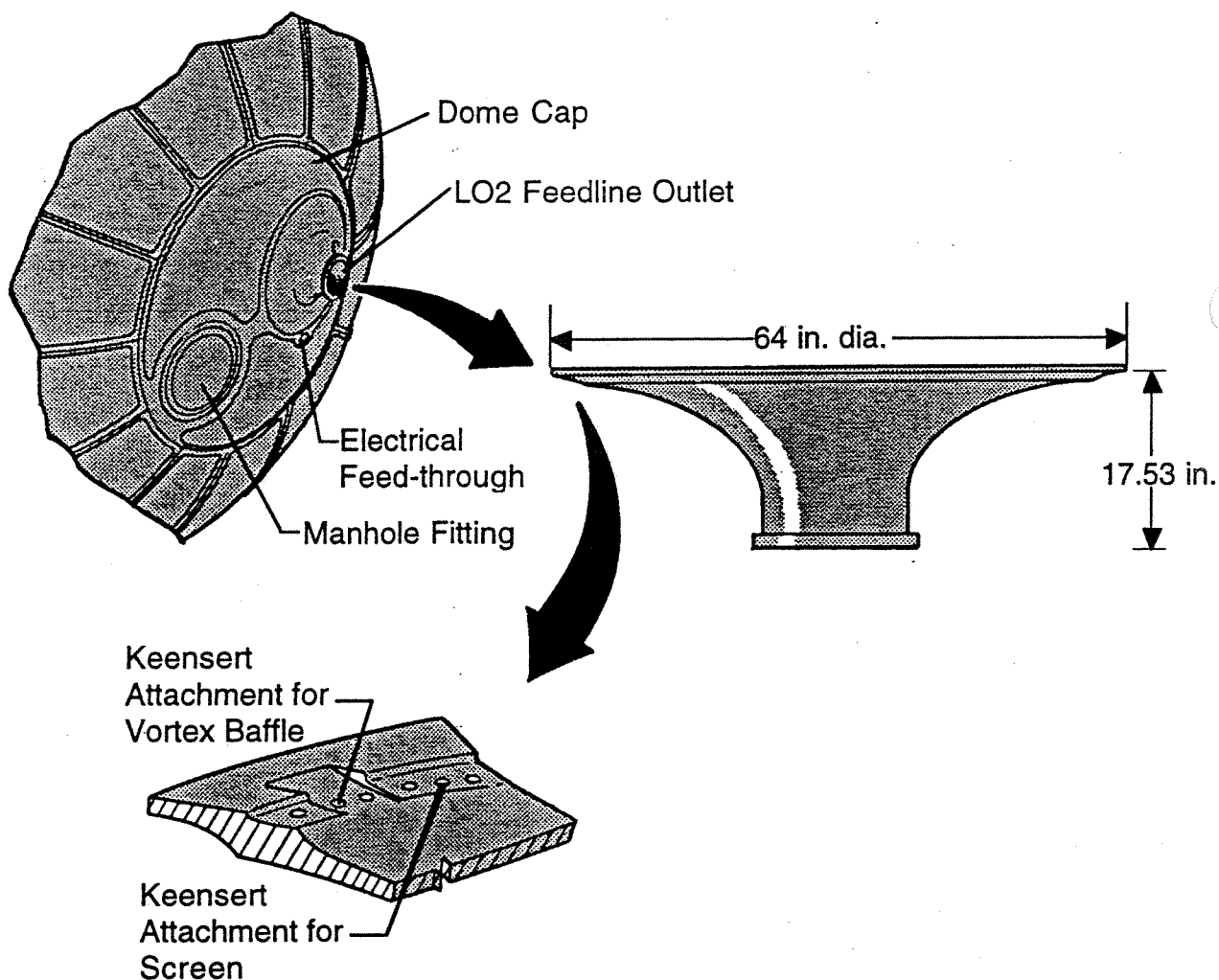


Figure 6-15: LO2 Outlet/Inlet Fitting

A vortex baffle is installed to the end-cap, internal to the tank, and centered over the off-centered LO2 feed outlet. This baffle reduces fluid swirl resulting from Coriolis effect about the outlet and prevents entrapment of gasses in the delivered LO2 thus eliminating unusable LO2 except for surface wetting.

The vortex baffle is 160 inches in diameter and is attached to the dome cap at four locations (two fixed and two slotted) with two fasteners at each location. The assembly includes four webs with upper and lower caps, and vertical stiffeners

stabilized with diagonal straps. The webs and caps are joined at the center with a splice plate at the bottom and a splash plate on top.

Webs are 0.02 inches thick and contain a total of 124 holes varying from 4.9 to 5.9 inches in diameter. The holes act to lighten the structure and to reduce slosh locally. The 2% and 5%-fill sensors are attached to the baffle assembly via a mast. A four-segment, 800-micron filter screen is mounted to the lower caps of the vortex baffle center-structure and to the outlet. The attachment of the screen helps to anchor the baffle assembly.

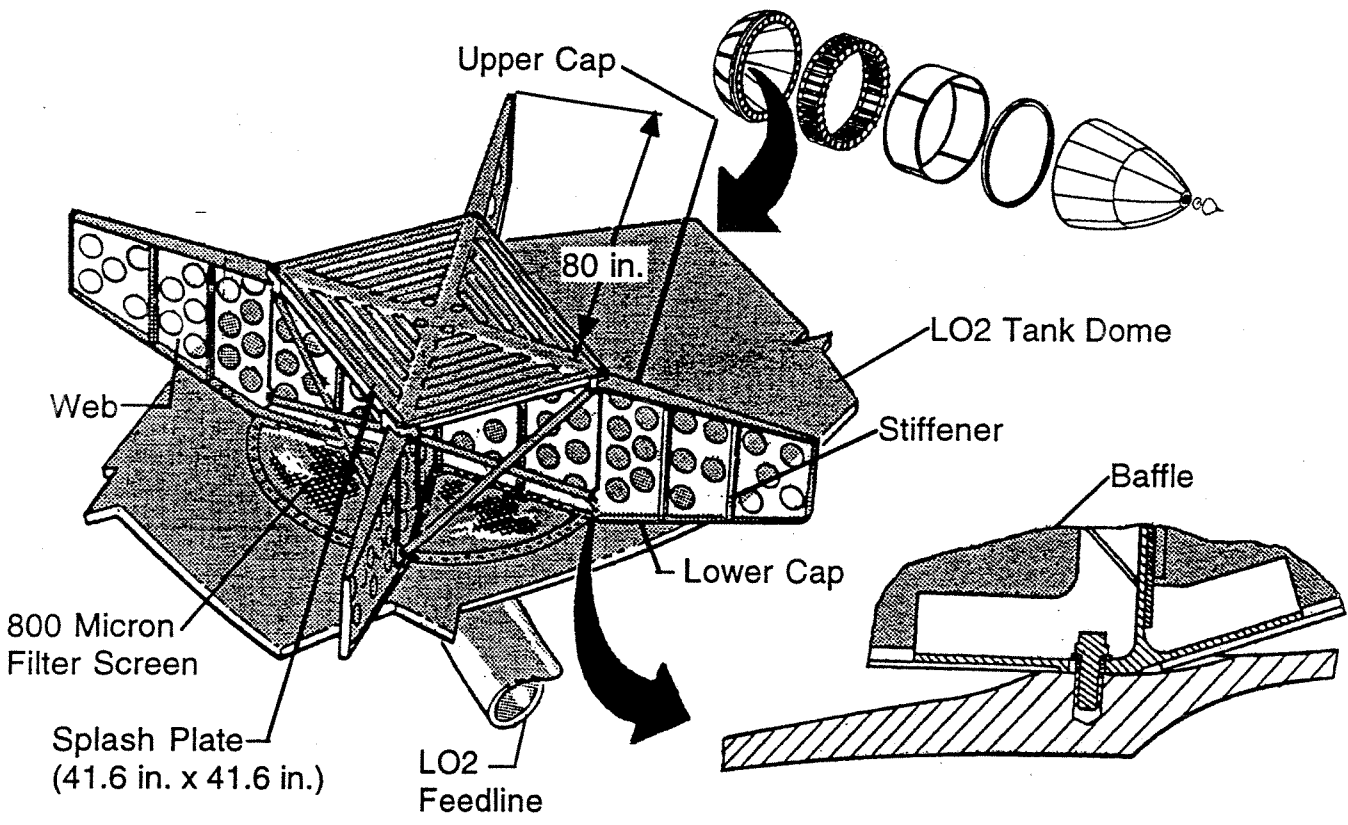


Figure 6-16: Vortex Baffle

A 45-inch diameter, machined manhole fitting is welded into the dome cap. This fitting provides a 36-inch diameter clear access to the tank interior. Ninety-two equally spaced attachment points are provided with 5/16-inch threaded inserts for attaching the manhole cover. The machined aluminum manhole cover has an overall diameter of 40.32 inches, is 0.185 inches thick at the center, weighs 57 pounds, and provides an interfacing sealing surface with the manhole fitting. The manhole cover is designed as a load-carrying structure since hoop tension loads are felt across the cover. The manhole

covers provide a means for making a leak check of the primary seal. Both the manhole fitting and the manhole cover each have two holes that are diametrically opposite each other. One hole in the cover and the hole diametrically opposite in the fitting have roll pins installed into each hole. The protruding portion of the roll pins are covered with heat shrinkable tubing to prevent scratching of sealing surfaces when the manhole cover is installed. The installation of the roll pins preclude the possibility of inadvertently interchanging the LO2 and LH2 manhole covers.

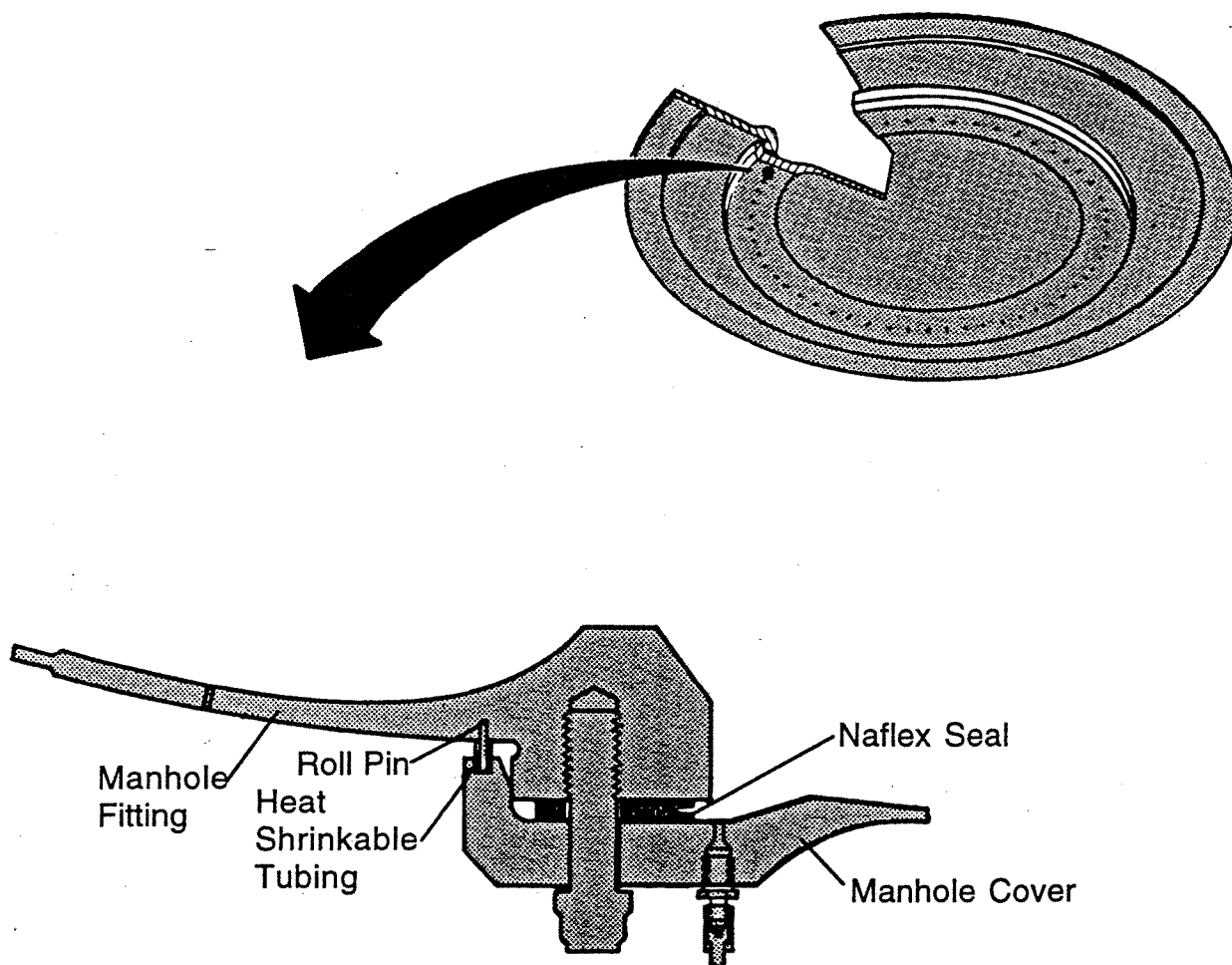


Figure 6-17: Manhole Fitting and Cover

6.3 COMPONENT DETAILS

Some of the major components of the LO2 tank are described in detail.

6.3.1 LANCE AND SENSOR ATTACHMENT

The lance serves as a mounting mast for the LO2 level and temperature sensors. It is an aluminum extrusion approximately 6.9 feet long with a 3.1 inch outside diameter, a wall thickness of 0.083 inches, and tabs approximately 1.2 inches wide on both sides of the tube.

The lance is attached by means of a single-axis, flex-joint junction with two A-frame supports attached to internal mounting pads in the forward ogive gore-panel. A-frame mounting supports are formed by aluminum extrusions and a web made of aluminum sheet. The supporting frames are pinned at the tank weld tabs and lance. This permits longitudinal thermal displacement of the lance and relative motion between the ogive forward ring and ogive walls. The tabs along the tube provide the means of attaching adjustable sensor saddle mounts of hat-section configuration.

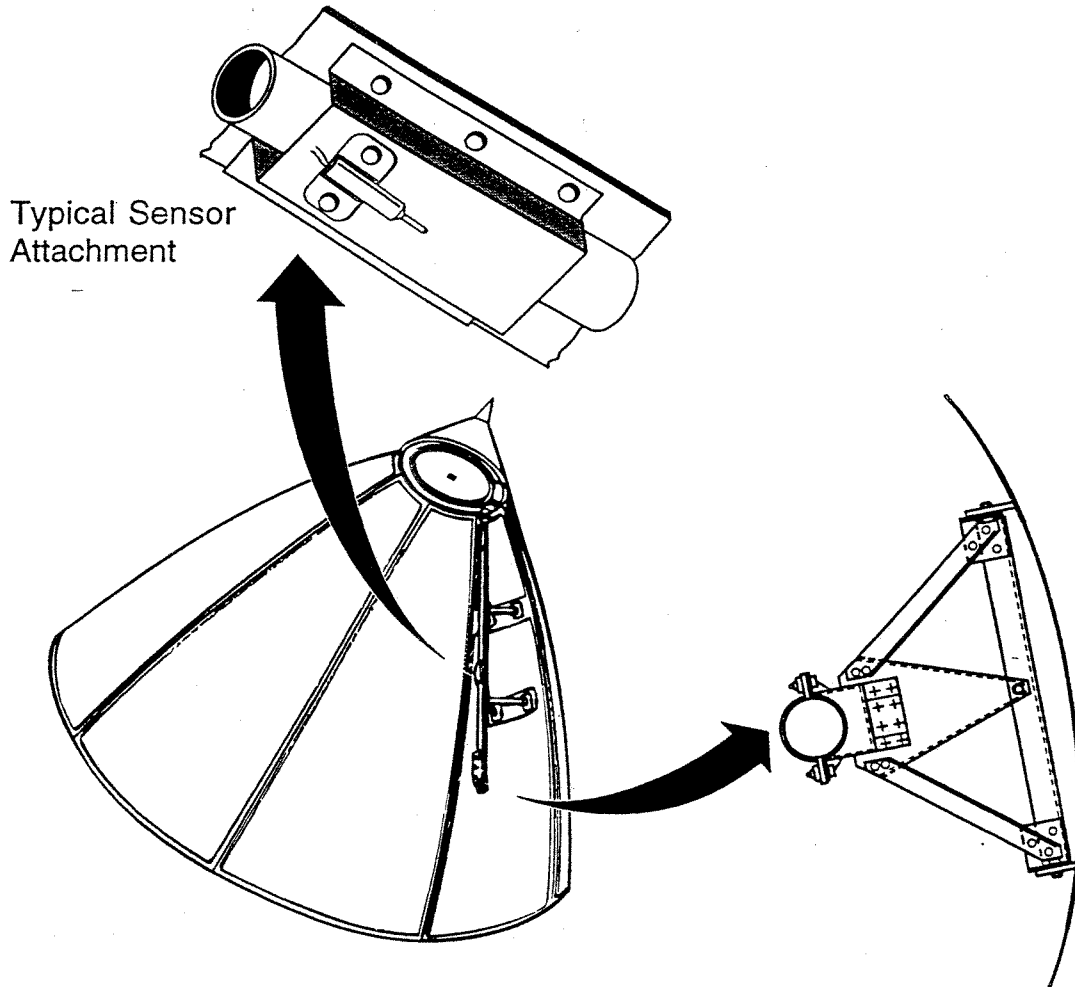


Figure 6-18: Lance Attachment

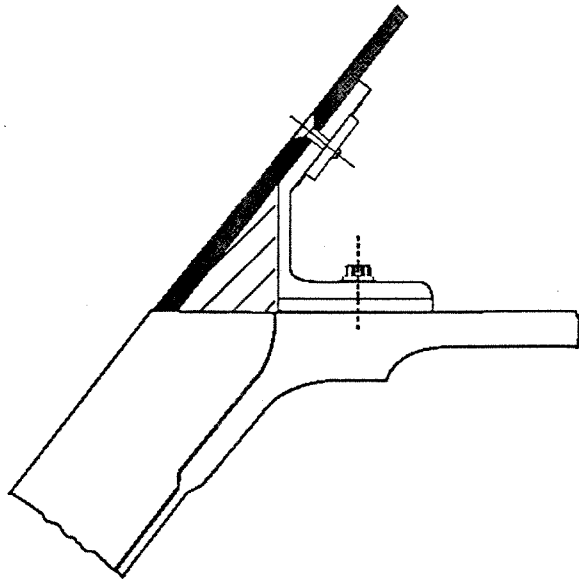


Figure 6-19: Nose Cone to Cover Plate Joint Detail

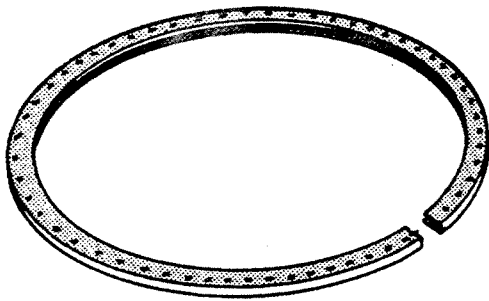


Figure 6-20: Naflex Seal

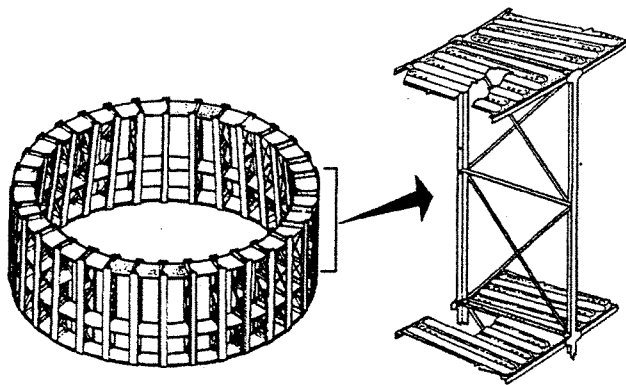


Figure 6-21: Stamp Webs (Typical)

6.3.2 NOSE CONE AND COVER PLATE ATTACHMENT

The forward ogive fitting is a single piece, machined 2219 aluminum (T-6) forging. This fitting is butt-welded to the forward ogive gore edges, and provides attachment and sealing features for the nose cone and the cover plate. The 36-inch diameter tank access opening provided by this fitting is common with the other four ET access openings in the LO2 and LH2 tanks for seal commonality.

The 79-pound cover plate is machined from 2219, T-87 aluminum plate, and is attached by 92 5/16-inch bolts. A Naflex metallic seal provides redundant sealing surfaces. The nose cap attachment is attached with 18 5/16-inch bolts through the extruded flange that forms the mating surface with the forward ogive ring frame. Blind threaded holes with threaded inserts are provided in the ring for attachment bolts.

The nose cone surface is aligned with the surface of the ogive so that final closeout of the insulating TPS results in the proper thickness and contour, and also covers the joint.

6.3.3 SLOSH BAFFLE

The LO2 slosh baffle assembly is fabricated in two sections, forward baffle assembly and main stabilizing frame assembly, and joined into one assembly during LO2 tank assembly. The two forward aluminum ring assemblies are made with stamped webs (thickness varies between 0.016 inches and 0.032 inches), aluminum stiffener splices and aluminum angle chords. The webs are beaded in a sine-wave pattern with multiple 1/4-inch drain holes to preclude fluid and/or air entrapment. The ring at Sta. 745 serves as the baffle forward support at the "T" frame juncture of the ogive section/barrel section.

The third ring is the main stabilizing ring frame and also serves as the aft baffle-support ring at the juncture of the barrel section and the LO2 tank dome at Sta 851. This ring is comprised of thirty-two machined forgings

alternating with thirty-two stiffened webs, and also includes aluminum chords. The installed baffle assembly contributes to the stability of the LO2 tank structure.

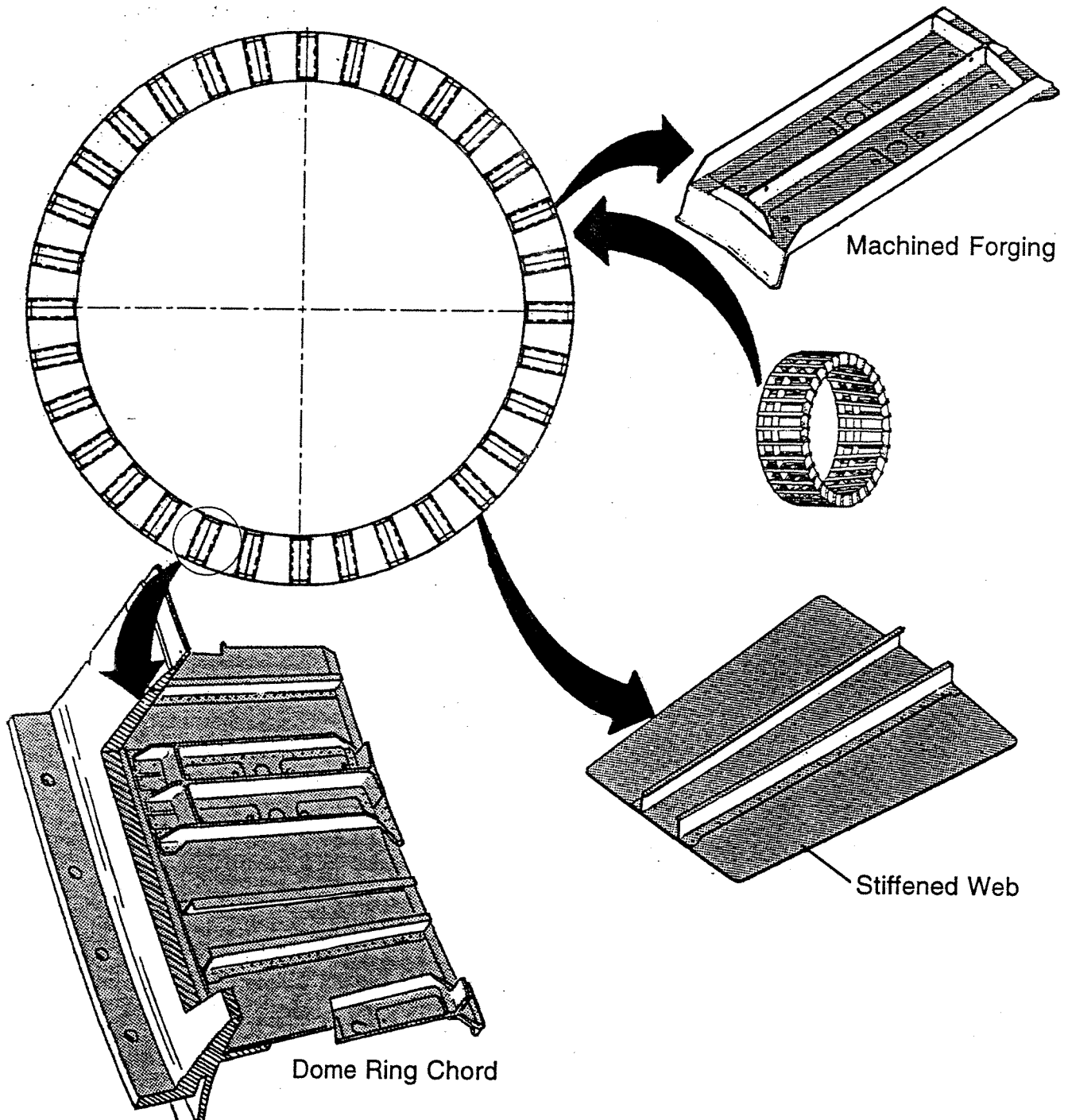


Figure 6-22: Aft Baffle Support Ring at Station 851

6.3.4 VORTEX BAFFLE

The 160-inch diameter vortex baffle is mounted over the suction outlet to the dome cap at four locations (two fixed and two slotted) with two fasteners at each location. The fixed attachments have 0.25 inch diameter holes. The slotted holes contain bushings which preclude clamping the structure thereby permitting relative motion between the tank dome and vortex baffle. The webs are joined at the center with a 32.5-inch-long cruciform splice plate 0.090 inches thick.

The caps are joined together at the bottom by means of a plate; the caps at the top are joined together by the splash plate located at the top of the assembly. There are provisions for 31 $\frac{3}{16}$ -inch anchor nuts on the lower caps, and 29 $\frac{3}{16}$ -inch threaded inserts on the periphery of the outlet for each pie-section of the screen. Rivet heads down stream of the screens have been avoided except beneath the center cruciform splice plate where it was more practical to install a rivet head catcher.

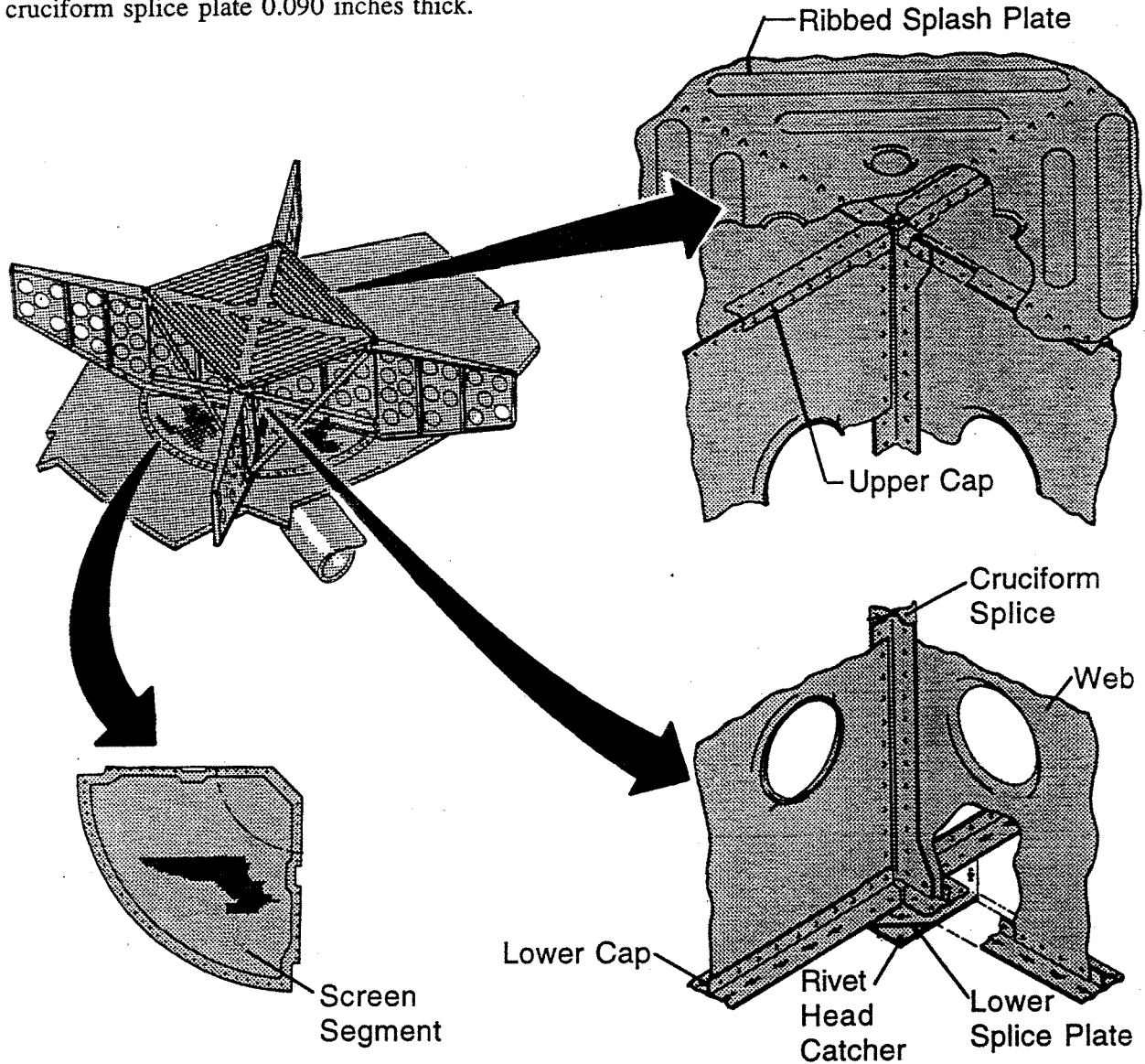


Figure 6-23: LO2 Vortex Baffle and Baffle Joint Detail

7. INTERTANK STRUCTURE

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7. INTERTANK STRUCTURE

The intertank is a semi-monocoque cylindrical structure with flanges on each end for joining the LO2 and LH2 tanks. Its primary functions are to receive and distribute all thrust loads from the SRBs and transfer loads between tanks to provide structural continuity with these assemblies.

7.1 DESCRIPTION

The intertank is the ET structural connection that joins with both the LO2 and LH2 tanks to provide structural continuity between these assemblies. Its primary functions are to receive and distribute all thrust loads from the SRBs and transfer loads between the propellant tanks. In addition, it provides an integral ET intertank carrier plate assembly that interfaces with the fluid, electrical, and pneumatic systems ground facilities, a non-structural access door, two pressure vent openings, and aerodynamic fairings for the LO2 feedline, the GH2 pressurization line

and the two electrical cable trays.

The intertank cylindrical structure consists of eight 45-degree mechanically joined panels (two thrust panels and six external stringer-stiffened skin panels), a main ring frame, four intermediate ring frames, and an SRB beam assembly with two forged thrust fittings.

The use of the intertank makes it possible for the ET to have separate propellant tank bulkheads, avoiding the design complexity and added operational constraints associated with a common bulkhead configuration.

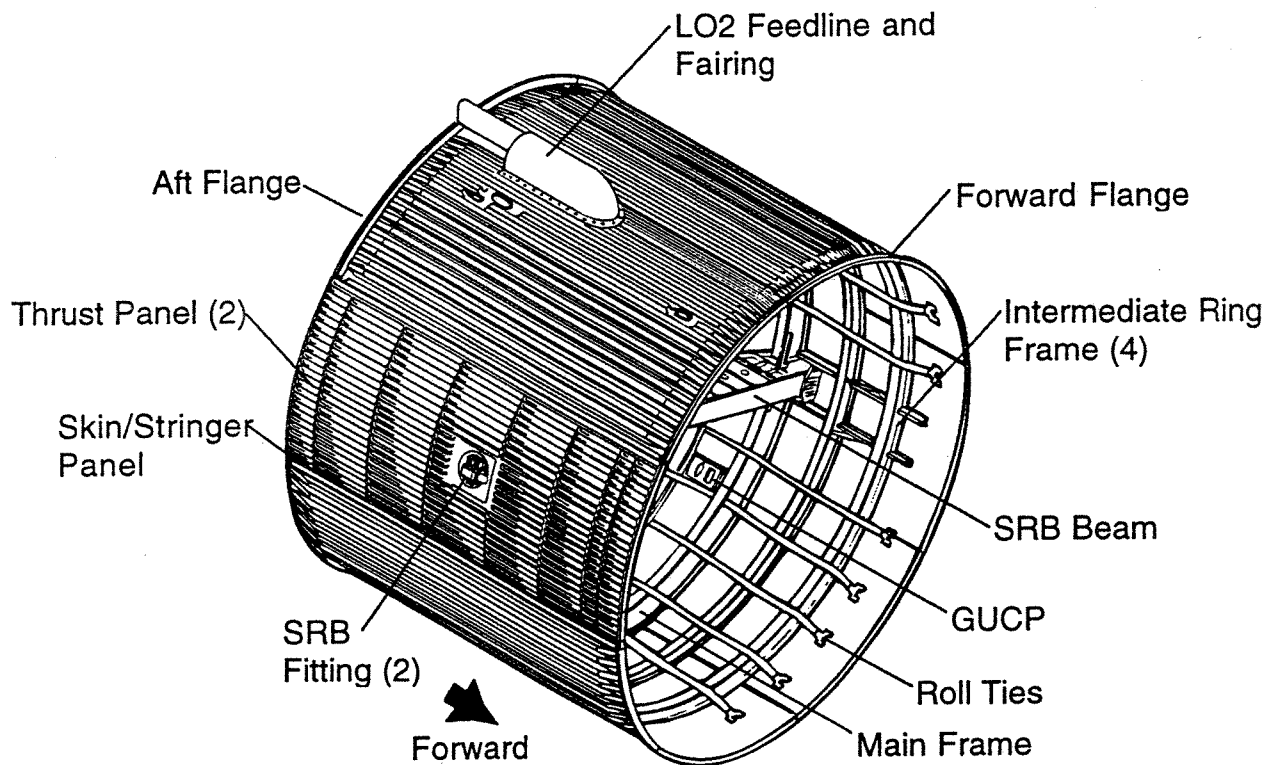


Figure 7-1: Intertank Structure

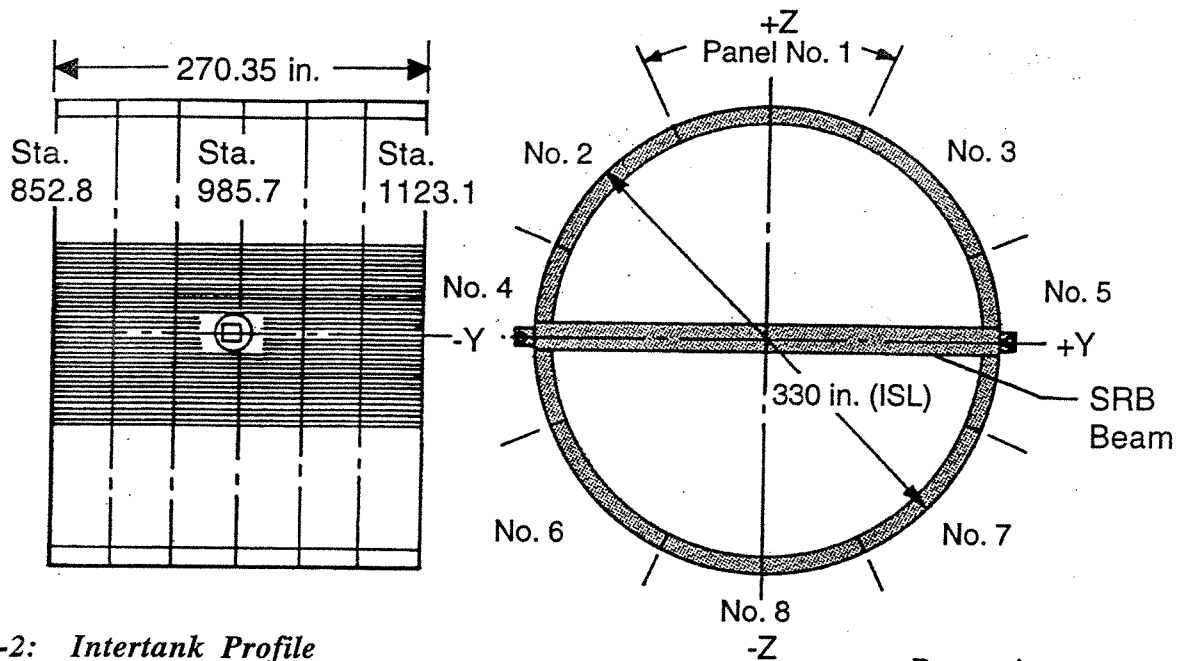


Figure 7-2: Intertank Profile

Thrust loads from the SRBs are transferred to the ET through SRB thrust fittings located at each end of a rectangular beam that extends across the intertank diameter between the two propellant tank domes. These fittings constitute the SRB forward attach points, and serve (by separate integral features) as forward ET handling attachments.

The intertank structural design is determined by load conditions that occur during liftoff, high-Q boost, maximum SRB acceleration and pre- and post SRB staging phases of flight. Critical loads for the intertank shell structure produce axial compression; thus the shell is designed to provide adequate buckling resistance for these loads.

The intertank crossbeam is located at Sta 985.675 and joins the +Y and -Y axis. The intertank crossbeam (commonly referred to as the SRB beam) is designed to limit the rotation at SRB thrust fitting. Due to FTB5 and FTB6 moment during all flight regimes. The crossbeam carries the FTB5 and FTB6 moment through the forward and aft crossbeam chords. The crossbeam has forward and aft fittings which assist in the transfer of load through the thrust fitting to the crossbeam chords. The crossbeam deflections are limited since the dynamic clearance between the LO2 and LH2 domes during flight are small.

A major ring frame located at Sta 985 distributes SRB tangential loads to the intertank skin. Four intermediate ring frames provide intertank skin panel stability, and additional thrust

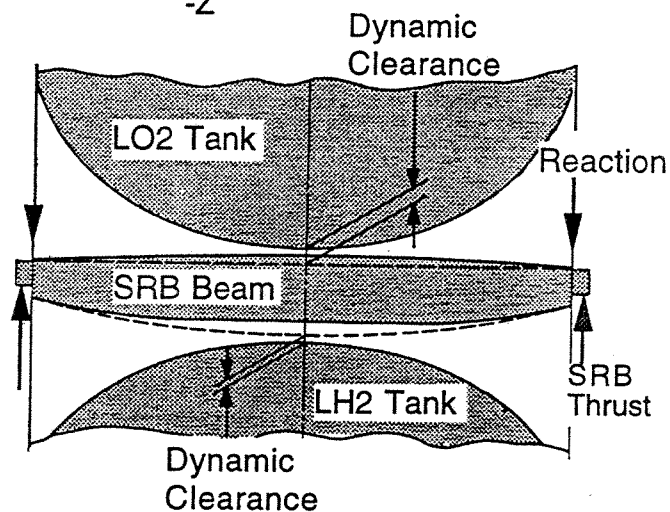


Figure 7-3: SRB Beam Load and Deflection Diagram

panel stability is provided by longerons located forward of the SRB beam.

The weight (approximately 11,500 pounds) and strength of the intertank structure is optimized by limiting the maximum structural temperature between 100° to 140°F during the boost phase of flight. Ground heated purge maintains the intertank above 32°F prior to and at liftoff to prevent ice/frost formation.

Aluminum alloys are used exclusively in the fabrication and assembly of the intertank structure, except for fasteners and the SRB fitting socket inserts which are steel. The construction materials for the SLWT are listed in the following table.

Table 7-1: SLWT Intertank Material

ELEMENT	MATERIAL	CONDITION
• Thrust Panels	2219 Plate	T87
• Skin/Stringer Panels		
Skins, Doublers	2090 Sheet	T83
Doublers	2090 Sheet	T83
Stringers, Rolled/Chem-milled	2090 Sheet	T83
Stringers, Extruded	2024 Extrusion	T8511
Buttstraps	2090 Sheet	T83
Attachment Flange	2024 Extrusion	T8511
Shims	6063 Extrusion	T6
• Thrust Panel Longerons	2090 Extrusion	T86
• Ring Frames		
Chords	2090 Extrusion	T86
Webs	7075 Sheet	T6
Stiffeners	2090 Extrusion	T73511
• SRB Beam		
Chords	7075 Extrusion	T73511
Webs	7075 Sheet	T6
Stiffeners	2090 Extrusion	T86
Bulkheads	7075 Sheet	T62
SRB Thrust Fittings	7050 Forging	T73

7.2 MAJOR STRUCTURAL ELEMENTS

The intertank cylindrical structure consists of two machined thrust panels and six stringer-stiffened panels joined mechanically - as are all parts of the intertank. No weldments are used. Flange rings are provided at the panel ends for attaching the intertank to the LO2 and LH2 tanks.

7.2.1 THRUST PANELS

The two thrust panels distribute the concentrated axial SRB thrust loads to the LO2 and LH2 tanks and to adjacent intertank skin panels. The panels are selectively machined with tapered skin thicknesses, and 26 external parallel ribs are integral with each panel. The panels are rough machined from aluminum plate stock, formed to cylindrical segments with a radius of 165 inches, and then final machined to a finished size of 2.06 x 130 x 270.35 inches.

The skin thickness is step-tapered to thinner sections radially from each SRB fitting cutout, from a maximum of 2.06 inches at the cutout to a minimum of 0.120 inches in areas of lower stress. Skin thickness is again increased to 0.310 adjacent to the LO2 attachment flange and 0.350 adjacent to the LH2 tank attachment flange.

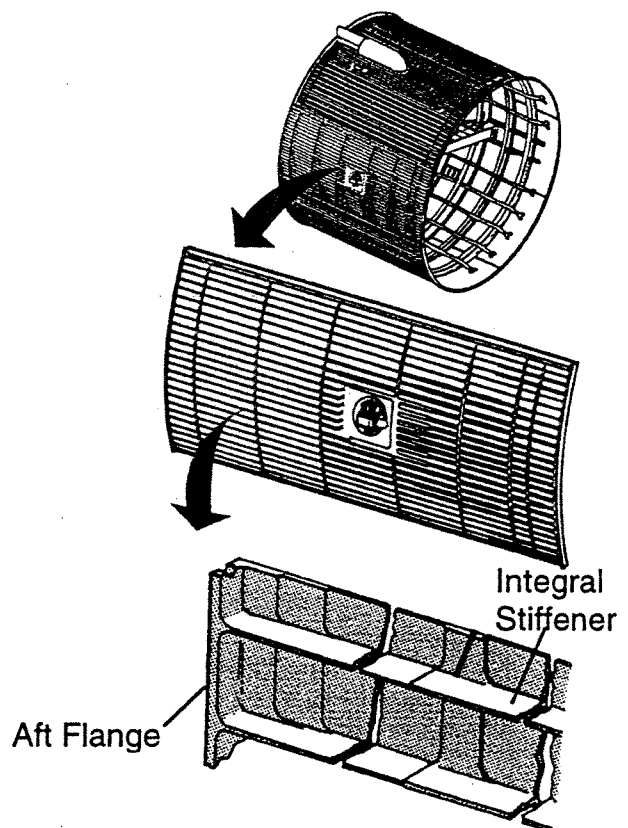


Figure 7-4: Thrust Panel

The 26 integral ribs and 7 circumferential ribs are designed to prevent buckling and provide flutter resistance. Integral rib thickness is reduced in steps from 1.05 inches near the SRB fittings to a minimum of 0.17 inches. The circumferential rib thickness varies from 0.5" at the center of the panel to 0.18" at the outer edge. The ribs provide strength and stability in the most weight-effective manner.

7.2.2 SKIN/STRINGER PANELS

The six stringer-stiffened panels are similar except for line penetration provisions, umbilical carrier plate installation, and an access door. The skin panels are each made of two aluminum skins mechanically spliced longitudinally by internal and external butt straps. Skin doublers provide the necessary reinforcement for areas where the skin is penetrated-providing for the ET intertank carrier plate assembly, the access door opening, venting and the entry of cables and lines.

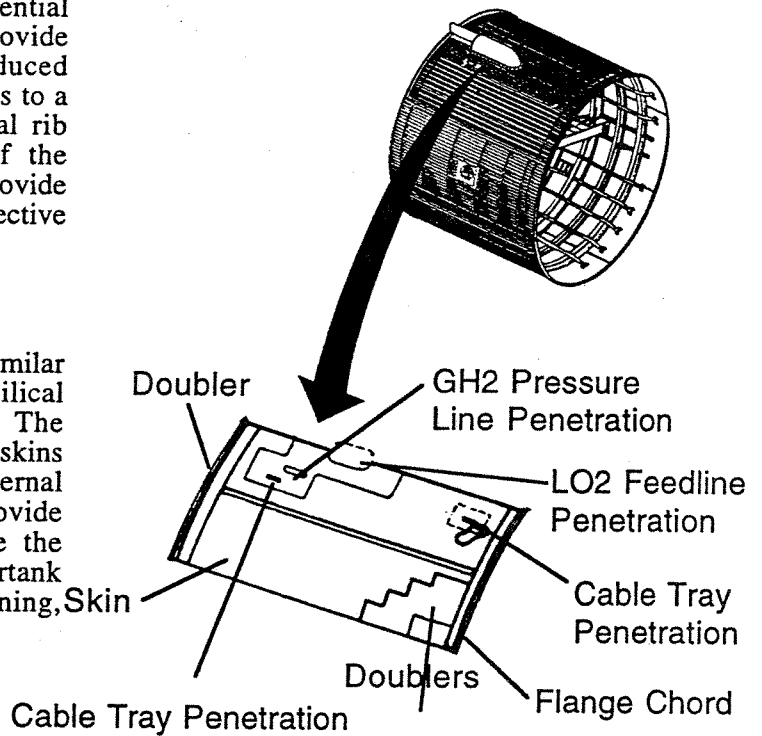


Figure 7-5: Skin/Stringer Panel
(Stringers omitted for clarity)

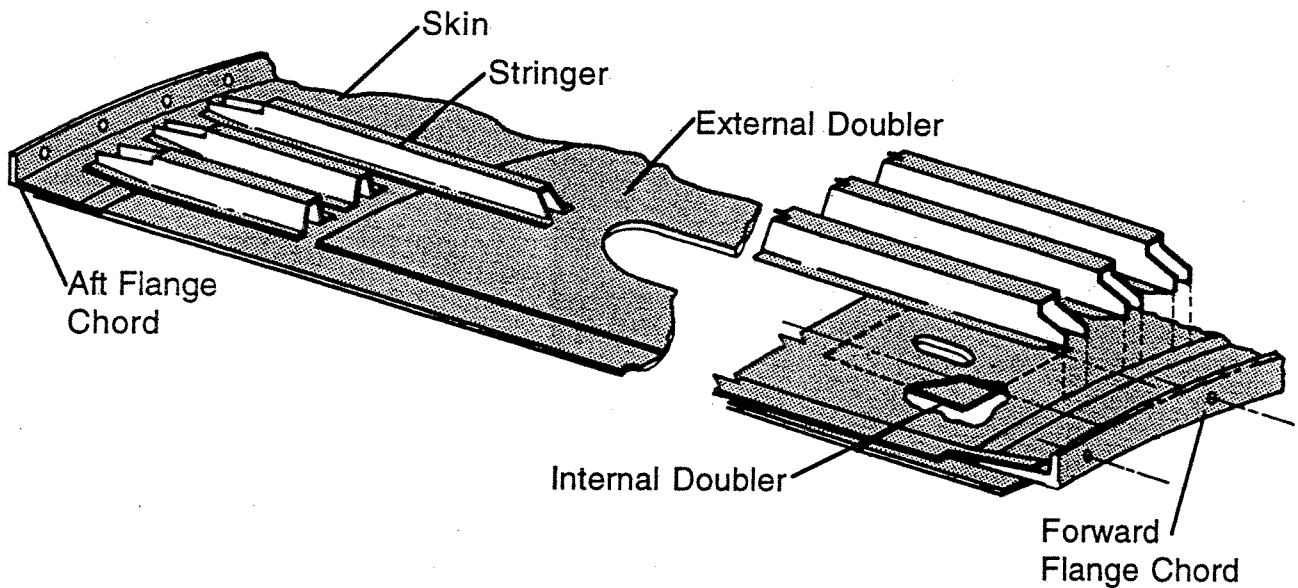


Figure 7-6: Panel Penetrations and Reinforcements

Additional skin reinforcing doublers are located adjacent to the thrust panels and the LO2 tank attachment flange ring to distribute SRB thrust loads. Skin doublers are external where required to provide an unobstructed mating surface for internally mounted ring frames, but are internal wherever practical to minimize stringer offsets.

There are eighteen external stringers most of which are roll-formed, and selectively chem-milled while some are machined from extrusions. They are equally spaced around each panel, providing buckling and flutter resistance, distributing loads to the attachment flanges, and providing for the attachment of mounting brackets for propulsion and electrical subsystem lines and cable trays. The stringers are mechanically fastened to the skin panels and flanges, and are of hat-section aluminum with suitable offsets for doublers and tapered offsets at the flanges.

The six stringer-stiffened panels and the two thrust panels are mechanically spliced using longitudinal butt-straps to form the intertank skin shell. Flange interface bolt holes are located by matched tooling. The LO2 and LH2 attachments require 194 9/16-inch diameter bolts and 178 9/16-inch diameter bolts, respectively.

Two thrust panel longerons provide added stability for the compressive loading of the forward section of each thrust panel. The longerons are extruded aluminum hat sections, 114 inches long, 3 inches wide and 5 inches high - with a maximum thickness of 0.22 inches. Two longerons are mechanically fastened to each thrust panel, one on each side of the SRB fitting. The aft end is mechanically fastened to the main ring frame by angles. The longerons extend through the two smaller ring frames terminating near the LO2 tank attachment flange ring. Extruded angles fastened mechanically to these ring frames maintain load path continuity through the longeron/ring-frame junction.

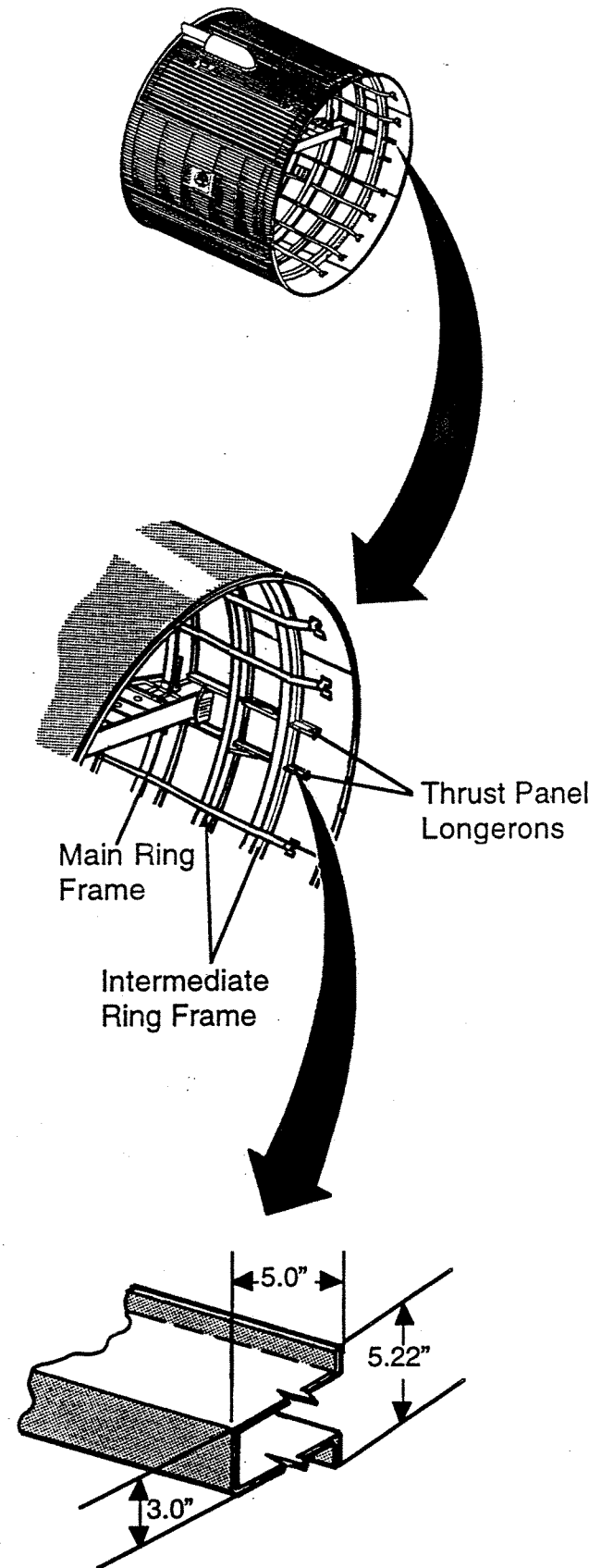


Figure 7-7: Thrust Panel Longerons

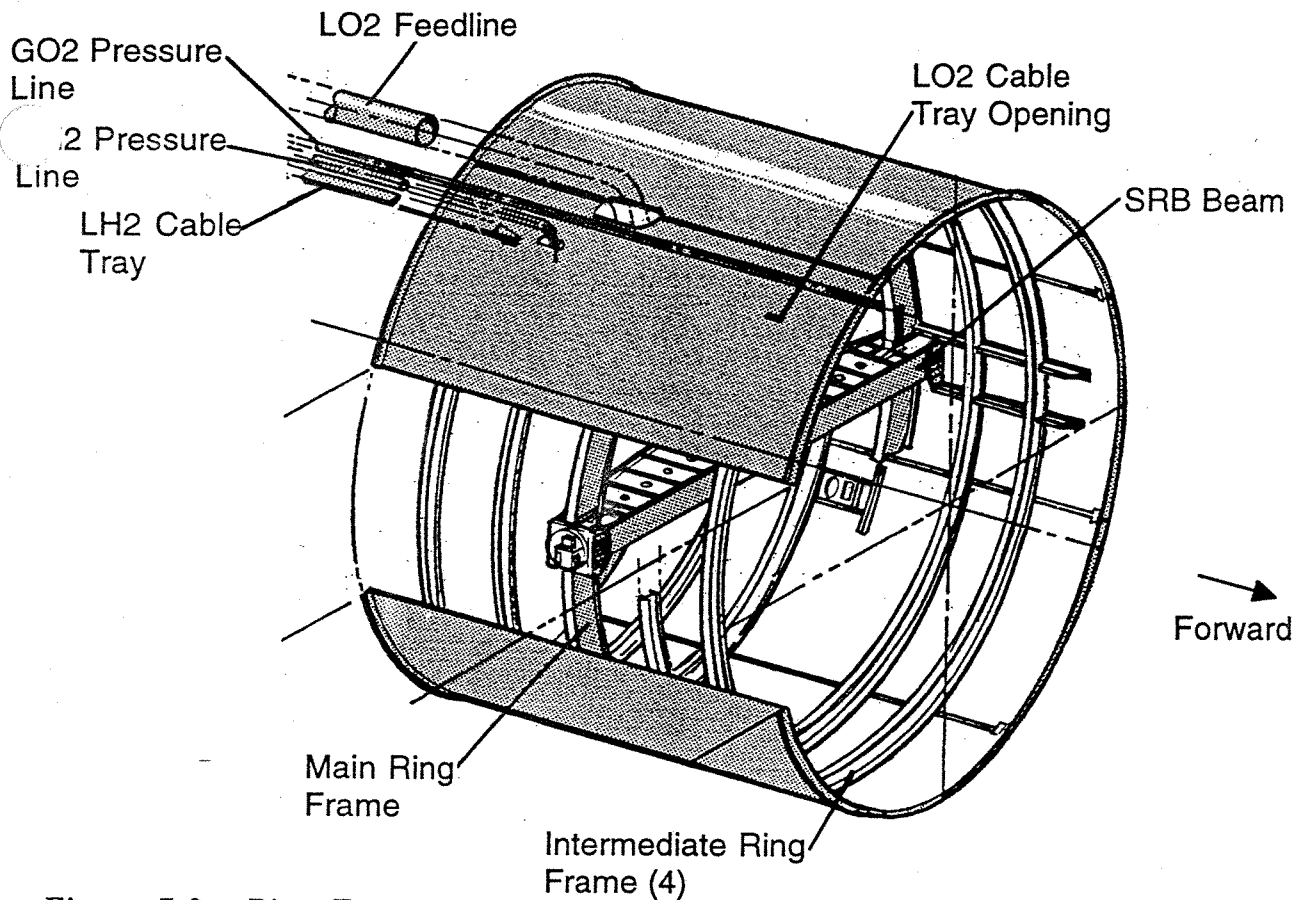


Figure 7-8: Ring Frames

7.2.3 RING FRAMES

One main ring frame at Sta 985.675 is employed to transmit the transverse SRB thrust loads and the ET handling loads into the shell. Four intermediate ring frames stabilize the cylindrical shell.

Main Ring Frame - The main ring frame, adjoining the SRB thrust fitting, is constructed of four quadrant subassemblies. One end of each quadrant is joined to an SRB fitting and are all fastened to effect a continuous load path through that joint and transfer loads from the fittings to the ring frame. The other ends are spliced together to form a continuous ring.

Each quadrant is constructed of outer and inner tee chords which are machined from 7075-T73511 aluminum extrusions and joined to webs to form an I-beam 20 inches deep. The outer chords are fastened to the cylindrical skin panels.

Rib and web thicknesses decrease with distance from the SRB fitting as frame loads are distributed to the skin. The width of each outer chord is 6 inches for a length of 53 inches at the end which fastens to the SRB fitting, 6 inches for a length of 54 inches adjacent to the access door in one quadrant, 3.8 inches at the end spliced to the adjacent chord, and 3.2 inches wide for the remainder of its length. The inner chord is a constant 3.86 inches wide to tailor this ring frame to the load distribution. The web thickness varies from 0.180 inches to 0.05 inches with increasing distance from the SRB fitting. Quadrants are mechanically spliced by a plate and angle at the inner chord, a tee at the webs and three straps at the outer tee chord.

The main ring frame is provided out-of-plane stability at twenty locations by aluminum straps and tee section bars attached to the adjacent intermediate ring frames.

Intermediate Ring Frames - Four smaller ring frames (12 inches deep) are constructed similar to the main frame using extruded aluminum tee chords to form the inner and outer chords, and quadrant webs of stiffened panels spliced by tees. These intermediate ring frames are stabilized at 24 places by aluminum straps and extruded tees tying two adjacent frames together.

The I-beam sections are 12 inches deep, with a 3-inch outer cap width, 3.09-inch inner cap width, and web thicknesses varying from 0.025 to 0.050 inches for the beaded web sections and 0.09 inches for the angle-stiffened web sections. The heavier, angle-stiffened web sections are positioned at the SRB thrust panels to help distribute SRB loads. All web sections are joined by extruded tee-section splices.

The frames are assembled in quadrant sections and spliced at each Z-axis juncture using

a splice plate to join the inner chord, a tee section to join the web, and a plate and angle fitted to the sides to join the outer chord. The two splices at the Y-axis junctures (adjacent to the SRB thrust panels) are joined by using splice plates for the inner chords and tee sections and sheets joining the webs.

While the four intermediate ring frames are nearly identical, there are two significant differences. The ring frame adjacent to the access door has a locally wider outer chord section (5 inches) where seven external intertank stringers terminate at the access door opening. The web for this quadrant is stiffened by tee sections. The two ring frames located in the forward half of the intertank have the outer chords cut and portions of the webs notched to straddle the two longerons. Angle clips and the thrust panel skin are employed to effect continuous load paths through these joints.

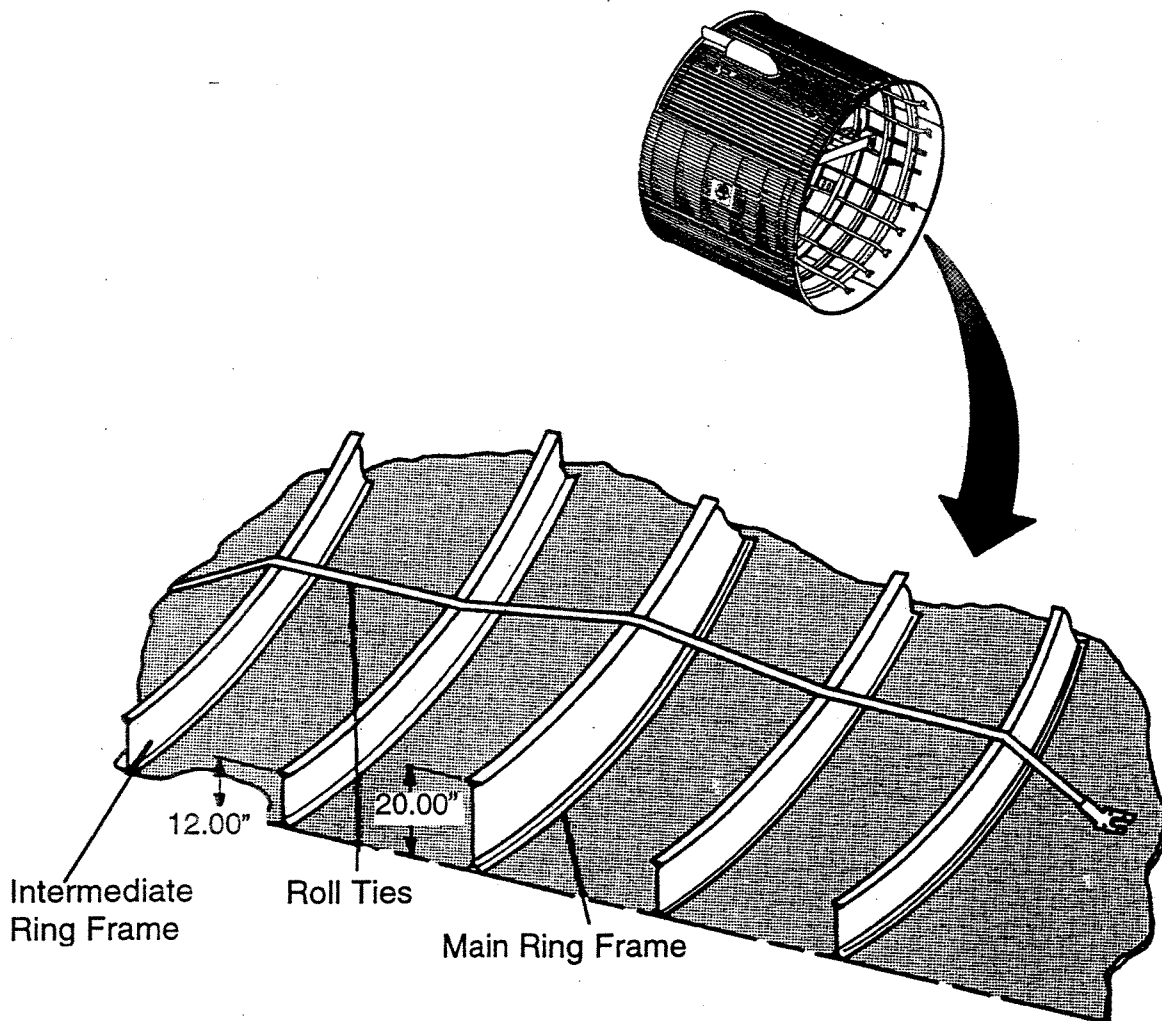


Figure 7-9: Ring Frames and Roll Ties

7.2.4 SRB BEAM

The SRB beam assembly is a rectangular box beam. It is 42.95 inches deep at the center and tapers to 26 inches (at the ends) by 15 inches wide, and spans 345 inches between the centerlines of the two SRB thrust fittings which form the ends of the assembly. It consists of top and bottom chords, stiffened webs, stability bulkheads, and SRB thrust fittings - all mechanically joined. The beam structural design considerations are strength, stability, and deflection at midspan (which is limited by the available space between the LO2 and LH2 tanks).

The top (forward) chord is designed primarily for compression loads resulting from SRB thrust. It is an extruded and machined aluminum channel with extensions for attaching web members. The bottom tension chord is similar to the top chord; both are fastened to the SRB fitting. Side webs of 0.032, 0.050 and 0.063 inch aluminum sheet, with fastener-access holes along the centerlines, are joined to the top and bottom beam chords. Webs are 0.125 and 0.190 inches thick and further stiffened with tee and angle stiffeners in the area of the ring frame junction with the SRB fitting. Two skin doublers provide further structural strength to this junction.

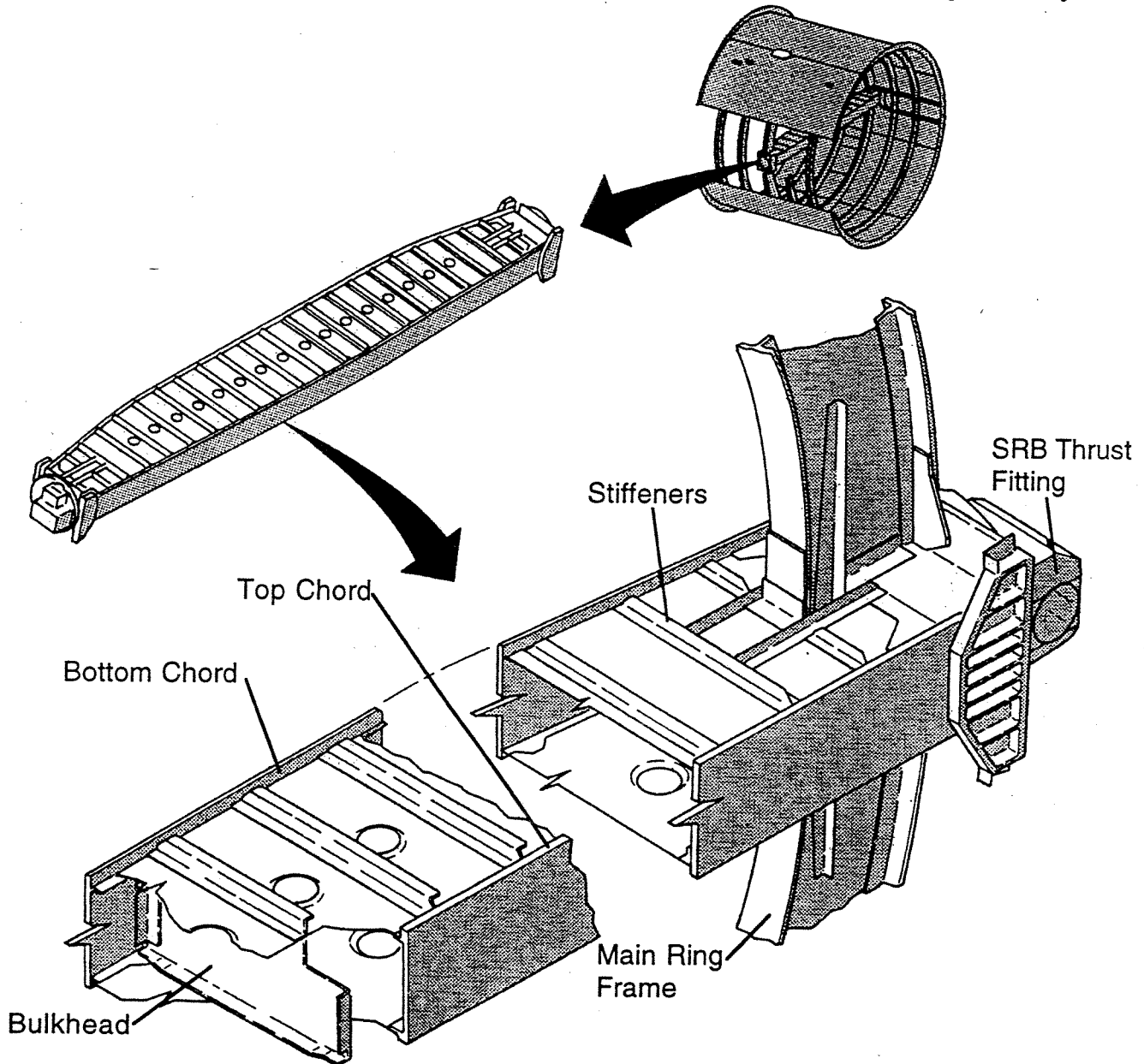


Figure 7-10: SRB Beam

SRB Thrust Fittings - The two SRB thrust fittings have a mirror image identity and are machined aluminum (7050-T73) forgings. An integral machined flange mates with the thrust panel.

Each thrust fitting is mechanically fastened to the chord ends of the SRB beam, the machined gusset fittings, and main frame outer chord, and to the thrust panel. Two machined gussets tie to the SRB fitting through the beam chords, and are fastened to the thrust panel to further strengthen this junction. The fitting is joined to the thrust panel with a close fitting, bearing surface which matches the circular panel cutout; and by an internal, rectangular mounting flange. The fitting has machined stainless steel socket inserts that mate with the SRB ball fittings and also incorporates a machined socket which interfaces with a special ground-handling fitting to permit the lifting and rotating of the ET.

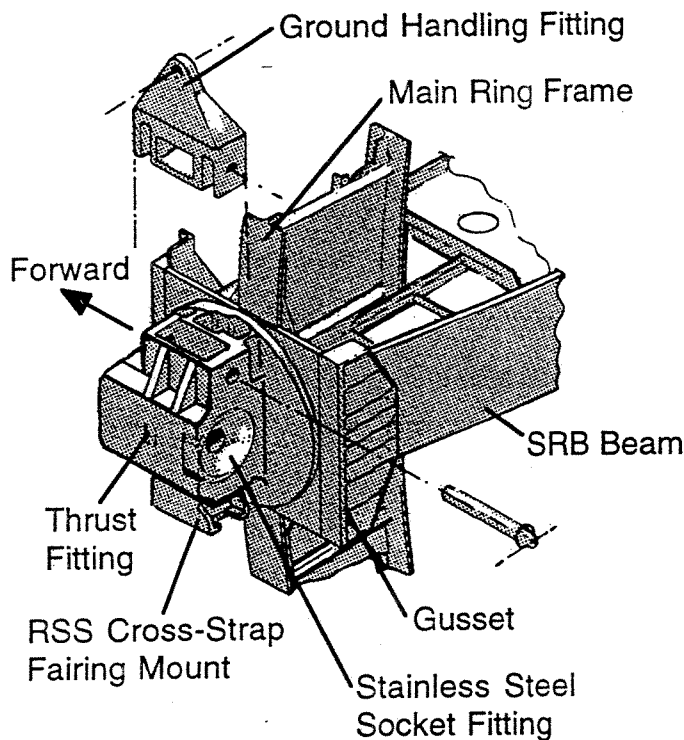


Figure 7-11: SRB Thrust Fitting

7.3 COMPONENT FEATURES AND DETAILS

A number of features peculiar to the intertank, along with a greater depth of component detail in specific areas of interest, are presented in the following pages. Some of the features to be discussed have minor structural influence, but are provisions for intertank service and access.

7.3.1 PRESSURE VENTS

Two vent openings, each with an area of six square inches, are provided at the forward end of the intertank for venting during preflight environmental conditioning and for equalization of internal/external pressures in flight. This 12.6 square-inch area is combined with other penetrations to provide a leak area varying from 54 to 63 square inches to maintain safe oxygen levels during high wind ground operations, and to maintain localized intertank pressures between -1.1 and +3.7 psig during flight. Indeterminate joint leakage is eliminated by sealers and foam insulation used to cover the entire intertank surface as a TPS requirement.

Each vent consists of an elliptical shaped tube. A flange is welded at the start of the bend, and the vent is installed on the intertank skin with the flange on the inside so that the tube extends between two stringers and to the top surface of the TPS. The tube bend direction is positioned toward the LO2 tank to prevent the entry of rain water during prelaunch operations.

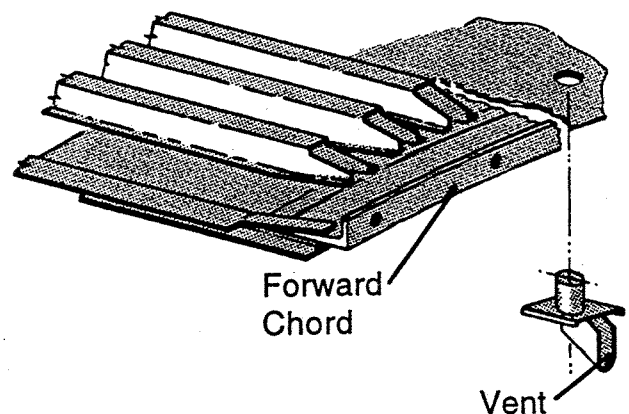


Figure 7-12: Intertank Vent

7.3.2 ACCESS DOOR

The intertank access door is located between the frames Sta 985.675 and Sta 1034.2 and the door centerline is located 214° clockwise from the +Z axis. The access door does not carry primary intertank structural loads, but is designed to withstand worst case intertank differential burst pressure during flight. The access door is made of

composite graphite polyimide material and consists of sixteen plies on the skin and eight plies on the stringers. The six stringers are cocured onto the inside of the access door. The access door is recessed from the intertank stringer tops. The access door is attached to the intertank with forty four low profile bolts with captive washers and floating nutplates to ensure that no intertank structural load is transferred through the door.

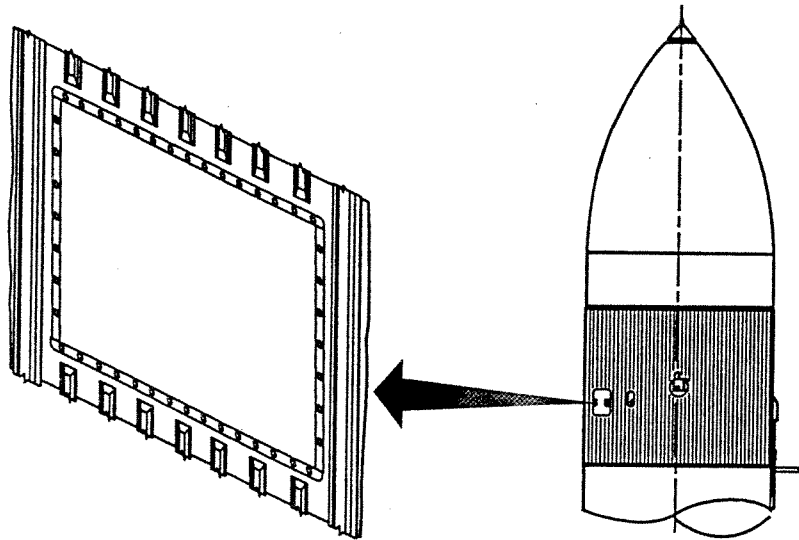


Figure 7-13: Intertank Access Door

7.3.3 PLATE ASSEMBLY

The ET intertank carrier plate assembly (ETCA) is a structural panel in the intertank shell that provides for interfacing with the ground facility's fluid, electrical, and pneumatic systems via the ground umbilical carrier assembly (GUCA). It is located 120 degrees clockwise from the +Z axis to coincide with the location of interfacing lines at the facility swing arm. The ETCA functions are described in Section XII, *Interface Hardware*.

The ETCA is machined from 2219 aluminum alloy plate, with two integral longitudinal channel sections and two transverse L-shaped sections constituting the peripheral edges. It is mechanically fastened to the skin panel by four flanges, with an external skin doubler reinforcement. The channel sections are fastened at one end to an intermediate ring frame with angle clips. At the other end they are fastened with angle clips to an I-beam reinforcement.

7.3.4 AERODYNAMIC FAIRINGS

Four aerodynamic fairings enclose each service penetration to the intertank interior. Fairings are fastened to the tops of the stringers immediately fore and aft of the penetration openings. The openings between the stringers are closed by formed-sheet panels fastened to the stringers and to the fairings.

Penetrations incorporating these fairings are for the LO2 feedline, the GH2 pressure line, and at the two electrical cable tray locations. The forward cable tray opening routes electrical cables and pneumatic lines into the compartment from the nose cap. The aft opening serves the same purpose for the electrical cables and lines originating at the ET/Orbiter aft interface.

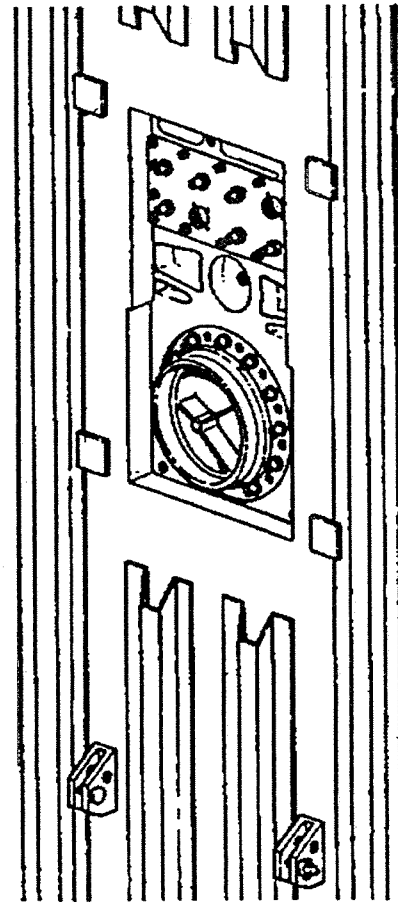


Figure 7-14: ET Intertank Carrier Plate Assembly

7.3.5 CABLE TRAY AND PRESSURIZATION LINE SUPPORTS

Supports for the cable trays and propulsion lines are fastened to the stringers by formed-sheet and machined brackets that bridge the stringer gaps.

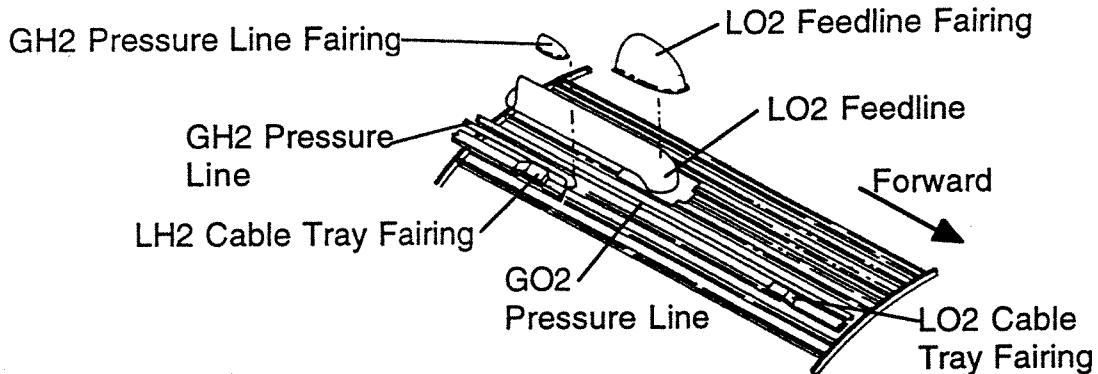


Figure 7-15: Aerodynamic Fairing and Service Supports

8. LH2 TANK STRUCTURE

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8. LH2 TANK STRUCTURE

The liquid hydrogen tank is a semi-monocoque structure designed to contain 227,641 pounds of propellant fuel; it measures 1160.75 inches long with an outside skin diameter of 331 inches, has a total volume of 53,518 cubic feet, and its empty weight is approximately 23,600 pounds.

8.1 DESCRIPTION

The LH2 tank is a welded assembly with forward and aft modified 0.75 ellipsoidal domes and four cylindrical orthogrid barrel sections joined by five major ring frames. Two longerons

are installed in the aft barrel section to receive Orbiter thrust loads.

Aluminum alloys are used exclusively in the fabrication and assembly of the tank structure.

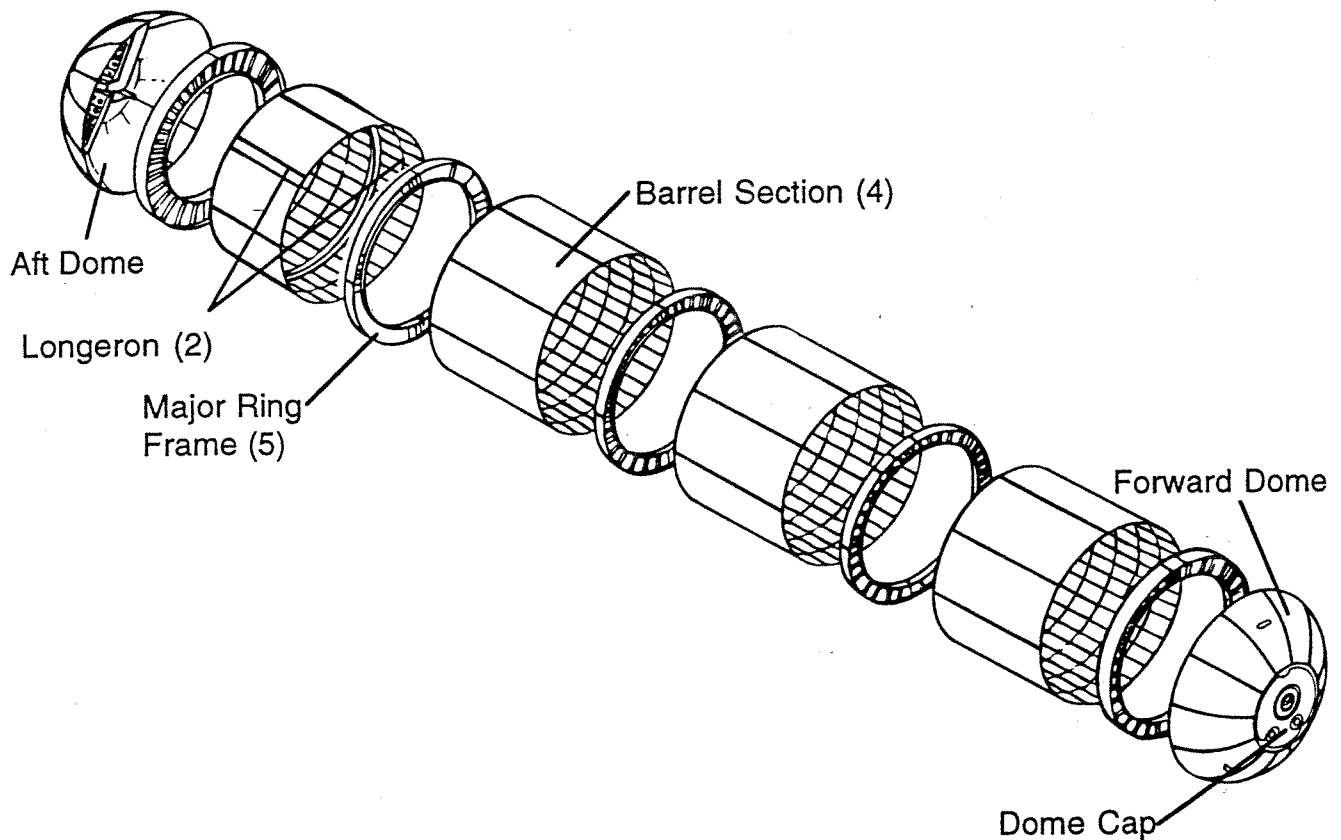


Figure 8-1: LH2 Tank Structure

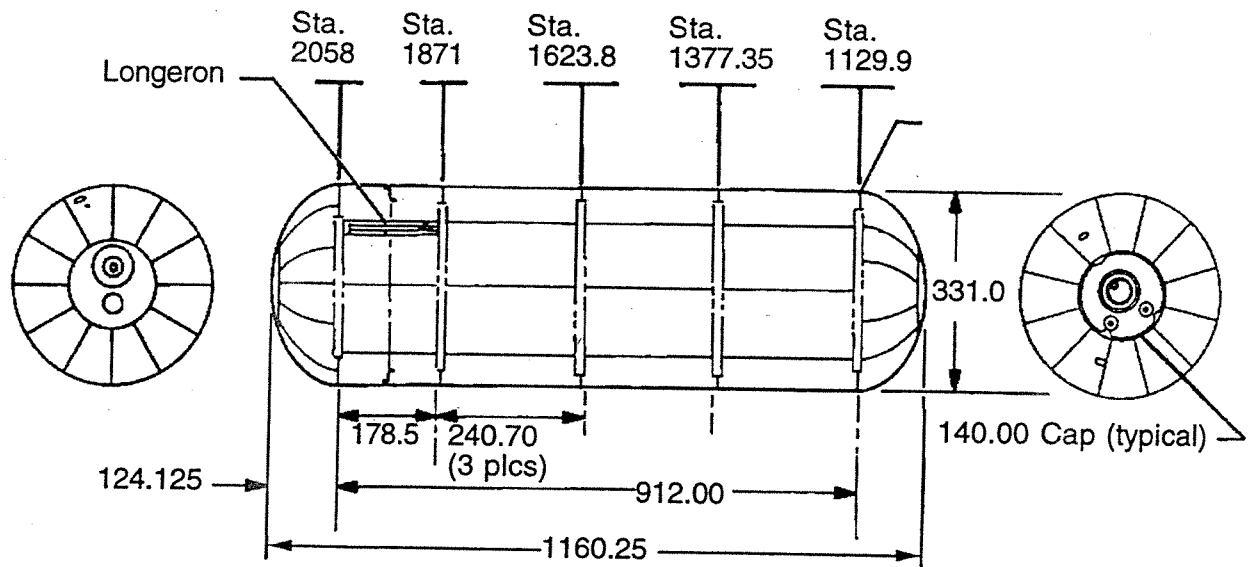


Figure 8-2: LH2 Tank Profile

Loads applied through the intertank structure are transferred to the LH2 tank through the LH2 tank/intertank mating flange. SRB balancing loads are reacted at the aft major ring frame of the LH2 tank. Orbiter loads are applied at forward and aft Orbiter support struts, described in Section XII, *Interface Hardware*, and are reacted at the forward and aft major ring frames and the aft barrel longerons. The forward and aft major ring frames at Station 1129.9 and Station 2058 are designed primarily for the material high-Q boost load occurring about fifty seconds after liftoff. Critical loads for the major ring frame at Station 1871 pass through the canted Orbiter thrust strut and occur at the maximum Orbiter thrust condition after SRB staging (post staging). LO2 feedline support loads also contribute to the major ring frame load distribution.

Proof test of the LH2 tank constitutes the primary load condition for design of the forward and aft domes and forward and aft barrels. Other load conditions which contribute to the design of the barrels are lift-off compression, post staging, and ground handling. Post staging is also the

primary design condition for the longeron sections.

Intermediate ring frames are critical for the prelaunch loads with the LH2 tank unpressurized. The tank's integrally stiffened skin is designed to be non-buckling at limit load to preclude the possible cracking of TPS material.

Many SLWT weld lands were increased in thickness compared with the LWT designs. Known as robust weld lands, the following SLWT weld lands were increased by up 0.35 in. to compensate for Al 2195 weld repair allowables:

- Longeron to barrel panel
- Barrel panel to barrel panel on Barrel No. 2 forward of the longerons
- Frame 1623 and 1377 chord to chord Al 2195 welds
- LH2 forward and aft dome gore to dome gore
- LH2 forward and aft chord to gore
- LH2 aft dome cap to dome body
- LH2 aft manhole and siphon plate

ELEMENT	MATERIAL	CONDITION
Dome Sections		
• Gores and Cap, Forward	2195/2219 Plate	T8A4/T87
• Gores and Cap, Aft	2195/2219 Plate	T8A4/T8Z6
Barrel Sections		
• Skin Panel	2195 Plate	T8M4
• Intermediate Ring Frames	2195 Plate	T8A3
• Longeron	2219 Forging	T6
•		
Major Ring Frames		
• Outer Chord	2195/2219 Extrusion	T8A3/T8511
• Inner Chord	2024 Extrusion	T8511
• Webs	2024 Sheet/2024 Plate	T81
• Fittings	2219 Forging/2219 Plate	T6/T87
• Stiffeners	2024 Extrusion	T8511
•		
Frame Stabilizers	2219 Tube/2024 Extrusion	T81/T8511

Table 8-1: SLWT LH2 Tank Materials

8.2 MAJOR ASSEMBLIES

The major assemblies which comprise the LH2 tank are the forward and aft domes, cylindrical barrel sections, and major ring frames. These assemblies are discussed here in detail.

8.2.1 LH2 TANK FORWARD DOME

The LH2 tank forward dome is a welded assembly of twelve gore segments and a dome cap. The dome shape (0.75 ellipsoid with a spherical cap that is approximately the 0.75 ellipsoid shape), and manufacturing techniques are the same as those used for the LO2 tank dome. Mounting provisions are incorporated in the dome cap for the LH2 vent valve, the LH2 pressure line fitting, the electrical feed-through fitting, and the forwardmanhole fitting, LH2 tank manhole covers

with TPS weigh approximately 34 to 40 pounds each.

Gore skin thickness is tapered to maintain stress uniformity and each gore is chemically milled on both sides to equalize skin stresses. Thickness varies from a minimum of 0.066 inches near the aft edge of the gore to 0.084 inches in the vicinity of the dome cap. The gore-to-gore, gore-to-cap, and gore-to-frame attachments are all 0.200 inch to 0.235 inch tapered welds. Weld land geometry is similar to that of the LO2 tank dome in that the membranes are reinforced by a series of circumferential chem-milled bands. The 140-inch diameter dome cap is machined to accommodate installation of the fittings previously described. Machining for the LH2 tank dome fitting is similar to that for the LO2 tank dome manhole fitting. Other than the weld lands and fitting locations, the dome cap thickness is 0.092 inches.

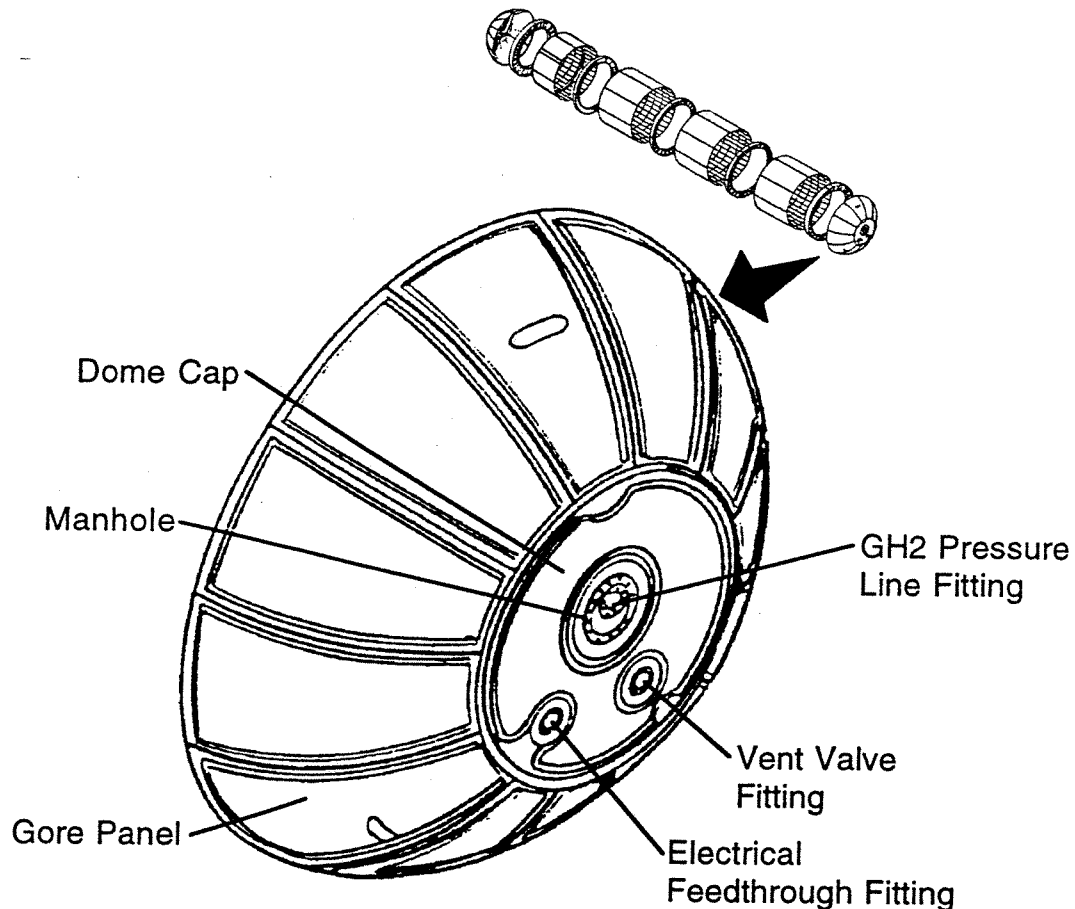


Figure 8-3: LH2 Tank Forward Dome

8.2.2 CYLINDRICAL SECTION

The cylindrical portion of the LH2 tank consists of four barrel sections joined by butt welds at five major ring frames.

LH2 tank barrel sections are welded assemblies made from eight orthogrid stiffened skin panels. Skin panels are machined from plate stock on numerically controlled skin mills with

longitudinal and circumferential stiffeners remaining as an integral part of each skin panel. The panel skin membrane thickness is sized to meet load requirements and varies from panel to panel from a minimum of 0.084 to a maximum of 0.555 inches. The thickness of the weld lands at the four edges of each panel is generally 0.325, but varies locally in the longeron area up to a maximum of 0.665 inches.

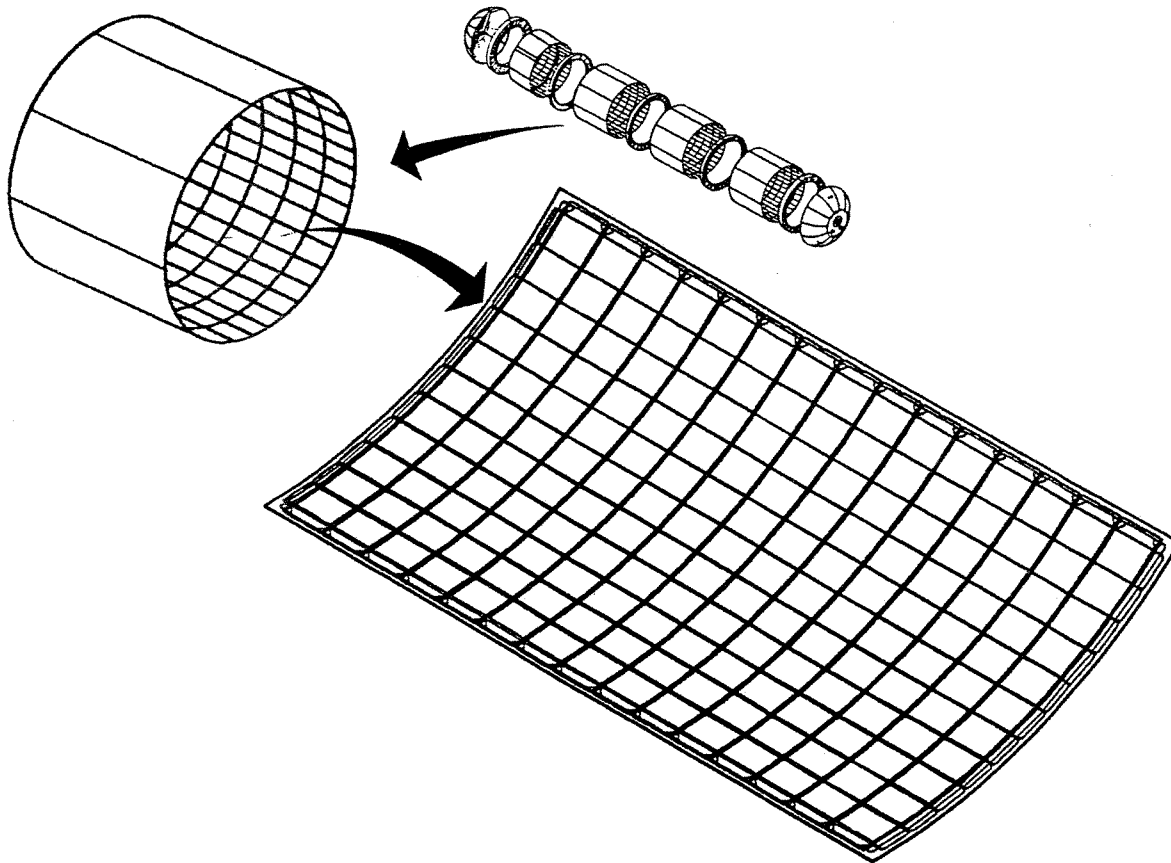


Figure 8-4: Barrel Section

Skin panels also include provisions for mounting support fittings for externally mounted propulsion system lines and electrical cable trays. Tapped holes with threaded inserts are provided in the skin panels for installation of the support fittings. Bosses are machined into the stiffener intersections where required to accept the threaded inserts.

The longerons are machined from aluminum forgings to a finished size of 181.75 inches long by 32.496 inches wide. The Orbiter thrust strut is bolted to an integral clevis on the forward end of each longeron. Assembly of the longerons into the

aft barrel section is accomplished by butt welding at 0.320 inch minimum to 0.670 inch maximum weld lands on both sides to adjacent skin panels. An electrical feed-through is provided for LH2 low level, and depletion sensor wiring at the aft end of the right longeron.

The aft barrel section includes two longeron sections welded into skin panels to distribute Orbiter loads which are reacted at the Orbiter truss and strut forward attach points. The longerons are located on the aft barrel section equidistant from the Z-axis and $101^{\circ} 15'$ between center lines of longerons.

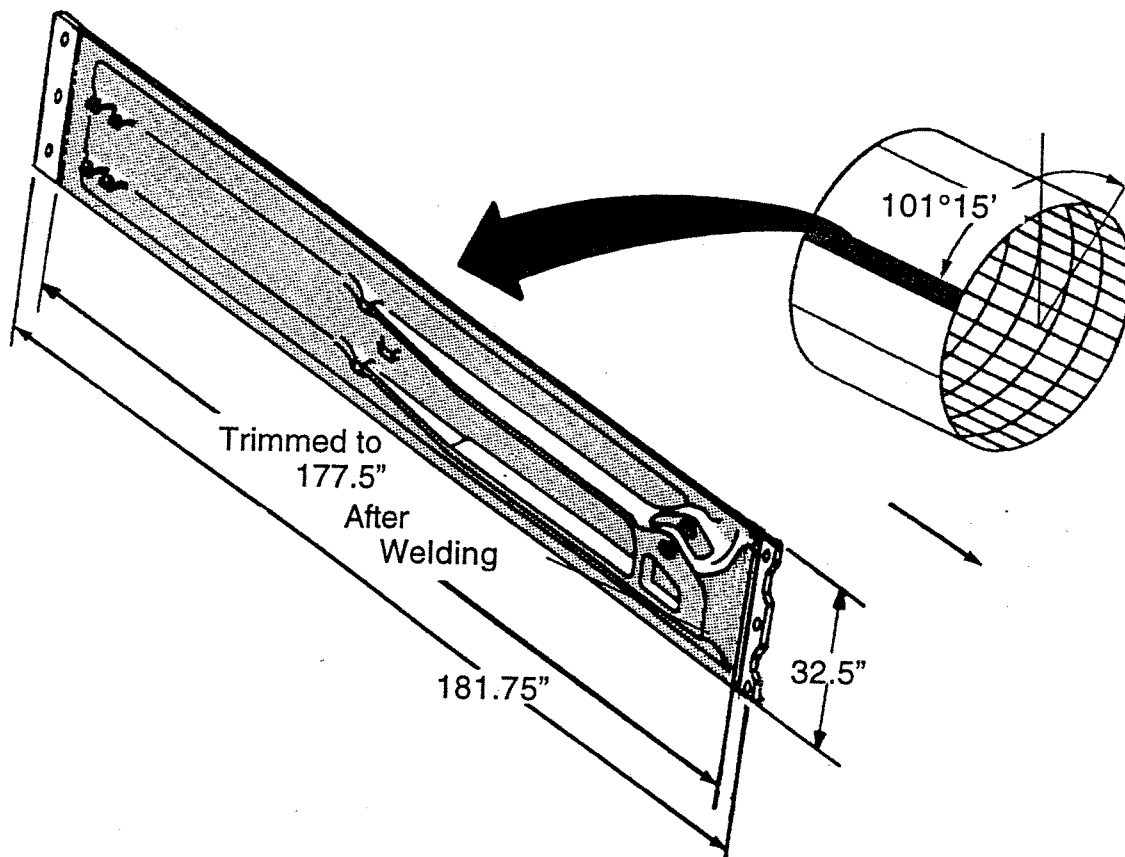


Figure 8-5: Longeron

There is one intermediate ring frame located at Station 1973.5 to provide stability for the integrally stiffened skin panels, particularly in the prelaunch/unpressurized tank condition. The

frame is a web-stiffened channel frame with extruded angle chords - a configuration which is consistent with the higher loads in the aft part of the LH2 tank apportioned to this frame.

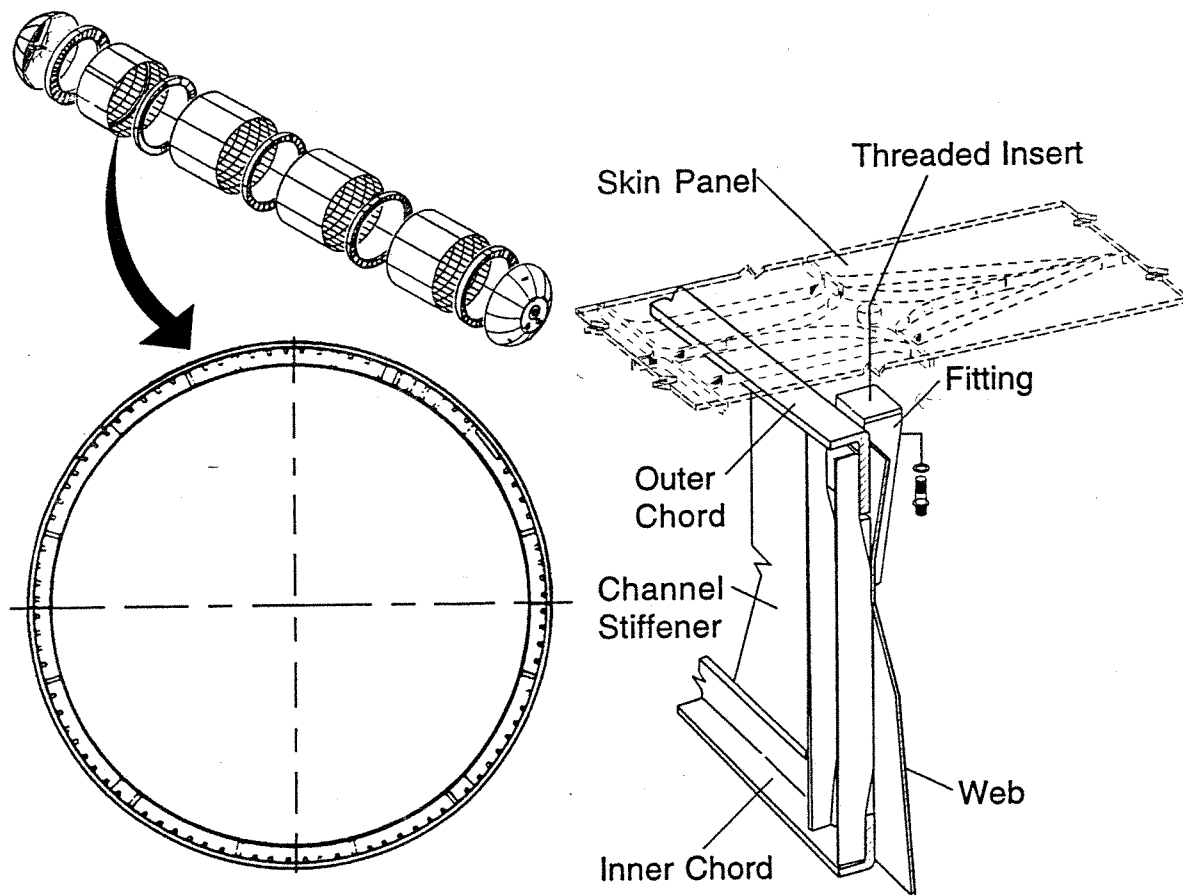


Figure 8-6: Intermediate Ring Frame at Station 1973.5

8.2.3 MAJOR RING FRAMES

Five major ring frames are used to join the dome and barrel sections, receive and distribute loads, and provide structural continuity to the other structural elements. These frames are I-Beam shaped with varying depths and chord configurations. The frames are fabricated in 90-degree segments at the subassembly level except for the frame at Station 1871 which has 5 unequal segments. The segments are spliced by circumferential weldments along the outer chord, and by mechanically attached splice plates and angles at the web and inner chord.

The forward dome-to-barrel frame at Station 1129.9 varies in depth from 10 inches in the lower half to 21.75 inches at the top centerline. Machined fittings are attached to the web and to the outer and inner chords of the frame to receive and distribute loads from the Orbiter/ET forward bipod attachment mounted on the outer chord and the liquid oxygen feedline support fittings. Integral with the outer chord of the frame is the flange for attaching the LH2 tank to the intertank. This attachment is made using 178 9/16-inch diameter bolts.

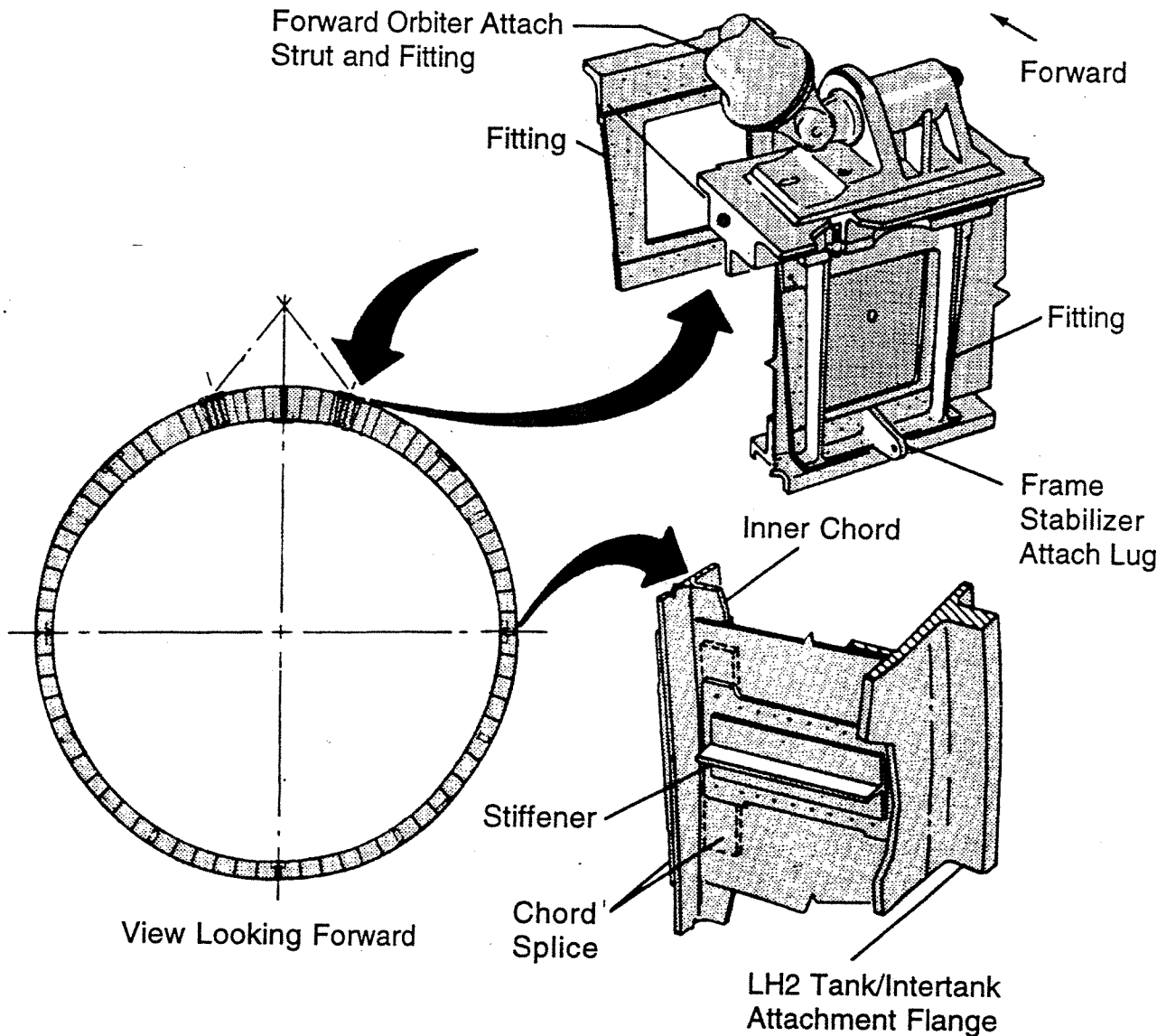


Figure 8-7: Major Ring Frame - Station 1129.9

The frames at Stations 1377.35 and 1623.80 are similar, both being I-Beams machined from extruded 2195 aluminum. These frames are six inches deep. The web thickness and chord material vary from a maximum under the LO2 feedline support to a minimum at the bottom centerline to match asymmetrical load distributions.

The four quadrants of the frame are spliced by a longitudinal butt weld at the outer flanges, and by splice plates attached mechanically to both sides of the web and inner flanges. A filler is used in the inner flange to bridge the gap provided in the frame for welding access.

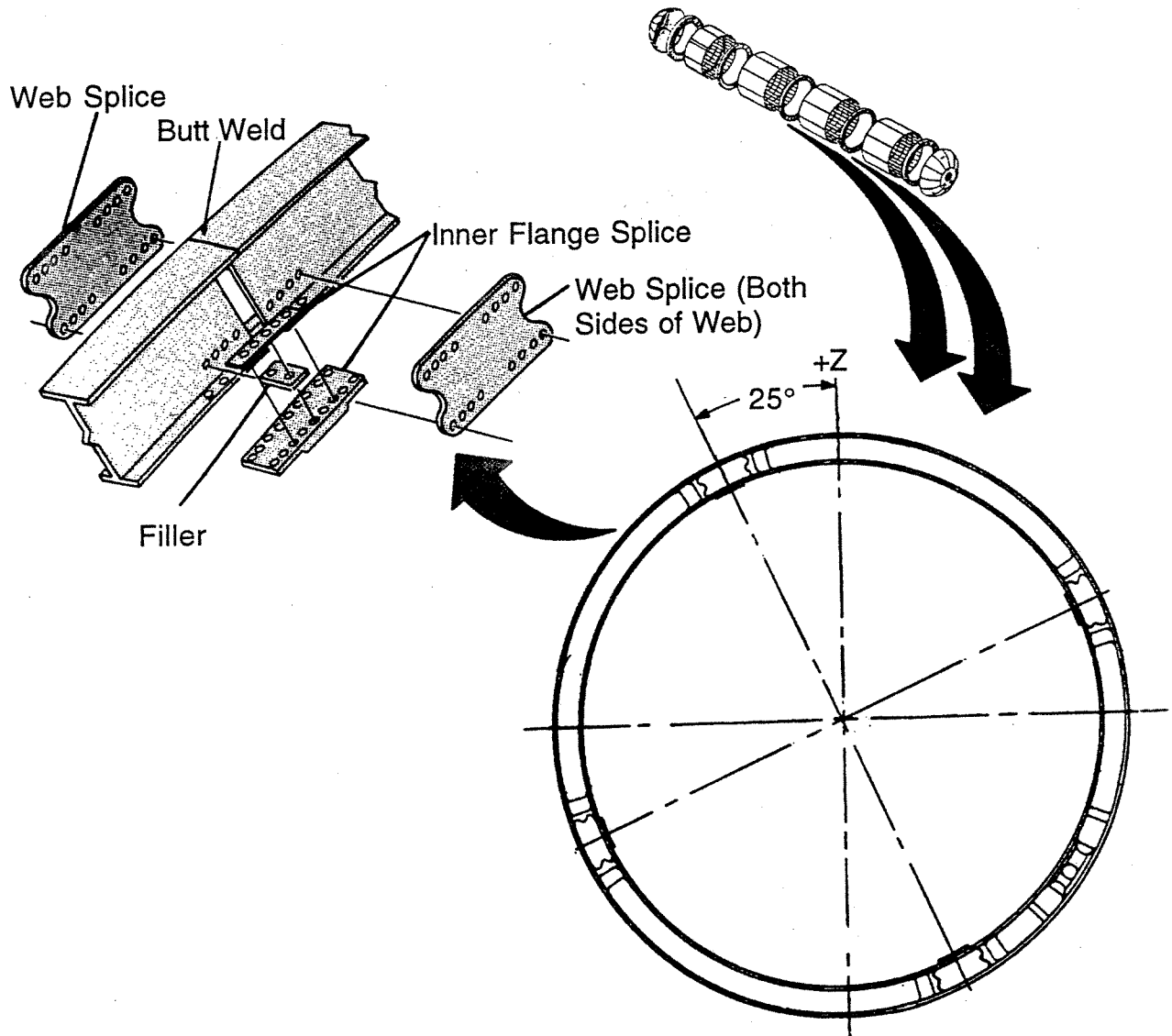


Figure 8-8: Major Ring Frames - Stations 1377.3 and 1623.8

The frame at Station 1871 has a constant depth of 20.00 inches. It is configured with a stiffened web, inner and outer chords, web and chord splices, and special fittings to distribute Orbiter thrust loads and LO2 feedline support loads. Orbiter thrust loads from the Orbiter thrust

struts are reached at the aft barrel section longerons. The radial components of these loads are transferred to the frame at Station 1871 by machined fittings which tie the longerons to the web of the frame. Chord material and web thickness vary according to the load distribution.

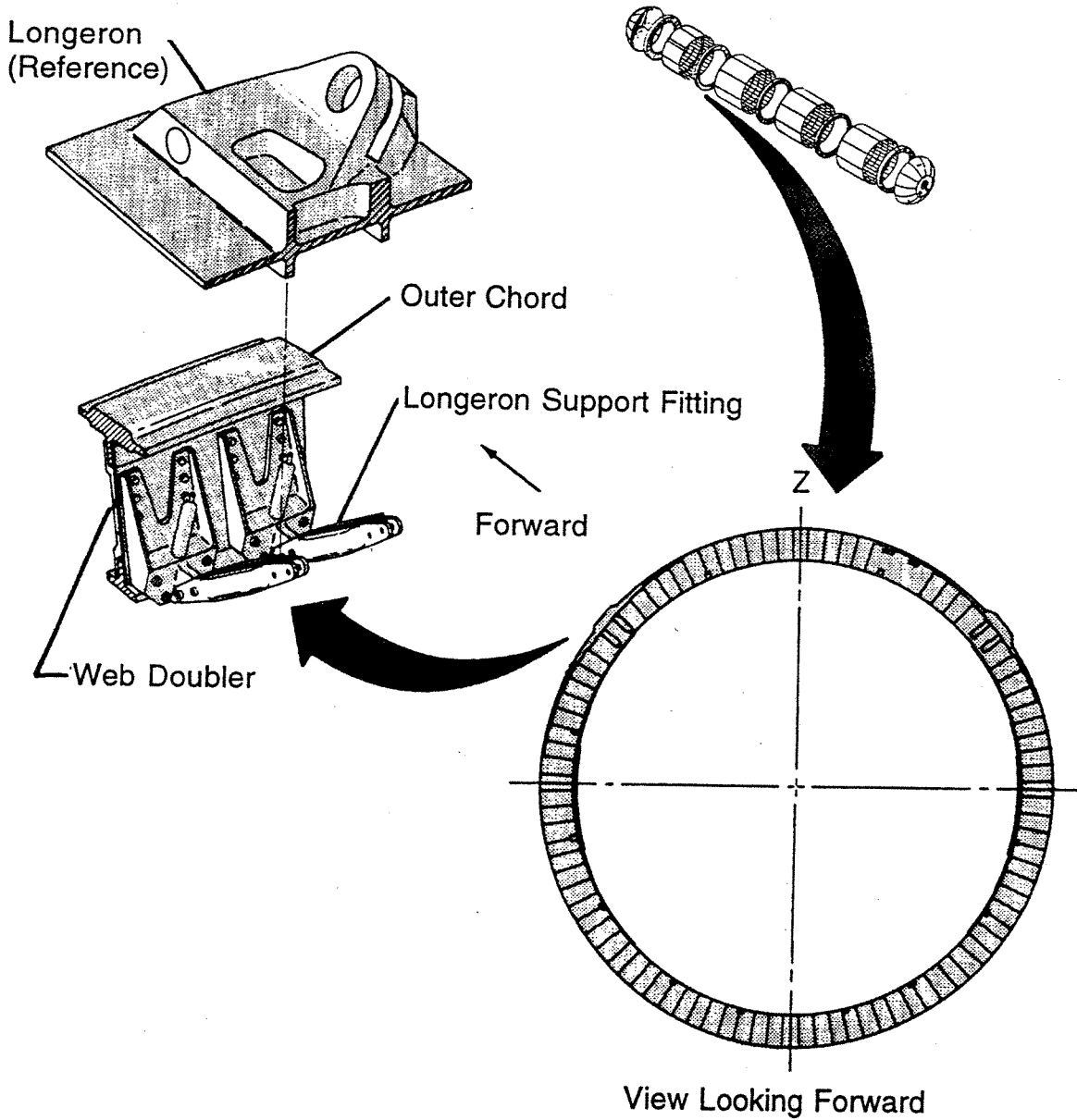


Figure 8-9: Major Ring Frame - Station 1871.0

The aft major ring frame at Station 2058 receives Orbiter induced loads from the aft Orbiter support and SRB induced loads from the aft SRB support. These loads are generally in the plane of the frame. Tangential loads are transferred directly to the outer chord by integral shear pins in the Orbiter and SRB attachment fittings. Radial loads

are transferred to the frame by large, machined reinforcement fittings which are attached to the web and to both frame chords. Additional reinforcement is provided for the aft transportation fitting. Chord material and web thickness vary as in the other major ring frames.

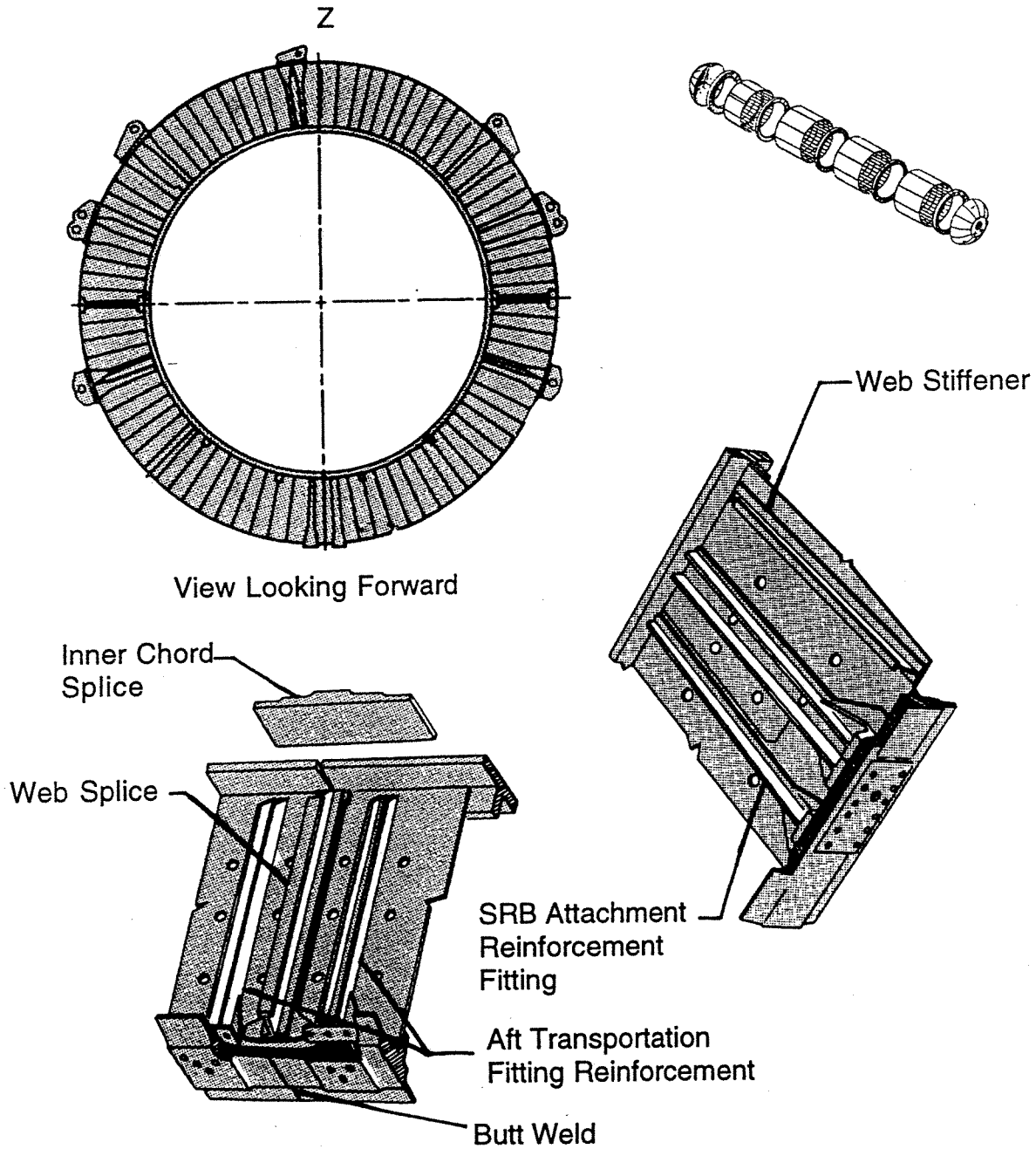


Figure 8-10: Major Ring Frame - Station 2058

The forward and two aft major ring frames at Station 1129.9, Station 1871, and Station 2058 are stiffened by radially-oriented web stiffeners. The frames at Station 1377.35 and Station 1623.80 require no web

stiffening. Each major ring frame is stabilized by struts which tie the frame inner chord to the barrel orthogrid at circumferential locations that satisfy frame stability requirements.

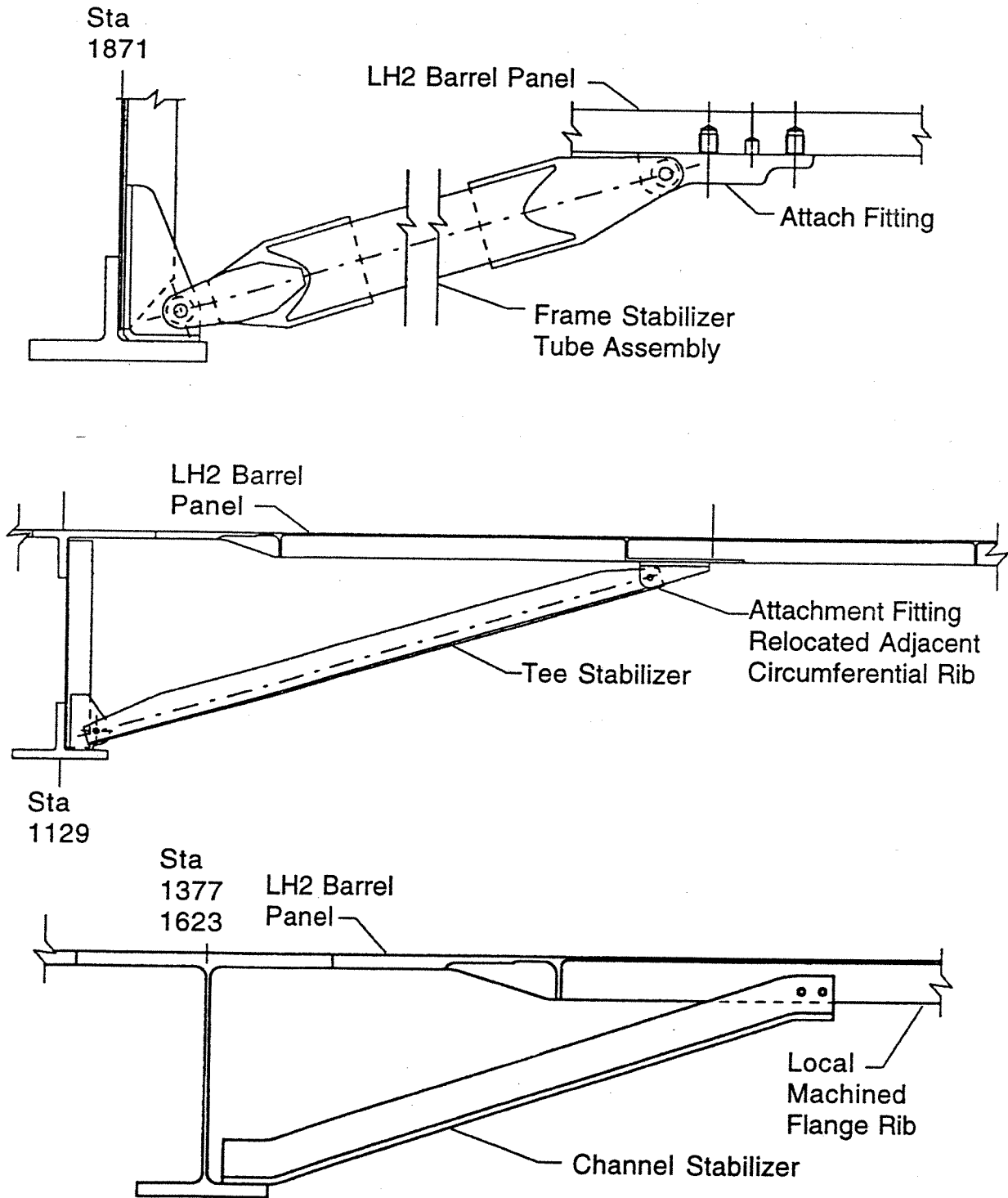


Figure 8-11: Typical Major Ring Frame Stabilizers

8.2.4 LH2 TANK AFT DOME

The LH2 tank aft dome is a welded assembly of the same modified ellipsoidal shape as the forward dome and the LO2 tank dome, and constructed with the same fabrication techniques. The major difference between the two LH2 tank domes is the provision for the mounting of fittings. Provisions for tank access are incorporated in the aft dome cap. The manhole fitting is similar to those on the LO2 tank dome and the LH2 tank forward dome. The siphon manhole fitting was modified for SLWT to eliminate the second manhole cover on the aft dome (weight savings). This fitting now includes a membrane to closeout the opening, and prevents direct access to the LH2 feedline screen.

The LH2 feedline penetrates the LH2 tank aft dome in a gore panel. A flanged fitting welded into the gore panel provides for connection of the interior and exterior LH2 feedline sections, thus providing feedline support at this location. The LH2 feedline fitting is unique because of the angle at which it penetrates the dome, and because of the compound curve of its flange. This fitting is machined on a five-axis mill which machines the contoured profile needed to match the dome contour. Additional feedline support is provided by a support assembly which ties the feedline to the inner chord of the frame at Station 2058. A similar but smaller installation in the same gore is made for the attachment of the LH2 recirculation line.

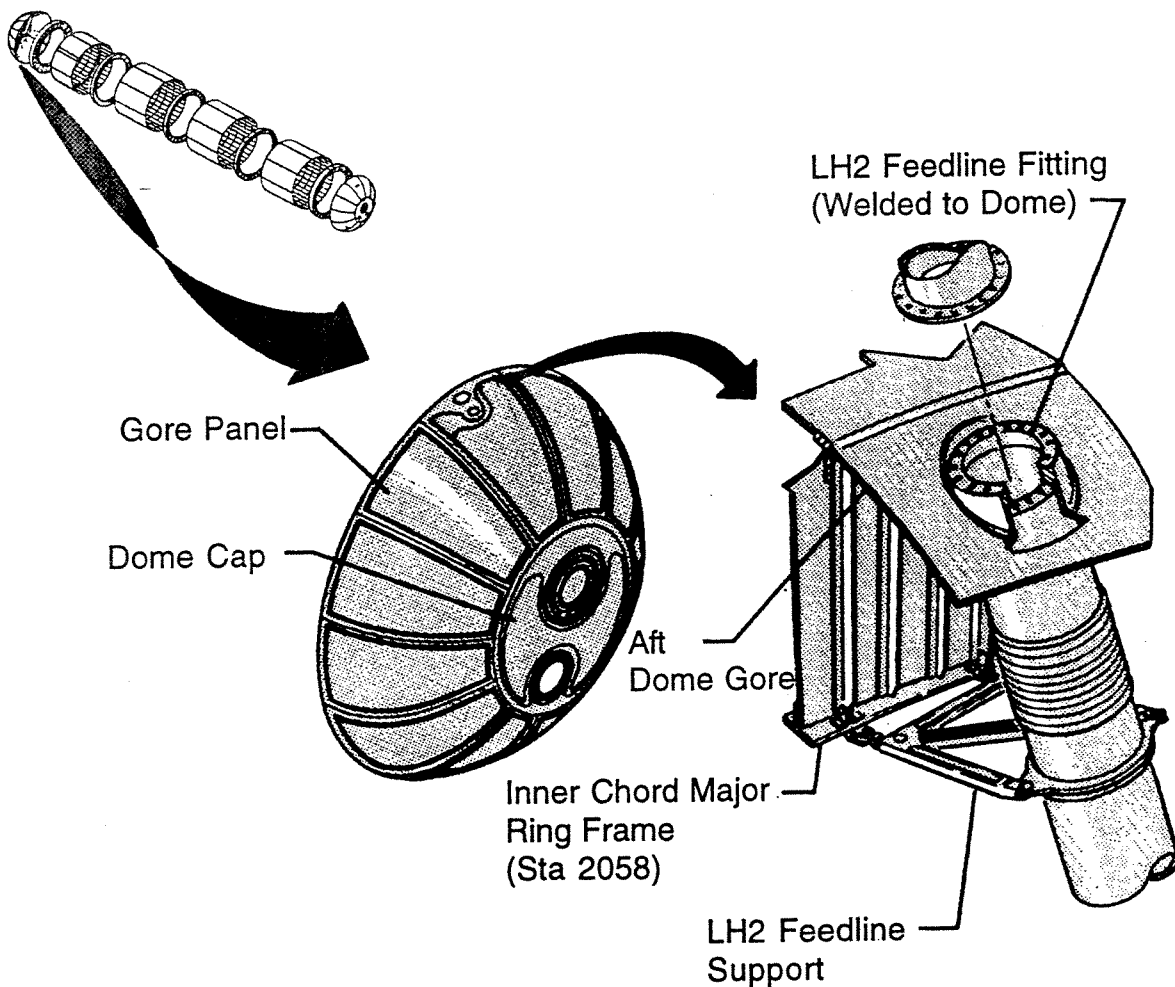


Figure 8-12: LH2 Tank Aft Dome

A vortex baffle assembly is located at the siphon outlet just above the aft dome of the LH2 tank. There are four identical baffle webs formed of 2024 aluminum. Outer frame chords of extruded tee shaped aluminum are riveted to each web. The webs contain fluid damping holes and stiffeners. Support for the webs is provided at the

LH2 feedline at a location 33 inches above the inlet where an attachment flange is welded to the feedline. The webs are attached to the flange by brackets of extruded aluminum channels. Tie rods attached to the webs and to the LH2 siphon provide additional support.

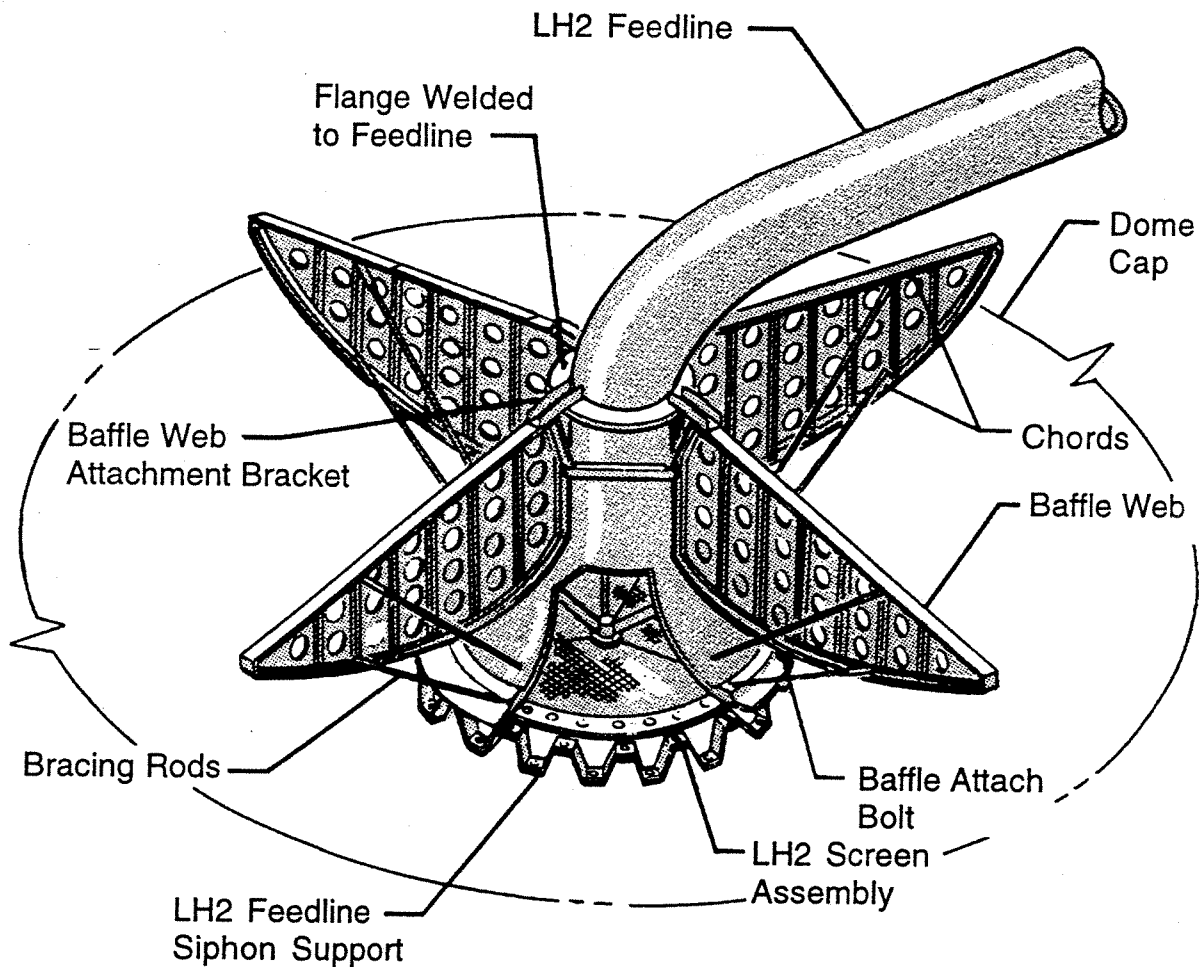


Figure 8-13: LH2 Vortex Baffle

The LH2 feedline siphon is supported by a circumferential ribbon-type support bolted to the

siphon and to the LH2 feedline siphon-support fitting welded to the LH2 tank aft dome cap.

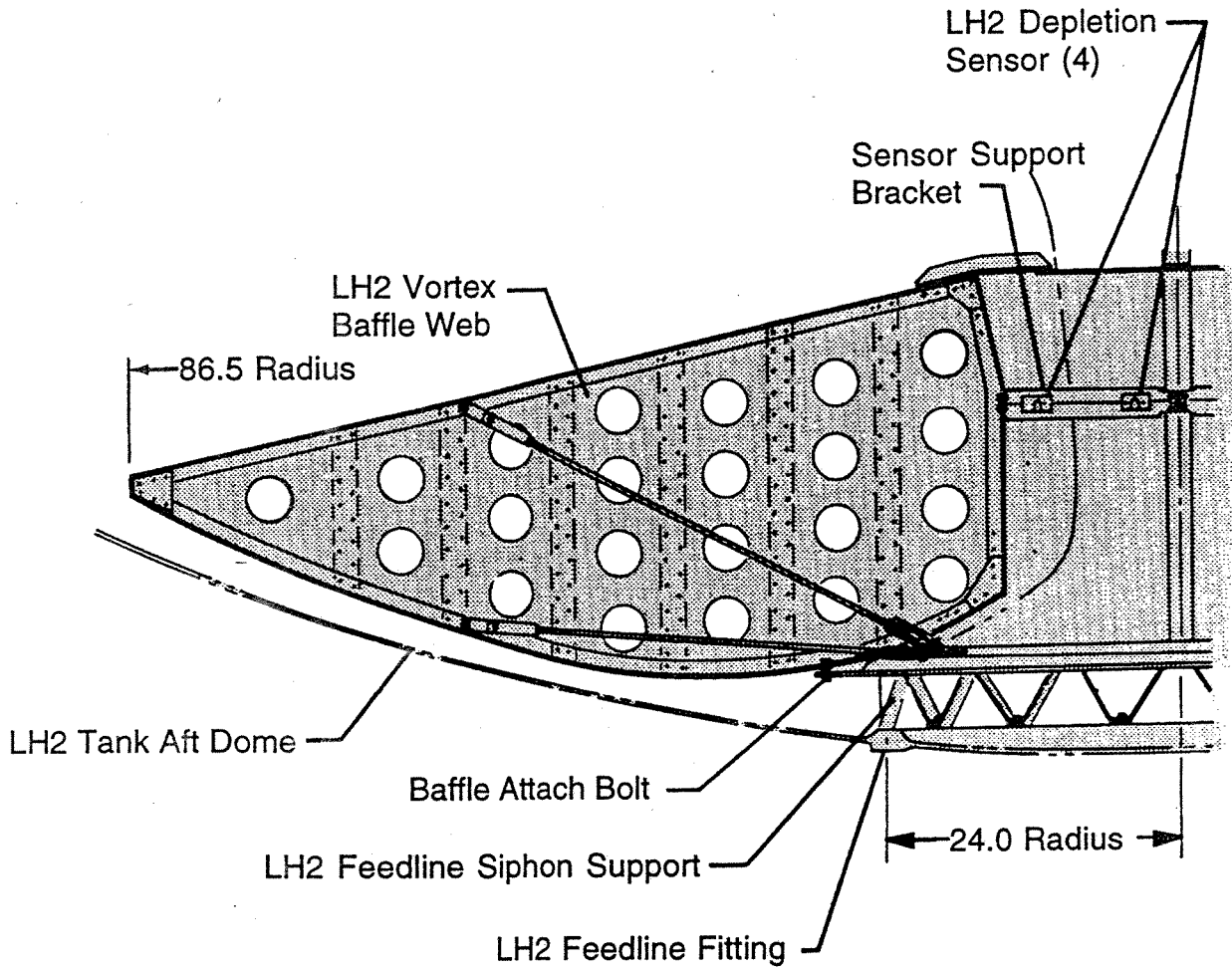


Figure 8-14: LH2 Feedline Siphon Support

8.3 COMPONENT DETAILS

Details of several structural components are presented here to highlight specific areas of interest.

8.3.1 LH2 TANK FWD DOME GORES

Gore-panel membrane thickness varies from a maximum near the dome cap to a minimum near the outer dome chord. Weld lands are provided along the gore edges for butt welding at gore-to-gore, gore-to-cap, and gore-to-chord junctures. Local weld lands are also provided for the welding of fittings for supporting the GH2 pressurization line and for the level sensor support mast.

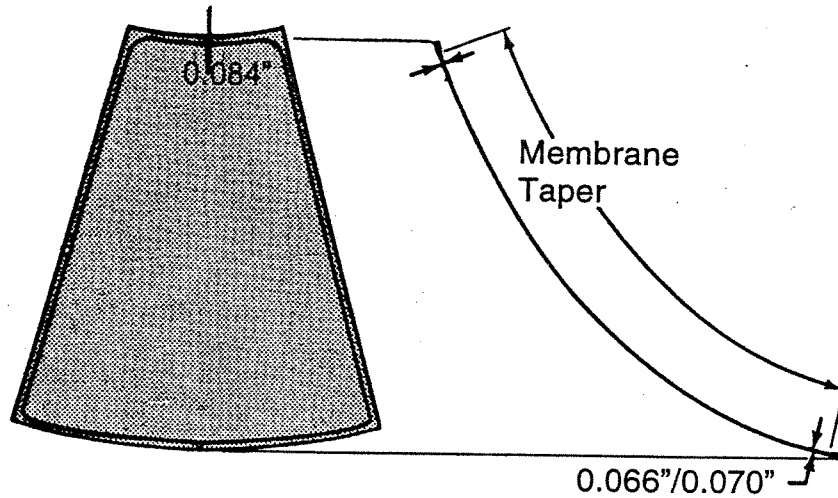


Figure 8-15: LH2 Tank Forward Dome Gores

8.3.2 LH2 TANK AFT GOES

The aft dome gore panels are tapered longitudinally by chem-milling to the required thickness. The membranes are reinforced by a series of circumferential bands sized to prevent

dome buckling during cryo loading. Weld lands are provided along the gore edges of all panels and a local weld land is provided on one panel for welding both the LH2 feedline fitting and the LH2 recirculation line fitting.

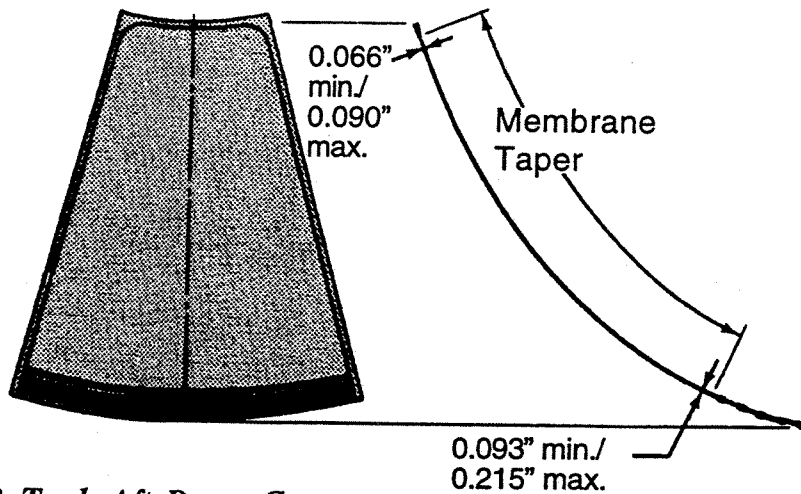


Figure 8-16: LH2 Tank Aft Dome Gores

8.3.3 LH2 TANK DOME CAP FITTING

Machined fittings for the attachment of manhole covers, and propulsion and electrical

system equipment, are butt welded into the forward and aft dome caps. All installations are similar except for different fitting diameters.

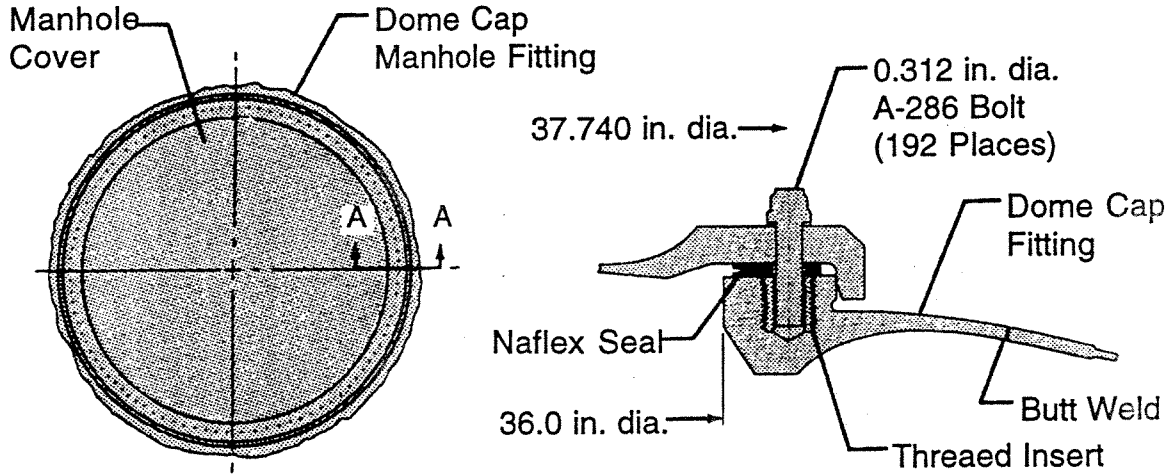


Figure 8-17: Typical Dome Cap Fitting (Manhole Shown)

8.3.4 BARREL SKIN PANELS

Barrel-section skin panels are designed to withstand and distribute loads imposed upon them, which include proof pressure test, liftoff compression, and post-staging loads. Orbiter thrust after staging introduces compression in the panels forward of the longerons and shear in panels

adjacent to the longerons. Panel design varies in accordance with the different panel load; the difference being primarily in skin thickness. Other panel differences are the result of provisions for the longerons, frame attachments, and external line support provisions. The two basic orthogrid pocket configurations used throughout the skin panels are shown below.

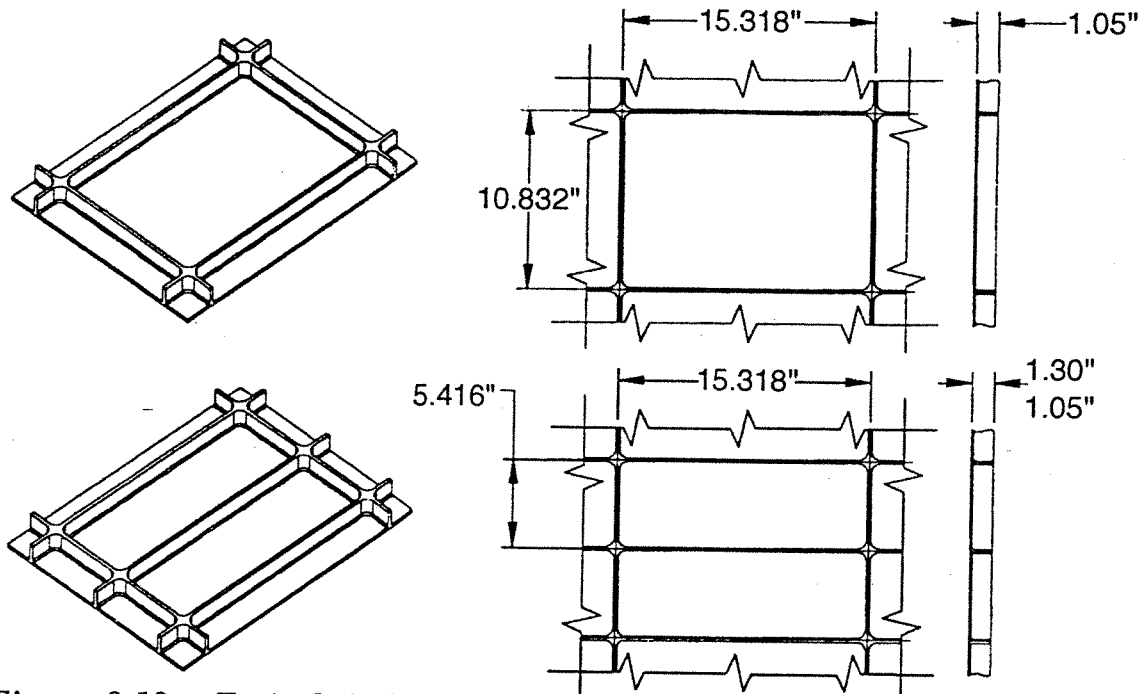


Figure 8-18: Typical Orthogrid Skin Panel Configuration

8.3.5 SENSOR MOUNTING

LH2 level sensors are mounted in the forward section of the LH2 tank. The forward level sensors and the ullage temperature sensor are mounted on a mast which is supported at the Station 1129.9 ring frame and at 2 places on the LH2 forward dome. The LH2 5% depletion sensor is mounted on a channel bracket supported by the 2058 ring frame. Four ECO sensors are mounted on the LH2 vortex baffle.

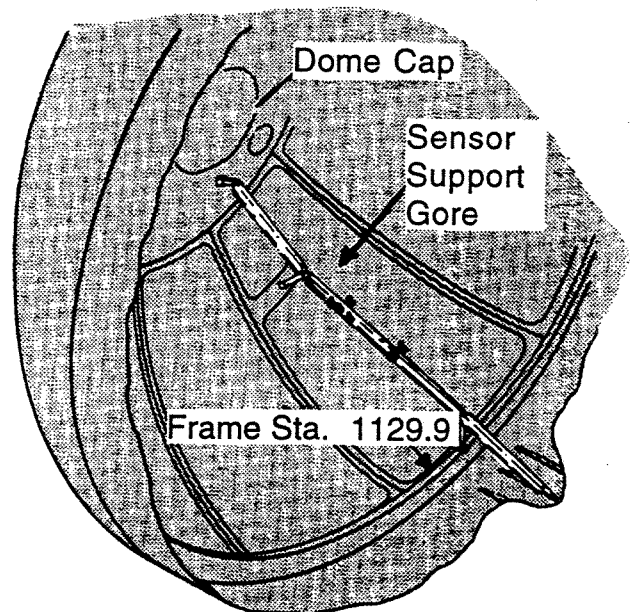


Figure 8-19: LH2 Level Sensor Mounting

8.3.6 PROPULSION LINES AND ELECTRICAL CABLE TRAY MOUNTING

The LO2 feedline support brackets are attached by means of threaded inserts in the outer

chords of the four forward major ring frames to which the feedline pivoting supports are bolted. These are the frames at Station 1129.9, Station 1377.35, Station 1623.8, and Station 1871. A fifth support is attached to aft barrel skin stringer bosses at Station 1973.5.

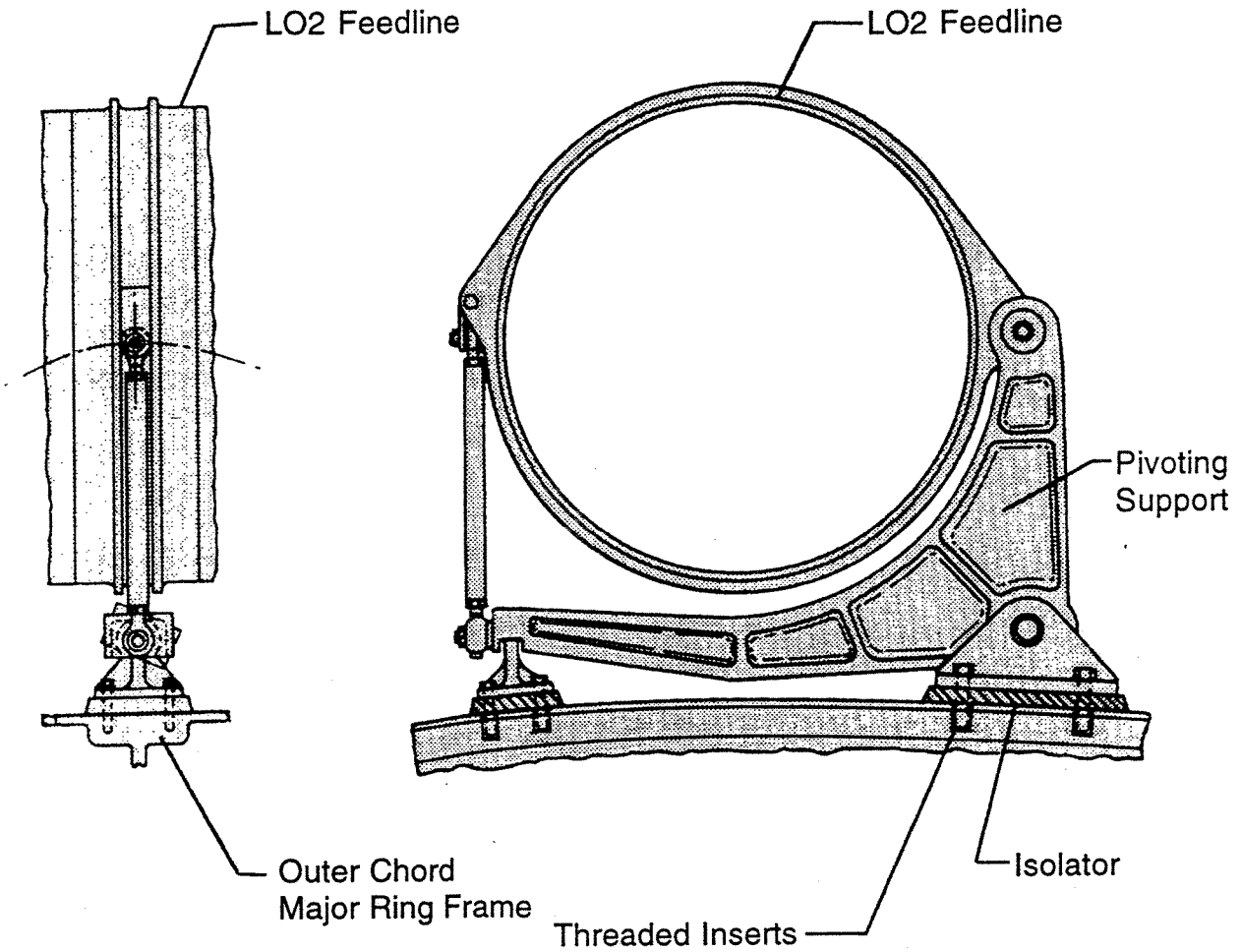


Figure 8-20: LO2 Feedline Support - LH2 Tank

In addition to the LO2 feedline, routing on the outside of the LH2 tank includes the GO2 pressurization line, the GH2 pressurization line, and electrical-system cable trays. The mounting of

supports for these lines and cable trays is accomplished by brackets bolted to threaded inserts in the skin stringer bosses.

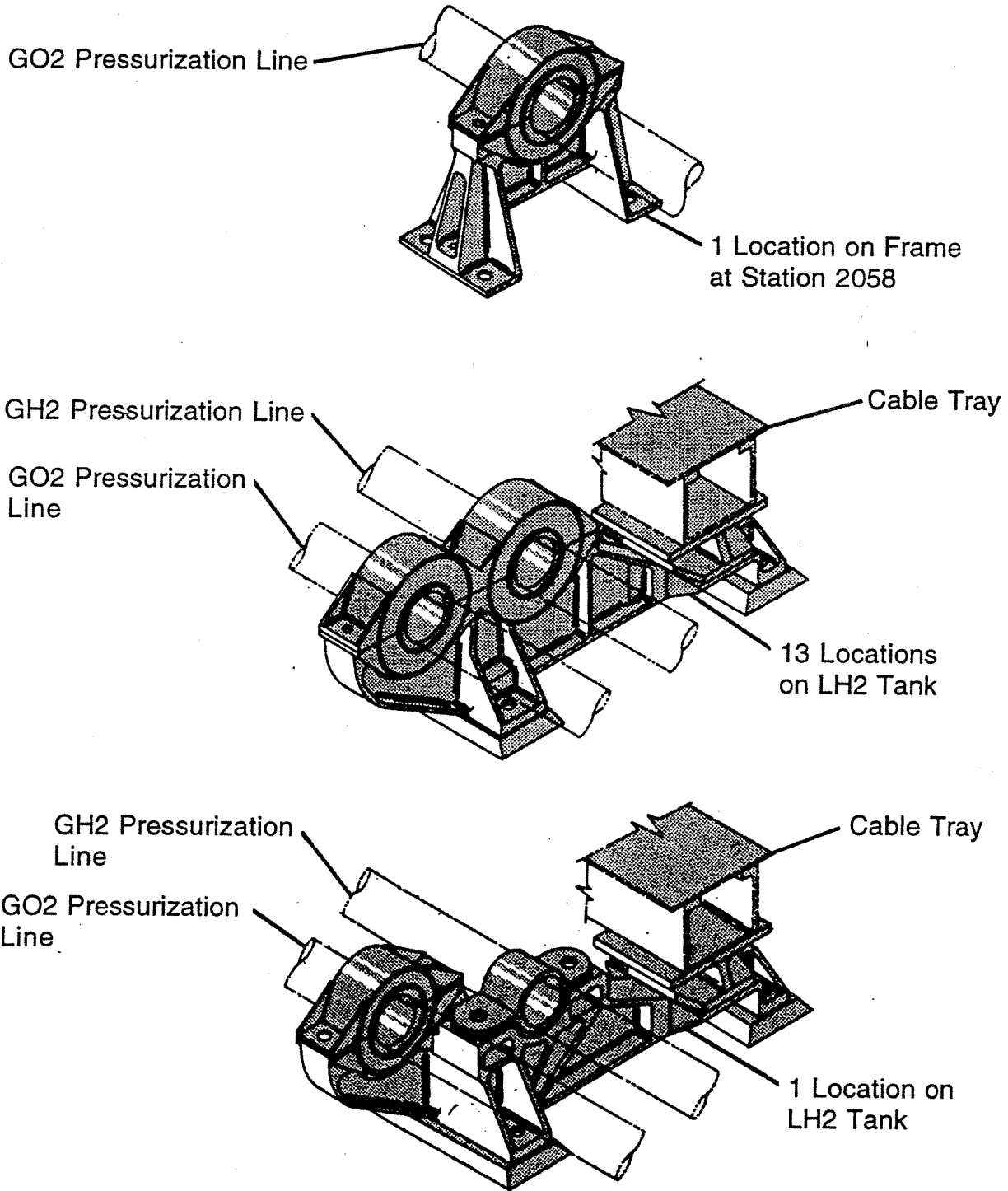


Figure 8-21: GO2 and GH2 Pressurization Line and Electrical Cable Tray Support

9. PROPULSION SYSTEM

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9. PROPULSION SYSTEM

The External Tank contains all the liquid hydrogen fuel and liquid oxygen oxidizer for the Orbiter main engine's, all of the various components and systems required to provide conditioned propellant at the interface with the Orbiter.

9.1 DESCRIPTION

The ET propulsion system primary function is delivery of oxidizer and fuel to the Orbiter interface. These LO2 and LH2 propellants are contained in individual tanks with separate bulkheads (tank domes), joined with an intertank structure. The complete system is comprised of:

- LO2 feed system;
- LH2 feed system;
- LO2 and LH2 tank pressurization and vent/relief systems;
- Intertank and tank environmental control systems;
- ET intertank carrier plate assembly.

All fluid controls and valves for main propulsion system operation - except for LO2 and LH2 vent/relief valves, check valves in the helium inject line, and those valves integral to the quick disconnects - are located in the Orbiter or the ground facility to minimize throwaway costs.

The attachment and support hardware is an integral part of the structures system. However, for clarity, the propulsion system attachments to structure are covered in this section. Configuration of the LO2 and LH2 tanks is detailed in Sections V, VI, and VIII. The propellant level/depletion sensors and the tank ullage pressure sensors are covered in Section X, *Electrical System*. The Orbiter and ET/Facility interfaces are described in Section XII, *Interface Hardware*.

The propulsion system has four external interfaces: one each located at the left and right ET/Orbiter umbilical disconnect plates, a third located at the intertank wall established between the ET and ground facilities until liftoff, and a fourth at the facility GO2 vent "coolie hat" system.

The first two plates form multiple quick-disconnect interfaces with the Orbiter that are maintained from prelaunch mating until post-launch vehicle separation.

Two propulsion system lines interface with the aft right ET/Orbiter umbilical disconnect plate. The LO2 feedline extends externally along the right shoulder of the LH2 tank to and within the intertank, then to the aft LO2 tank dome. (Approximately 30 degrees clockwise from the +Z axis looking forward.) A gaseous oxygen (GO2) pressurization line parallels the LO2 feedline up the LH2 tank, and continues on along the intertank and LO2 tank into the nose fairing to a penetration in the forward cover plate of the LO2 tank ogive.

Three propulsion system lines mate to the aft left ET/Orbiter umbilical disconnect plate. The LH2 feedline penetrates the upper portion of the aft LH2 tank dome and travels within the tank to a point near the dome base (approximately 30 degrees counterclockwise from the +Z axis looking forward) where it flares into a tuba-shaped siphon. An LH2 recirculation line parallels the feedline to an LH2 tank aft dome penetration. The LH2 pressurization line is routed along the crossbeam and up the right shoulder of the LH2 tank and into the intertank, and then into the forward LH2 tank dome.

The outlet of the LH2 vent valve located on the forward LH2 tank dome cap connects within the intertank to a vent line. The vent line runs to the intertank umbilical carrier plate located 120 degrees counterclockwise, looking forward from the +Z axis. This ET intertank carrier plate assembly also provides disconnects for the following ground services that are provided to the ET; helium inject, GO2 vent valve actuation, GH2 vent valve actuation, intertank heated GN2 purge, nose cap heated GN2 purge, hazardous gas detection and GH2 vent stack (7-inch).

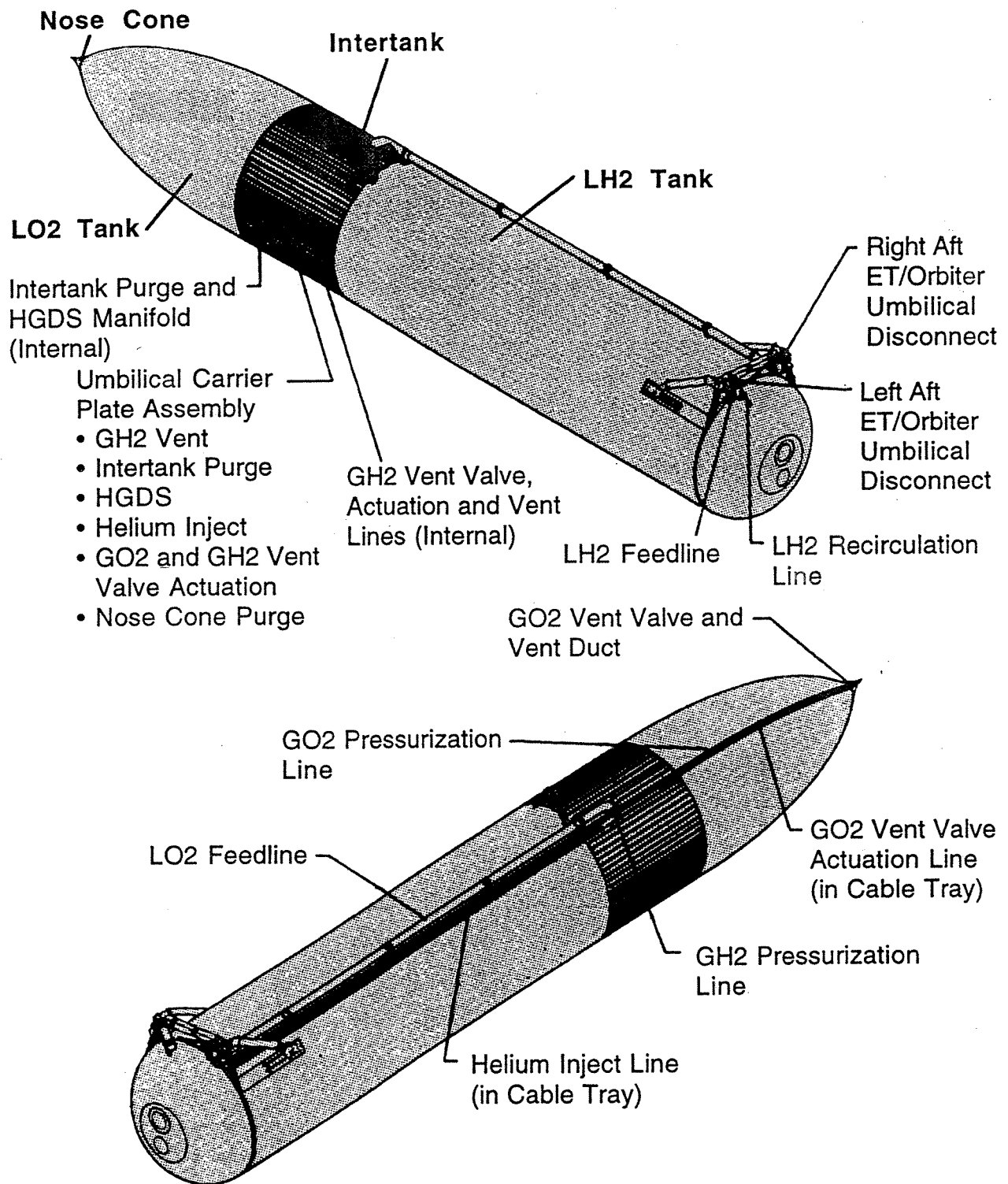


Figure 9-1: Propulsion System Configuration

Table 9-1: Propulsion Line Summary

Line Description	Line size (inches)	Material	Qty of Sections	Mechanical Joints			Flexible Joints			Insulation
				Qty	Type	Seal	Bellows	Gimbal/Bellows	Univ	
LO2 Feed	17	CRES and Aluminum	9	9	Bolted flange	Raco-Creavey *	--	5	--	SS-1171
LH2 Feed	17	CRES and Aluminum	4	4	Bolted flange	Raco-Creavey *	4	--	--	SS-1171 over SLA-561 Cryopumped jacket (exterior section)
LH2 Recirc	4	CRES	1	2	Bolted flange	Raco-Creavey *	2	--	--	SS-1171 over SLA-561 Cryopumped jacket around bellows
Helium Inject	3/8	CRES	27	50	MS and B-Nut	K				
GO2 Press.	2	CRES	9	10	Bolted flange	Naflex	1	8		
GH2 Press.	2	CRES	8	9	Bolted flange	Naflex	--	11		
GO2 Vent	5 1/8	CRES	3	3	V-Band	Raco	2			
GO2 Vent Actuation	1/4	CRES	10	20	MS and B-Nut	K				
GH2 Vent	5	CRES	1	2	Bolted flange	Raco-Creavey	1	1	--	SS-1171
GH2 Vent Actuation	1/4	CRES	2	5	MS and B-Nut	K				
Intertank Purge	3/8 and 1/2	CRES	1	2	MS and B-Nut V-Band Coupl					
Nose Cap Purge	3/8 and 1/2	CRES			MS and B-Nut	K				
HGDS	1/4	CRES	4	3	MS and B-Nut					

* Naflex Seal at Disconnect

9.1.1 OPERATION

A summary of the operation of the ET helps in understanding the propulsion system even though the sequence times may be approximate. A schematic of the Orbiter/ET main propulsion system is presented here to help follow this operational description.

Ground Positive Pressurization - The ET propellant tanks are maintained at a nominal positive pressure of 3.7 psig while a part of the assembled Space Shuttle vehicle prior to propellant loading and launch. Positive pressurization is used to preclude structural damage from possible negative delta pressure that could develop due to thermal and atmospheric pressure changes. The pressurization medium is supplied from ground systems through Orbiter pressurization lines. Prior to ET/Orbiter vehicle assembly, a desiccant breather system or positive pressurization is used as needed during transportation, test and storage.

ET Conditioning - The LO2 and LH2 tanks are purged with gaseous helium (GHe) before loading to assure a dry condition and the removal of residual air and GN2. The system is sampled and dewpoints checked during this period.

Countdown - Propellant is supplied to the LO2 and LH2 tanks from ground propellant storage facilities via the Orbiter through the LO2 and LH2 feed systems. Geysering in the long LO2 feedline is suppressed during loading and during the countdown prior to launch by injecting helium into the feedline at the LO2 aft elbow. The purpose of the helium inject is to provide evaporative cooling of the LO2 in the feedline to reduce the possibility of the LO2 reaching local saturation temperature, which in turn would cause a geyser. The refill of the feedline after a geyser would result in damaging water-hammer effects. As an additional safeguard, a plate covering the feedline outlet from the LO2 tank, and attached to the vortex baffle, is used to disperse a small geyser should one occur, to preclude ullage pressure collapse.

The propellant loading operation is controlled by the ground LPS in conjunction with ET-mounted, propellant level sensors and pressure

Table 9-2: Propellant Liquid Level Sensors

LOCATION - % OF FULL

LO2 Tank	LH2 Tank	Baseline Quantity
5	5	1
98	98	2
100 (-)	100 (-)	1
100	100	2
100 (+)	100 (+)	1
Overfill	Overfill	1

and temperature measurements. Eight liquid level sensors are mounted in each tank. These sensors indicate the presence or absence of propellant.

The loading sequence, including chilldown, slow fill to 2% and fast fill to 98%, must be capable of being accomplished between T-120 minutes and T-45 minutes. Topping to 100% may be accomplished after T-45 minutes. (KSC flights will not meet these times due to LO2 facility flow limitations.) Replenishment of boil-off propellant is accomplished until approximately T-5 minutes through the LO2 feedline disconnect, and through the LH2 recirculation line for the LH2 system.

During Orbiter engine preconditioning, LH2 is delivered from the LH2 feedline to the engine inlets by electrically driven recirculation pumps in the Orbiter after which it is returned to the LH2 tank via a recirculation line. During LH2 recirculation, replenish flow is diverted to the recirculation manifold to preclude warm LH2 from entering the main Orbiter pumps. LO2 is bled through the engines for engine conditioning throughout the countdown.

Propellant Tank Drain - The LO2 and LH2 tanks can be drained simultaneously or sequentially if a problem should preclude the launch of a loaded vehicle. The vent/relief valves are closed, and the tanks are pressurized via the pressurization lines while draining the propellant through the ET and Orbiter fill/drain lines to the facility system.

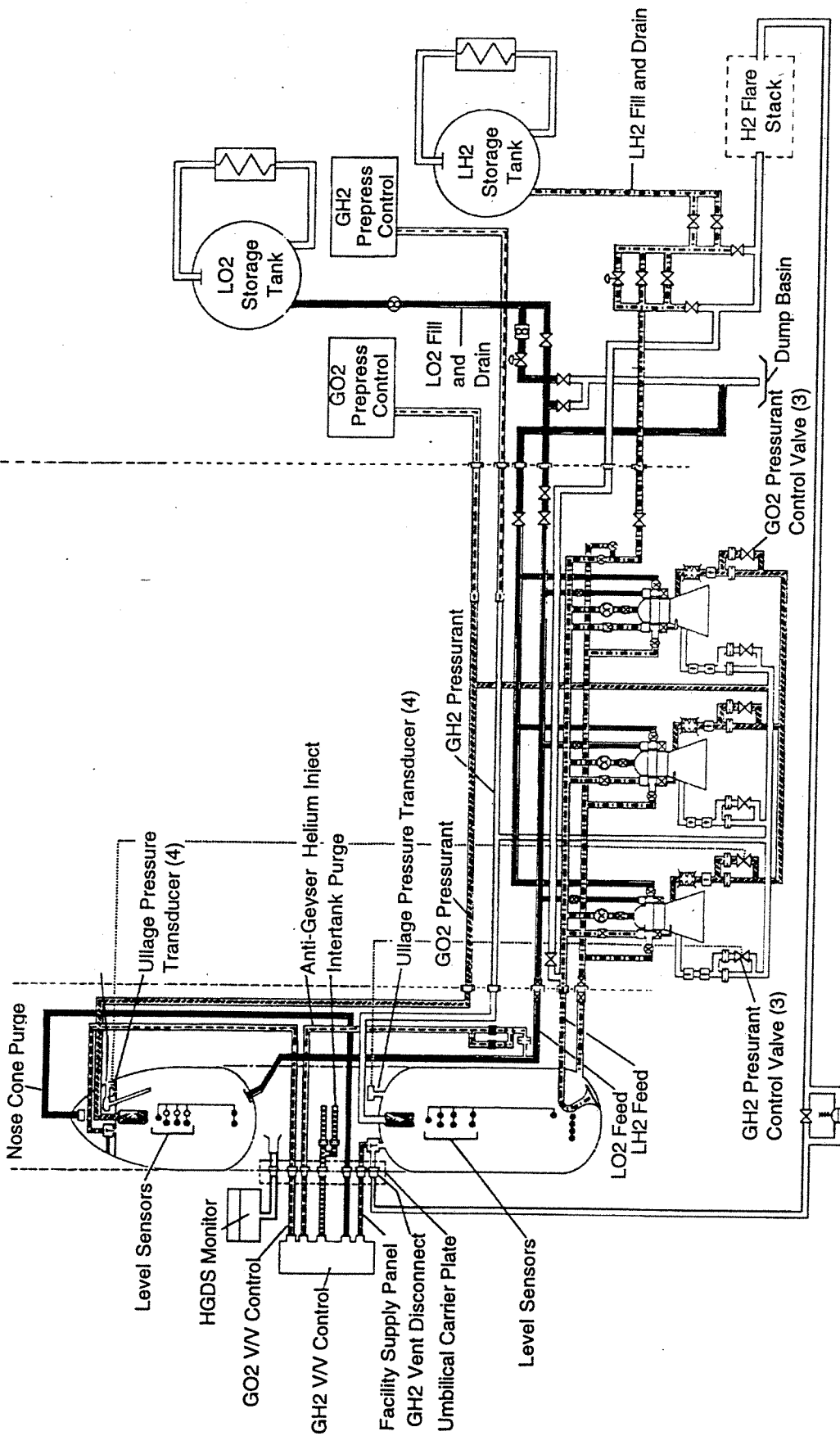


Figure 9-2: Main Propulsion System Schematic

Propellant Tank Vent/Relief - The ET has a capability to vent the excess LH2 and LO2 converted into gases during the ET propellant loading operation. The ET also has the capability to relieve automatically any pressure buildup within the LH2 and LO2 tanks over predetermined limits. Both the vent and relief operations are accomplished with a single dual-purpose valve for each propellant tank. For the venting operation, the vent valves are opened at T-6 hours in preparation for the propellant loading sequence.

The valves are actuated OPEN by the application of 750-psig helium supplied through the ET vent-valve actuation lines via a facility vent arm from a ground source. In the absence of pressure to the actuation lines, the vent valves assume their normally CLOSED position, and act as safety relief valves to protect against tank overpressurization. The LO2 vent valve relieves at 30-32 psig while the LH2 valve relieves at 35-37 psig.

GH2 from the LH2 tank vent valve is routed via an intertank vent line and facility vent arm to a burn stack during ground operations. Vented GO2 is routed through a vent duct within the nose cone and dumped into the vent system hood which is part of the ground facility. The vented GO2 is ducted away from the vehicle to preclude ice formation around the vent louvers. The GO2 exits the nose cone through two vent louvers on opposite sides of the nose cone to accommodate virtual non-propulsive venting. GO2 and GH2 are both dumped overboard during flight in the event of valve-contingency relief action.

The LO2 tank's maximum pressure of 29.5 psig, and the LH2 tank's maximum regulated pressure of 34 psia during flight, are below the respective vent/relief valve minimum cracking pressures of 30 psig and 35 psig. Therefore, relief action will not normally occur during flight or within 100 seconds after Orbiter/ET separation. Failure of the Orbiter hydrogen pressurization valves in the open position may result in valve relief action. However, the relief flow rates will maintain tank pressure within structural limits.

Intertank Purge - The intertank compartment is purged with dry GN2 during propellant loading until launch to prevent condensation of moisture, to preclude air ingestion through the intertank vents, and to avert a buildup of hazardous gases. The system also thermally conditions electronics. The dry heated GN2 is provided from ground facilities via a facility vent arm to the ET intertank carrier plate assembly

disconnect, and through a purge manifold within the intertank. A ground hazardous-gas detection system, utilizing a mass spectrometer, connects an intertank manifold to sample the intertank environment for hazardous gas concentrations during propellant loading. The ground system will be able to sense hydrogen, oxygen, helium and argon concentrations.

Launch - LO2 and LH2 venting is discontinued at approximately T-3 minutes. The tank ullage is then pressurized with ground facility helium through the Orbiter and ET pressurization lines. The LO2 tank is pressurized to 20-22 psig and the LH2 tank to 41-44 psia. Pressurization is maintained by facility helium flow until liftoff. Following engine ignition at about T-6 seconds, the ullage pressure is supplemented using propellant gases vaporized in the engine heat exchangers and routed to the ET propellant tanks.

Pressure control, based on data inputs from ullage pressure sensors in each tank, is accomplished in the Orbiter by orifice control of flow rate to maintain LO2 tank ullage at 25-29.5 psig and bi-level modulation of flow rate to maintain LH2 tank ullage at 32-34 psia during flight. Tank ullage pressure plus static propellant head provide the necessary net-positive-suction pressure (NPSP) at main engine LH2 and LO2 pump inlets for engine start, with acceleration head added for operation. LO2 ullage, while on the ground, is pressurized above minimum engine prestart requirements to provide the necessary tank structural strength to withstand liftoff shear loads.

Main Engine Cut-Off (MECO) is normally initiated by the Orbiter guidance, navigation and control subsystem when the proper mission velocity is obtained. A propellant flight performance reserve is provided to assure adequate velocity at cutoff.

In aborted flights or missions where the propellant reserve is expended, the engine cutoff command will be initiated by LO2 engine cutoff depletion sensors located in the Orbiter. An 1100-pound LH2 bias is available on all missions to normally provide LO2 depletion cutoff prior to LH2 depletion. In the event that an off-nominal condition results in premature LH2 depletion, four sensors in the LH2 tank aft dome will initiate engine cutoff with approximately 1400 pounds of propellant in the LH2 tank. These sensors are used to prevent effects of a fuel depletion (LO2 rich) shutdown. The ET is jettisoned within 10 seconds after MECO.

9.2 LO2 FEED SYSTEM

The LO2 feed system consists of the LO2 feedline, and the helium inject line.

9.2.1 LO2 FEEDLINE

The LO2 feedline is a 17-inch I.D. insulated pipe, fabricated of aluminum and corrosion-resistant steel. The feedline runs from the ET half of the LO2 disconnect on the right ET/Orbiter umbilical-disconnect plate, up the side of the LH2 tank approximately 23 degrees clockwise (looking forward) from the +Z axis, through a slotted port in the intertank skin to a joint on the outlet of the LO2 tank.

The LO2 tank outlet is a contoured design which flares from 64 inches to 17 inches in a distance of 17.53 inches. It is located 30.482 inches (8 deg) from the tank centerline on the +Z axis which is near the nominal burnout acceleration vector. The outlet is fabricated of 2219 aluminum and welded into the tank dome cap.

An aluminum vortex baffle, to reduce propellant swirl from coriolis effect, is installed in the LO2 tank concentric to the outlet centerline. It is topped by a 41.6-inch square anti-geyser plate which will disperse a small geyser should one occur. The vortex baffle is further described in Section VI, *LO2 Tank Structure*.

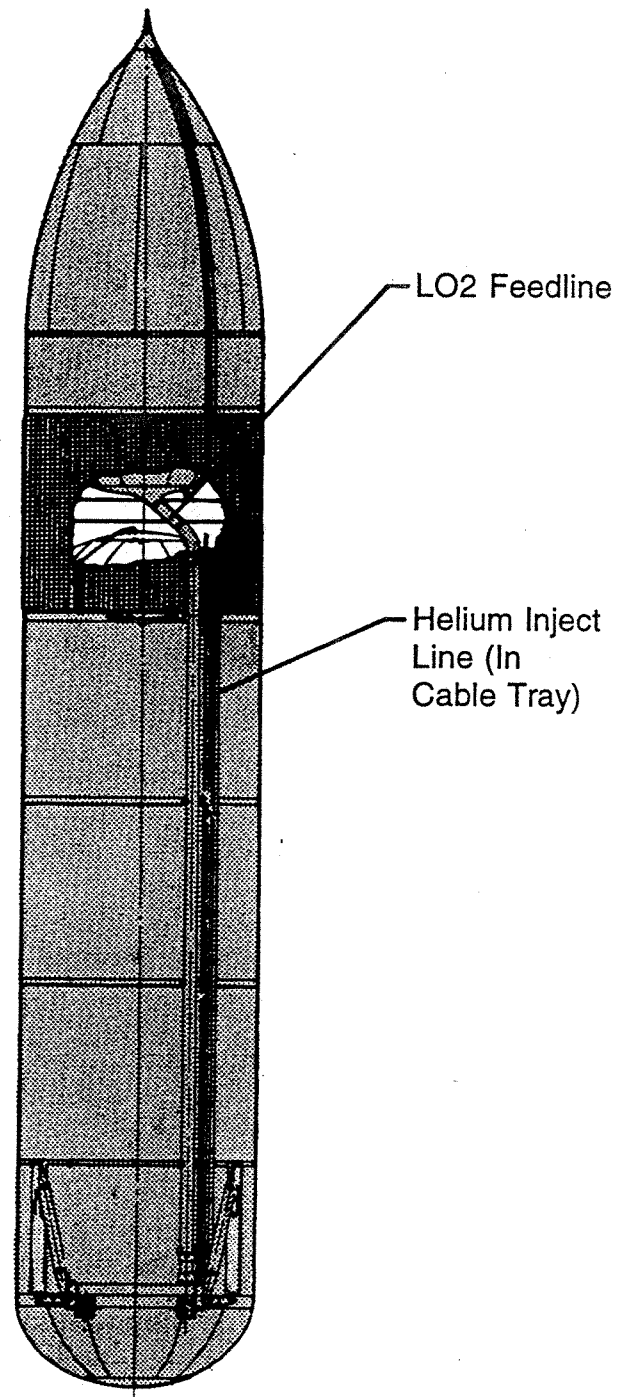


Figure 9-3: LO2 Feed System

Particulate matter is filtered by an 800-micron, glass-bead-rated, fine-mesh screen mounted at the LO2 outlet. The screen, approximately 58 inches in diameter, is constructed in four 90 degree quadrant sections which bolt to the base of the vortex baffle and to the tank outlet. The screen is fabricated of 304L corrosion-resistant, sintered-steel wire mesh with a 321 CRES frame. The screen may be reached for service by way of the access hatch in the LO2 tank aft dome.

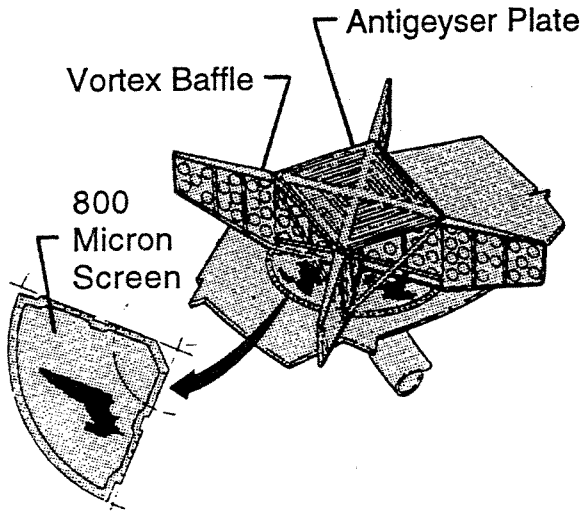


Figure 9-4: LO2 Tank Vortex Baffle and Screen

The LO2 feedline assembly consists of nine sections. These include the forward flexible assembly, flexible elbow, four straight sections, an aft flexible assembly, an aft elbow, and the ET/Orbiter disconnect assembly.

The forward flexible assembly is located entirely within the intertank. It bolts at one end to the LO2 tank outlet, then bends and runs across the intertank where it mates to the elbow assembly. The elbow assembly penetrates the intertank skin and runs down the side of the ET a distance of approximately nine feet. The feedline protrusion is protected by a fairing at the penetration point.

Four straight sections run down the side of the LH2 tank from the flexible elbow to the aft flexible assembly, a distance of approximately 70 feet. The upper section is 247.7 inches long, the middle two sections are 246.7 inches long, and the lower section is 102.5 inches long.

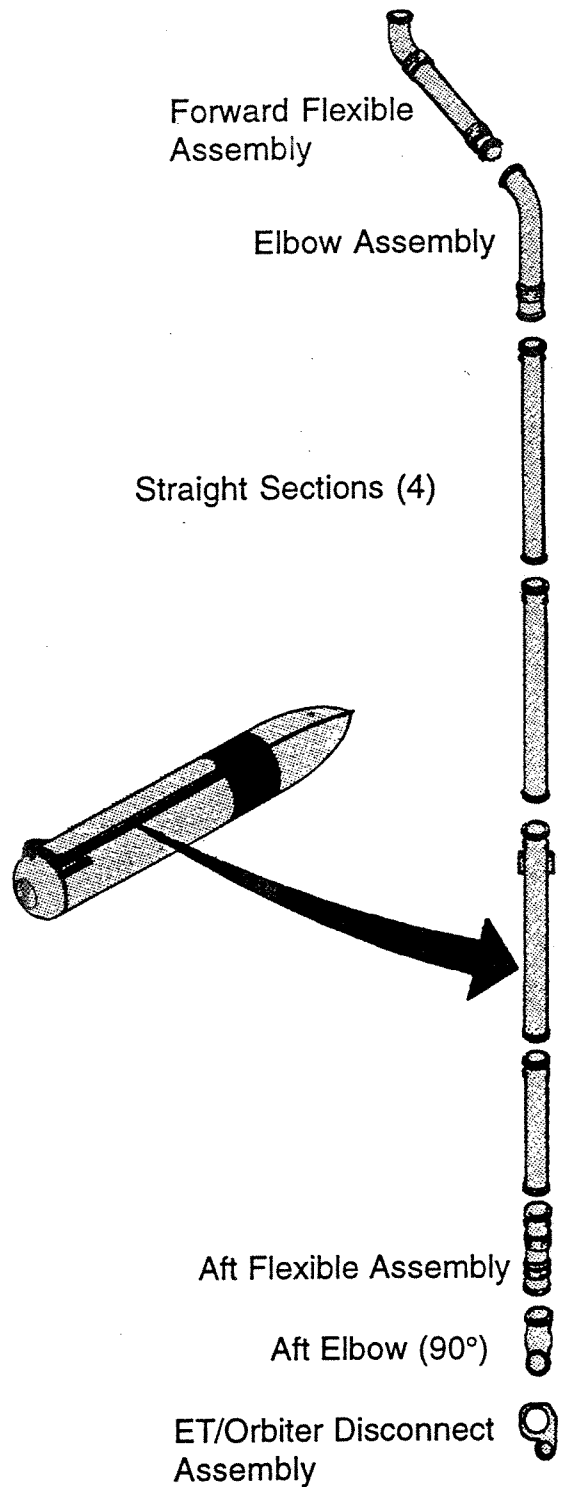


Figure 9-5: LO2 Feedline

The aft elbow joins the 76.6-inch long aft flexible assembly to the ET half of the LO2 disconnect at the right ET/Orbiter umbilical disconnect plate.

The straight sections are fabricated of 2219 aluminum alloy and the aft elbow is a casting of A357T6 aluminum. The flexible sections, including the Ball-Strut-Tie-Rod-Assembly (BSTRA), are fabricated of 347 stainless steel, 21-6-9 stainless and Inconel 718.

The feedline has five flexible joints (BSTRA); two in the forward flexible section, one in the flexible elbow section, and two in the aft

flexible section.

These flexible joints allow for fabrication and installation tolerances, differential thermal expansion between the line and tank structure, and relative motion during lift-off and flight.

The feedline is supported at seven places other than at its interface with the LO2 tank. The first, a tie rod incorporating monoballs (rod end bearings), connects the forward flange of the elbow assembly to a bracket mounted to structure within the intertank wall. This tie rod restricts lateral motion while allowing motion in the plane of feedline travel by a pivoting action.

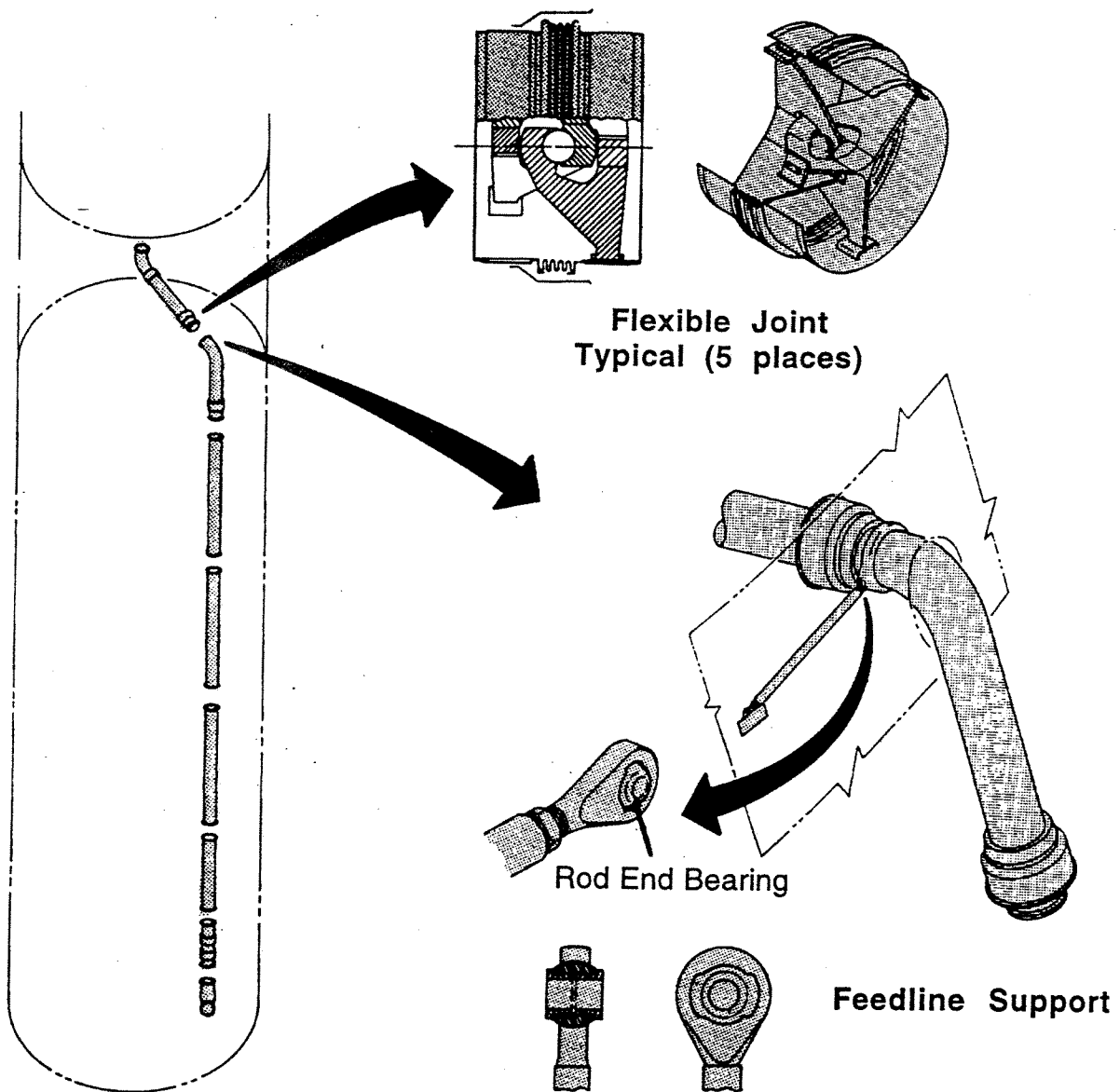


Figure 9-6: LO2 Feedline Flexible Joint and Feedline Support in Intertank

Five pivoting supports secure the feedline to tank structure along the length of the LH2 tank. These pivoting supports attach to pipe support sections built into the forward ends of the four straight LO2 feedline sections and the aft flexible assembly. The pivoting supports incorporate pin-and-ball joints to accommodate misalignments due to tolerance buildup, line movement resulting from thermal contraction, and to react to vehicle induced and protuberance airloads on the feedline. Further details are included in Section VIII, *LH2 Tank Structure*.

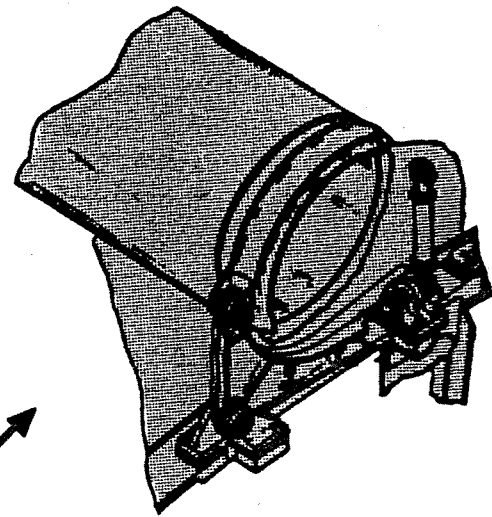
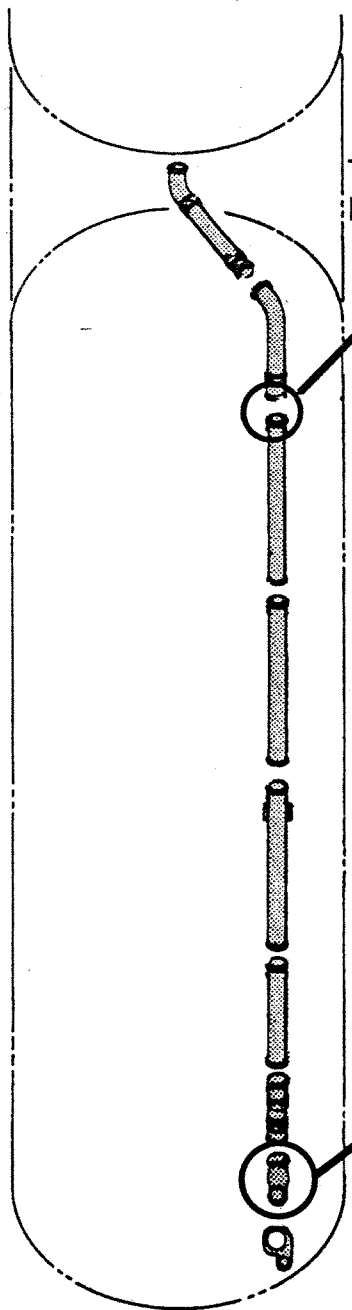


Figure 9-7: LO2 Feedline Pivoting Support

The seventh feedline support secures the aft elbow to the crossbeam of the thrust structure assembly by means of an arm from the crossbeam to support bosses on either side of the aft elbow. Further details of the Orbiter supporting structure and arms are included in Section XII, *Interface Hardware*.

The LO2 feedline sections are joined with bolted flanges which contain seals to control leakage. The primary seal is a Raco-Seal which is a pressure activated seal consisting of a Teflon jacket over an Inconel 718 spring. The secondary seal is a Creavey Seal which is a teflon covered,



Typical 5 Places

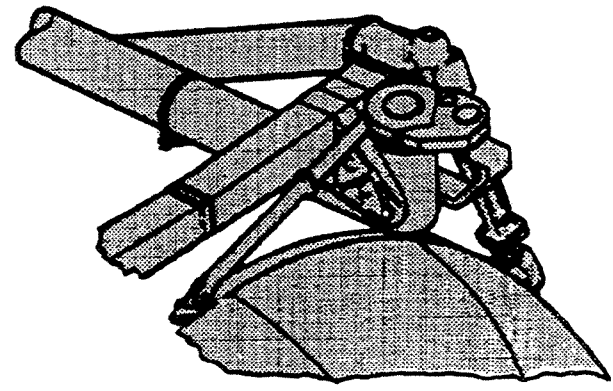


Figure 9-8: LO2 Feedline Fixed Support

stainless steel spring core, "O" ring seal. These seals fit into grooves in one side of the flanged joint. The two seal arrangement provides the means to conduct leak tests of the primary and secondary seals in Final Assembly after the system installations are completed. The Racocreavey seal combination is used at all LO2 feedline joints except the aft elbow to ET/Orbiter disconnect joint where a Naflex seal is used. The Naflex seal is a flange spacer seal fabricated of Teflon coated Inconel 718. This seal has both primary and secondary sealing surfaces which provide a means of checking leakage of the primary and secondary seals.

Allowable joint-seal leakage for Racocreavey seals is 0.183 SCIM of helium with 50 ± 5.0 PSID applied to the seals through the leak test port at ambient temperature.

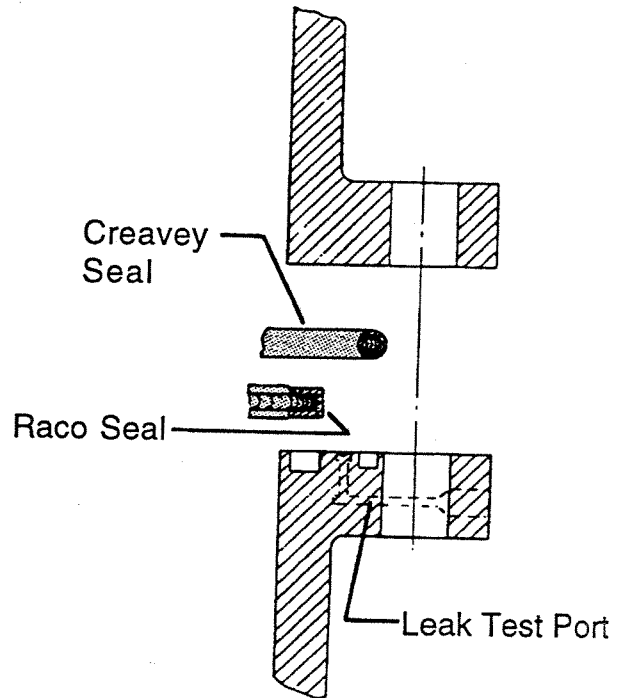
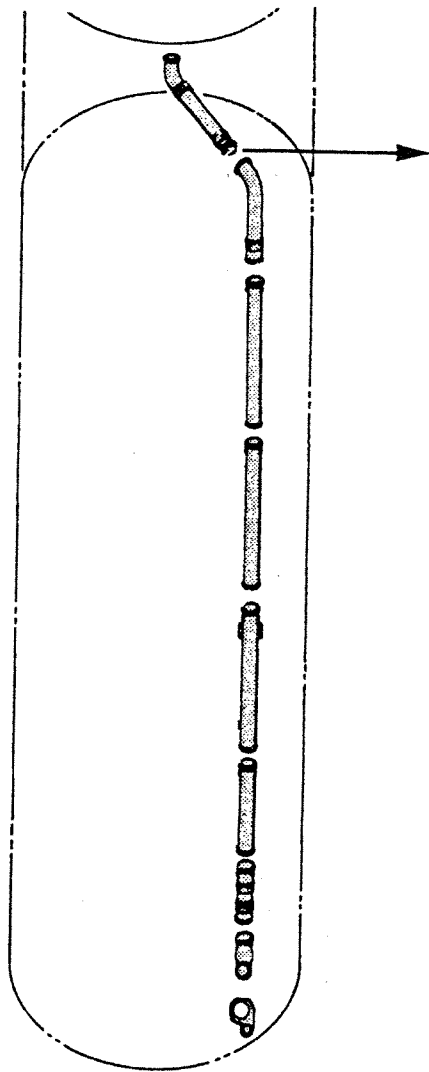


Figure 9-9: *Racocreavey Seal Joint Typical (8 places)*

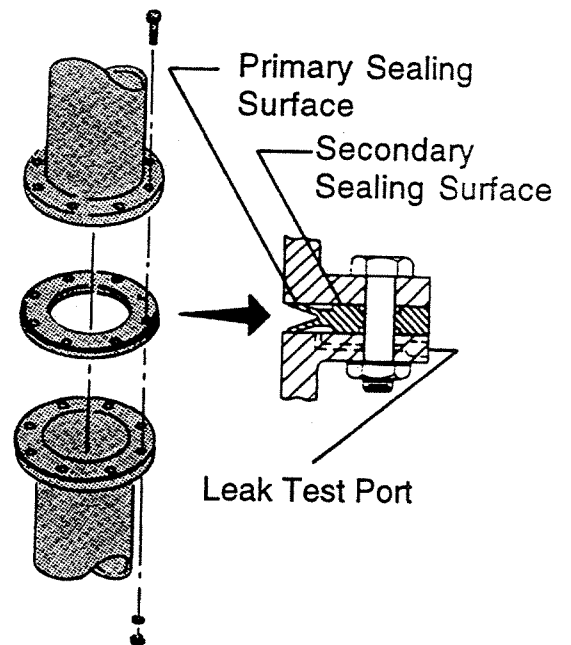


Figure 9-10: *Naflex Seal Joint*

9.2.2 HELIUM INJECT SYSTEM

The helium inject system introduces a controlled flow of helium into the aft end of the LO2 feedline to prevent geysers during propellant loading and hold before launch. Gaseous helium from the launch facility is supplied at a 3/8-inch disconnect fitting on the ET intertank carrier plate assembly. The 3/8-inch OD stainless steel tubing helium inject line is routed through the intertank, down the LH2 tank, inside the cable tray, and into the LO2 aft elbow. A quad-redundant filter/check valve assembly is installed at the aft end to prevent backflow of LO2/GO2 during flight. A small orifice is installed immediately downstream of the check valves to control helium flow rate. Line sections are joined with flared fittings. Flex hoses and sliding supports are provided to allow for fabrication and installation tolerances, differential thermal expansion between the line and tank structure, and relative motion during liftoff and flight. This system is non-operational during flight.

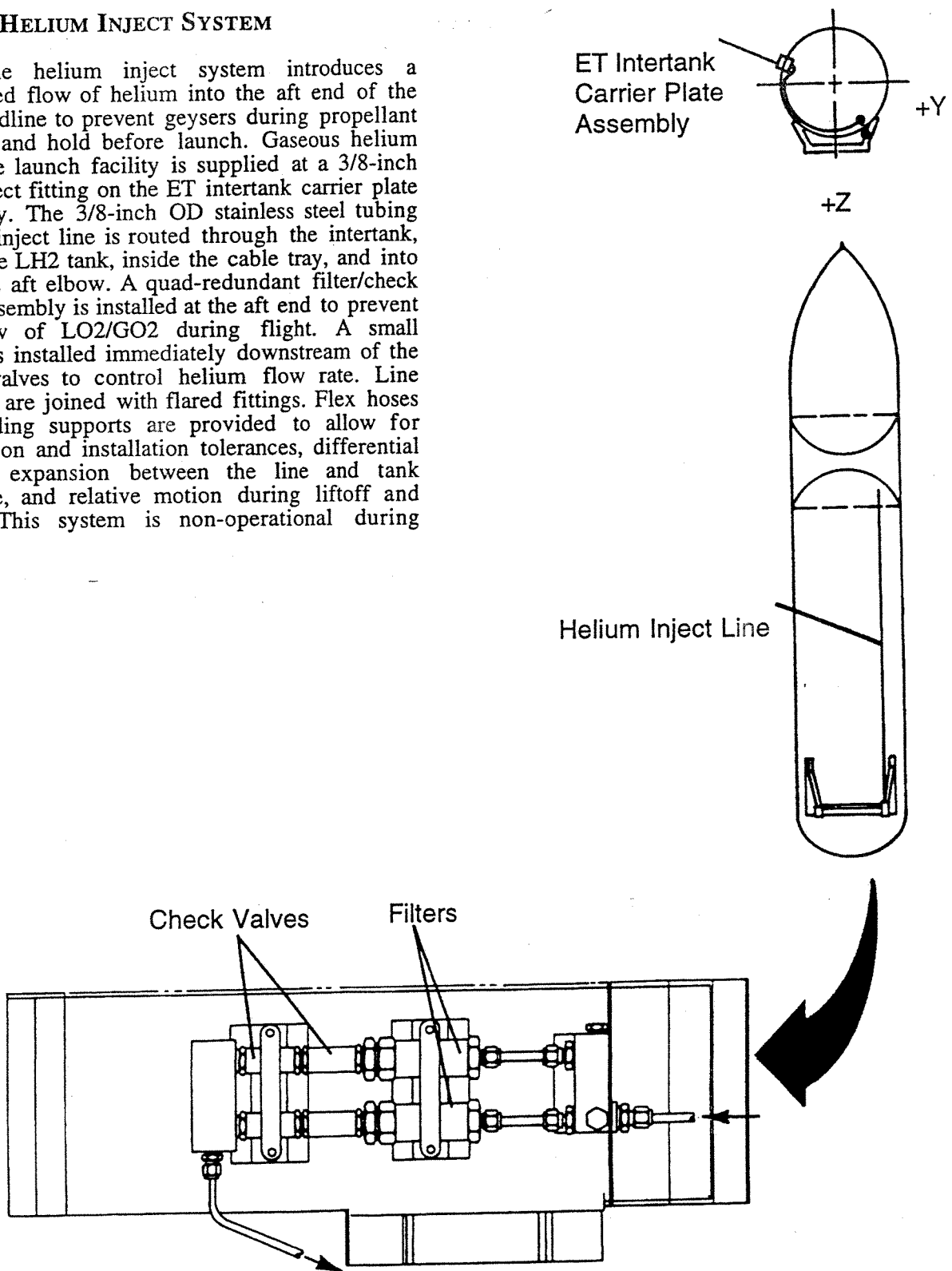


Figure 9-11: Helium Filter/Check Valve Assembly

9.3 LH2 FEED SYSTEM

The LH2 feed system consists of the LH2 feedline, the LH2 recirculation line, and associated hardware.

9.3.1 LH2 FEEDLINE

The LH2 feedline is a 17-inch I.D. pipe fabricated of aluminum and corrosion-resistant steel. The line runs from the ET half of the LH2 disconnect on the left ET/Orbiter umbilical disconnect plate, through a flanged port on the upper LH2 tank aft dome, to the bell-mouth within the tank near the bottom of the dome.

The external/internal feedline configuration minimizes the length of costly jacketed line which would be required for an external exit like that employed with the LO2 line. The internal configuration also reduces problems associated with base heating and acoustics effects on the ET emanating from the SRBs and the Orbiter main engines.

The uninsulated internal feedline section consists of a bellows segment and a bell-mouth siphon segment. Like the LO2 tank outlet, the LH2 siphon inlet is offset eight degrees so that its centerline is near the nominal acceleration vector at MECO. It is located 30.482 inches from the LH2 tank centerline on the +Z axis, and approximately four inches off the tank bottom.

The LH2 siphon inlet position, and its distance above the tank bottom, is established and maintained by mechanical attachment to supporting structure on the tank aft dome. The "picket fence" supports bolt between the dome and siphon inlet at sixteen places around the circumference. A four-vane aluminum anti-vortex baffle is attached to the feedline/siphon inlet at its base and at a baffle support welded to the feedline 33 inches above the inlet. Tie rods provide further support between the siphon and the anti-vortex baffle. Additional information on the baffle and feedline supports is included in Section VIII, *LH2 Tank Structure*.

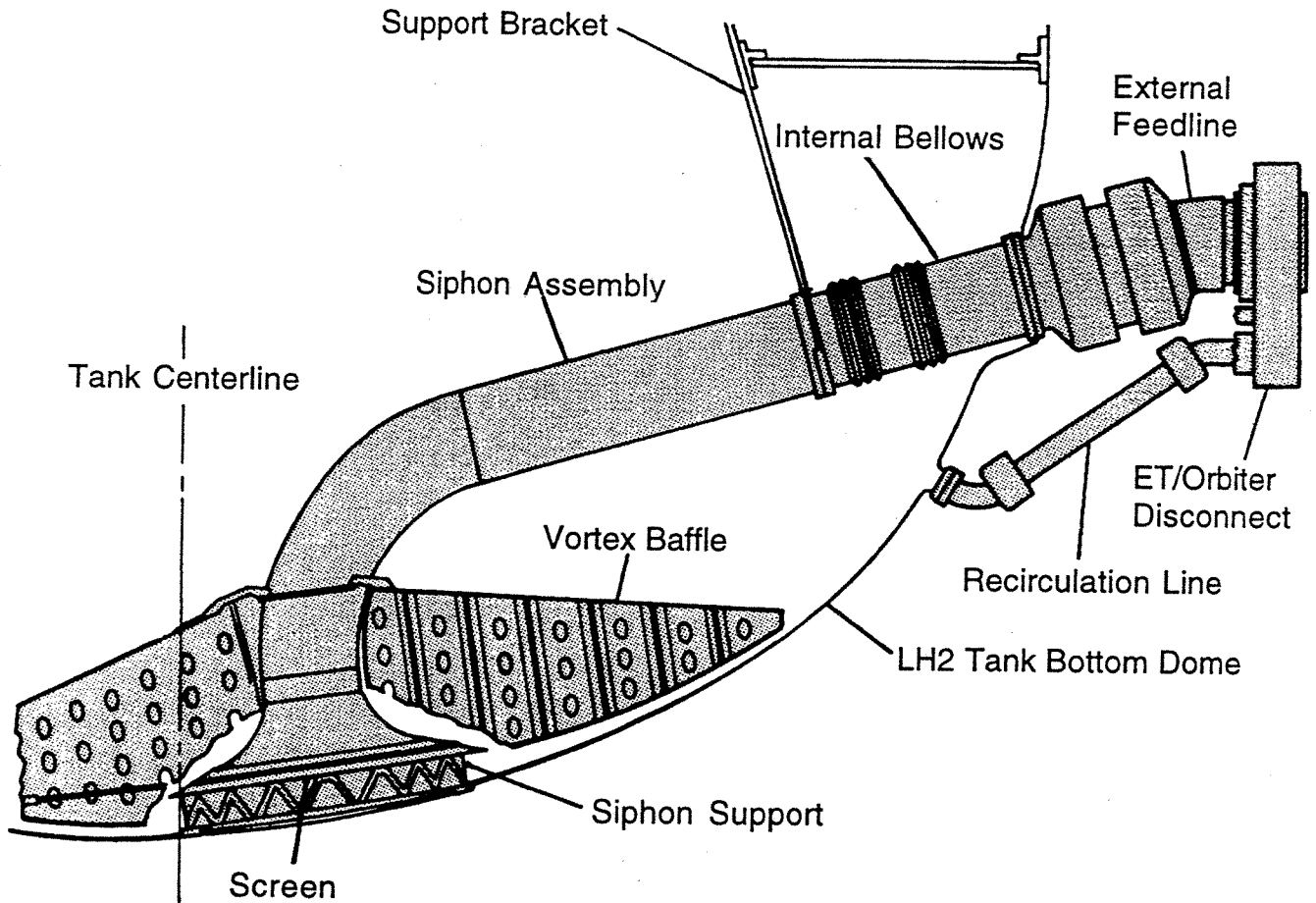


Figure 9-12: LH2 Feedline

A 400-micron, glass-bead-rated, sintered fine mesh screen is mounted inside the siphon inlet. The 46-inch diameter screen is fabricated in four 90 degree sections. The screen is fabricated from 304L stainless steel and the screen frame is fabricated from 321 stainless steel.

The LH2 internal feedline is a 35-inch long articulated bellows pipe section which is installed between the siphon assembly and the flanged outlet in the tank dome. The flanged joints inside the LH2 tank do not contain seals. The free

bellows section accommodates manufacturing and installation tolerances and relative motion between the feedline and tank structure during loading of cold propellant, tank pressurization, liftoff and flight. The flange that mates with the siphon assembly contains two lugs with spherical bearings for attachment of a bracket which supports the line from the 2058 frame structure. The tank end is provided with a floating ring flange. The line assembly is fabricated from 304L and 321 stainless steel. The floating flange is 6061-T6 aluminum alloy.

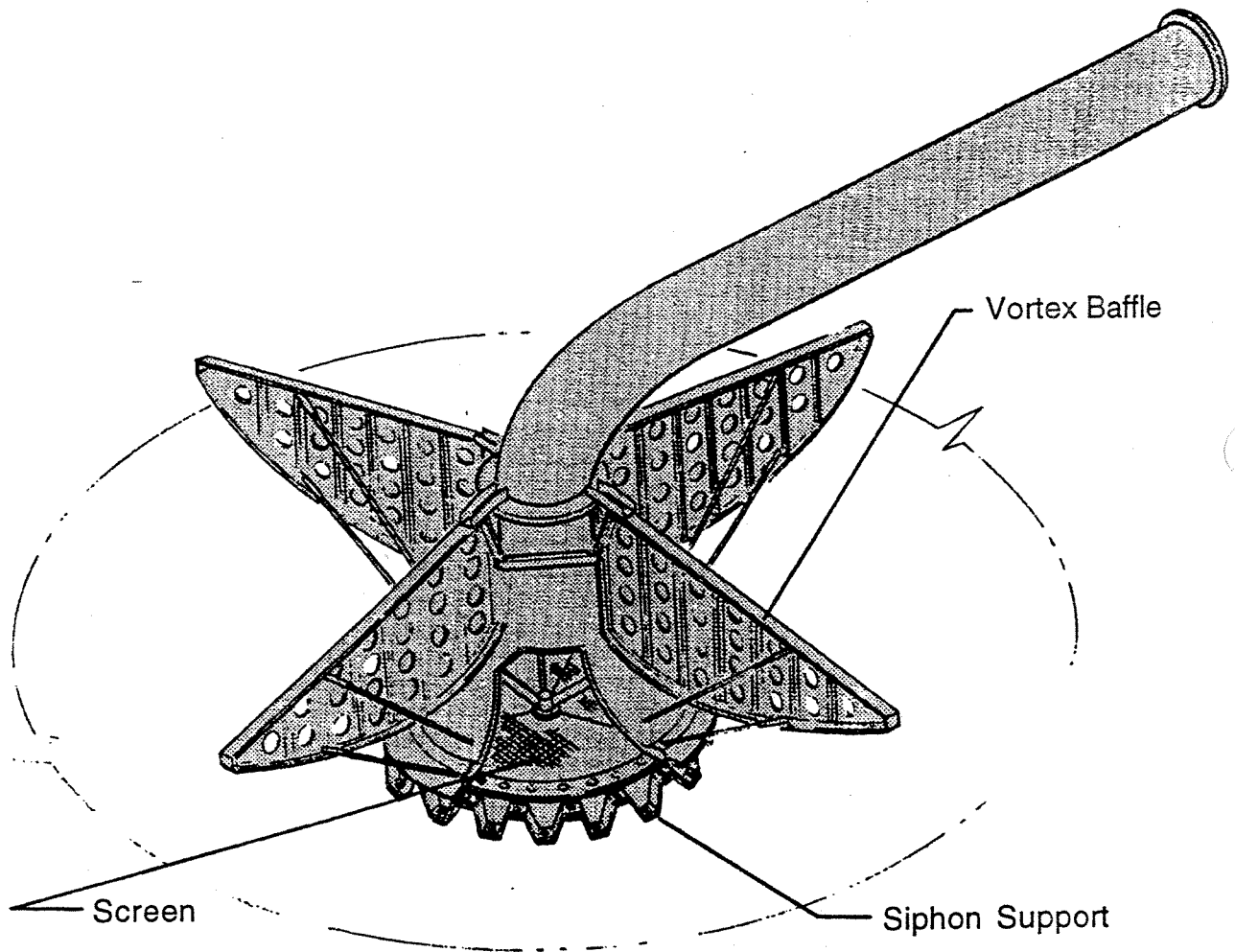


Figure 9-13: LH2 Feedline Siphon Inlet

The 42-inch long external feedline section contains an articulated bellows assembly with a cryopumped argon insulation jacket to prevent the formation of liquid air during countdown and launch operations. The line is jacketed over and between the two bellows. The annulus is filled with argon gas at 1.0 psig. As LH2 is loaded, the cryogenic temperatures solidify the argon in the jacket, creating a vacuum therein. The vacuum jacket then becomes an effective insulator to preclude fuel heating and prevent air liquefaction on the lines. An insulated shroud surrounds the bellows to provide thermal protection during ascent, and to protect the bellows from damage during ground operations. Rigid line sections on either side of the bellows are insulated with SS-1171.

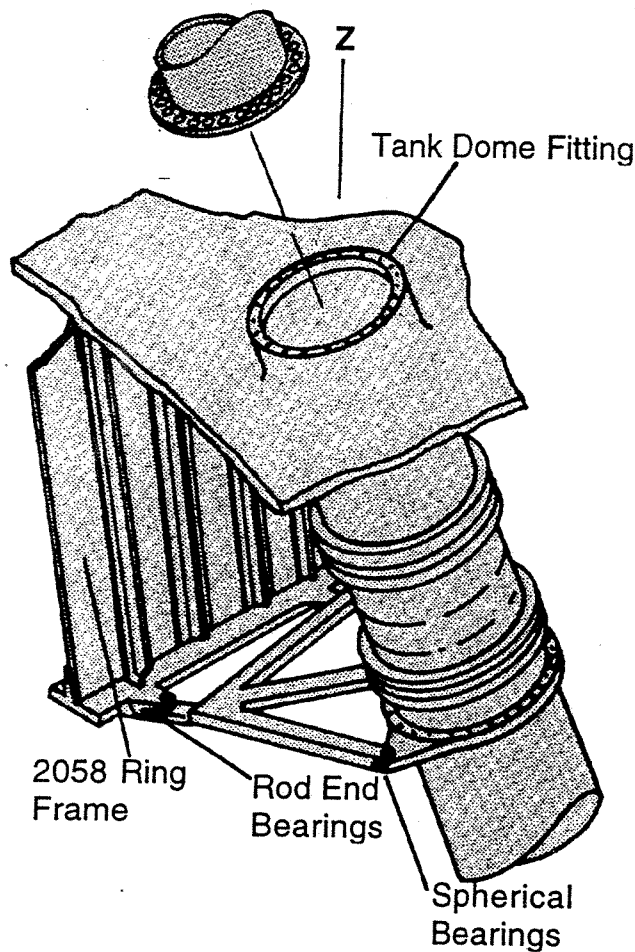


Figure 9-14: LH2 Feedline Internal Bellows and Support

The external feedline is supported by two arms which are attached to the cross beam assembly and are bolted to pads on each side of the feedline elbow section. One end of the line is bolted to the LH2 outlet flange in the lower dome and the other end supports the ET/Orbiter umbilical assembly. The line assembly is fabricated of 321 and 347 stainless steel, 21-6-9 stainless steel, and Inconel 718. The tank end flanged joint has Raco-Creavey seals and the umbilical end has a Naflex seal.

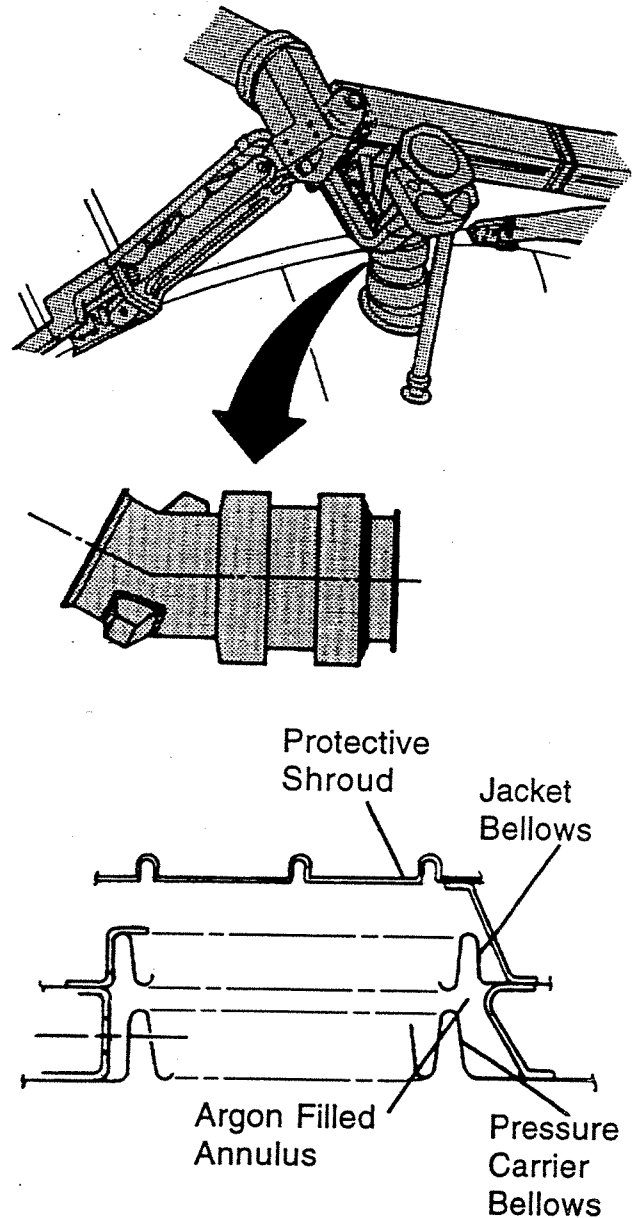


Figure 9-15: LH2 Feedline External Line Assembly

9.3.2 LH2 RECIRCULATION LINE

The recirculation line is a single section of four inch line approximately five feet long. It connects the four inch disconnect valve in the ET/Orbiter umbilical assembly with the LH2 tank and carries warm LH2 from the engine back to the ET during propellant loading and hold. The line incorporates two free bellows assemblies to provide for fabrication and installation tolerances and relative motion during propellant loading and flight. The bellows sections have argon gas filled jackets, similar to the LH2 feedline, which become effective insulators when loaded with LH2. A two piece load carrying shield over the bellows sections provides protection during ground operations and flight. The ET flange joint incorporates Raco-Creavey seals and the ET/Orbiter disconnect flanged joint has a Naflex seal. The recirculation line is constructed of 21-6-9 stainless steel. The line is insulated with SS-1171 and SLA-561 to prevent formation of liquid air and to protect from aerodynamic heating and plume radiation heating.

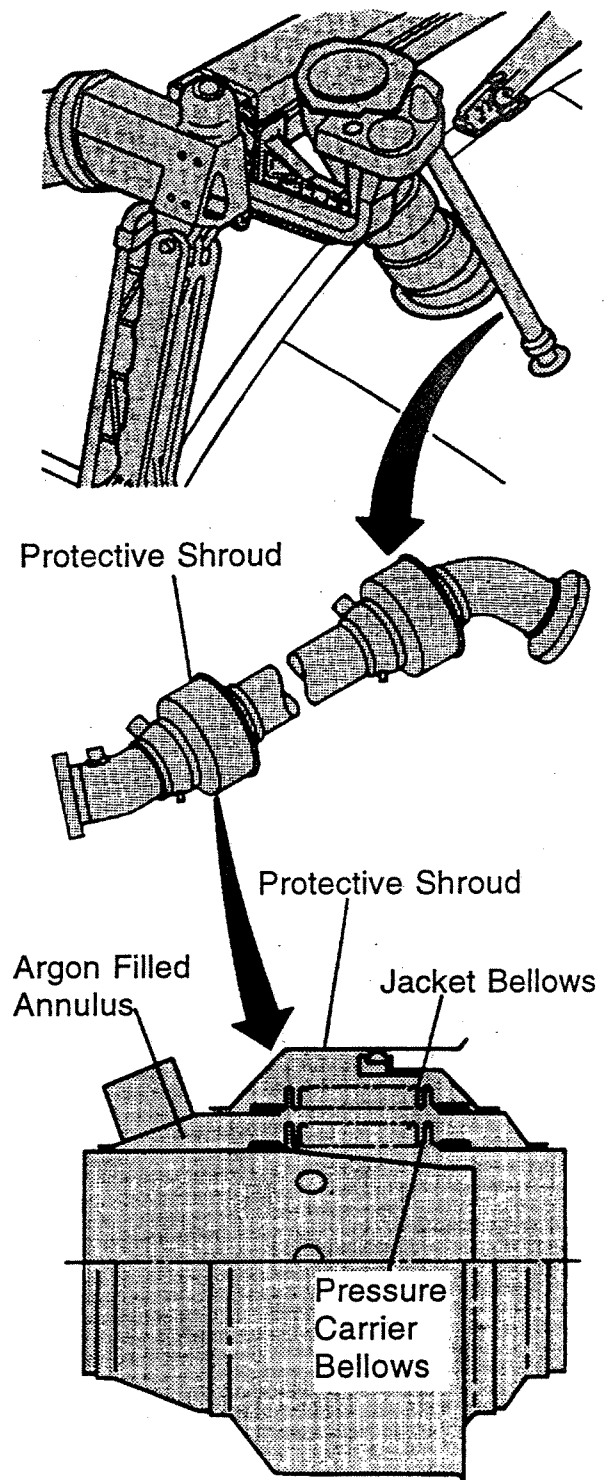


Figure 9-16: LH2 Recirculation Line

9.4 PRESSURIZATION AND VENT/RELIEF SYSTEM

The pressurization and vent system consists of the LO2 tank pressurization subsystem, the LH2 tank pressurization subsystem, the LO2 tank vent/relief subsystem and the LH2 tank vent/relief subsystem.

9.4.1 LO2 TANK PRESSURIZATION SUBSYSTEM

The GO2 pressurization line is an uninsulated 2 inch O.D. tube fabricated of corrosion resistant steel. The line extends from the GO2 pressurization disconnect on the aft right ET/Orbiter umbilical, up the right shoulder on the exterior of the LH2 tank, intertank, and LO2 tank. It continues into the nose fairing and nose cap to a flanged connection on the LO2 tank forward coverplate. A GO2 diffuser is mounted within the tank to the same port.

The pressurization line consists of nine separate line assemblies. The upper flex line assembly originates at the dome pressurization fitting centered on the LO2 tank cover plate. It rises approximately 14 inches, then angles over to the nose cap fairing and starts down the ET right shoulder to a point approximately three feet below the cover plate where it joins the 20 foot long upper curved line assembly.

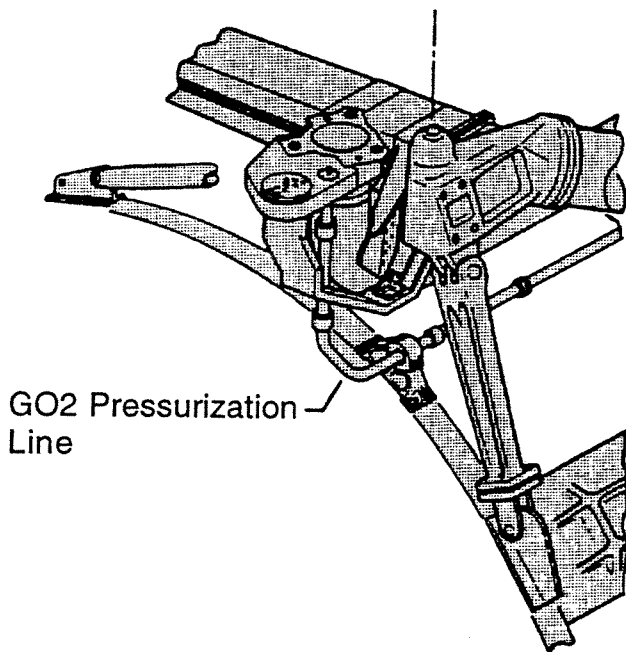
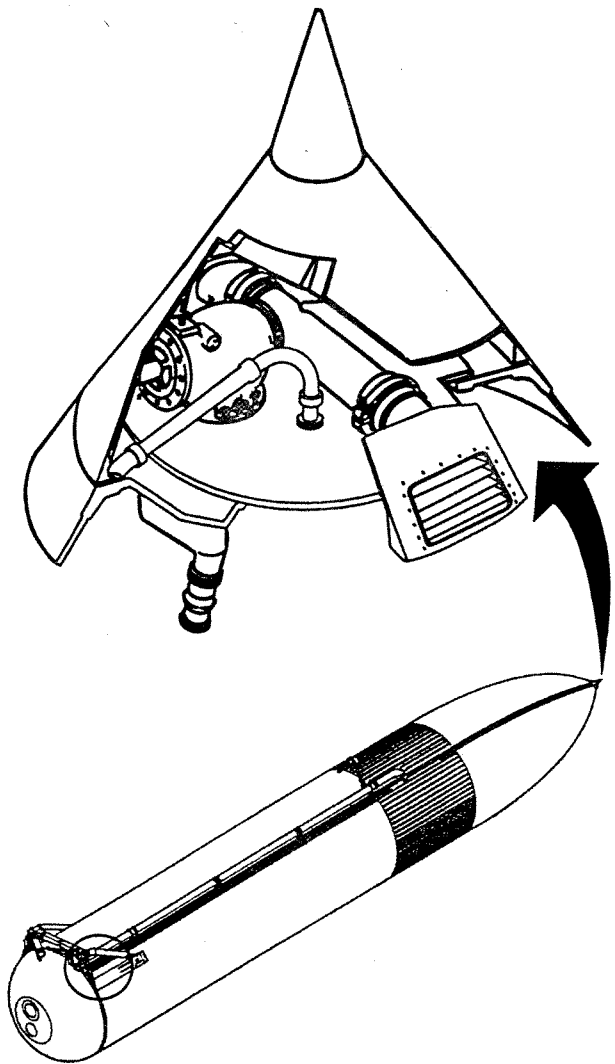


Figure 9-17: GO2 Pressurization Line

The curved assembly (617-inch radius) extends along the LO2 tank ogive section to mate with the upper transition line assembly. This 20-foot section continues along the ogive section and LO2 barrel section. A 20-foot long mid flex line assembly traverses the intertank mating with four similar straight assemblies which extend down the length of the LH2 tank for a distance of approximately 80 feet.

The lower flex line assembly continues down the LH2 tank another 35.72 inches, then angles over (left) 6.91 inches and out (+Z direction) 51.54 inches to mate with the GO2 pressurization disconnect.

The GO2 pressurization line is fabricated of Inconel 718 tubing with 21-6-9 CRES flanges. Flexible joints are made of Inconel 718, 321 CRES and other alloys.

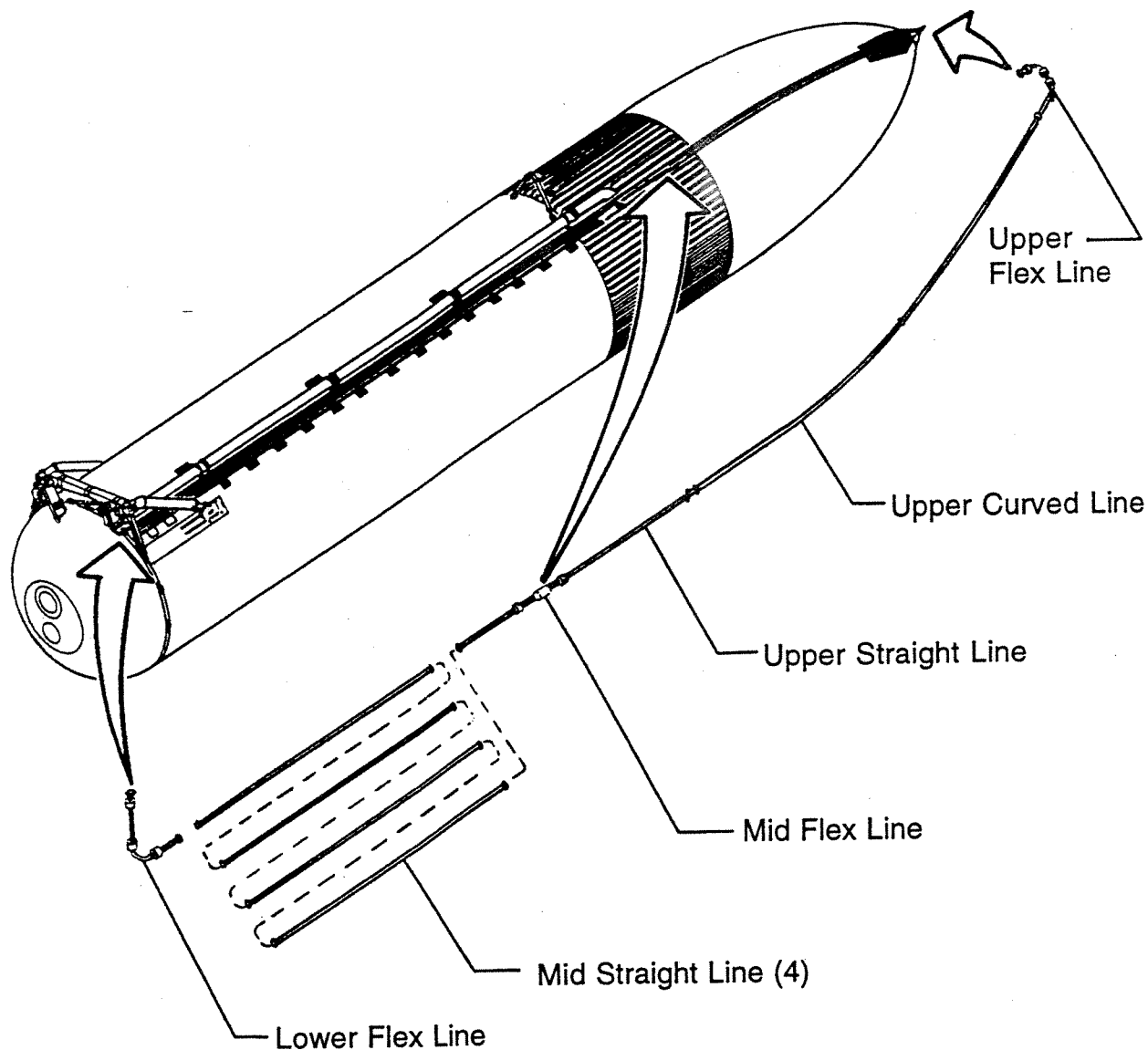


Figure 9-18: GO2 Pressurization Line

All line sections are mated to each other, and to their interfaces with the LO2 tank and ET half of the ET/Orbiter disconnect with flanged joints using an eight-hole bolt pattern. Bolts used at all joints are 5/16-inch A286 CRES except that 1/4-inch bolts are used at the disconnect interface.

Naflex seals are used at each mechanical joint and a leak-test port is located at each joint to provide access between the primary and secondary sealing surfaces.

The Naflex Inconel 718 seal is silver-coated for all the GO2 line joints, except for the joint at the LO2 tank cover plate which is Teflon coated. The silver coated seal is unique to the GO2 pressurization line; all other applications are Teflon coated. The silver coating is used because of the 600°F upper temperature limit requirement for the GO2 line.

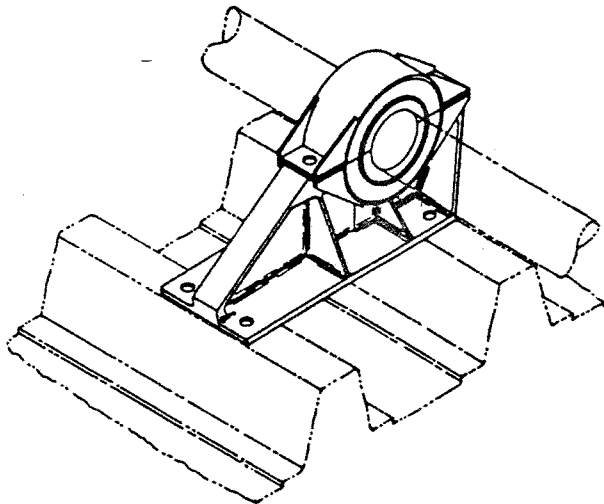


Figure 9-19: GO2 Pressurization Line Sliding Support on Intertank

The pressurization line is supported by 33 sliding supports and two fixed supports. The fixed supports are located at the aft end of the intertank and at the forward end of the LO2 tank. Fixed support brackets built into the pressurization line sections bolt to fixed support bases mounted to the tank structure.

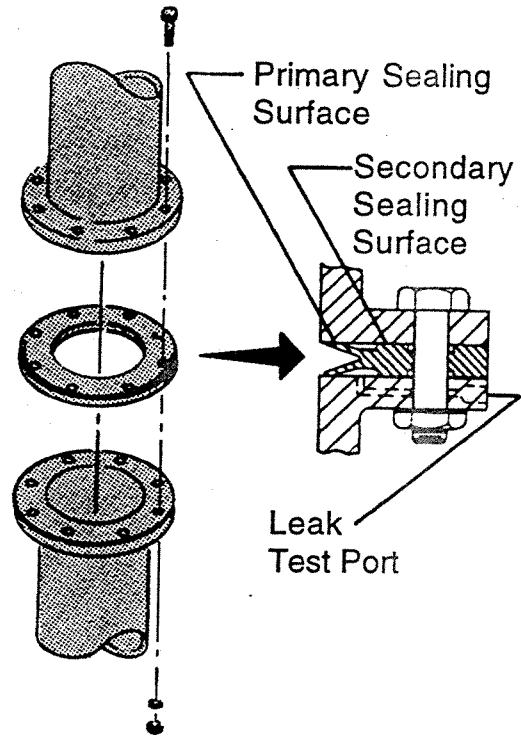


Figure 9-20: Naflex Seal Joint

Two forward intertank sliding supports carry the pressurization line along with the cable tray. These supports are similar to the 12 pressurization line sliding supports on the LO2 tank.

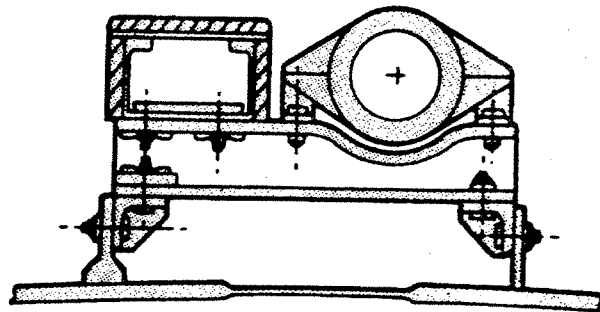


Figure 9-21: GO2 Pressurization Line Sliding Support on LO2 Tank

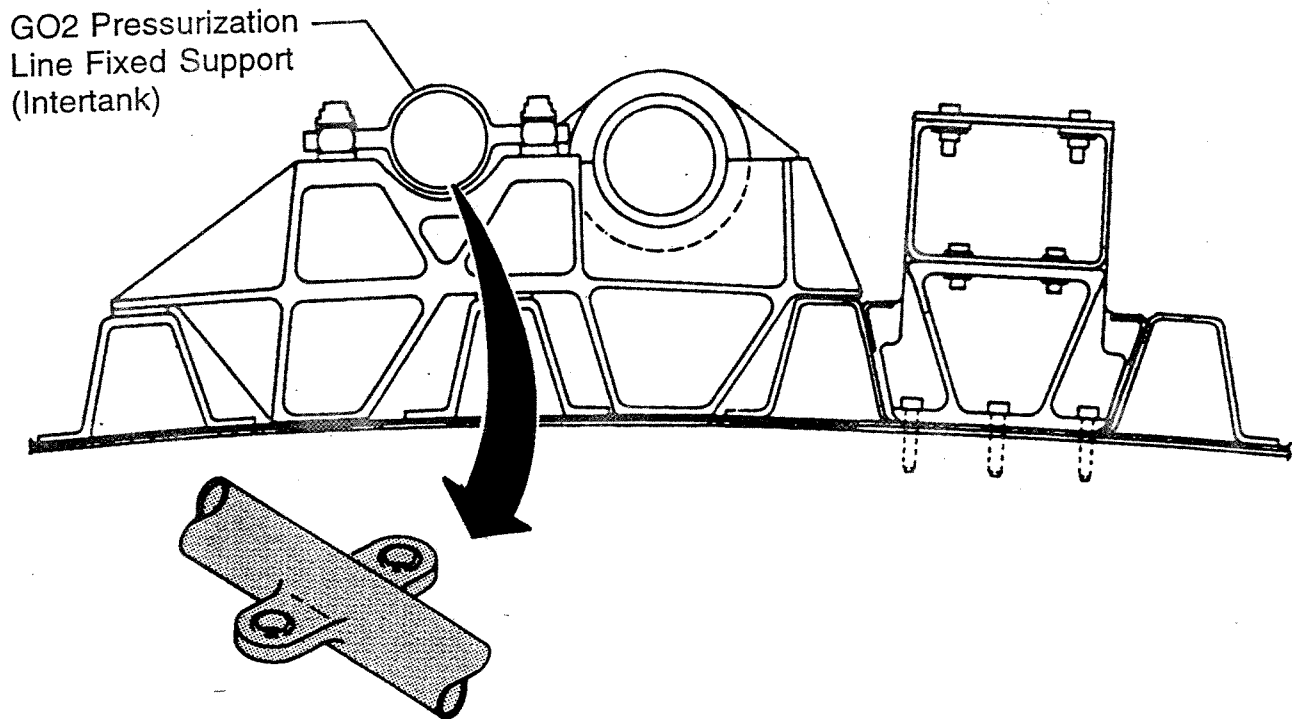


Figure 9-22: GO2 Pressurization Line Fixed Support on Intertank
(Forward Fixed Support Similar)

Nine flexible joints accommodate installation tolerances and thermal and dynamic deflections. Three flexible joints are located in the upper flex assembly and three in the lower flex assembly. In addition, two flexible joints and a sliding bellows are located in the intertank mid flex line assembly.

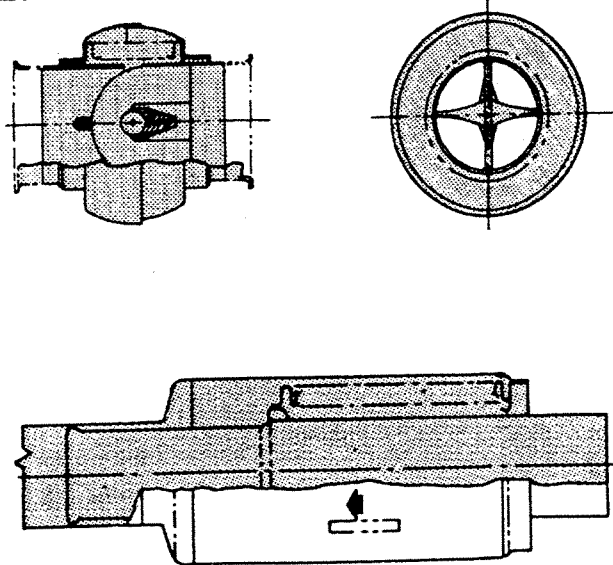


Figure 9-23: Pressurization Line Flexible Joint and Sliding Bellows

A cylinder shaped diffuser is secured internally to the LO2 tank at the GO2 pressurization line outlet. The diffuser consists of a perforated inner core covered with a wire mesh screen cover assembly. The diffuser inlet flange contains a 1.4-inch diameter nozzle that is used to control line velocity. The gas flow exits from the core through 1512 1/8-inch holes and expands into the volume between the core and the screen cover. Further gas pressure and velocity reduction is attained as the gas expands into the LO2 tank ullage through the small holes in the wire screen mesh cover.

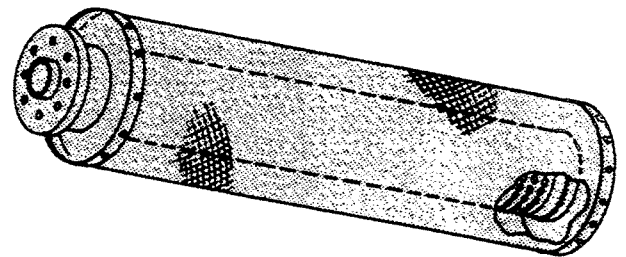


Figure 9-24: GO2 Diffuser

9.4.2 LH2 TANK PRESSURIZATION SUBSYSTEM

The GH2 pressurization line is a 2-inch O.D. tubing that is fabricated of corrosion resistant steel. The line extends from the GH2 pressurization disconnect on the aft left umbilical, along the crossbeam to the aft right shoulder of the LH2 tank, up the LH2 tank into the intertank, to a flanged connection on a cover plate mounted to the LH2 tank forward dome cap. A GH2 diffuser, similar in design to the GO2 diffuser, is mounted to the cover plate inside the LH2 tank.

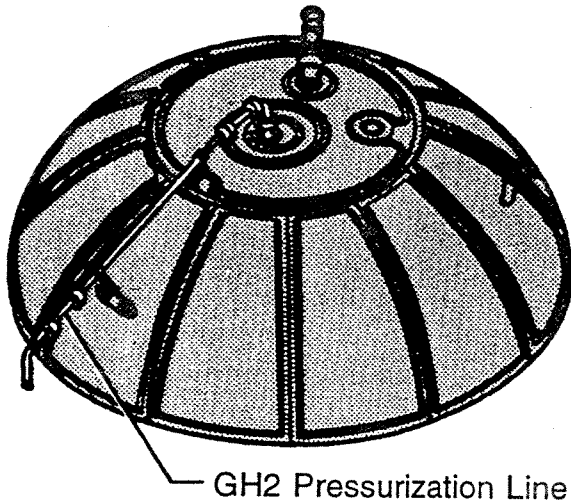


Figure 9-25: GH2 Pressurization Line on LH2 Tank Forward Dome

The GH2 pressurization line consists of an upper flex assembly that originates at the cover plate fitting on the LH2 dome cap. The assembly traverses the LH2 tank dome and terminates down the ET right shoulder at a point about 1 foot below the intertank fairing. It joins a straight line assembly, four of which traverse the LH2 tank for a distance of about 72.5 feet.

The lower flex assembly continues down the LH2 tank then angles over to mate with a straight line section mounted to the crossbeam. The aft flex assembly continues from the straight section to the GH2 disconnect. Eleven flexible joints similar to the GO2 configuration accommodate thermal and dynamic deflections; five are located

in the upper flex assembly and three are located in each of the lower flex and aft flex assemblies.

Two supports for the GH2 pressurization-line upper assembly are located within the intertank along the LH2 tank dome. Support-fitting mounting provisions are included on the line assembly. These monoball-type supports will allow limited line motion through a pivoting action.

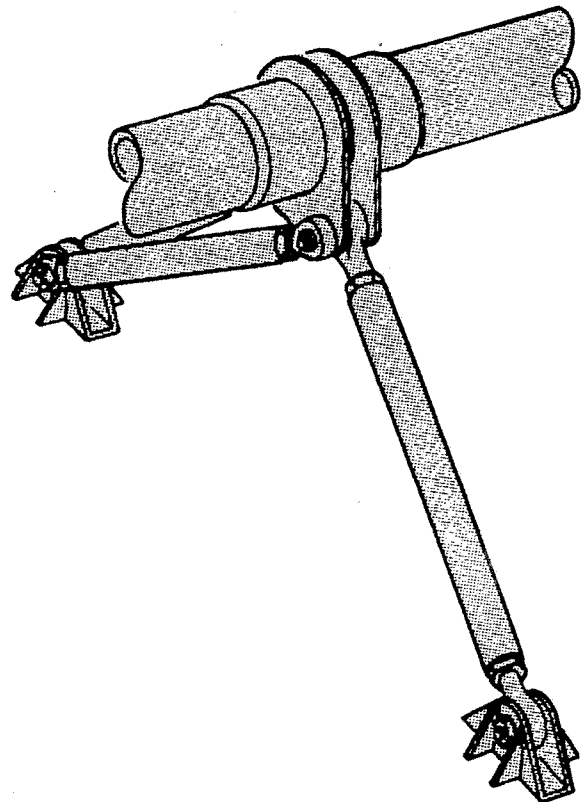


Figure 9-26: GH2 Pressurization Line Support in Intertank

The line external to the ET is supported by 16 sliding supports on the side of the LH2 tank, 3 sliding supports on the crossbeam, a fixed support at station 1593 on the LH2 tank and a fixed support on the crossbeam. Fixed support brackets built into the pressurization line sections bolt to fixed support bases mounted to structure.

Thirteen sliding supports on the LH2 tank are common to the GO2 pressurization line sliding support. Other supports on the aft LH2 tank and crossbeam provide support for the GH2 pressurization line only.

The GH2 pressurization line is fabricated from 21-6-9 CRES tubing and flanges. Flexible joints are made from 21-6-9 CRES and other alloys.

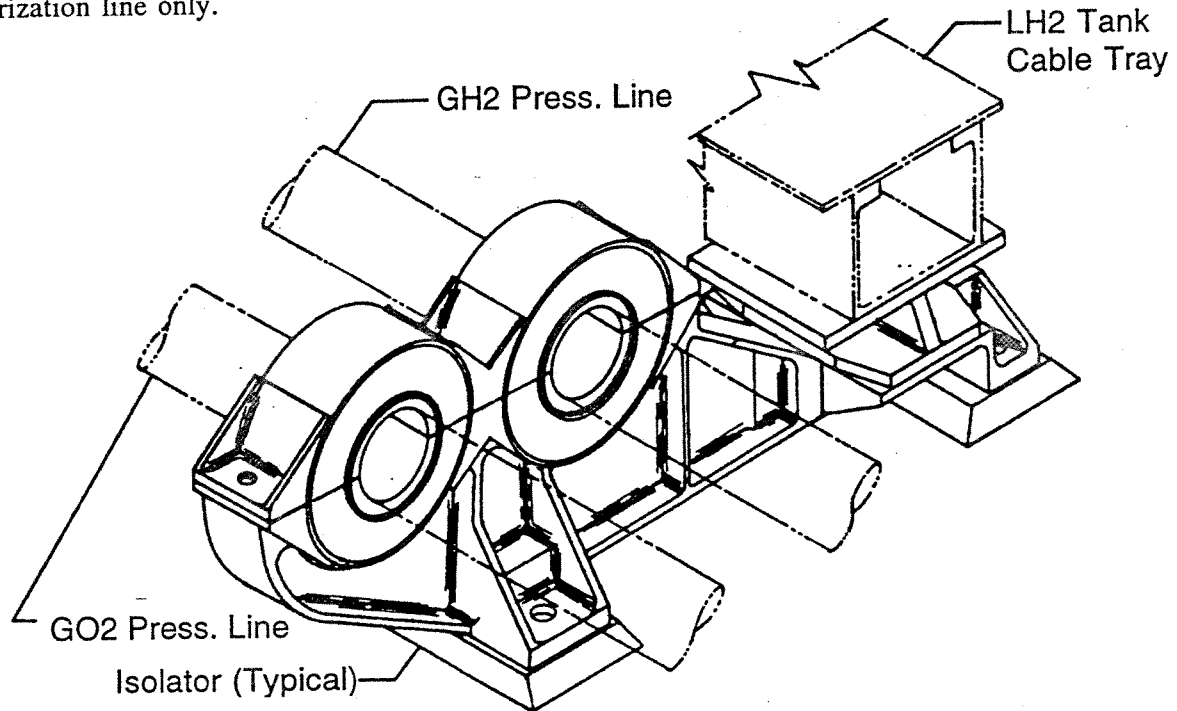


Figure 9-27: GO2/GH2 Pressurization Line Sliding Supports on LH2 Tank (13 Places)

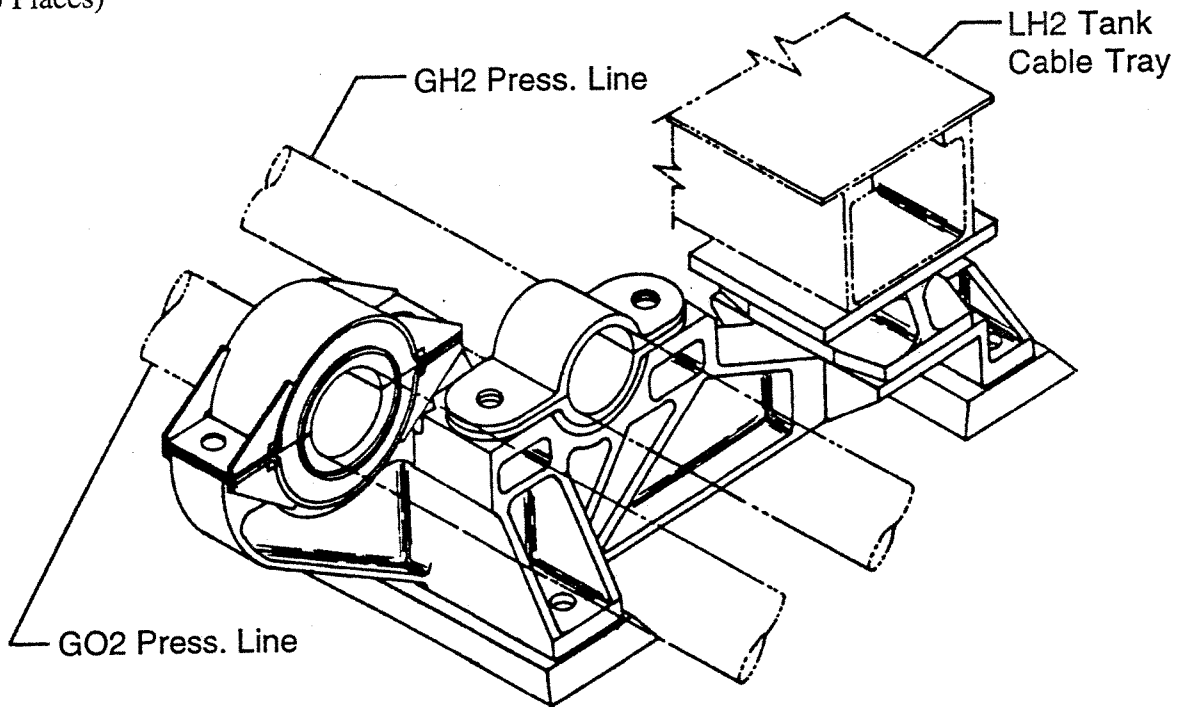


Figure 9-28: Fixed and Sliding GO2 Press. Line and GH2 Press. Line (Station 1583)

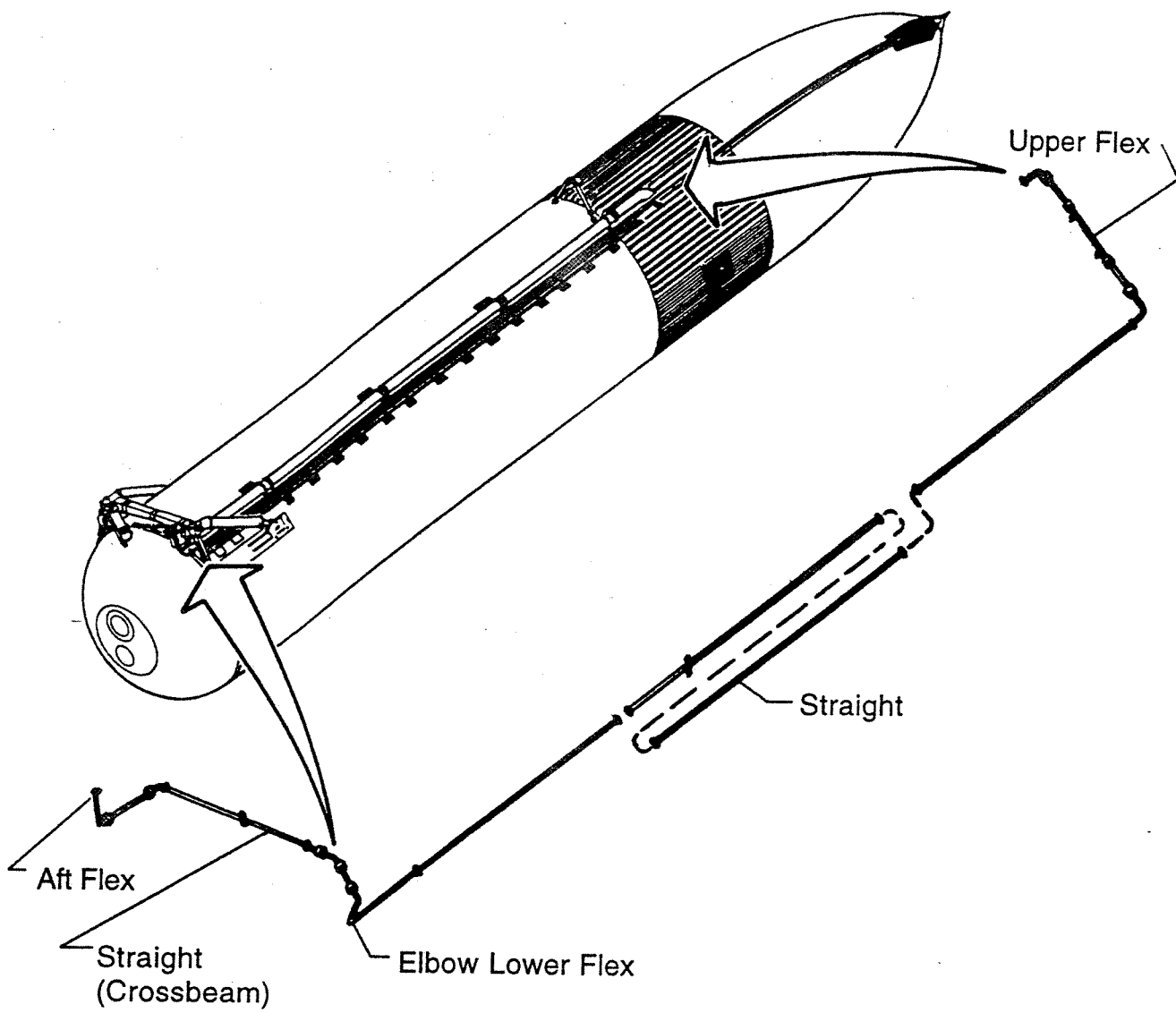


Figure 9-29: GH2 Pressurization Line

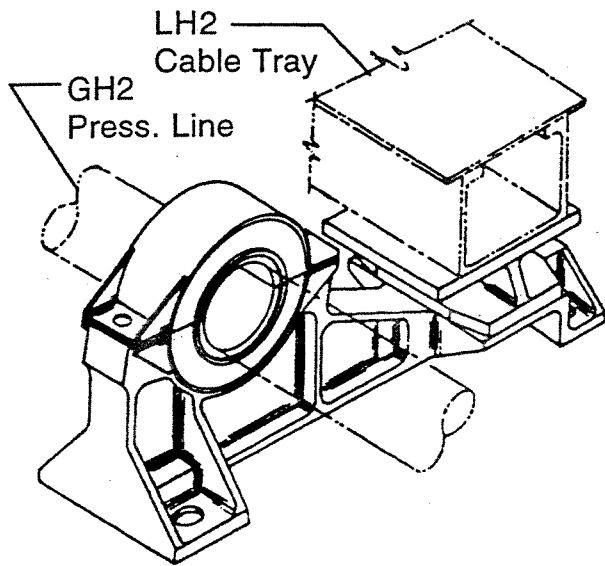


Figure 9-30: Single Sliding GH2 Press. Line at Sta. 2028

A GH2 diffuser located within the LH2 tank is secured to the inside of the pressurization line fitting on the forward dome cap cover plate with eight 5/16 inch bolts. A sonic nozzle 1.5 inches in diameter is located at the inlet to the diffuser to ensure a line velocity of less than Mach 0.3.

The diffuser is cylindrical shaped with a 3 inch I.D. inlet tube leading to a 6-inch diameter core. The diffuser core contains 925 1/8-inch diameter holes. A 9.5-inch diameter screen cylinder, 21-inches long, made of 200 x 1400 Dutch-twill CRES wire cloth covers the diffuser core. The

screen assembly is bolted to the inlet flanges on the diffuser tube. Shoulder bolts on the aft flange allow screen motion and retention.

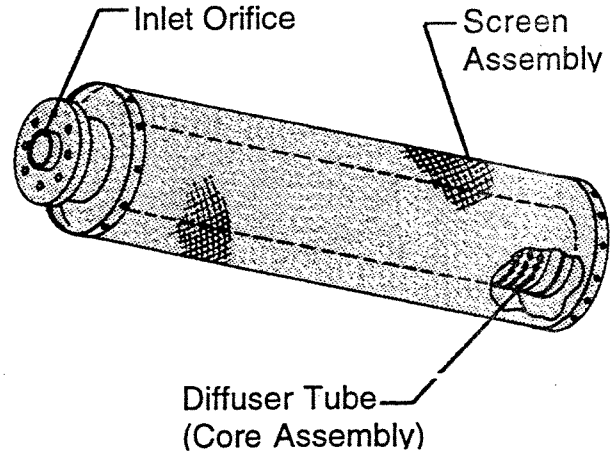


Figure 9-31: GH2 Diffuser

9.4.3 LO2 TANK VENT/RELIEF SUBSYSTEM

The LO2 tank vent/relief subsystem consists of a two stage, pilot operated, GO2 vent/relief valve, a vent manifold, and two exhaust louver assemblies. The 7-inch I.D. flanged inlet of the vent/relief valve is bolted to a port on the LO2 tank forward bulkhead cover plate. The 5-1/8-inch outlet connects to a T-shaped manifold that terminates at two 7-inch I.D. discharge louvers. The valve inlet flange has a 12 bolt hole pattern for 3/8-inch bolts. The outlet is configured for connection to the vent manifold with a V-band clamp.

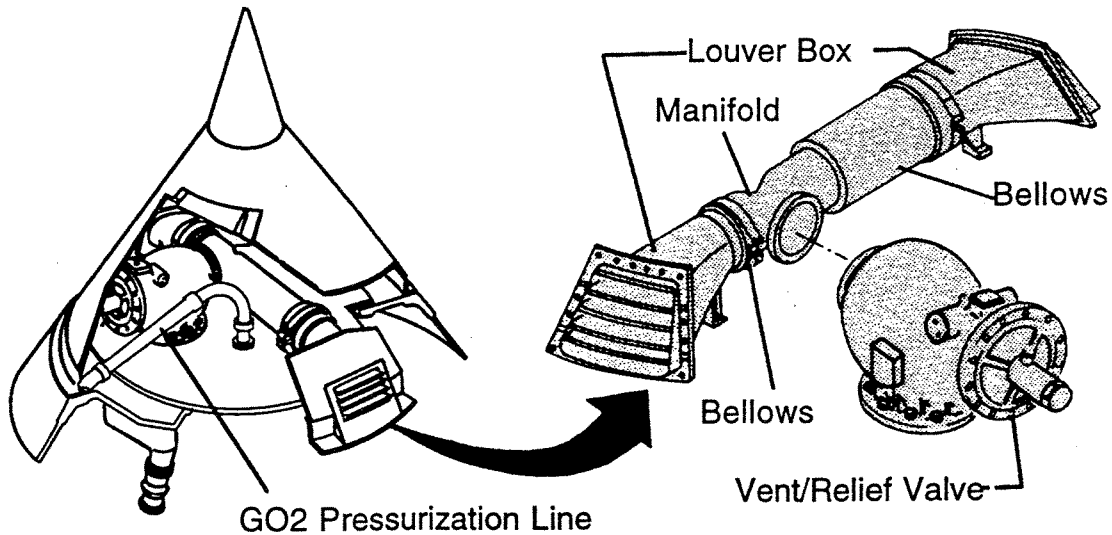


Figure 9-32: GO2 Vent/Relief Valve and Manifold

The 5-1/8-inch I.D. CRES manifold extends about four inches out from the valve outlet to the tee. One branch of the tee extends about 6 inches and the other about 20 inches to mate with outer louver boxes, using V-band clamped, Raco-sealed joints. The louver boxes are secured to the forward LO2 tank ring frame and to the forward cover plate. Vent louvers are attached to each louver box outlet with the edges of the nose cap cut-out and a seal sandwiched between the louver and the louver box attachment flanges. GO2 is discharged on opposite sides of the nose cap through the louvers. The inner manifold contains a bellows assembly on either side of the tee.

The GO2 vent/relief valve actuation line, for ground control of the valve in its vent mode, extends from a quick disconnect on the intertank umbilical carrier plate (located 240° clockwise from the +Z axis) to a port on the valve. From the disconnect, the 1/4-inch O.D., 0.028 thick wall CRES tube is routed within the intertank to the

233.75° roll tie. It follows the roll tie to the station 897.1 ring frame where it follows the ring frame clockwise to the cable tray opening (centered 32.5° clockwise of the +Z axis).

The actuation line extends within the cable tray to the nose cap and then to the actuation port on the vent/relief valve. Line sections are joined by tube fittings and secured to structure with tube clamps.

GO2 Vent/Relief Valve - The GO2 vent/relief valve is a normally closed valve that contains a spring loaded control actuation piston that opens the main poppet when pneumatic pressure is applied and closes the main poppet when the control pressure is vented. The main poppet will also open, in the relief mode, if the LO2 tank ullage pressure increases to 31 ± 1.0 psig (valve reseal pressure is 29 psig minimum). During normal flight operations, the LO2 tank ullage pressure will remain below 22 psig.

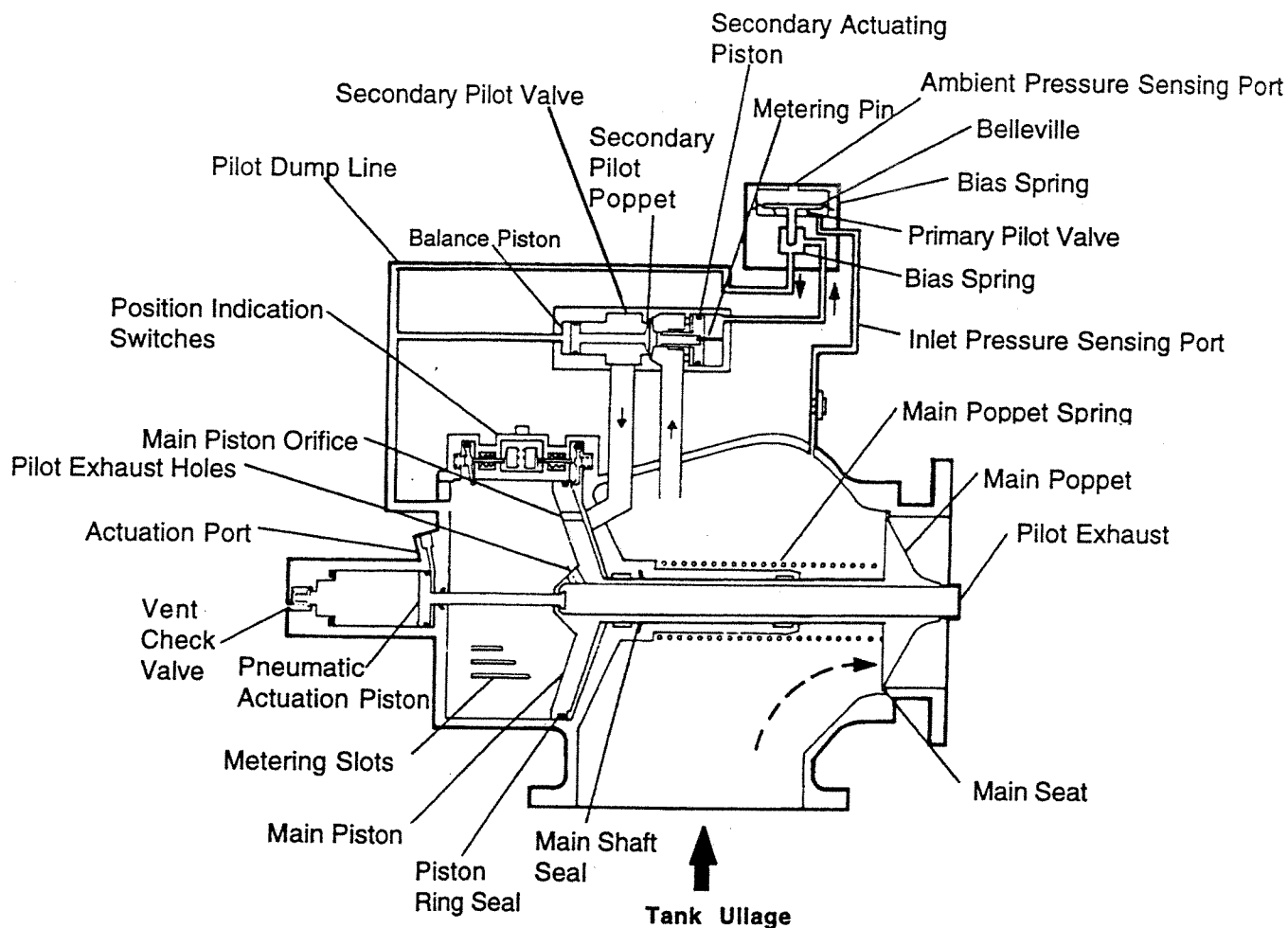


Figure 9-33: GO2 Vent/Relief Valve (2 Stage) - Closed Position

Prior to LO2 tank loading, 775 psig helium is applied to the vent actuation port to open the main poppet. The valve remains in the open mode throughout LO2 tank loading, LO2 tank topping, and standby periods. At T-2:00 minutes, the 775 psig helium is vented and the main poppet closes. The ullage is then pressurized to 20-22 psig with helium.

Valve Vent Mode Operation - The vent/relief valve is opened for tank filling by applying helium pressure to the pneumatic actuation port. Pressure forces the actuation piston to move while pulling the main poppet off its seat. Helium leakage is controlled during piston travel by a split-ring seal on the actuation piston.

A flat-face seal provides positive sealing at the full-open position, thereby reducing helium leakage to a minimum. The gas originally occupying the space beyond the actuation piston is exhausted to the atmosphere through the vent check valve.

As the main poppet leaves its seat, movement of the main piston releases the closed position indicator.

The main spring will close the valve when the pneumatic pressure is vented from the actuation port. Travel of the main piston trips the closed position indicator switch.

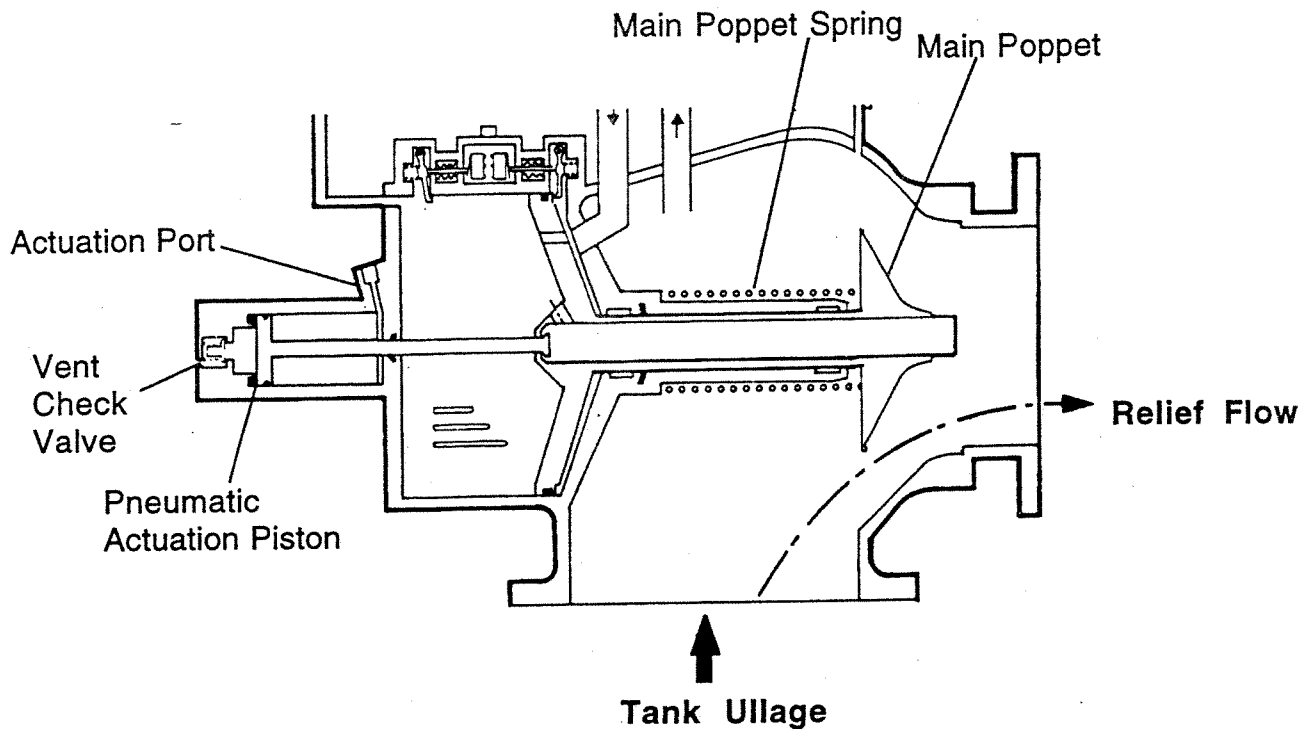


Figure 9-34: Vent/Relief Valve - Vent Mode

Valve Relief Mode Operations - The two stage valve design utilizes a primary sensing pilot and a secondary slave pilot. The primary pilot uses local ambient pressure in the ET nose cap as a reference pressure (sensed at ambient pressure sense port). The primary pilot bellville and bias spring provide control so that valve relief will occur 31 ± 1.0 psig above the nose cap reference pressure. The secondary pilot allows flow to the main piston in response to a signal from the primary pilot during relief operation. The primary and secondary pilot inlets are connected to the main valve inlet cavity.

The primary pilot is connected to the secondary via drilled passages and is physically bolted to the outside surface of the main body.

It utilizes a Ni-Span-C Belleville spring referenced vented to nose cap atmosphere on one ported to valve inlet pressure on the other side. Leakage past the bellville barrier is prevented by a thin stainless steel diaphragm which lays against the bellville face and is welded and clamped to the pilot housing.

The pilot poppet is caused to move with the diaphragm bellville by action of a spring which also acts to open the pilot as the bellville moves outward due to increasing tank gas pressure to the secondary pilot.

The bellville sensing unit is fabricated with a low spring rate as required to function within the pressure tolerance allowed. The moving

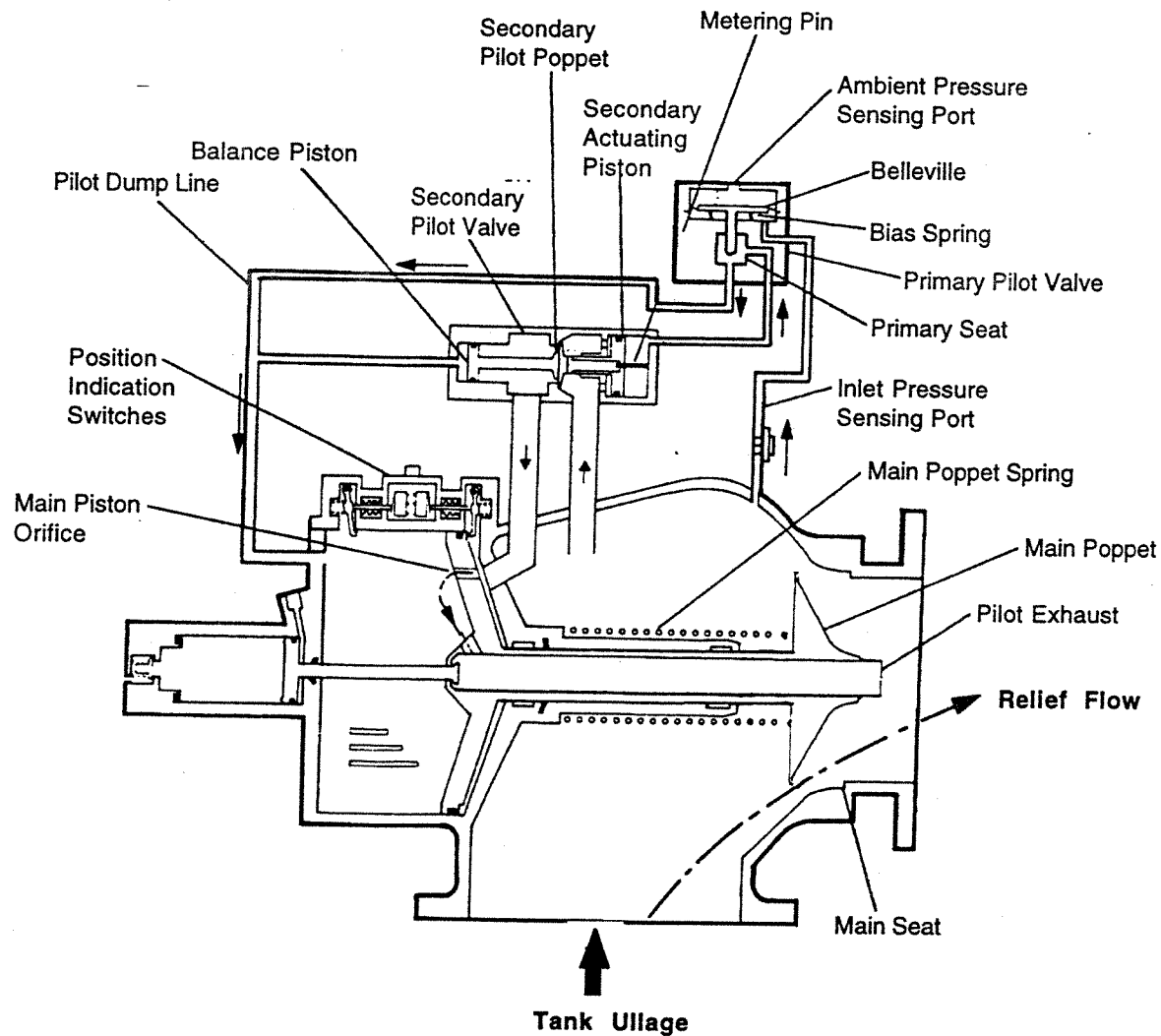


Figure 9-35: Vent/Relief Valve - Relief Cracking Mode

parts of the primary are light weight which, in conjunction with the belleville support damping, provides good vibration resistance. The sliding interface of the pilot is Teflon which prevents galling of this element.

Secondary pilot inlet pressure is admitted to both sides of an actuating piston which is directly coupled to the pilot poppet. The down stream side of the actuating piston is ported to the primary pilot poppet. When the primary pilot opens, flow past the restrictor metering pin causes pressure drop across the secondary actuating piston head which unseats the secondary pilot poppet allowing flow to the main valve actuator piston. This, in turn, forces the main poppet open thereby relieving the tank.

The secondary pilot incorporates a balancing piston, the downstream side of which is vented to a low pressure area. This prevents instability which would be caused by pressure fluctuation in the main valve actuator section.

9.4.4 LH2 TANK VENT/RELIEF SUBSYSTEM

The 7-inch I.D. inlet of a single vent/relief valve is bolted to a fitting welded into the LH2 tank forward dome. The flanged outlet is bolted to a vent duct, which in turn bolts to the vent disconnect on the intertank umbilical disconnect plate. Both inlet and outlet flanges of the valve have a 12-bolt pattern for 3/8-inch bolts.

The valve inlet is centered 47.5 inches from the tank centerline, and 120° counterclockwise from the +Z axis. As in the case of the LO2 valve, Raco/Creavey seals are used at the inlet and a leak test port is built into the inlet flange.

The valve outlet angles down 12°40' due to the curvature of the tank dome. The 5-1/8-inch I.D., corrosion-resistant steel vent duct is bolted to the outlet and extends at this angle for 12.15 inches where it changes to a 3°53' downward slope; it continues at this angle for 90.06 inches to the 7-inch vent disconnect. The duct increases to 7 inches in diameter just before its end. Two flexible joints are included in the line; an unrestricted bellows near the inlet valve, and a gimbal joint near the outlet.

Twelve 3/8-inch bolts secure the vent duct to the vent valve, and sixteen 5/16-inch bolts fasten the outlet to the disconnect. The line is also supported outboard of the bellows joint, at the point where the downward slope changes, by a pivotal assembly (using rod end bearings) attached

to the tank dome and to brackets welded to the vent duct. There are no leak test provisions included in the vent duct flanges; these are provided in the valve outlet and disconnect inlet.

A 1/4-inch diameter x 0.28 inch wall, corrosion-resistant steel, vent-valve actuation line leads from a 3/8-inch disconnect at the intertank umbilical carrier plate to an actuation port on the valve. The line follows, and is attached to the side of the vent duct. The line is attached to belly bands around the vent duct in six places, to tabs attached to the vent duct inlet and outlet flanges, and to clips welded to the LH2 tank dome, using tube clamps. The primary pilot sense line is similarly attached to the vent line.

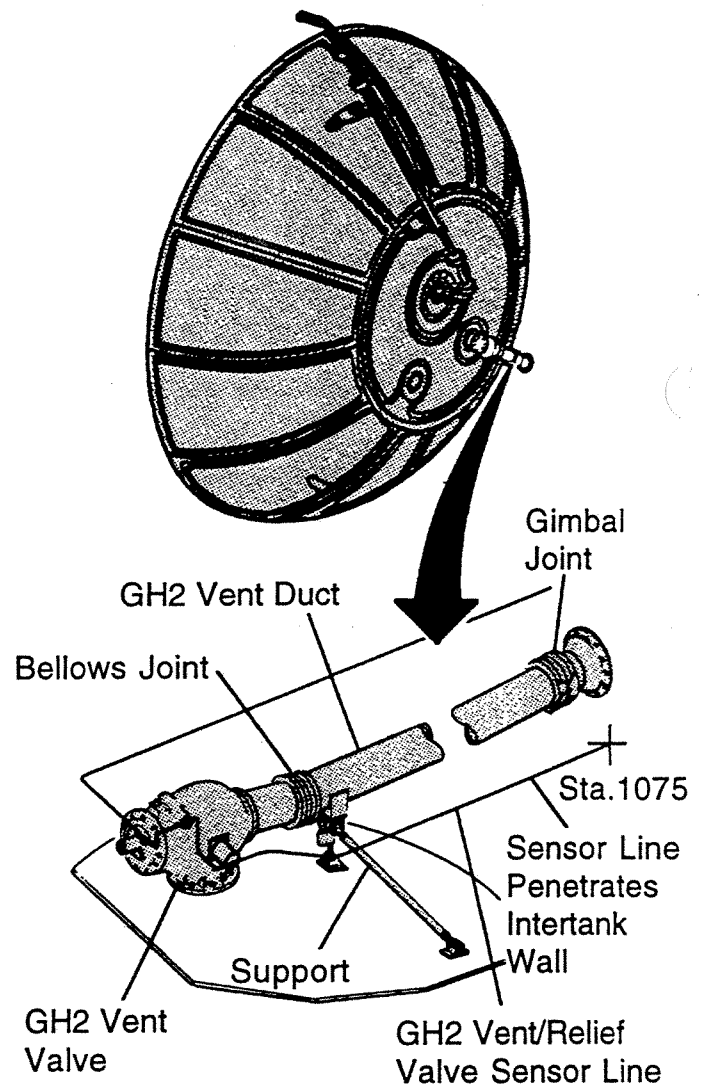


Figure 9-36: GH2 Vent/Relief Valve and Duct

The GH2 vent/relief valve is similar to the GO2 valve previously described except as follows:

- Relief pressure is 36+1.0 psia.
- Reseat pressure is 34 psig minimum.
- An internal 500 SCIM Helium purge provides inerting and prevents cryopumping for the position switch and primary pilot sensing line when Helium actuation pressure is applied to open the valve.
- A vent port check valve is installed on the primary pilot to prevent inadvertent overpressurization.
- The primary pilot senses local ambient pressure through a 1/4-inch tube routed to the intertank outer skin line at station 1075 on the -Z axis.

9.5 ENVIRONMENTAL CONDITIONING SYSTEM

The environmental conditioning system consists of the ET systems which purge the intertank, the nose cap, and propellant tanks and sample the intertank environment for gas composition during propellant loading operation.

9.5.1 INTERTANK PURGE

The ET intertank is purged with dry, heated GN2 during propellant loading to prevent condensation of moisture, preclude air ingestion through the intertank vents, and to avert a buildup of hazardous gases and to provide temperature conditioning of the Range Safety System components and other electronics.

A 3/8-inch tubing, 0.035-inch thick wall, made of corrosion-resistant steel extends from the

3/8-inch purge disconnect on the intertank umbilical disconnect plate, and up the intertank 24 inches to the station 985 ring frame. The line branches in a tee during this run. Two branches mate to 2-inch O.D., 0.028-inch wall aluminum manifolds at station 985.

A flow control orifice is located in each 3/8-inch branch. These two orifices are 0.193 inches in diameter for the lines to the purge manifold, to limit the flow rate between 103 and 158 pounds per minute. This flow rate will limit the concentration of GO2 in the intertank to a maximum of 3.5% under 65 knot wind conditions, will maintain the ambient environment between 37°F and 103°F, and will not generate unacceptable pressures on the tank domes. GN2 pressure supplied to the purge system disconnect is approximately 2810 psig. The gas temperature at the ET interface will be a maximum of 346°F.

The aluminum purge manifolds are run circumferentially around the intertank to blanked off ends. Tube clamps approximately 30 inches apart support the manifold 2 inches off the Station 985.675 ring frame. The manifold halves are routed over the SRB beam, then return to the ring frame on their routing around the intertank. The manifold halves are each constructed in three parts, joined by V-band couplings.

Seventy-eight 0.25-inch diameter holes discharge the nitrogen purge gas into the intertank. Perforation patterns are located every 36 inches around the intertank, with two alternate patterns used. One pattern has one hole up and down, and one hole 120-degrees down and inboard; the other pattern has one hole up and down, and one hole 60 degrees up and inboard.

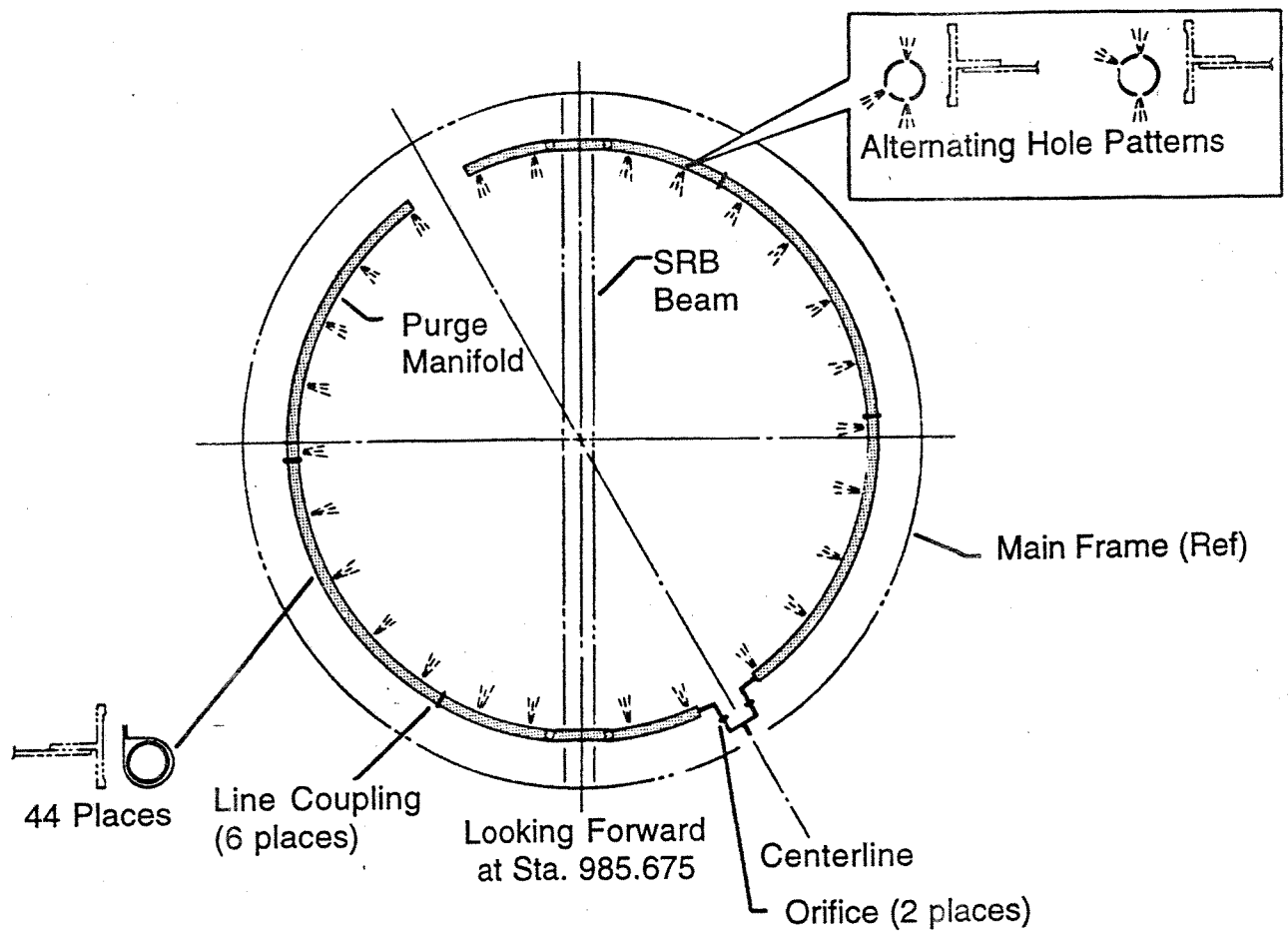


Figure 9-37: Intertank Purge Subsystem

9.5.2 HAZARDOUS GAS DETECTION SYSTEM

The hazardous gas detection system (HGDS) is used by the ground facilities to sample the intertank environment for hazardous gas concentrations during propellant loading. The HGDS originates at a 3/8 inch disconnect on the ET intertank carrier plate assembly. At the disconnect the line reduces to a 1/4 x 0.028 CRES tube which is routed to the intertank 233.75° roll tie. There it tees with one branch following the roll tie to the station 897.1 ring frame and the other branch following the roll tie to the station 1034.2

ring frame. At the station 897.1 ring frame, the HGDS tees again with one branch going clockwise and the other counterclockwise around the ring frame. They terminate at the aerodynamic vents located 2.5° from the +Z and -Z axis on the intertank skin. At the station 1034.2 ring frame, the HGDS tubing is routed toward the +Z axis where it approaches the LO2 feedline opening in the intertank.

These lines terminate with plugs which are orificed to balance the system and to allow detection of the intertank gases.

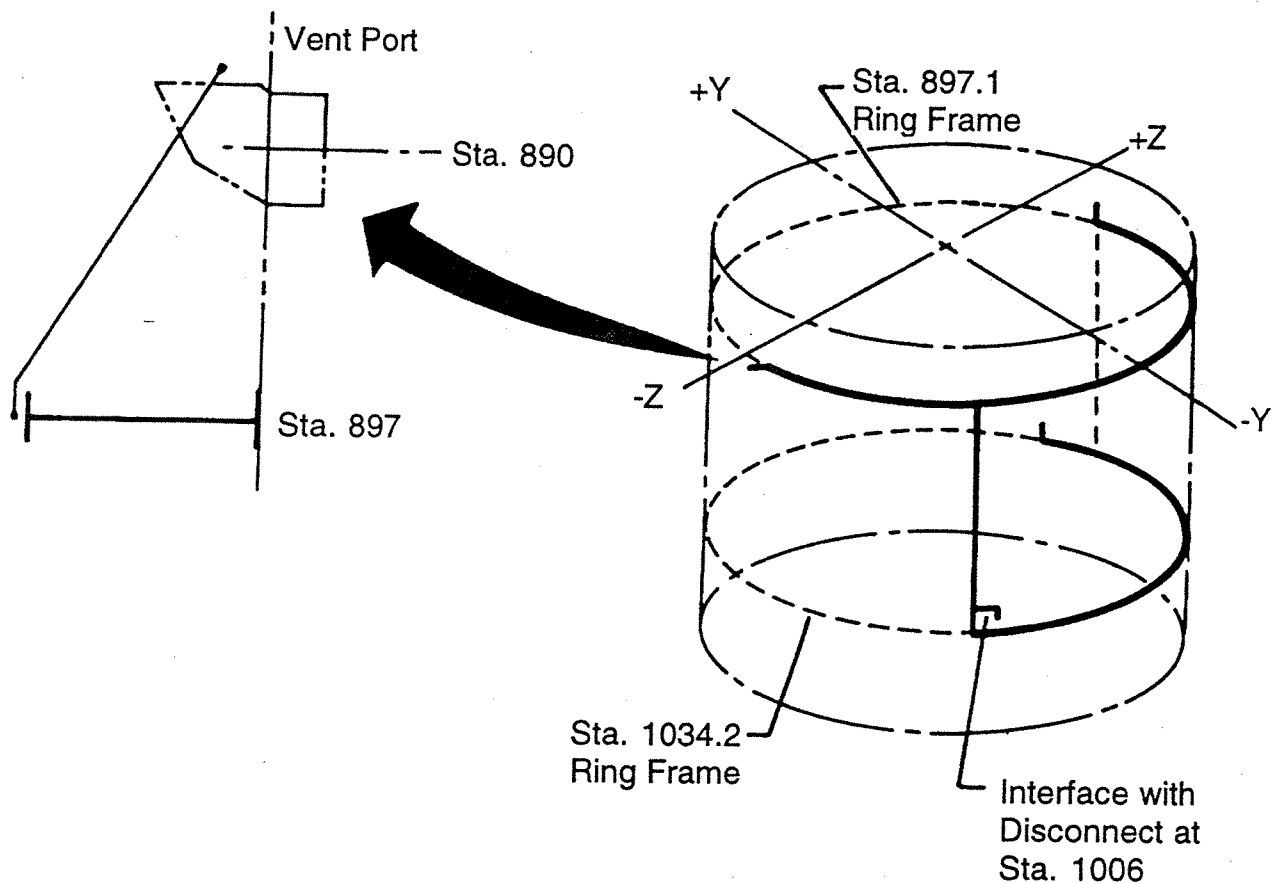


Figure 9-38: Hazardous Gas Detection System (HGDS)

9.5.3 NOSE CONE PURGE

A heated gaseous nitrogen (GN2) purge is supplied to the ET nose cone cavity. The heated purge gas provides an inert atmosphere and minimizes the ice/frost formation that would be caused by cold vent gas. The heated purge gas ensures that the temperature of the ullage pressure transducers is above 40°F and that the venting purge gas does not cause ice at the discharge area. A GN2 purge gas line, 3/8-inch O.D. CRES, runs from a disconnect on the ET intertank carrier plate assembly through the intertank, reduces to a 1/4-inch O.D. CRES line and runs up the LO2 tank cable tray, into the nose cone terminating in a diffuser assembly. Ground facility GN2 is provided at the ET intertank carrier plate assembly interface at 2000 psig at a temperature of 262°F. The gas flow rate is approximately 13.5 pounds per minute.

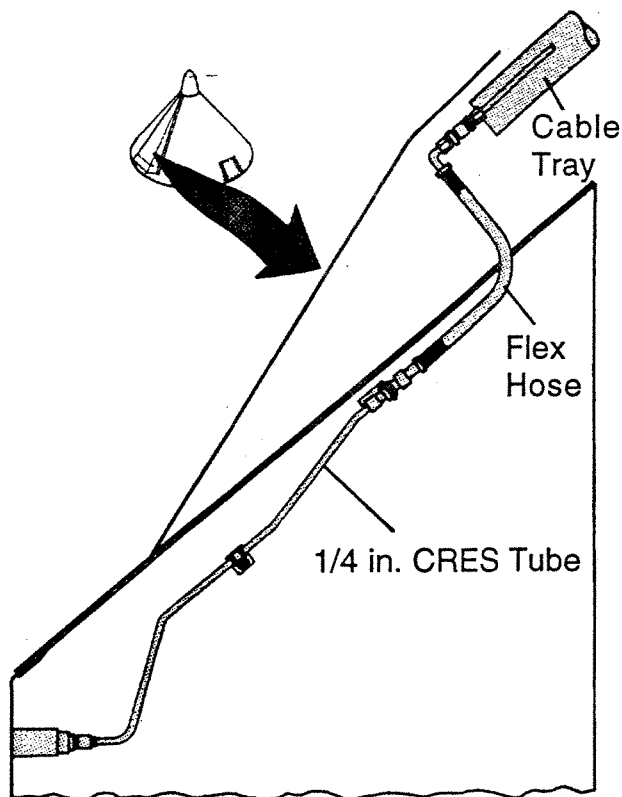


Figure 9-39: Nose Cone Purge

9.5.4 PROPELLANT TANK PURGE

The propellant tanks contain no onboard equipment unique to purging. The purge gases flow in through either the feedlines or pressurization lines, and flow exists through the feedlines or the vent valves. Purging of the LH2 and LO2 tanks is accomplished with helium (GHe) prior to propellant loading to obtain an inert environment.

9.6 ET INTERTANK CARRIER PLATE ASSEMBLY

The Space Shuttle External Tank launch umbilical system provides the interface between the ground facility and the ET for the pressurization and vent system, hazardous gas detection system, operational instrumentation system and electrical power.

The ET sections of the disconnects used to provide these services are contained in the ET intertank carrier plate assembly (ETCA) which is the flight half of the ET/ground umbilical interface. The ETCA is an integral load carrying member of the intertank structure and is located at station 1006. The ground umbilical carrier assembly (GUCA) and the facility lines mate to the ETCA. The description and operation of the GUCA are provided in Section XII, *Interface Hardware*.

The disconnects used on the ETCA are a non-latching type. The disconnect sections are held in a mated mode by a pyrotechnic bolt which attaches the GUCA to a threaded insert in the ETCA. With the breaking of the bolt, the GUCA pivots away from the intertank on the pivot supports, retracts, and falls downward and away from the ET.

The ET sections of the disconnects are opened with only the ground section of the hydrogen vent disconnect containing a check valve. The pressurization and the electrical disconnects are mounted to a small removable panel section in their respective carrier assembly. These panels allow design flexibility without major ET or ground facility modification. The ETCA disconnects are covered with protective caps until the GUCA is mated to the ETCA.

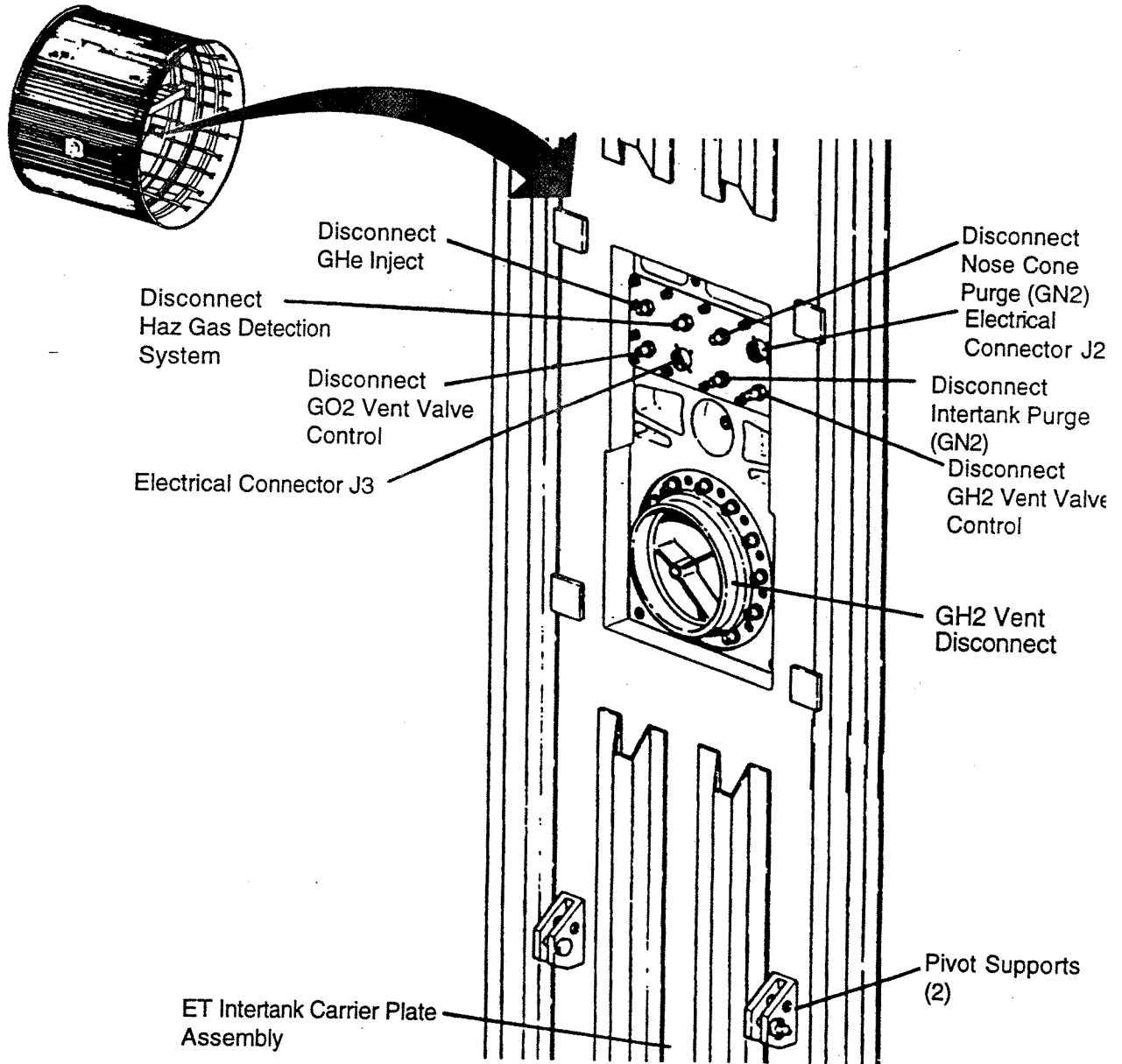


Figure 9-40: ET Intertank Carrier Plate Assembly

10. ELECTRICAL SYSTEM

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10. ELECTRICAL SYSTEM

The External Tank Electrical System provides operational instrumentation, ET cabling, Orbiter/SRB interface cabling, electromagnetic compatibility, and lightning protection to satisfy operational configuration requirements.

10.1 DESCRIPTION

The electrical system provides the operational instrumentation (OI) and bipod heaters and includes the ET cabling, Orbiter/SRB cabling, electromagnetic compatibility, and lightning protection.

10.2 OPERATIONAL INSTRUMENTATION

The Operational Instrumentation contains 35 sensor) and three switches that provide status data to the Orbiter or to the launch facility (prior to launch). The status data sent to the Orbiter is recorded for subsequent retransmission to ground stations or can be transmitted directly to the ground facilities if required. All power for the flight sensors and switches is supplied by the Orbiter. The general location and cable routing for these components that interface with the Orbiter and SRB-to-Orbiter cables are shown on the following Operational Instrumentation Sensors and Switches diagram.

The system also contains the ice/frost heating components and wiring. The location of the system components and cable routing are shown on the following Operational Instrumentation Systems Components diagram. The sensors, that send status data to the launch facility prior to launch are also shown on this diagram.

10.2.1 SENSOR DESCRIPTION

Ullage Temperature Sensor (2) - This sensor is a resistance-type transducer where resistance varies with temperature. The LO2 sensor has an ice point resistance of 100 ohms and a temperature range from -325°F to +500°F. The LH2 sensor has an ice point resistance of 100 ohms and range from -430°F to +200°F.

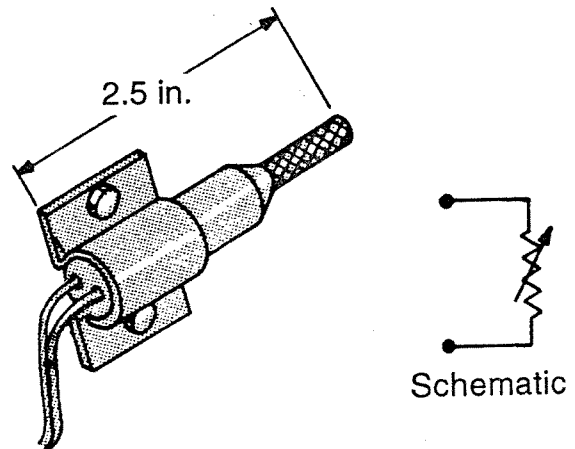


Figure 10-1: Ullage Temperature Sensor (Typical)

Intertank Compartment and Nose Cone Gas Temperature Sensors (4) - This sensor is a resistance type transducer where resistance varies with the temperature. The sensor has an ice point resistance of 1380 ohms and a temperature range of -4°F to +158°F. There are two sensors mounted on the SRB beam in the intertank and two sensors (one is redundant) mounted on the nose cone plate. The sensors are used by the launch facility to allow the temperature to be maintained between 32°F and 85°F in the intertank and between 40°F and 140°F in the nose cone prior to launch.

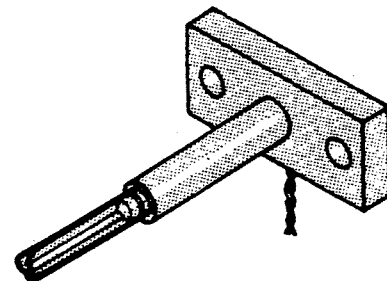


Figure 10-2: Intertank Compartment and Nose Cone Gas Temperature Sensor (Typical)

Legend

- LS – Level Sensor
- PS – Pressure Sensor
- TS – Temperature Sensor
- VP – Valve Position Indicator
- Switch
- – Spliced Connection

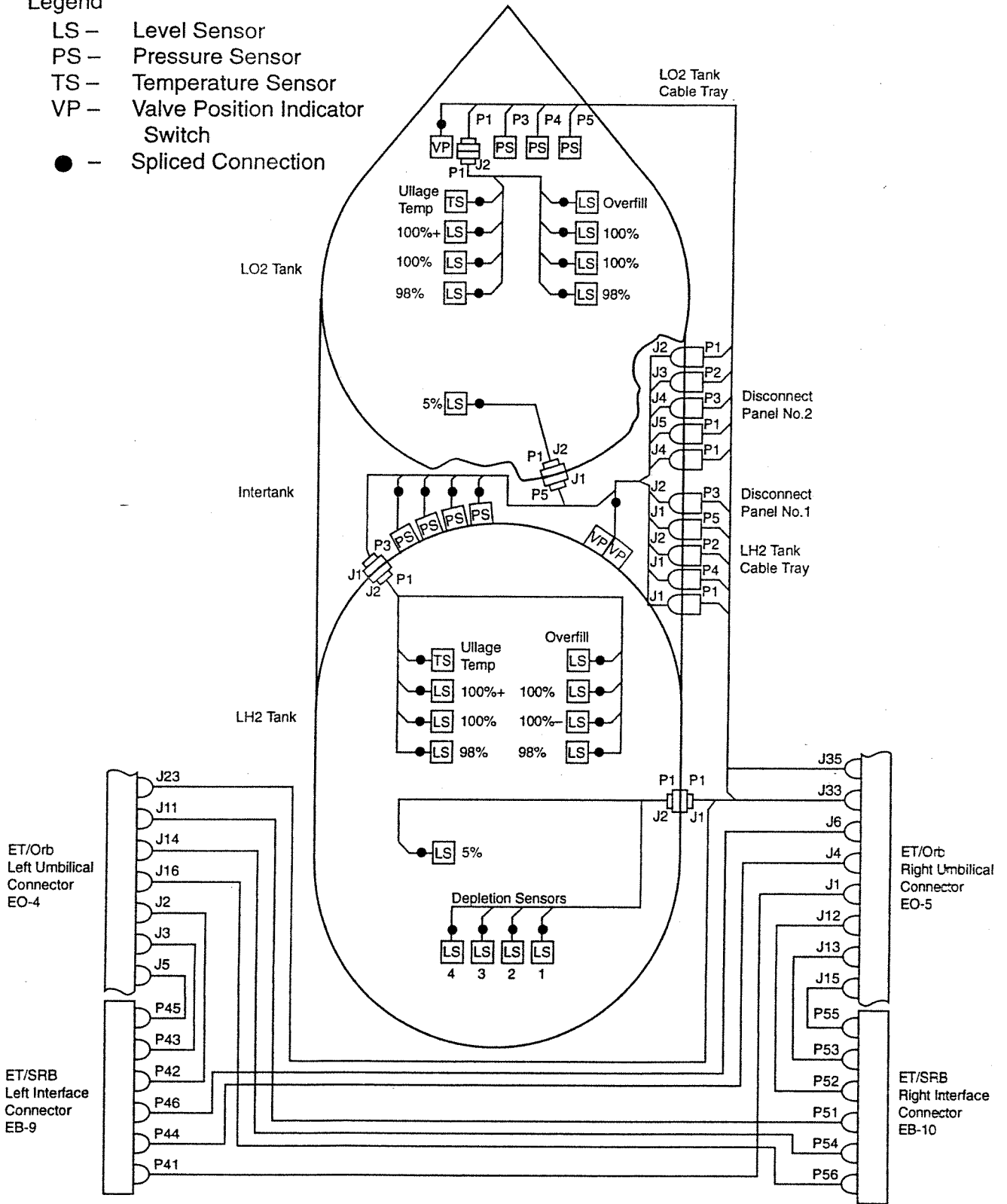


Figure 10-3: Operational Instrumentation Sensors and Switches

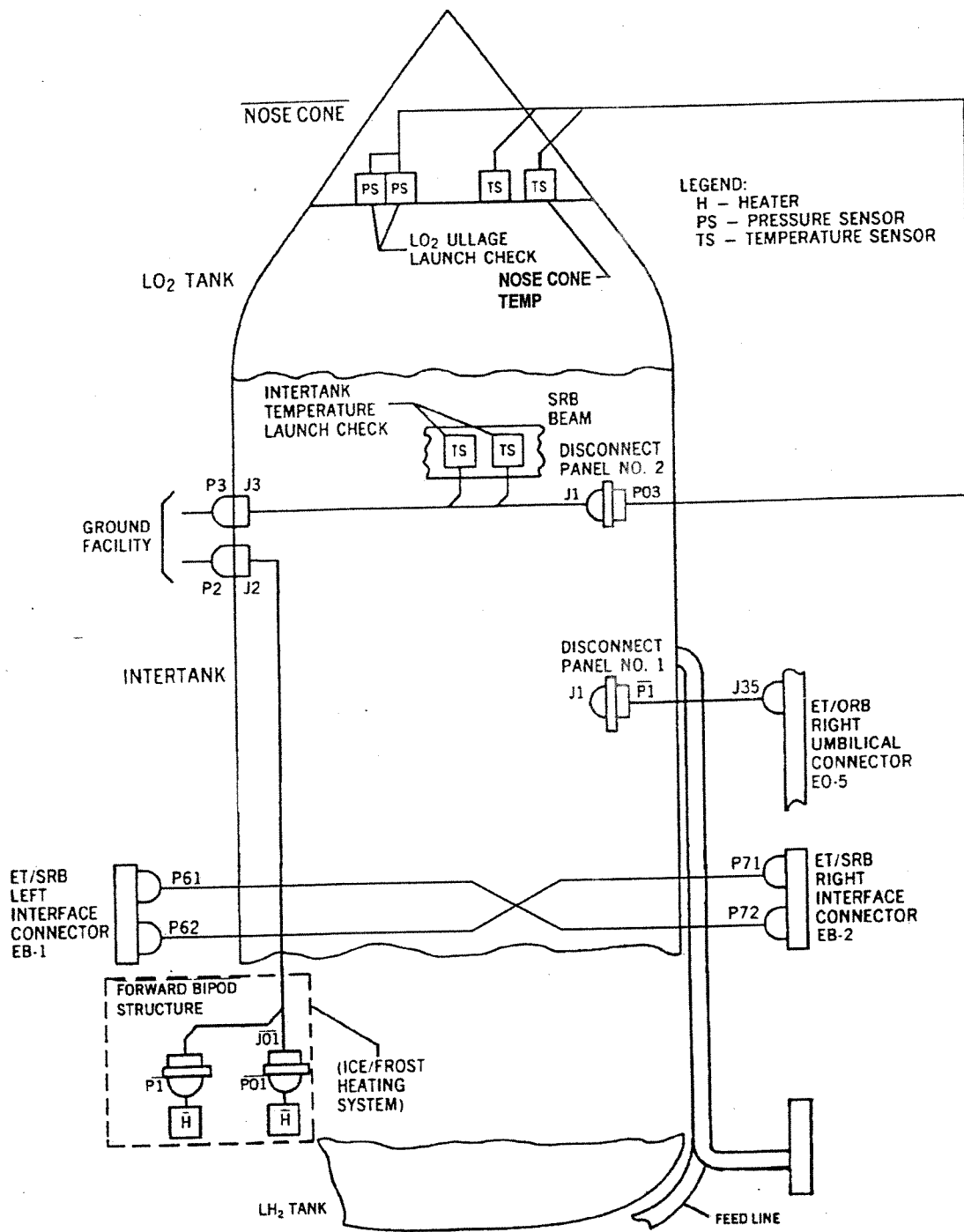


Figure 10-4: Operational Instrumentation Systems Components

LH2 Ullage Pressure Sensor (4) - This sensor is a potentiometer-type, absolute-pressure transducer with a voltage output of 0 to 5 VDC directly proportional to the amplitude of the absolute pressure present. The pressure range for the LH2 sensor is 12 to 52 psia. The system error for tank pressure is +0.4 psi from 32 to 34 psia, +0.8 psi from 34 to 47.5 psia and 1.2 psi throughout the remaining pressure range. One of the four sensors is for backup purposes only and can be switched in by the ground facility as required prior to launch.

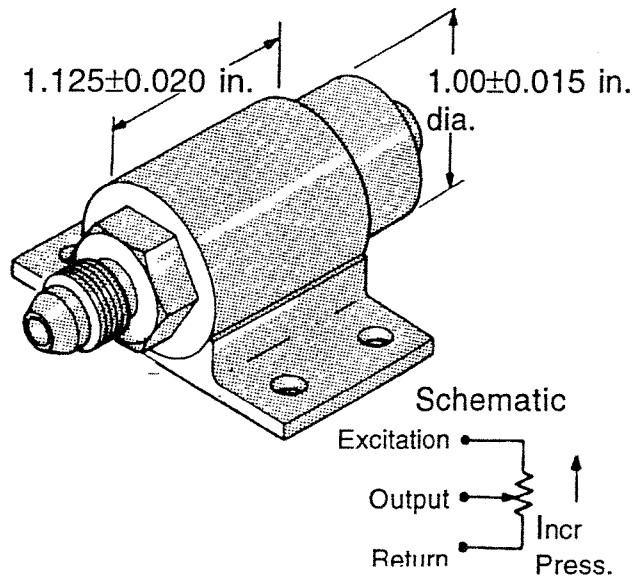


Figure 10-5: LH2 Ullage Pressure Sensor (Typical)

LO2 Ullage Pressure Sensor (3) - This sensor is a variable reluctance type, differential pressure transducer with a voltage input of 0 to 5 VDC directly proportional to the amplitude of the LO2 tank/nose cone differential pressure present. The transducer's range is 0 - 30 psid. The system error for tank pressure is ± 0.3 psid from 20 to 22 psid and ± 0.9 psi throughout the remaining pressure range.

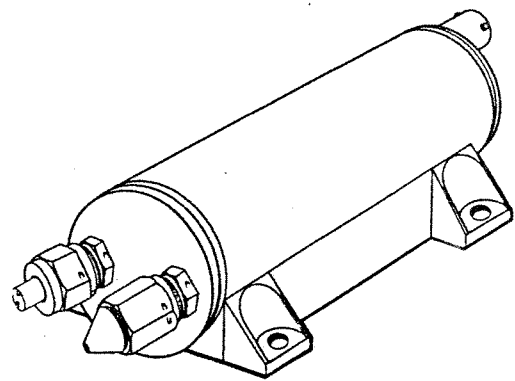


Figure 10-6: LO2 Ullage Pressure Sensor (Typical)

LO2 Ullage Loading Pressure Sensor (2) - This sensor is a variable reluctance type pressure transducer. The pressure range of the transducer is 0 to 5 psig. The transducer input voltage is 28 VDC and the output is 0 to 5 VDC. This sensor is used to control LO2 tank pressure (1.7 psig minimum) during LO2 loading and subsequent holds as required. These pressure signals are routed through the umbilical carrier plate for use at the launch facility.

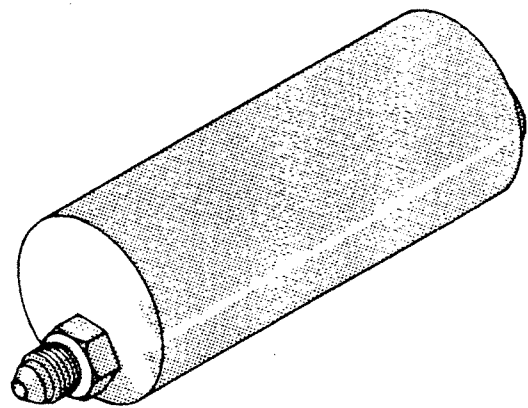


Figure 10-7: LO2 Ullage Loading Pressure Sensor (Typical)

Liquid Level and Depletion Sensors
 (20) - Liquid level (point) sensors are used in both propellant tanks to indicate the presence or absence of LO2 or LH2. In the LH2 tank, five sensors at the tank bottom are used to control engine cutoff and propellant loading; four of these monitor depletion, and the remaining one indicates propellant loading stations. Seven additional loading sensors are installed in the forward LH2 tank. The LH2 sensors are keyed for identification purposes. Eight level sensors are installed in the LO2 tank; one senses loading levels at the tank bottom while seven more are located in the tank top for sensing loading levels.

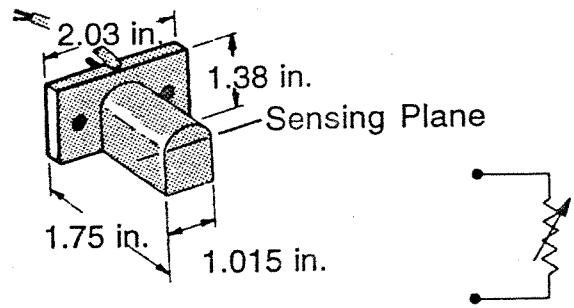


Figure 10-8: Liquid Level Sensor (Typical)

Table 10-1: LO2 Upper Propellant Sensors (Quantity)

Sensor	Location (Station)	Quantity
Overfill	399.7	1 (1)
100+% -	409.5	1 (1)
100%	412.6	2 (1)
100-%	415.5	1 (1)
98%	455.0	2 (1)

(*) Wired from sensor to Orbiter/ET Interface

Table 10-2: LH2 Upper Propellant Sensors (Quantity)

Sensor	Location (Station)	Quantity
Overfill	1033.4	1 (1)
100+%	1040.6	1 (1)
100%	1044.6	2 (1)
100-%	1048.6	1 (1)
98%	1102.1	2 (1)

(*) Wired from sensor to Orbiter/ET Interface

All of the described sensors are designed to Rockwell International Specification MC432-0205 and are used in conjunction with the point-sensor electronics package located in the Orbiter. MMC Standard Specification 74L4 is used to purchase these sensors. The point level sensors element consist of platinum wire that changes resistance when wetted by cryogenic propellants. Each point level sensor weighs approximately 2.4 ounces.

Vent Valve Position Indicator Switch - The LH2 tank vent valve incorporates two environmentally sealed, position indicator microswitches to denote valve OPEN or CLOSED positions prior to launch. The LO2 tank valve has a CLOSED position only. Electrical connections between switch wiring from the vent valve and the ET cabling are provided through crimped splices to pigtail leads supplied with the valve assemblies. The vent valve switches are integral parts of the valve assemblies.

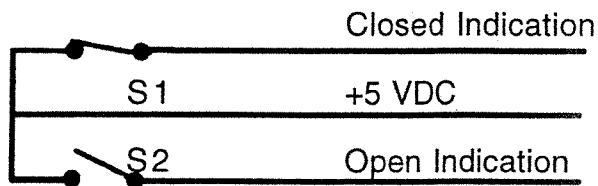


Figure 10-9: Vent Valve Position Indicator Switch Schematic

10.2.2 SENSOR INSTALLATION

Five pressure sensors and two temperature sensors are installed on the nose cap cover plate. Wiring and mounting provisions for sixth transducer are in place if necessary. The temperature sensors are mounted on a phenolic isolator secured to a bracket on the cover plate. Four pressure sensors are shock mounted on the LH2 tank dome cap. They are mounted on a thermal insulator block of laminated glass fiber and phenolic resin. Each is connected to the tank with a pressure line and joined to the electrical cable through fixed-splice connections.

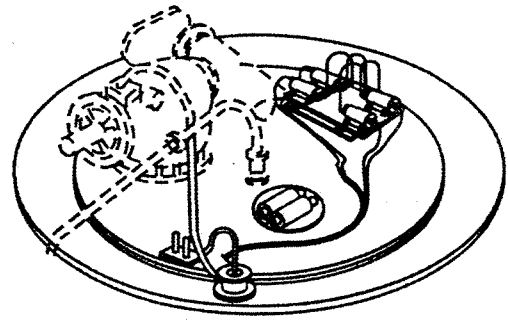


Figure 10-10: LO2 Upper Tank Sensor Mounting

Liquid level sensors and one ullage temperature sensor are installed inside the LO2 tank on a mast. The corresponding LH2 sensors are similarly mounted inside the tank on a forward sensor support frame. A 5% liquid level (point) sensor is mounted at the bottom of the LO2 tank on the vortex baffle mast. The LH2 level sensors are mounted at the tank bottom. The 5% unit is mounted a formed channel and four depletion units are vibration isolated on the vortex baffle.

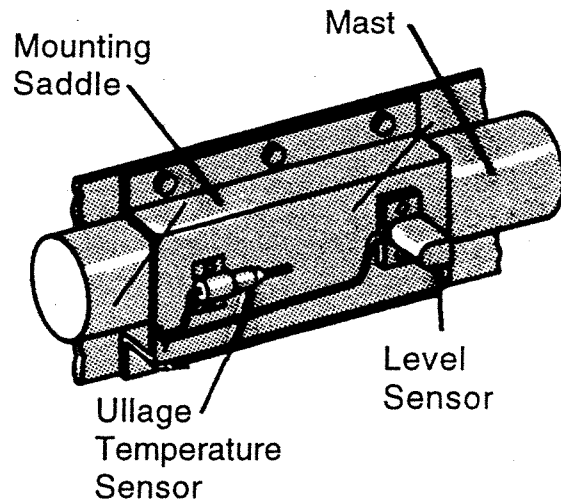


Figure 10-11: Temperature Sensor Installation Liquid Level and Ullage

10.2.3 ICE/FROST HEATING SUBSYSTEM

The ice/frost heating subsystem minimizes ice accumulation on the bipod fitting. The system consists of two calrod heaters mounted on each of the forward bipod spindle assemblies.

The heaters are powered and regulated by the launch facility by controlling the voltage level required to maintain temperatures to minimize ice/frost formation. The rating of the two calrod heaters is 150 watts.

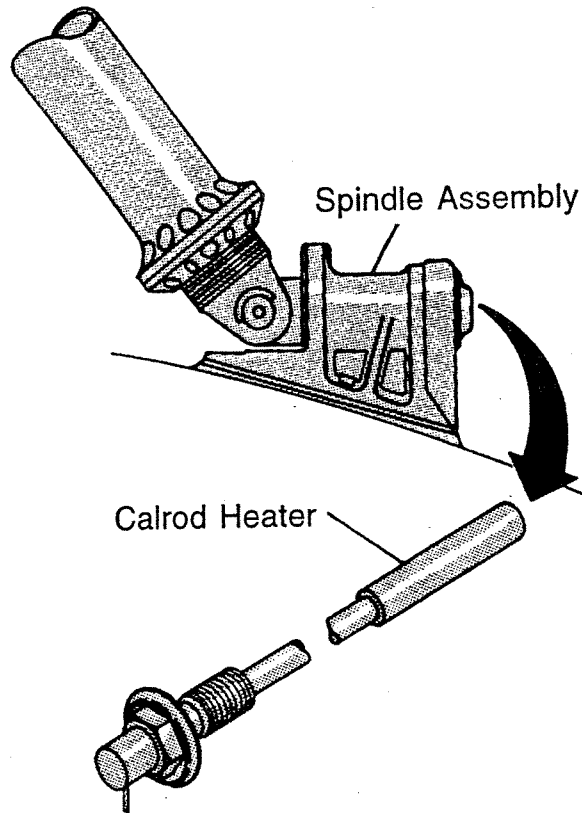


Figure 10-12: Forward Bipod Heater and Sensor

10.3 ET CABLING

The ET Cabling consists of wiring, protected wire splices, connectors, cabling, and disconnect panels. The cabling provides hardware connections between the ET electrical components and Orbiter interfaces. The cabling

system is constructed to protect wiring from undesirable natural and induced electrical interference. External cabling on the ET is routed through closed metal cable trays that provide EMI and physical protection. Cabling length between brackets is made to compensate for vehicle thermal compression and expansion.

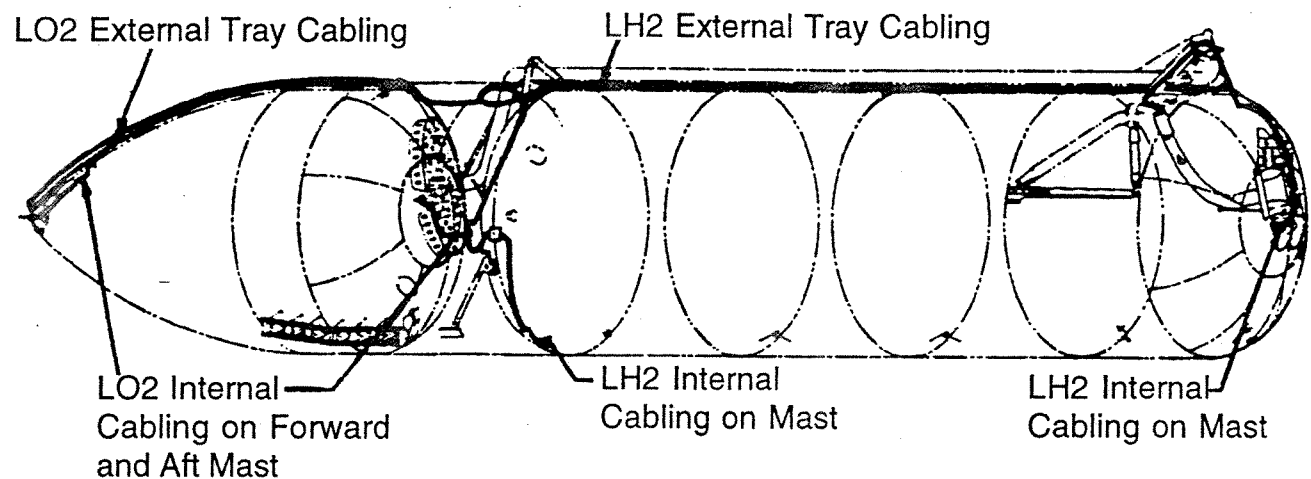


Figure 10-13: ET Cabling

10.3.1 CABLE PROTECTION

The external cables are enclosed in aluminum cable trays that protect them from flight aerodynamic and thermodynamic heating, and from lightning effects. In addition, shielded cables are used in the cable trays to provide further lightning protection. Cable trays have removable covers and are protected by TPS applied to external surfaces. Slip joints are incorporated in the cable tray design which will accommodate differential thermal expansion between trays and mounting structure.

The primary tray run is along the right shoulder of the ET, 32 degrees from the +Z axis. The LO2 tray extends from the nose cap of the LO2 tank to the intertank. The LH2 cable tray traverses the length of the LH2 tank from the intertank to the ET/Orbiter right-aft attach struts. Cable trays are also provided on the aft crossbeam, on both vertical I-Beam struts, and around the tank circumferentially in two short sections between the top SRB strut and each vertical ET strut.

The LO2 tray carries all cabling associated with LO2 tank functions, except for the 5% level sensor located in the tank bottom. All of these LO2 cables meet within the intertank where they are joined by the remaining ET cabling, excluding the LH2 low-level propellant and depletion sensors. The complete bundle traverses the full length of the LH2 tank, meets the LH2 lower sensor cables, and is then routed up the vertical strut to the right Orbiter interface and across the beam to the left Orbiter interface. All the cabling on the aft interface hardware is enclosed in trays. All wiring in the LO2 tank have varglass (a fiberglass raft) over it to provide a fireproof shield.

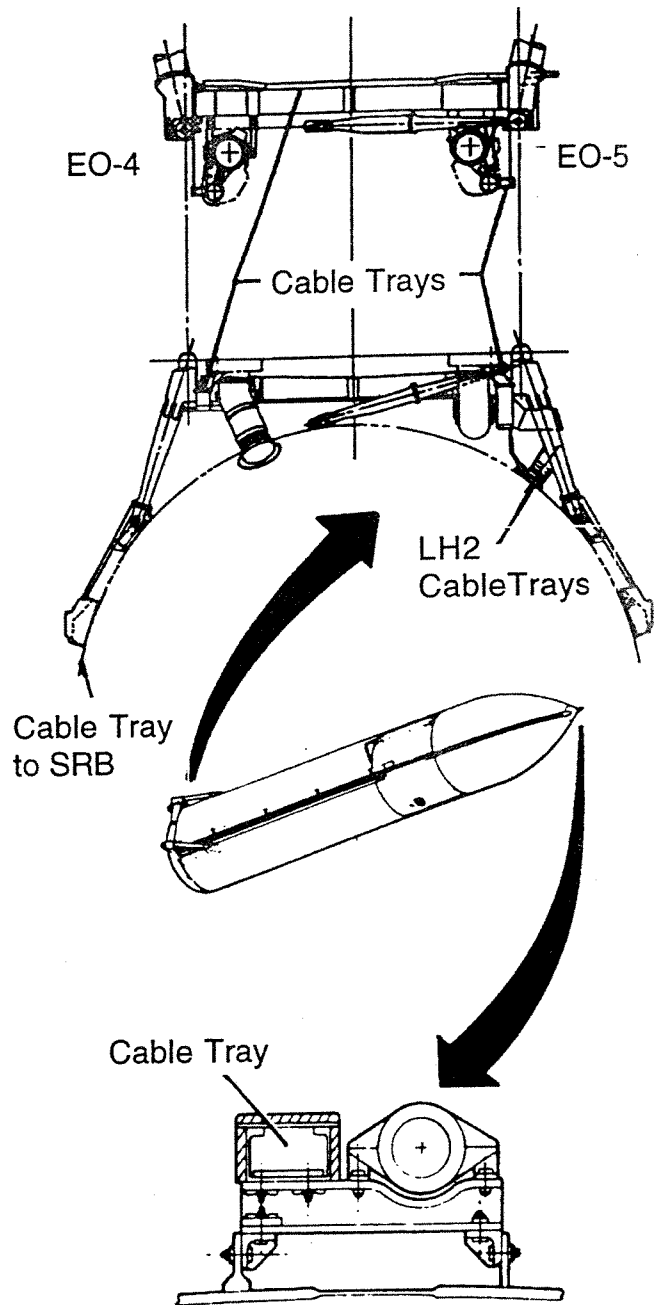


Figure 10-14: Cable Trays

10.3.2 WIRING

The following types of wire are used in the ET:

- Kapton (Polyimide-FEP Teflon) insulated wire is used for all wiring external to cryogenic tanks to provide for adhesive bonding and abrasive protection.
- FEP Teflon-insulated wire is used inside the LH2 tank. TFE wire is used inside the LO2 tank.
- Nickel-coated copper, or nickel-coated copper alloy wire is used external to electronic assemblies.

Wire sizes vary from AWG-22 to AWG-12. The majority of the wire is AWG-22 size. The SRB cables include a special AWG-24 data buswire. Wire shielding and cable segregation are used extensively throughout the ET to minimize the possibility of one signal being inadvertently coupled into another, and to preclude other electromagnetic interference.

10.3.3 CONNECTORS

Electrical connectors are used for propellant tank feed-throughs, intertank disconnect panels, ET/Orbiter umbilicals, and at ET/SRB separation points. One of the connector types used is a panel-mounted receptacle with a mating plug. A 6-pin connector is used for wiring associated with ullage pressure measurements. A 55-pin connector is used in multiple wiring applications. Five connectors are used on intertank disconnect panel number one and seven connectors on panel number two. These connectors are used for the cables that are routed out of the intertank.

Feed-through 37-pin connectors are used at the top and bottom of the LO2 tank and at the top

and side near the aft attach strut on the LH2 tank. Leakage through this connector is prevented by a pin-to-pin hermetic seal. Leakage around the connector is prevented by a lead-alloy coated, stainless steel mounting seal in the LH2 tank, and a Teflon-coated seal in the LO2 tank. The feed-through connector (part number 81L2) is installed in the propellant tank with the seal on the outer side. The connector is held in place with a jam nut on the inside of the tank.

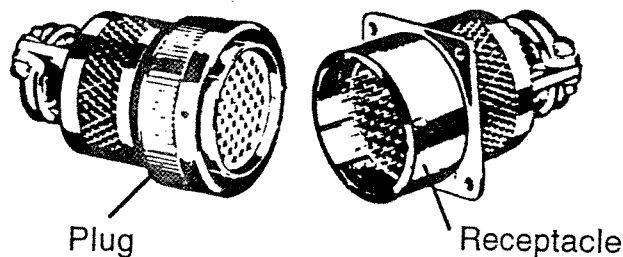


Figure 10-15: General Purpose Electrical Connector

The electrical disconnect plates at ET/Orbiter umbilical assemblies EO-4 and EO-5 can each accommodate up to 12 connectors. There are seven connectors at EO-4 and 8 connectors at EO-5. Two 55 pin EO interface connectors, J23 (EO-4) and J33 (EO-5), provide electrical interface for the LO2 and LH2 tank OI functions. Orbiter/ET electrical interface for the vent valve position switches is provided by a 41 pin connector J35 (EO-5). Shuttle Range Safety is provided through 55 pin ET/SRB interface connectors P61 (EB-1) and P71 (EB-2) and 19 pin connectors P62 (EB-1) and P72 (EB-2).

Pull away connectors used at the ET/SRB interface are separated when the ET/SRB struts are severed, as described in Section XII, *Interface Hardware*.

Table 10-3: ET/Orbiter Umbilical Circuits

LH2 ET/Orbiter Umbilical (EO-4) Connector J23		LO2 ET/Orbiter Umbilical (EO-5) Connector J33	
LH2 Tank Functions	LO2 Tank Functions	LH2 Tank Functions	LO2 Tank Functions
Ullage Press. No. 1 and 3	Ullage Press. No. 2 and 4	Ullage Press. No. 2 and 4	Ullage Press. No. 1 and 3
Depletion Sensors No. 3 and 4	--	Depletion Sensors No. 1 and 2	--
Loading Sensors 5% Level	Loading Sensors 98% Level No. 1	Loading Sensors 98% Level No. 1	Loading Sensors 5% Level
98% Level No. 1	100% Level No. 2	100% Level	98% Level No. 2
100% Level No. 1	100 (-) % Level	100 (-) % Level No. 2	100% Level No. 1
100 (+) % Level	--	Overfill	--

ET/Orbiter Umbilical (EO-5) Connector J35	
LH2 Vent Valve No. 1 Indication	LO2 Vent Valve No. 1 Indication

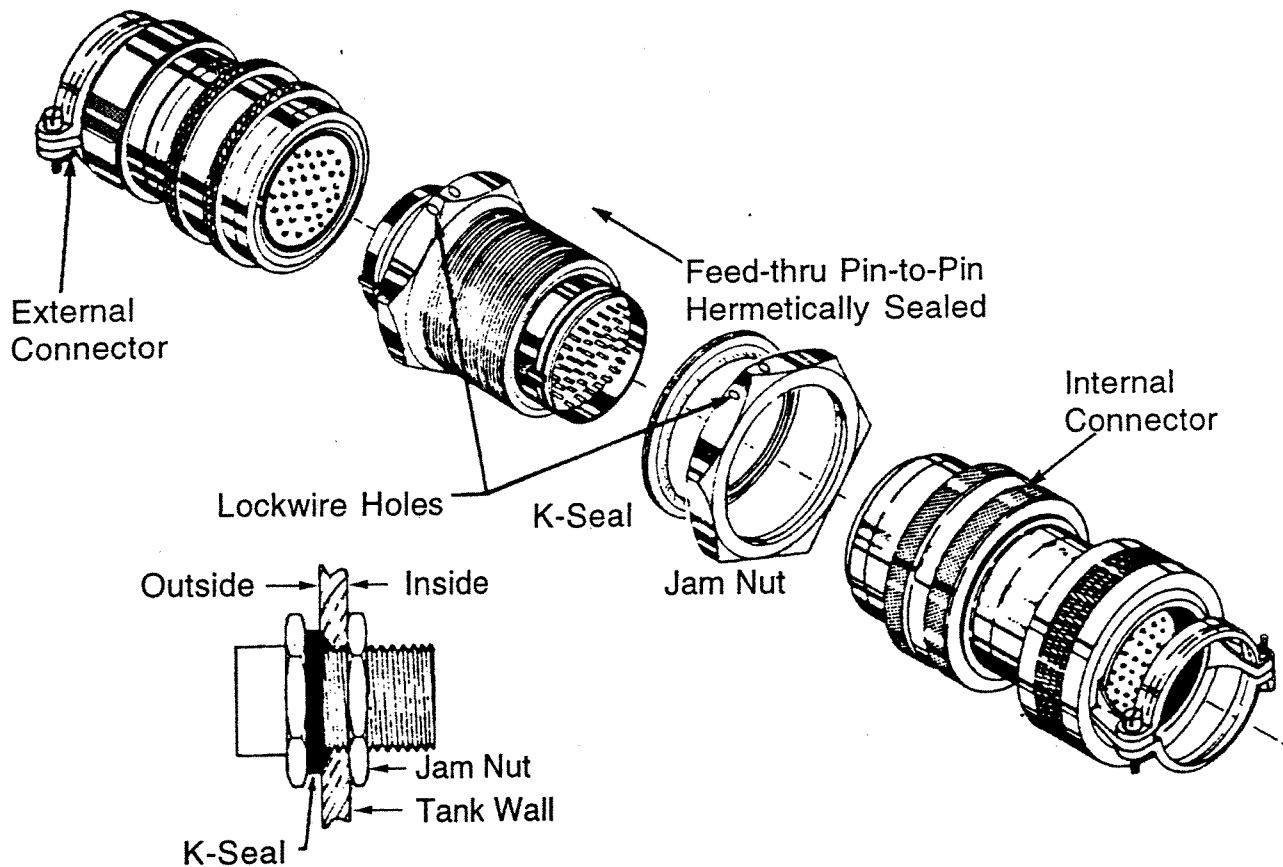


Figure 10-16: Electrical Feed-through Connector and Installation

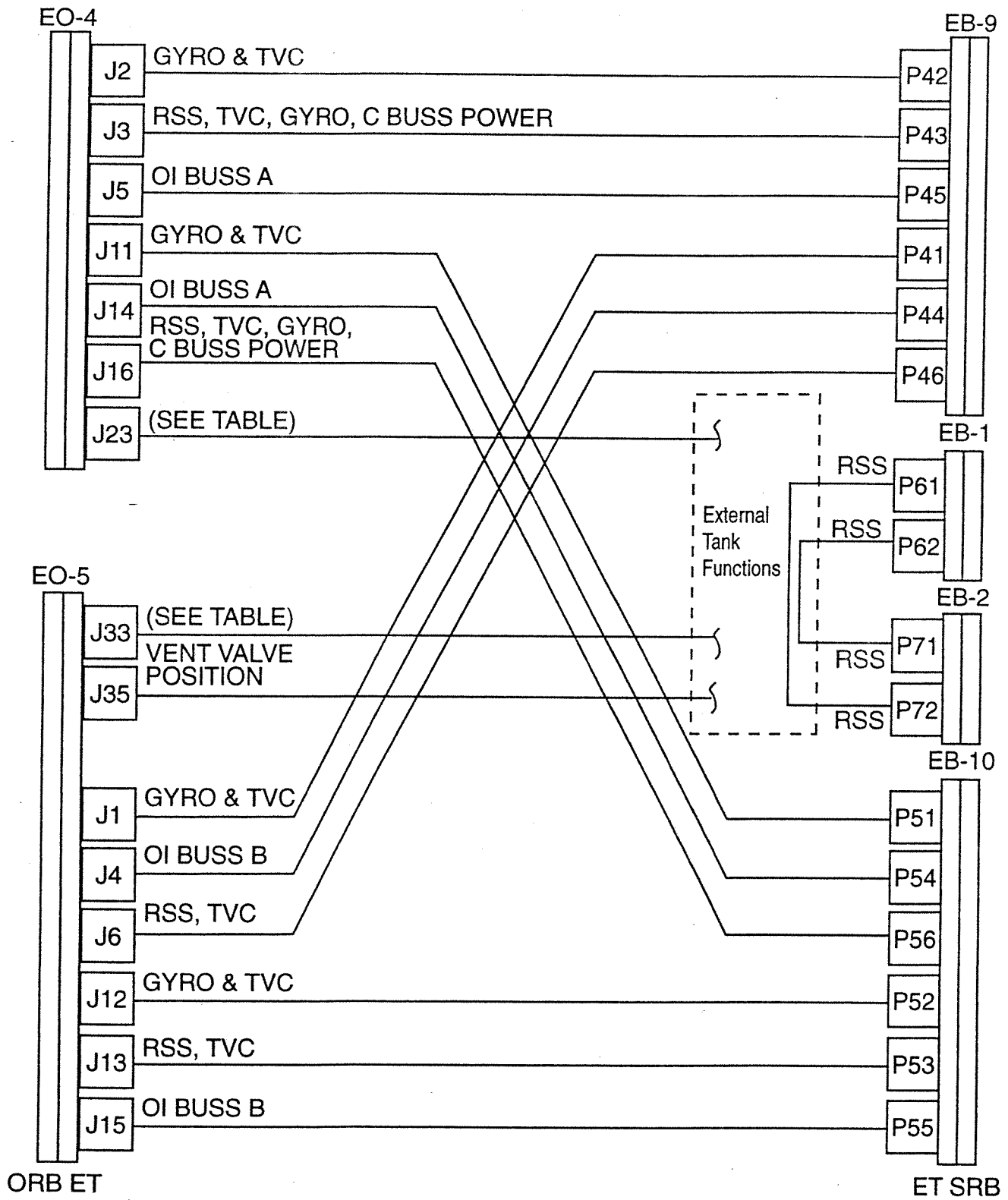


Figure 10-17: ET/Orbiter/SRB Interface Harnesses

10.3.4 DISCONNECT PANELS

Two electrical disconnect panels are located in the intertank compartment. One is mounted near the LH2 cable tray penetration and the other near the LO2 cable tray entry into the intertank compartment. Each disconnect panel is a bracket that holds bulkhead connectors that mate with cables from the cable tray. Mating connectors terminate intertank internal cables.

10.3.5 WIRE SPLICES

Wire splices are used in areas where connectors are not required. All of the sensors are connected to cable leads in this manner. Splices are employed using crimped ferrules that are insulated and sealed against moisture with a FEP Teflon liner, heat-shrinkable TFE Teflon covering and meltable FEP Teflon filler.

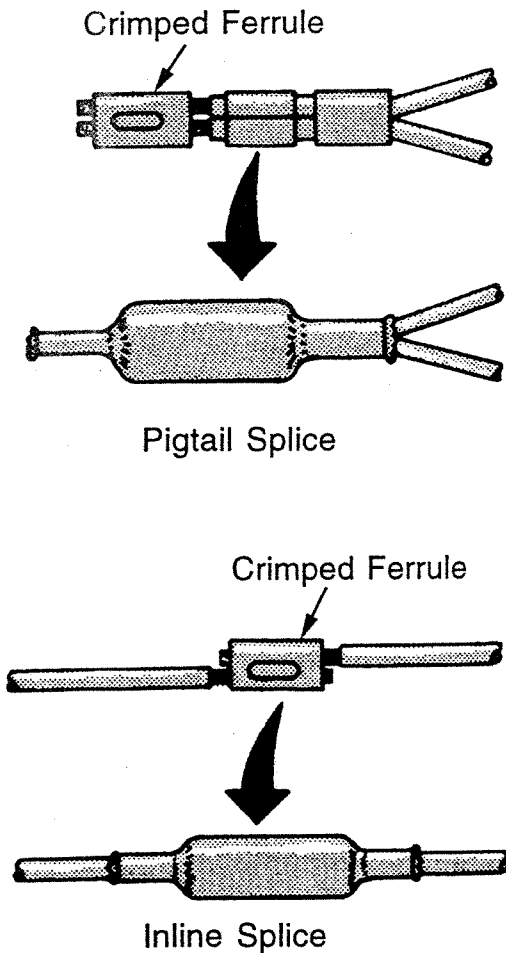


Figure 10-18: Splice

10.4 ORBITER/SRB INTERFACE CABLING

The Orbiter monitors the condition of, and issues control signals to, the SRBs during ascent. The signals between the Orbiter and the SRBs are routed through 12 interface cables on the ET. The cables are connected between Orbiter interfaces EO-4 and EO-5 and SRB interfaces EB-9 and EB-10. These interfaces are shown in Section XII, *Interface Hardware*. The multi-wire cables are routed through protective cable trays. There are no wires in these cables that connect into the ET electrical system.

10.5 ELECTROMAGNETIC COMPATIBILITY (EMC)

Operational instrumentation EMC designs provide grounding, shielding, and circuit isolation. There are no circuit grounds connected to the ET structure; all sensor leads are individually returned to the Orbiter for single-point grounding. Cable shields are, however, grounded to the ET structure to provide a continuous shield to meet the EMC requirements.

Cable harness assemblies are constructed to minimize induced interference resulting from the coupling of signals within the harness. Where practical, circuits carrying signals less than 100 mv are separated from high-level signal circuits. The Orbiter provides current-limiting protection for those circuits penetrating the ET tanks. This prevents the accidental generation of ignition sources. Structural electrical bonding is provided to assure electrical continuity between structural members.

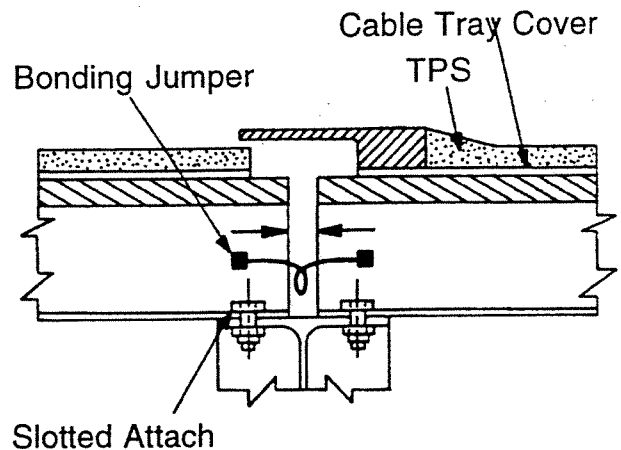


Figure 10-19: Cable Tray Joint

10.6 LIGHTNING PROTECTION SYSTEM

The ET Lightning Protection System incorporates features which protect the structure and subsystems from the effects of direct lightning strikes. During transit to the launch pad the nose spike located on the nose cone provides protection. In addition weather restrictions are in force. While on the launch pad the vehicle is under a cone of protection provided by the facility Lightning Protection System.

The primary lightning protection feature for flight is the nose spike located on the nose cone.

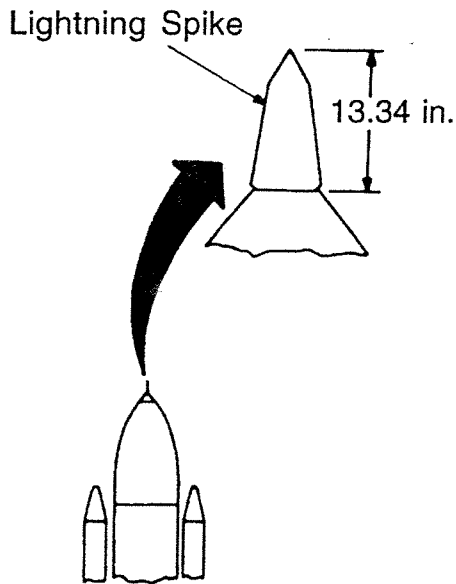


Figure 10-20: Lightning Protection System

The initial lightning strike will attach to this spike. A low resistance path is provided from the spike through the ET structure to the SRB and Orbiter interfaces where the current is passed to the other elements. NSTS 07636 Lightning Protection Criteria Document defines system requirements and provides model lightning strikes the system must withstand.

After the initial attachment of the lightning channel to the spike, and as the vehicle moves the channel is swept back over the surface of the ET. The dielectric strength of the TPS along with the air boundary layer will discourage the strike from reattaching to the forward part of the LO2 tank.

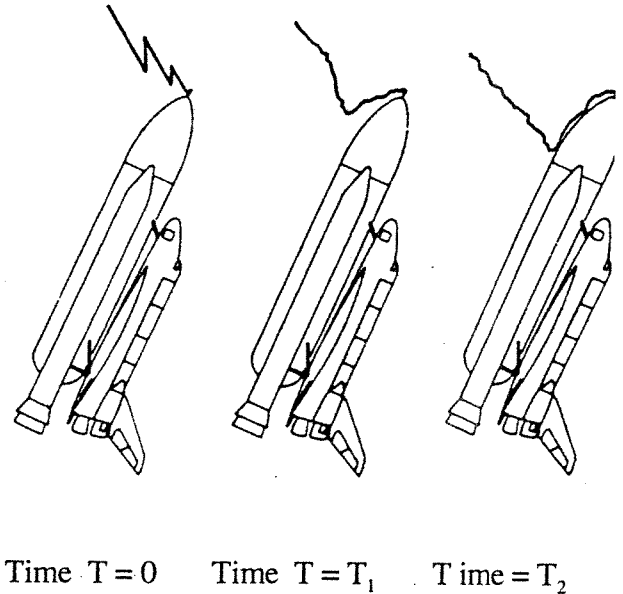


Figure 10-21: Lightning Arc Behavior on Moving Vehicle (Swept Stroke)

11. THERMAL PROTECTION SYSTEM

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11. THERMAL PROTECTION SYSTEM

The External Tank Thermal Protection System is designed to maintain the quality of the propellants and protect the primary structure and its subsystem components to within design temperature limits during prelaunch and ascent phases. It consists of two types of materials to meet a variety of mission and surface application conditions.

11.1 DESCRIPTION

There are basically two types of Thermal Protection System (TPS) materials utilized on the External Tank (ET): Low density closed cell foams, used for high insulation efficiency, and denser composite materials, used for high heat capability. Each type has variations that provide for application ease (spray, pour, pre-mold/bond installations) and specific mission requirements. Foams are used at low heating rates and the composites are used where the foams are inadequate.

The majority of the ET TPS is NCFI 24-124 (SOFI) sprayed on foam insulation and SLA-561 bonded ablator. The SOFI is applied over the SLA when both highly efficient insulation and high heating capability are required. In areas not exposed to ascent heating (LO2 tank aft dome and LH2 tank forward dome) and in various closeout areas, urethane foams (SS-1171 and PDL-1034) are used due to their more liberal application constraints. The aft LH2 tank dome is protected by NCFI 24-57 SOFI.

The prelaunch requirements basically define the foam installation thicknesses. Maintaining good quality/stable propellants and minimizing ice are the primary considerations. Protuberances and interface hardware utilize thermal isolators, heaters, and foam cover as required to provide an equivalent ice deterrent.

In summary, the TPS prior to launch serves the following functions:

- Maintains LO2, and LH2 boil-off rates below the vent valves capabilities
- Contributes to loading accuracy and increased propellant densities

- Insures LO2 and LH2 specified temperatures at the Orbiter interface
- Minimizes air liquefaction on the LH2 tank
- Minimizes ice formation on the ET surface

The ascent mission phase primarily defines the ablator thicknesses. Maintaining the primary structure and subsystem components within the design temperature limits is the primary consideration. Heat input is obtained from aero convective flow, the engine plumes, the SRB separation motors and autogenous tank pressurization gas. Most TPS thicknesses are defined for the Western test range abort once-around (3A-AOA) mission. The TPS configuration summary shows the acreage areas where ablator is required.

Another function of the TPS occurs during ET re-entry when structural temperatures and tank pressures contribute to the ET fragmentation process and consequential debris size and impact area (footprint). The TPS is defined by prelaunch and ascent requirements. The residual material is adequate to provide the entry function and assure low altitude fragmentation to meet the 100 x 600 nautical mile footprint limits.

11.1.1 TPS MATERIALS AND APPLICATIONS

The primary foam material is NCFI 24-124 sprayed on foam insulation. It is a blown closed cell rigid foam system with higher temperature stability than conventional urethane foams. The NCFI 24-57 is similar to NCFI 24-124 and provides improved temperature stability for the aft dome engine plume heat environment.

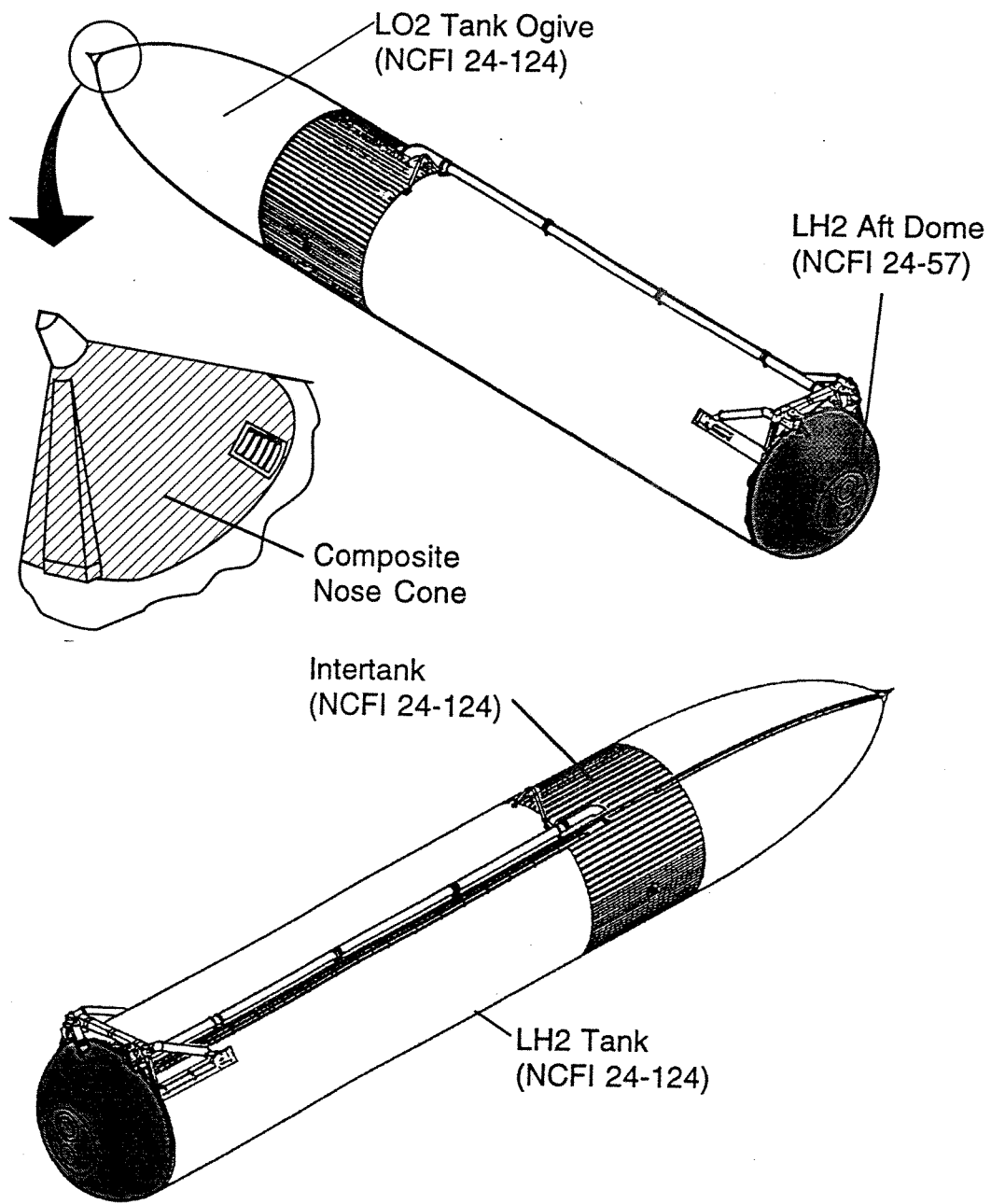


Figure 11-1: TPS Configuration

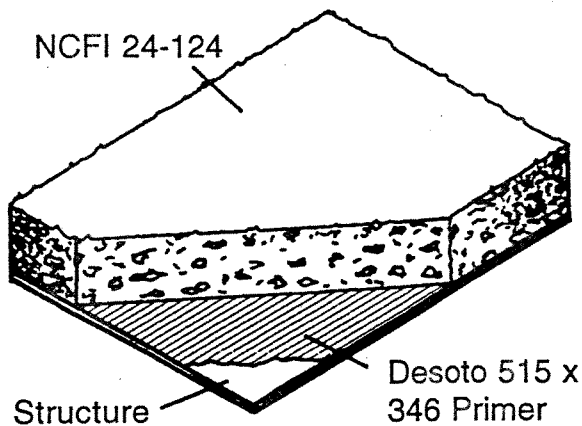


Figure 11-2: NCFI 24-124 Sample Cross Section (Typical of all foams)

Foam Insulation - The foam acreage materials are low viscosity, two component liquid systems, which are applied to the acreage structure by automated spray equipment. The application is controlled to provide an "as-sprayed" finish within the required ET thickness, roughness and waviness constraints without machining. The application is closely controlled to provide the strength and adhesion properties.

The application cannot be accomplished easily in other than a specially designed cell. For this reason, two urethane closed cell rigid foams are used for applications which do not require the high temperature stable materials. Both are two part liquid systems. The SS-1171 is a material which has a short work time and is suitable for spray-pour operations with automatic mix equipment. The PDL-1034 is a material which has a longer work time (40 seconds) and is suitable for hand pour operations or for filling difficult shape cavities. Both have similar overall properties to CPR-488 except they have limited thermal substrate conditions and have limited ablation capability. Application can be accomplished in near normal factory environments.

Other foam materials such as Great Stuff (aerosol can caulking kit) are used in limited applications where cryogenic and thermal performance are not critical.

Ablators - The primary ablator material is molded SLA-561. It is a composite mixture of silicone resins highly filled with cork particles, silica glass eccospheres, silica fibers and phenolic microballoons which, after fabrication, is bonded onto the prepared structure. Ambient and heat cure, during fabrication, are required to achieve strength. Similar formulations are used to accomplish sprayed and gas injection molded (GIM) parts and to accomplish "pack in place" ambient cure applications. The materials are compatible with cryogenic stressed structure (within design constraints).

The closed cell foams resist moisture absorption and the elements without significant performance degradation.

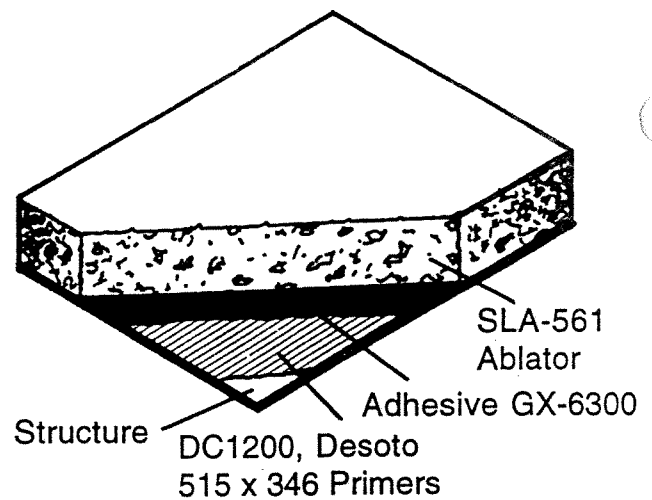


Figure 11-3: SLA-561 Sample Cross Section

ble 11-1: Foam Material Properties

Foam/Property	NCFI 24-124	NCFI 24-57	PDL-1034	SS-1171					
• Application	LO2, LH2, Intertank sidewall	LH2 aft dome	Closeouts, repairs	LO2 aft dome, LH2 forward dome, closeouts					
• % of Total Foam	77%	7%	1%	14%					
• Process	Spray	Spray	Pour/Mold	Spray					
• Description	Isocyanurate	Isocyanurate	Urethane	Urethane					
Requirements	Spec Reqmt	Typ Prop	Flt Reqmt	Spec Reqmt	Typ Prop	Flt Reqmt	Spec Reqmt	Typ Prop	Flt Reqmt
• Density (pcf)	2.0-2.5	2.2	N/A	2.6	2.3-3.1	N/A	2.6	2.6	N/A
• Tensile, RT (psi)	30 min.	44	19	113	60	19	113	53	19
• Tensile, -423°F (psi)	N/A	34	19	50	N/A	19	50	N/A	19
• Tensile, +300°F (psi)	N/A	32	19	71 ¹	N/A	19	71 ¹	62	19
• Compression (psi)	25 min.	33	20	61	30	20	61	30	20
• Recession Rate @ 7 Btu/ft sq. sec.) (in./sec.)	N/A	.0094	N/A	.0303	N/A	N/A	.0303	N/A	N/A
• Thermal Conductivity @ RT (Btu/hr ft°F)	.025	.017	N/A	.015	.016	N/A	.015	.015	N/A
• Cryostrain (ksi)	61 @ -423°F	65 @ -423°F	pass	60 @ -423°F	N/A	pass	60 @ -423°F	N/A	65 @ -423°F

(¹) +200°F values (²) @4 btu/ft sq. sec. (³) Maximum density 3.0" in dome area allowed

11.1.2 PROVISIONS FOR MISSION ENVIRONMENTS

The ET is subjected to aerodynamic heating (with and without shock impingement), SRB and Orbiter main engine plume heating, and SRB separation motor plume impingement during separation. The degradation effects of these ascent-induced environments can cause the foam to char and recede. The loss of insulating characteristics, due to the environmental effects, is taken into consideration in determining the initial thickness requirements and/or the need for underlying SLA-561. The sprayed form or GIM form of SLA-561 is used on complex shape detail parts.

SLA-561 is used on vehicle interface attachments, and at high heat areas on the ogive and down the length of the ET. During flight the ascent environments cause the SLA-561 to ablate and char. These phenomena are considered when determining the initial thickness requirements. Reductions in ascent heating environments (IVBC-3) has allowed the reductions in SLA-561 areas shown in the configuration summaries.

Although non-structural from an overall load carrying standpoint, the foam and ablator insulations must withstand aero/thermal and induced-load stresses without failures that would degrade their thermal efficiency. The TPS materials are selected to be compatible with all conditions imposed on the ET by the Space Shuttle environment.

11.1.3 ISOLATOR AND VACUUM INSULATIONS

Thermal Isolators - Thermal isolators are required for LH2 tank attachments to preclude the liquefaction of air on attachments, and to eliminate thermal shorts allowing heat flow into the LH2. Air will not liquefy at LO2 temperatures, obviating the need for isolators for the LO2 tank. Thermal isolators are in the form of standoffs or insulation blocks of glass phenolic. The LO2 feedline, pressurization line support brackets, and attachment structure on the LH2 tank all require thermal isolation. Attachment of the LO2 feedline to the main ring of the LH2 tank is typical of this thermal isolation technique.

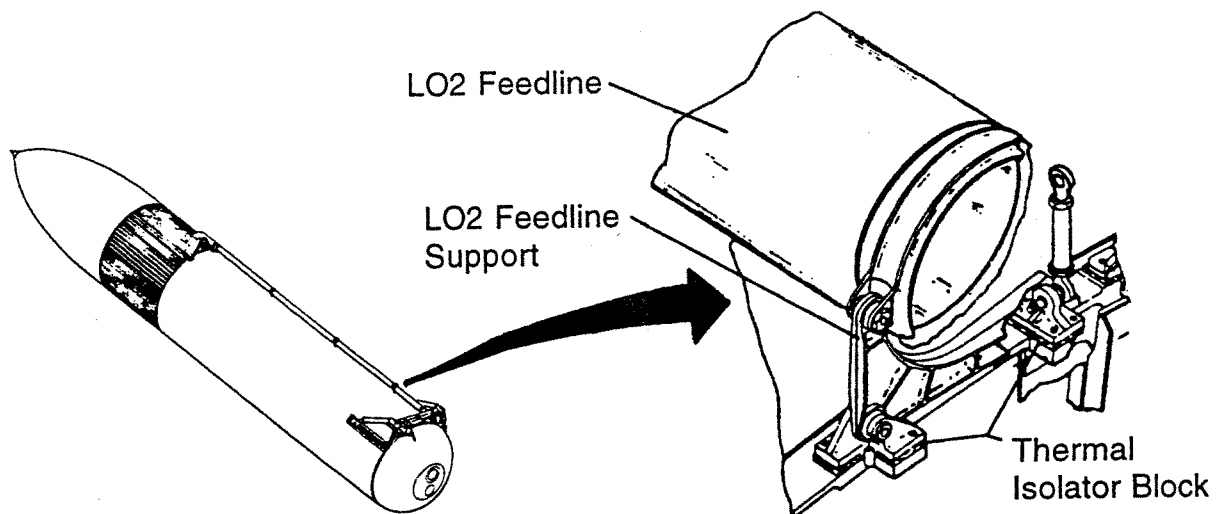


Figure 11-4: LO2 Feedline Thermal Isolation

Cryopumped Line Assemblies - The LH2 feedline and the recirculation line each require bellows to permit line flexing resulting from thermal and loading effects. In addition, the lines must be insulated to minimize air liquefaction and propellant heating during prelaunch operations. These line assemblies consist of bellows and tube sections. The insulation technique used is a jacketed bellows and insulated line, with the annulus filled with 2.0 psig of argon. As LH2 is loaded, the cryogenic temperatures solidify the argon and create a vacuum in the jacket (cryopumped). The vacuum jacket then becomes an effective insulator on the lines. Shrouds, covered with 0.4 inches of SLA-561, surround the bellows to provide thermal protection during ascent. These shrouds also provide mechanical protection for the bellows during ground operations.

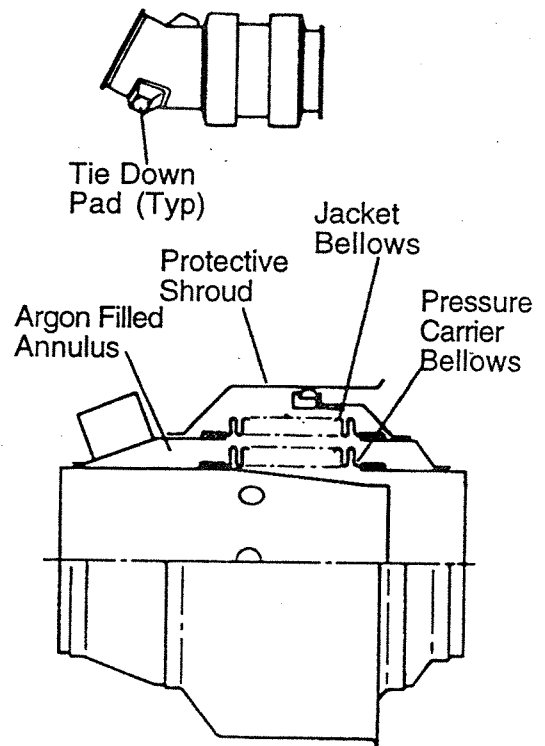


Figure 11-5: Cryopumped External LH2 Feedline Assembly

Table 11-2: TPS Configuration Summary

Area	TPS Material
• Acreage	
- LO2 Tank	SLA-561
• Tank Ogive	NCFI 24-124
• Barrel	BX-250/SS-1171
• Ogive Cover Plate	NCFI 24-124
• Aft Dome	NCFI 24-124
- Intertank	NCFI 24-124
• Thrust Panels and High Heat Areas	NCFI 24-124/BX-250/SS-1171
• LO2 and LH2 Splice Closeouts	BX-250/SS-1171
- LH2 Tank	
• Forward Dome	BX-250/SS-1171
• Aft Dome	NCFI 24-57
• Aft Dome Apex	SLA-561
• Manhole Cover	SLA-561
• Barrel	SLA-561
- Protuberance Airload Ramps	BX-250/SS-1171
- Ice/Frost Ramps	PDL-1034
• Penetrations-	
- LO2 Feedline	BX-250/SS-1171
- LH2 Feedline	SLA-561
- LH2 Recirculation Line	SLA-561
- LH2 Vent Line	BX-250/SS-1171
- LO2/LH2 Crossbeam Cable Tray and Covers	SLA-561
- Cable Tray and Covers	SLA-561
- LO2 Feedline Fairing	SLA-561
- LO2 Cable Tray Fairing	SLA-561
- LH2 Cable Tray Fairing	SLA-561
- Aft Upper ET/SRB Fitting Fairing	SLA-561
- Aerovents (2)	PDL-1034
• Structural Attachments	
- LO2 Feedline (5) Yokes, Struts	SLA-561
- LO2 Feedline (5) Support Brackets	SLA-561
- GO2 and GH2 Pressurization Line Slide Mounts	SLA-561
- LH2 Cable Tray Supports (17)	SLA-561
- GO2 Pressure Line/LO2 Cable Tray Supports	SLA-561
- Bipod Fittings	BX-250/SS-1171
• Interface Structure	
- Forward ET/Orbiter Attachment Strut (Bipod)	MA-25
- Aft ET/Orbiter Thrust and Vertical Strut	SLA-561
- Diagonal Strut	SLA-561
- Aft ET/Orbiter Crossbeam	SLA-561
- Forward ET/SRB Attachment	None required
- LO2 and LH2 Feedline to Tank Attachment Closeout	BX-250/SS-1171

11.2 CONFIGURATION DETAILS

Each of the main elements of the ET has its own TPS requirement, determined on the basis of environments and mission conditions. The details of these applications are discussed in the following paragraphs and figures.

11.2.1 LO2 TANK TPS

The LO2 tank upper ogive is covered with NCFI 24-124 between stations 371 and 841 where the LO2 tank joins the intertank. The LO2 aft dome is covered with a 0.25-inch (minimum) to a 1.40-inch (maximum) thickness of SS-1171. The joining flange where the LO2 tank meets the Intertank is covered with SS-1171 during manufacturing closeout.

11.2.2 INTERTANK TPS

Machined NCFI 24-124 insulation over the intertank external surfaces maintains structural temperatures within limit. The smooth contour reduces effective heating and allows application of sufficient NCFI 24-124 thickness to meet heating requirements.

The high heat areas of the intertank which require additional TPS are at interference heat areas between the Orbiter and SRB, and from their attachment structures. The flange joining the intertank to the LH2 tank is closed out (after mating these structures) with SS-1171 foam.

The intertank access door perimeter is masked during TPS application and left uninsulated to permit access to the intertank for final assembly and checkout operations without requiring the removal and subsequent replacement of TPS.

The intertank weight/load capability is optimized by controlling the maximum structural temperature during ascent. The prelaunch thermal control of the intertank is accomplished by purging the intertank with heated GN2 to maintain a gas temperature at lift-off of 32°F to

80°F. This intertank preconditioning results in structural temperatures from 32°F to 80°F at liftoff, except in areas adjacent to the intertank/LO2 and LH2 tank splices where temperatures reach -297°F and -423°F respectively.

11.2.3 LH2 TANK TPS

The LH2 tank barrel TPS configuration primarily consists of NCFI 24-124 to minimize icing. Exceptions are the domes and areas under protuberances and attachments. The aft dome TPS requirement is primarily driven by propellant quality requirements (temperature and pressure). The aft dome is exposed to high plume (radiant) heating associated with the Orbiter engines and SRBs and also convective heat. In addition, the aft dome TPS must preclude LH2 film boiling. LH2 thermal stratification during ascent would result in unusable liquid propellant.

This environment requires an initial aft dome TPS thickness sufficient to preserve its function after the dome area has experienced considerable recession in flight. The aft LH2 tank dome requires 1.50 inch thickness of NCFI 24-57. The TPS configuration on the aft dome minimizes stratification and permits all of the liquid propellant to meet interface delivery requirements for engine operation.

A 0.5-inch thickness of SS-1171 is provided on the forward dome to prevent liquefaction/freezing of the nitrogen used in the intertank purge, and also to stabilize tank temperature for maintaining LH2 loading accuracy. The area of the LH2 tank, in the vicinity of the ET/Orbiter forward and aft interface attachments and the longerons, require added SS-1171 thickness to counteract localized, high aerodynamic heating rates. SS-1171 thickness on the barrel ranges from 0.88 inch to 1.52 inch depending on local aeroheating rate. The LO2 feedline has 1.0-inch nominal SS-1171 and the LH2 feedline and recirculation lines have SS-1171 an underlayer of SLA-561.

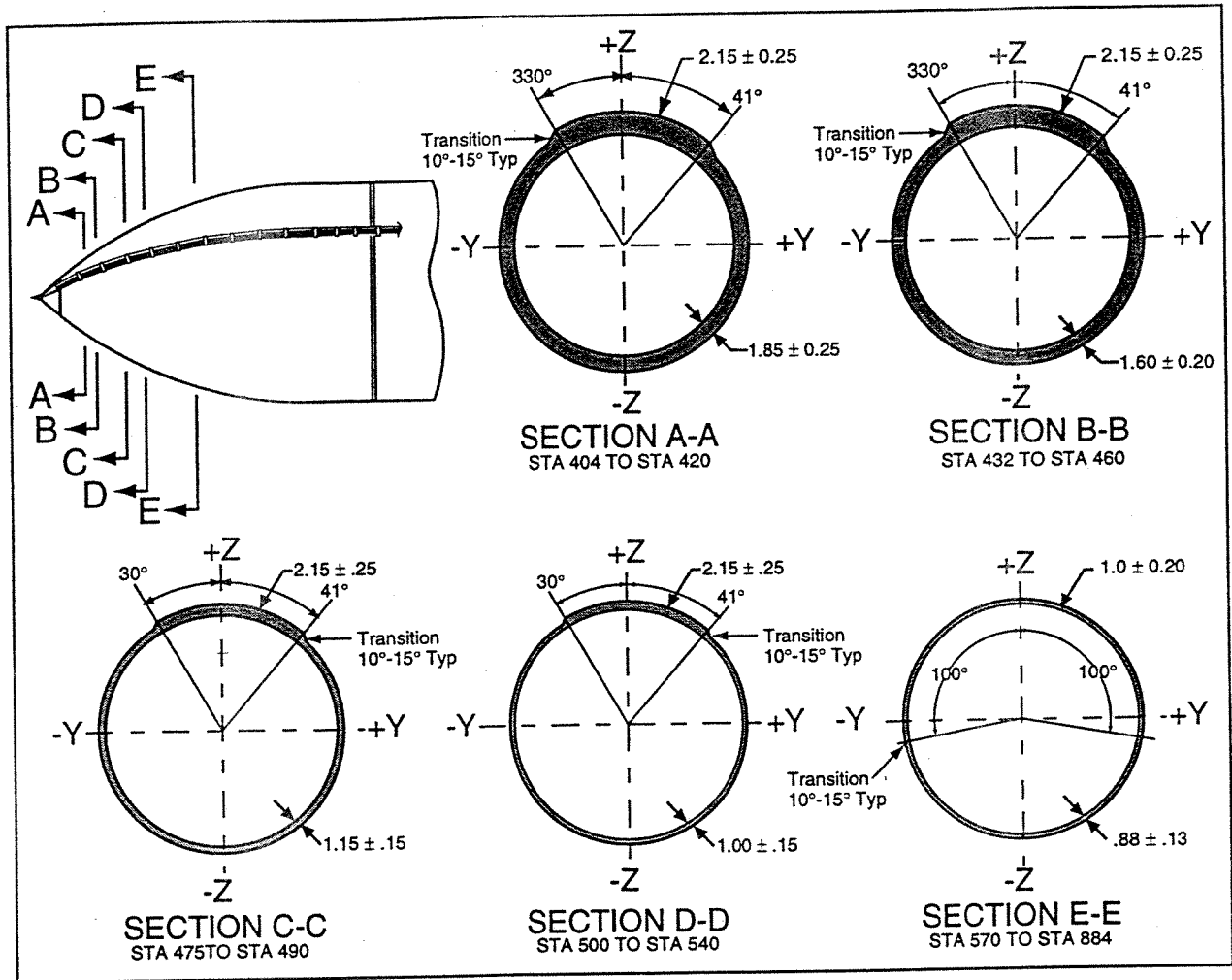


Figure 11-6: L02 Tank Minimum Foam Thickness Requirements

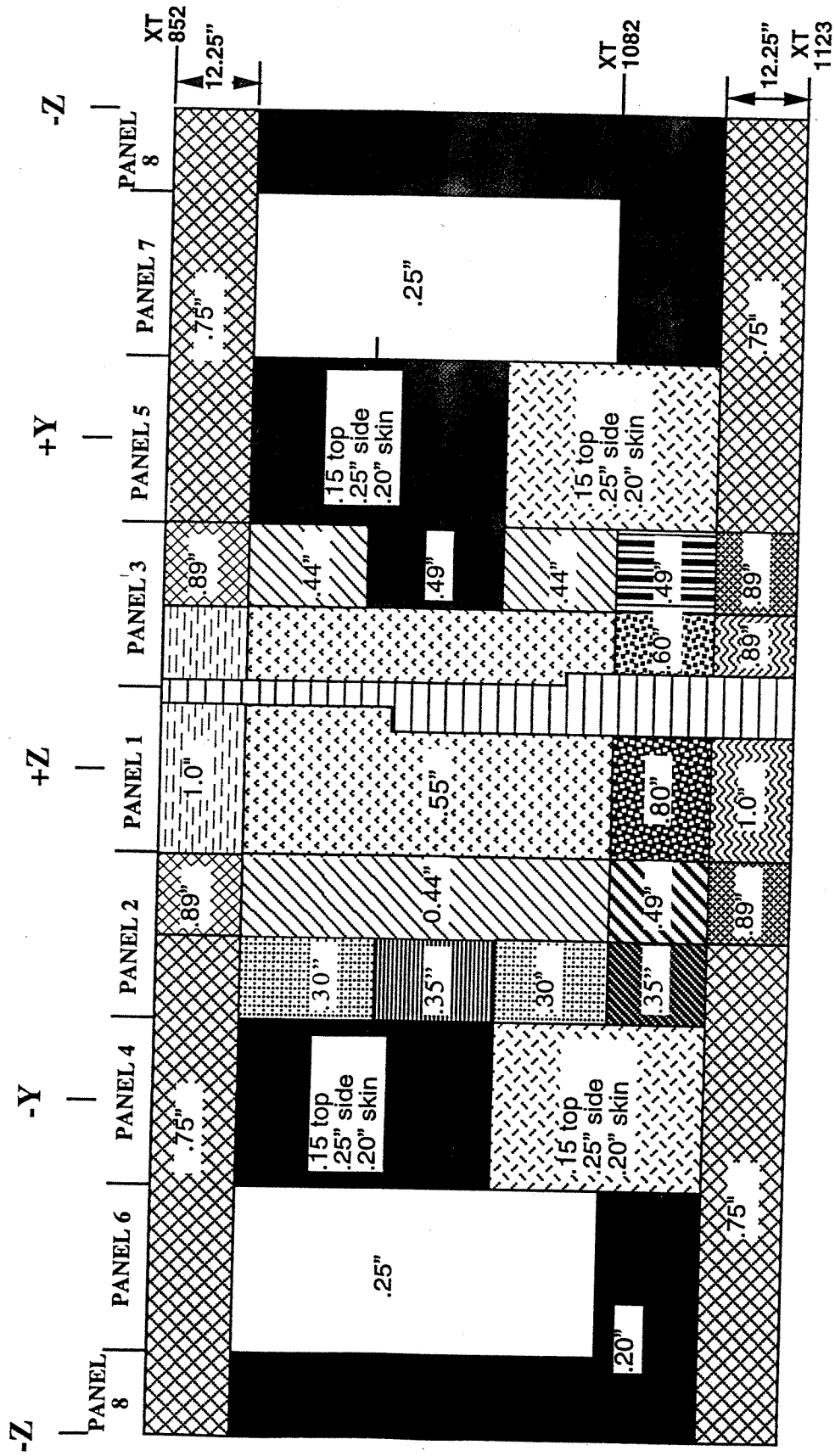


Figure 11-7: Intertank Minimum Foam Thickness Requirements

Thrust panels
 at ±Y-axis
 location
 +Z is toward
 the orbiter

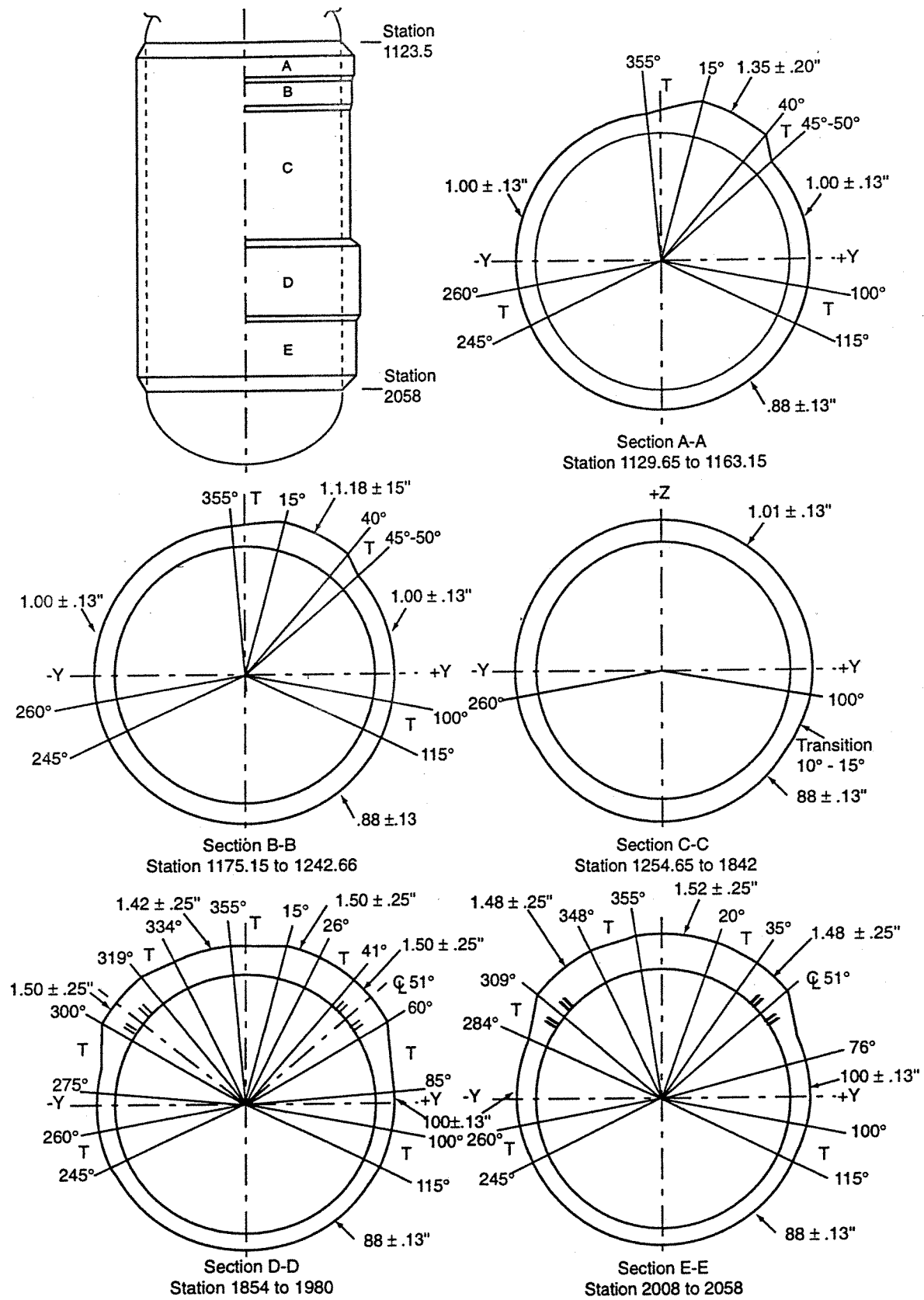


Figure 11-8: LH2 Tank Minimum Foam Thickness Requirements

11.3 TPS CLOSEOUTS

Closeouts are TPS applications conducted after final assembly and checkout to assure that all surfaces are insulated as required. These closeouts are made under controlled temperature, humidity and cleanliness conditions using a portable environmental shelter and additional equipment where required. Some areas are closed out by spraying while smaller holes are poured.

Closeouts are most critical on areas where the insulation is applied on surfaces subjected to cryogenic temperatures. Unsealed closeouts or voids can result in a loss of insulation due to cryopumping- a phenomenon where air is sucked

in and converted to liquid (-16°F) or solid (-358°F) as a result of the LH2 temperature (-423°F). This phenomenon can reduce insulation efficiency causing a thermal short in the insulation and could cause failure of the insulation during ascent when the solid/liquid air converts back to a gas.

Most closeouts are made during assembly while a minimum number are made at the launch site after checkout procedures have been completed. Additional TPS closeouts or repairs may be required as a result of component replacement or the need to refurbish damaged areas. A TPS closeout summary is listed in the table that follows.

Table 11-3: TPS Closeout Summary

Closeout	TPS Material	Closeout Location
• Intertank		
- Intertank/LH2 and LO2 Tank Splice	BX-250/SS-1171	MAF
- Intertank ΔP Measurement	PDL-1034	MAF
- Intertank Aerovent	PDL-1034	MAF
- Bipod Heater Wire Box Cover	SLA-561/BX-250/SS-1171	MAF
• LH2 Tank		
- Thrust Strut Fitting (2)	PDL-1034/BX-250/SS-1171	MAF
- Tooling Third Hard Point	SS-1171	KSC
- Aft Longeron Tool Fitting (2)	BX-250/SS-1171	MAF
- LH2 Feedline at LH2 Tank	BX-250/SS-1171	MAF
- LH2 Recirculation Line at LH2 Tank	SLA-561/BX-250/SS-1171	MAF
- Longeron Electrical Connector	SLA-561/BX-250/SS-1171	MAF
- Aft Dome Manhole Cover	SLA-561/BX-250/SS-1171	MAF
- Aft Dome Cover Leak Port	SLA-561/PDL-1034	MAF
- LH2 Tank Bipod Fitting Jack Pad	PDL-1034	KSC
- Aft Upper - ET/SRB Fitting Fairing	PDL-1034	KSC
- Bipod Strut Support Clevis/Aero Ramp	PDL-1034/SS-1171	MAF
• Propulsion Lines		
- LO2 Feedline Flanges	PDL-1034	MAF
- LH2 Feedline Leak Ports	PDL-1034	MAF
- LH2 Recirculation Line Lead Port	SLA-561/PDL-1034	MAF
- LH2 Feedline to Umbilical Plate	BX-250/SS-1171	MAF
- LH2 Recirculation Line to Umbilical Plate	BX-250/SS-1171	MAF
- Helium Inject Line	Thermal Barrier Tape	MAF
- Helium Inject Box/Cover	PDL-1034	MAF
• Nose Cone		
- Cap Sealant	Great Stuff	MAF

12. INTERFACE HARDWARE

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12. INTERFACE HARDWARE

The External Tank is the central element of the Space Shuttle vehicle, and provides for a variety, of interface attachments - which are umbilical (fluid or electrical) or structural accommodations - to the other vehicle elements.

12.1 INTERFACE DEFINITION

The ET is the source of the liquid propellants for the Orbiter's main engines, and - as the largest and central-most element of the vehicle - must accommodate the loads, structures and umbilicals necessary to the interface functions. These functions require that the ET be equipped with:

- Structural interconnections with the two SRBs and the Orbiter;
- Fluid and electrical interfaces with the Orbiter;
- Fluid and electrical interface with the launch facility;
- Orbiter-to-SRB interface cabling.

The illustrations here depict the basic configuration and relative orientation of the ET flight-configured interfaces, and will be useful references for the contents of this section.

The ET also includes interface provisions which facilitate the attachment of transportation and handling support equipment. Some of these interfaces are described in this section, and the support equipment items are discussed in Section XIII, *Launch Site Facilities/Equipment*.

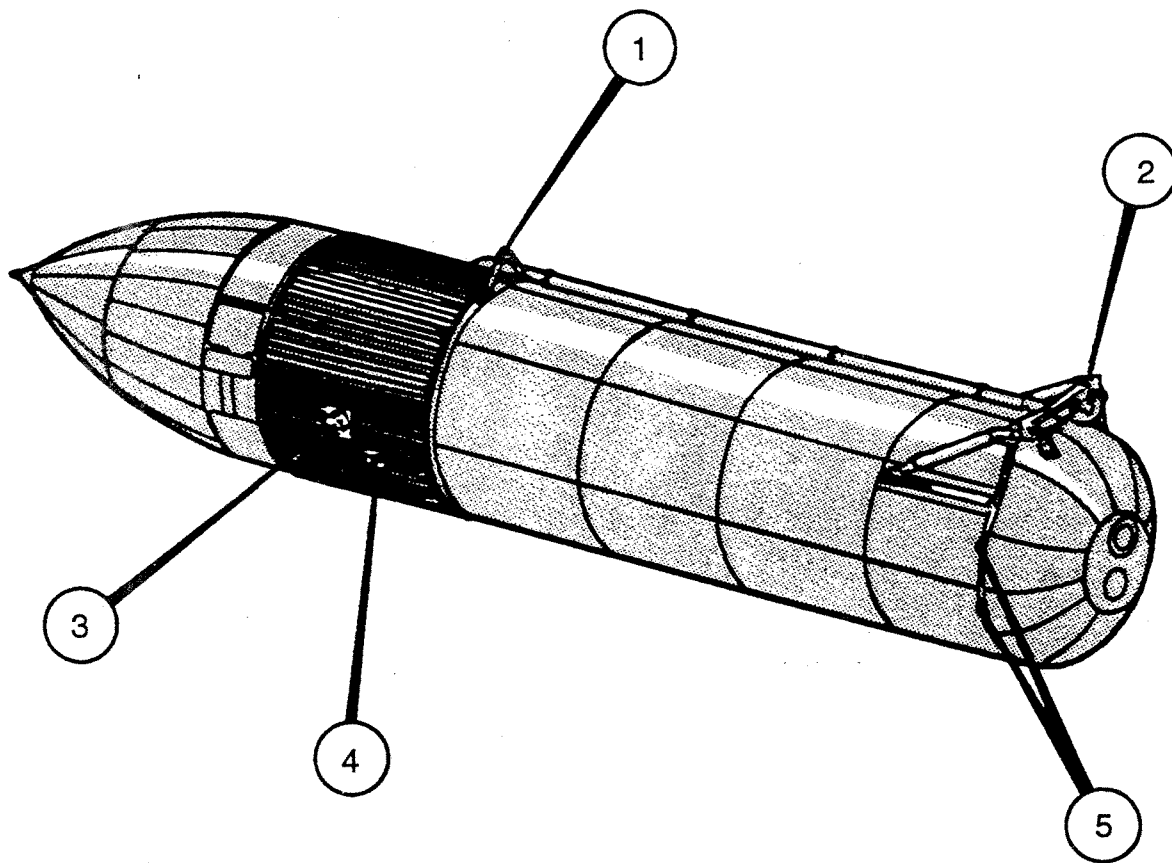


Figure 12-1: ET Interface Configuration

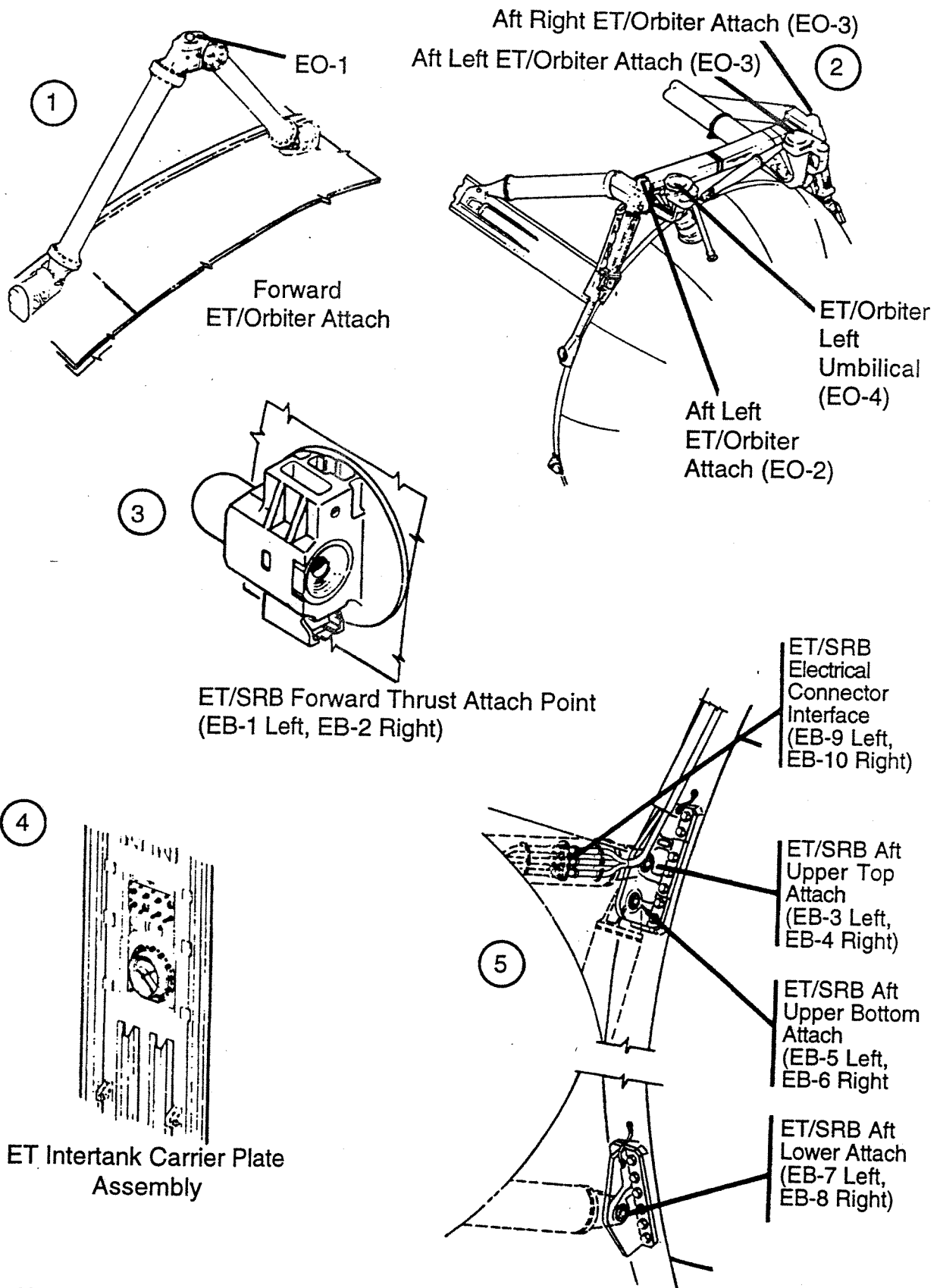


Figure 12-2: ET Interface Locations

12.1.1 ET/SRB INTERFACES

The ET/SRB (EB) structural interfaces consist of four attachment points on each side of the ET. One forward interface for SRB attachment and thrust transmission is located on each side (EB-1 left, EB-2 right) of the ET intertank at Sta. 985.675. Six aft stabilization interface points (EB-3, -5 & -7 left; EB-4, -6 & -8 right) are attached to the ET aft major ring frame as vehicle Sta. 2058. Adjustment provisions are on the SRB sides of each interface, and are used to align the ET and SRB centerlines and make them coplanar.

The pull-away electrical interfaces (EB-9 left and EB-10 right) between the ET and the SRBs are located on the aft top stabilization struts (those emanating from EB-3 and EB-4) approximately half way between the ET and SRB mold lines.

All ET/SRB interface attachment hardware is SRB-provided and consists of a frangible bolt at each of the forward interfaces, and a shear pin at each of the aft strut/tank interfaces. At separation, the ET side of these interfaces remains passive in that they neither initiate nor provide separation signals or forces.

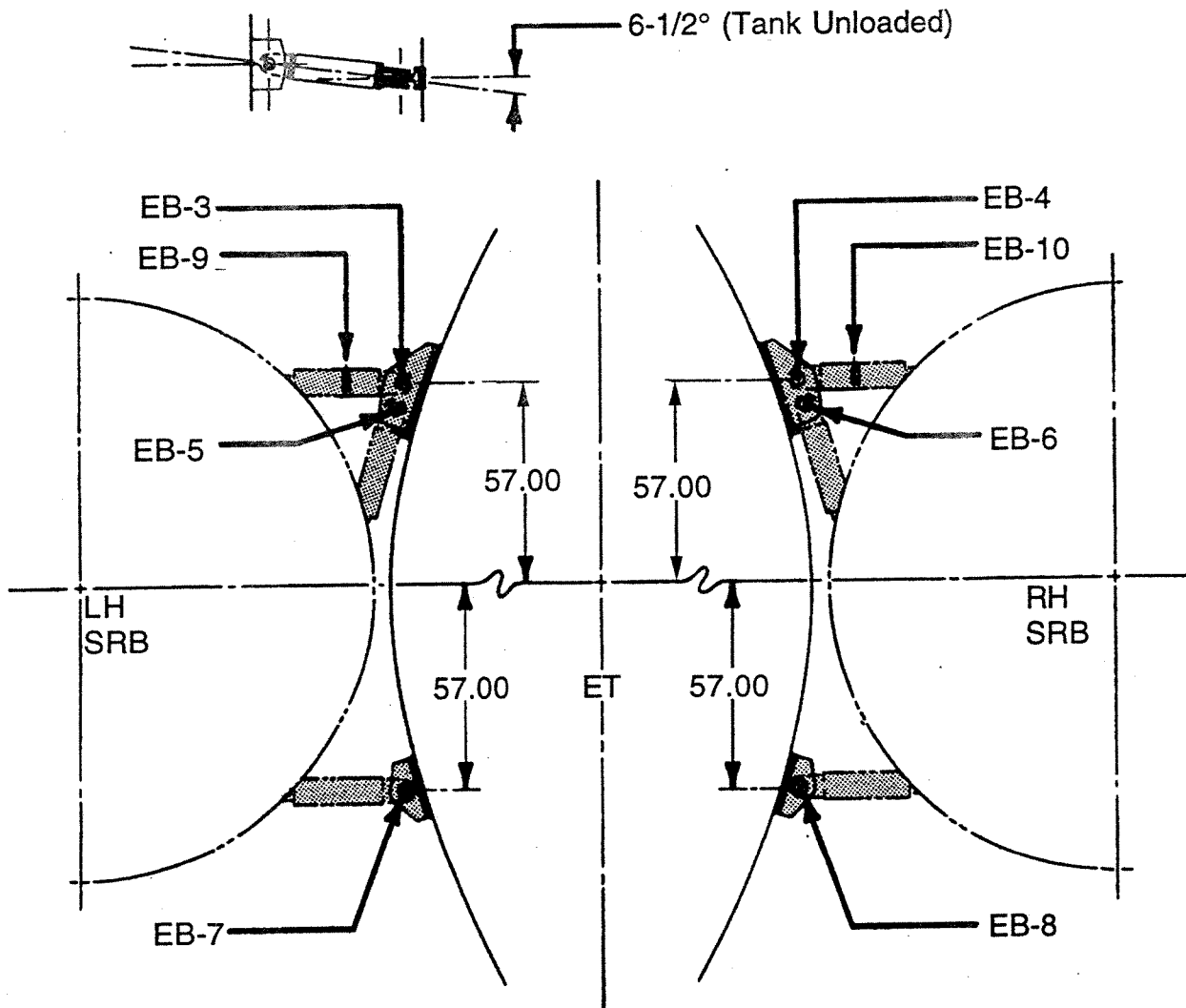


Figure 12-3: Aft ET/SRB Orientation (Looking Forward)

ET/SRB Forward Thrust Interfaces - The ET/SRB forward thrust attach points are identical and consist of permanently fixed, 5-inch radius spherical seats of stainless steel housed in large aluminum thrust fittings. An SRB-provided frangible tension bolt of approximately 2.5 inches diameter is installed through each of these forward interfaces. The bolt bore diameter in the seats and the adjacent ET fitting are a minimum of 0.8-inch diameter larger than the SRB bolt, which precludes the imposition of shear loads into the bolt. The spherical seat and bolt transmit all loads at the SRB forward interface, including all thrust/drag X-axis components. Thrust components are as high as 1,754,000 pounds, and drag as much as 178,000 pounds, per SRB - the latter after SRB burn-out.

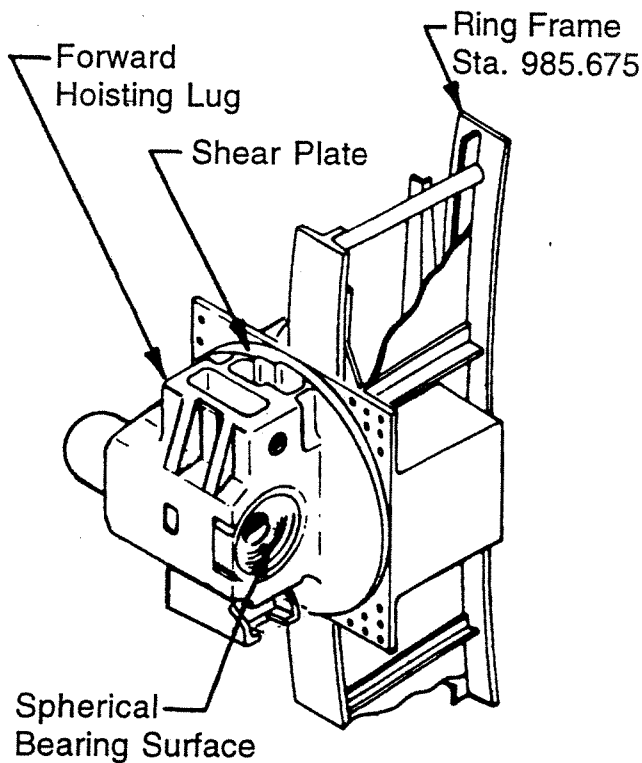


Figure 12-4: ET/SRB Forward Attachment (Typical 2 Places)

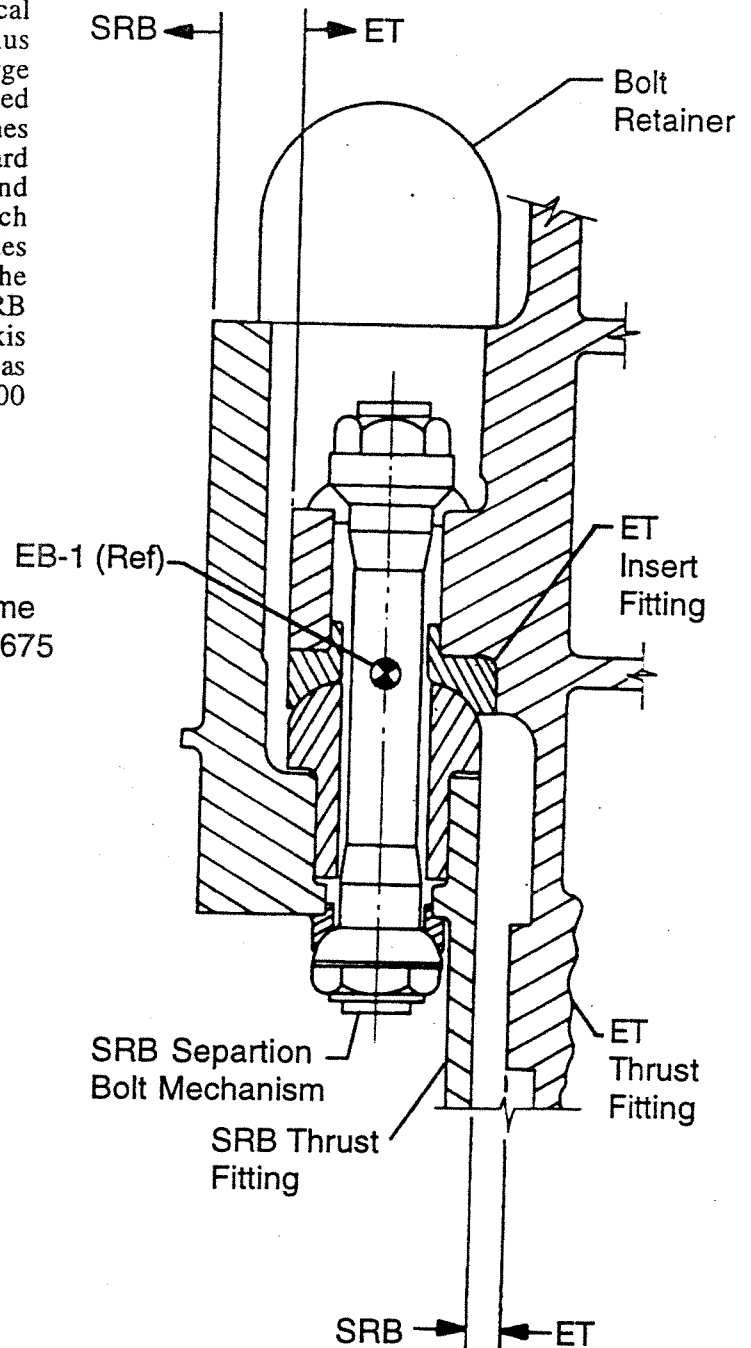


Figure 12-5: ET/SRB Separation Bolt

Each of the stainless steel interface seats is inserted into the respective machined/forged aluminum thrust fitting, and retained by three 1/4-inch diameter, 3-inch long cap screws.

The two (left and right) forged aluminum alloy thrust fittings are configured as mirror images and weigh approximately 400 pounds each. The SRB-provided interface bolt and associated pyrotechnics are housed in a machined 7-1/2-inch diameter, 7-inch long cavity on the forward face of each fitting. Final torquing of the interface bolt is to 1000 ft-lb. A bolt catcher covers the thrust fitting cavity and retains the interface bolt once it fractures in tension at Sta. 985.968.

The SRB pyrotechnic cable at each forward thrust interface exits from the ET bolt retention cavity through the retention plate, and is routed to a pull-away disconnect located at the aft +Z

surface of the thrust fitting. This disconnect is separated as the ET/Orbiter translates from the staging SRBs. An integral 26-inch diameter shear plate with a forward-to-aft stepped thickness of 2.2 to 1.1 inches transfers the SRB thrust/drag X-component loads into the intertank thrust panel through its peripheral bearing surface. Inboard of the shear plate, yet still integral to the thrust fitting, is a rectangular-shaped extension that transmits the Z-axis bending moment (resulting from the 7-inch outboard offset of the EB-1 and EB-2 interface points) to the chords of the intertank SRB beam. Attachment of the thrust fittings to this beam, to the intertank thrust panels, and to the adjacent major ring frame is described in Section VII, *Intertank Structure*.

The thrust fittings also include provisions on the +Z side of the interface bolt hole for attachment of the ET forward hoisting fittings.

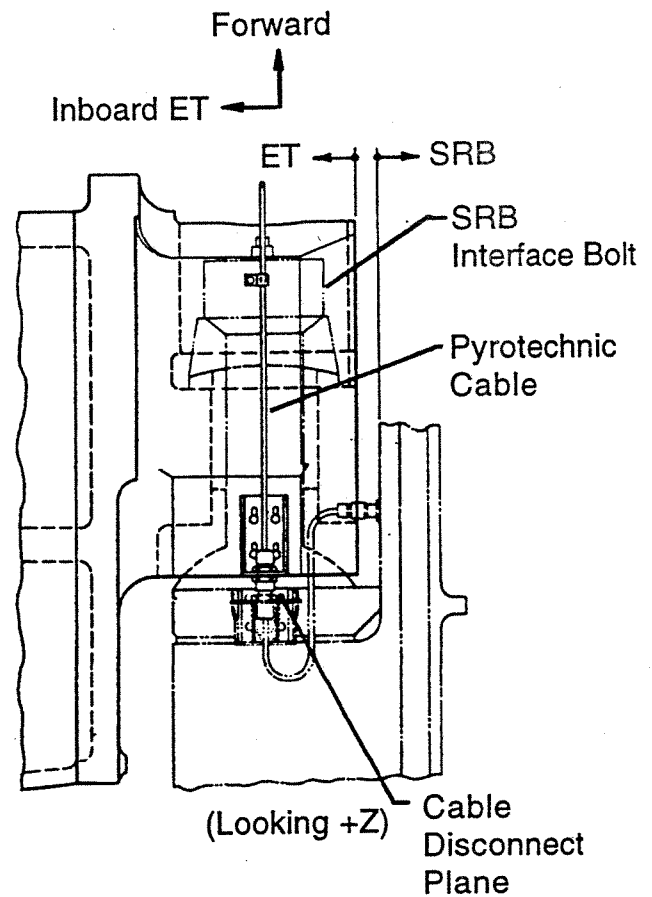
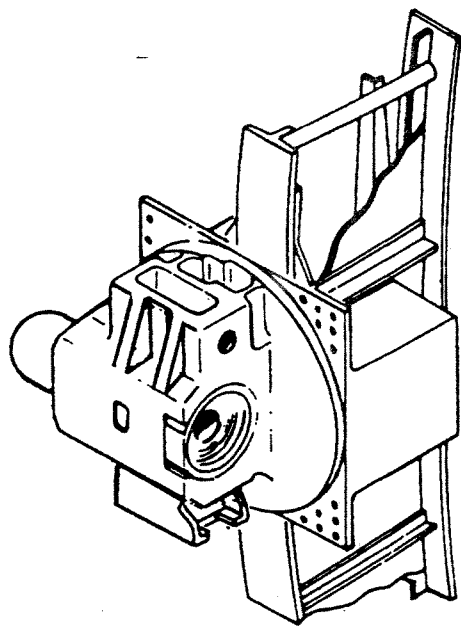


Figure 12-6: Forward SRB Pyrotechnic Cable Disconnect (Typical 2 Places)

ET/SRB Aft Structural Attachments – Each of the six aft SRB stabilization struts incorporate clevis ends that attach to the ET lug fittings located on the Sta. 2058.0 major ring frame. The right SRB aft attachment to the ET is a mirror image of the left, and consists of an upper and lower fitting. Each fitting is manufactured from a titanium alloy and is attached to machined flat lands on the ring frame by means of shear pins and tension bolts. These lug fittings experience primarily in-plane stabilization loads induced at each fitting-to-SRB strut juncture as presented in the table. Thermally induced, longitudinal deflections between the ET and SRBs impose out-of-plane loads in the order of 20,000 to 35,000 pounds applied to the lower and upper fittings, respectively.

Table 12-1: Aft SRB Attach Loads

Interface	Max Tension (KIPS)	Max Compression (KIPS)
EB-3/EB-4	265	-299
EB-5/EB-6	244	-258
EB-7/EB-8	393	-291

The titanium alloy upper fitting weighing approximately 75 pounds, connects to one lateral and one diagonal SRB strut using independent, yet identically configured interfaces. Each interface consists of a 3-1/4-inch diameter monoball having a 2.26-inch diameter bore, through which the SRB-provided shear pin is installed. The lateral and diagonal strut interface points are 57.0 and 49.82 inches, respectively, above the ET centerline.

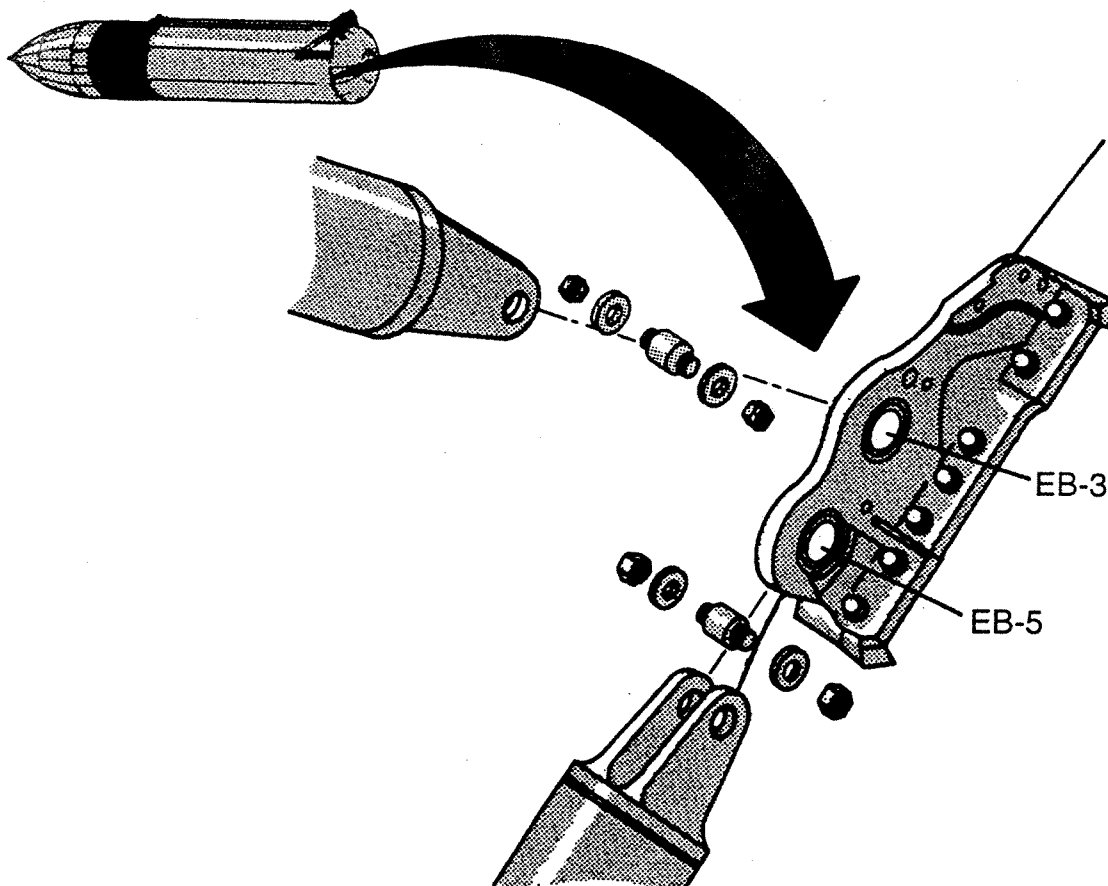
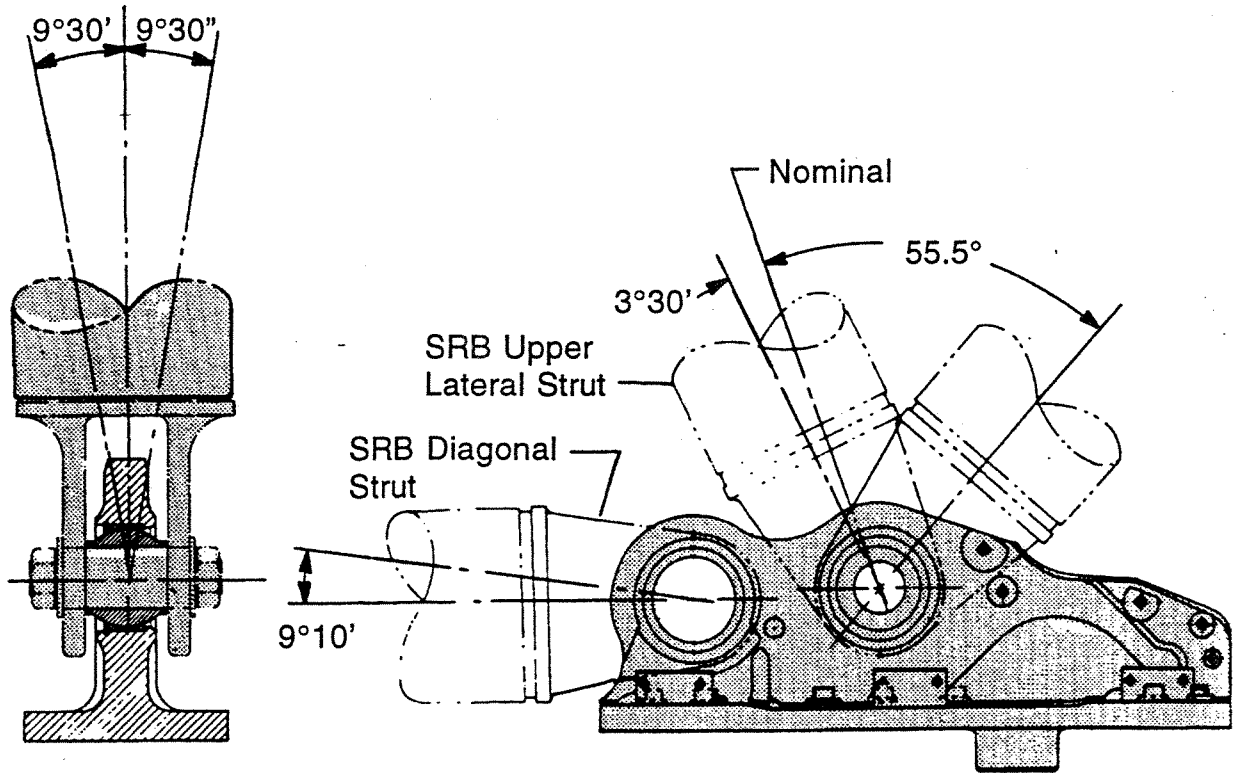


Figure 12-7: ET/SRB Aft Upper Fitting

The monoball-configured interface allows fore and aft pivoting of the SRB strut. The struts are attached to the ET fittings with a forward cant angle of 6.5 degrees with respect to the ET interface point. Repositioning of the struts occurs as a result of cryogenic and airborne-thermal-environment induced deflections, and is physically limited to 9.5 degrees forward and aft of the Y-Z plane. X-axis rotation of the SRB struts after separation is limited by the fitting design so as to prevent strut contact with the LH2 tank structure.

Each upper fitting has a base width of 7 inches and is 26 inches in length. The lug, a nominal 1.5 inches thick, extends along the entire length of the base and protrudes a maximum of 10 inches from the ring frame land surface. A 0.4-inch thick glass phenolic isolator is located between the fitting base and the land surface, and serves to maintain the fitting above -300°F. Both

the fitting underside and the land on the ring frame are machined flat. Attachment is provided by eight 3/4-inch diameter, and six 5/8-inch diameter tension bolts, an integral 3-3/4-inch diameter shear pin, and a shaped key that fits into an oversized slot in the frame land to allow for thermal distortion. This key is designed to react only transverse (fore/aft) shear loads. The fourteen bolt holes in the fitting base are oversized to preclude stressing the bolts during tank thermal distortion, and to ensure that the bolts experience only tension loads. A compatible lubricant on each bolt prevents cryopumping and the consequential collection of liquid air between the bolts and the tank.



Post-Separation Pivot Restraint

Figure 12-8: SRB Strut Motion

The titanium-alloy lower fitting weighing approximately 50 pounds is configured similar to the upper fitting- employing a monoball interface with the lower lateral SRB stabilization strut (one per SRB). This interface point is located 57 inches below the ET centerline, and is in the plane of the aft major ring frame. The monoball inserted into this lower fitting is identical to those in the upper fitting, and therefore has the same rotational capability. Post separation rotation of the SRB strut is terminated by stop blocks, machined into the fitting lug. These stop blocks ensure that the

strut does not contact the LH2 tank structure as with the upper fitting.

Twelve 3/4-inch diameter tension bolts, an integral 2-inch diameter shear pin, and a 1 x 0.5-inch platform key attach the 19 x 6.5-inch base of each lower fitting to the machined flat land on the aft major ring frame. A glass phenolic thermal isolator is placed between the tank land and each fitting, and the bolts are lubricated in a manner similar to the upper fitting bolts once they have been final torque.

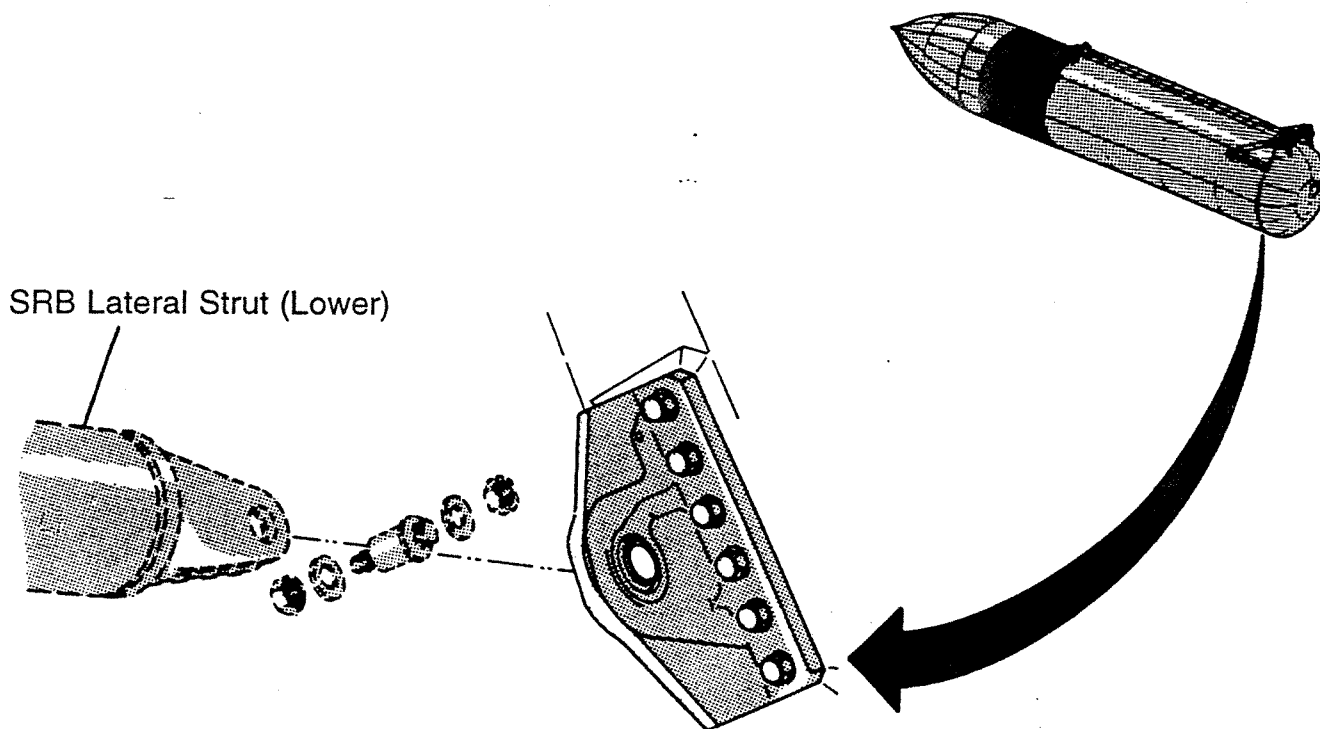


Figure 12-9: ET/SRB Lower Fitting

SRB/Orbiter Electrical Interfaces - The ET provides the electrical cabling necessary to transmit signals and power between the Orbiter and the SRBs. Twelve cables are required to provide this interface, resulting in six clustered ET/SRB electrical cable interfaces per SRB. The

six pull-away disconnects per SRB are supported from connector plates located adjacent to the separation plane of the aft upper lateral strut. Two of the six are 12-pin power cables, and four are 55-pin signal cable connectors. The ET halves of the ET/SRB electrical connectors are female.

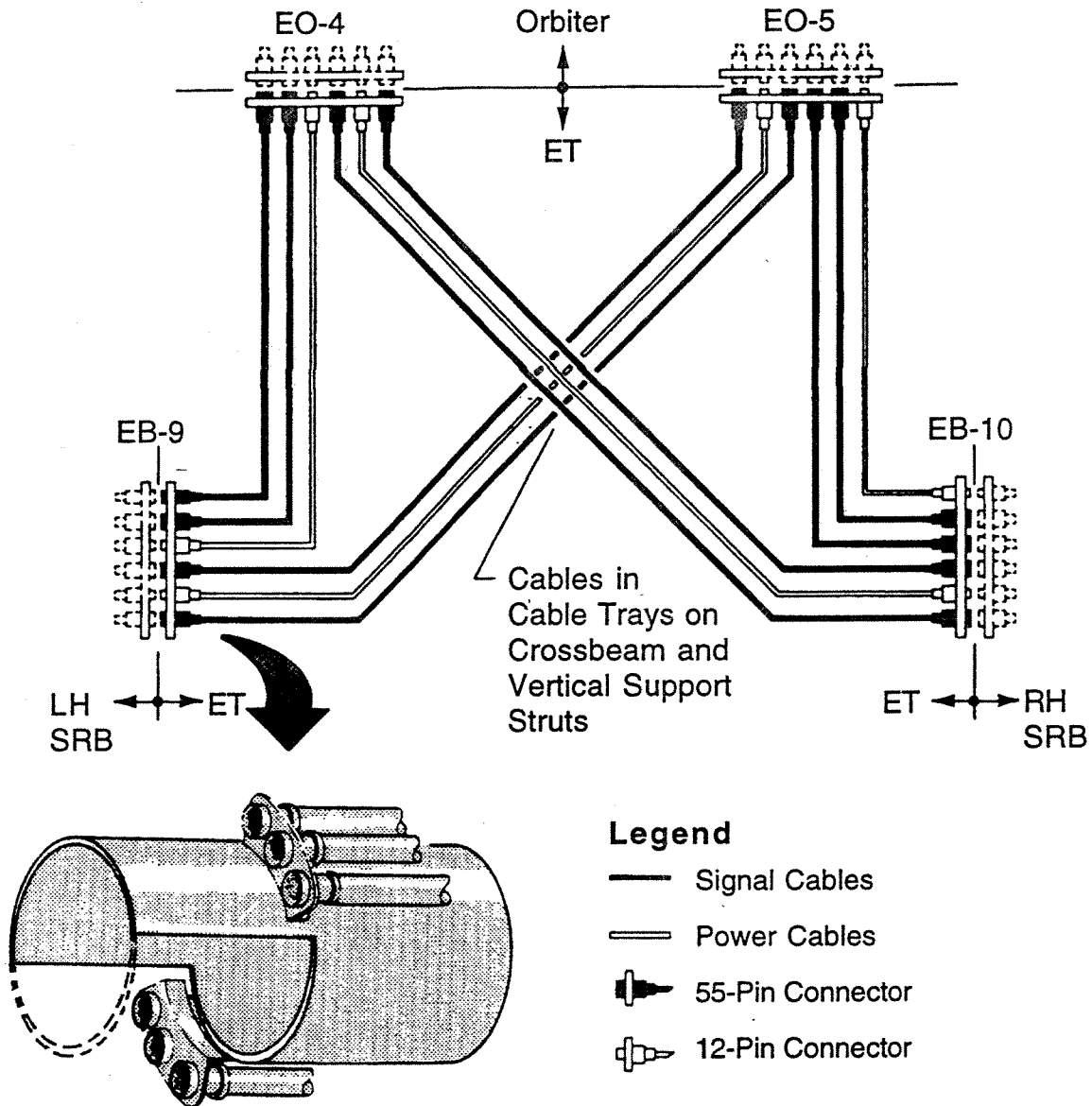


Figure 12-10: SRB/Orbiter Electrical Interface (through ET)

12.1.2 ET/SRB COMPONENT DETAILS

ET/SRB Thrust Fittings - The two thrust fittings are 7050 aluminum-alloy die forgings that are heat treated to the T736 condition prior to final machining. A machined flat surface on the aft end of the interface bolt retention cavity serves as the seating surface for the SRB interface hardware. The bore in the fitting for the 2.5-inch diameter interface bolt is in excess of 4.5 inches in diameter, thereby precluding the induction of shear loads into the bolt.

The inboard rectangular extension on each of these fittings has an overall height ($\pm X$) of 26.5 inches and a width ($+Z$) of 12.5 inches, and extends inboard of the ET inner skin line 13 inches to provide an interface surface for the intertank SRB beam.

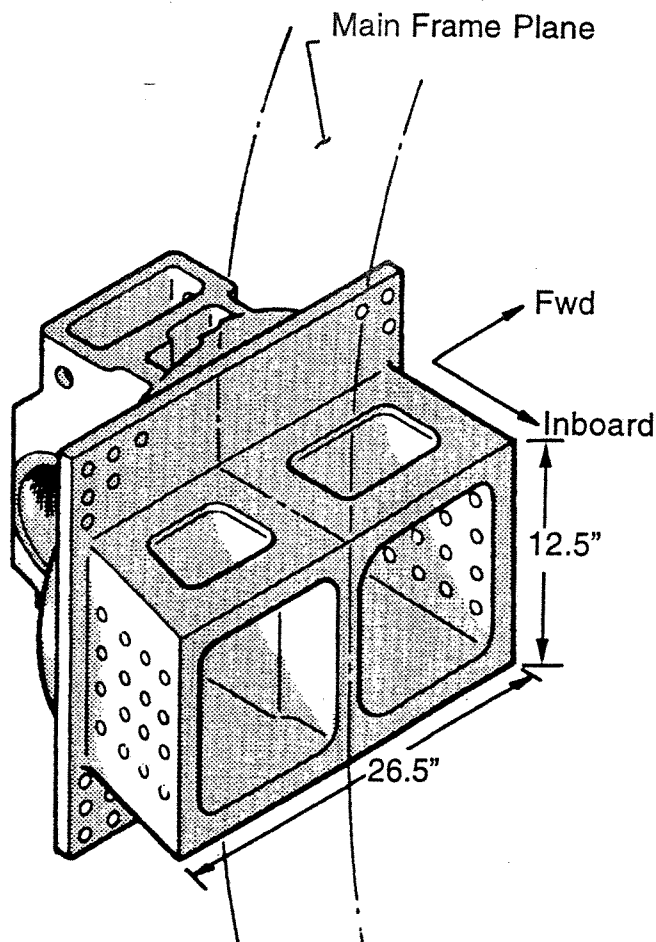


Figure 12-11: Forward Thrust Fitting, Inboard

An intermediate web with a stepped thickness, from 1-1/4 inches outboard to 0.625 inches inboard, provides stiffness to the long sides of the rectangle at the intertank main frame intersection.

ET/SRB Thrust Fitting Insert - Two stainless steel inserts provide the seating surface for the forward SRB hemispheres; they are machined from AMS-5629 corrosion-resistant steel. The machined 5-inch, spherical-radius interface surface has a tolerance of +0.000, -0.002 to ensure maximum interface surface contact - to maintain bearing stress uniformity at the interface. The three 1/4-inch diameter cadmium plated cap screws that secure each of these inserts to the respective thrust fitting are torqued to 56 in.-lb and are treated with a locking compound to prevent loosening because of vibration.

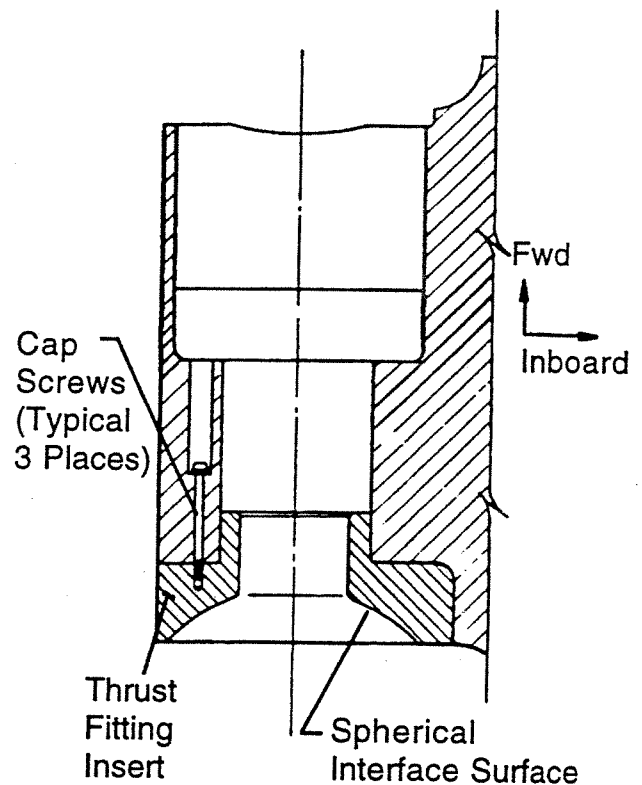


Figure 12-12: Thrust Fitting Insert

ET/SRB Aft Upper Fitting Construction -
 The two aft ET/SRB interface upper fittings are machined from annealed titanium alloy (Ti6AL4V) castings. Two Inconel 718 3.25-inch diameter monoballs per fitting, housed in stainless steel races, are retained by a steel retaining ring and eight fittings. Web stiffeners are machined into the fitting lug surfaces to provide shear and bending load paths from the monoball to the fitting base. Two shear pins are provided; one of which is integral. The integral 3-1/4 inch diameter shear pin, located 5.5 inches forward of the lateral strut interface point (EB-3 left, EB-4 right), reacts shear loads in all directions. The other pin is designed to react only transverse shear (resulting

from the struts being canted out of the plane of the ring frame).

The key-way in the frame (for the transverse pin) is elongated circumferentially, and the bolt holes in the fitting base are oversized to allow relative distortion between the ring frame and the fitting by motion about the integral shear pin axis.

ET/SRB Aft Lower Fitting Construction -
 Two aft ET/SRB interface lower fittings utilize the same materials, type of subassemblies, and design approach as the aft ET/SRB upper fittings. The monoball configuration is identical to the upper fitting monoballs.

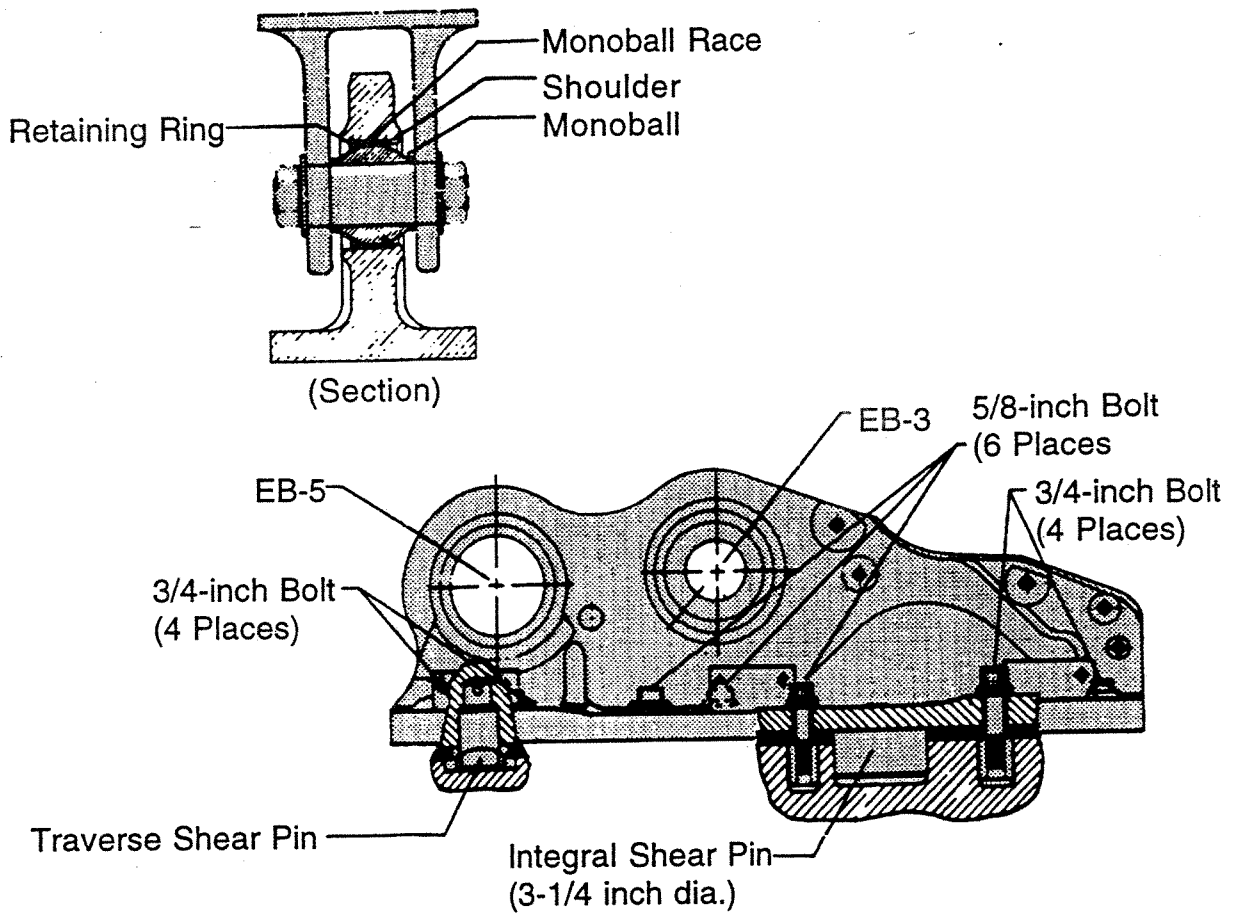


Figure 12-13: Aft Upper Fitting-to-Tank Attachment

12.1.3 ET/ORBITER INTERFACES

The ET/Orbiter structural interfaces provide a three-point mount: two aft with support structure emanating from the ET aft major ring frame and the LH2 tank longerons; and one forward, supported from the LH2 tank forward ring frame. The right (Looking forward) aft support is a tripod, making it fixed, while the other two are bipods; with the left aft permitting lateral pivot motion and the forward allowing fore/aft motion. Numerous pinned and spherical joints exist within the support structures that allow for multi-directional motion, but minimizes the magnitude of bending induced in the support structures as a result of thermal and structural load environments. Strut shims are used to provide adjustment of the attachment points on the aft ET/ORB structure and by an adjustable threaded sleeve on the right-hand bipod strut of the forward ET/ORB attachment. Thus, motion and adjustment for alignment, tolerance, strain and thermal distortions are provided.

All ET/Orbiter structural interface attachment hardware is Orbiter-provided and consists of a frangible bolt and hex nut at the forward interface, and a frangible nut and tension bolt at each of the aft structural interfaces. ET/Orbiter separation occurs subsequent to Orbiter MECO and ET/Orbiter umbilical separation, and is an Orbiter-controlled event.

The ET/Orbiter fluid and electrical interfaces are located at two aft umbilical assemblies (EO-4 left, and EO-5 right), adjacent to - but separated from - the two ET/Orbiter aft structural interfaces. These two umbilical assemblies consist of clustered disconnects that mate with the ET fluid lines and ET (and Orbiter/SRB) electrical cables described in Section IX, Propulsion System, and Section X, Electrical System. The Orbiter/ET and Orbiter/SRB electrical interfaces utilize both paths to provide critical redundancy where necessary. This routing is depicted in Volume II.

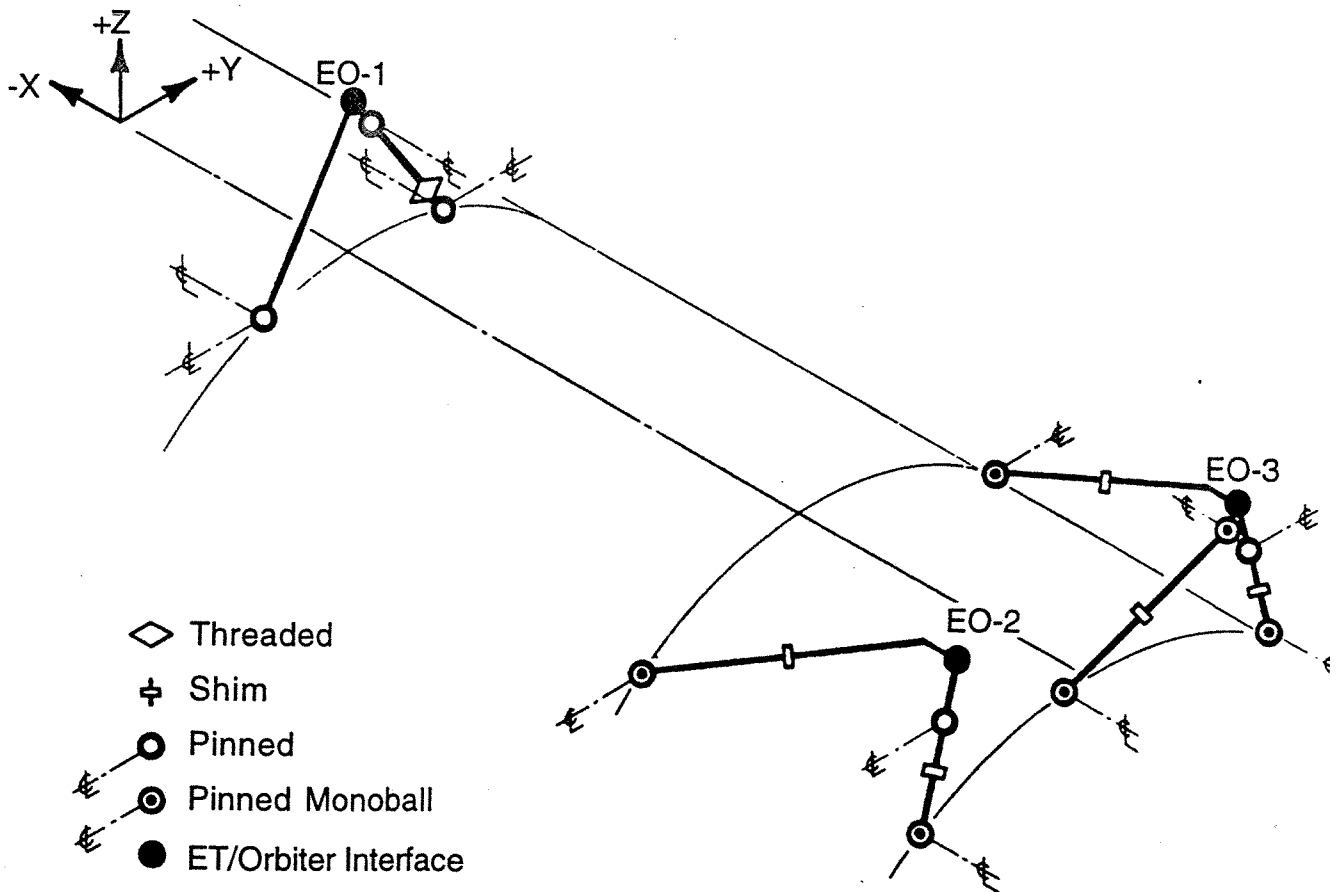


Figure 12-14: ET/Orbiter Support Structure Flexibility

Aft LO2 and LH2 feedline support brackets provide support to both umbilical assemblies, and transfer X- and Z-axis interface loads to the aft crossbeam structure. Both feedline/umbilical assemblies are tied laterally to the adjacent ball interface fitting, necessitating a translating linkage attachment of the left umbilical to the crossbeam, which is fixed to the right ball interface fitting. The crossbeam is slip joined to the left interface

fitting, thereby permitting the bipod to be unrestrained laterally.

Clearance of two inches minimum is maintained between the +Z surface of the ET crossbeam structure (including TPS) and the Orbiter TPS moldline, to preclude contact of the two surfaces during flight.

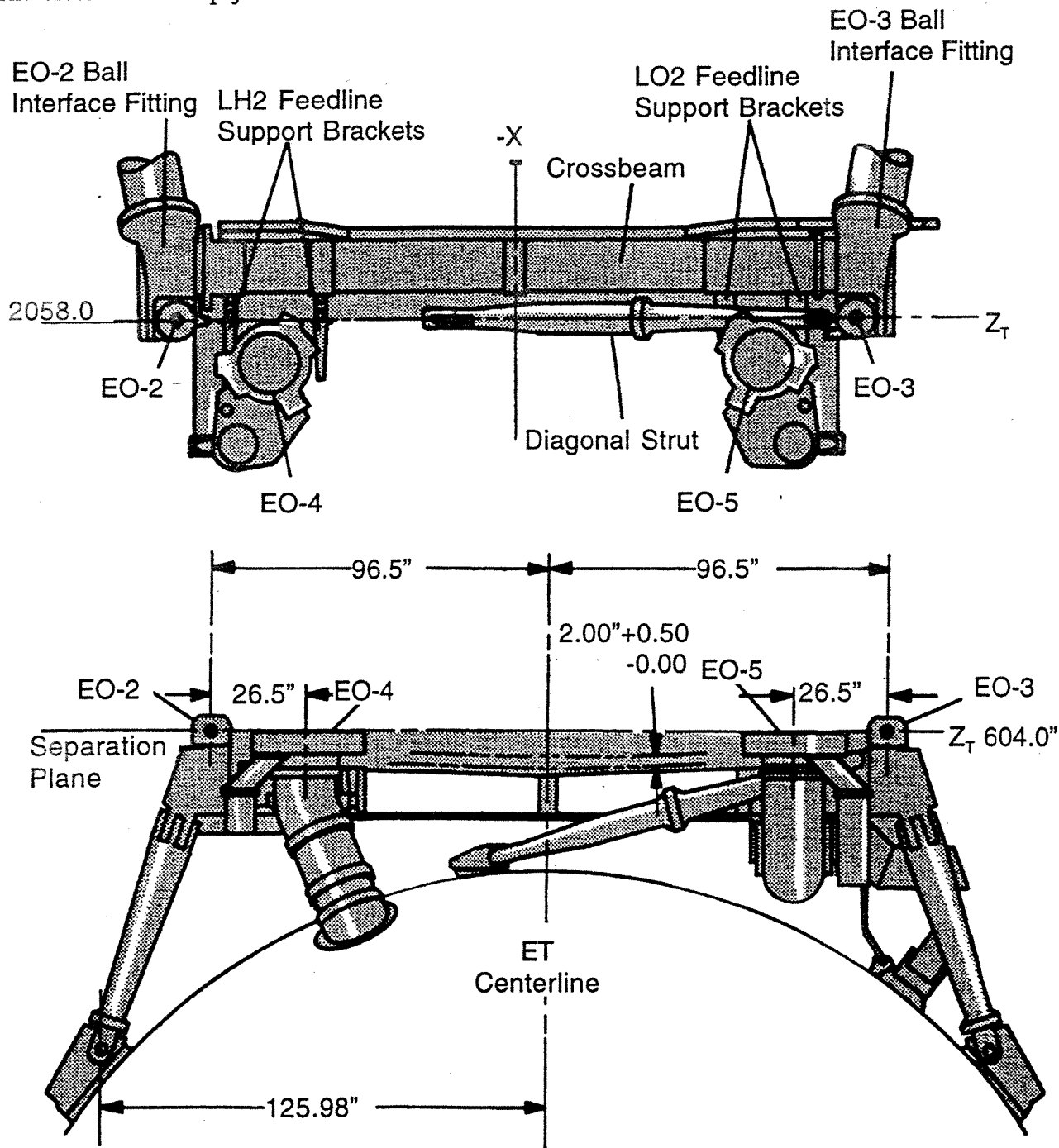


Figure 12-15: Aft ET/Orbiter Interface Orientation

ET/Orbiter Forward Attachment - The forward Orbiter attachment (EO-1 interface) hardware is a bipod weighing approximately 190 pounds. It has rotational freedom at its attachments to the forward LH2 tank ring frame, and rotates about a Y-axis reference line so that changes in ET length resulting from thermal effects will not induce loads into the Orbiter. The bipod is canted 0.5 degrees forward when mated to the Orbiter; however, cryogenic shrinkage of the ET results in an additional 5.5-degree forward cant. The structure is configured as a locked kinematics chain, thereby constrained to carry loads in the Y-Z plane, and is designed to be partially retracted forward upon Orbiter separation. This retraction (pivot action) is accomplished with leaf springs affixed to the spindles that attach the struts to the tank.

A spindle assembly on each ET shoulder provides limited post-separation pivotal freedom, and attachment of the struts to the LH2 tank forward ring frame structure. The mechanism is about 10 inches high and 14 inches long; and, by means of an attached laminar force spring, applies 314 in.-lb of torque on each strut end. The titanium housing containing the operating mechanisms has a machined flat underside, with the exception of the integral 2 1/2-inch diameter shear pin, that mates with the lands on the LH2 tank ring thermal isolator between each housing base and the frame lands maintains the temperature of the assembly above -300°F. The fasteners are lubricated to seal all voids to prevent

the collection of liquid air between the bolts and tank. There is one Calrod heater installed in the spindle to minimize any ice buildup during and after propellant loading. The heater is shown and described in *Section X, Electrical System*.

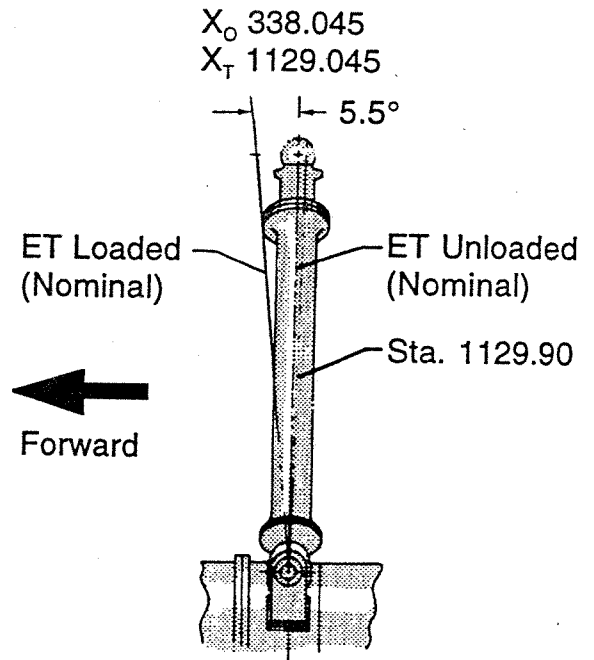


Figure 12-16: Forward Bipod Cant Angle (Fore/Aft)

The two identical aluminum struts are hollow tubes approximately five feet long with flanges on each end. The Orbiter end of the left strut is attached to a yoke fitting that mates to the Orbiter. The attachment of the strut flange to the yoke-fitting flange is accomplished with twelve 5/8-inch steel bolts.

The yoke fitting is a large machined titanium casting that forms a 74 degree apex angle between the two struts. This fitting has a 2.125-inch diameter bore through its apex, which encases the Orbiter provided frangible bolt. Within this bore is a smaller diameter shoulder support that retains the bolt in the fitting after separation. A flat ellipse-shaped surface is machined such that it is perpendicular to the interface bolt centerline and provides the interface surface for the Orbiter-provided truncated sphere. The Orbiter-provided interface nut seats against the ET-provided stainless-steel spherical washer located on the underside of the yoke fitting. Tension,

compression, and side loads (+Y) exceeding 100,000 pounds are transmitted to the yoke from the Orbiter. The right side of this fitting consists of an integral clevis that connects to the dual clevises on the right strut upper end fitting by means of a 1-3/8-inch O.D. steel shear pin.

The right strut upper end fitting attaches to the right strut with twelve 5/8-inch diameter bolts through the 9-inch O.D. flanges.

The ET end of both struts is flanged identically to mate with the flanged lower end fitting. One end fitting is cast titanium and the other is Inconel. Both end fittings are configured with a 3-forked clevis. A 1-1/8-inch steel shear pin connects the clevis with the inner end of the spindle assembly. The right strut lower end fitting has an adjustable sleeve to provide lateral adjustment for ET/Orbiter mating at the EO-1 interface point.

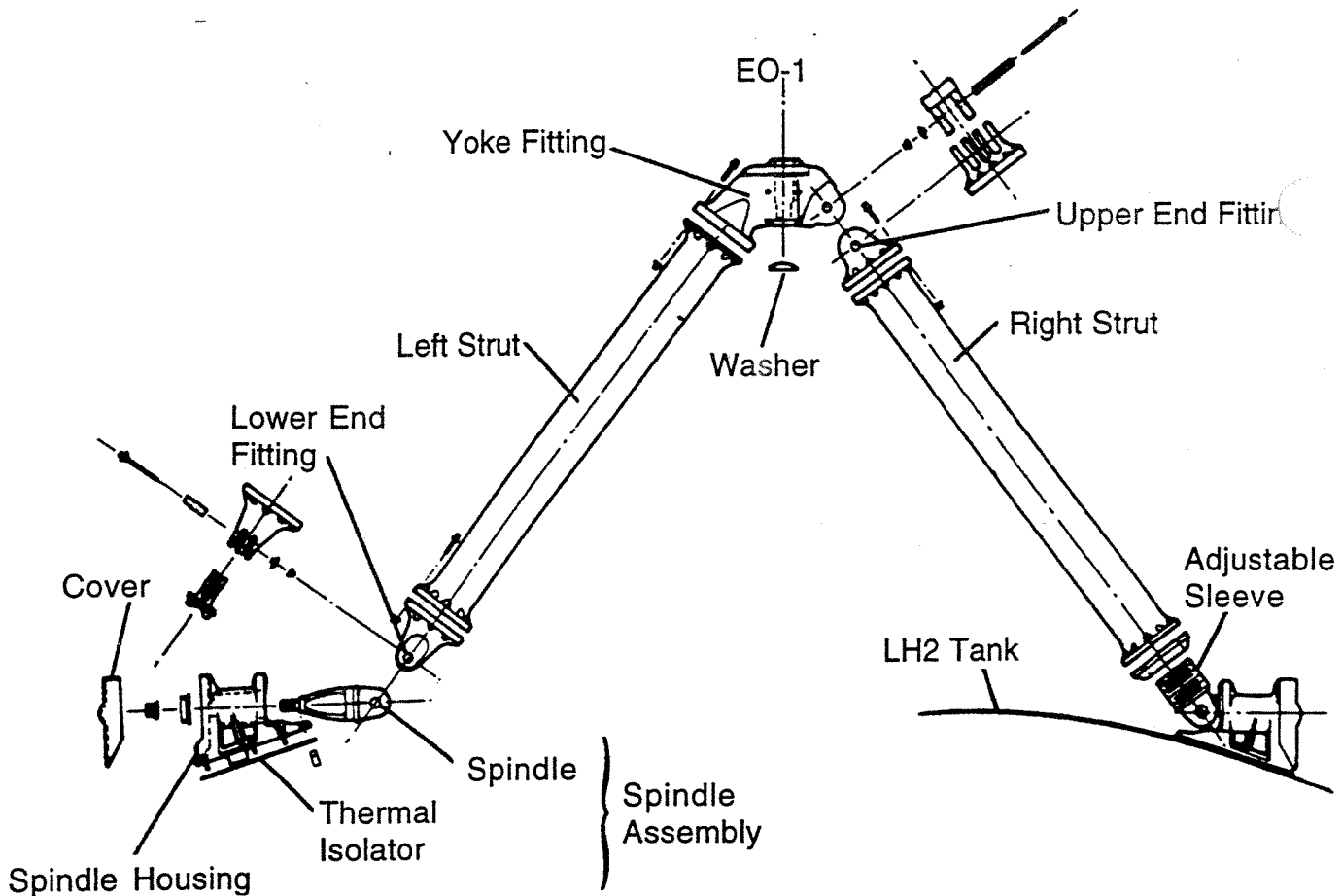


Figure 12-17: ET/Orbiter Forward Attachment

ET/Orbiter Aft Left Attachment - The EO-2 interface hardware consists of a bipod structure originating from the integral lug juncture at the forward end of the LH2 tank left longeron, and a lug fitting on the aft major ring frame. Once mated to the Orbiter, this structure is free to pivot laterally about these ET junctures, thereby permitting unrestrained relative lateral distortion between the aft ET and the Orbiter. The bipod is canted 18 degrees inboard from the X-Z plane when the tank is in the unloaded condition. The direct physical interface with the Orbiter is formed by a large hemispherical surface at the bipod apex that engages with the Orbiter socket. Attachment hardware is Orbiter-provided, and consists of a 2.5-inch diameter tension bolt coupled with a frangible nut housed in the Orbiter.

The forged aluminum-alloy ball interface fitting, weighing approximately 530 pounds, joins the tubular thrust strut and the I-section vertical strut to provide the Orbiter interfacing hemispherical surface. This surface is machined to a 5.275-inches spherical radius, but is flattened 4-1/2 inches above the spherical center to compensate for an Orbiter protuberance. A Z-axis bore of 2.875-inches diameter extends 1.5 inches below this flattened surface, where it enlarges to a 5.5-inch diameter and continues through the base of the fitting. This 5.5-inch diameter cavity allows installation of the interface bolt and associated torquing tool.

Orbiter thrust loads up to 727,000 pounds are transmitted to the ET at this structural interface. A honeycomb bolt stop pad and aluminum closure plate are attached to the base of this bolt insertion cavity by three 9/16-inch bolts.

Two 5/8-inch diameter threaded inserts are located on the fitting underside, at the aft inboard corner, to allow attachment of the alignment/transportation strut. This strut provides stability to and allows lateral adjustment of the bipod until the Orbiter EO-2 socket has captured the ET hemisphere during mating.

An integral two-lug clevis is located on the inboard (+Y) surface of the fitting and provides an attachment point for the tie plate from the outboard LH2 feedline support bracket. This tie maintains the constant 26.5-inch lateral separation between the feedline centerline and EO-2. The inboard surface of this fitting also includes two Y-axis 2.5-inch diameter holes into which are press-fitted 10.5-inch long shear pins. These steel pins slide on steel, self-aligning bearings housed in lugs

on the left end of the crossbeam, thus establishing EO-2/crossbeam lateral independence.

The outboard surface of this fitting also includes provisions for attachment of ET aft hoisting equipment used during tank erection/de-erection. The fitting flairs forward from EO-2 approximately 28 inches to form a 21-inch diameter flange that connects directly to the 16.6-inch I.D. thrust strut by means of twenty-four 3/4-inch diameter bolts. The ten-foot long aluminum-alloy thrust strut has tapered thickness between the 21-inch flange and the base. Larger walls at the upper end of the thrust strut are necessitated by the large bending loads in excess of 1×10^6 in.-lb introduced at the interface with the EO-2 ball fitting. The lower end of the thrust strut is flanged to 20-9/16 inches O.D. and with twenty-four 5/8-inch bolts forms the connection to the lower end fitting. An aluminum laminate shim, nominally 3/4-inch thick, is inserted between the thrust strut and end fitting to allow EO-2 fore and aft adjustment.

The forged aluminum lower end fitting tapers from the hollowed out 0.5-inch thick strut end flange to a 3-1/8-inch by 9-3/8-inch lug. A 4-inch diameter stainless steel shear pin, inserted through a 5-3/4-inch diameter stainless steel monoball in the end fitting lug, connects the strut end fitting to an integral clevis on the LH2 tank left longeron. This monoball enables the EO-2 bipod assembly to pivot about its X-axis, thereby allowing relative ET/Orbiter lateral distortion. In addition, the pinned monoball ensures that the Orbiter (EO-2) thrust/drag loads are transmitted to the longeron as a uniaxial load applied through the thrust strut centerline. Longeron characteristics are described in Section VIII, *LH2 Tank Structure*.

The forged aluminum vertical strut, approximately five feet long, connects to integral clevis lugs on the underside of the EO-2 ball interface fitting by means of a 4-inch diameter steel shear pin. This pin is of the same configuration as the pins used in the forward bipod (EO-1) support structure. The upper end of the vertical strut is eleven inches in depth (across the lugs). The lugs taper to a 9.2-inch deep I-section that continues to taper to a 6.3-inch depth. The strut then flairs into a 12.5-inch square flange approximately 1-inch thick. The strut width varies from 7.5 inches at the lugs to 5.2 inches before flaring to the lower flange. Web thickness also tapers from top to bottom. Single X-axis bending loading in excess of 750,000 tn.-lb resulted in the selection of the I-section vertical strut.

Sixteen 7/8-inch diameter steel tension bolts connect the vertical strut to the strut end fitting, separated by a laminated shim comprising a nominal 3/4 inches.

The aluminum strut end fitting flairs from the mirror-image, 1-inch thick strut flange into two 2 1/2-inch thick clevis lugs. A 2-3/4-inch wide lug of the tank/vertical strut fitting is positioned between these clevis lugs. A 3-inch diameter stainless steel shear pin and a 4-1/4-inch diameter monoball connects and provides the required flexibility at this juncture, which is 115.78 inches above the ET centerline.

The tank/vertical strut fitting is a titanium casting that transfers the uniaxial load from this pinned monoball juncture to the aft major ring frame - primarily as shear and in-plane kick loads. Six 5/8-inch diameter and four 7/8-inch diameter steel bolts, and a 3-3/4-inch diameter integral shear pin attach the fitting to a machined flat land on the ring frame. Thermal isolation of the fitting and bolt lubrication are accomplished in the same manner as the forward bipod (EO-1) fittings.

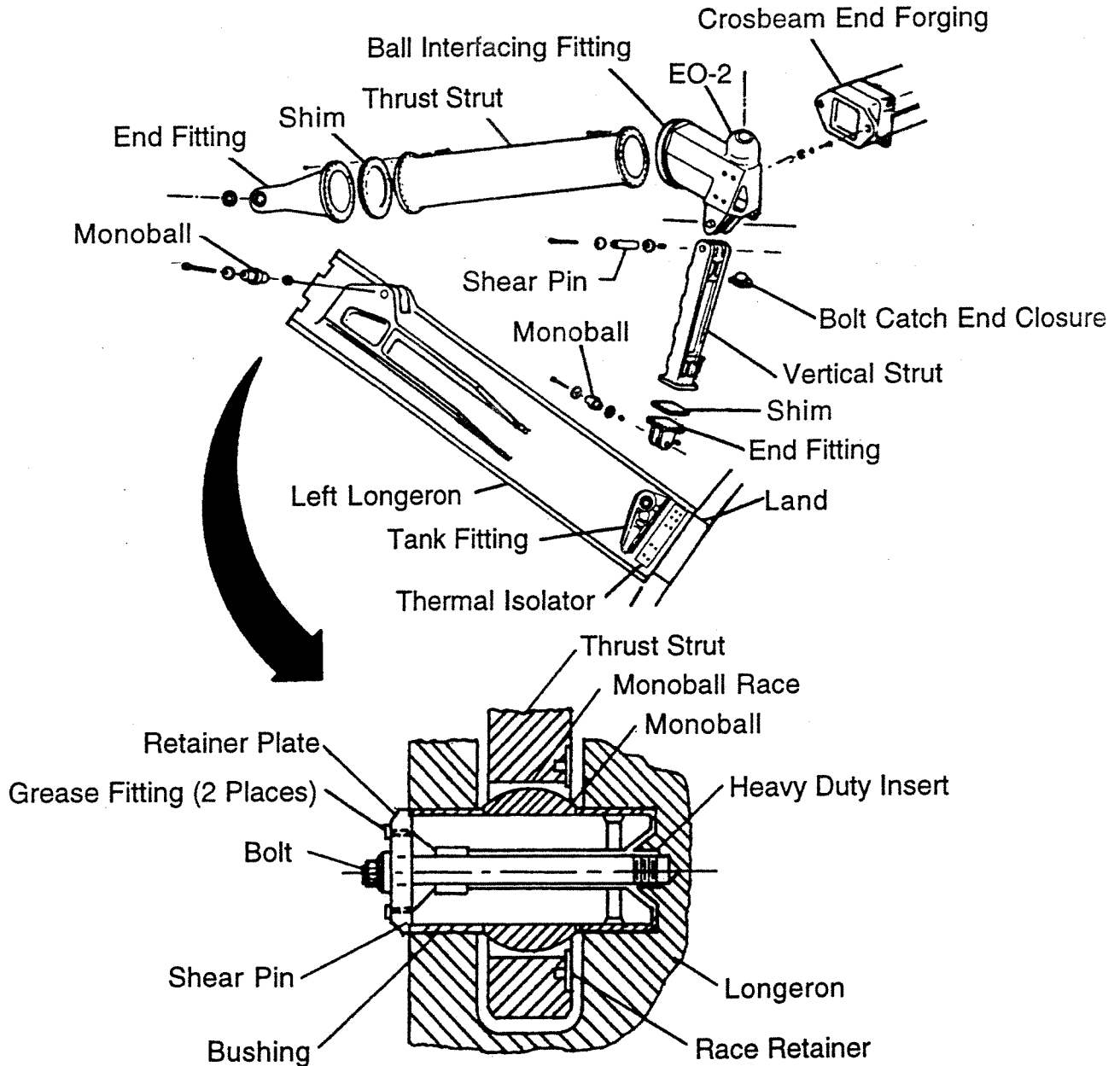


Figure 12-18: Aft Left Thrust Strut

ET/Orbiter Aft Right Attachment - The EO-3 interface is supported by a tripod structure originating from two points on the aft major ring frame, and from an integral clevis on the forward end of the right longeron. The tripodal geometry of this support structure results in the fixity of the EO-3 interface, thereby enabling it to be used as a datum from which EO-1 and EO-2 alignment tolerances are referenced.

The aluminum ball interface fitting is basically a mirror image of the EO-2 fitting with three exceptions: the 18-inch by 19.2-inch flange that bolts to the mirror-image crossbeam flange; the integral 1-7/8 inch thick lug that provides the bearing surface for the upper end of the diagonal strut; and the large double-lug clevis, located aft of the diagonal strut lug. The LO2 feedline support

brace attaches to this double lug clevis. The EO-3 ball interface fitting weighs 530 pounds.

The thrust strut-to-ball interface fitting flanged connection is similar to the previously described EO2 configuration. Twenty-eight 3/4-inch diameter bolts are required at this juncture. As a result of the higher bending loads (induced from LO2 umbilical interface loads, and carried to the EO-3 ball interface fitting) transferred through this connection, the upper end wall thickness of this strut is 0.1 inches larger than that of the EO-2 thrust strut. The left and right thrust struts are identical, with the exception of wall thickness. Left and right vertical struts, and associated joints, are exact mirror images. Orbiter imposed thrust loads at this interface are in excess of 682,000 pounds.

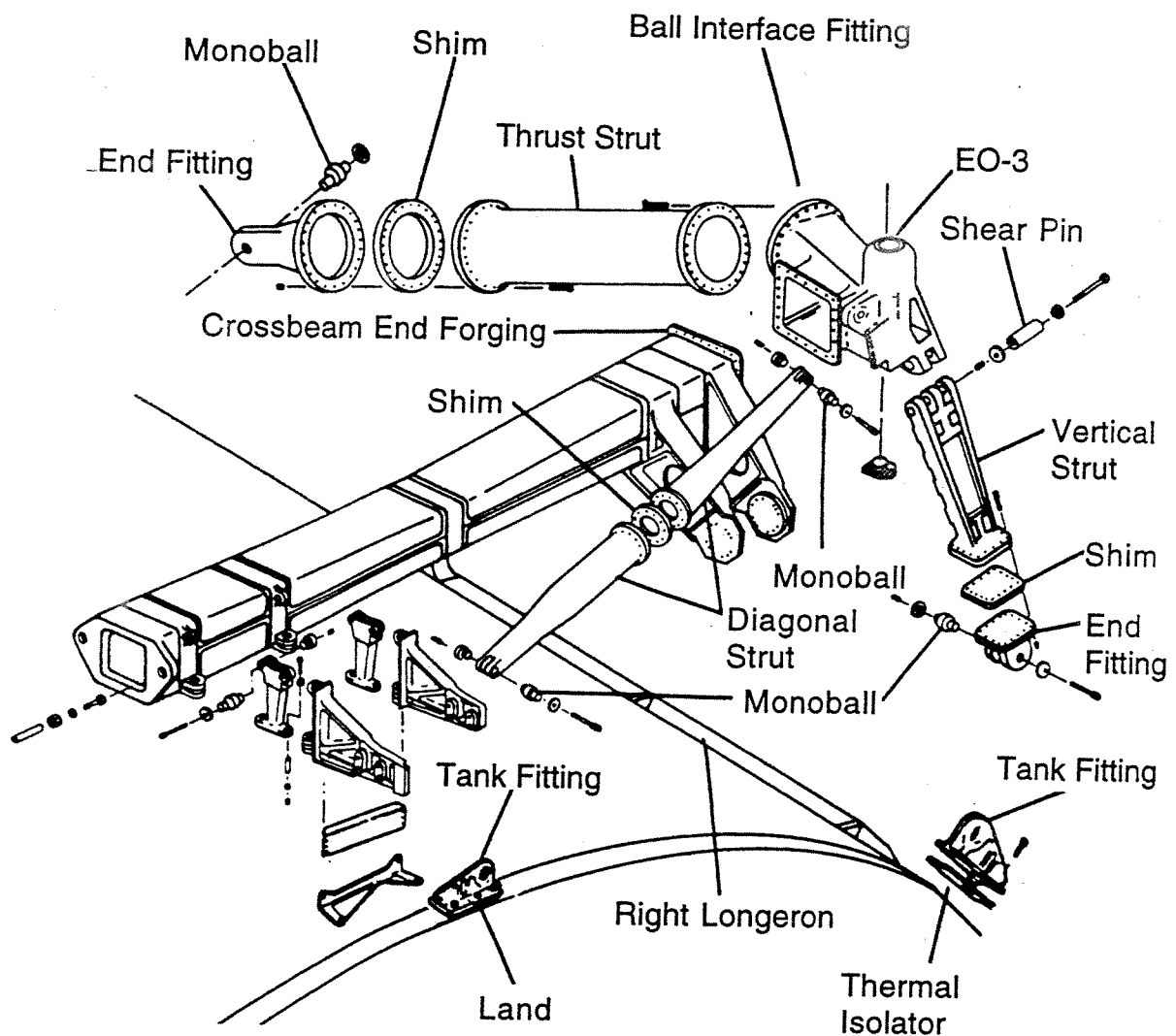


Figure 12-19: Aft Right Tripod Support Structure

ET/Orbiter Crossbeam & Aft Feedline/ Umbilical Supports - The rectangular-shaped aluminum crossbeam is bolted to the inboard flange of the right-ball-interface fitting by means of twenty-four 5/8-inch bolts and is slip-joined to the left fitting, as previously described. The structure is 14 feet 8 inches long and is comprised of extruded channel sections and integral forgings welded together to form a single assembly. The right end of the crossbeam contains two bulkhead forgings that support the LO2 feedline elbow (and the EO-5 interface plate), with the outboard support also containing the integral 18inch by 19-inch flange that attaches to the right-ballinterface fitting. An 11-3/8-inch by 15-3/8-inch bulkhead forging is located at the midpoint of the assembly, resulting in a crossbeam cross-sectional taper consistent with the Orbiter outside mold line. The left end of the crossbeam contains two integral bulkhead forgings that provide attachment for the LH2 feedline hinge brackets, and terminates with a 14-1/2-inch by 15-3/8-inch end forging, housing two self-aligning bearings. These bearings, combined with the shear pins located in the left-ball-interface fitting, result in the required slip-joined interconnection.

Feedline and associated umbilical interface X and Z-axis loads are transmitted to the outboard ends of the crossbeam as torque, therefore necessitating the larger outboard cross section. The extruded channel sections, welded end-to-end to form a box section, are stiffened longitudinally by two integral beads per side, thereby controlling panel buckling.

The LH2 (EO-4) feedline support brackets connect to the left end of the crossbeam by means of two forged, aluminum hinge brackets resulting in a fourbar linkage arrangement. This configuration permits the brackets to float laterally (3/4-inch max) with the EO-2 ball-interface fitting, and independent of the crossbeam. A 5-1/2-inch long, aluminum tie plate maintains constant 26-1/2-inch lateral distance between the LH2 feedline/umbilical and the EO-2 interface centerlines, and provides stability to the fourbar linkage. This tie is attached to the previously described two-lug clevis on the EO-2 ball-interface fitting by a 5/8-inch steel flat-head bolt, and attaches to a flange on the outboard feedline/umbilical support bracket. This aluminum outboard support bracket is a 25-1/2-inch long member that bolts to an integral flange on the outboard side of the LH2 feedline with four 5/8-inch bolts. The outboard bracket also provides

support to the cable tray, which traverses from the EO-4 interface to the forward face of the crossbeam. The inboard support bracket is slightly smaller (due to the crossbeam taper) than the outboard bracket, and bolts to an inboard flange on the LH2 feedline. The two are interconnected forward of the LH2 feedline by a Z-shaped stiffener bottom and Tshaped stiffener top. The purpose of these stiffeners are to transfer the force, associated with the lateral movement of the EO-2 bipod, across the two feedline support braces, thereby precluding the imposition of resultant radial loads to the relatively thin feedline walls. It also acts as the fourth member of the four-bar linkage.

In addition to this stiffener, the four-bar linkage interconnecting the LH2 feedline/umbilical support braces and the crossbeam is comprised of the tangs/clevises located on the aft face of the crossbeam, and two image-identical forged aluminum hinge members that span the eight inches between the crossbeam and the braces. The upper joints of these members are configured as Y-axis-pinned monoballs, while the lower joints are Z-axis shear-pin connections. This configuration allows limited Z-axis rotation of the linkage about the crossbeam joints, accomplishing lateral translation of the feedline/umbilical support braces (+3/4-inch max). This translation is performed in consonance with the aft left Orbiter support structure.

The forged LO2 feedline/umbilical (EO-5) support brackets are integral to the right end of the crossbeam, and serve to transmit X- and Z-axis loads, resulting from LO2 dynamics and ET/Orbiter umbilical interface loads, directly to the crossbeam as torque. The brackets attach to integral lugs on either side of the LO2 feedline. Lateral (Y-axis) umbilical interface loads are transmitted from the outboard support bracket directly to the EO-3 ball-interface fitting through an interconnecting brace, thereby minimizing out-of-plane bending in the two support brackets.

This aluminum brace attaches to the outboard LO2 feedline umbilical support bracket with thirteen 3/8-inch bolts, and to the previously described lug on the ball-interface fitting with eight 3/8-inch bolts. The cable tray emanating from the EO-5 interface that traverses to the forward face of the crossbeam is supported from the Z-side of this beam.

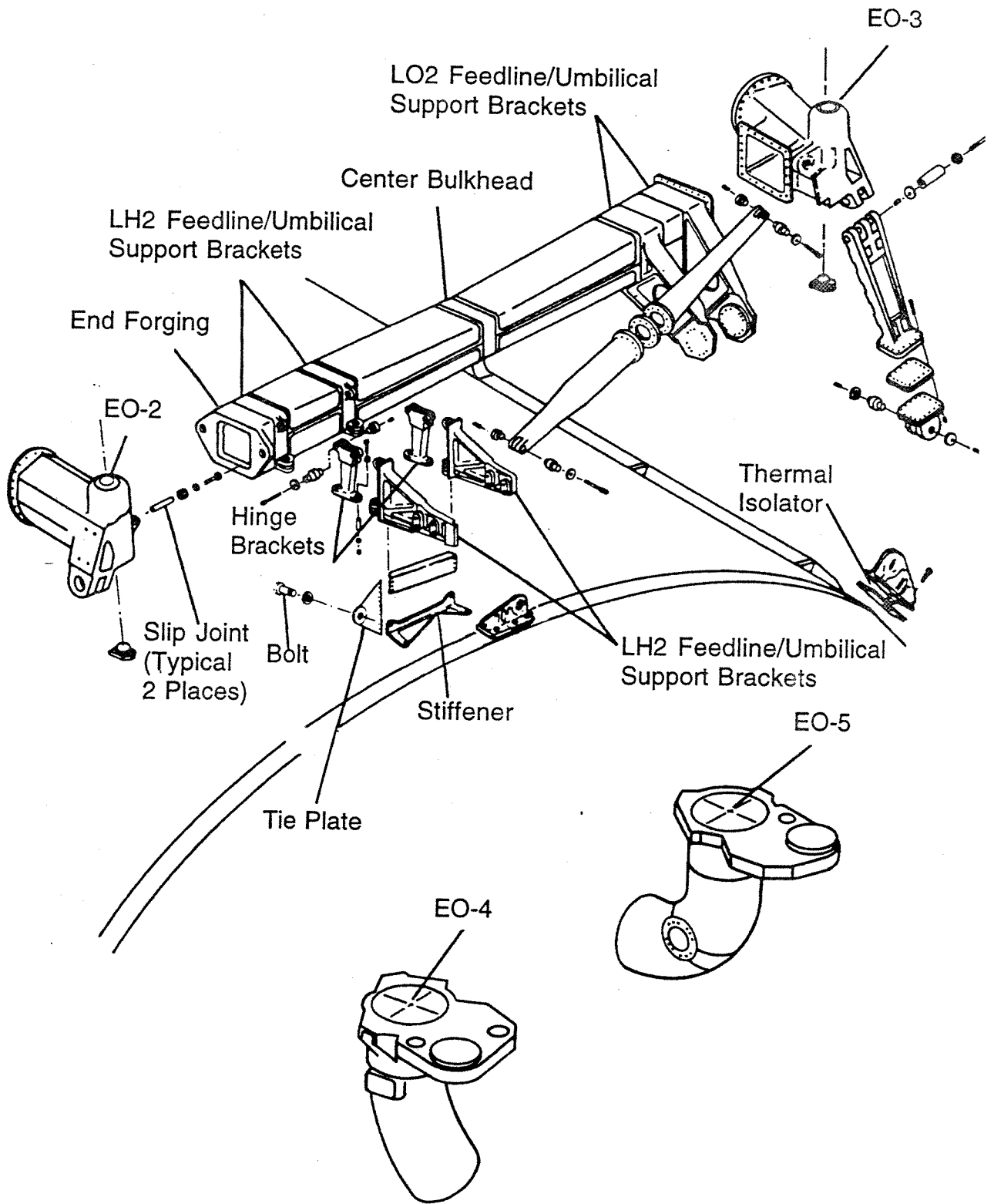


Figure 12-20: Crossbeam and Aft Feedline/Umbilical Supports

ET/Orbiter Left Umbilical (EO-4) – The ET halves of the 2-inch GH2 pressurization line disconnect, 4-inch recirculation line disconnect, and pullaway ET/Orbiter and Orbiter/SRB electrical disconnects are mounted in a single cluster plate. This plate is, in turn, mechanically attached to the ET half of the 17-inch LH2 feedline disconnect that serves as the structural support for the umbilical assembly. Attachment of the ET and Orbiter umbilical disconnect halves is accomplished with three bolts, concentric to the feedline disconnect, coupled with frangible nuts located on the Orbiter half. All interface loads are transferred from this interface to the LH2 feedline, through a flanged connection, and distributed to the crossbeam and EO-2 ball-interface fitting, as described previously.

Both the ET and Orbiter halves of the fluid disconnects contain shutoff valves that are Orbiter activated CLOSED prior to the retraction movement of the Orbiter umbilical plate (approximately 2-1/2 inches). Eight (6-SRB and 1-ET OI) electrical receptacles with pin contacts are mounted in a single electrical disconnect plate assembly on the ET side of the interface. This assembly, in turn, mounts to the aforementioned cluster plate. Disconnection is accomplished through Orbiter umbilical plate retraction. Section IX, *Propulsion System*, and Section X, *Electrical System*, describe the ET/Orbiter functions transferred through this and the EO-5 interface.

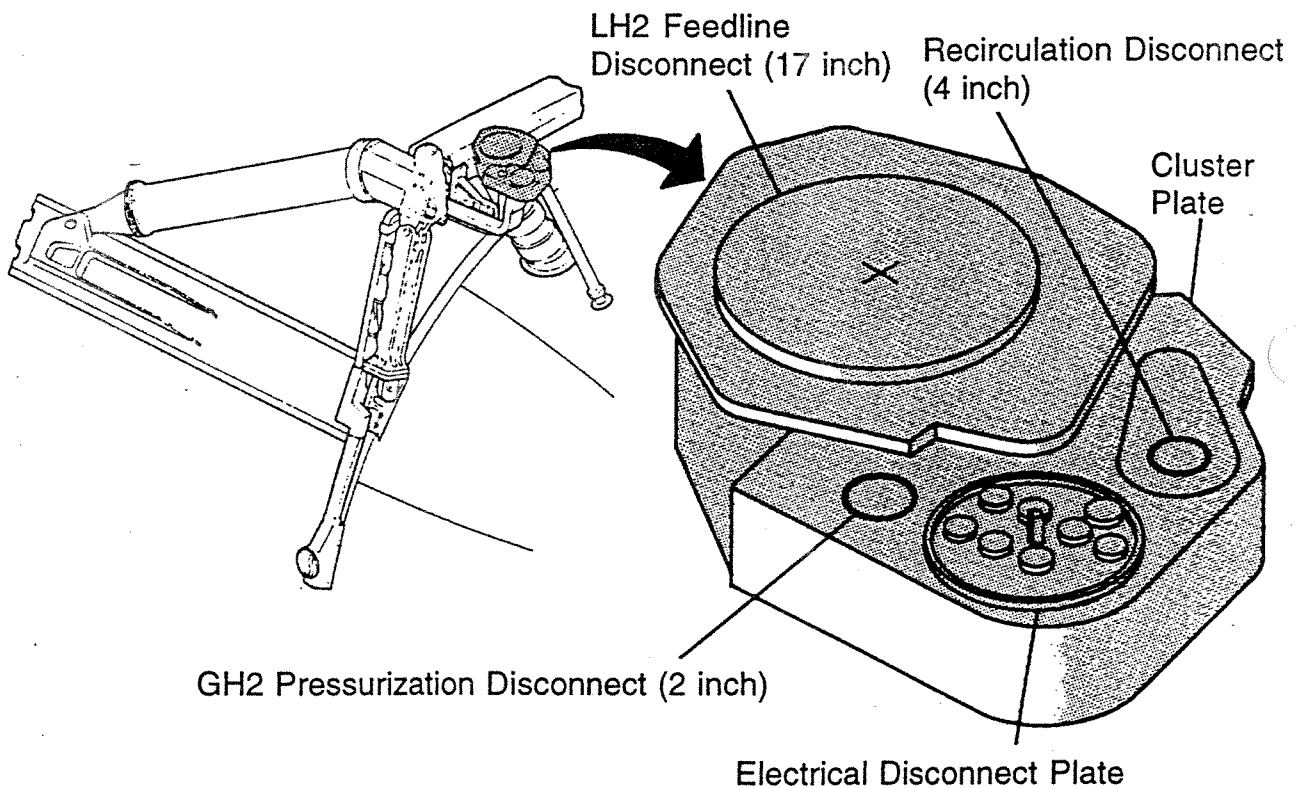


Figure 12-21: ET/Orbiter Left Umbilical Assembly

ET/Orbiter Right Umbilical (EO-5) - The right ET/Orbiter umbilical assembly is configured similar to the left assembly, except for the absence of the 4-inch fluid disconnect.

Interface loads are transferred from this umbilical interface to the LO2 Feedline (flanged connection) and distributed to the crossbeam and EO-3 ball-interface fitting, as previously described.

12.1.4 ET/ORBITER INTERFACE COMPONENT DETAILS

Forward Bipod Structure - The components of the forward bipod structure, and the materials used to make them, are summarized below.

Table 12-2: Forward Bipod Materials

ELEMENT	MATERIAL	CONDITION
• Yoke Fitting	Ti-6AL4V Casting	Annealed
• Right Strut Upper End Fitting	7075 Forging	T736
• Struts (2)	7050 Forging	T736
• Strut Lower End Fitting, L.H.	Ti-6AL4V Casting	Annealed
• Strut Lower End Fitting, R.H. and Adjustable Sleeve	Inconel 718, Bar	
• Spindle (2)	Inconel 718, Bar	
• Spindle Housings (2)	Ti-6AL4V Casting	Annealed

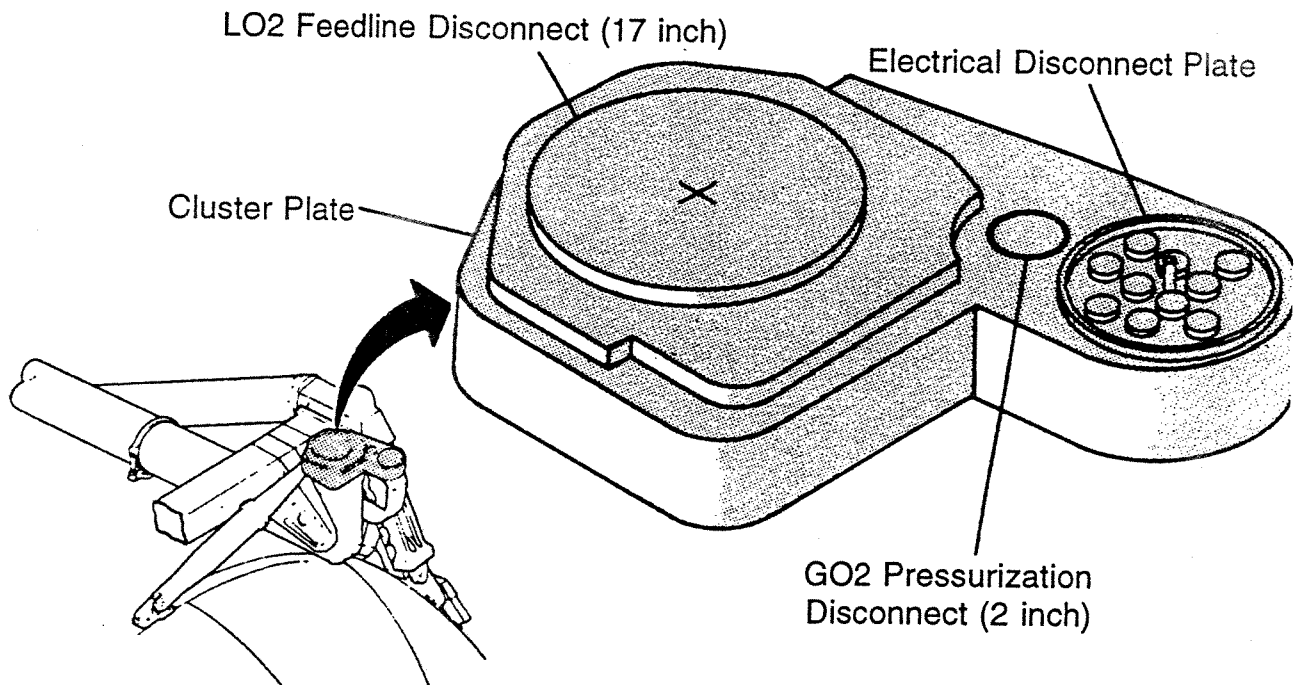


Figure 12-22: ET/Orbiter Right Umbilical Assembly

Bipod Attach Spindle Assembly (2) - The spindle assembly is housed by a cast titanium structure which is machined to mate with the Sta 1129.9 ring frame 16 degrees left and right of the X-Z plane, respectively.

The housing flairs from the 0.5-inch thick mounting base to a hollow cylinder 4-1/4-inches O.D., 3-1/2-inches I.D., and 8-inches long. The outboard end is drilled to a 2-inch diameter.

The spindle device, machined from Inconel 718 bar stock, is retained in the housing by a 1-1/4-inch diameter nut that attaches to the spindle. The inboard end of the spindle is a clevis, inserted between and pinned to the three clevis lugs on the strut end fitting. The pin used at this joint is a 1-1/8-inch O.D. steel shear pin with a 0.344-inch wall thickness.

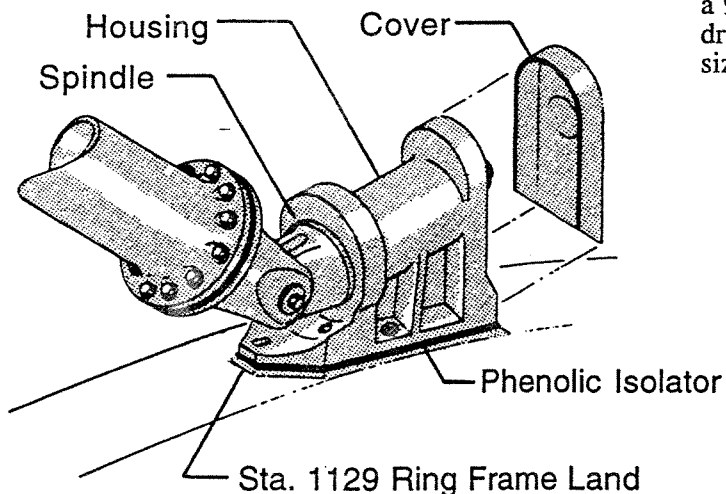


Figure 12-23: Forward Bipod Spindle Assembly

Yoke Fitting - The 74-degree bipod apex angle is formed by the configuration of the cast yoke fitting. From the two 0.96-inch thick clevis lugs on the right end, the fitting flairs out and bends 37 degrees to form the Orbiter interface surface.

This ellipse-shaped surface is machined flat to be consistent with the Orbiter truncated sphere. The Orbiter bolt hole in this fitting is drilled to 2.2525 (+0.0015, -0.0000) inches diameter to a point 5.4 inches below the interface surface where the diameter decreases to form a shoulder stop. This stop will retain the shoulder on the Orbiter bolt once bolt fracture occurs. The underside of the fitting is machined to a 3-inch spherical radius into which a stainless steel washer is inserted.

The left end of the fitting bends 37 degrees and flairs from the 3-inch wide interface surface to a 9-inch O.D., 5/8-inch thick flange. This flange is drilled with twelve slightly oversized bolt holes (bolt size is 5/8-inch diameter).

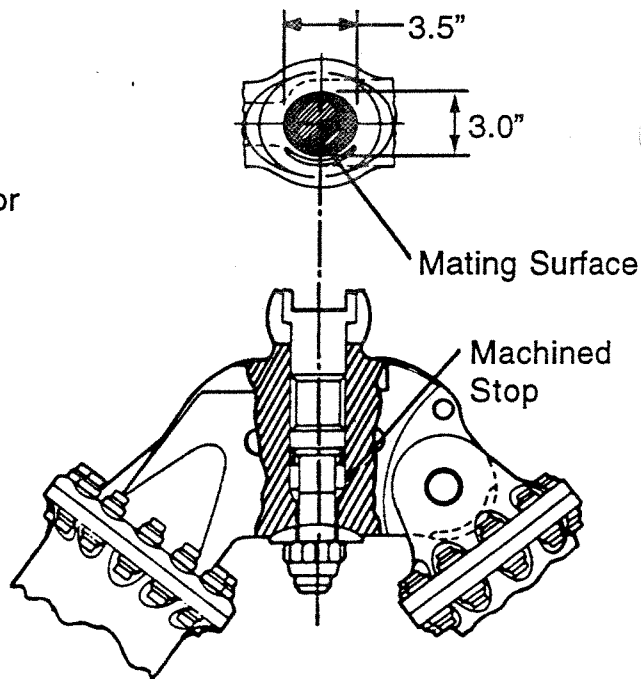


Figure 12-24: Yoke Fitting Details

Left Aft Bipod Structure – The components of the aft left Orbiter support structure, and the materials used to make them, are summarized here.

Table 12-3: Aft Left Orbiter Support Materials

ELEMENT	MATERIAL	CONDITION
• Ball Interface Fitting	7050 Forging	T736
• Thrust Strut	7050 Spin Forging	T73
• Thrust Strut End Fitting	2219 Forging	T6
• Vertical Strut	7050 Forging	T736
• Vertical Strut End Fitting	2219 Forging	T6
• Vertical Strut Tank Fitting	Ti-6AL4V Casting	Annealed
• Shim, Laminate	MIL-S-22499B	

Ball Interface Fitting – The hemispherical interface surface of the ball interface fitting is machined to a 5.275-inch spherical radius with a closely controlled tolerance of +0.000 to -0.005 inches to ensure a maximum interface bearing area. The interface bolt bore through the Z-axis of this fitting is a minimum of 0.375-inches oversize, thereby precluding the transfer of shear loads through the bolt.

The forward transition of this fitting, from the spherical interface surface to the thrust strut flange, is configured as an I-section whose major axis is approximately perpendicular to the thrust strut/vertical strut plane. This orientation results in maximum bending-load-carrying efficiency. The I-section terminates at an integral flat plate that provides the transition to the cylindrical thrust fitting flange.

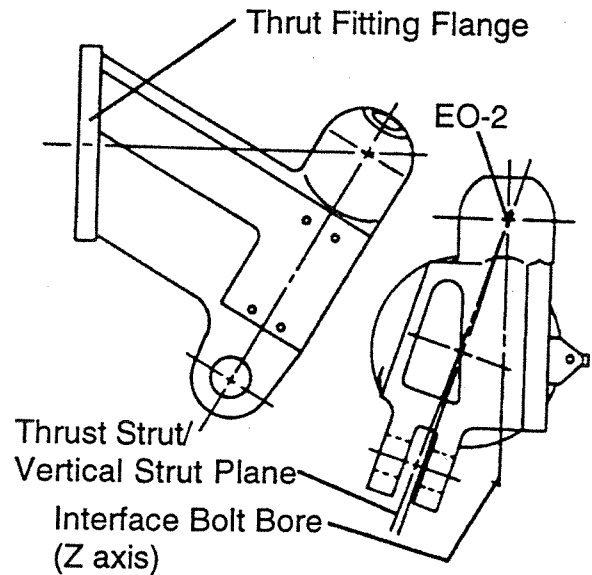


Figure 12-25: Left Ball Interface Fitting Details

Following separation, the interface bolt is retained in the fitting cavity by the closure plate that attaches to the fitting underside by means of three 9/16-inch bolts. Integral to this closure plate is a 5 1/4-inch diameter, 2-inch long honeycomb bolt stop pad that partially absorbs the force of the retracting bolt. Any remaining force is reacted by the 9/16-inch bolts.

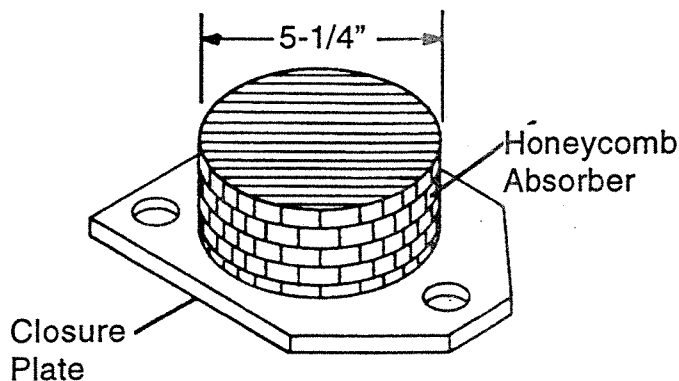


Figure 12-26: Closure Plate/Bolt Stop

Right Aft Tripod Structure - The components of the right aft tripod, and the materials used to make them, are summarized here.

Table 12-4: Diagonal Strut Materials

ELEMENT	MATERIAL	CONDITION
• Diagonal Strut	2219 Forging	T6
• Diagonal Strut Tank Fitting	Ti-6AL4V Casting	Annealed

Crossbeam Structure - The components of the aft crossbeam structure and umbilical/ feedline support structures, and the materials used to make them, are summarized here.

Ball Interface Fitting - All Orbiter interfacing characteristics of this aft fitting are identical to the previously described EO-2 fitting. The I-section transition of this EO-3 fitting includes the top and bottom chord inboard extensions that form the crossbeam interface flange.

Table 12-5: Crossbeam and Umbilical/ Feedline Support Materials

ELEMENT	MATERIAL	CONDITION
• Channel Sections (8)	6061 Extrusions	T6511
• Left End Fitting	2219 Forging	T6
• LH2 Feedline Support Bracket Bulkheads (2)	2219 Forging	T6
• Center Bulkhead	2219 Forging	T6
• LO2 Feedline Support Bulkheads (2) (Includes R.H. End Fitting)	2219 Forging	T6
• Hinge Brackets (2)	7050 Forging	T736
• LH2 Feedline Support Brackets (2)	7050 Forging	T736
• LH2 Feedline Bracket Stiffener	2219 Forging	T62
• LO2 Feedline to Ball Fitting Brace	2219 Plate	T62
• Tie Plate	Aluminum	

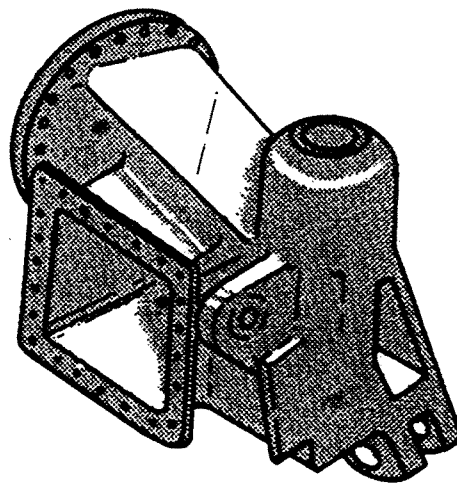


Figure 12-27: Right Ball Interface Fitting Details

Crossbeam/LH2 Feedline Support Brackets – The four-bar translating linkage interconnects the left end of the crossbeam and the LH2 feedline/umbilical support brackets, and allows relative +Y displacement (+3/4-inch) of the latter. The geometry of this linkage consists of four pinned bar elements; two lying in the Y-Z plane (the crossbeam and the feedline support bracket stiffener), and two lying in the X-Z plane (the two hinge members). Each element juncture consists

of being a Z-axis shear pin (1-inch diameter) connection, and the upper joint being comprised of a Y-axis shear pin (1-inch diameter) and self-aligning bearing (monoball) combination.

This combination of joints results in the limited swivel capability of the two hinge members about the fixed crossbeam, and the single-axis lateral motion of the feedline/umbilical support brackets.

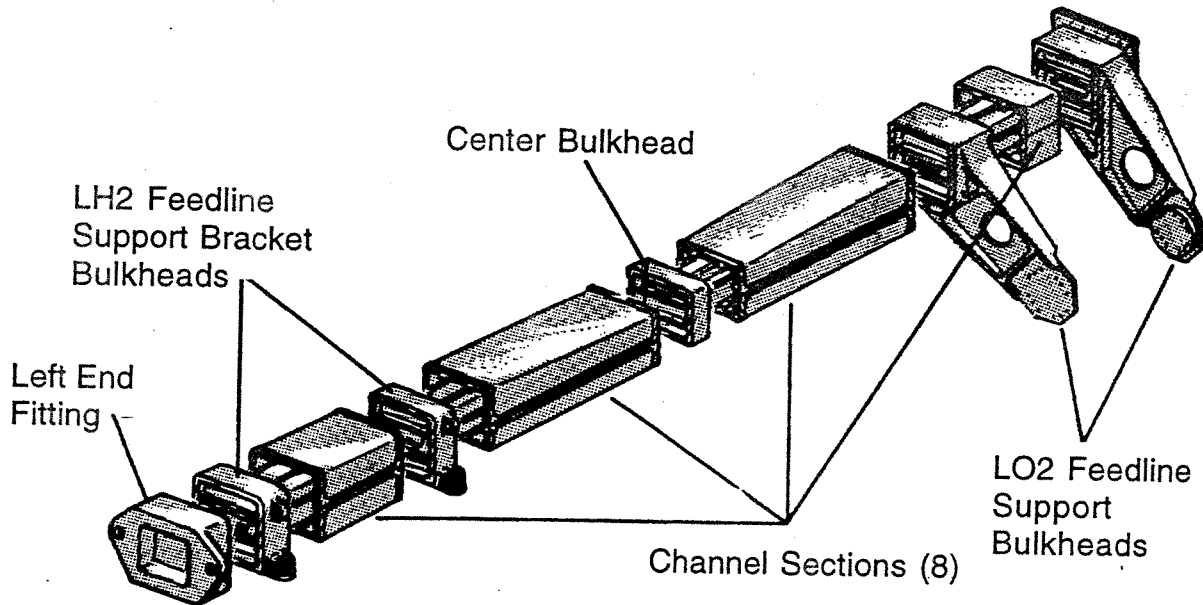


Figure 12-28: Crossbeam Components

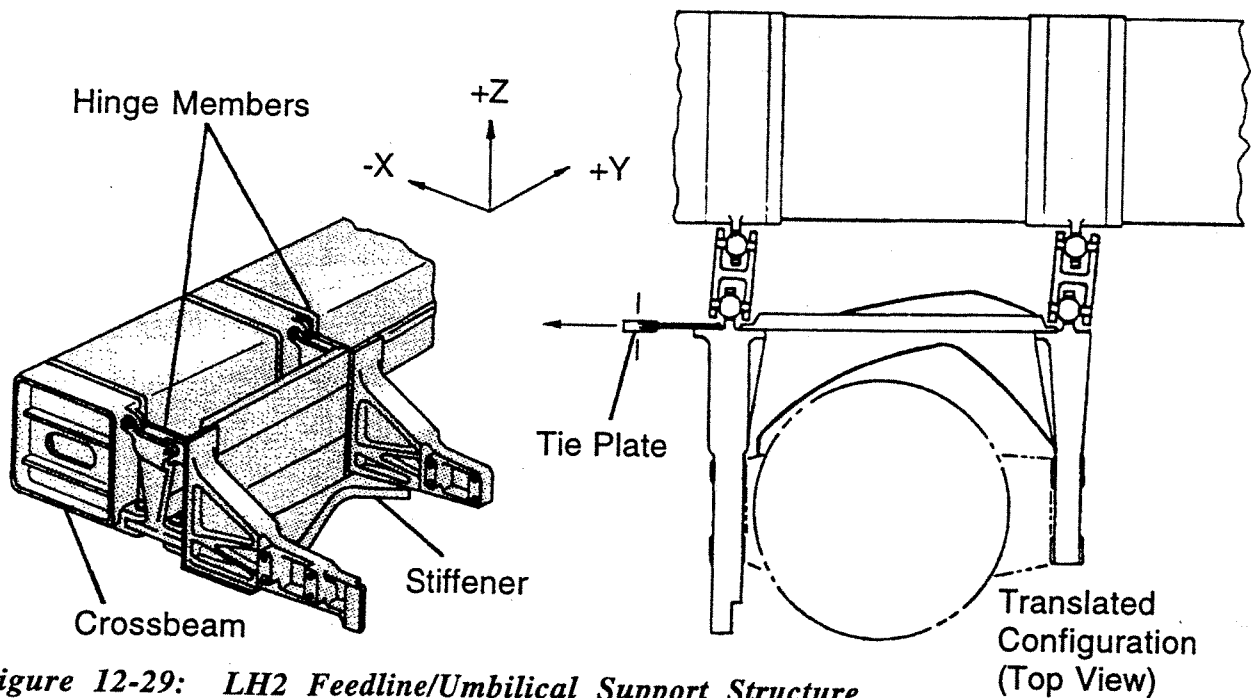


Figure 12-29: LH2 Feedline/Umbilical Support Structure

EO-2 Bipod Structure/Crossbeam Connection
 – The left aft Orbiter support structure is allowed to float laterally relative to the left end of the crossbeam by means of a slip joint. This joint is comprised of two 2.5-inch diameter by 10.5-inch long steel pins press fitted 6.5 inches into the EO-2 ball interface fitting. Two (fore and aft) lugs integral to the left end forging of the crossbeam each house a steel, selfaligning bearing through which the pins are allowed to slide a maximum of 3/4 inches in either direction. A 2-3/4-inch diameter steel retainer plate is bolted to the inboard end of both pins and serves to limit the bipod outboard translation to 3/4 inches, and prevents the pin from escaping the bushing.

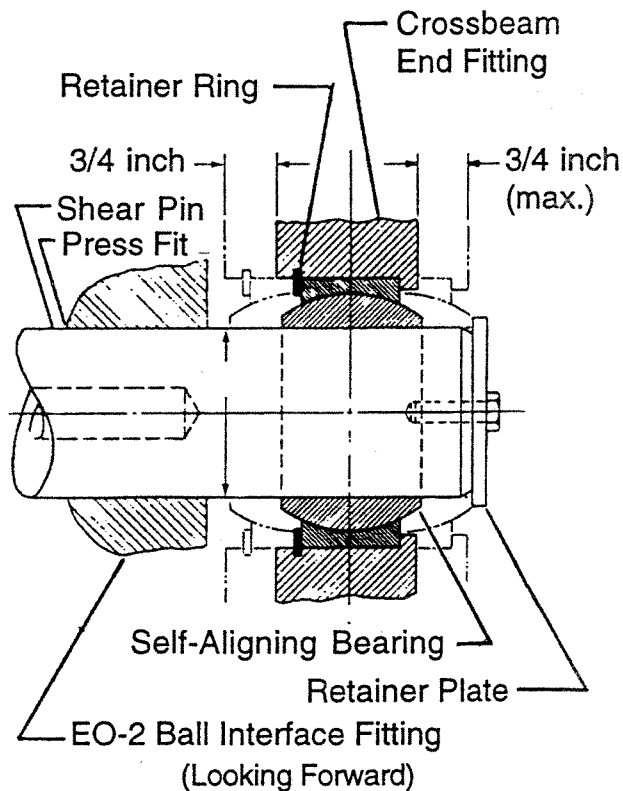


Figure 12-30: Crossbeam/Left Bipod Slip Joint

Umbilical Disconnects – The LO₂ and LH₂ feedline disconnects are 17-inch diameter disconnects that provide propellant feed-through capability between the ET and the Orbiter, and the capability to separate and close-off the interconnecting feedlines. A bolted flange and a Naflex seal connects each disconnect with its respective ET feedline 11-inches below the ET/Orbiter separation plane. With the tank mated to the Orbiter, the disconnect halves are held

together by the 2-1/4-inch diameter umbilical separation system bolts. The Orbiter half includes and retains a compression type interface seal. After the disconnect halves are mated, the flapper closures located on either side of the interface are actuated OPEN. These closures act as butterfly valves when open, imposing a minimum flow resistance. Prior to umbilical separation, the disconnect closures are pneumatically actuated CLOSED by an Orbiter actuator. Drive linkages across the interface close the tank half of the disconnect, which in turn drives the closure in the Orbiter half. The closures are mechanically driven to the CLOSED position when the Orbiter disconnect halves are retracted. This mechanical operation occurs regardless of the pneumatic actuator position. The trapped propellant between the disconnect closures is allowed to dump externally during separation.

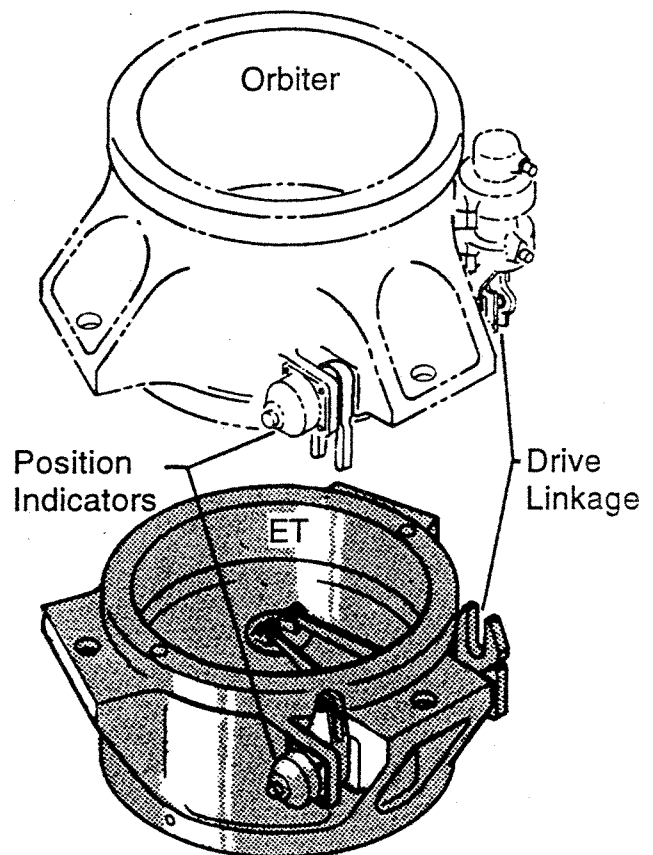


Figure 12-31: ET/Orbiter Feedline Disconnects

LH2 Recirculation Disconnect - The 4-inch disconnect provides the capability to separate and isolate the interconnecting LH2 recirculation and tank replenishment line between the Orbiter and the LH2 tank. A bolted flange connects the ET disconnect half and the LH2 tank recirculation line approximately six inches below the ET/Orbiter separation plane. A Naflex seal is provided at this interface. When mated, the disconnect halves are mounted together by the umbilical separation system described above. The separation interface is sealed by three Orbiter-supplied compression type seals whose effectiveness is enhanced by media pressure. Two of these nonmetallic seals are located at the disconnect surface, and one interfaces with the ET and Orbiter shutoff closure housing. Swing arm closure disks located in each disconnect half are gear driven, and are capable of pneumatic or mechanical opening and closing. These disks are actuated OPEN by Orbiter pneumatic pressure once the disconnect halves are mated. The opening pneumatic pressure is maintained throughout the boost period. After

MECO, Orbiter pneumatic pressure is withdrawn actuating both swing arm disks to the CLOSED position. Spring forces on each disk serve as a backup for disk closure. Fluid trapped between the two closed disks is dumped externally as the disconnect sections are disengaged.

GO2 and GH2 Pressurization Disconnects - These 2-inch disconnects transmit pressurant flow from the Orbiter to the LO2 and LH2 tanks during preload positive pressurization and conditioning, and for ullage pressure maintenance. The ET disconnect halves attach to flanges on the pressurization lines located approximately six inches below the ET/Orbiter separation plane. A Naflex seal is provided at this interface. ET/Orbiter disconnect halves, once mated, are secured by the umbilical separation system bolts. Interface sealing is accomplished by a metal-to-metal seal. Coaxial poppet valves are contained in both disconnect halves and are forced closed by springs as the Orbiter umbilicals are retracted.

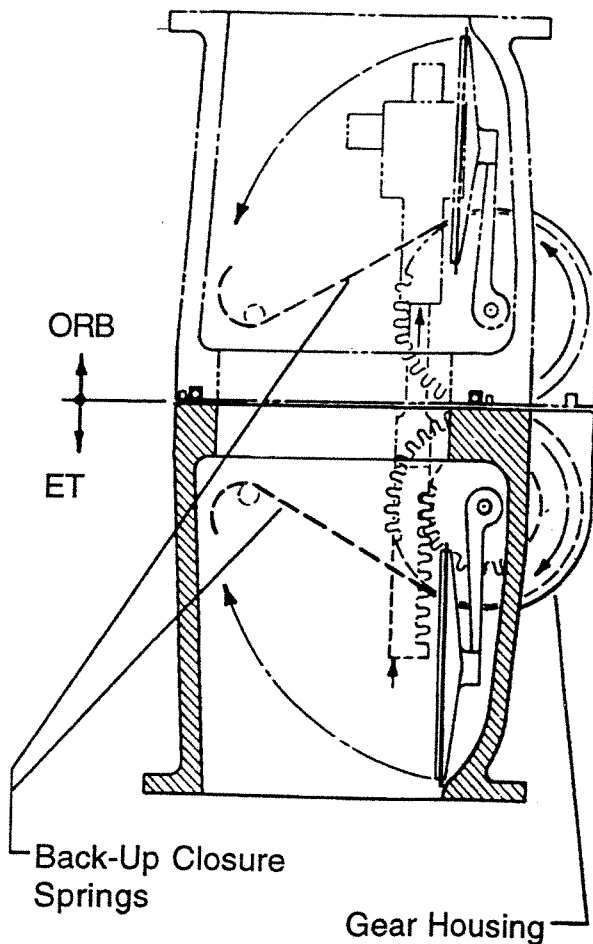


Figure 12-32: 4-Inch Recirculation Disconnect

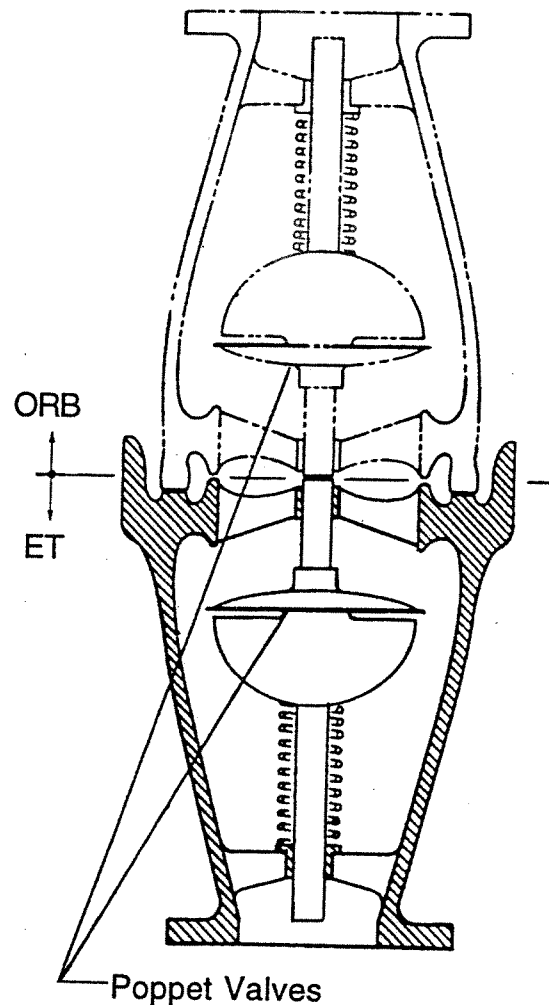


Figure 12-33: 2-Inch Recirculation Disconnect

Electrical Disconnects - The eight left (EO-4) and eight right (EO-5) electrical disconnects all use size-22 shell receptacles.

The connectors are each affixed to a common cluster plate at the respective umbilical interface, and are located approximately 2 inches on center.

Table 12-6: Electrical Disconnects, ET/Orbiter

EO-4			EO-5		
QUANTITY	FUNCTION	MAX. NO. PINS	QUANTITY	FUNCTION	MAX. NO. PINS
4	SRB Signal	55	4	SRB Signal	55
2	SRB Power	12	2	SRB Power	12
1	ET OI	55	1	ET OI	55
			1	RSS	41

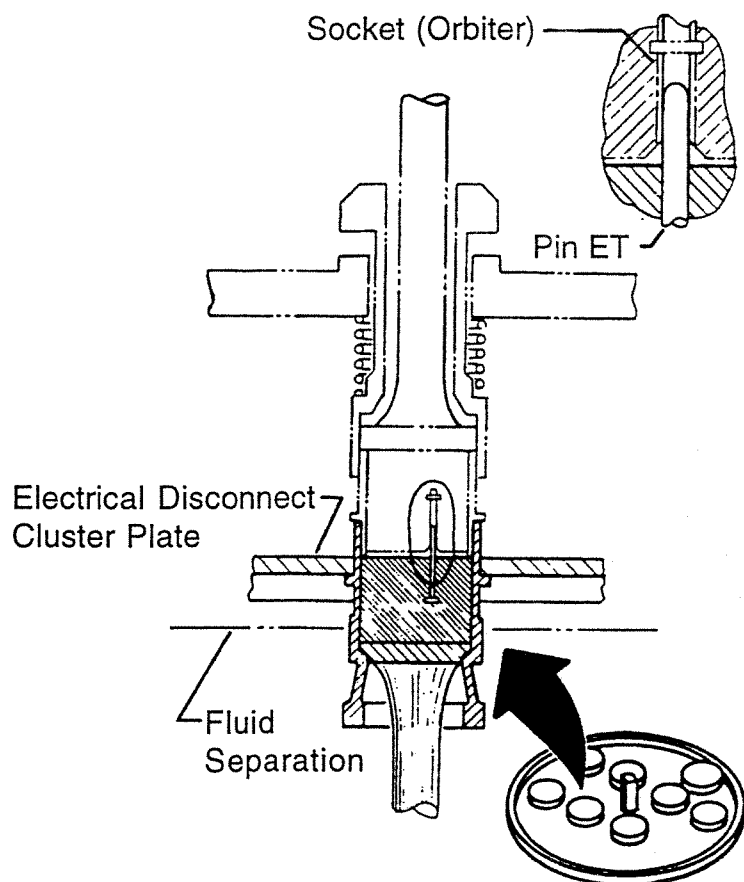


Figure 12-34: ET/Orbiter Electrical Disconnects

12.1.5 ET/FACILITIES INTERFACES

An ET intertank interface with the ground facility pressurization, vent and electrical systems is provided through a fallaway launch umbilical system. This system is referred to as the ET hydrogen vent umbilical system. The umbilical consists of a hardline subassembly, which is the main structural member between the ground

facility and the ET intertank. The hardline subassembly is a part of the GH2 vent system. Flexibility is provided in the umbilical through flex hoses at each end of the hardline subassembly. Other pneumatic and electrical lines and cables are routed on bracket ties to the hardline subassembly.

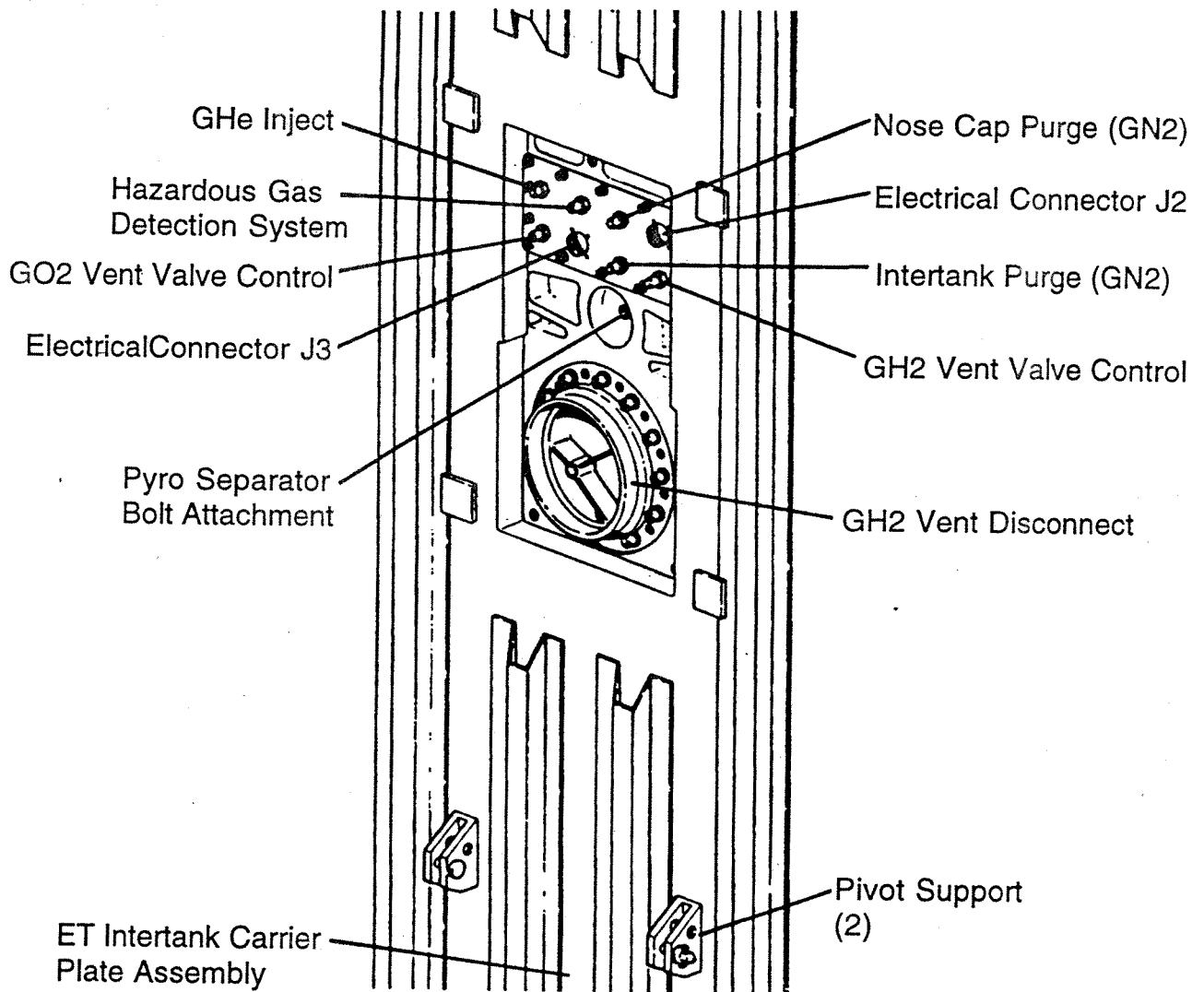


Figure 12-35: ET Intertank Carrier Plate Assembly

The hardline subassembly terminates with a ground umbilical carrier assembly (GUCA). The GUCA interfaces with the ET intertank carrier plate assembly (ETCA). Each of these carrier assemblies contain their respective sections of the disconnect component for the electrical or gas system. A pyrotechnic bolt (pyro separator assembly) is used to attach the GUCA to the ETCA.

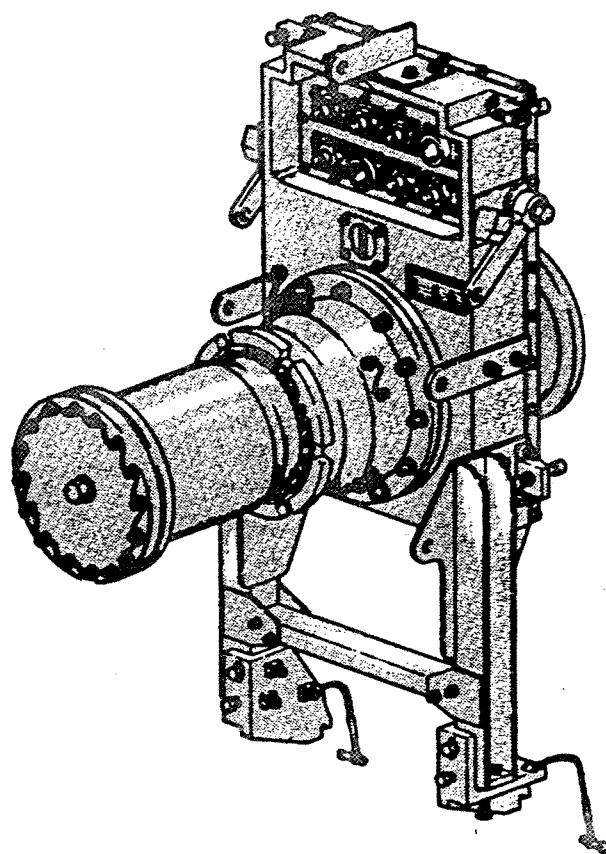


Figure 12-36: Ground Umbilical Carrier Assembly (GUCA)

The pyro separator assembly (pyrotechnic bolt) is a cartridge actuated device used to attach and release the -GUCA. Upon receipt of an appropriate electrical stimulus, one or both pyrotechnic cartridges will fire. This will generate sufficient gas pressure to operate an internal piston in the separator assembly causing the assembly to break at the pre-determined fracture point. The pyro separator assembly consists of a separator bolt, an internal piston, an adapter, and two pyrotechnic cartridges. Each cartridge incorporates a NASA Standard Initiator (NSI) that is welded into the cartridge body. The NSI is used to initiate the cartridge.

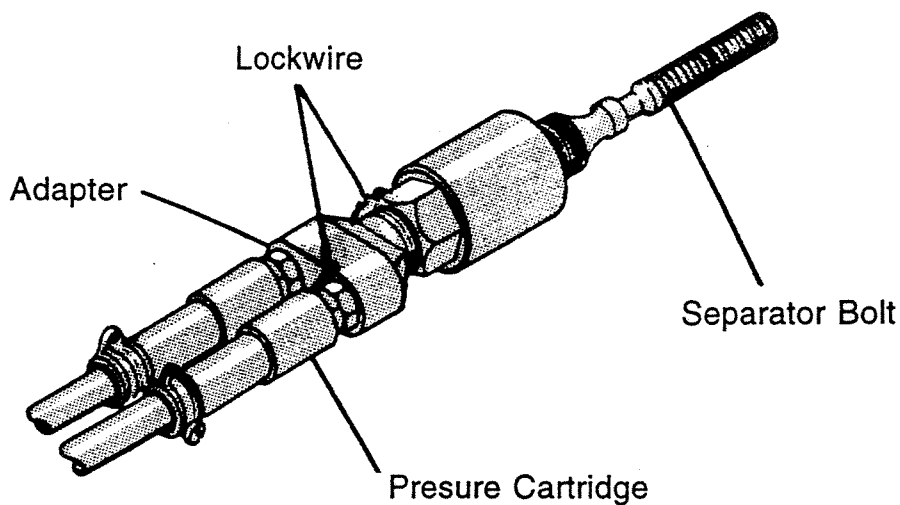


Figure 12-37: Pyro Separator Assembly

The ET hydrogen vent umbilical is separated from the intertank at T-0. Firing of the pyrotechnic bolt frees the GUCA from the intertank. This is the primary mode of separation. In the event that the pyrotechnic bolt failed to actuate, a facility lanyard which is attached to the GUCA will provide a secondary mode of release. The bolt is designed with a frangible section. The lanyard force produced by the vehicle rise will break the bolt.

With the breaking of the pyrotechnic bolt, the GUCA pivots on the ET intertank supports. After approximately 20 degrees of rotation, the GUCA leg assemblies are free from the support pivot pins. The hydrogen vent umbilical continues retracting downward and away from the vehicle. The umbilical motion is achieved through the facility launch pivot assembly and a dead weight withdrawal system. The withdrawal system

maintains a constant load on the umbilical from the time the umbilical installation is completed on the launch pad up to the point of separation at T-0.

The launch pivot assembly, after completing its retract motion, is mechanically locked to prevent motion toward the vehicle as the umbilical follows its drop path. An arresting cable is provided to decelerate the umbilical. A mechanical latching device secures the umbilical in the retracted position.

The GUCA complete with the disconnects and the pyrotechnic bolt is mated to the ET intertank at the VAB. On the launch pad, an access arm is used to provide for the prelaunch servicing and checkout of the ET intertank area, for the lifting and mating of the hardline subassembly to the GUCA.

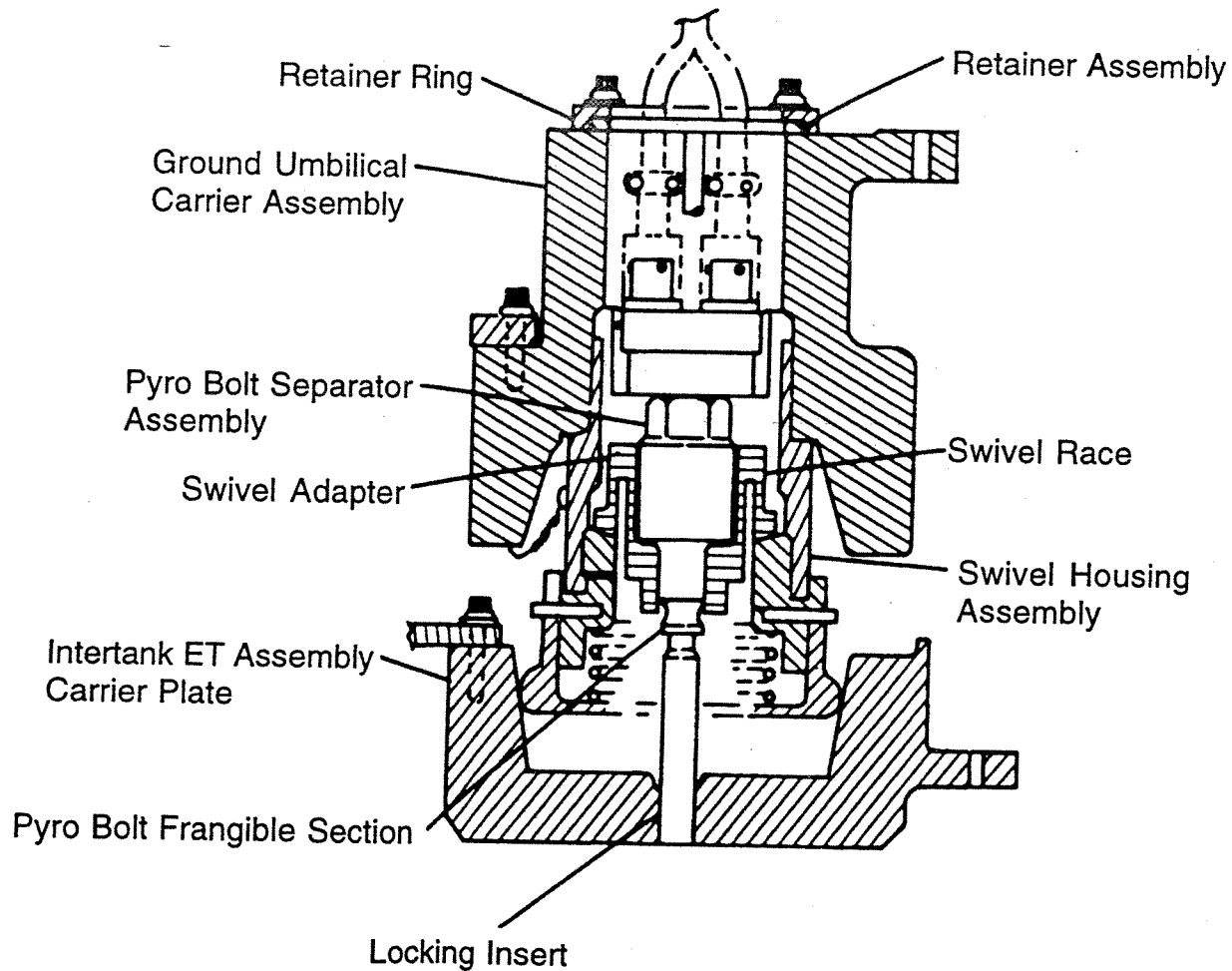


Figure 12-38: Separation Assembly Installation

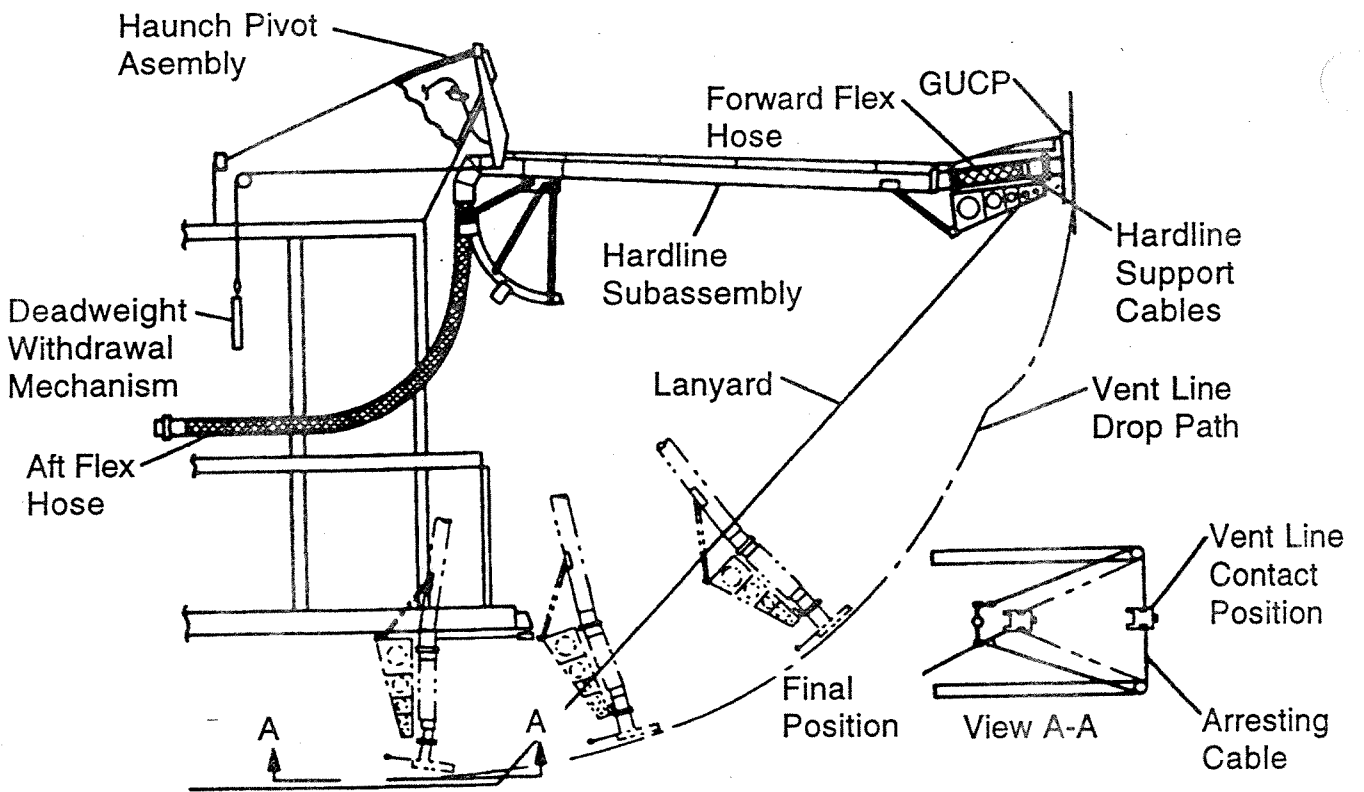


Figure 12-39: ET Hydrogen Vent Umbilical System

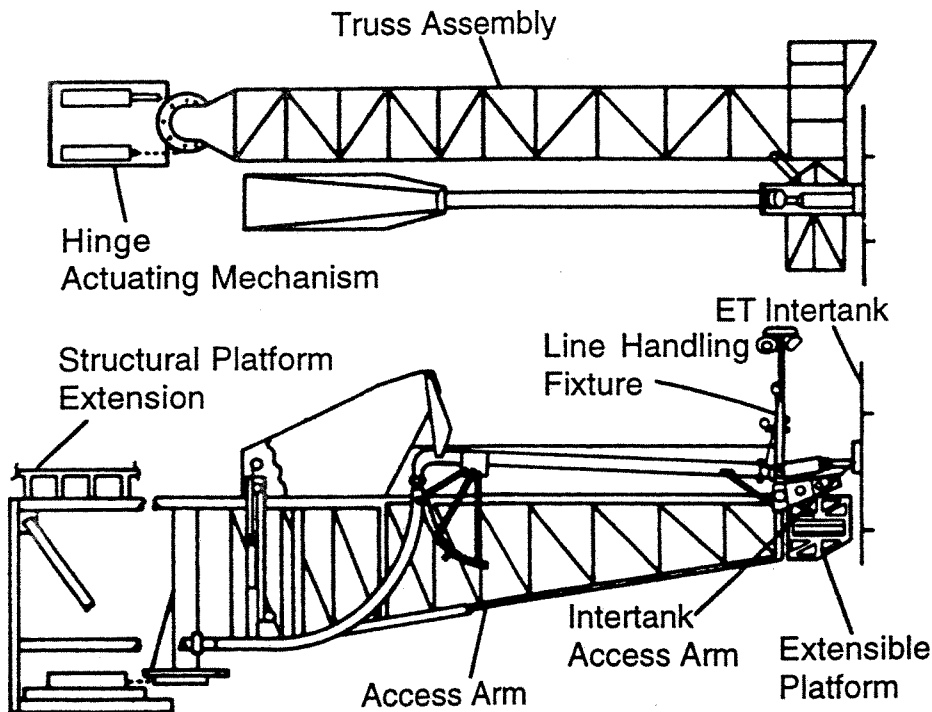


Figure 12-40: Intertank Access Arm

12.1.6 ET TRANSPORTATION AND HANDLING INTERFACES

ET ground handling and transportation interface provisions are designed integral to the flight hardware, and are located to minimize any associated weight impact. Appropriate support equipment, categorized as transportation and support equipment (TSE) and described in Section XIII, Launch Site Facilities/Equipment, is attached to these handling interfaces to accomplish ET intersite transportation, erection/de-erection, and mating with the SRBs and Orbiter. After the TSE is removed, TPS closeouts are applied as required.

12.1.7 TRANSPORTATION INTERFACES

ET ground mobility is achieved through the use of modified Saturn-1B transporters. One aft and two forward TSE transportation fittings provide the interface between the ET and the transporter. This three-point mount prohibits the introduction of torque loads into the ET resulting

from transporter rocking, and provides a structurally determinate load system. The forward interfaces are located at the SRB forward thrust interface points (EB-1, left; EB2, right). Each interface consists of two TSE fitting halves that bolt together through the respective flight interface centerline. The half of the fitting adjacent to the stainless steel spherical insert is tapered linearly to preclude direct contact with this flight interface surface.

The aft ET transportation interface provisions are symmetrically located with respect to the ET -Z axis, and consists of two external lands on the Sta 2058 main frame and two threaded inserts located in integral stiffeners at Sta 1973.5. All fore and aft transportation loads (+0.5g) are reacted at the main frame lands as shear, while bending resulting from the Winch ET-to-transporter offset are transferred to the Sta 1973.5 frame through the H-shaped TSE transportation fitting. These loads are introduced to the frame as kick loads.

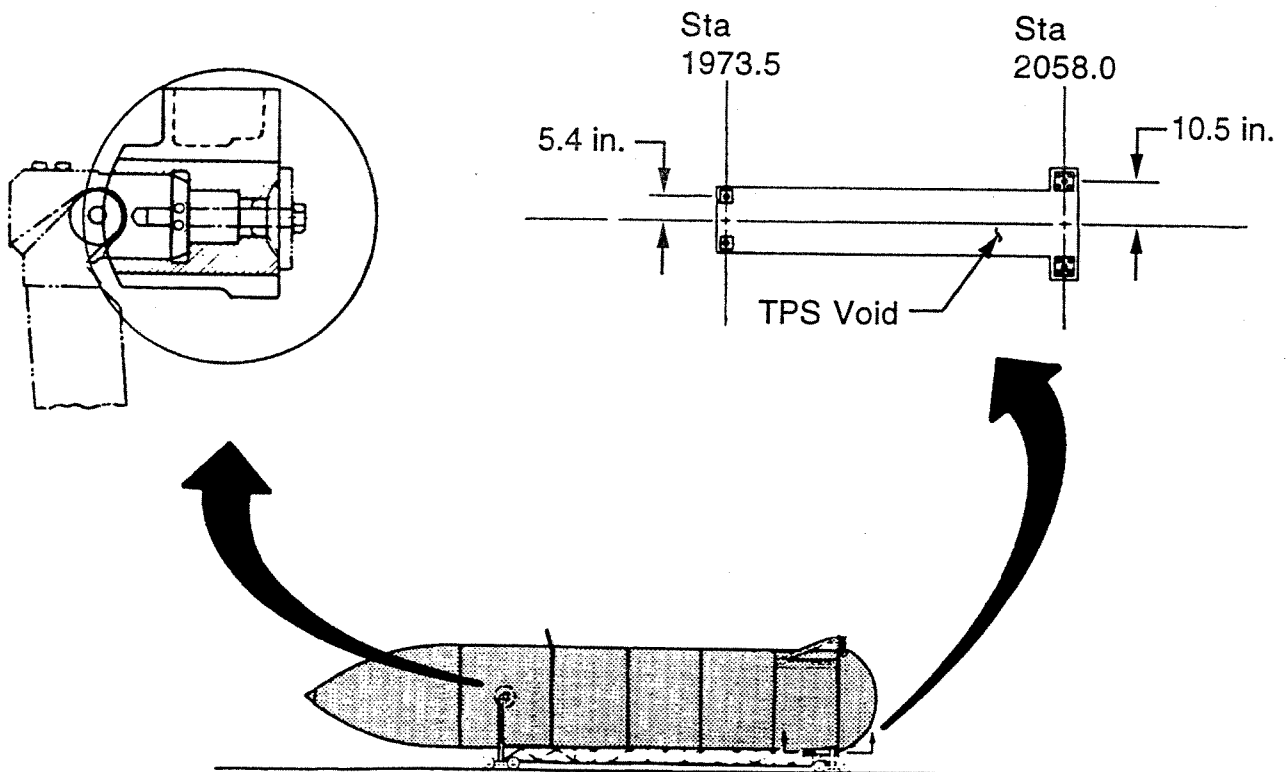


Figure 12-41: ET/Transporter Interfaces

12.1.8 AFT BIPOD SUPPORT STRUT

The aft (EO-2) Orbiter support structure is aligned and stabilized by means of a TSE support strut. The strut remains affixed to the ET until the aft bipod structure has been attached to the respective Orbiter interface. This strut represents a minimal interface impact to the flight hardware, and is therefore described in Section XIII, *Launch Site Facilities/Equipment*

12.1.9 HOISTING INTERFACES

The ET is erected/de-erected from two forward hoist fitting interfaces that are machined integral to the SRB forward thrust fittings, and two aft hoist fitting interfaces adjacent to the aft ET/Orbiter interfaces.

Each of the forward TSE hoist fittings are pinned to the integral rectangular lug located on the +Z side of the respective forward thrust fitting using a single 1.5-inch diameter pin. The hoist fittings extend in the +Z direction to a point 20 inches above the tank centerline.

Each of the aft TSE hoist fittings is attached to the outboard side of the respective ball interface fitting with four 3/4-inch diameter bolts and a 3-7/8-inch by 3-inch shear pin located within the TSE fitting. Threaded inserts are contained in the ball interface fittings to accommodate this attachment.

All hoisting interfaces and related equipment are designed to a 2g load environment.

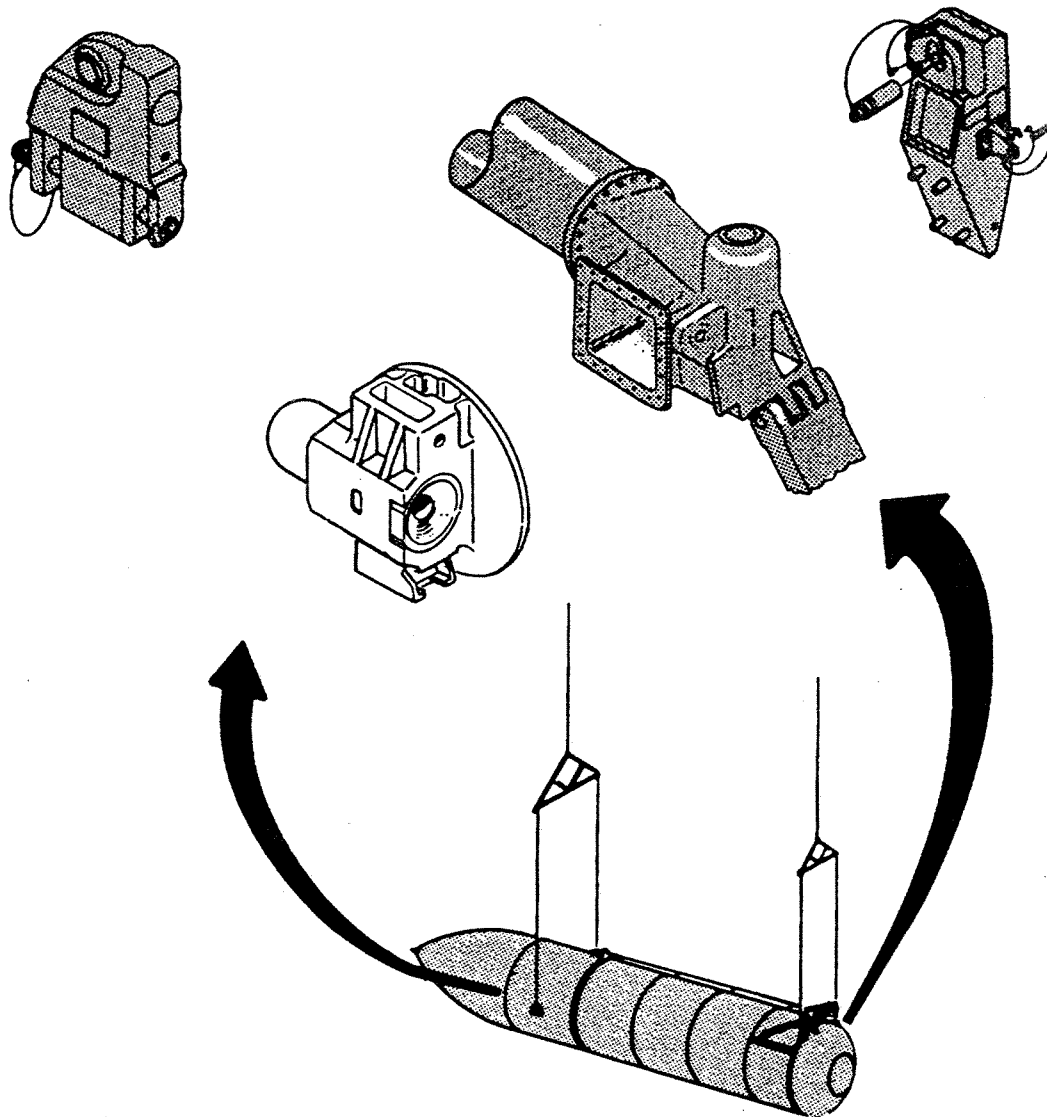


Figure 12-42: ET Handling Interfaces

12.2 OPERATIONS

Mating and separation characteristics of the previously described ET/Space Shuttle vehicle interfaces are presented here in the sequence of occurrence.

12.2.1 ET/SPACE SHUTTLE VEHICLE INTEGRATION

Integration of the ET with the Space Shuttle vehicle at KSC is performed on the MLP in the VAB. The assembly process starts with attachment of the ET to the two assembled SRBs, followed by the addition of the Orbiter. After integrated vehicle checkout is completed, the MLP is moved to the launch complex where fluid connections are completed between the ETCA and the launch facility fluid lines.

ET/SRB Assembly – ET-to-SRB assembly begins by positioning the two SRBs on the MLP so that the span between the SRB forward thrust attach points and their elevation coincide with the

geometry of the forward attach fittings on the ET (EB1, left; EB-2, right). The ET, suspended from a sling attached to handling lugs integral with the ET forward SRB fittings, is then lowered onto the SRB forward fittings. GSE guides and pins are used to facilitate final seating alignment, and are then replaced by the flight frangible bolt/nut assembly. At this point the ET is suspended entirely from the two forward attach points. The sequence of attaching the aft ET/SRB stabilizing struts begins with the attachment of the right and left diagonal struts to the ET upper fittings (EB-5, left; EB-6, right). One strut is preadjusted to length, the other is adjusted to fit. The upper lateral struts are assembled to the SRBs, adjusted to fit, and attached to the upper ET fittings (EB-3, left; EB-4, right). The lower struts are then similarly attached to the SRBs, adjusted and bolted to the ET lower fittings (EB-7, left; EB-8, right). The ET/SRB attachment is completed by mating electrical pull-away connectors located on two aft lateral struts, and by completing the electrical connections to the forward attach point frangible bolt.

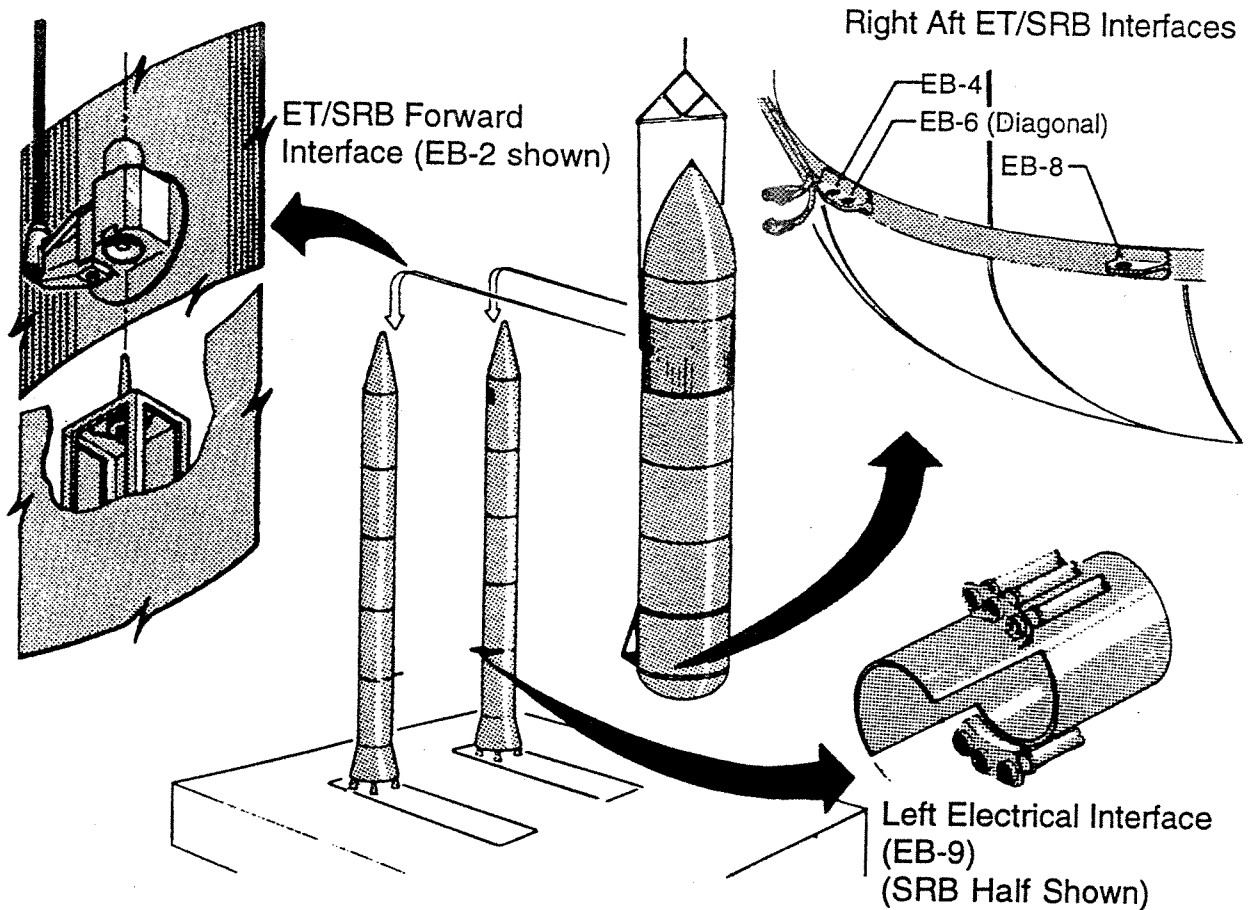


Figure 12-43: ET/SRB Integration

ET/Orbiter Assembly – The Orbiter is erected and vertically aligned with the ET by means of a sling set and jacks attached to the Orbiter. The two aft ET/Orbiter structural interface points (EO-2, left; EO-3, right) are attached first. Both attachment points are hemisphere (ET) to socket (Orbiter) interfaces with concentric, retaining bolt/frangible nut assemblies.

The right interface (EO-3) is a fixed reference point; the left ET attach point (EO-2) is free-floating laterally once the Orbiter socket has captured the ET hemisphere. Prior to this, a temporary adjustable support strut is employed to hold the left attach point in position. The two Orbiter-supplied interface bolts are installed, but final torquing is deferred until the forward attachment (EO-1) is completed.

The forward ET/Orbiter interface is assembled in a two phase operation. The first phase requires the ET bipod struts to be installed at the two tank fittings. The apex yoke fitting is preinstalled to the Orbiter truncated sphere, prior to the Orbiter hoisting operation, with a frangible bolt/nut assembly.

Final assembly of this forward interface then occurs by drawing the Orbiter, via the ET-provided yoke fitting, onto the ET pivotal bipod. The strut flanged joints are then bolted together. One of the struts has an adjustable sleeve that is used to obtain the required lateral (+Y) alignment tolerance for EO-1 with respect to the ET/Orbiter fixed datum (EO-3).

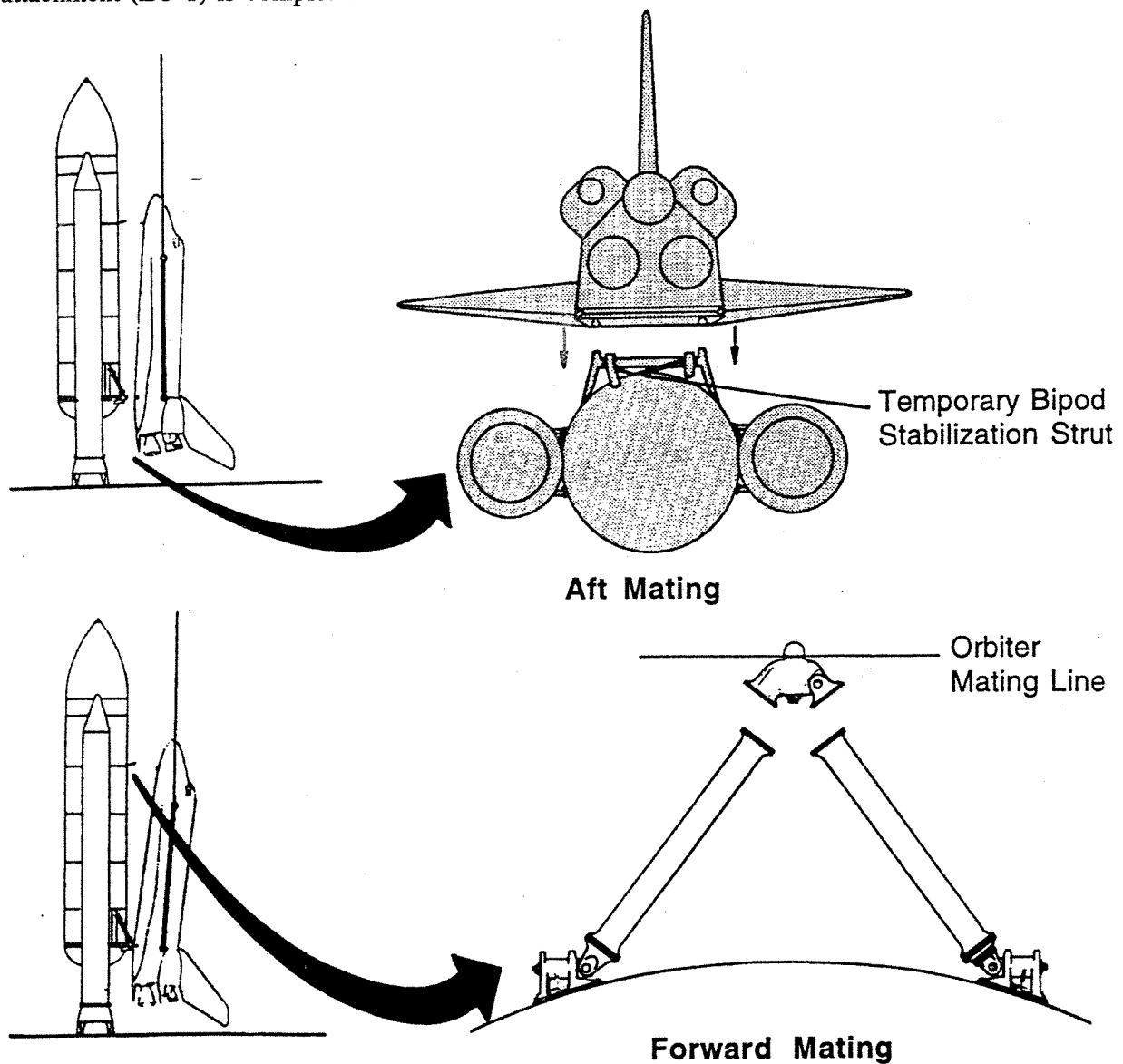


Figure 12-44: Orbiter/ET Mating

The ET/Orbiter aft umbilical disconnects (EO-4 and EO-5) are the next interfaces to be mated. Once interface protective covers are removed from both the disconnect halves, the Orbiter halves of both umbilical plates are extended from their retracted position and aligned with the ET halves (ET halves are fixed with respect to the ET/Orbiter aft structural interfaces). They are secured using three Orbiterprovided, frangible nut/bolt combinations per cluster assembly. Shut-off valves, located in each disconnect half of the fluid interfaces, are in the CLOSED position during mating, and are pneumatically opened (Orbiter-controlled function) once the umbilical interfaces are secure.

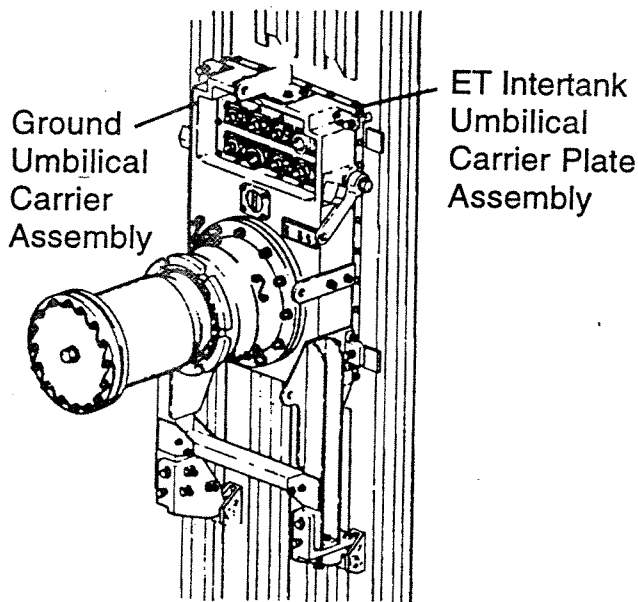


Figure 12-45: Mated Ground Umbilical Interface

ET/Facility - The GUCA, having been installed on the intertank ETCA during ET checkout, remains with the ET throughout the vehicle integration flow. The six facility fluid transfer lines, an electrical grounding cable, two disconnect lanyard cables, and two support lanyard cables emanating from the launch complex tower are permanently attached to the GUCA after the integrated vehicle (supported from the MLP) has been positioned at the launch complex.

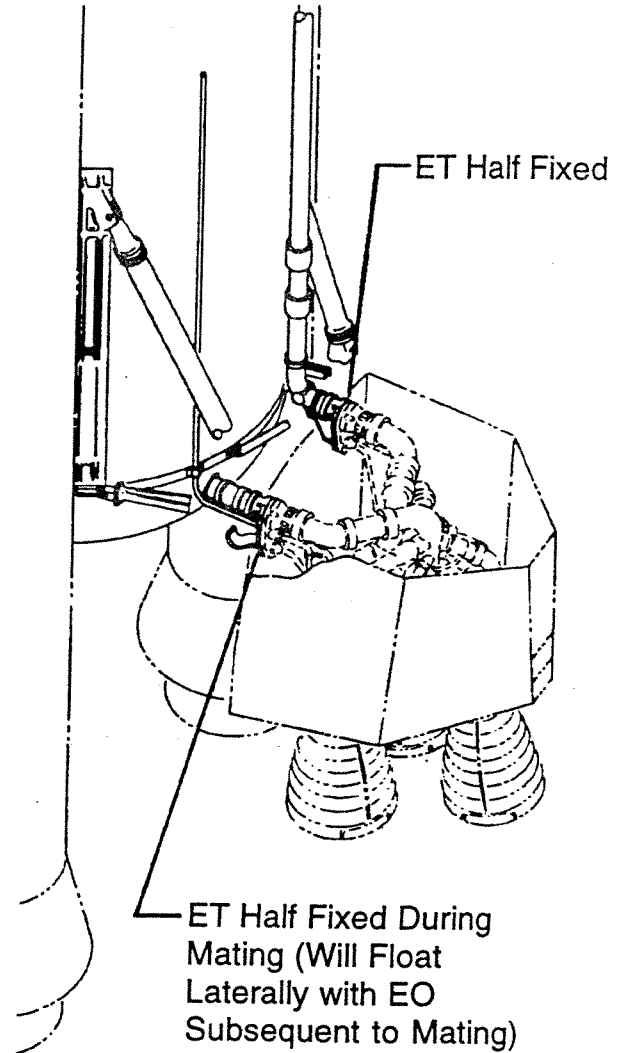


Figure 12-46: ET/Orbiter Umbilical Plates Mated

12.2.2 SEPARATION

Ground and flight separations require a variety of interface disconnects and disconnect functions.

Ground Separation Functions - The GUCA separates from the ET intertank carrier plate assembly through fracture of a pyrotechnic bolt. This separation occurs at T-0. The fluid and pneumatic lines utilizing this umbilical interface remain open throughout the remainder of flight.

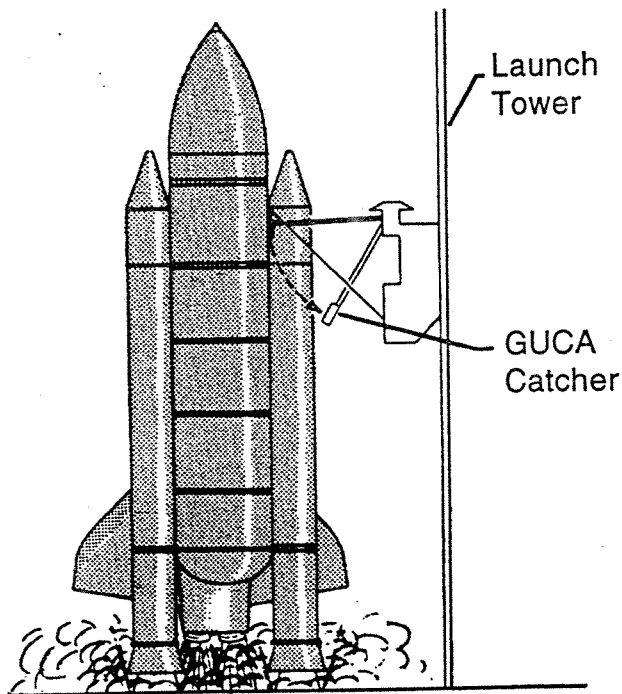


Figure 12-47: Ground Umbilical Carrier Assembly Separation

Flight Separation Functions - SRBs are staged simultaneously at 126 seconds into the flight and at an altitude of 24 nautical miles. The staging sequence, initiated by the Orbiter after SRB burnout, consists of a pyrotechnic fracture of all retaining interface bolts or structure and activation of SRB staging rockets to avoid recontact with the still accelerating Orbiter/ET assembly. The ET performs a passive role, providing neither separation signals nor forces.

At separation the two forward SRB frangible bolts (EB-1 and EB-2) fracture in tension at ET Sta 985.968. Each half of the fractured bolt is reWned by the ET and SRB, respectively, by design of the interface fittings.

The six aft SRB struts (EB-3 through EB-8) are designed to separate near their midpoints when self-contained pyrotechnic charges are initiated by Orbiter command. The ET retains approximately one-half the length of each strut after separation. Pull-away electrical connectors, mounted on two of the struts in the plane of the separation, are separated as the SRBs move away.

ET/Orbiter separation occurs approximately 488 seconds into flight at an altitude of 59 nautical miles. The separation sequence is controlled by the Orbiter; the ET has a totally passive role in this operation.

After the Orbiter main engines have reached zero thrust (zero vehicle acceleration), the Orbiter main propulsion system's prevalues are commanded CLOSED, followed by closure of the LH2 recirculation disconnect valve and the 17-inch propellant feed disconnects. Each of the valve assemblies have closures on both sides of the separation interfaces. After the three frangible nuts at each aft umbilical interface fracture, the two Orbiter umbilical disconnect assemblies (EO-4 and EO-5) are then pneumatically retracted approximately 2.5 inches toward the Orbiter, separating all fluid and electrical disconnects.

The 2-inch pressurization lines contain poppet valves at each of the umbilical interfaces that are spring-actuated closed through this retraction movement. The disconnect assemblies are locked in the retracted position for the remaining Orbiter flight period.

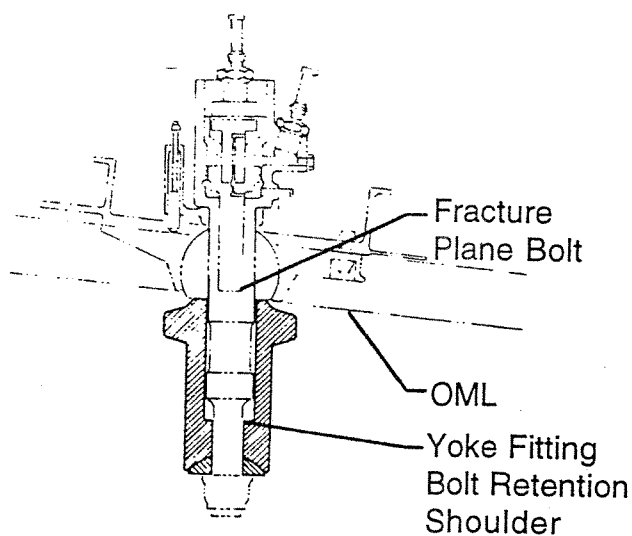


Figure 12-48: Forward ET/Orbiter Attachment Hardware

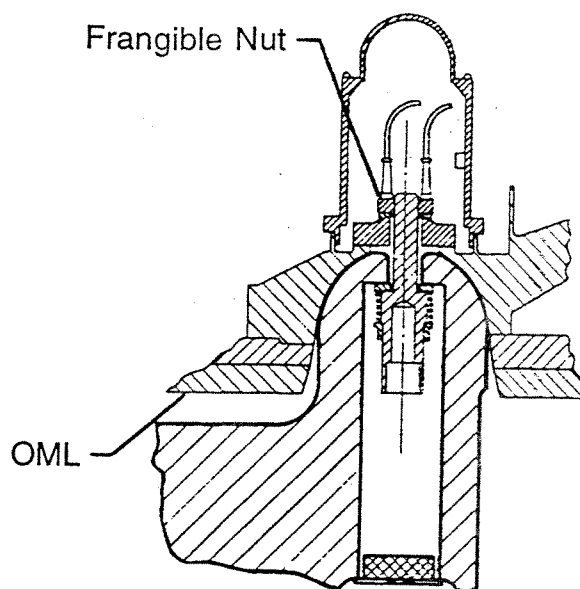


Figure 12-49: Aft ET/Orbiter Attachment Hardware

All structural attachments are pyrotechnically separated by simultaneous signals. This completes the separation of the ET from the Orbiter. The Orbiter translates from the inactive ET with Orbiter RCS propulsion and subsequently gains the additional velocity required for orbital insertion using its OMS engines.

The mechanical attachments consist of one frangible bolt/nut assembly at the forward interface (EO-1) and a frangible nut-bolt at each of the aft structural attach points (EO-2 and EO-3). When these attachments are pyrotechnically separated, the fractured parts of the separation bolts and nuts are retained by the respective ET and Orbiter attach fittings. The aft ET attachment struts remain passive; the forward bipod structure is pivoted and restrained forward by a spring and restraint mechanism. This pivot action precludes recontact with the Orbiter during the separation sequence.

13. LAUNCH SITE FACILITIES/EQUIPMENT

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13. LAUNCH SITE FACILITIES/EQUIPMENT

The ET is off-loaded at the KSC Barge Turning Basin and towed to the VAB High Bay Transfer Aisle. It is erected vertically and placed in the ET Checkout Area of High Bay 2 or 4 for Premate checkout and then hoisted to the Integration Area of High Bay 1 or 3 for stacking on the MLP with Orbiter and SRBs. Final movement is in the stacked mode to the Launch Pad for final Space Shuttle checkout and launch.

13.1 PROCESSING/FLOW

The ET and associated ship-loose hardware will be transported to KSC by barge.

13.1.1 KENNEDY SPACE CENTER

Upon arrival at Kennedy Space Center (KSC), the ET and associated ship-loose hardware will be off-loaded and transferred from the barge to a vertical storage or checkout cell in the VAB, one checkout cell and one storage cell in High Bay 4 and one checkout cell and one storage cell in High Bay 2.

Operations for erecting the ET in the High Bay begins with positioning of mobile access platforms to facilitate visual inspection, disconnection of special shipping instrumentation, and attaching forward and aft hoist slings. The ET will be hoisted from its transporter by the high bay cranes and rotated to vertical. The ET will then be translated into a vertical storage cell or checkout cell in High Bay 2/4. The storage cell provides only the minimum access and equipment required to secure the tank in position, release the crane,

and perform operations incidental to the storage function. Optical alignment measurements needed to determine the amount of shimming required to erect the ET between the SRBs will normally be done in the storage cell, but can, if necessary, also be performed in the checkout cell. In the latter case, checkout operations would be interrupted to provide stability of the ET and platforms while the measurements are made. After transfer to the checkout cell, both permanent and mobile platforms will be positioned to provide access to inspect the ET for possible damage experienced in transit and to remove hoisting equipment.

At KSC the ET checkout, as with all Space Shuttle operations, will be controlled and accomplished with the KSC developed Launch Processing System (LPS). This is an automatic computerized approach to checkout operations, organized by facility area functions or locations and resulting in what are termed Station Sets. Each Station Set will contain a computer input/output arrangement for connecting to flight hardware and/or SE, thereby automatically accomplishing all checkout activities in a particular facility area or location.

13.2 MAJOR FACILITIES

The major facilities required for support of the ET at KSC consist of the Barge Turning Basin, Vehicle Assembly Building, and Launch Pad.

KSC Major Facilities Requirement – The KSC/ET major facilities requirements and associated services required are shown in the following matrix.

Table 13-1: KSC/ET Facility Requirements Matrix

FACILITY	SERVICES REQUIRED
Barge Turning Basin	<ul style="list-style-type: none"> • Dock and apron for Transporter/ET off-loading from barge
VAB High Bay Transfer Aisle	<ul style="list-style-type: none"> • Transporter towing and parking space. • Hoisting Capability <ul style="list-style-type: none"> – ET Hoist from Transporter – ET Erection – ET Transfer to Checkout Area – ET Transfer to Integration Area
VAB High Bay 2 or 4	<ul style="list-style-type: none"> • ET to Facility Support Brackets - One set for each ET per High Bay • ET to Facility Positioning Brackets - One set for each ET per High Bay • Fixed and Movable ET Access Platforms - Access Platforms shall include facility lighting, electrical power, and facility compressed air as required • Facility air conditioning for Intertank area access • Orbiter Umbilical Simulator Carrier Support • GHe and GN2 supply for Pneumatic Console
VAB High Bay 1 or 2	<ul style="list-style-type: none"> • Nose Cone Access Platform with 110/60/1 facility service and lighting • Forward Orbiter and SRB connection, and Intertank area Access Platform with 110/60/1 facility service, lighting and air conditioning for Intertank area access (Contingency requirement for Intertank area.) • Aft Orbiter, Umbilical and SRB Connection Access Platform with 110/60/1 facility service and lighting
Launch Pad A/Pad B	<ul style="list-style-type: none"> • LH2 Propellant Servicing - 392,900 Gal. at a Maximum Flow Rate of 12,000 GPM • LH2 Propellant Main Feed Line Umbilical Connection Access Platform • Television Coverage of the LO2 and LH2 Umbilical Connections • Intertank Area Access Platform with 110/60/1 facility service, lighting, air conditioning for Intertank area access, He for LO2 and LH2 Tank vent valve actuation and He inject, He for Umbilical Intercavity Purge, an HGDS connection, a grounding connection, GN2 for Intertank area purge and an LH2 ET vent. (Contingency Requirement for Intertank area.) • Propellant Servicing- 145,700 Gal. at a Maximum Flow Rate of approximately 1,400 GPM

KSC/ET Base Support Facilities Requirements - Base Support requirements consist of support services and consumable supplies provisioning requirements that are controlled and furnished by NASA/KSC for use by NASA and contractor organizations. The level of support required for ET operations will be determined by KSC/ET contractor personnel during the course of ET test and checkout

planning activities. Detailed forecasts and justifications will be submitted on a timely basis and as a continuing effort to NASA/KSC. This will enable NASA to furnish support services and consumable supplies as scheduled by the ET contractor. The following table references the support services which may be required for ET operations.

Table 13-2: ET Operations Support Services

Barge Turning Basin	<ul style="list-style-type: none"> • Transporter Tractor • Operational Communications - RF • Truck with Lift Gate • Quality Support • Safety Support
VAB Transfer Aisle	<ul style="list-style-type: none"> • Transporter Tractor • Hoisting Capability, East/West and North/South • Operational Intercommunications - Audio (OIS) • Mobile Platform Parking Area • Handling Sling Storage Area • Truck with Lift Gate • Quality Support • Safety Support
VAB High Bay 2 and 4 ET Checkout Areas	<ul style="list-style-type: none"> • Hoisting Capability, East/West • Operational Intercommunications - Audio (OIS) • Operational Communications - Wideband/Message Center/ • Audio Tape Recording System/Television or Wideband • Data Tape Recording • Administrative Communications - Telephones • Gaseous Nitrogen/Gaseous Helium/Ozone/Liquid Nitrogen • Vacuum Pump • Portable Air Conditioning (Contingency Requirement) • Shoe Cleaners • Vacuum Cleaners • Instrumentation Support • Sampling and Fluid Analysis • Photography Support • Precision Cleaning Support • Quality/Safety Support • Office Space - Comfort Air Conditioned • Tool Crib - Comfort Air Conditioned • Warehousing- Comfort Air Conditioned • Proof Testing • Pick-up Trucks • Passenger Vehicles • Bulk Freon/Alcohol • Personnel Protective Equipment • Furniture and Fixtures • Office Equipment • Instrument Calibration and Repair • Supply Support

Table 13-3: ET Operations Support Services (continued)

VAB High Bay 1 and 3 Integration Areas	<ul style="list-style-type: none">• Hoisting Capability, East/West• Operational Intercommunications - Audio (OIS)• Gaseous Nitrogen• Gaseous Helium• Portable Air Conditioning (Contingency Requirement)• Shoe Cleaners• Instrumentation Support• Photography Support• Quality Support• Safety Support
Launch Pads and Launch Complex 39	<ul style="list-style-type: none">• Operational Intercommunications - Audio (OIS)• GN2 High Pressure• GN2 Low Pressure• Gaseous Helium• Portable Air Conditioning (Contingency Requirement)• Liquid Oxygen• Liquid Hydrogen• Instrumentation Support• Photography Support• Quality Support• Safety Support• Operational Television System

Access Provisions - Access to the different levels required for visual inspection, disconnection of special shipping instrumentation, and attaching

forward and aft hoist slings is provided by positioning the VAB extensible platforms

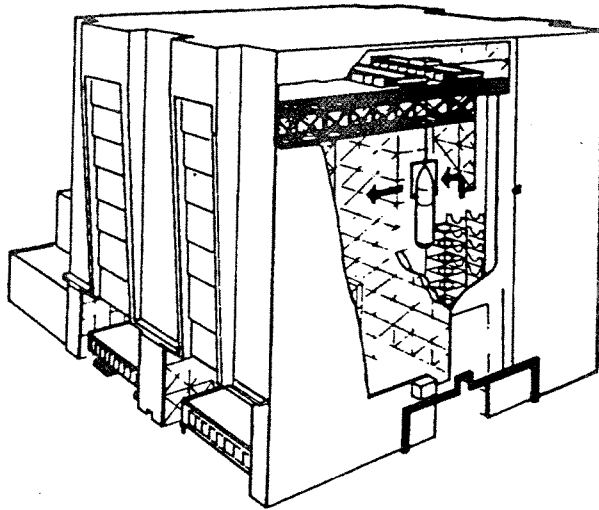


Figure 13-1: Vertical Assembly Building

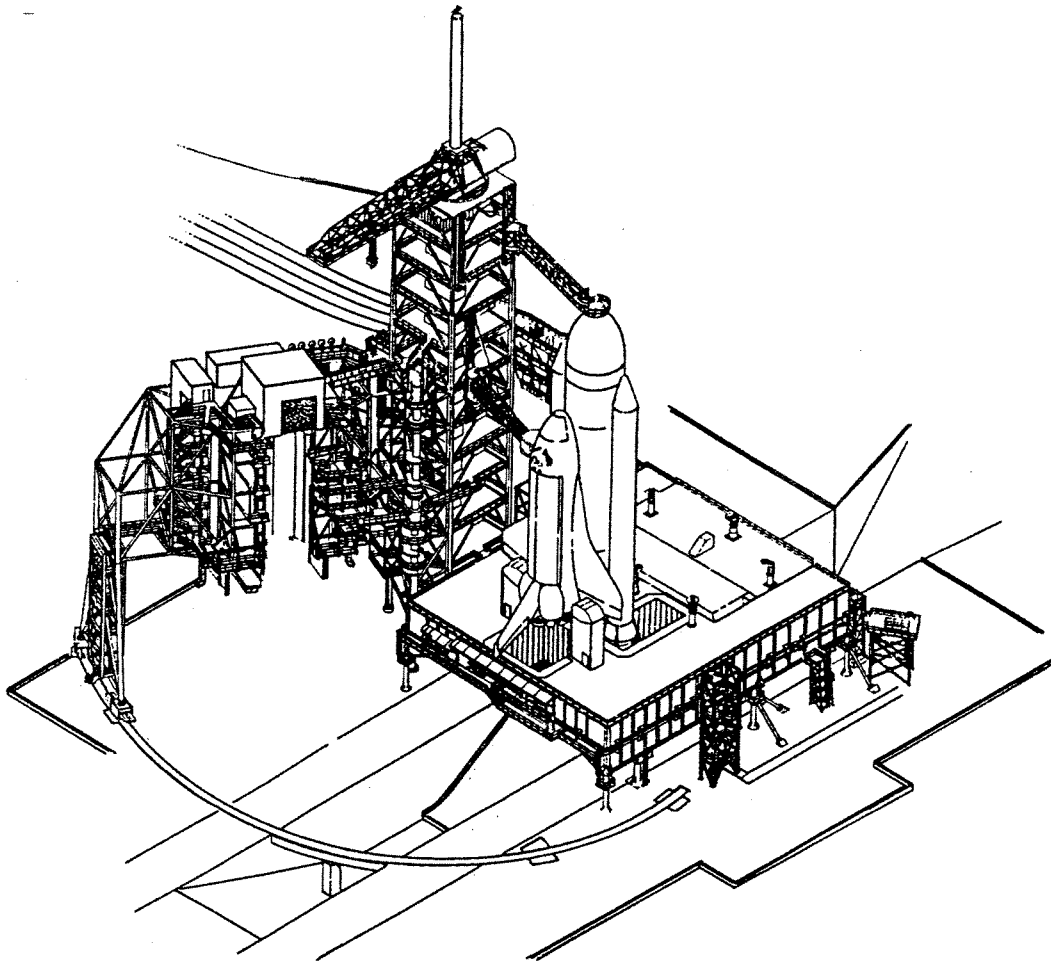


Figure 13-2: Space Shuttle Launch Pad at KSC

13.3 MAJOR SUPPORT EQUIPMENT

Numerous items of equipment are required to support the ET to provide the capability for transportation and handling, test and checkout, TPS closeout, and internal access (to and at the launch site). This support equipment is frequently discussed in two different manners. In this SDH they are identified in an operational category and a functional category. The "Support Equipment" table lists the SE in an alpha-numeric sequence.

The operational category is divided into three commonly used sub-categories; rotational support equipment (RSE), common support

equipment (CSE), and contingency equipment (CE). The RSE is used to deliver an ET to the launch site, removed from the ET, and returned to MAF for reuse with another ET. The CSE is used to support ET handling and maintenance at the launch site. CE is used at the launch site to support unplanned ET operations such as tank entry, LO2 feedline replacement, etc.

The functional category is divided into four subcategories; transportation and handling, test and checkout, TPS closeout, and internal access. The remainder of this section briefly discusses the SE in a functional sub-category arrangement.

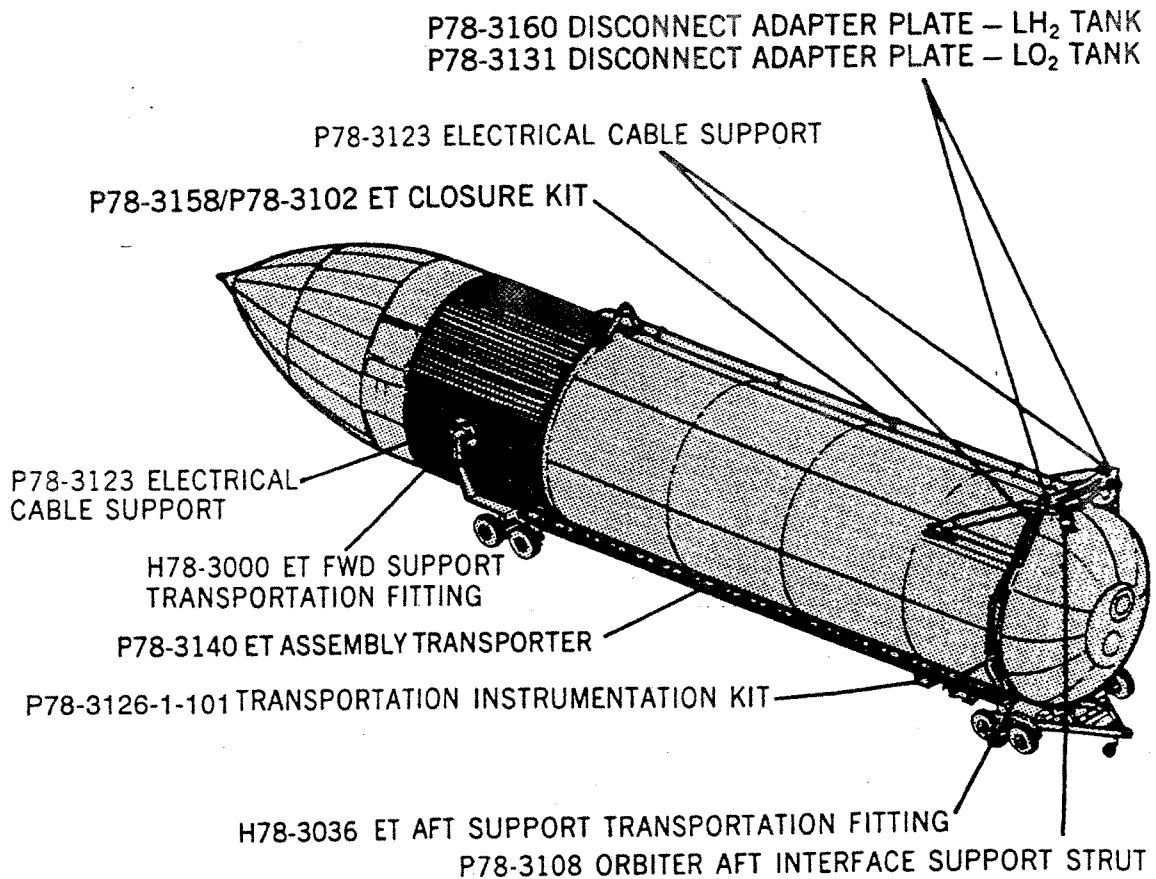


Figure 13-3: Rotational Support Equipment Interface

Table 13-4: Support Equipment

Tool No.	Nomenclature	Operational Category			Functional Category			
		RSE	CSE	CE	Trans. and Handling	Test and Checkout	TPS Closeout	Internal Access
A78-3602	LO2 Internal Access Platform (Vertical)			X				X
A78-3603	LH2 Internal Access Platform Set (Vertical)			X				X
A78-3604	Internal Vertical Intertank Access Kit		X					X
A78-3605	Intertank Access Door		X					X
A78-3606	LO2 Aft Dome Access Kit			X				X
A78-3607	LH2 Aft Dome Access Kit (Manhole Protector)			X				X
A78-3616	LH2 Tank Internal Access Equipment (1-man)			X				X
A78-3619	LH2 Fwd Manhole Installation Removal Tool			X				X
C78-1316	GO2 Vent Duct Leak Test Covers		X				X	
H78-3000	ET Fwd Support Transportation Fitting	X				X		
H78-3004	ET Aft Sling Set		X			X		
H78-3006	ET Fwd Sling Set		X			X		
H78-3007	ET Aft Hoisting Adapter Fittings		X			X		
H78-3008	ET Fwd Hoisting Adapter Fittings		X			X		
H78-3016	Ogive Cover Plate Handling Set			X			X	
H78-3017	Manhole Cover Handling Set			X			X	
H78-3019	Aft SRB Attach Fittings Handling Set			X			X	
H78-3020	LH2 Feedline Handling Set			X			X	
H78-3021	Bellows Support, LH2 Vent Line			X			X	
H78-3022	LO2 Feedline Handling Set			X			X	
H78-3028	ET Fwd Transportation Fittings Handling Set		X			X		
H78-3034	ET Fwd Hoisting Adapter Handling Set		X			X		
H78-3035	ET Restraint System Fitting Set			X			X	
H78-3036	ET Aft Support Transportation Fitting	X			X			
H78-3040	ET Aft Hoisting Adapter Fittings		X		X			
H78-3041	ET Fwd Sling Set		X		X			
P78-3101	Breather Set	X			X			
P78-3108	Orbiter Aft Interface Support Strut	X			X			
P78-3123	Electrical Cable Supports	X			X			
P78-3126-1-101	Instrumentation System	X			X			
P78-3131	LO2 Disconnect Adapter Plate	X			X			
P78-3137	GH2 and GO2 Pressurization Line Blank-Off Plate Kit	X			X			
P78-3140	ET Assembly Transporter	X			X			
P78-3158	Closure Kit Ball Ftgs	X			X			
P78-3160	LH2 Disconnect Adapter Plate	X			X			
P78-3171	Dehydrator	X			X			

13.3.1 TRANSPORTATION AND HANDLING

The major support equipment used for transportation and handling of an ET to and at the launch site is briefly described in the following paragraphs.

ET Forward and Aft Support Transportation Fitting - The ET Forward and Aft Support Transportation Fittings, H78-3000 and H78-3036 respectively, provide the support and interface necessary between the ET and the ET Transporter. These fittings provide a three-point mount for the ET which prohibits the introduction of torque loads resulting from transporter rocking, and provides a structurally determinate load system. The fittings are complete with attaching hardware for installation to the ET and Transporter.

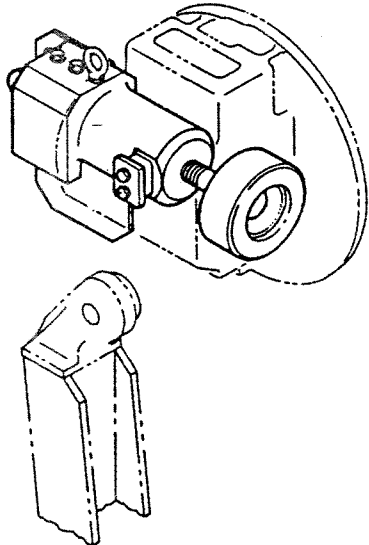


Figure 13-4: ET Forward Support Transportation Fitting (H78-3000)

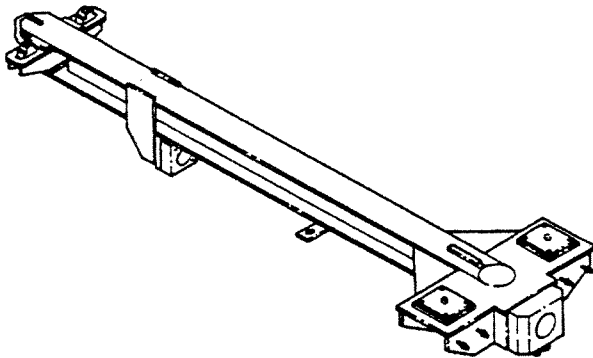


Figure 13-5: ET Aft Support Transportation Fittings (H78-3036)

ET Aft Sling Set - The H78-3004 ET Aft Sling Set is a spreader bar type lifting device that is utilized in combination with the H78-3006 ET Forward Sling Set during ET hoisting and handling operations at KSC for lifting the complete ET assembly on and off the ET Transporter, and for ET erection.

ET Forward Sling Set - The H78-3006 ET Forward Sling Set is a spreader bar type lifting device. It is utilized in combination with the H78-3004 ET Aft Sling Set, H78-3040 ET Aft Hoisting Adapter Fittings, H78-3008 ET Forward Hoisting Adapter Fittings and facility overhead cranes for ET Hoisting and Handling Operations. These operations include lifting the horizontal ET out of the P78-3100/P783140 ET Transporter, vertical erection and vertical alignment of the ET in the VAB as required.

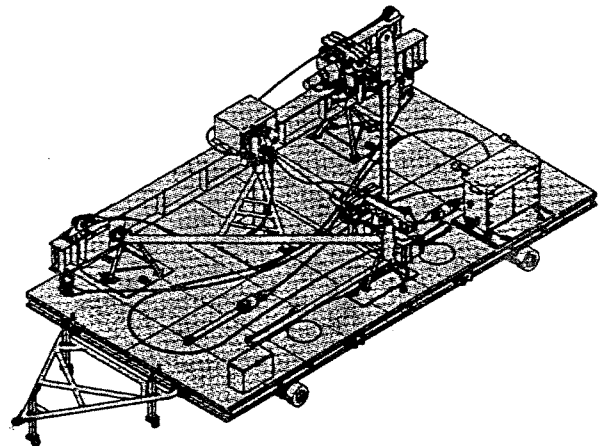


Figure 13-6: ET Forward Sling Set (H78-3006)

ET Aft Hoisting Adapter Fittings – The H78-3040 ET Aft Hoisting Adapter Fittings are designed to interface with the Aft ET/Orbiter Attach Strut Interface Assembly, the H78-3004 ET Aft Sling Set, the third leg sling attachments of the H78-3006 ET Forward Sling Set, and the H78-3035 Restraint Fittings. The H78-3040 Fittings are installed at KSC and utilized in all ET handling operations including erection and de-erection.

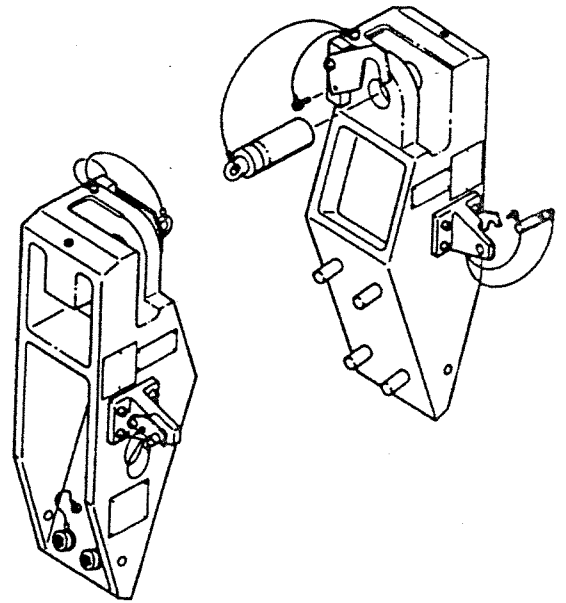


Figure 13-7: ET Aft Hoisting Adapter Fittings (H78-3040)

ET Forward Hoisting Adapter Fittings – The H783008 ET Forward Hoisting Adapter Fittings are utilized in combination with the H78-3040 ET Aft Hoisting Adapter Fittings for ET lifting operations when using the H78-3004 and H78-3006 Sling Sets at KSC. The H78-3008 Set provides the interface between the ET Forward Sling Set (H78-3006) and the ET Forward SRB fittings. Each H78-3008 fitting is provided with an interface for attaching an H78-3035 Restraint Fitting.

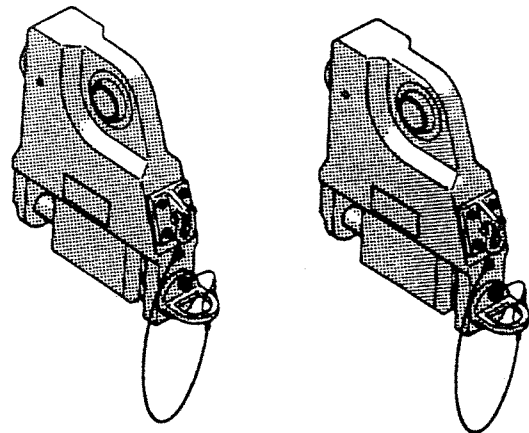


Figure 13-8: ET Forward Hoisting Adapter Fittings (H78-3008)

ET Forward Transportation Fittings Handling Set – The H78-3028 ET Forward Transportation Fittings Handling Set is a single leg wire rope sling. One end terminates with master link and thimble and the other into a swayed ferrule clevis which has a ball pin secured to the sling by lanyard. The H78-3028 Handling Set provides the capability for removing and replacing the H78-3000 Forward ET Transportation Fittings (Horizontal Arm) when the ET is in either the horizontal or vertical attitude. It interfaces with the H78-3000 ET Transportation Fitting Horizontal Arm and the using site (KSC) overhead crane hoist cable hook.

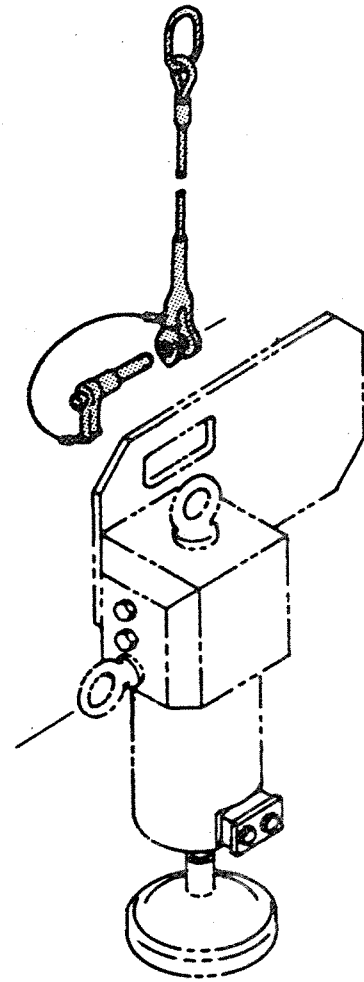


Figure 13-10: ET Forward Transportation Fittings Handling Set

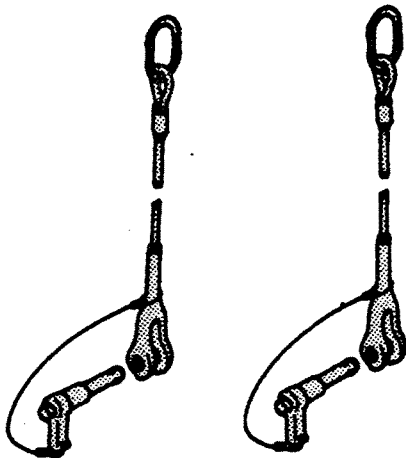


Figure 13-9: ET Forward Hoisting Adapter Handling Set (H78-3034)

ET Forward Hoisting Adapter Handling Set – The H78-3034 ET Forward Hoisting Adapter Handling Set is comprised of two single leg wire rope slings. One end terminates with master link and thimble, and the other into a standard fork jaw clevis which has a ball pin secured to the sling by lanyard. The H78-3034 Handling Set provides the capability for removing and replacing the H78-3008 ET Forward Hoisting Adapter Fittings when the ET is in the vertical attitude at the using facility (KSC). It also interfaces with the facility overhead crane hoist cable (sister) hooks.

ET Assembly Transporter – The P78-3140 ET Assembly Transporter consists basically of two independently steered fourwheel dolly assemblies which support a pallet assembly. The pallet is comprised of two support structures, one forward and one aft, connected by truss weldment sections. Each dolly set consists of two identical assemblies. Each assembly has its own steering system, electrical system, pneumatic or air brake system, and operator station. The two dolly assemblies assume the same centerline dimensions for wheel locations. Each dolly has power generating equipment mounted on a utility cart attached to the dolly assembly.

The electrical system is powered by a propanefueled generator. This generator supplies the electrical power for the hydraulic system. The unit also generates 12V DC for re-charging the starting battery. Power for the steering hydraulic is

supplied by a variable displacement, pressure compensated, axial piston pump set at 2800 PSI. The hydraulic power unit consists of a pump, heat exchanger, reservoir assembly, motor, carburetor, and propane fuel system, plus the various hydraulic transmission lines and valves required to distribute and control its use.

The brake system has a fail-safe, pneumatically operated, braking system activated with compressed air supplied by the prime mover. The braking system is an all-air system utilizing dual chamber spring brake actuators. Normal air pressure for the system is 90 to 100 PSI. The brake system will automatically lock (brakes applied) if air pressure drops below 40 PSI. The air supply is furnished by the prime mover, or by an auxiliary source when moving the transporter.

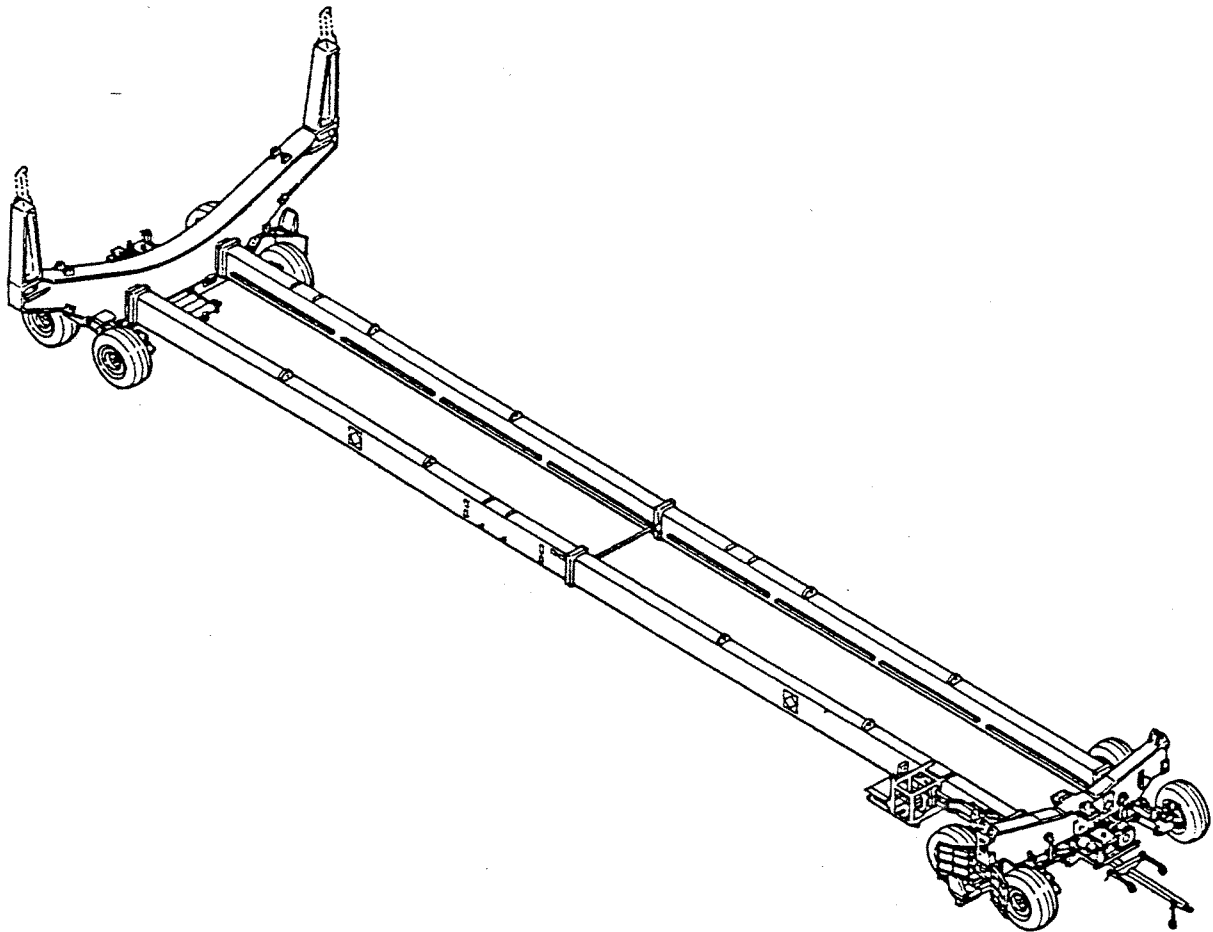


Figure 13-11: ET Assembly Transporter (P78-3140)

ET Closure Kit – The P78-3102/P78-3158 ET Closure Kit was designed to provide closures and protection for flight hardware interfaces on the ET during land and water transportation and during storage. It also was designed for easy installation and removal without causing damage, contamination or wear to flight hardware, and includes locking devices to preclude unintended

removals. Locations on the ET protected by these devices are interfaces EO2 and 3 ET/Orbiter Aft Attach Points, and EB-3 through -8 ET/SRB Aft Attach Points. Shipping/ storage containers are provided for stowing the kit after use.

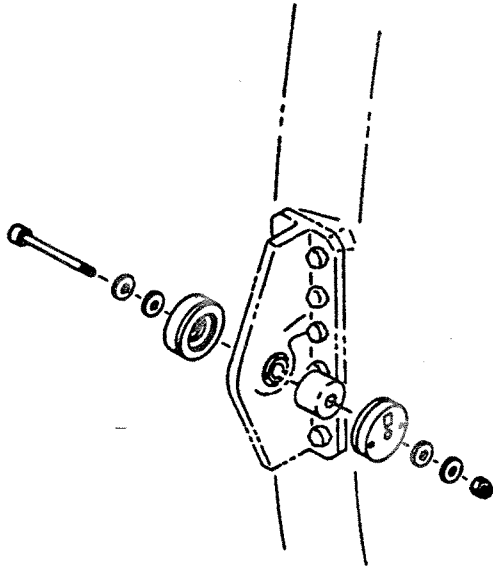


Figure 13-12: Closure Kit, SRB Fittings (P78-3102)

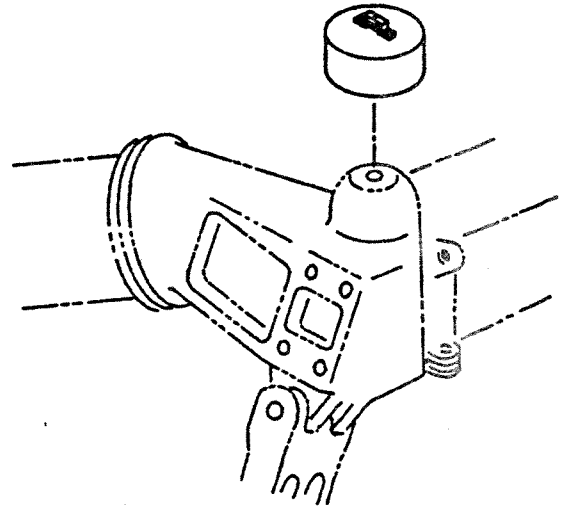


Figure 13-13: Closure Kit, Ball Fittings (P78-3158)

The P78-3184 pressurization system is installed on the ET at MAF and then removed prior to shipment to the launch site. The ET is shipped with the P78-3160/P78-3131 breather disconnect adapter plates installed. Each adapter plate has a P78-3187 pressure gage installed to monitor LO2 and LH2 tank pressure.

Disconnect Adapter Plates - There are two identical adapters plates P78-3131 for the LO2 tank and P78-3160 for the LH2 tank. One mounts on the LO2 feedline and is anodized green, and the other mounts on the LH2 feedline and is anodized red. The parts of each are in matched sets and when the adapters are installed, all loose items such as the protective covers are to be retained in the matched set storage container.

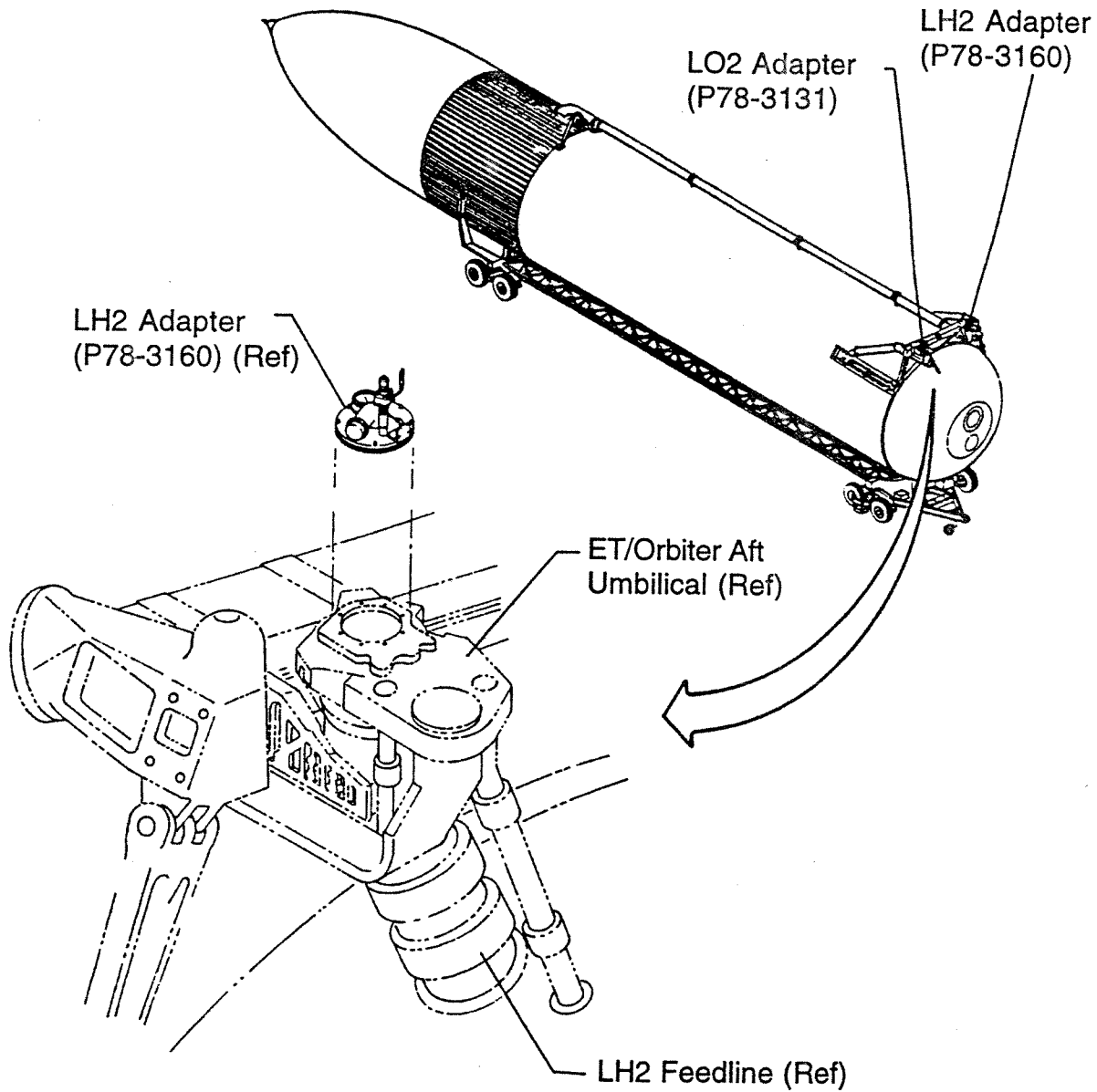


Figure 13-14: Disconnect Adapter Plate Installation (Typical)

Instrumentation System - The P78-3126-101-1 Instrumentation System is designed to record acceleration up or down, right or left and front and rear during marine transportation. A stylus records the trace on chart paper. The accelerometer module assemblies are contained in a box, each attached to the P78-3140 transporter on opposite sides, forward and aft locations. Chart speed is approximately 3/4 inches per hour.

Orbiter Aft Interface Support Strut - The P78-3108 Orbiter Aft Interface Support Strut provides lateral support and rigidity to the aft left (looking forward) ET/ORB Bipod Assembly by adding a third member which forms a tripod arrangement. The support strut is adjustable which permits alignment of the left bipod assembly to the right bipod structure (rigidly attached) for proper seating of the Orbiter. One end of the strut attaches to the ET structure at the same bracket to which the right hand flight tripod strut attaches. The opposite end attaches to the left aft bipod.

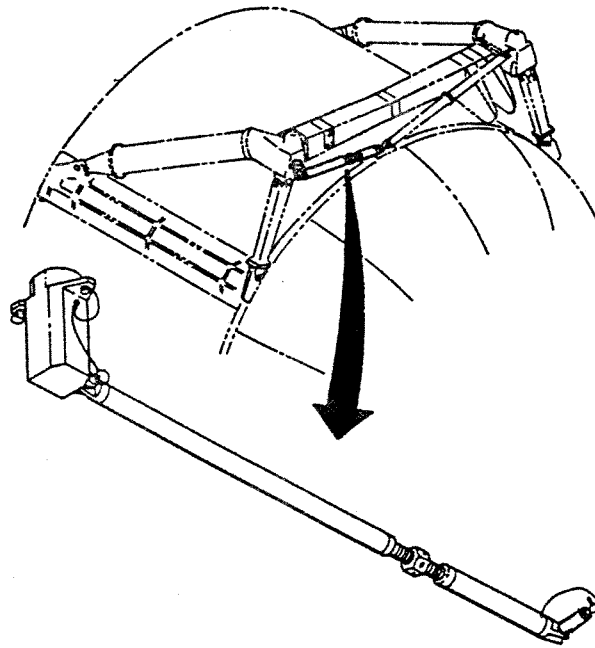


Figure 13-15: Orbiter Aft Interface Support Strut (P78-3108)

LH2 Forward Manhole Installation/Removal Tool - The A78-3619 manhole cover handling set provides the means to lift and handle the ET Forward LH2 Tank manhole covers with or without TPS applied.

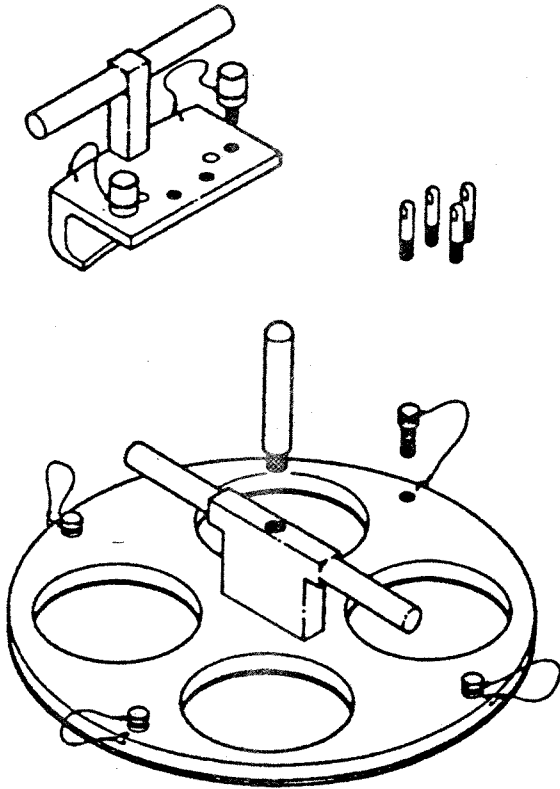


Figure 13-16: LH2 Forward Manhole Installation/Removal Tool (A78-3619)

Aft SRB Attach Fittings Handling Set - The H78-3019 Aft SRB Attach Fittings Handling Set is a balance beam type lifting device. This tool is designed to provide handling capability for the Aft SRB Attach Fittings during removal/replacement while the ET is in the vertical position. The Handling Set consists of a balance beam assembly and a two-leg sling.

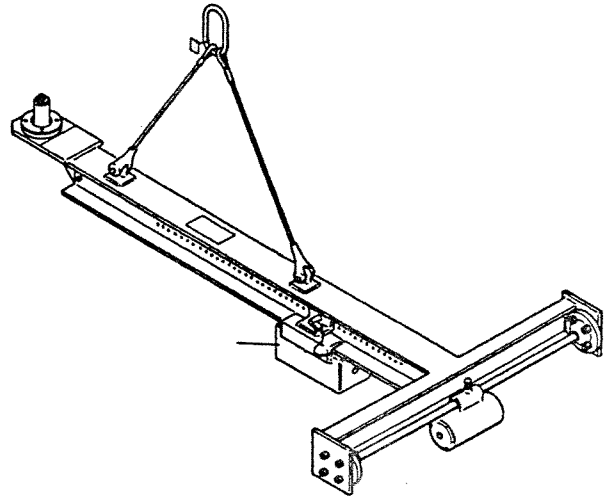


Figure 13-17: Aft SRB Attach Fittings Handling Set (H78-3019)

LH2 Feedline Handling Set - The H78-3020 LH2 Feedline Handling Set provides the tools required to support/remove the external LH2 Feedline for seal inspection/removal/replacement with the ET in vertical attitude. The Handling Set consists of the following tools:

- H78-3020-107 Flange Wedge (3 each). These tools provide the means to separate the LH2 Bellows from interface with the Feedline Flange on the LH2 Tank (after the Feedline retaining bolts are removed) for insertion of the Bellows Offset tools.
- H78-3020-110 Bellows Offset (2 each), H78-3020-111 Bellows Offset (1) each. These tools are adjustable and provide the means to further separate the bellows and feedline

flange for insertion of the Bellows Offset Locator Tools.

- H78-3020-106 Bellows Offset Locator (2 each). These tools when properly positioned provide the means to maintain separation of the Bellows from the Feedline Flange for seal removal/replacement by use of the Seal Extractor and Flange Lever.
- H78-3020-108 Seal Extractor (1 each). This tool provides the means for removing the seals after Bellows and Feedline Flange separation.
- H78-3020-109 Flange Lever (1 each). This tool provides the means to assist in seal removal/replacement when used to expand the Bellows and Feedline Flange separation slightly.

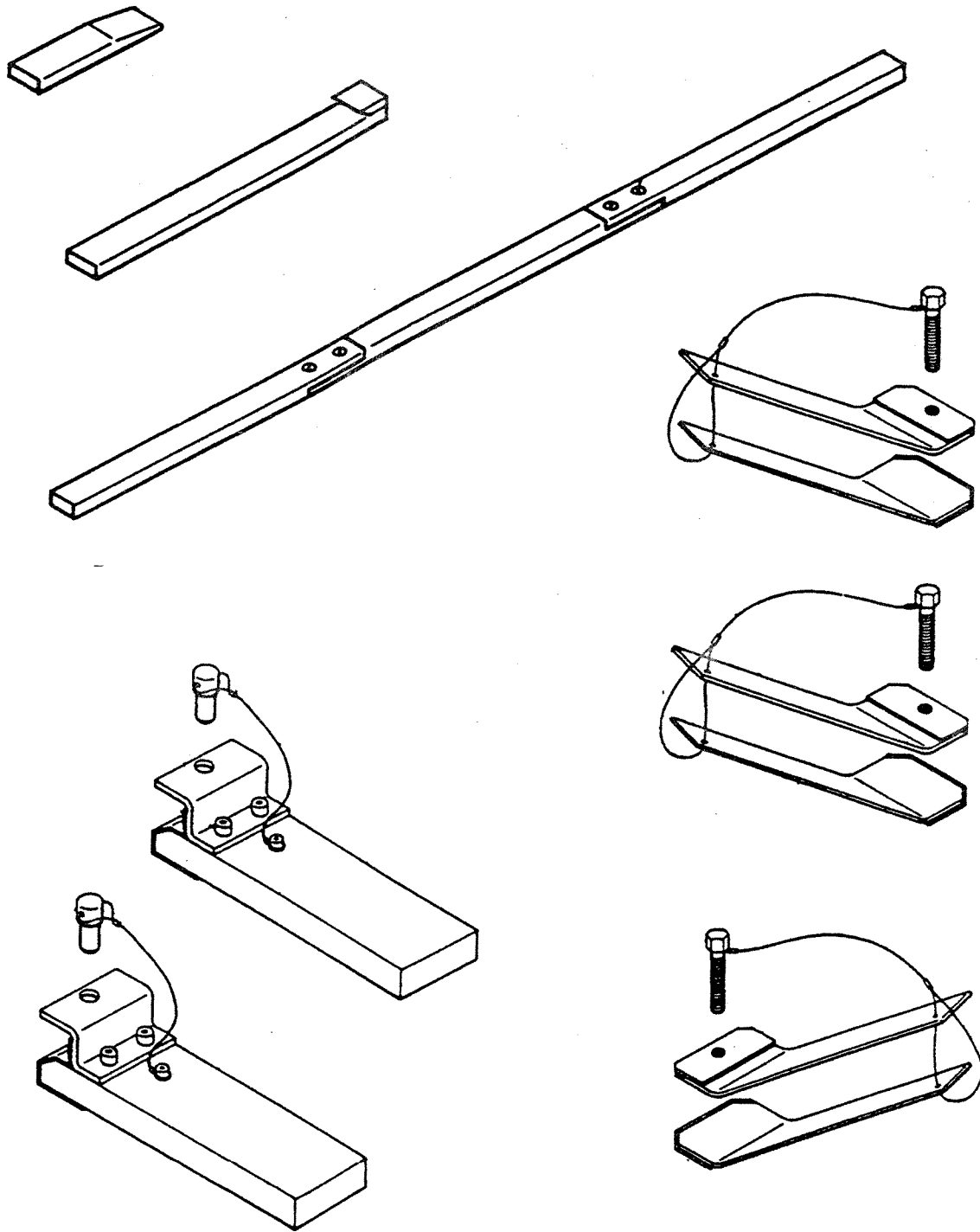


Figure 13-18: LH2 Feedline Handling Set (H78-3020)

Bellows Support, LH2 Vent Line - The H78-3021 Bellows Support, LH2 vent line, is a bellows compressor tool. It is designed to properly compress and retain the bellows section of the LH2 tank vent line which carries released GH2. Bellows compression is required for removal and replacement of the GH2 relief valve, vent line, or the seals at each end of the vent line. It is an adjustable tool consisting of a support bracket attachment yoke, a movable yoke, three adjustable tie rods, and three wing nuts.

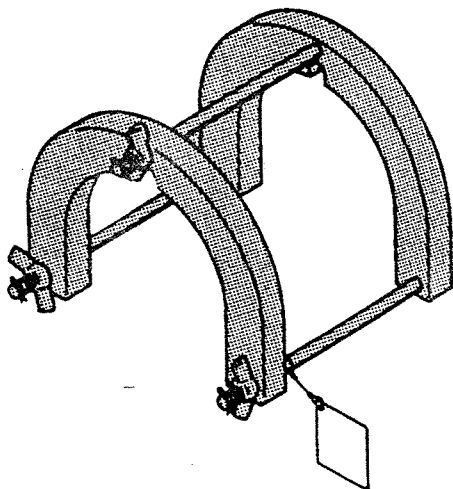


Figure 13-19: Bellows Support, LH2 Vent Line (H78-3021)

LO2 Feedline Handling Set - The H78-3022 LO2 Feedline Handling Set consists of five basic assemblies:

- The Vertical Lifting Collar Assembly (H78-3022-3-107) is a collar and clamp assembly. A pair of two ton shackles are provided on the forward end of the collar for attachment to facility lifting devices.
- The Forward Feedline Support Ring and Sling Assembly (H78-3022-3-101) is a clamp ring, spreader bar, lifting collar and sling assembly. A shackled master link is provided at the forward end for attachment to facility lifting devices.
- The Forward Elbow Clamp and Strap Assembly (H78-3022-4-101) is an elbow configured clamp and strap assembly. A hole is provided at the forward end for attachment to facility lifting devices.

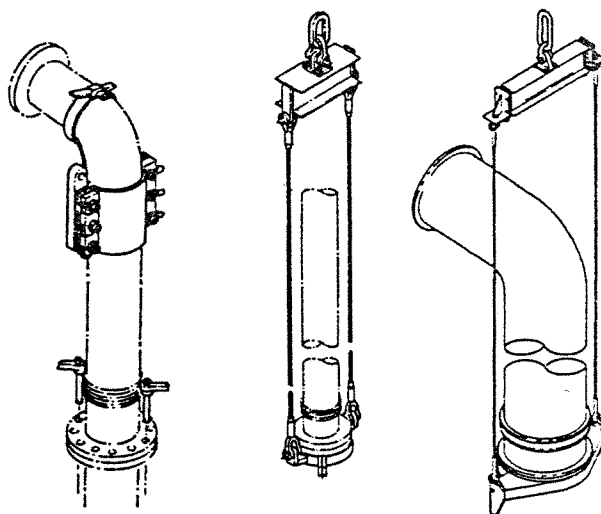


Figure 13-20 LO2 Feedline Handling Set (H78-3022)

Ogive Cover Plate Handling Set - The H78-3016 Ogive Cover Plate Handling Set provides the capability to remove/install the Ogive Cover Plate from/on the LO2 Tank ogive mating surface with the ET in the vertical attitude only. The Handling set interfaces with facility crane or hoists either directly through the master link or by facility adapter(s). The Handling Set consists of three-leg wire rope sling, master link and three lift lugs.

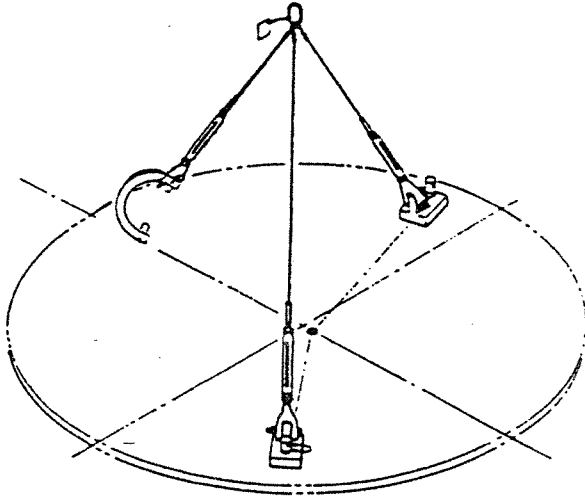


Figure 13-21 Ogive Cover Plate Handling Set (H78-3016)

Manhole Cover Handling Set - The H78-3017 Manhole Cover Handling Set provides the means to lift and handle the LO2 and aft LH2 Tank Manhole Covers with or without TPS applied. It is comprised of two handles provided with attaching hardware secured on each end which prevents loss.

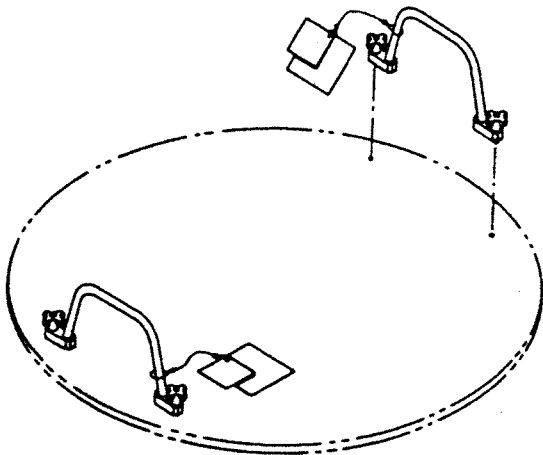


Figure 13-22: Manhole Cover Handling Set (H78-3017)

ET Restraint System Fitting Set - The H78-3035 ET Restraint System Fitting Set provides the capability for attaching facility tag lines/restraints to the ET during handling operations at the test sites as required. The fittings are basically commercial type swivel lift eyes that interface with the H78-3040, H78-3008, H78-3010 Forward and Aft ET Handling Fittings, LH2 Tank Transportation Structure, and Tag Lines/Restraints.

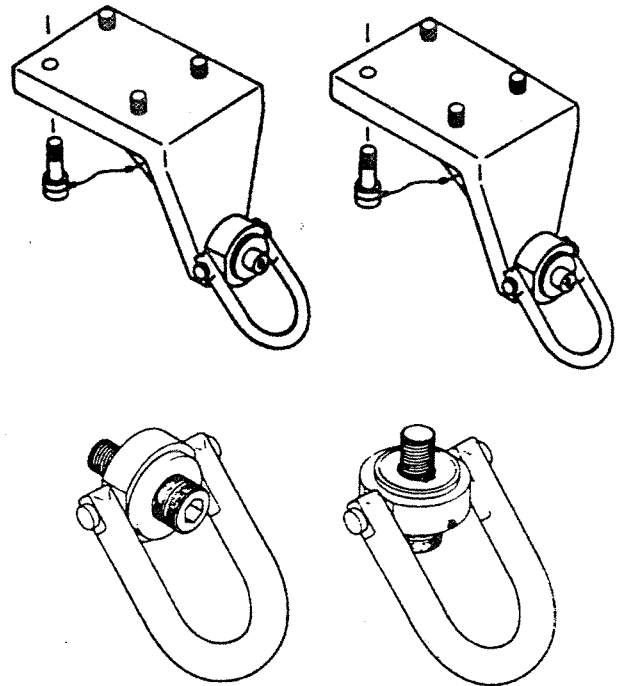


Figure 13-23: ET Restraint System Fitting Set (H78-3035)

Vent Duct Leak Test Covers - The C78-1316 Vent Duct Leak Test Covers consist of two aluminum cover plate assemblies with seflon gaskets, ball valves, and attaching hardware. The C78-1316 is used to leak test the GO2 vent ducts at KSC and VAFB.

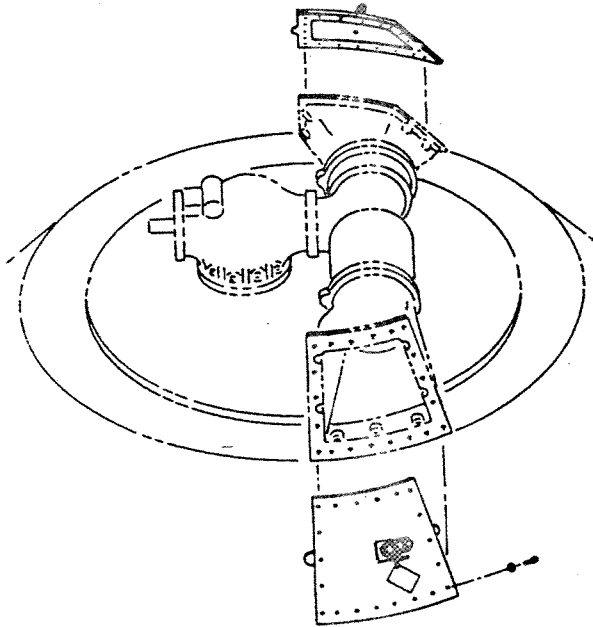


Figure 13-24: Vent Duct Leak Test Covers (C78-1316)

GH2 and GO2 Pressurization Line Blank Off Plate Kit - The P78-3137 Blank-Off Kit provides a means of isolating the ET from the Shuttle main engines. The kit consists of the aluminum blank-off plates, two seflon gaskets, two "K" seals and fastening hardware (two cap screws), washers and nuts. The P78-3137 is used to isolate the LO2 and LH2 tanks from high pressure required for leak checks of the Shuttle main engines. The tests are conducted at KSC and VAFB launch pads.

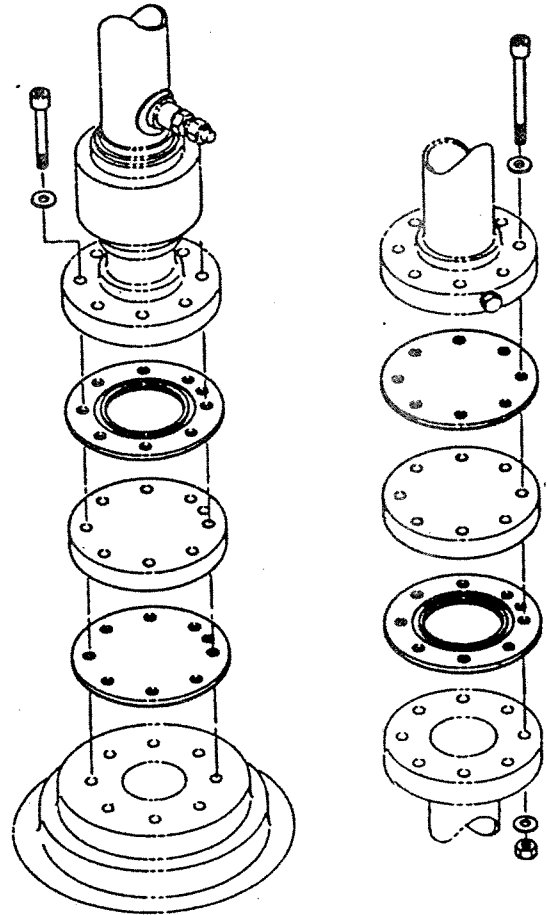


Figure 13-25: GH2 and GO2 Pressure Line Blank-Off Plate Kit (P78-3137)

Electrical Cable Supports - The P78-3123
Electrical Cable Supports are installed on the ET
in four locations to position electrical cables in a

fixed attitude to preclude damage during
transportation, test and checkout operations.

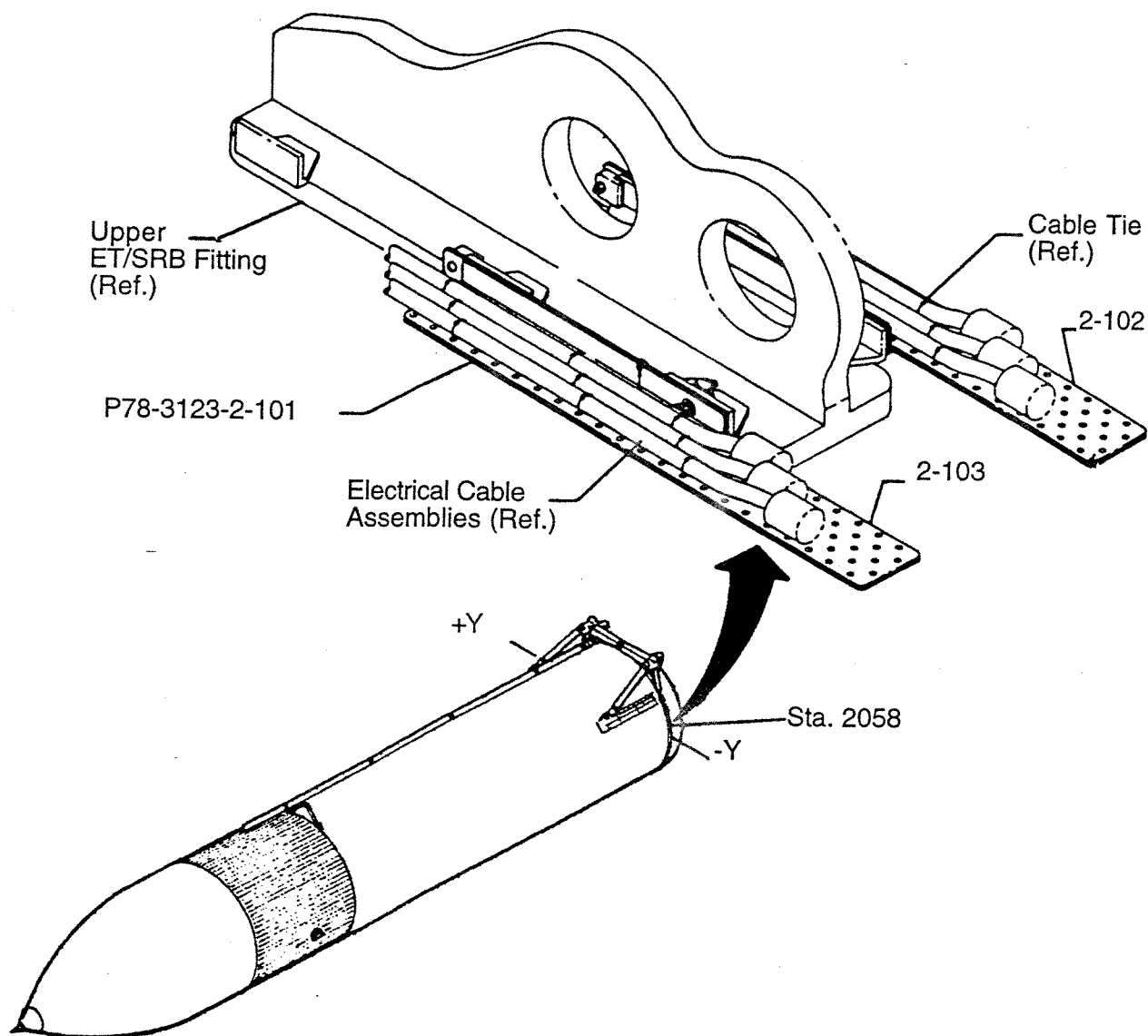


Figure 13-26: Electrical Cable Supports (P78-3123)

13.3.2 INTERNAL ACCESS

The major support equipment required for ET internal access at the launch site is briefly described in the following paragraphs.

LO2 Internal Access Platform Set (Vertical) - The A78-3602 LO2 Internal Access Platform Set (Vertical) was designed to provide access to the LO2 Tank dome, barrel and ogive interior, thereby providing the capability to perform inspection, maintenance, modification, repair and cleaning tasks. During and following installation, personnel entry into the LO2 Tank is made through the LO2 Tank aft dome manhole from the Intertank.

The access set assemblies introduced into the LO2 Tank were designed as modular units to facilitate installation and allow passage of the assemblies through the LO2 Tank aft dome manhole and the Intertank Access Door. The access set may be in

stalled in any one of two basic configurations to provide access to different LO2 Tank levels:

- Configuration A is installed to perform tasks at levels approximately between stations 422 and 886.
- Configuration B is installed to perform tasks at levels approximately between stations 371 and 447.

Exterior tank mounted components of the access set include four base quadrant assemblies, a nose fitting assembly, a winch assembly and a safety cable assembly. Interior tank components of the access set include a base platform assemblage, positioning cables, stationary platform assemblage, mobile platform assemblage, extendable/retractable platform assemblies, crownblock assemblage, a safety net, two manual hoist fixtures, attaching lines and lifting hardware.

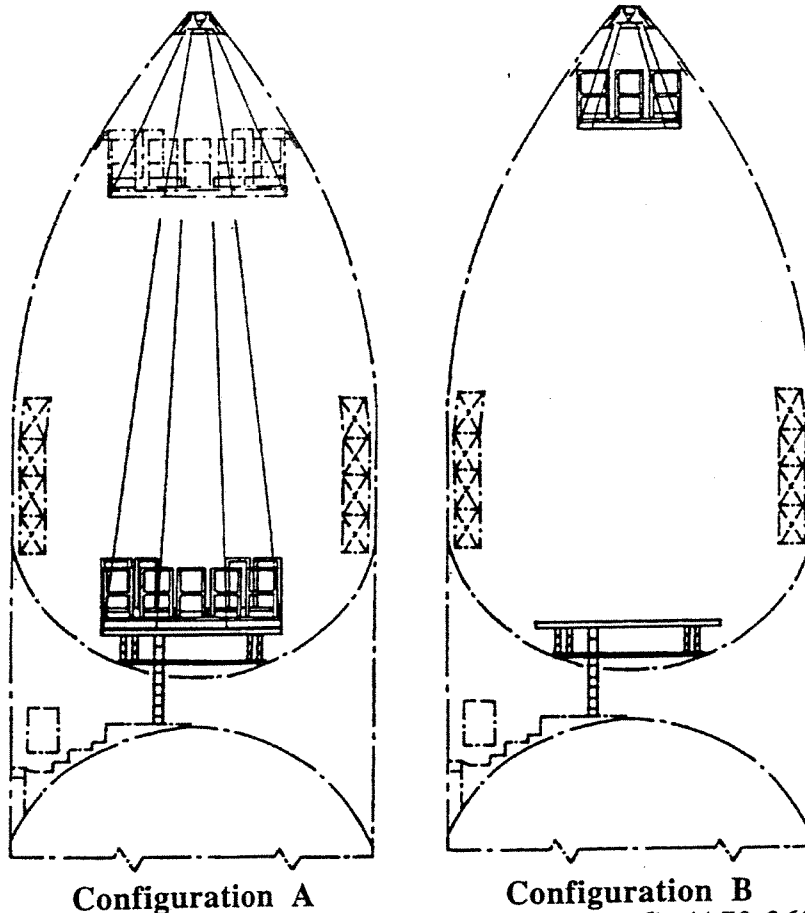


Figure 13-27: LO2 Internal Access Platform Set (Vertical) (A78-3602)

LH2 Internal Access Platform Set (Vertical) - The A78-3603 LH2 Internal Access Platform Set (Vertical) was designed to provide access to the LH2 Tank interior, thereby providing the capability to perform removal, replacement and repair tasks. During and following installation, personnel entry into the LH2 Tank is made through the LH2 Tank aft dome manhole. The access set provides the capability for two man access to the LH2 Tank interior with the ET in a vertical attitude.

The access set assemblies introduced into the LH2 Tank were designed as modular units to facilitate installation and allow passage of the assemblies through the LH2 Tank forward dome manhole from the Intertank access door and the LH2 Tank aft dome manhole. LH2 Tank components of the access kit include a ladder assembly, protective pads, pivot and rest assemblies, two tripod supports, a safety net, safety harnesses, tethered tool kits and a movable work platform with electric hoists.

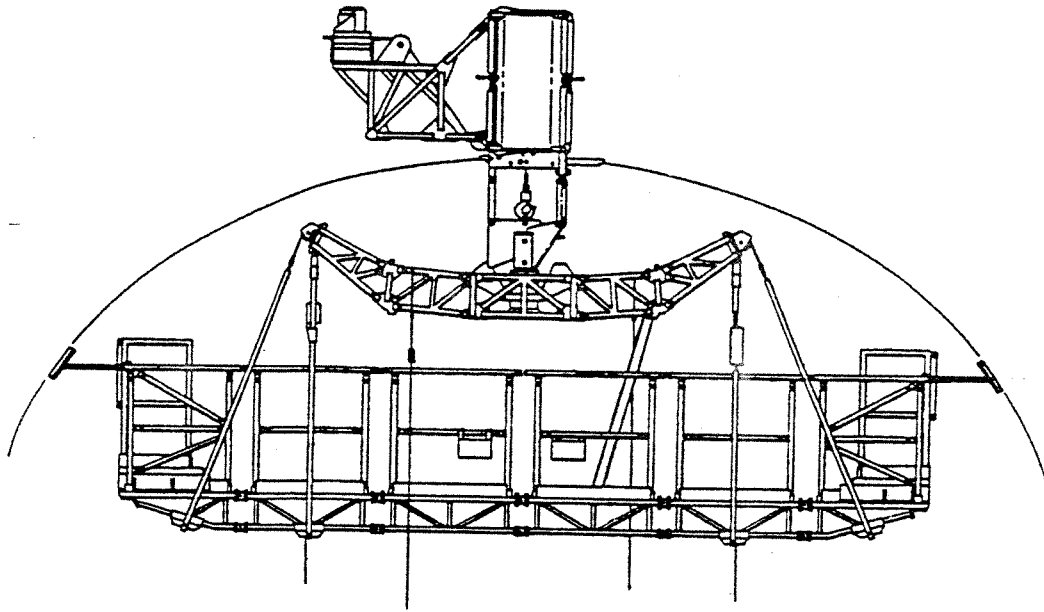


Figure 13-28: LH2 Internal Access Platform Set (Vertical) (A78-3603)

Internal Vertical Intertank Access Kit - The A78-3604 Internal Vertical Intertank Access Kit was designed to provide internal access to ET components within the intertank while the ET is in the vertical attitude. The kit consists of protective steppads and covers which cover the forward LH2 tank dome, and a ladder and a platform for gaining access to the upper regions of the intertank. Basic Protective Pad Construction is fiberglass covered foam, coated with conductive material and having sponge rubber bonded to interface surfaces. The ladder and platform are made of aluminum. The A78-3604 Intertank Access Kit is utilized whenever access to the intertank is required for component installation, removal, tooling hook-up, instrumentation checkout, propellant system leak checks, and inspection. It is also required for entry into the LO2 and LH2 tanks while the ET is in the vertical attitude.

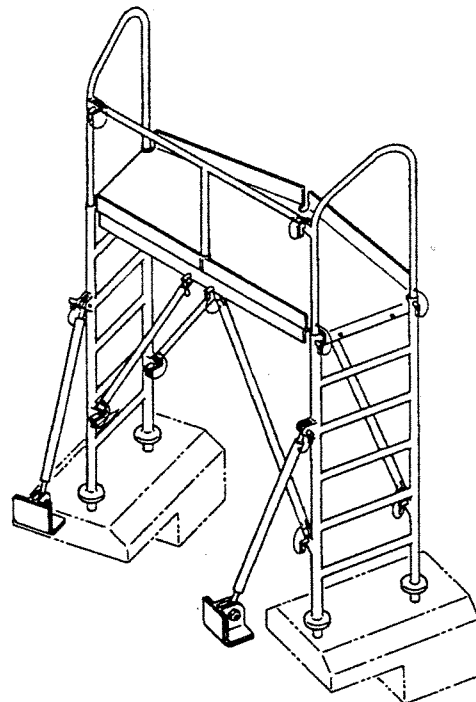
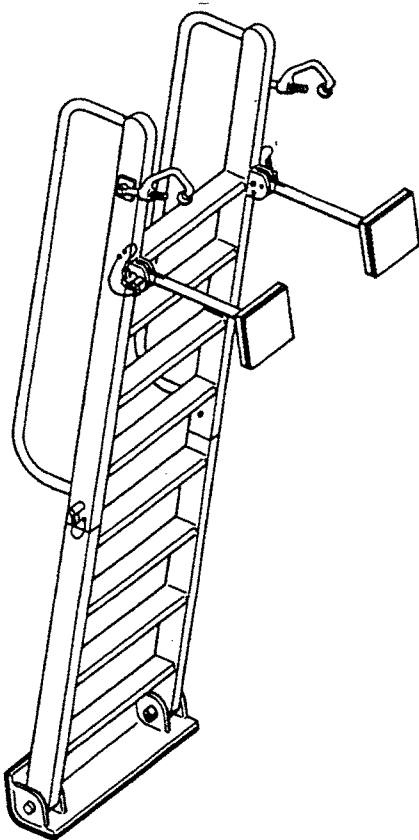
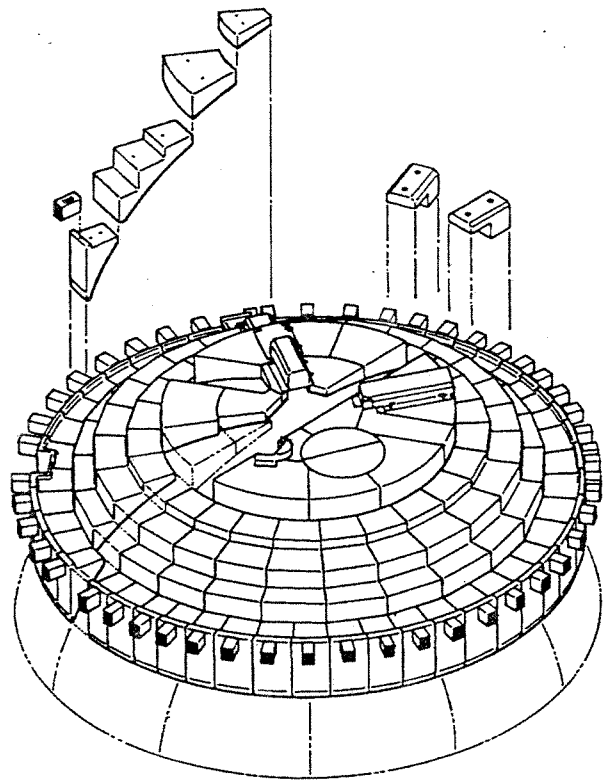


Figure 13-29: Internal Vertical Intertank Access Kit (A78-3604)

Intertank Access Door Sill Protector - The A78-3605 Intertank Access Door Sill Protector provides protection for the intertank door mating surfaces on the intertank when the door is removed. It protects the edges of the intertank access opening from damage that could occur during personnel and equipment ingress/egress while test operations are being performed; it also provides the means for closing the access opening to the elements when test operations are not required.

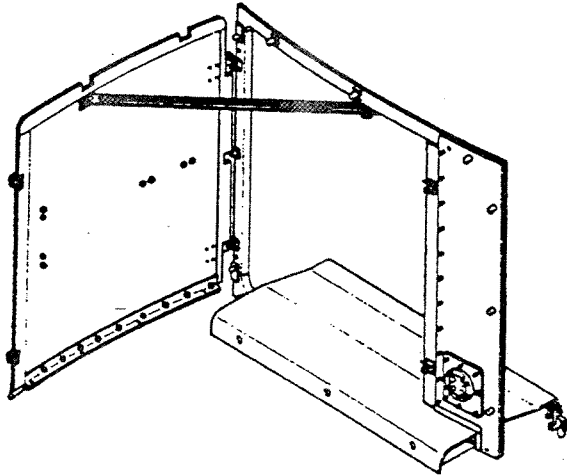


Figure 13-30: Intertank Access Door Sill Protector (A78-3605)

LO2 Aft Dome Access Kit - The A78-3606 LO2 Aft Dome Access Kit was designed to cover and protect the LO2 Tank Aft Manhole Cover seal surface and provide ready access into the aft portion of the LO2 Tank for internal inspection while the tank is in the vertical attitude. The kit consists of a manhole cover seal surface protector, and a two section aluminum ladder.



Figure 13-31: LO2 Aft Dome Access Kit (A78-3606)

LH2 Aft Dome Access Kit - The A78-3607 LH2 Aft Dome Access Kit (Manhole Protector) was designed to cover and protect the LH2 Tank Aft Manhole Cover seal surface, and also protect the tank during personnel entry. The kit is manufactured from materials compatible with the LH2 Tank cleanliness requirements.

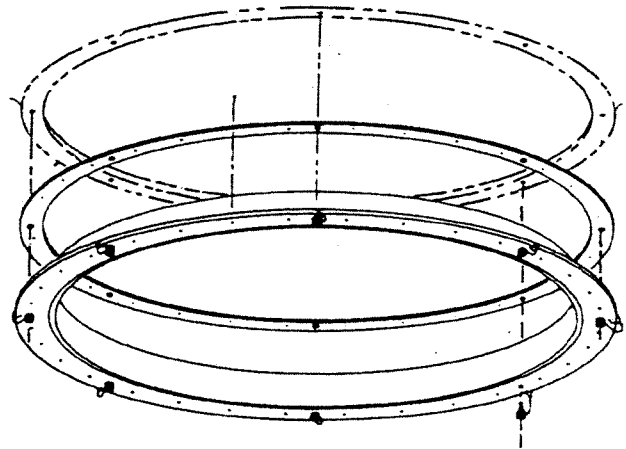


Figure 13-32: LH2 Aft Dome Access Kit (Manhole Protector)

LH2 Tank Internal Access Equipment -
The A78-3616 Internal LH2 Tank (1-Man) Access Equipment was designed to provide one-man access to the interior portion of the LH2 Tank when it is in a vertical attitude. The access equipment was constructed in modular form for ease of assembly and for passage through the Intertank Access Door and the Aft Dome Manhole as required.

Access equipment installed inside the Intertank consists basically of an Electric Sky-Climber, wire rope cable with hoisting hook, support structure, cable guide, manhole protector,

and an electric power extension cable, and attaching parts consisting primarily of lock pins.

Access equipment installed/assembled inside the LH2 Tank consists basically of a ladder assembly, safety net, hoisting boom assembly, two-leg sling set, chair assembly, counterweight, tag lines, safety line, safety belt and harness, tool belt (with tethered tools), ring frame protective pads for seating the chair and counterweight, and attaching parts, which are primarily lock pins secured to subassemblies with lanyards.

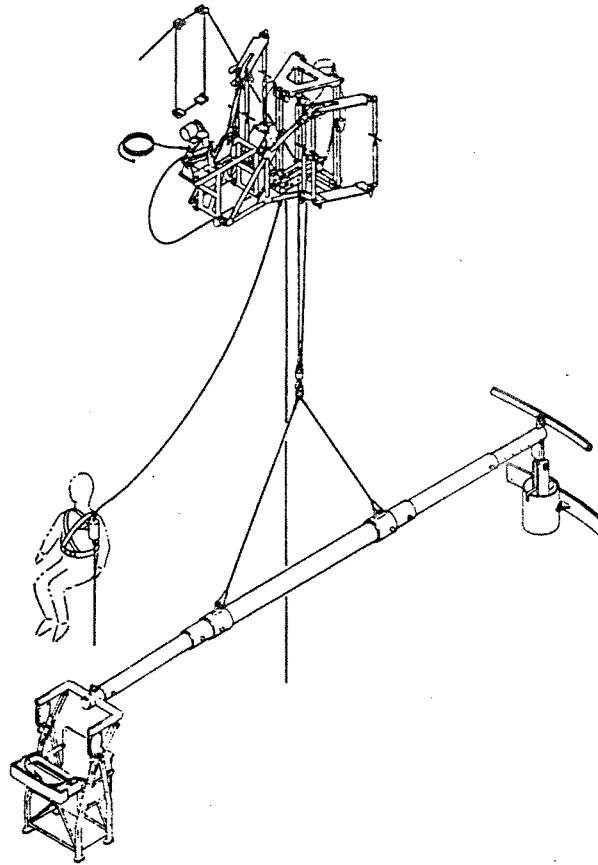


Figure 13-33: LH2 Tank Internal Access Equipment (1-Man) (A78-3616)

14. PRODUCTION

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14. PRODUCTION

The use of "Hard Tooling" for major welding and structural assemblies permits the precision manufacturing of large External Tank Structures at increasing rates to meet Space Shuttle Program requirements.

14.1 EXTERNAL TANK MANUFACTURING

The External Tank is manufactured at NASA's Michoud Assembly Facility in New Orleans. The major assemblies of the ET are shown below.

The use of "Hard Tooling" for major welding and structural assemblies permits the precision manufacture of these large structures at increasing rates to meet the Space Shuttle Program requirements. The manufacturing approach for the LO2 tank and LH2 tank assemblies is to weld structural components into subassemblies such as domes, ogives and barrels and then perform mechanical installations at these subassembly levels wherever possible in order to minimize downstream operations at the completed tank or ET level. Structural subassemblies of each tank are welded into a complete tank, internal mechanical installations completed, and the tank proof tested. Subassemblies of the intertank are mechanically assembled prior to structural assembly which is followed by mechanical, propulsion, and electrical system installations. After completion of proof test the LH2 tank is cleaned, iridited, primed and TPS applied. The LO2 tank is cleaned, iridited, primed and mated to the intertank to form the LO2/Intertank stack and TPS application is completed. The LO2/IT stack is spliced to the LH2 tank in the vertical attitude and TPS closeout performed. The mated ET assembly is then moved to the horizontal final assembly area for completion.

14.1.1 LO2 TANK ASSEMBLY

The LO2 ogive nose section is fabricated in two sections: the forward section consisting of eight gore panels and a forward ring fitting and the aft section consisting of 12 gore panels.

The forward ogive is welded in a vertical trim and weld fixture. The eight gores are welded first into four quarter panels, then into two half-body assemblies and finally into one assembly. The forward ring fitting is then welded to the forward ogive gore assembly. All edges are custom-trimmed prior to welding with proper allowances made for weld shrinkage. These trim operations are performed right in the weld fixture.

The aft ogive is also welded in a vertical fixture and the operations are the same as those for the forward ogive except that there is no forward fitting.

The T-frame which makes the transition from ogive section to barrel section consists of four extruded segments that are welded together in a trim and weld fixture that effectively controls the contour and flatness of the ring.

The LO2 barrel section consists of four pre-formed panels which are welded together in a vertical weld fixture. Panel edges are pre-trimmed at a trim station in the welding area.

Fabrication of the LO2 dome begins with the dome gore/gore welded assembly. The gore panels are loaded on the gore-to-gore fixture and the longitudinal abutting edges are saw-trimmed and welded. The completed quarter panel is routed to the dome quarter panel/chord trim and weld fixture. The quarter panel and a mating chord are located in the fixture and the abutting edges are trimmed and welded. Two quarter panel-chord assemblies are located in the half dome body trim and weld fixture and the abutting edges are welded to produce a half dome body. Two half dome assemblies are positioned in the dome weld fixture; the two halves are brought together and the abutting edges trimmed and welded together to form a dome body. Circumferential control is maintained by gage blocks on the tool and sizing is achieved by precise trimming of the closeout joint to a pre-determined dimension, allowing for weld shrinkage.

The completed dome body is then routed to the dome body/cap weld fixture for welding into a completed dome.

The LO2 dome cap is routed first to the manhole fitting trim and weld fixture and then to the suction outlet trim and weld fixture. In each of these fixtures, the operations consist of trimming the fitting penetration undersize to provide an interference fit, shrinking the fitting in LN2 for ease of assembly and welding the fitting into the cap.

The dome cap is welded to the dome body in a trim and weld fixture. Dome body trimming is accomplished in the fixture by rotating a router head around the stationary dome body at the cap opening. The dome cap is mounted on separate trim fixture, rotated past a stationary router, and trimmed precisely to provide a gap-free joint. The fixture is then removed from the turntable with the cap still in position and mounted in its correct location on the dome body/cap weld fixture. The dome body/cap weld is then made.

The LO2 Fwd slosh baffle individual ring segments and truss assemblies are pre-pilot hole drilled and assembled in a floor-mounted assembly fixture. Then they are fabricated into a three-level baffle assembly. The LO2 aft baffle ring is assembled on a floor-mounted assembly fixture.

LO2 tank major weld is accomplished in a horizontal rotational weld fixture. Internal mandrels and external roll rings are used for all weld joints to constrain component shape and align weld joints for controlled welding conditions. The major tank components are welded together from forward to aft. The slosh baffle is installed into the ogive/barrel assembly prior to welding on the aft dome. The aft dome weld, which is the tank closeout weld, is made using an expanding mandrel that is disassembled after welding for removal from the tank.

The completed LO2 tank is proof-tested in the hydrostatic test facility using demineralized water to which a chromate corrosion resistant solution is added. A vacuum is drawn on the aft dome to provide the required proof pressure gradient. After proof test, the LO2 tank receives a post proof X-ray and is routed for cleaning and TPS application.

14.1.2 INTERTANK STRUCTURAL ASSEMBLY AND INSTALLATION

The structural assembly of the intertank begins with the splicing of the intermediate and main frame 90° segments into 180° segments. The (5) minus Z axis, 180° frame segments are then loaded and aligned into a half section tack station along with the

(3) skin stringer panels, where approximately 409 to of the total panel to frame fasteners are installed. The panel to panel butt splices are tack fastened and the rollties are installed.

The intertank minus Z half section is then positioned on the automatic riveter and the plus Z half section is started on the tack station. While on the automatic riveter the remaining panel to frame and butt splice fasteners are drilled and installed. The minus Z half section is then moved to the finish/inspect station where the fasteners installed by the automatic riveter are inspected and all systems substructure is installed. The plus Z half section is in the automatic riveter.

The minus Z half section is then off loaded and operations are repeated for the plus Z half section.

Splice details and closure panels for the SRB beam are pre-drilled in a pre-assembly fixture. The SRB beam is pre-aligned in the fixture and two locating pads are set to match the final assembly fixture pads.

The pre-aligned SRB beam is placed in the assembly fixture. The half sections are then loaded in and their frames spliced at the +Y axis. Thrust panels are then installed. Longeron tie ins and thrust panel butt straps and rollties are installed. The fwd and aft interface flange hole patterns are also drilled.

After removal of the intertank from the assembly fixture, it is placed in the second position installation fixture. This fixture provides an unrestricted working area with required access platforms for installation of propulsion and electrical systems.

The intertank is moved from Position #2 to Position #3 for TPS application. The TPS application involves spray and hand trim SS-1171 foam wedges/ground planes and PDL pour on aerovents. The intertank is then moved to Cell "G" or "H" where SOFI is applied to sidewalls with automatic (2) gun spray system. After completion of SOFI trim operations the intertank is moved to Cell "J" for LO2 tank stacking.

14.1.3 LH2 TANK ASSEMBLY

The LH2 forward and aft domes are fabricated in the same manner as that described for the LO2 dome. The weld fixtures which are used are common to all three domes.

The LH2 aft barrel section is welded in the same vertical weld fixture as is used for the LO2 barrel section. The LH2 barrel panels are pre-trimmed to a developed, curve-shaped width in order to eliminate the "coke-bottle" effect which is the result of weld-shrinkage. Curved shoes and contour headers are installed on all panels prior to loading in the weld fixture.

The three LH2 forward barrel sections are welded in a horizontal barrel weld fixture. The panels are sequentially loaded and welded; the trim for the closeout panel is calculated from measurements taken on the portion of the barrel section already welded; allowances are made for temperature variations and weld shrinkage, to assure correct circumference control for each barrel section.

The three LH2 T-ring frames (Stations 1377, 1623, and 1871) are welded in the same fixture used for the LO2 T-ring. The weld lands vary in thickness from 0.320 to 1.00 inch.

The LH2 tank major weld is accomplished in a horizontal rotational weld fixture similar to that used for the LO2 tank. The LH2 tank assembly sequence begins with the loading of the aft dome into the weld

fixture followed by the loading of the aft barrel section. After the mating edges have been prepared for welding, the internal expanding back-up mandrel is moved into position and the circumferential weld made. The tail stock of the weld fixture is then repositioned to accept the next barrel section and a ring frame. The remaining barrel sections and ring frames that make up the LH2 tank are loaded, prepared for welding, and welded in like manner. The welded assembly, less the forward dome, is then removed from this weld fixture and loaded into a second position fixture where X-ray and mechanical installations are performed. The assembly is then moved to a third fixture where the final circumferential weld of the LH2 tank is made between the forward dome and the forward barrel section. The closeout mandrel which is installed prior to joining the dome to the barrel section has been made so that it can be disassembled after welding and removed through the forward manhole opening. The weld of the forward dome to barrel section completes the LH2 tank assembly.

The completed LH2 tank is then routed to proof test. This test is unique in that it combines a pneumatic (GN2) pressure test with a hydraulic load test. While the tank is pressurized, loads are applied to simulate the loads from the SRBs and the Orbiter. An automatic abort system monitors critical parameters to halt operations if a test anomaly develops. Upon successful completion of the proof test, a leak test is performed. After test the tank is transported to Building 103 for post proof X-ray operations.

14.1.4 TPS APPLICATION

The TPS application sequence is shown on Chart No. 4. This chart shows the sequence and flow for application of SLA and SOFI on the major assemblies. It also includes the mating and splicing of the LO2 tank/intertank stack to the LH2 tank.

After completion of proof test and post proof X-ray the LO2 tank is cleaned and iridited internally and cleaned externally. Internal installations are made, welds are iridited and external surfaces primed, and SOFI is then applied to the aft dome using an automated spray approach.

The LO2 tank is then mated and spliced to the intertank. Mechanical hook-up of LO2 feedline and installation of feedline brackets and SLA handpack operations are performed. The LO2/Intertank stack is then routed to a specifically equipped cell for automated SOFI application to the LO2 tank. Mechanical installations are performed. Close-out/trim of flange and cable tray brackets are completed and the LO2 stack is ready for mating to the LH2 tank.

After proof test and post proof X-ray the LH2 tank is routed for cleaning, priming, and TPS application. The first steps are external cleaning, prime and mechanical installations.

The LH2 tank is then routed to the cleaning cell and internally cleaned and iridited. Internal installations in the aft dome are then completed and the tank moved to the SOFI spray cell where SOFI is applied to the barrel section areas and the forward dome. SLA panels are bonded to the apex aft dome area. The tank is then moved to another SOFI spray cell where SOFI is automatically applied to the aft dome.

The LH2 tank is moved to Cell A for mating with the LO2 tank/intertank assembly. TPS closeout of the splice area is performed. SRB attachment fittings are installed and ICD alignment requirements

are verified prior to movement to Building 103 for Horizontal Final Assembly.

14.1.5 FINAL ASSEMBLY AND CHECKOUT

Upon completion of Cell A operations, the ET is moved to Building 103, Horizontal Final Assembly, where feedlines, cable trays, interface hardware and electrical wiring installations are completed. The ET/Orbiter interface hardware is also installed at this time. Interface Control Tooling is used to verify the location of the Orbiter-supporting ball fittings and the LO2 and LH2 umbilical interfaces. The location of the forward bipod interface is also verified.

Beginning in the TPS cells and continuing throughout final assembly and checkout, TPS closeouts are completed following installations of electrical and mechanical hardware.

Test and checkout, including wiring integrity testing, mechanical joint leak check and subsystem functional testing, is performed in Building 420.

Test and checkout begins with a wiring integrity test which checks continuity and isolation of ET wiring. This is followed by mechanical joint leak tests using flow meters, subsystem testing using the Ground Station in the control room and, finally, an All Systems Test which simulates the Flight Profile. The only interfaces between the vehicle and test equipment in the All Systems Test are the Aft Orbiter Umbilicals and the Ground Umbilical Carrier Plate. Pack and ship activities also are completed in Building 420. The LO2 and LH2 tanks are purged with GN2, and pressurized to 6 psig for shipment to the launch site via barge from the MAF/NASA dock.

14.2 MANUFACTURING SEQUENCE AND HANDLING FLOW

Detailed "Manufacturing Sequence and Handling Flow" charts are provided in Volume II as Section VII.

15.0 ET Performance Data Reference Matrix

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15. ET PERFORMANCE DATA REFERENCE MATRIX.....15-2

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TABLE 15-1: ET PERFORMANCE DATA REFERENCE MATRIX15-3

15. ET Performance Data Reference Matrix _____

This section of the handbook serves as a reference guide for External Tank performance data. The documents referenced in the matrix provide specific information relating to each system.

Table 15-1: ET Performance Cross Reference Matrix

	80900000069	Fracture Control Plan	Stress Report	Thermal Data Book	Loads Data Book	MPS Prediction Report	Weights Report	MPS Post Flight Evaluation	SDH Vol I	CIL	ET Aero/Thermal Entry Data Book
Thermal											
TPS				X							
Propulsion System									X		
Electrical System						X		X	X		
Aerodynamics						X		X	X		
Mass Properties											X
Requirements											
Mass Properties and Inert Center of Gravity							X				
Structures							X				
Requirements	X	X	X						X		
Propulsion											
Requirements						X			X		
Tank Loading Procedures											
Pressurization Performance						X					
Propellant Performance						X					
Electrical						X					
Requirements									X		
Operational Instrumental											
Loads											
Requirements					X						
Critical Items and Failure Modes											X