

4.1 SRB OVERVIEW

4.1.1 General

The solid rocket booster (SRB) element of the space shuttle (Figure 4.1-I) is made up of six subsystems:

- The solid rocket motor
- The structural subsystem
- The thrust vector control subsystem
- The separation subsystem containing mechanical and ordnance equipment
- The recovery subsystem containing mechanical and parachute equipment
- The electrical subsystem

4.1.2 Reusable Solid Rocket Motor

The reusable solid rocket motor (RSRM) , is the primary propulsive element providing impulse and thrust vector control (TVC) from ignition to SRB staging. The RSRM consists of a lined, insulated, segmented rocket motor case loaded with solid propellant; an ignition system complete with electromechanical safe and arm device, initiators, and loaded igniter; a movable nozzle; systems tunnel bracketry; instrumentation; and the necessary integration hardware.

The major elements required to assemble one RSRM are a forward rocket motor segment, two center rocket motor segments, an aft rocket motor segment, and a nozzle assembly. The RSRM components and subsystems are physically interchangeable and replaceable. Performance, interchangeability, and replaceability between a flight set of RSRM's can be maintained by matching the burning rates of motor segments cast in matched pairs from the same propellant lot. Sea level thrust for an RSRM is 3.3 million lb. The two RSRM's provide 71.4 percent of the thrust at liftoff and during first stage.

4.1.2.1 Case

The function of the case is to provide a pressure vessel in which thrust can be developed. Each case consists of 11 segments. The material used in the construction of each case segment is D6AC steel. The details of SRB casing are discussed in systems brief 4.2.

4.1.2.2 Propellant

The propellant is a composite-type solid propellant. The propellant grain is designed to fulfill the performance requirements of the shuttle program. Systems Brief 4.3 includes descriptions of

the propellant formulation, grain design, burn rate, manufacturing process, propellant mixing, and propellant casting.

4.1.2.3 Insulation

The insulation includes chamber insulation, propellant relief flaps, and forward and aft facing inhibitors. The insulation material used for the chamber, relief flaps, and forward inhibitors is an asbestos-silica-filled nitrile butadiene rubber (NBR). The aft inhibitor material is an asbestos-filled carboxyl-terminated polybutadiene polymer (CTPB polymer). The purpose of the insulation in the RSRM is to protect the case from the hot gases during motor operation and inhibit propellant burning on the forward faces of the segments.

4.1.2.4 Liner

The liner material has been designed to provide a bond between the insulation and propellant in RSRM's. The liner is compatible with the selected insulation and propellant and has acceptable aging characteristics to maintain the insulation/liner/propellant bond throughout the service life of the RSRM. The selected liner material is an asbestos-filled CTPB polymer.

4.1.2.5 Nozzle

The nozzle is a convergent-divergent movable design that uses a flexible bearing as the gimbal mechanism. The nozzle is also constructed to be able to withstand water impact and retrieval operations. The assemblies that make up the nozzle are described in Systems Brief 4.4.

4.1.2.6 Ignition System

The ignition system for the RSRM consists of a forward end internally-mounted solid-rocket-type igniter, an igniter initiator, an igniter adapter, and a safe and arm device. Details of the ignition system are found in Systems Brief 4.5.

4.1.2.7 Instrumentation

The instrumentation supplied with the RSRM consists of pressure transducers. For operational flight instrumentation (OFI), three motor chamber pressure transducers are installed on the RSRM. The triple-redundant motor chamber pressure transducers are used primarily by the orbiter for SRB separation commanding logic and secondarily for motor performance monitoring.

4.1.2.8 Manufacturing Operations

Each steel segment is manufactured by hot forging and cold forming operations from a 31,000-lb D6AC steel billet. After the segments are formed and rough machined, they are heat treated, finish machined, inspected, and proof tested. The segments are then shipped to the Thiokol facility in Utah for loading, where they are solvent cleaned in preparation for assembly and loading.

4.1.3 Structures

The SRB structural subsystem provides the necessary structural support for the shuttle vehicle on the launch pad; transfers thrust loads to the orbiter and ET; and provides the housing, structural support, and bracketry needed for the recovery system, the electrical components, the separation motors, and the TVC system. This subsystem consists of the nose cone assembly (frustum and nose cap), the forward ordnance ring, the forward skirt including the forward SRB/ET attach fitting, the aft SRB/ET attach ring and attach struts, the aft skirt including the heat shield, and the systems tunnel and structure of mounting other SRB subsystems components. In addition, frustum flotation, weighing, hoisting and towing provisions, and structural thermal protection are provided. Most structures components will be used for 10 to 20 flights.

4.1.3.1 Nose Cone Assembly

The nose cone assembly, shown in Figure 4.1-II, includes the nose cap, the frustum structure, the frustum flotation components, and hardware for attaching the forward separation motors and nose cap thrusters. The nose cap is an aluminum monocoque structure with a hemispherical section at the forward end. The base is 68 inches in diameter, and the overall length is 75 inches. This structure is a riveted assembly consisting of machined 2024 aluminum sheet skins, formed ring segments, machined fittings, formed cap, and a machined separation ring, and weighs about 290 lb. The nose cap houses both the pilot and drogue parachutes and is separated from the frustum by three nose cap thrusters. They are fired at approximately 15,704 feet altitude during the entry phase. The nose cap is initially positioned/oriented on the frustum by six alignment pins, which serve as guides until sufficient clearance has been attained between the cap and frustum during separation.

The frustum structural assembly is composed of machined 2219 aluminum shear beams, ring, fittings, separation motor supports, main chute supports and 7075 aluminum formed skins, and weighs about 3200 lb. The frustum minor base diameter is 68 inches, the height is approximately 10 feet, and the major base is 146 inches in diameter. The frustum houses the main parachutes, provides the structural support for the forward separation motors, and incorporates flotation devices and handling hardware for water recovery.

4.1.3.2 Forward Ordnance Ring

The forward ordnance ring, 146 inches in diameter, provides a plane of separation between the frustum and forward skirt assemblies. The ring is precision-machined from a 2219 aluminum ring forging and provides mounting provisions for the linear-shaped charge used in the severance function.

4.1.3.3 Forward Skirt

The forward skirt is the cylindrical structure between the forward RSRM segment and the ordnance ring (Figure 4.1-III). It includes an SRB/ET attachment fitting, which transfers the thrust loads to the ET, and a forward bulkhead that seals the forward end of the skirt. The skirt provides the structure to react parachute loads during deployment, descent, and towing. The tow pendant assembly mainly comprises formed sheet metal parts, nylon and steel cables.

Secondary structure is provided for mounting components of the electrical and instrumentation (E&I) subsystem, the rate gyro assembly, range safety panels, and the systems tunnel components. The skirt assembly at completion of installation is sealed to provide additional flotation capability.

The forward skirt, 146 inches in diameter and 125 inches long, consists of a 2219 aluminum welded cylinder assembly made from precision-machined and brake-formed skin panels and a welded thrust post subassembly weighing approximately 5700 lb. Welded to this are the forward ring, RSRM attach ring, intermediate rings, gussets, beams, etc. The skirt is then artificially aged and machine finished.

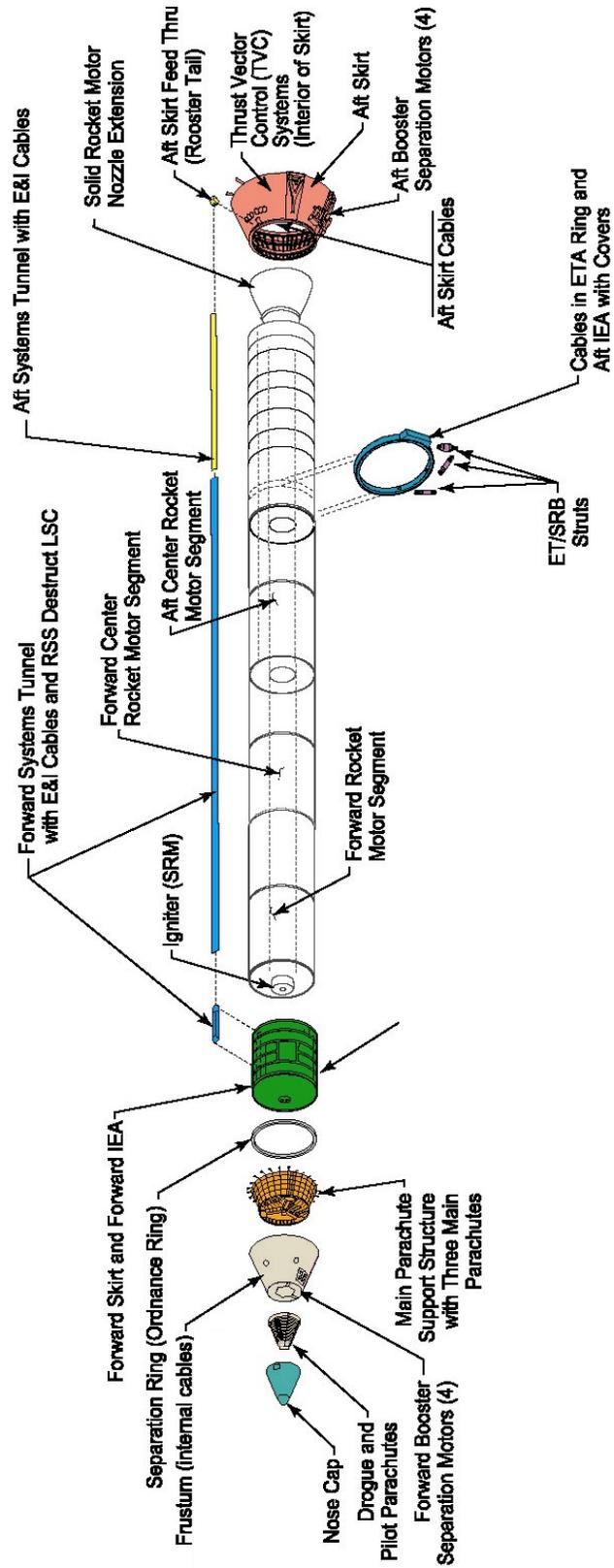


Figure 4.1-1 – SRB Components

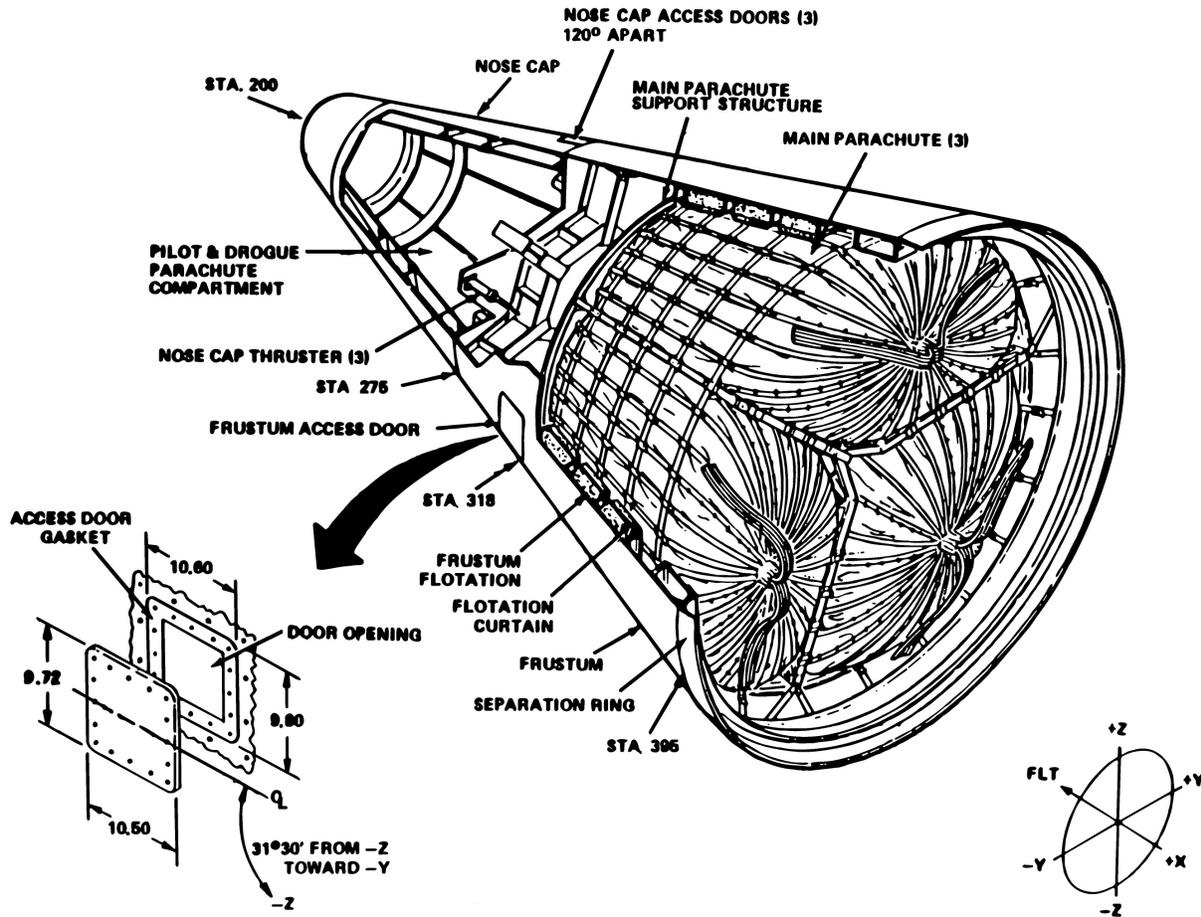


Figure 4.1-II - SRB nose cap and frustum (Ref. 1).

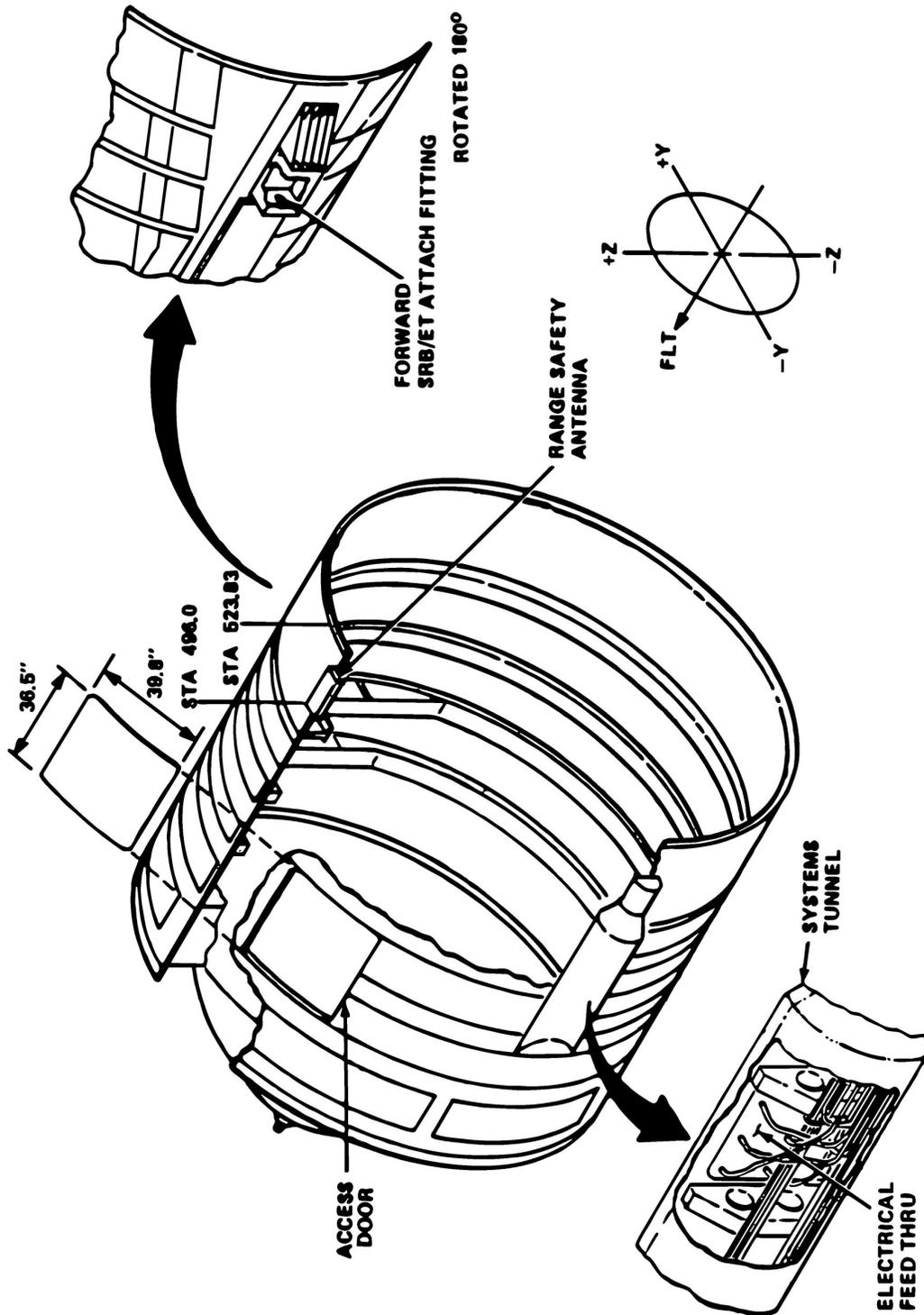


Figure 4.1-III – SRB Forward Skirt (Ref. 1).

4.1.3.4 Systems Tunnel

The SRB systems tunnel, located outboard of each SRB, houses the electrical cables associated with the E&I subsystem and the linear-shaped charge (LSC) of the Range Safety System (RSS). The tunnel provides lightning, thermal, aerodynamic protection, and mechanical support for the cables and charge. The tunnel is manufactured from 2219 aluminum alloy material and extends from the forward skirt along the motor cases to the aft skirt. The tunnel is approximately 10 inches wide and 5 inches high.

4.1.3.5 SRB/ET Attach Ring and Attachments

The SRB/ET aft ring and attachments are composed of a steel ring and three struts that physically attach the SRB to the ET, Figure 4.1-IV. These attachments are designed to react loads of the attach ring and allow unrestrained contraction/expansion of SRB or ET in the longitudinal direction. The aft attach ring is a three-segment construction, made from 4340 steel; it is approximately 162 inches in diameter, 7 inches high, 16 inches wide, and weighs about 3700 lb.

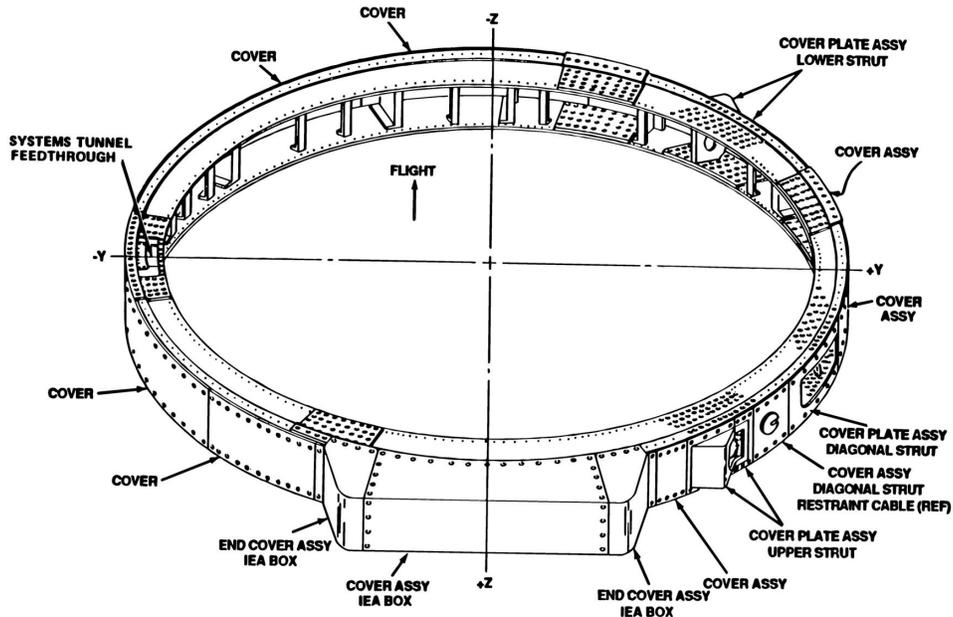
Each strut assembly incorporates separation devices midway between the elements that release the SRB upon command, and the upper portion of each strut remains with the ET. A set of struts and attachments consists of three each of the following: ET clevis end, SRB clevis end, strut segment, adjustment butt, and required washers and bolts. The SRB end of the struts attaches to the aft ring. This hardware weights approximately 1550 lb.

4.1.3.6 Aft Skirt

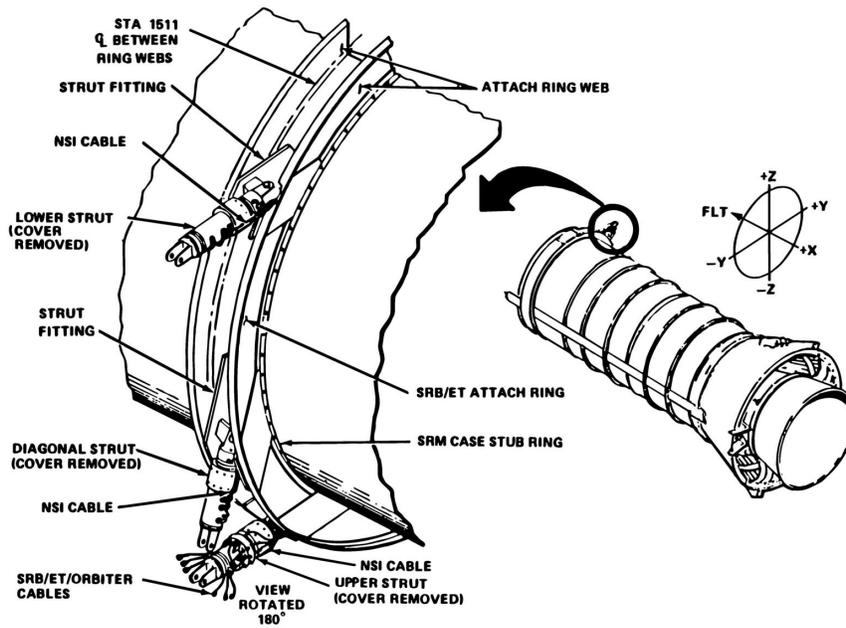
The aft skirt (Figure 4.1-V) provides attach points to the launch support structure and supports the shuttle on the launch pad for all conditions prior to booster ignition. Hold-down posts attach at flanges in the aft skirt and serve as the launch support structure-orbiter stack attach mechanism. Figure 4.1-VI illustrates the holddown assembly

The aft skirt provides aerodynamic protection, thermal protection, and mounting provisions for the TVC subsystem, the aft mounted separation motors, and the E&I subsystem components. The aft skirt also provides sufficient clearance for the RSRM nozzle at the null position plus full gimbal travel. The kick ring at the forward end of the aft skirt provides the necessary structural capability to absorb and transfer induced prelaunch loads.

The aft skirt structure assembly is a conical shape, 146 inches in diameter at the top, 208 inches at the bottom, and 90.5 inches long. It is configured for left- and right-hand assemblies and is fabricated using D6AC steel rings and 2219 aluminum, weighing approximately 11,700 lb.



SRB/ET ATTACH RING (INSULATION OMITTED FOR CLARITY)



SRB/ET AFT ATTACH STRUTS (INSULATED COVERS OMITTED FOR CLARITY)

Figure 4.1-IV – SRB/ET Attach Ring and Struts (Ref. 1).

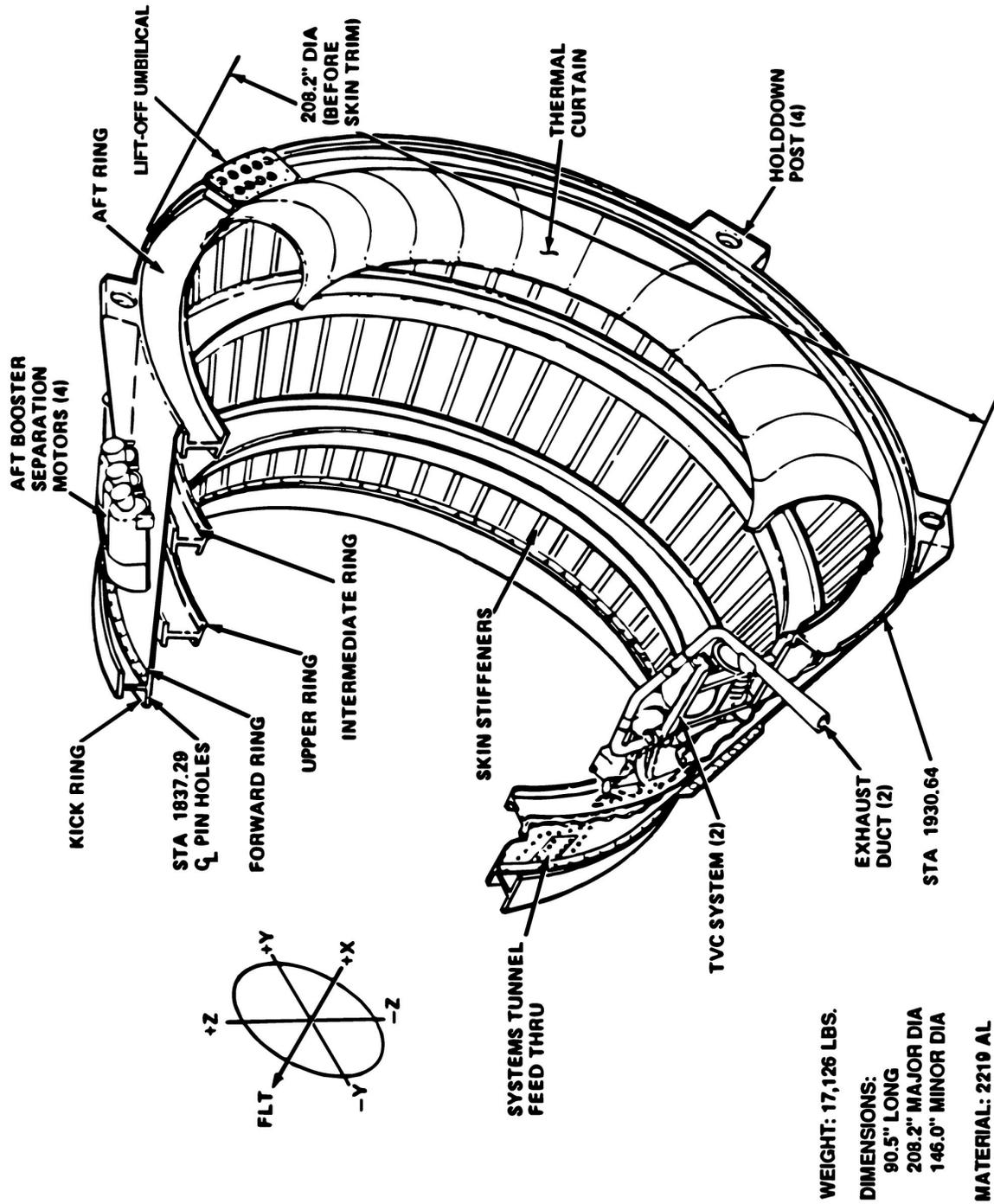


Figure 4.1-V – SRB Aft Skirt (Ref. 1).

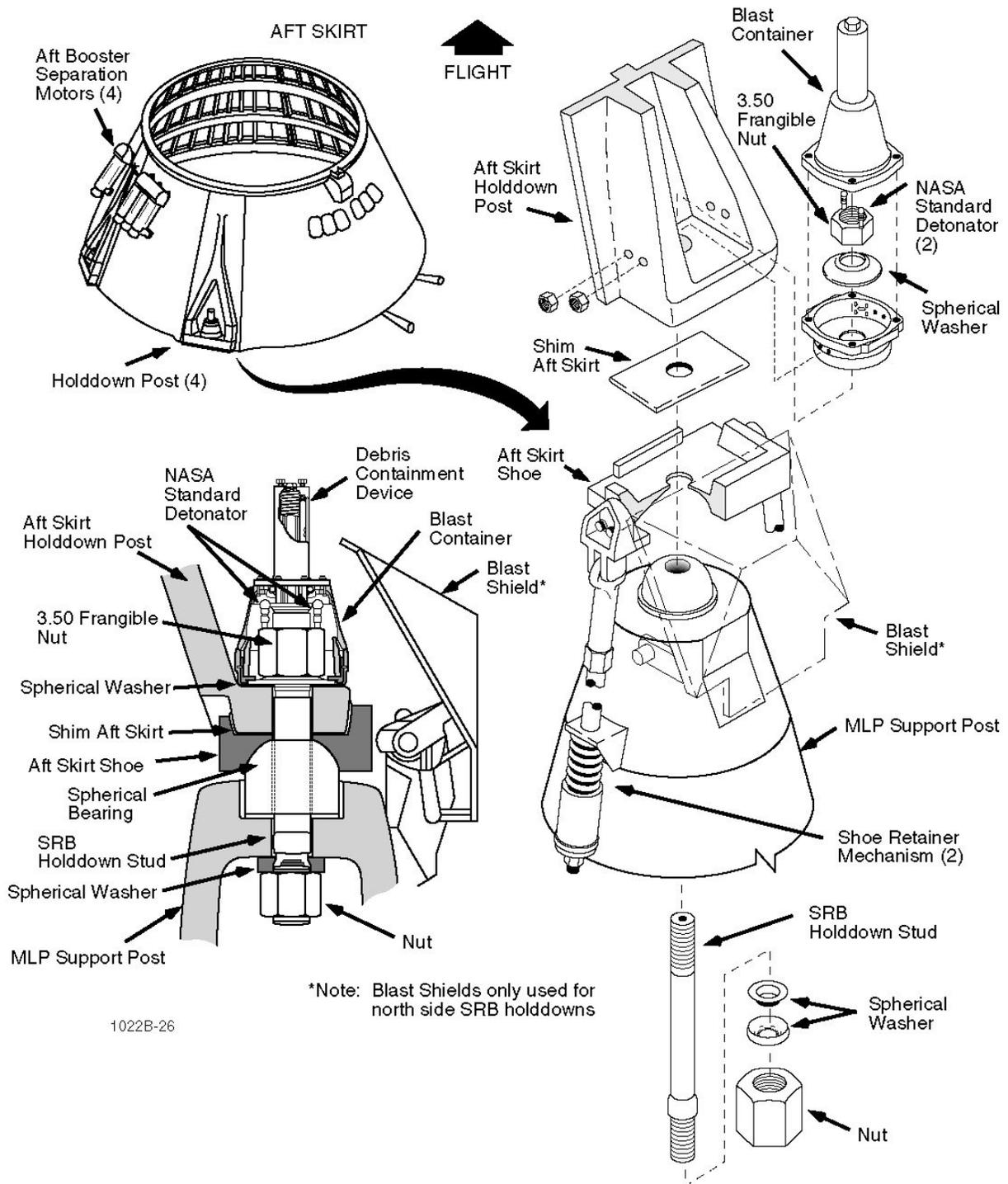


Figure 4.1-VI – SRB Holddown Assembly.

4.1.4 Thrust Vector Control

The thrust vector control subsystem, in conjunction with the RSRM, provides pitch, roll, and yaw vehicle movements as required by the orbiter command system. The subsystem, mounted in the aft skirt, consists of two hydraulic power units and two servoactuators (Figure 4.1-VII).

4.1.4.1 Servoactuators

The servoactuators, linear double-acting type, are attached to the skirt just aft of the kick ring and to the nozzle at the RSRM nozzle compliance ring. The actuators are approximately 53 inches long pin to pin. The actuator stroke is 6.4 inches. The actuators are designed to retain the nozzle in the null position throughout the separation and to water impact. The actuators are oriented at 45°, outboard, to the vehicle pitch and yaw axis.

4.1.4.2 Hydraulic Power Units

Each SRB has two hydraulic power units (HPU's) as a part of the TVC system. On an SRB, each HPU is connected to both the rock actuator and the tilt actuator. One HPU serves as the primary hydraulics on the actuator, and the other HPU serves as the secondary hydraulics. Each actuator has a switching valve that allows the secondary hydraulics to power both actuators if the primary hydraulic pressure drops below 2050 psig (± 150 psig). Details of the HPU are found in systems brief 4.6.

4.1.5 Separation

The separation subsystem is designed to ensure safe separation of each of the SRB's from the ET without damaging or recontacting the orbiter/ET during or after separation. The separation subsystem consists of a release system, sensors, and separation bolts located in the SRB/ET forward attach fitting and in each of the aft attach struts; also included are eight solid booster separation motors (BSM's) - four mounted in the SRB nose frustum and four mounted externally on the aft skirt (Figure 4.1-VIII). The aft motors are mounted asymmetrically, which causes a small roll movement to be imparted to the SRB such that the SRB moves from the orbiter/ET in a way that reduces the plume and particle impingement on the orbiter. The BSM motor has a diameter of 12.85 inches and a length of 31.1 inches. The maximum expected weight for this motor is 152 lb. At a nominal 70° F, the motor propellant weight of 70.6 lb will provide an average thrust of 22,505 lb for 0.55 second. The separation subsystem also includes an umbilical pull-away unit weighing about 675 lb. All sequencing and commands are issued by the orbiter Master Events Controller (MEC/EMEC/AMEC, see Systems Brief 5.1).

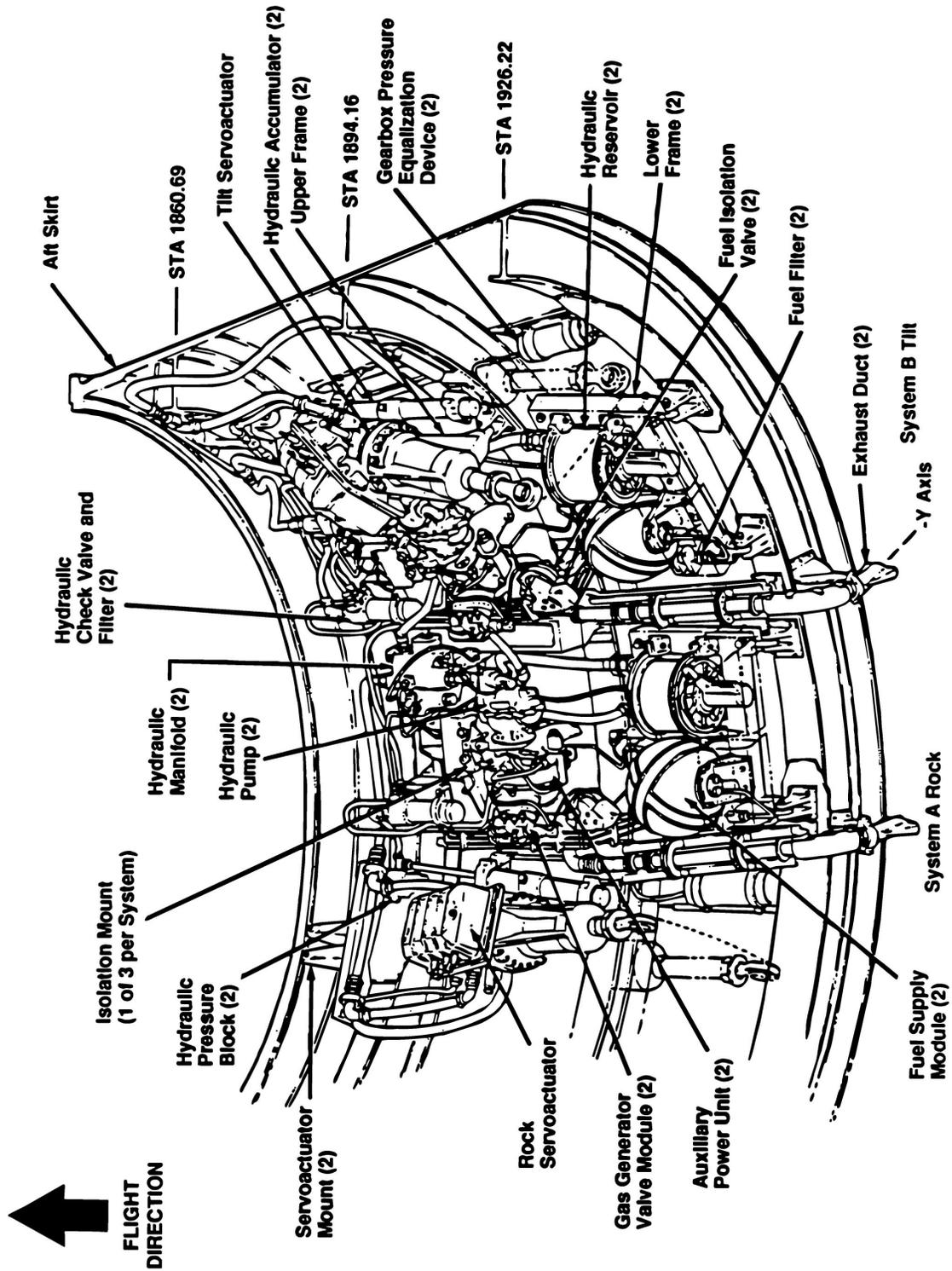


Figure 4.1-VII – SRB TVC components (Ref. 1).

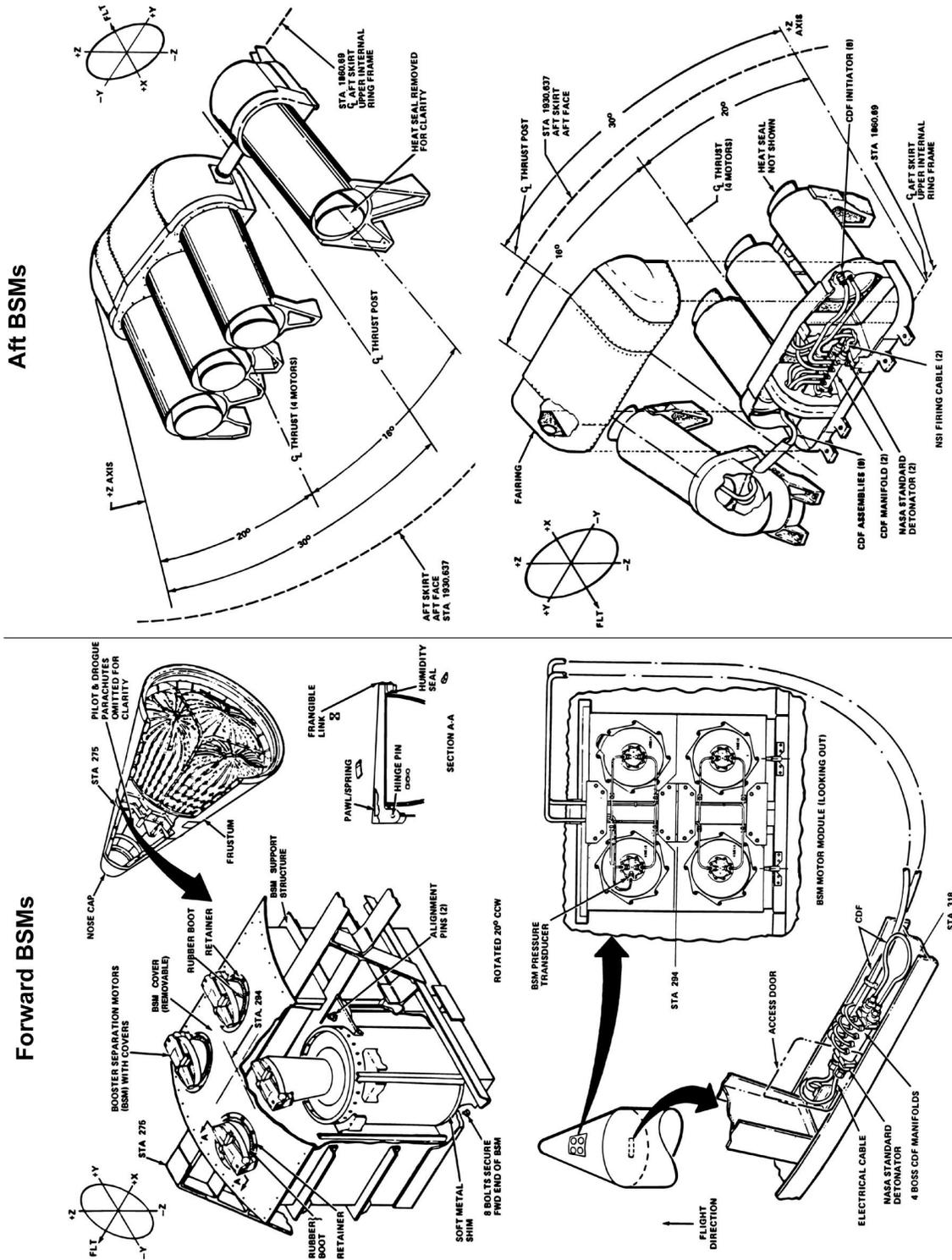


Figure 4.1-VIII – SRB Booster Separation Motors (Ref. 1).

4.1.6 Recovery

The booster recovery subsystem provides the necessary hardware to control the SRB final descent velocity and attitude after separation. The recovery subsystem includes parachutes, methods of sequencing and deploying these parachutes, parachute separation components, and location aids that help in search and retrieval operations for the expended booster and for the parachutes. The parachute deploy sequence is shown in Figure 4.1-IX.

4.1.6.1 Pilot and Drogue Parachutes

The first two parachutes are housed in the SRB nose cap and are deployed as the nose cap separates from the frustum (Figure 4.1-X). The nose cap separation is initiated by the Altitude Switch Assembly (ASA). The nose cap deploys the pilot parachute, which in turn deploys the drogue parachute. The pilot parachute bag and nose cap are released after deployment of the drogue parachute and are not recovered. The drogue parachute, nominally 54 feet in diameter, stabilizes and decelerates the SRB and opens through one reefing stage to full open.

A second ASA output initiates separation of the frustum. As the drogue parachute pulls the frustum away from the SRB, the main parachutes are deployed. The drogue parachute decelerates the frustum for recovery.

4.1.6.2 Main Parachutes

The main parachute assembly decelerates the SRB to a 81-ft/sec nominal water impact velocity. The parachute cluster assembly consists of three parachutes, each approximately 136 feet in diameter, and is housed in the frustum structural component. The main parachutes are deployed as the frustum separates from the booster and are opened through two reefed stages to full open. At booster impact, the main parachutes are disconnected and the SRB directional finding beacons and lights are actuated. The main parachutes have flotation gear and location aids to help in recovery operations.

4.1.6.3 Recovery Operations

A command is sent from the orbiter to the SRB just before separation to apply battery power to the recovery logic network. A second, simultaneous command arms the three nose cap thrusters (for deploying the pilot and drogue), the frustum ring detonator (for main parachute deployment), and the main parachute disconnect ordinance. Two outputs of the Altitude Switch Assembly, which sense barometric pressure, are set to close at high altitude (below 19,000 feet) and at low altitude (below 10,000 feet). At high altitude, the nose cap thrusters fire, pushing the nose cap away from the booster, which deploys a pilot parachute. This pilot parachute deploys the drogue parachute that serves to orient the SRB into a nozzle-first attitude and to provide some initial deceleration of the SRB.

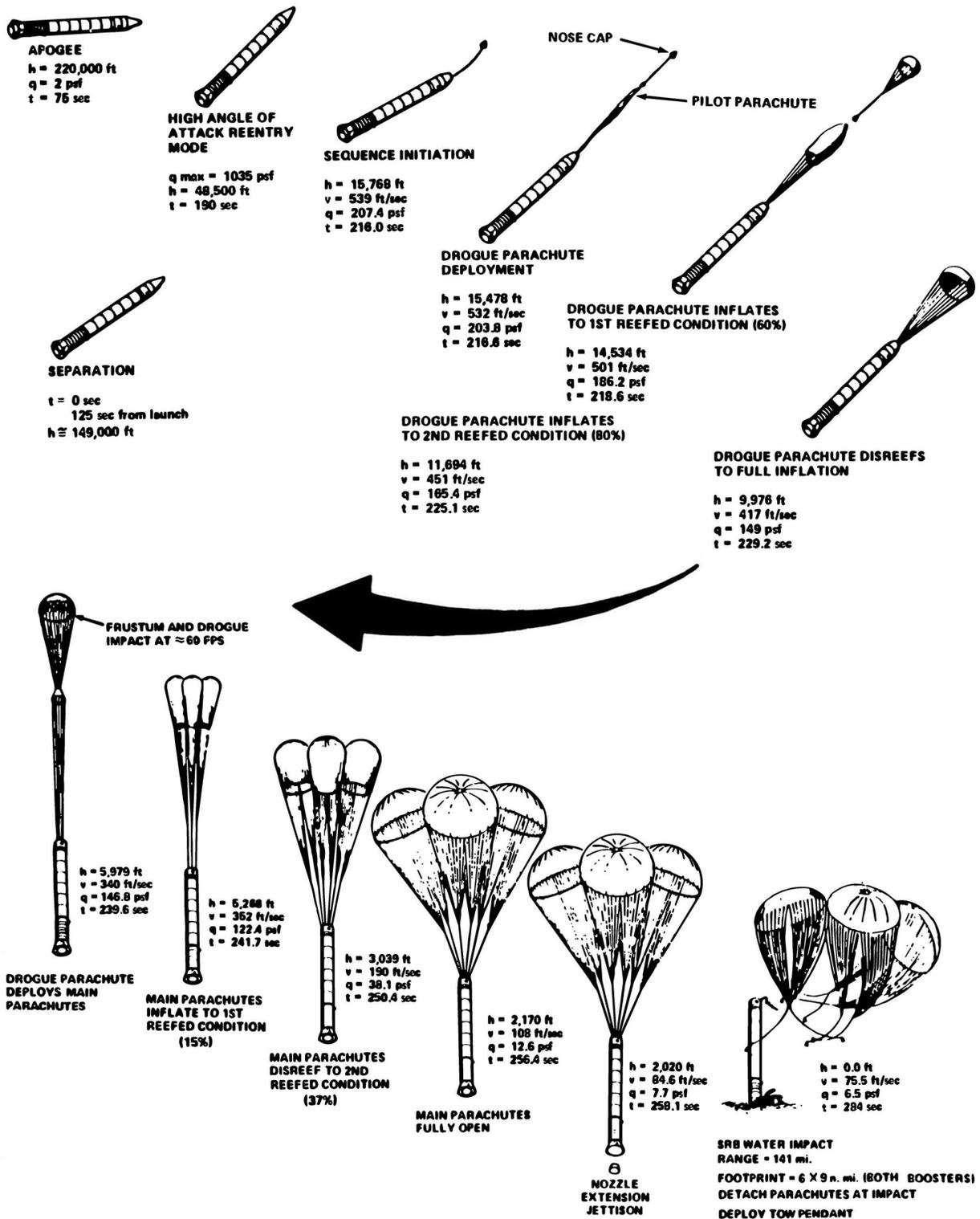


Figure 4.1-IX – SRB parachute deployment sequence (Ref. 1).

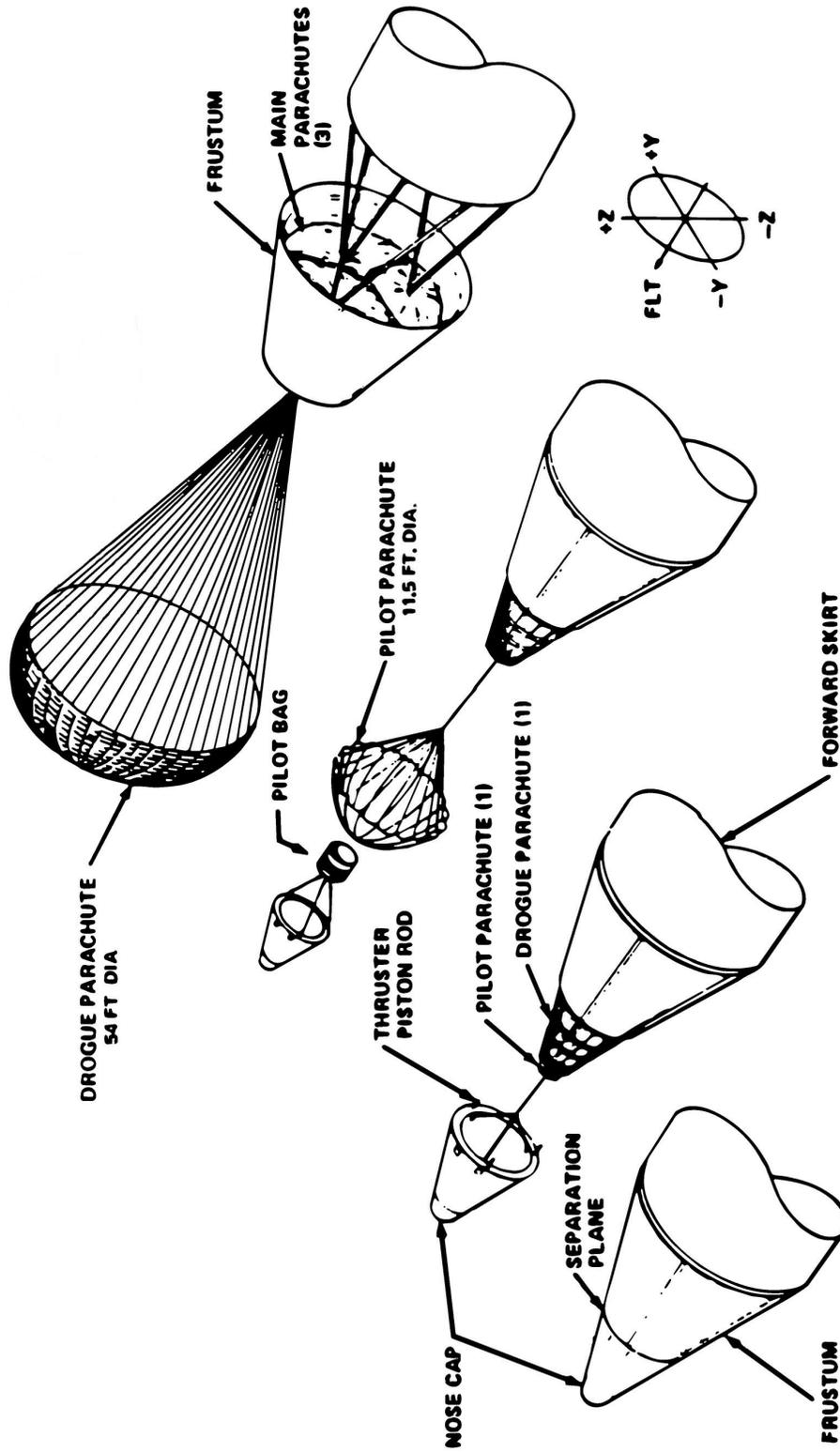


Figure 4.1-X – SRB Nose Cap Separation (Ref. 1).

At the low altitude switch output, the frustum ring detonator fires, and a shaped charge frees the frustum. The drogue parachute pulls the frustum away from the booster, thus deploying the main parachutes. The SRB radio-direction-finding beacon and light are turned on at booster impact, and the main parachutes are disconnected using saltwater-sensing disconnect devices at water slapdown.

The nominal velocity for the booster at water impact is designed at 81 feet per second. The frustum, lowered by the drogue parachute, impacts within approximately one mile of the SRB at a nominal 50 ft/sec. The frustum provides buoyancy and location aids for the drogue parachute, and the main parachutes have flotation gear and location aids. Retrieval of the boosters, parachutes, and frustums is accomplished using surface vessels. The retrieval vessels tow the boosters to Kennedy Space Center and other objects recovered are brought on board the vessels. The boosters are expected to impact at a point approximately 140 n.m. downrange, +/-5 n.m.. Once the boosters are located, the Diver Operated Plug (DOP) is maneuvered by divers into place to plug the SRB nozzle and dewater the motor case. Dewatering, pumping air into and water out of the SRB, causes the SRB to change from a nose-up floating position to a horizontal attitude more suitable for towing. The recovery assemblies are planned for 10 flights.

4.1.7 Electrical and Instrumentation

The SRB E&I subsystem for operational flights consists of two major functional systems dedicated to two specific portions of the SRB mission. One system is operational from prelaunch until SRB/ET separation and will be referred to as the ascent system. The other system is operational from just prior to SRB/ET separation until SRB splashdown and will be referred to as the recovery system. These systems are identical on both the left and right SRB's. E&I subsystem components are generally designed for recovery, refurbishment, and reuse on 19 subsequent flights or a total of at least 20 uses.

4.1.7.1 Ascent System

This system consists of the E&I subsystem components necessary to respond to Orbiter Vehicle (OV) commands for controlling SRB prelaunch functions, ignition, power ascent, and SRB separation. In addition, it provides the data acquisition element necessary to implement the Operational Flight Instrumentation (OFI) program. As a purely responsive system, the ascent system relies on the OV for all power and stimuli. The system is redundant in all critical functions.

4.1.7.2 Recovery System

The system consists of the E&I subsystem components that bring about the successful recovery of the SRB after burnout and separation, by performing the following functions:

- Deployment of the drogue and main chutes
- Severance of the nozzle extension
- Powering of location aids
- Severance of main chute at water impact

The recovery system is simplex and self-contained, except for initial power-on command, which is derived from the separation fire commands from the OV.

4.1.7.3 Operational Components

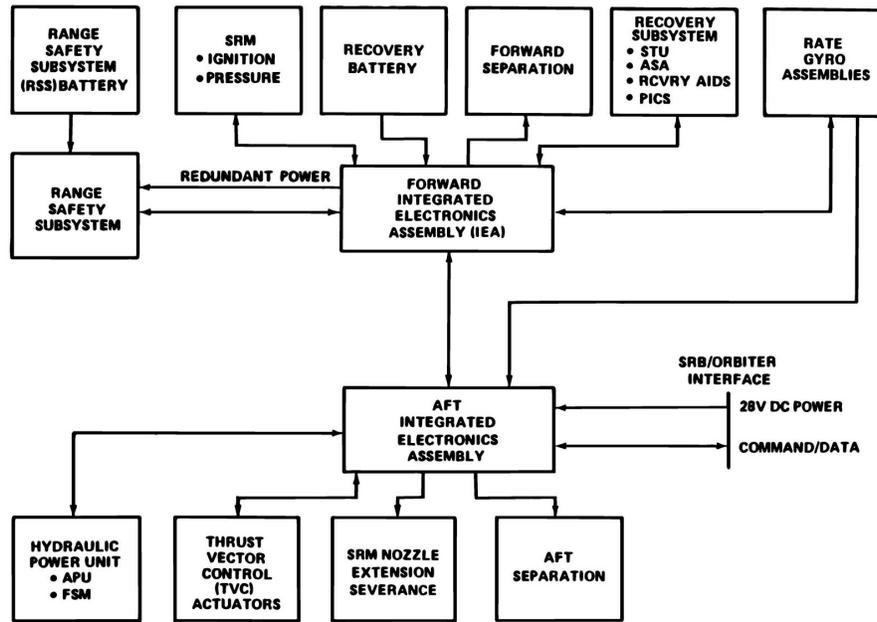
The E&I subsystem components can generally be divided into eight elements: the forward and aft integrated electronics assemblies (IEA's), the rate gyro assemblies (RGA's), the instrumentation sensors, SRB location aids, recovery battery, altitude switch, frustum location aids, and interconnecting cable assemblies.

4.1.7.4 Integrated Electronics Assemblies

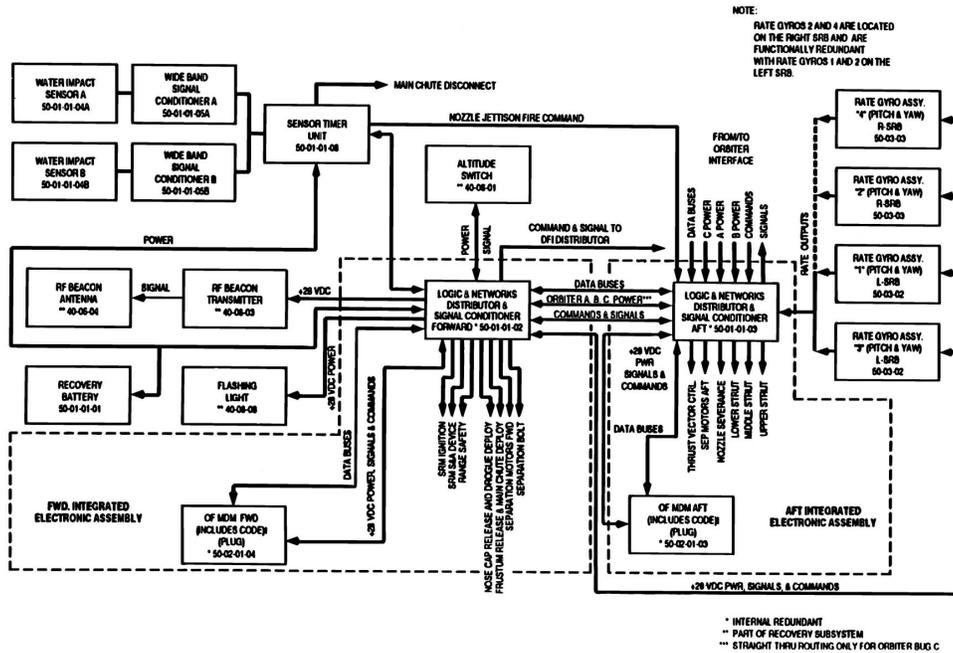
The forward and aft IEA's are identical in many of the functions they perform; power distribution, command/control switching distribution, data bus termination, signal conditioning, multiplexing of SRB measurements, and demultiplexing of OV commands. The forward IEA also contains the recovery logic-sequencer and is mounted on a structural ring in the watertight forward compartment, and the aft IEA is mounted in the ET/SRB attach ring. In addition to the functions listed above, the aft IEA is also used for the routing of all interface wiring from the OV and provides the control electronics for the TVC hydraulic power units. Figure 4.1-XI illustrates the interfaces and functions of the IEA's.

Each IEA is divided into three elements:

- A distributor for power distribution and command/control switching and distribution. The distributor contains: the pyrotechnic initiator controllers (PIC's) for SRB ignition, PIC's for ET/SRB separation and recovery, solid state switch cards, TVC APU controller card in the aft IEA, and the recovery logic sequencer and impact switch in the forward IEA.
- A signal conditioner for the conditioning of instrumentation sensor outputs that are not suitable for direct interface with the SRB MDM's.
- An MDM for multiplexing SRB measurement data to the OV and demultiplexing OV commands and interrogations directed to the SRB. The MDM is redundant and transmits and receives via two independent data buses.



E&I HARDWARE INTERFACE BLOCK DIAGRAM



E&I SUBSYSTEM FUNCTIONAL DIAGRAM

Figure 4.1-XI – SRB E&I Subsystem (Ref. 1).

4.1.7.5 Rate Gyro Assemblies

Each SRB contains two RGA's, with each RGA containing one pitch and one yaw gyro. These provide an output proportional to angular rates about the pitch and yaw axis to the orbiter computers and guidance, navigation, and control system during first stage ascent flight in conjunction with the orbiter roll rate gyros until SRB separation. At SRB separation a switchover is made from the SRB RGA's to the orbiter RGA's. The SRB RGA rates pass through the SRB aft IEA to the orbiter.

4.1.7.6 Instrumentation Sensors

Instrumentation sensors are provided to meet the requirements of the OFI program.

4.1.7.7 SRB Location Aids

The SRB location aids consist of an RF beacon and a flashing light. The beacon antenna and the flashing light are mounted on the apex of the forward pressure dome.

4.1.7.8 Recovery Battery

The recovery battery is a primary 50ampere-hour, silver/zinc battery that provides all power for the recovery system and is not designed for reuse. This battery also provides power for one of the redundant channels in the Range Safety Subsystem (RSS).

4.1.7.9 Altitude Switch

The altitude switch assembly, mounted in the frustum area, provides initiation of drogue and main chutes, deployment, and recovery aids power on.

4.1.7.10 Frustum Location Aids

The frustum location aid is a self-contained assembly, having a flashing light, RF beacon, salt water sensing switch, and battery.

4.1.7.11 Cable Assemblies

Cable assemblies are provided for interfacing with the ET-provided cable assembly at the pullaway connectors and for interconnection of ascent or recovery system components. In general, operational flight cable assemblies are designed for reuse on subsequent flights. Some exceptions to this are: cables that have connectors that are exposed during recovery and retrieval operations and cables that are connected directly to ordnance initiators.

4.1.7.12 Range Safety System (RSS)

The RSS contains the necessary equipment to destroy the SRB in case of a malfunction requiring premature flight termination. The system is ground-operated and redundant. It is monitored, tested, and safed via the MDM in the forward IEA. The destruct reaction time sequence is outlined in Figure 4.1-XII and the functional diagram is given in Figure 4.1-XIII. The RSS components include the following:

- RSS Distributor - Contains the PIC's and switch cards, necessary to detonate the linear-shaped charges. The distributor contains two redundant systems powered from the RSS battery and the recovery battery.
- Decoder - Provides the arm and fire commands for the distributor. There are two redundant decoders.
- Receiver - Provides the demodulated message that serves as an input to the decoder. There are two redundant receivers.
- Couplers - There are two couplers for the antenna - one is a directional and the other a hybrid coupler. The hybrid coupler provides a ground input to the receiver for test purposes. The couplers have redundant channels.
- Antennas - There are two antennas mounted 180° apart on the forward skirt.
- S&A - The safe and arm device with two redundant channels and NSI's (NASA Standard Initiators).
- LSC – The Linear Shaped Charge, installed in the systems tunnel over 70% of the motor case, cuts through the motor case to allow rapid combustion of all propellant, destroying the SRB's, the ET, and the Orbiter

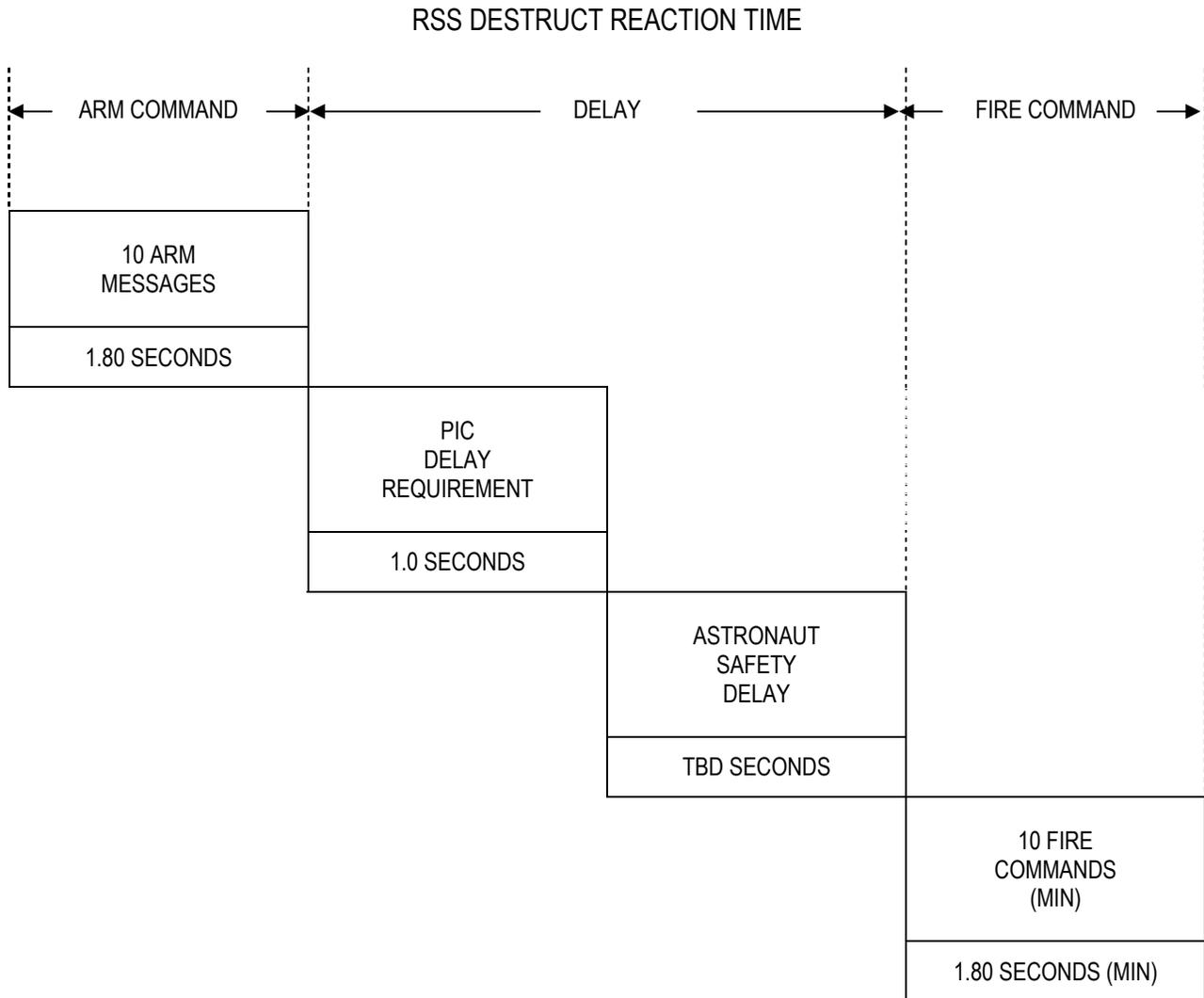
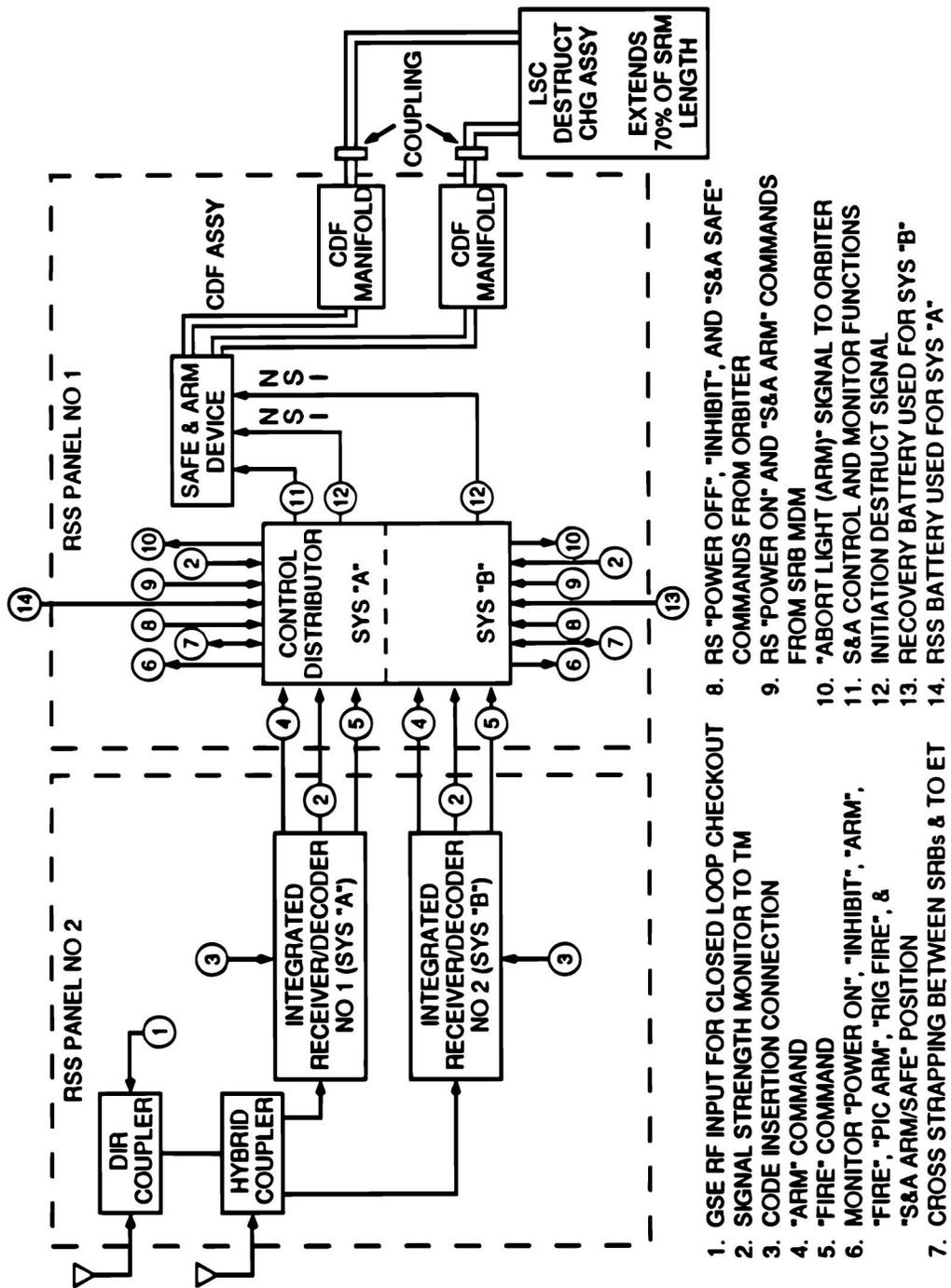


Figure 4.1-XII – RSS destruct reaction time.



1. GSE RF INPUT FOR CLOSED LOOP CHECKOUT
2. SIGNAL STRENGTH MONITOR TO TM
3. CODE INSERTION CONNECTION
4. "ARM" COMMAND
5. "FIRE" COMMAND
6. MONITOR "POWER ON", "INHIBIT", "ARM", "FIRE", "PIC ARM", "RIG FIRE", & "S&A ARM/SAFE" POSITION
7. CROSS STRAPPING BETWEEN SRBs & TO ET
8. RS "POWER OFF", "INHIBIT", AND "S&A SAFE" COMMANDS FROM ORBITER
9. RS "POWER ON" AND "S&A ARM" COMMANDS FROM SRB MDM
10. "ABORT LIGHT (ARM)" SIGNAL TO ORBITER
11. S&A CONTROL AND MONITOR FUNCTIONS
12. INITIATION DESTRUCT SIGNAL
13. RECOVERY BATTERY USED FOR SYS "B"
14. RSS BATTERY USED FOR SYS "A"

Figure 4.1-XIII – RSS Functional Diagram (Ref. 1).

4.1.8 Mission Operations

The times given (see Figure 4.1-XIV) could vary flight-to-flight. These times are for information only.

4.1.8.1 SRB Prelaunch Timeline

<u>Time*</u>	<u>Events</u>
T ₀ -10:00:00	SRB aft skirt GN2 purge activation
T -9:00:00	SRB buses A and B power applied (PC1 & PC2 active)
T ₀ -5:00:00	Check LH and RH SRB TVC SYS A and B FSM pressure (350 psia minimum prior to T-31 sec)
T - 8:00:00	SRB field joint heaters enabled
T ₀ -3:00:00	Final SRB bus C power applied (PC3 active)
T - 1:30:00	Check RSRM Pc transducer calibration
T - 1:00:00	Turn on SRB RGA's for pretest warmups
T - 0:35:00	SRB RGA tests
T ₀ - 0:30:00	RSS checks (RSS inhibit-on)
T ₀ - 0:29:00	Turn ATVC power on (ATVC sw (4)-ON)
T ₀ - 0:09:00	Start auto launch sequence (LPS) Verify igniter heater off and field joint heaters are off
T ₀ - 0:05:00	Arm RSS S&A device (3) Arm RSRM ignition S&A devices (2)
T ₀ - 0:00:30	Issue SRB actuator OVERRIDE commands
T ₀ - 0:00:25	Transfer launch control from LPS to RS LAUNCH SEQ
T ₀ - 0:00:20	Start SRB HPU's
T ₀ - 0:00:16	Remove SRB actuator OVERRIDE commands
T ₀ - 0:00:12	Start monitoring PIC voltages Hold if PIC voltage drops below 37.5 V dc
T ₀ -0:00:07	Remove RSS inhibit
T ₀ -liftoff	<ul style="list-style-type: none">• Arm PIC's• SRB ignition• Hold down release• T-O umbilical release• ET vent arm release

*Time in hr; min; sec

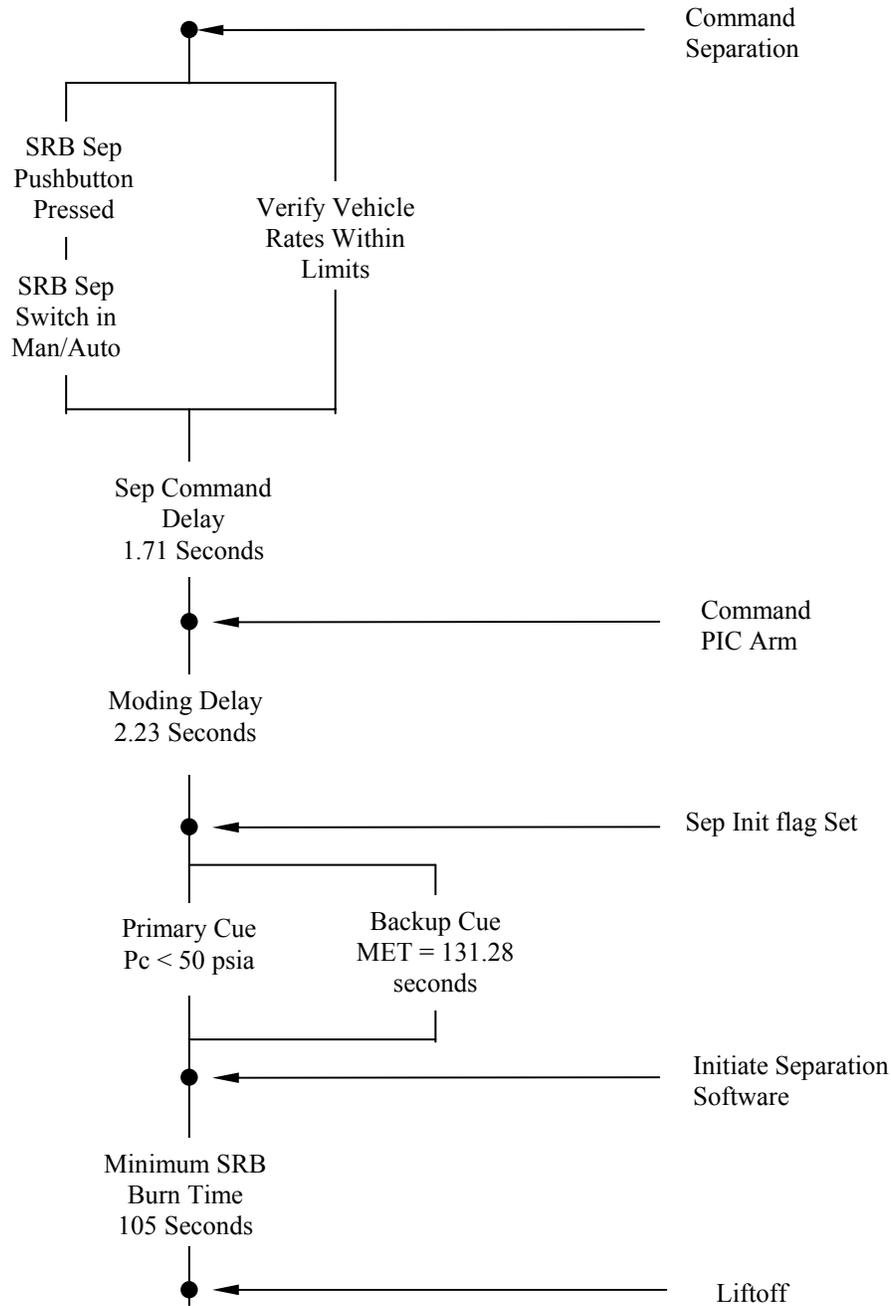


Figure 4.1-XIV – SRB separation overview (Refs. 2,3).

4.1.8.2 SRB Ignition Timeline

<u>Time*</u>	<u>Events</u>
T ₀ -0:00:06.6	Issue SSME START ENABLE command
T ₀ -0:00:06.5	Issue SSME START command PAD SHUTDOWN if: (1) PIC voltage <37.5 V dc (2) Launch sequence abort flag set (3) Any SSME not >90 percent Pc within 4 sec
T ₀ -0:00:06	SRB systems ready for launch
T ₀ -0:00:00	SSME (3) >90 percent Pc (nominal) Issue SRB actuator override commands Issue RSRM ignition FIRE 1 command Issue RSRM ignition FIRE 2 command (defines T ₀) <ul style="list-style-type: none"> • Ignites RSRM's • Blows holddown bolt NSI's • Resets MET to zero (T₀)
T ₀ +0:00:00.04	Issue T-O umbilical release FIRE 1 command Issue T-O umbilical release FIRE 2 command Remove SRB actuator OVERRIDE commands

4.1.8.3 SRB First Stage Ascent Timeline

<u>Time*</u>	<u>Events</u>
T ₀ +0:00:19.7	Maximum RSRM thrust
T ₀ +0:00:35.5	SSME throttle-down to thrust bucket
T ₀ +0:00:63	SSME throttle-up to nominal power level
T ₀ +0:00:69	Maximum dynamic pressure (q)
T ₀ +0:01:40	Start monitoring Pc and MET

4.1.8.4 SRB Separation Timeline

<u>Time*</u>	<u>Events</u>
T ₀ +0:02:00	Pc<50 psia on both SRB's or when MET=131.3 sec If Dt between LH and RH SRB's is > 5.0 sec, then go to MET<131.3 (STS-65) sec cue Arm SRB separation PIC's Configure systems for separation
T ₀ +0:02:06	Issue SRB SEP FIRE 1 and 2 commands

*Time in hr: min: sec

 SRB SEPARATION OCCURS

4.1.9 References

1. SRB Pictorial Representations Handbook, USBI 10MNL-0028, 4/30/1990.
2. Space Shuttle Orbiter Operational Level C FSSR GN&C Sequence Requirements, STS 83-0026-29, 11/4/1999, Section 4.2.2, SRB Separation Sequence.
3. STS-105 I-loads

4.2 SRB CASING

4.2.1 General

The SRM case functions as a pressure vessel in which thrust can be developed and as a structural frame through which flight loads are transmitted and reacted. The case is designed to withstand ascent, entry, and water impact loads and to be reusable after refurbishment and propellant loading. The case is designed for a maximum expected operating pressure (MEOP) of 1016 psia at 90° F. The case construction is a D6AC steel forging with no welds forming each of 11 segments. These segments are designated as the forward dome segment, six cylindrical segments, the ET attachment segment, two stiffener segments, and the aft dome segment, Figure 4.2-I – Case Segments.

4.2.1.1 Forward Segment

The forward segment is swaged from a pancake billet of D6AC steel material. The use of a relatively flat 1.6:1 ellipse allows for a completely weld-free part. The dome thickness is tapered to maintain a constant stress. A short stub skirt with a male (tang) interface has been provided for attaching the SRB forward skirt assembly. A 21-inch inside diameter (ID) polar boss with bolted attachment provisions is provided at the apex of the forward dome for attachment of the ignition system. Forty 0.75-inch bolt holes are provided for this purpose. An aft facing, male (tang) joint, has been incorporated for attachment of this segment to the cylinder case segment.

4.2.1.2 Cylindrical Segment

The six cylindrical segments are roll-formed from rolled ring forgings. The basic cylindrical wall is a roll-formed "net" and no additional machining is required. Tang and clevis joints at either end are machine-finished after heat treatment in order to achieve the close tolerances required. In the past, all cylinder segments were interchangeable since they all shared the same joint design. The configuration of factory and field joints was the same. With the incorporation of the redesigned field joint, the interchangeability has been limited to segments sharing the same joint configurations. The basic wall thickness is nominally 0.479 inch with a tolerance of +0.020 inch. The final nominal wall thickness after 20 uses is expected to be 0.470 inch (0.450-inch minimum).

4.2.1.3 SRB/ET Attachment Segment

The attachment segment is roll-formed from a rolled ring forging. This segment contains two attach flanges symmetrically located about motor station 1511 for attaching the SRB/ET aft attach ring. This segment has tang and clevis joints on either end for attachment to the adjacent cylindrical segment and stiffener segments. The attachment stubs and clevis joints are machined after heat treatment.

4.2.1.4 Case Stiffener Segment

The two case stiffener segments are roll-formed from rolled ring forgings. This segment contains attach flanges for attaching two circumferential stiffener ring assemblies. The function of the stiffener rings is to prevent case buckling due to the cavity collapse loads during water impact. Only the aft stiffener segment has externally attached rings. The flanges provide sufficient buckling stiffness for the forward segment. The segments are identical and interchangeable.

4.2.1.5 Aft Segment

The preform for the aft segment is swaged into a hemispherical shape from a cylindrical rolled ring forging. A short stub skirt, with a male (tang) interface, is provided for attaching the SRM to the SRB aft skirt assembly. A polar boss with bolted attachment provisions for the nozzle assembly is provided on the aft end. One hundred 1.375-inch bolt holes are provided at bolt circle diameter of 106.1 inches. Nominal wall thickness of the hemispherical aft dome is 0.362 inch with a +0.020-inch tolerance.

4.2.1.6 Stiffener Ring

Two stiffener rings are attached to the aft case stiffener segment to prevent case buckling instability during water impact. Each ring assembly consists of three 120° sections. These sections are formed into complete 360° segments after attachment to the case by the use of splice plates. The material used for the stiffener rings is the same as that of the case in order to preclude any corrosive action due to dissimilar metal. Like the case, the stiffener rings are coated with Rust-Oleum protective coating and are reusable through a minimum of 20 times.

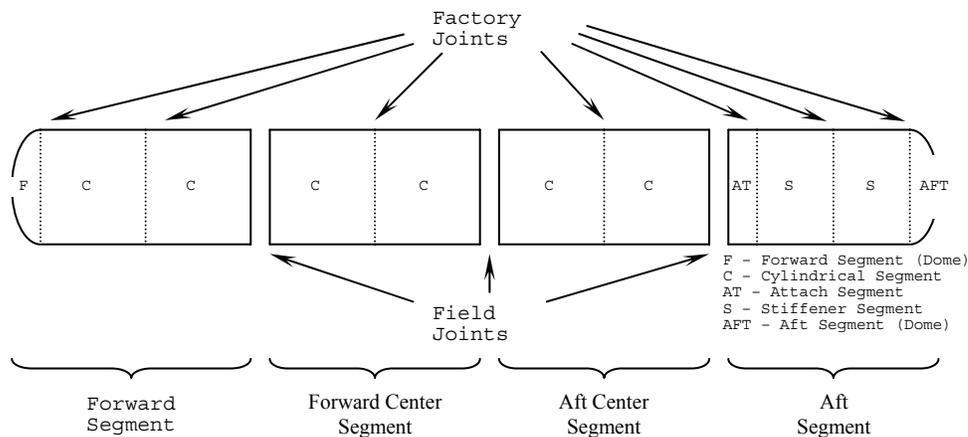


Figure 4.2-I – Case Segments

4.2.1.7 Factory Joints

The factory joints of the SRB casing (Figure 4.2-II) are tang and clevis-type joints. The factory joints connect the 11 case segments into 4 casting segments; the forward segment, the forward center segment, the aft center segment, and the aft segment. There are seven factory joints on the SRB casing. The factory joints employ two fluorocarbon "viton" O-rings, a pin retainer band, a leak check port, and a vulcanized weather seal. Additional insulation piles are layered on the interior to insure joint integrity.

4.2.1.8 Field Joints

The SRB case incorporates three field joints into its design (Figure 4.2-III). These joints are used where the four case segments are joined during vertical assembly at Kennedy Space Center. Like the factory joints, the field joints are also tang and clevis type, but have several additional features to protect against any type of hot gas leak. The most notable difference between the field and factory joint is the tang capture feature. This is intended to provide a positive metal-to-metal interference fit around the circumference of the tang and clevis ends of the joined segments. The interference fit limits the deflection between the tang and clevis O-ring sealing surfaces caused by motor pressure and structural loads. The joints are designed so that the seals will not leak under twice the expected structural deflection. The field joints also have three O-rings, with the additional third O-ring in the capture feature. There are also two leak check ports, and a pin retention band. The joints also have external heaters with integral weather seals, which were incorporated to maintain the joint and O-ring temperature at a minimum of 75° F. The seals also prevent water from penetrating into the joint. The internal case insulation for the joints features a J-seal, which includes a pressure actuated flap.

4.2.1.9 Case to Nozzle Joint

These joints (Figure 4.2-III) incorporate 100 radial bolts, and 100 axial bolts to minimize joint gap opening during pressurization. The unvented joint involves filling the joint with an ambient cure adhesive and allows the stress relief flap to account for growth variations with the joint due to temperature and motor pressurization. The joint also contains a wiper O-ring designed to keep adhesive away from the primary seal during assembly. Vent ports and slots vent assembly pressure and position the primary O-ring.

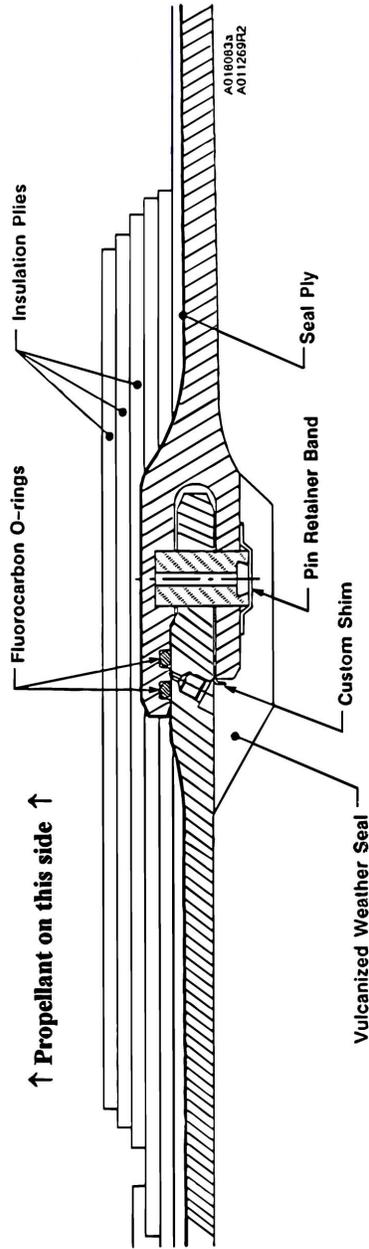


Figure 4.2-II – Factory Joint

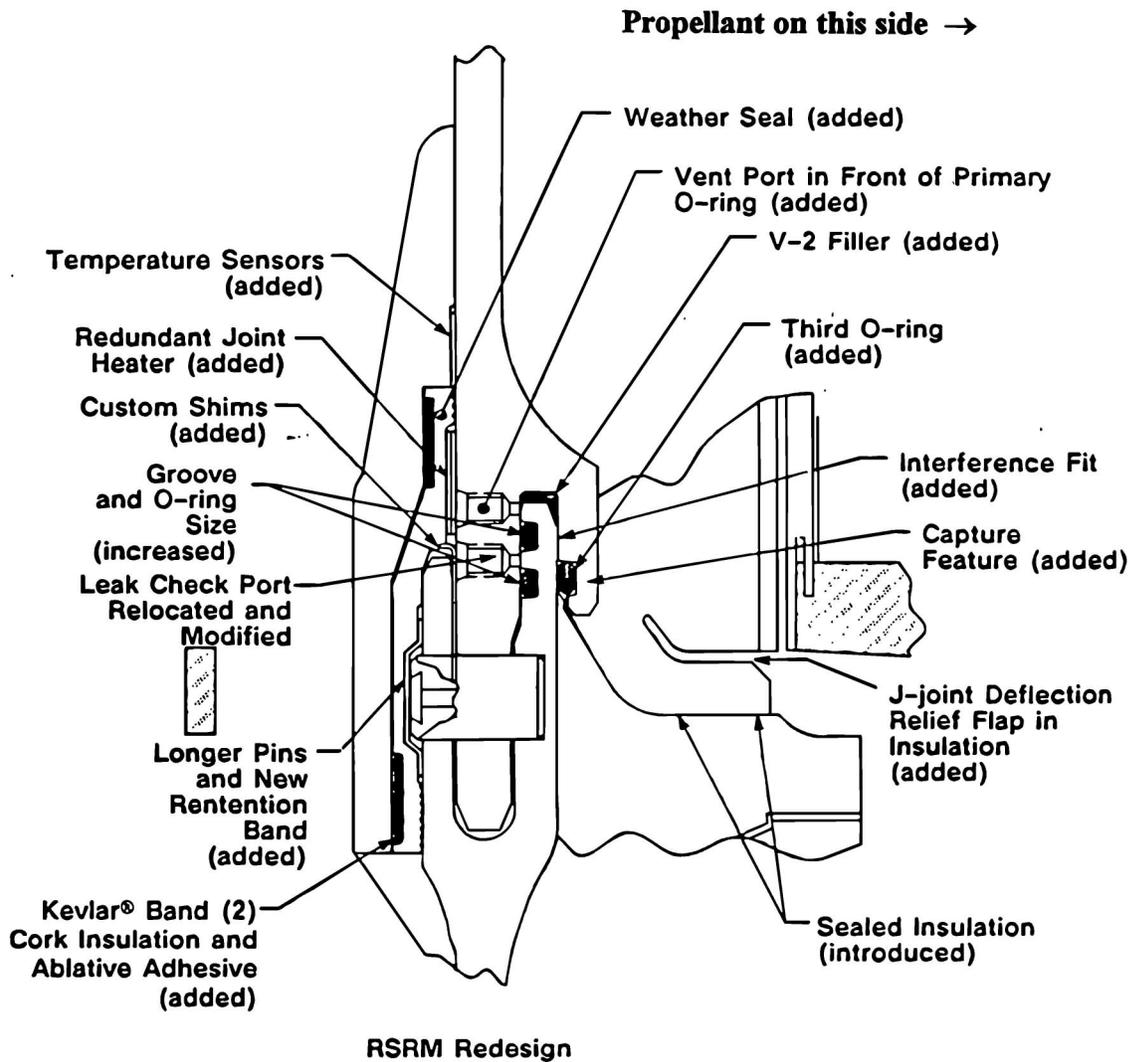


Figure 4.2-III – Field joint

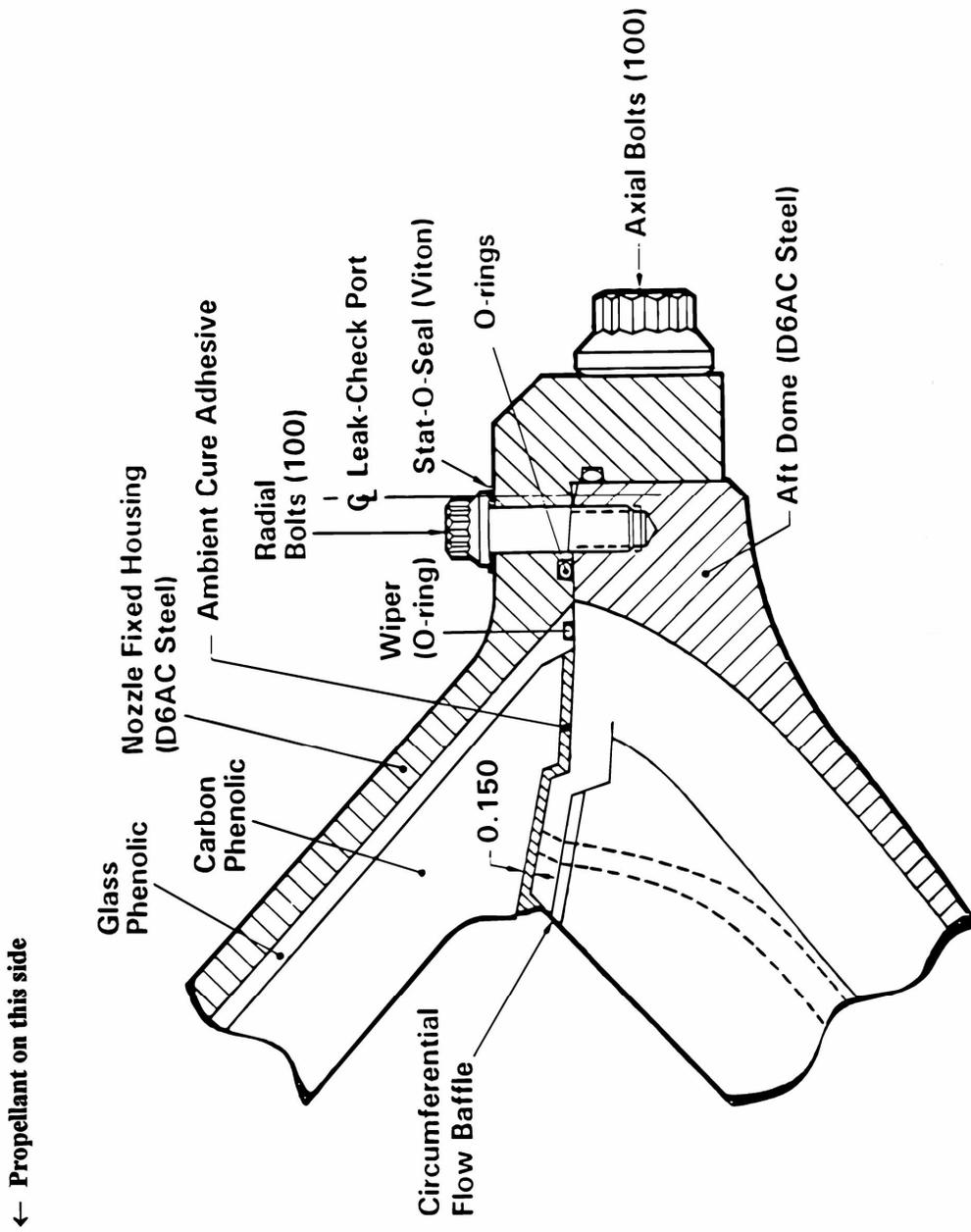


Figure 4.2-IV – Nozzle-to-Case Joint

4.2.2 Functional Description

4.2.2.1 *SRM Case*

The 11 case segments are preassembled in four subassemblies prior to propellant casting. These four subassemblies are designated as the forward casting segment, the center casting segment (two required), and the aft casting segment (Figure 4.2-I).

The forward casting segment consists of a forward dome segment and two cylindrical segments. The two center casting segments each consist of two cylindrical segments, and the aft casting segment consists of an attach segment, two stiffener segments, and the aft segment.

The individual segments are joined with pinned clevis joints and pin retainer bands, which hold the pins in place and also provide environmental seals for each joint. The clevis joints utilize 180 cobalt alloy pins. Three of these pins, located at approximately 120 degree intervals, are used for case alignment during assembly. The remaining 177 pins are load bearing and after assembly are held in place by the retainer bands. Attachment of the ignition system and the nozzle is by means of polar bolt circles in the forward and aft segments, respectively. The igniter components in the forward dome use Gask-O-Seals and are dual sealing surfaces. Pressure seals at each segment joint are dual O-rings.

The assembled SRM case has a nominal overall length (boss to boss) of 1388.77 inches. The outside diameter (OD) of the basic cylindrical wall is 146.000 inches and the maximum OD of the metal parts is nominally 149.478 inches at the attach stub. The total empty case weight is 98,010 lb. The external surface of the assembled case is protected from general corrosion and stress corrosion by the Rust-Oleum paint.

4.2.2.2 *Insulation*

The insulation subsystem includes chamber insulation, propellant relief flaps, and forward and aft facing inhibitors. The insulation material used for the chamber, relief flaps, and forward inhibitors is an asbestos-silica filled nitrile butadiene rubber(NBR). The aft inhibitor material is an asbestos-filled carboxyl terminated polybutadiene polymer (HC polymer). As of March, 2001, the Thiokol Corporation had tested asbestos free insulation material in static ground fire tests on Flight Support Motors, but has not used the new insulation on a flight motor.

The insulation configuration has been designed to protect each casting segment during motor operation. The internal insulation subsystem for each casting segment includes the primary insulation, forward facing full web propellant grain inhibitors, and propellant grain stress relief flaps. The primary chamber insulation propellant stress relief flaps at the aft end of each of the forward and center segments are provided to reduce insulation-liner-propellant bondline loads induced at propellant grain termination surfaces following propellant cure, thermal shrinkage, and during SRM pressurization.

The insulation components (i.e., primary insulation, propellant stress relief flaps, and forward full web inhibitor) are fabricated as integral assemblies within each casting segment. These components are laid up in the SRM casting segment, bonded, and autoclave-cured in one operation prior to propellant casting.

The inhibitors must provide thermal protection to the propellant grain and prevent the propellant from igniting and burning perpendicularly to the inhibitor surface. The forward facing full web propellant inhibitor is fabricated as an integral part of the casting segment insulation. The aft facing partial web inhibitor will be cast and troweled on the aft face of the propellant during propellant cure. The inhibitor material must provide a chemically compatible stratum to which the liner/propellant is bonded.

4.2.2.3 Liner

The liner material has been designed to provide a bond between the insulation and propellant in solid rocket motors. The liner is designed, formulated, and selected for the SRM to provide a liner/propellant bond that will fail cohesively in the propellant. The liner is compatible with the selected insulation and propellant and has acceptable bond throughout the service life of the SRM. The selected liner material is an asbestos-filled CTPB polymer.

As of March, 2001, Thiokol Corporation had tested an asbestos free liner in static ground fire tests on Flight Support Motors (FSM), but has not used the new liner on a flight motor. Static fire of FSM-8 on Feb 17, 2000 included a demonstration test of asbestos free insulation, liner, castable inhibitors, and adhesives. This was done to protect for the possibility of asbestos materials becoming unavailable. There is currently no plan to use these asbestos free materials on flight motors.

4.3 RSRM PROPELLANT

4.3.1 Propellant Formulation

The RSRM propellant is a composite-type solid propellant (refer to SB 8.2 for more information on solid rocket motors). Its basic formulation is polybutadiene acrylic acid acrylonitrile terpolymer (PBAN, or HB polymer) with an epoxy curing agent, ammonium perchlorate as oxidizer, and aluminum powder as fuel. A small amount of burning rate catalyst (iron oxide) is added to achieve the desired propellant burning rate. The basic propellant consists of 86 percent total solids with the following chemical breakdown:

69.8 percent ammonium perchlorate (AP), NH_4ClO_4
16.0 percent aluminum powder
00.2 percent iron oxide, Fe_2O_3

The remaining 14 percent of the propellant is a combination of the HB polymer and the epoxy curing agent.

This type of propellant is usually referred to as PBAN propellant after the HB polymer, which is used as the binder and also as fuel.

4.3.2 Grain Design

The amount and design of the solid propellant in each segment of the RSRM has been tailored to fulfill the performance requirements of the shuttle program. A typical thrust versus time profile is shown in Figure 4.3-I. The propellant grain design consists of a forward segment with an 11-point star, which transitions into a cylindrical perforated (CP) configuration in the cylindrical portion of the segment, two identically-configured center segments which are tapered CP configuration, and an aft segment with a dual taper CP configuration. The aft face of the forward segment, both ends of the center segments, and the forward face of the aft segment are inhibited to a prescribed pattern to achieve the required thrust-time profile. Stress relief flaps are provided in the dome of the forward segment and in the aft end of each segment to prevent possible propellant pull away due to differential thermal contraction during post-cure and cool down. The high thrust level during the lift-off portion of the shuttle flight results from the 11-point star configuration in the forward segment. After the lift-off portion of the flight, the thrust is reduced with the burnout of the star sliver, which in turn constrains flight dynamic pressure. The thrust is then progressed from the continued burn of the CP configurations in all the segments. Nearly full inhibiting of all exposed end faces was required to achieve progressive burning of all segments (forward faces are fully inhibited while aft faces are partially inhibited). The thrust decay is designed to limit vehicle acceleration. It is achieved as the triple taper bore of the aft segment burns out. The linear 10-second thrust decay (tail off) is produced as the final burnout of slivers in all four segments is occurring.

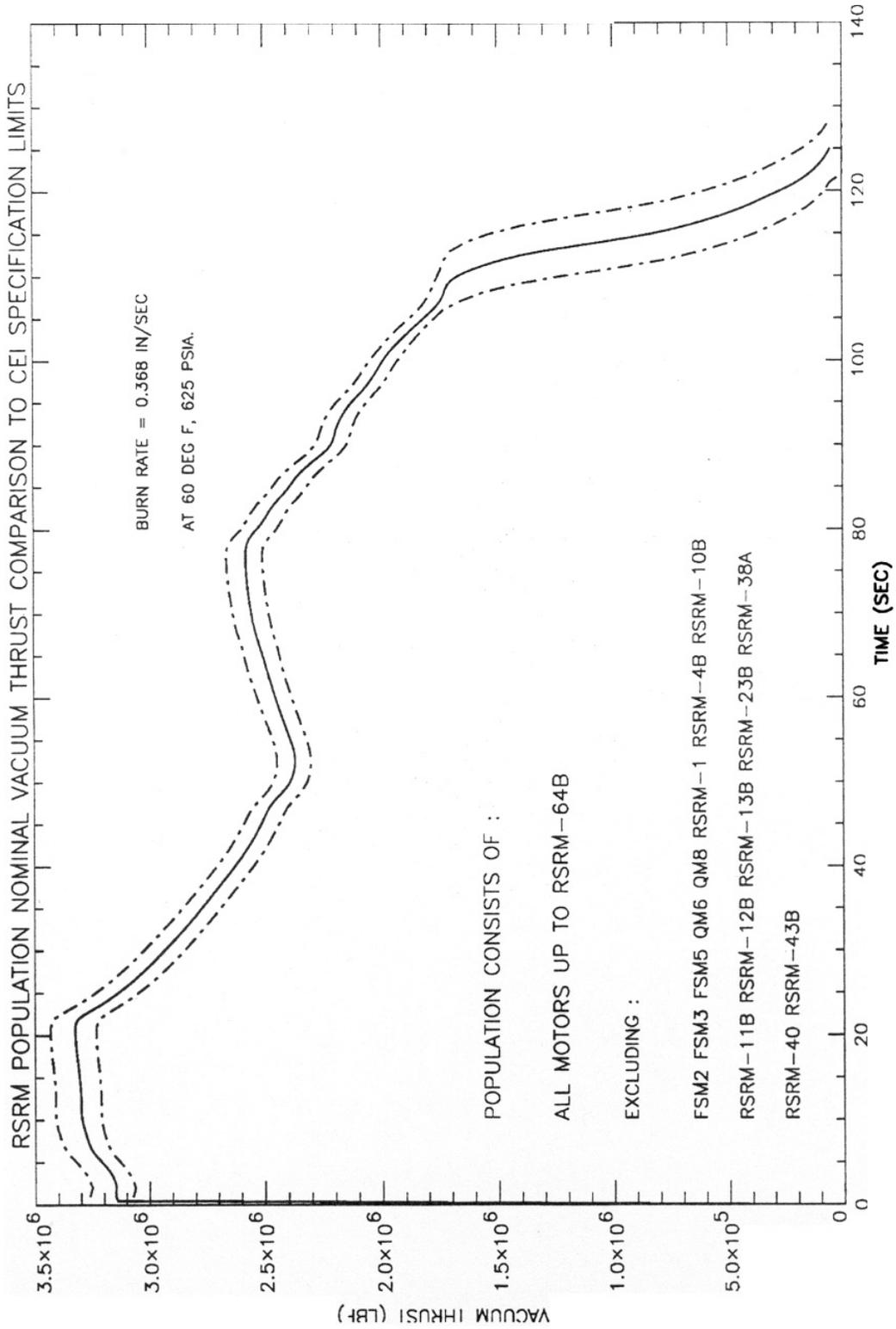


Figure 4.3-I – RSRM nominal thrust profile (Ref. 1)

4.3.3 Manufacturing Process

Prior to mixing and casting of the propellant into the casting segments, definite operations must be performed. These operations are the standardization and verification of the propellant.

4.3.3.1 Standardization

Standardization is the process for characterizing designated lots of raw materials in order to select the amounts of propellant ingredients that will give the desired (target) ballistic and mechanical properties going into an RSRM flight set.

Sufficient raw materials are purchased to load two RSRM's (one flight set) from one standardized lot of ingredients (=2.3M lb total). Prior to any use, the propellant ingredients are subjected to acceptance testing. Tests for specific ingredients are shown in Table 4.3-I.

Table 4.3-I - RSRM Propellant Formulation and Acceptance Tests (Ref. 2)

Ingredient	Weight (%)	Typical raw material acceptance tests
HB polymer (terpolymer of butadiene, acrylic acid and acrylonitrile)	14	Viscosity, acid content, moisture, antioxidant content
Epoxy curing agent (liquid epoxy; bis-phenol Aepichlorohydrin type)		Epoxy content, viscosity moisture
Aluminum Atomized aluminum powder	16	Chemical properties, particle size distribution
Ammonium perchlorate, NH ₄ ClO ₄ (70% ungraded & 30% graded)	70*	Particle size distribution, chemical properties, moisture
Iron oxide, Fe ₂ O ₃	≅0.30*	Specific surface, chemical properties

*Determined by standardization

Once the acceptance testing of the propellant materials is complete, the standardization of the propellant can be started. The purpose of the standardization is to determine the amount of iron oxide required to give the required target burn rate (in/sec) and the amount of HB polymer to give the required mechanical properties. A minimum of five, 5- gallon propellant mixes are made at the levels of iron oxide and HB polymer that are selected, based on historical data, to bracket the target properties, as shown in Figure 4.3-II.

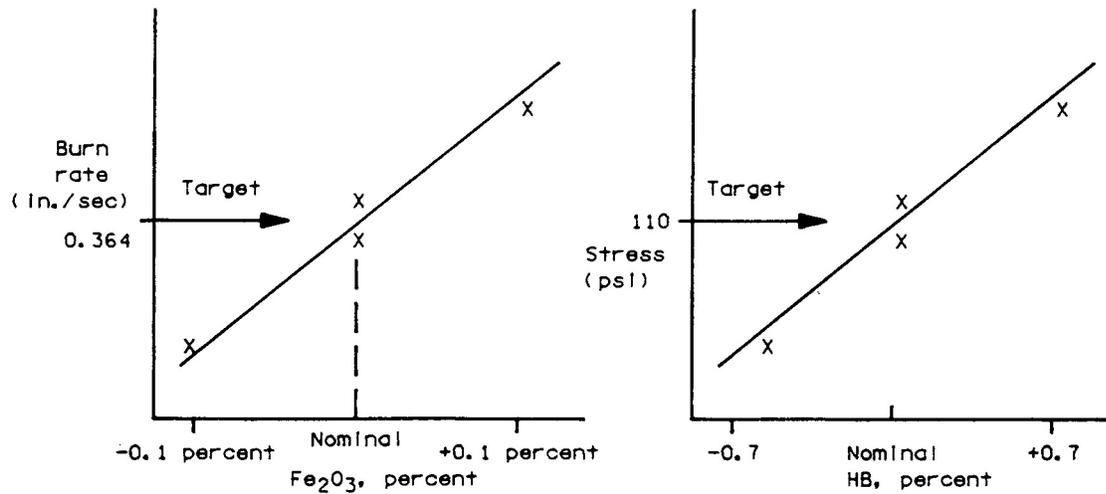


Figure 4.3-II – Standardization target properties. (Ref. 2)

To determine the burn rates, three 5-inch cylindrical perforation (CP) motors are cast from each of the 5-gallon mixes. (The 5-inch CP is a 5-inch outer diameter ballistic test motor having a 3-inch-diameter CP in a \cong 9-inch long grain containing \cong 7 pounds of propellant. The 1-inch web burns for \cong 3 seconds.) These 5-inch CP's are fired, the burn rate is measured and then plotted as in Figure 4.3-II. The target burn rate in the 5-inch CP's is related to the RSRM target burn rate by a scale factor (SF):

$$SF = \frac{\text{RSRM target burn rate}}{\text{5-inch CP target burn rate}}$$

The scale factor used to predict full-scale RSRM burn-rates is derived from a “moving average” technique, first implemented on RSRM-88 (STS-107). The “moving average” scale factor is calculated as the average actual flight performance scale factor measured over the previous seven flights. For RSRM-88 (STS-107), the prediction scale factor = 1.0235. Prior to the implementation of the “moving average” predictor, a constant value was set at 1.0194, based on evaluation of 38 flight motors between RSRM-48 to 70, and first implemented at RSRM-71 (STS-99) However, a divergence between the predicted and delivered scale factors was detected such that the delivered scale factors were larger than the prediction value. Therefore, the “moving average” scale factor was implemented to allow the predictions to respond to trends or shifts.

To determine the mechanical properties, three 0.5 gallon ice cream cartons are cast and cured. The lab then tests the cured propellant for mechanical properties, which are plotted as shown in Figure 4.3-2.

From the previous curves the percentage of Fe_2O_3 and HB polymer that gives the desired burn rate and mechanical properties for these lots of materials may be selected.

In addition to the 5-inch CP's and the ice cream cartons that are cast from each 5-gallon mix, a 1-pint sample is taken for in-process tests.

4.3.3.2 Verification

Once the amount of Fe_2O_3 and HB polymer is determined by standardization, verification is required. This is accomplished by making a minimum of four full-scale (600 gallons, 7000 pounds) mixes of propellant at the selected Fe_2O_3 and HB polymer amounts. From each 600-gallon mix, the following are cast, cured, and tested:

- Six 5-inch CP's - for burn rate
- Three 0.5-gallon ice cream cartons - for mechanical properties
- One 1 pint - for in process tests

From these verification mixes, the Fe_2O_3 and HB polymer content for the full scale mixes are selected to give the target properties in the RSRM (refer to Figure 4.3-III).

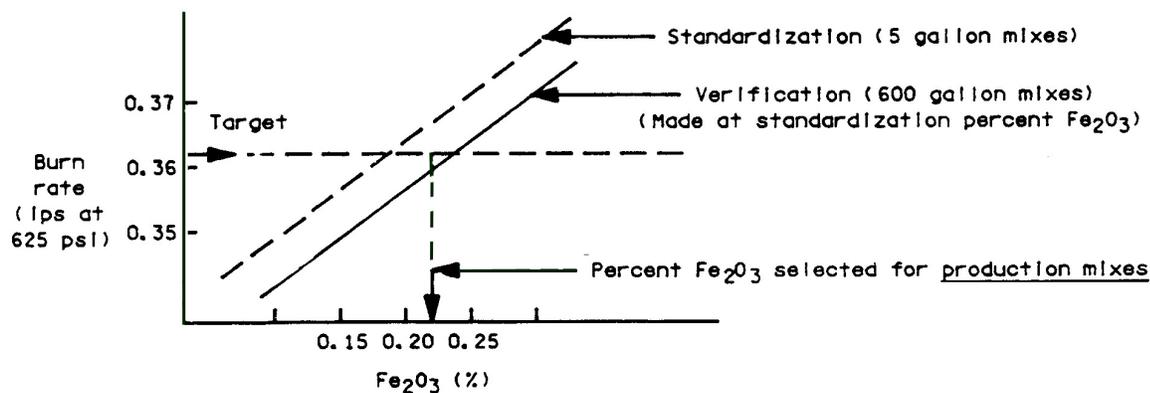


Figure 4.3-III – Verification target properties (Ref. 2)

These four full-scale verification mixes are not discarded but are cast into the previous flight set. Usually no more than two of these mixes are cast into any one casting segment.

4.3.4 Propellant Mixing

A flowchart of the RSRM propellant process mixing is given in Figure 4.3-IV. The first step in the mixing process occurs in the premix building. A premix consists of HB polymer, aluminum powder and iron oxide combined and premixed in a 600-gallon mixer bowl for 5 minutes. The Epoxy Curing Agent (ECA) is then puddled on top of the premix. ECA addition is usually held until the last minute since the propellant mix must be cast into a segment no longer than 6 hours after ECA addition.

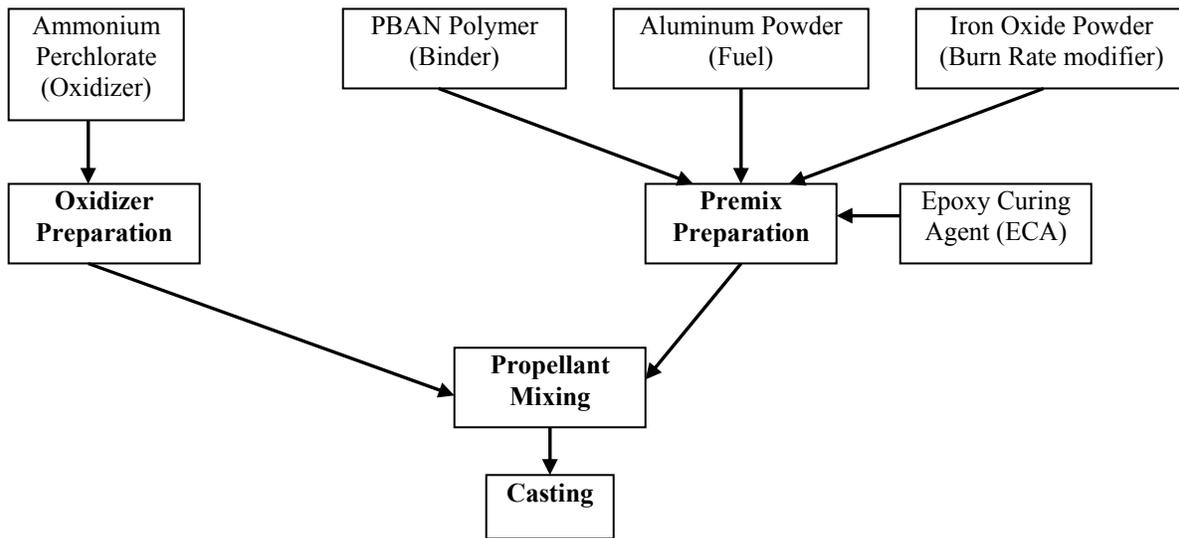


Figure 4.3-IV – RSRM propellant process flow (Ref. 2)

The premix is then taken to the mixer building where final mixing is done with the incremental addition of ground and unground AP (oxidizer). This is done with extreme care, as ammonium perchlorate is extremely unstable, decomposing with explosive violence under heat or shock. A bimodal mixture (ground and unground) of AP is used in the propellant to give optimum propellant processing and physical property characteristics and to provide a propellant burn rate in the desired range (refer to Figure 4.3-V).

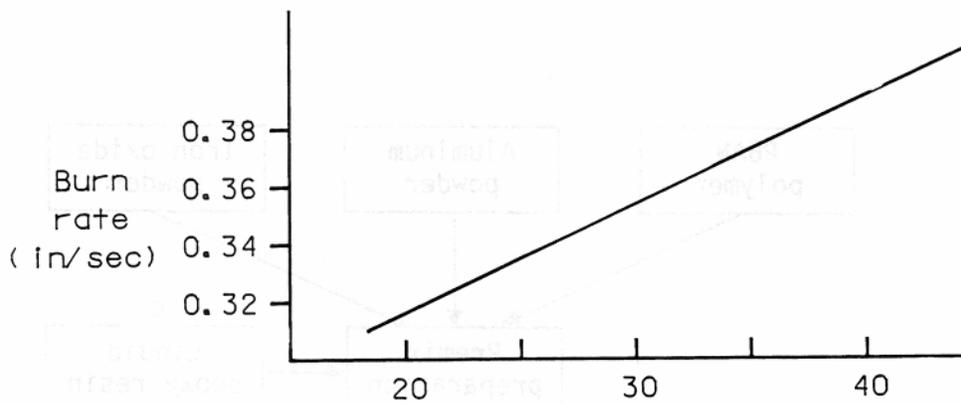


Figure 4.3-V – Percent ground oxidizer versus burn rate. (Ref. 2)

For the RSRM's a 70/30 unground/ground ratio of AP has been selected to optimize the processing properties. Fine tuning of the target burn rate is accomplished by the addition of the Fe_2O_3 , as determined by the standardization/verification processes. The target burn rate is 0.368 in/sec (Ref. 1). A total mixing cycle is $\cong 50$ minutes with the AP addition taking 25 minutes of that time. A minimum of 15 minutes mixing is required after completion of AP addition. The mixer bowl is then moved to the casting pit and dumped into a hopper above the segment being cast.

Before casting the propellant into a segment, the following in-process tests are made through laboratory analysis:

- Burn rate - liquid strands, six per mix
- Total solids
- HB polymer content
- Ground oxidizer particle size distribution (run on ground oxidizer only; not propellant)
- Al and Fe_2O_3 content
- Oxidizer content (AP)

All tests must be within specification before casting the mix in a segment. If the mix is not within specification it is scrapped.

4.3.5 Segment Casting

Each casting segment takes approximately forty 600-gallon mixes. Casting is accomplished by casting two identical segments sequentially to assure that the two RSRM's of a flight set have burn rates that are as close as possible; i.e., cast two aft, or two center segments, etc. From the mixes that are cast into the RSRM segments, the following steps are performed to verify the propellant characteristics:

- From each mix
 - Cast a 0.5-gallon ice cream carton for mechanical properties
 - Collect a pint sample for testing in-process quality control testing
- From every third mix, load a 5-inch CP

After curing the propellant and test samples at 135° F for 96±4 hours, the following properties are determined:

- Mechanical properties from ice cream cartons
 - Stress-maximum 60° F- 100 psi

- Strain at Rupture-0° F-40 percent, 74° F-41 percent, 100° -38 percent

- Burn rate from 5-inch CP's

The 5-inch CP burn rate data from the mixes cast into the segments are then used in developing the flight motor performance prediction.

4.3.6 References

1. Space Shuttle STS-89 Flight Evaluation Report, Volume III—Reusable Solid Rocket Motor Project, TWR-75330, Thiokol, Feb. 1998
2. An Orientation - Training Course on the Redesigned Solid Rocket Motor (RSRM), TWR-16468 Rev C, Morton Thiokol, Inc. October, 1987.

4.4 RSRM NOZZLE

4.4.1 General

The RSRM hot exhaust gases are channeled through a convergent-divergent nozzle using an ablative carbon cloth phenolic liner over a steel and aluminum support structure. The nozzle is a modular-type construction with parts grouped into assemblies to facilitate maximum reuse and refurbishment of structural members. Figures 4.4-I, 4.4-II, and 4.4-III show configurations of the RSRM nozzle from different perspectives.

The RSRM nozzle has gimbal capability provided by dual hydraulic rock and tilt actuators transmitting nozzle rotation about a flexible bearing. The nozzle is partially submerged in the aft RSRM segment to minimize erosive conditions in the aft end of the motor and to fit within envelope length limitations.

Requirements that drove the design of the RSRM nozzle to its present configuration include the following:

- Suitable RSRM thrust versus time profile during ascent
- Maximum gimbal angle and gimbal rate for thrust vector control
- System reuse, checkout, and maintenance before and after each flight
- Capability for jettisoning the aft half of the exit cone after burnout to reduce water impact loads on reusable parts in the nozzle.
- Survivability during water impact post SRB burnout and parachute reentry. Ability to withstand a corrosive saltwater environment during tow back to KSC

A breakdown of the primary materials used in the RSRM nozzle components is shown in Figure 4.4-IV. The structural safety factor required for all components is 1.4. The erosion safety factor required for all nozzle ablatives is 2.0, excluding the last 48 inches of the exit cone, where it is 1.5. Some areas of the nozzle have safety factors less than these requirements as a result of approved waivers and deviations from MSFC and JSC. Redundant and verifiable seals exist between major assemblies as identified in Figure 4.4-III to protect against hot gas erosion and blowby.

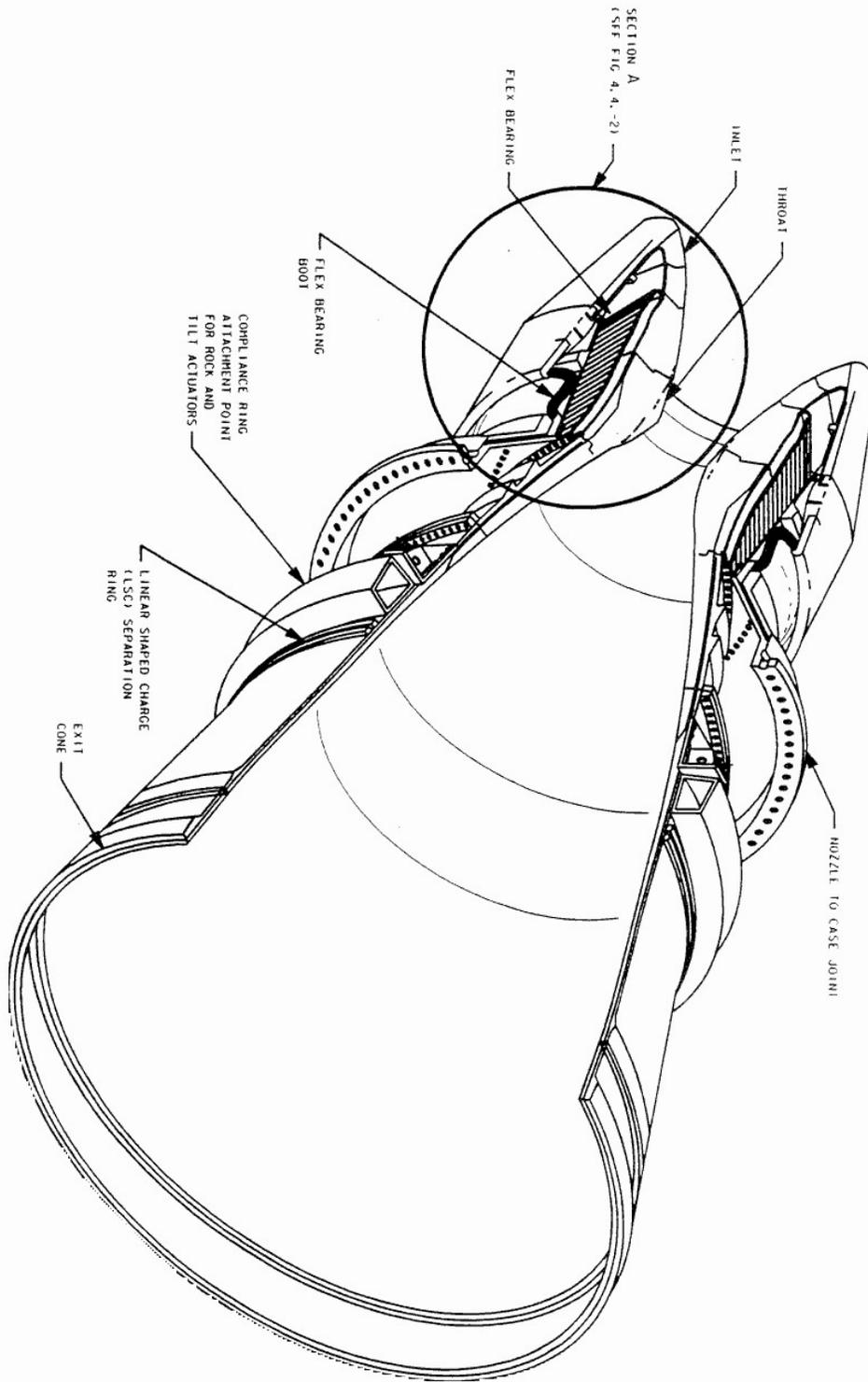


Figure 4.4-I – RSRM nozzle

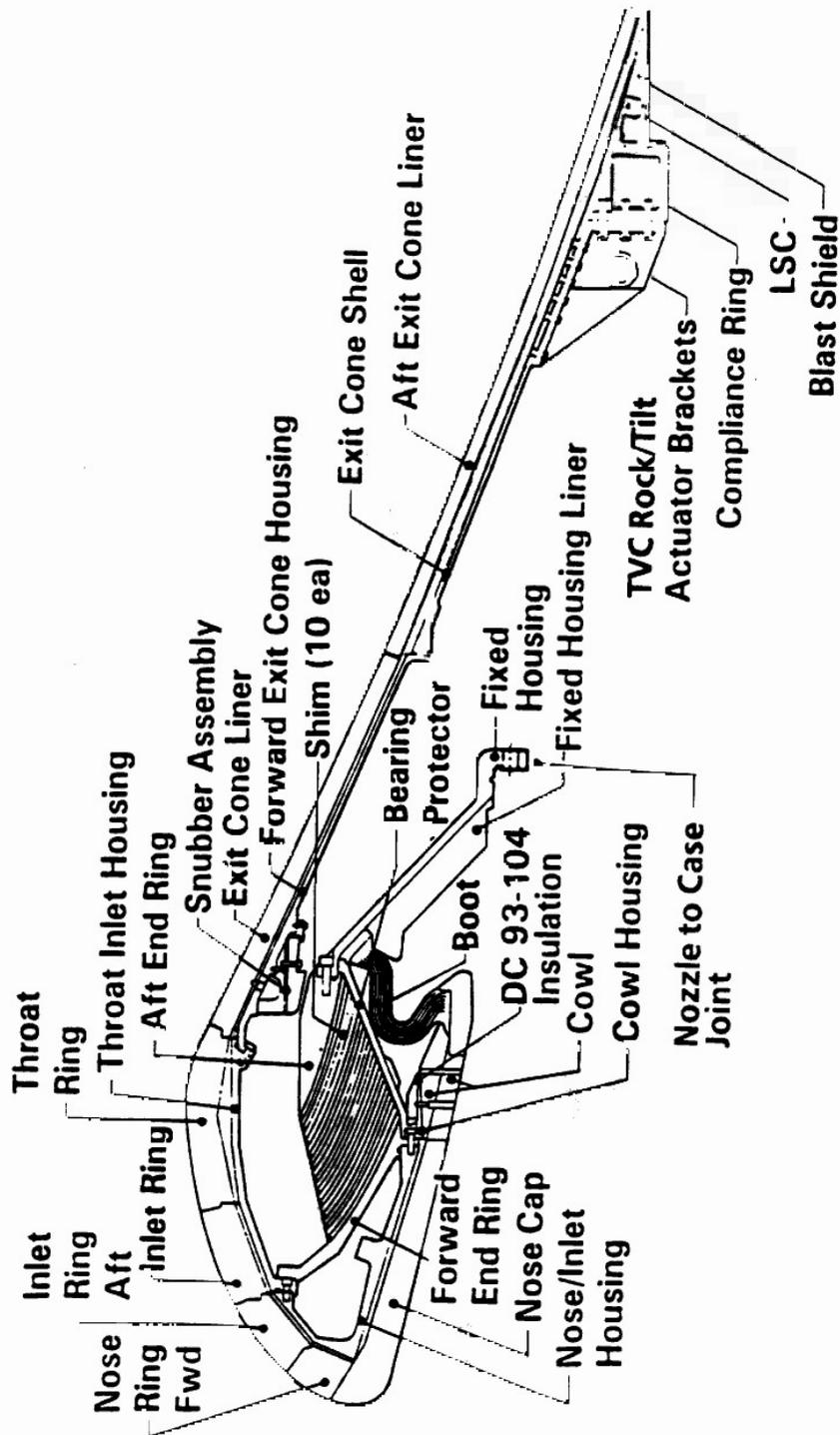


Figure 4.4-II – RSRM nozzle configuration (section A)

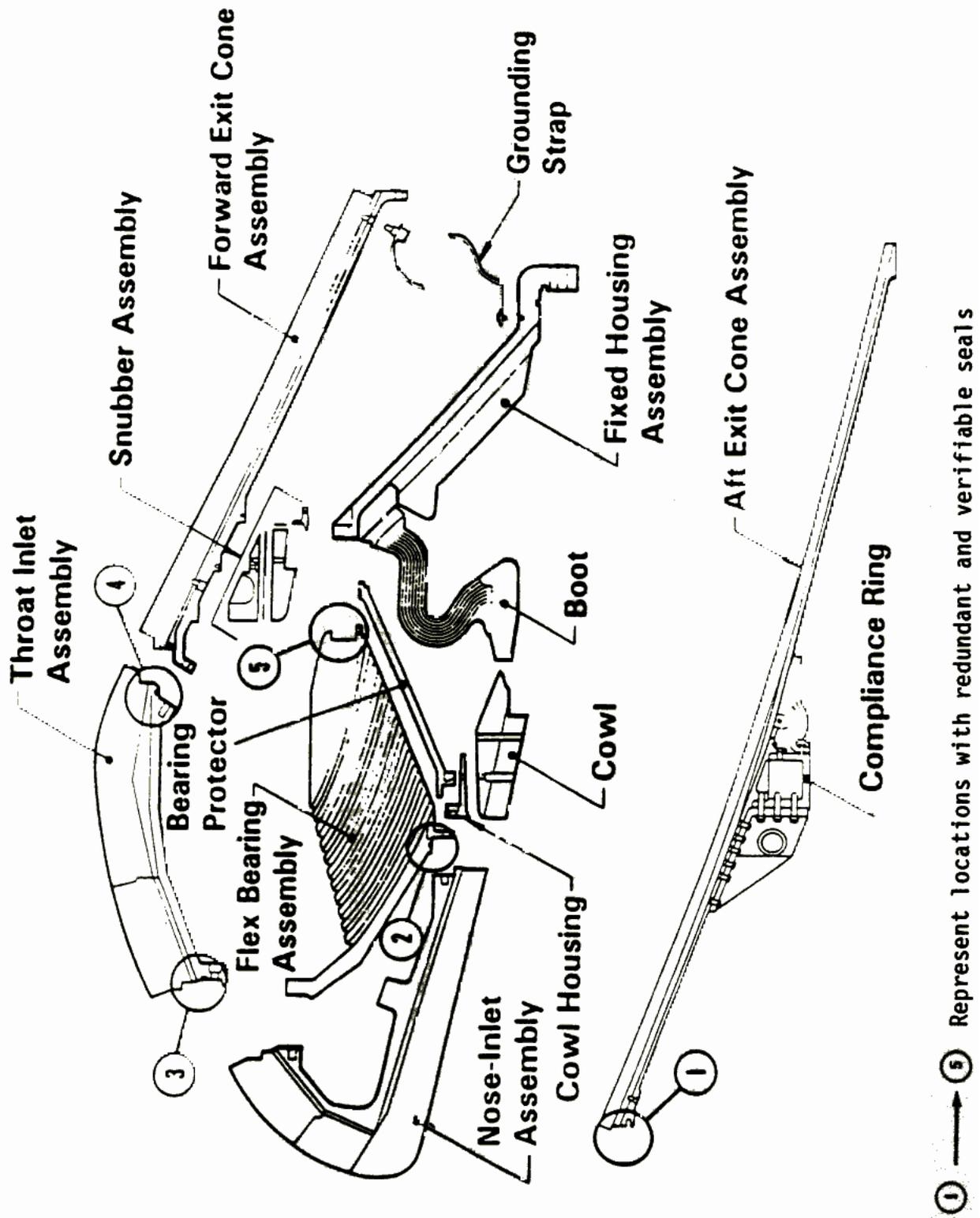


Figure 4.4-III – Nozzle internal joints

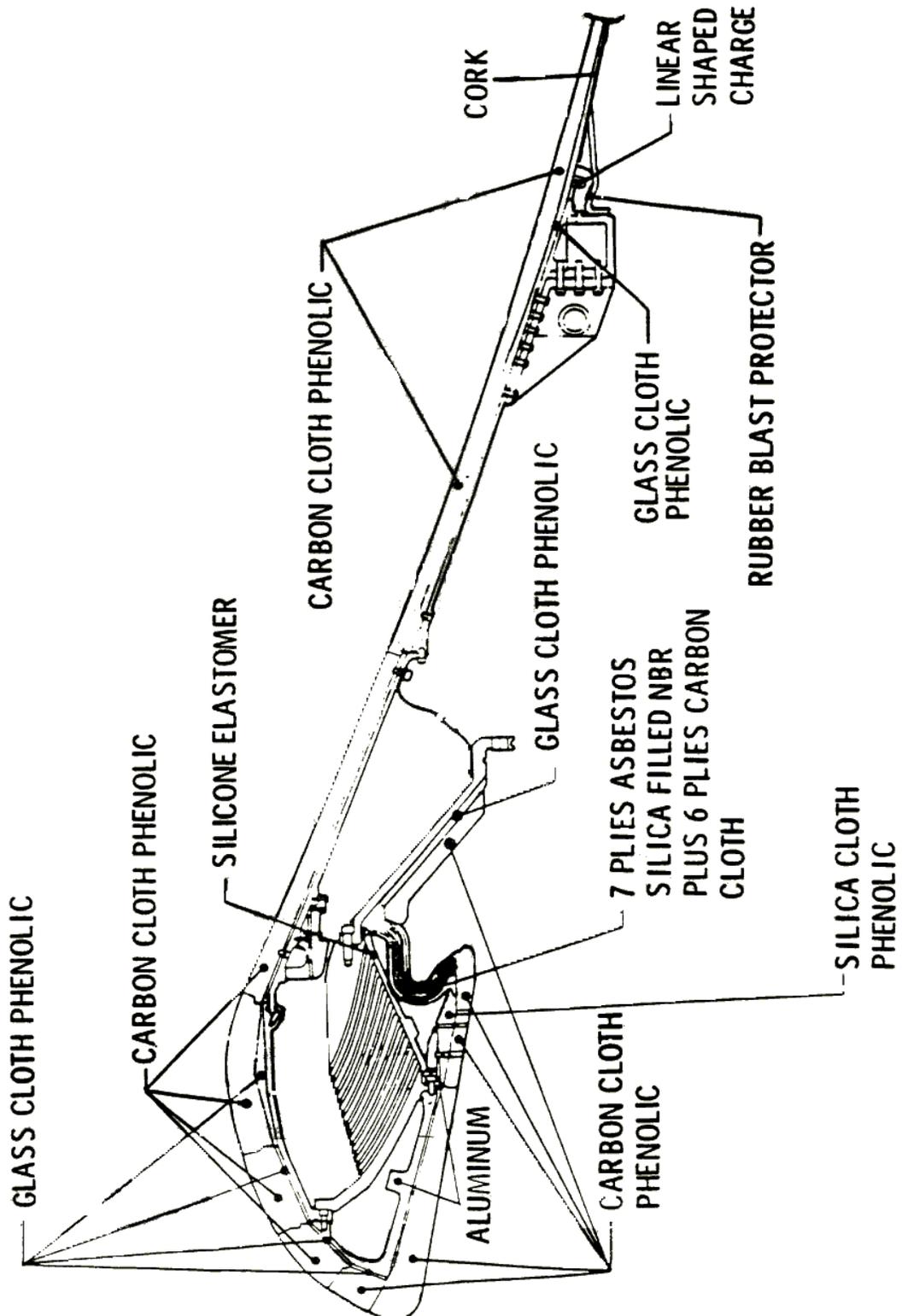


Figure 4.4-IV – RSRM nozzle materials

Additional nozzle characteristics are shown in table 4.4-I.

TABLE 4.4-I - SRB NOZZLE CHARACTERISTICS

Nozzle type	Contoured
Expansion ratio	7.72:1
Final predicted exit diameter (inch)	150.21
Initial throat diameter (inch)	53.9
Nozzle total length (inch)	177.7
Submerge ratio	0.226

4.4.2 Functional Description

4.4.2.1 Cowl Assembly

The cowl assembly consists of an aluminum housing that attaches to the nose/inlet/bearing assembly and supports the outer diameter liner (refer to Figure 4.4-III). The inner diameter of the cowl housing is protected by an elastomer liner. This assembly protects the boot and flex bearing from chamber radiation conditions and thermally protects the nozzle structure. Vent holes located in the cowl allow equal pressure to occur on both sides of the flexible boot.

4.4.2.2 Nose/Inlet Assembly

The nose/inlet assembly interfaces with the throat assembly and bearing forward end ring (refer to Figure 4.4-III). It consists of an aluminum superstructure that is insulated and lined. The liner forms the gas flow contour around the nose. The forward nose ring traps the aft ring against forward motion. The nose cap, in turn, traps the forward nose ring to provide positive redundant retention. The assembly is sealed at each end to preclude penetration of hot, high pressure gas from the chamber into its void area.

4.4.2.3 Throat/Inlet Assembly

The throat/inlet assembly consists of a steel housing covered by ablative and insulative liners. Refer to Figure 4.4-III. The assembly interfaces with the nose/inlet, the forward exit cone assembly, and the flex bearing assembly; and it is sealed at each end to preclude penetration of hot, high pressure gas. The shell is convergent to contain and support the throat and inlet rings, preclude downstream movement, and prevent ejection loads from reaching the exit cone.

4.4.2.4 Exit Cone Assembly, Forward

This assembly consists of a full-length steel structural housing and a composite liner-insulator, which is bonded and pinned to the structural member for positive retention. Dual O-rings at the forward end composite structure interface preclude gas penetration along the bonded interface. Refer to Figure 4.4-III.

4.4.2.5 Exit Cone Assembly, Aft

This assembly consists of composite liner, aluminum shell outer structure, compliance ring, and linear shaped charge (LSC) separation device. Refer to Figures 4.4-III and 4.4-V. The metal structure extends along the exit cone assembly to the compliance ring. The freestanding cone aft of the compliance ring is supported structurally by high strength glass-cloth tape overwrap. O-ring seals prevent potential penetration of exhaust gases along bonded or interfacing surfaces. The structural compliance ring of aluminum contains provisions for attachment of interfacing actuators. A separation ordnance ring, which is a linear-shaped charge, provides capability to jettison the aft portion of the exit cone after burnout. Figure 4.4-V shows the attachment configuration of the SRB actuator to the aft skirt and nozzle compliance ring.

4.4.2.6 RSRM Nozzle Plug

The RSRM nozzle plug is a hemispherical polyurethane foam structure of an average diameter of 60.5 inches that is inserted in the nozzle just aft of the throat ring. The polyurethane foam has an outer coating of silicone rubber and primer and utilizes a circumferential polysulfide stiffener band. Room temperature vulcanizing (RTV) rubber is used around the perimeter of the nozzle plug to hold it in place.

The function of the plug is to provide the nozzle environmental protection during shipping and stacking and to protect the RSRM propellant from premature ignition from SSME exhaust gas during ignition transient and pad fires. The plug is designed to be expelled upon RSRM ignition without damaging the nozzle or orbiter.

4.4.2.7 Fixed Housing Assembly

The fixed housing assembly consists of a conical steel shell insulated with carbon-filled silicone rubber. It extends from the aft case to the flexible bearing aft end ring and is the primary support structure for the nozzle assembly. Refer to Figure 4.4-III. It is subjected to both case pressure loads and axial compressive blowout loads. The fixed housing interfaces with the aft case boss and provides for dual O-ring seals to ensure positive sealing of this critical interface. A pressure port between the two seal locations allows pressure testing of both seals after installation of the forward nozzle assembly on the motor aft segment.

4.4.2.8 Flexible Bearing Assembly

The flexible bearing assembly provides an omnidirectional gimbal capability. Refer to Figure 4.4-III. The bearing consists of a flexible core that is contained between two D6AC end rings and is thermally protected by a flexible silica-filled nitrile butadiene rubber (NBR) boot. The flexible core is a laminated structure consisting of 10 spherical D6AC shims and 11 natural rubber pads. End rings and shims absorb the applied loads while simultaneously controlling bearing motion during vectoring. Elastomeric pads transmit the loads while allowing relative motion to occur between the structural members. The inside and outside surfaces of the flexible core are protected from environmental effects by coatings of RTV rubber. The end rings have a protective coating of paint.

4.4.3 RSRM Nozzle Non-Destructive Testing

The following processes and techniques are currently used to provide non-destructive testing (NOT) of the nozzle prior to each flight:

- Metal parts - ultrasonics, magnetic particle inspection, and dye penetrant inspection
- Phenolic components - alcohol wipes for delamination indications, tag end testing, percent volatiles, compressive strength, percent resin, hardness, specific gravity, radial and tangential X-ray inspections
- Bondline evaluations - tensile button tests to verify adhesive
- Flex bearing acceptance testing/axial deflection - spring rate, tensile leak, pivot point eccentricity, torque characterization, structural verification to maximum expected operating pressure (MEOP), and stretch test for bond inspection.

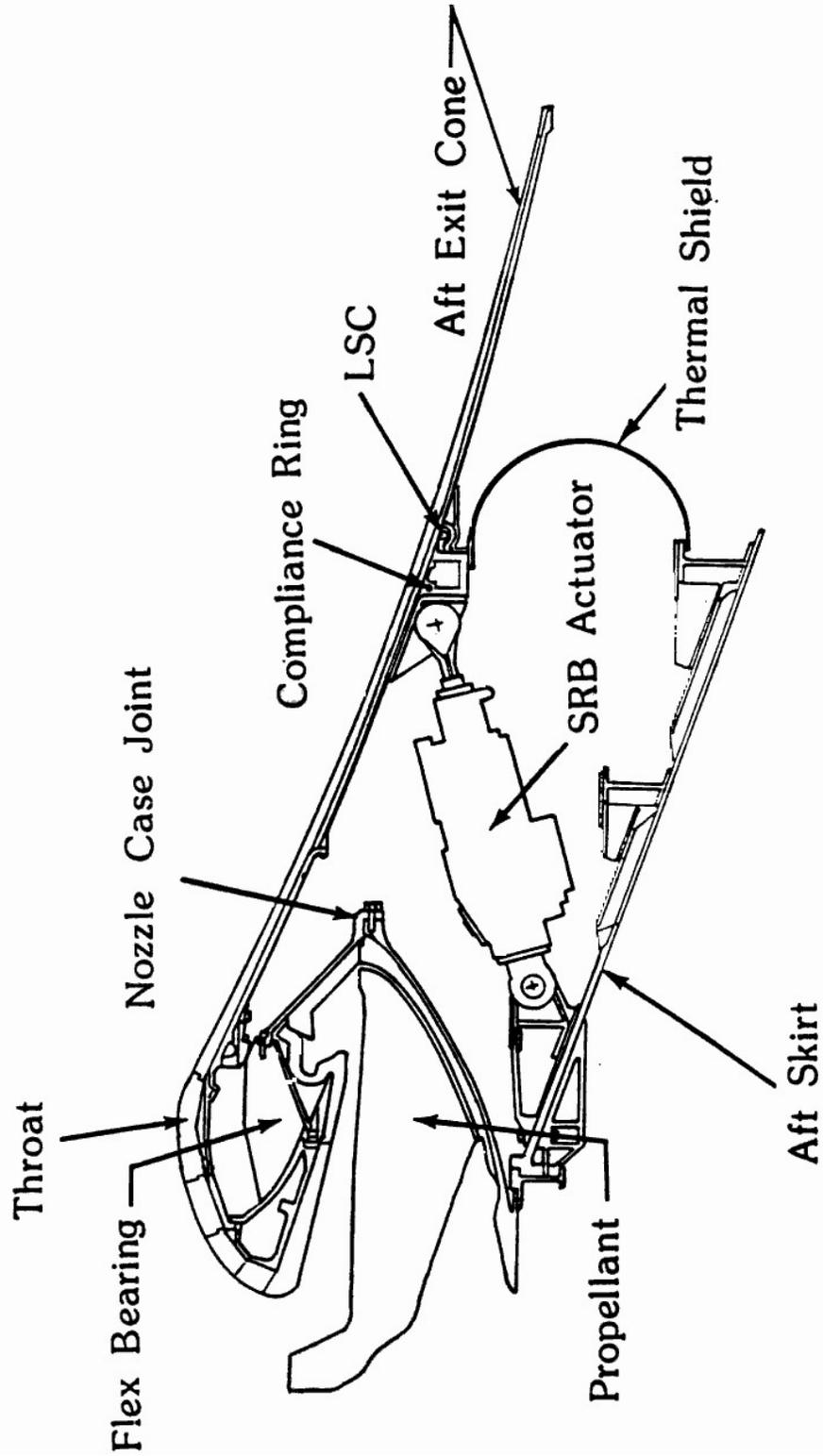


Figure 4.4-V – Nozzle actuator design

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4.5 REUSABLE SOLID ROCKET MOTOR (RSRM) IGNITER

4.5.1 General

4.5.1.1 Ignition System Components

The RSRM ignition system is a forward end, internally-mounted, solid-rocket-type igniter. It is 43.8 inches long and contains 191 lb. of propellant. The ignition system shown in Figure 4.5-I consists of the following:

- A Safe and Arm (S&A) device that has a reusable electromechanical actuation and monitoring assembly containing an electric motor, a manual safing and locking mechanism, a visual position indicator, and an electrical circuit switch deck. It also contains a non-reusable barrier booster assembly containing the motor pressure seal, the safety barrier (rotated to "ARM" by the actuation and monitoring assembly), two NASA standard initiators (NSI's) with a pyrotechnic booster charge and an "armed" and a "safe" indicator electrical switch.
- An igniter adapter that provides the mounting point between the other ignition system components and the motor forward case segment.
- An igniter initiator which is a small, multi-nozzle, steel cased, solid propellant igniter containing a case bonded 30-point star propellant grain.
- A rocket motor igniter which is a single nozzle, steel cased, internally and externally insulated solid propellant igniter containing a base bonded 40-point star propellant grain.
- Propellant in the igniter and initiator is identical and they are cast at the same time from the same batch of propellant. The propellant consists of 69 percent ammonium perchlorate, 10 percent spherical aluminum, 3 percent ferric oxide, and 18 percent PBAN polymer and epoxy resin.

Improvements in the igniter design were made with the introduction of a thicker adapter plate beginning with STS-50. Further improvements were implemented with STS-59 to include a bonded igniter J-seal and pressure sensitive adhesive (PSA) to replace the zinc chromate putty. These changes reduced the likelihood of hot gas erosion and blowby to the igniter gasket seal region.

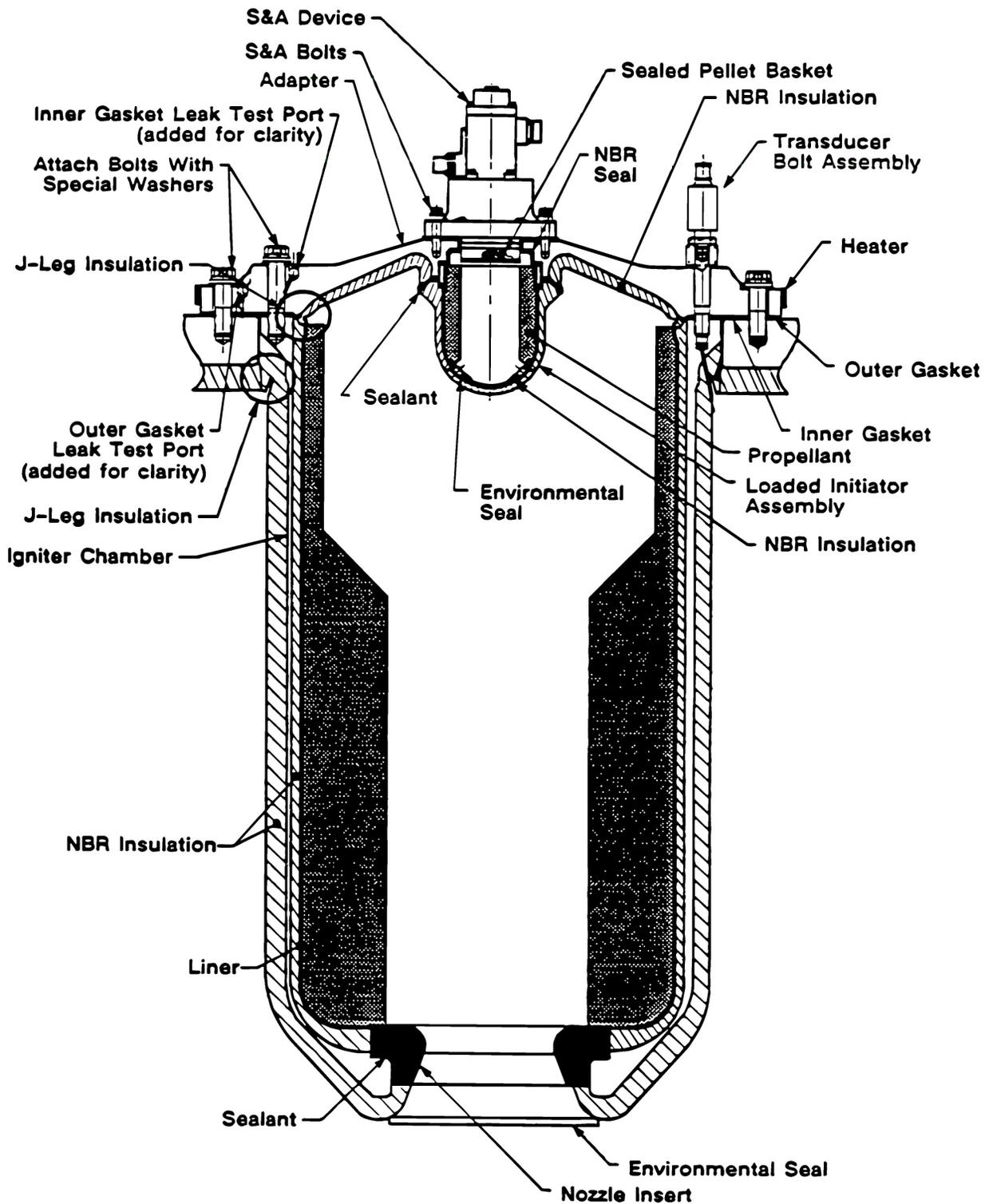


Figure 4.5-I –RSRM igniter.

4.5.1.2 Ignition Design Characteristics

For the ignition sequence, the manual lock pin must be removed from the S&A device; an electrical arming signal to the S&A device causes the rotor to move into the armed position. In the armed position the NSI's fire through a thin barrier seal into the pyrotechnic pellet charge which is retained in the S&A device behind a perforated plate. The pellet charge ignites the propellant of the igniter initiator whose combustion products in turn ignite the propellant of the rocket motor igniter. A profile of the RSRM initiator, igniter, and motor chamber pressure as a function of time is shown on Figure 4.5-II. The igniter initiator is threaded directly into the igniter adapter with thread sealing compound, whereas the S&A device is bolted to the adapter with redundant, verifiable seals. Both the igniter initiator and adapter are insulated to provide protection from the heat of the propellant gases. The adapter is reusable and has heavy insulation to ensure structural and dimensional integrity for 20 uses. The igniter initiator is not reusable. The steel igniter chamber is bolted to the adapter with redundant, verifiable seals and is insulated both externally and internally. The insulation is provided to ensure a low temperature profile in the igniter chamber during motor operation and RSRM descent. It is primarily required because of radiant heating and recirculation of motor gases through the large axial, aft throat of the igniter. The silica-phenolic throat insert has a thick profile to ensure reusability of the igniter chamber without degradation due to excessive heating. The igniter adapter is bolted to the forward motor segment with redundant, verifiable seals.

4.5.2 Functional Description

4.5.2.1 S&A Device

The Safe and Arm Device shown in Figure 4.5-III consists of an Actuation and Monitoring (A&M) assembly containing an electromotive drive element, electrical switch, and manual mechanical safing features that are designed to be reused a total of 20 times and a pyrotechnic Barrier-Booster (B-B) assembly that contains provisions for mounting two NSI's, a mechanical safe-arm barrier, and a pyrotechnic booster assembly. The B-B assembly is not reused.

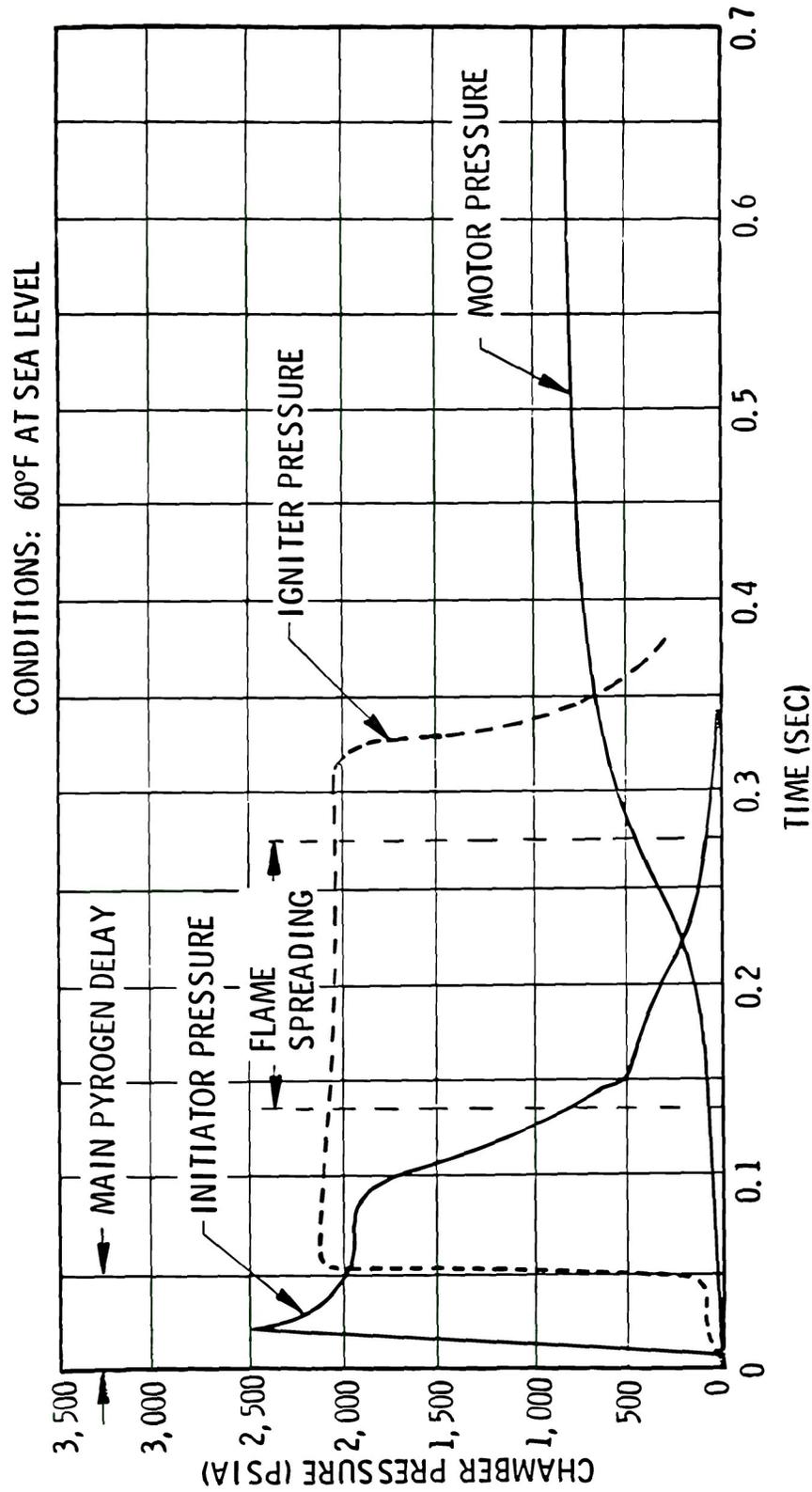


Figure 4.5-II - RSRM Ignition Sequence

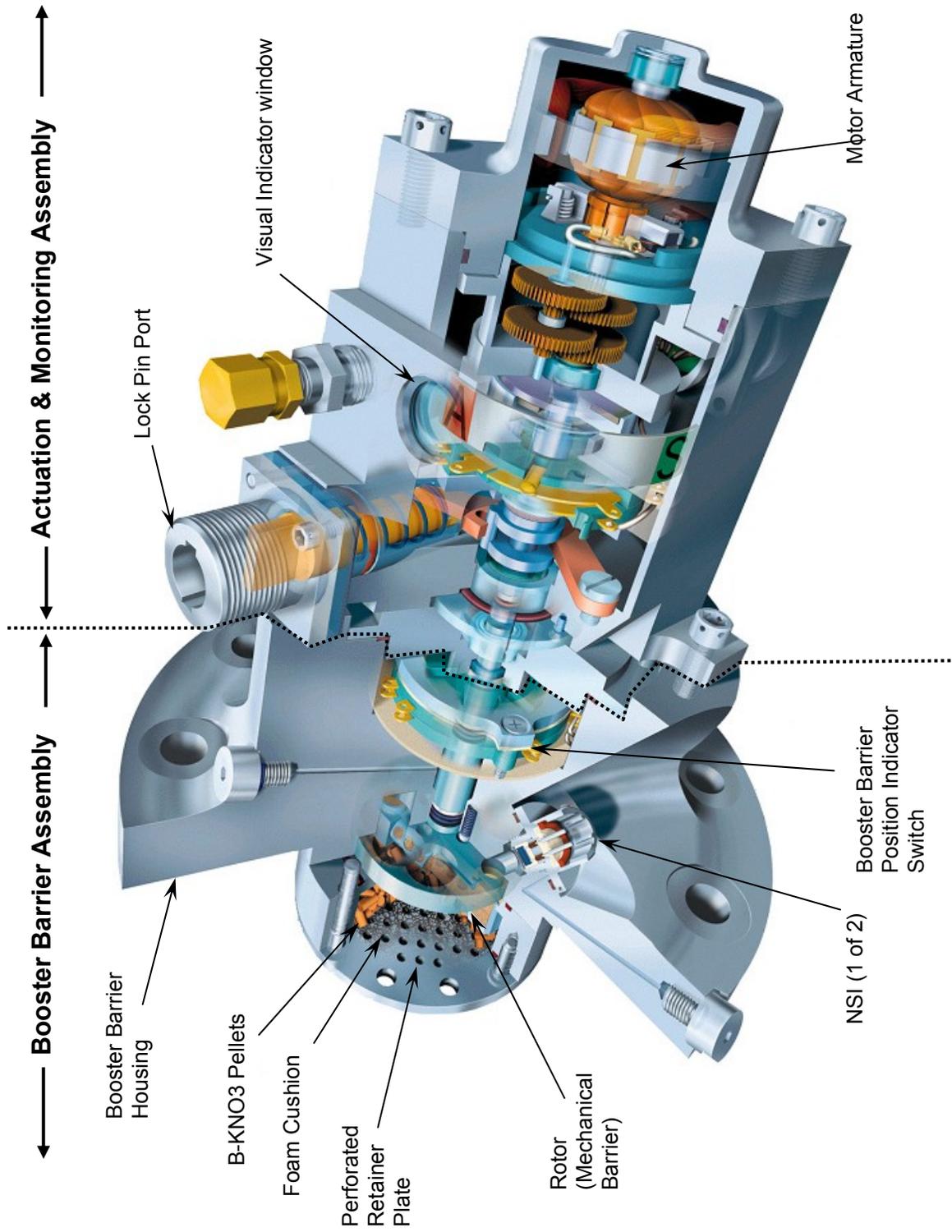


Figure 4.5-III – RSRM Ignition Safe & Arm Device

4.5.2.2 Igniter Adapter

The igniter adapter is a machined steel forging, internally insulated with silica-asbestos filled NBR. The adapter is mounted on the RSRM forward polar boss with forty 0.75-inch-diameter, high-strength steel bolts. "Gask-O-Seals" are used on the bolt circle to provide redundant seals with leak test provisions. Four special bolts are provided for mounting the pressure transducers to measure the motor chamber pressure. One machined port is provided for installation of the igniter pressure transducer. Two 0.25-inch tube ports are also provided for leak testing the igniter-to-adapter and adapter-to-motor redundantly verifiable seals. Provision is also made in the S&A device to leak check the unit. See Figure 4.5-IV for a comparison of the previous igniter adapter design and the post STS-50/59 (current) design.

4.5.2.3 Igniter Initiator

The igniter initiator is basically a small multi-nozzle rocket motor. The igniter for the igniter initiator is the pellet charge in the S&A device. In order to provide a simple attachment, this component is threaded directly into the adapter. The steel case is externally insulated with silica-asbestos filled NBR which is pre-molded and secondarily bonded in place with adhesive. This adhesive is also used to bond in the carbon-phenolic throat inserts and the silica-asbestos filled NBR internal insulation in the forward end. The entire case is lined with 0.05-inch-thick liner. A case bonded grain of propellant is cast into the lined case in a 30-point star configuration.

4.5.2.4 Rocket Motor Igniter

The rocket motor igniter consists of a steel chamber bolted to the igniter adapter. In order to obtain the desired igniter ballistics, the chamber ID is 17.8 inches with 0.35 to 0.65-inch of silica-asbestos-filled NBR internal insulation. Since the forward motor case opening is fixed at 20.97 inches, it is necessary to bolt the igniter to the adapter using external bolts to maintain positive structural margins for the igniter chamber flange for 20 uses. Thirty-two 0.75-inch, high-strength steel bolts are used to attach the chamber to the adapter. Redundant seals are provided by using Gask-O-Seals inside and outside the bolt circle and Stat-O-Seals under each bolt. Leak test provision is made in the adapter to ensure that there is no leakage in any of the seals after assembly. The igniter case is insulated externally with 0.98-inch of silica-asbestos filled NBR to protect it from motor gas temperatures both during RSRM firing and subsequent heat soak during descent. The silica-phenolic throat insert is also designed to provide similar protection. The internal insulation of the igniter is coated with a 0.05-inch-thick layer of liner to ensure adhesion between the propellant grain and the internal insulation. The case bonded propellant consists of a 40-point star grain of propellant having an initial surface area of 8410 sq.². When ignited at 600° F, this grain produces a nominal operating pressure of 2020 psia and nominal mass flow of 550 lb./sec for 0.270 seconds. The 7.200-inch ID igniter throat consists of a machined silica-phenolic insert with a 0.030-inch shear ply of silica-asbestos filled NBR between the steel case and the throat. The silica-phenolic cloth layers of the throat insert are oriented to provide the optimum strength of the part to prevent any possibility of ejection.

PREVIOUS DESIGN

CURRENT BASELINE DESIGN

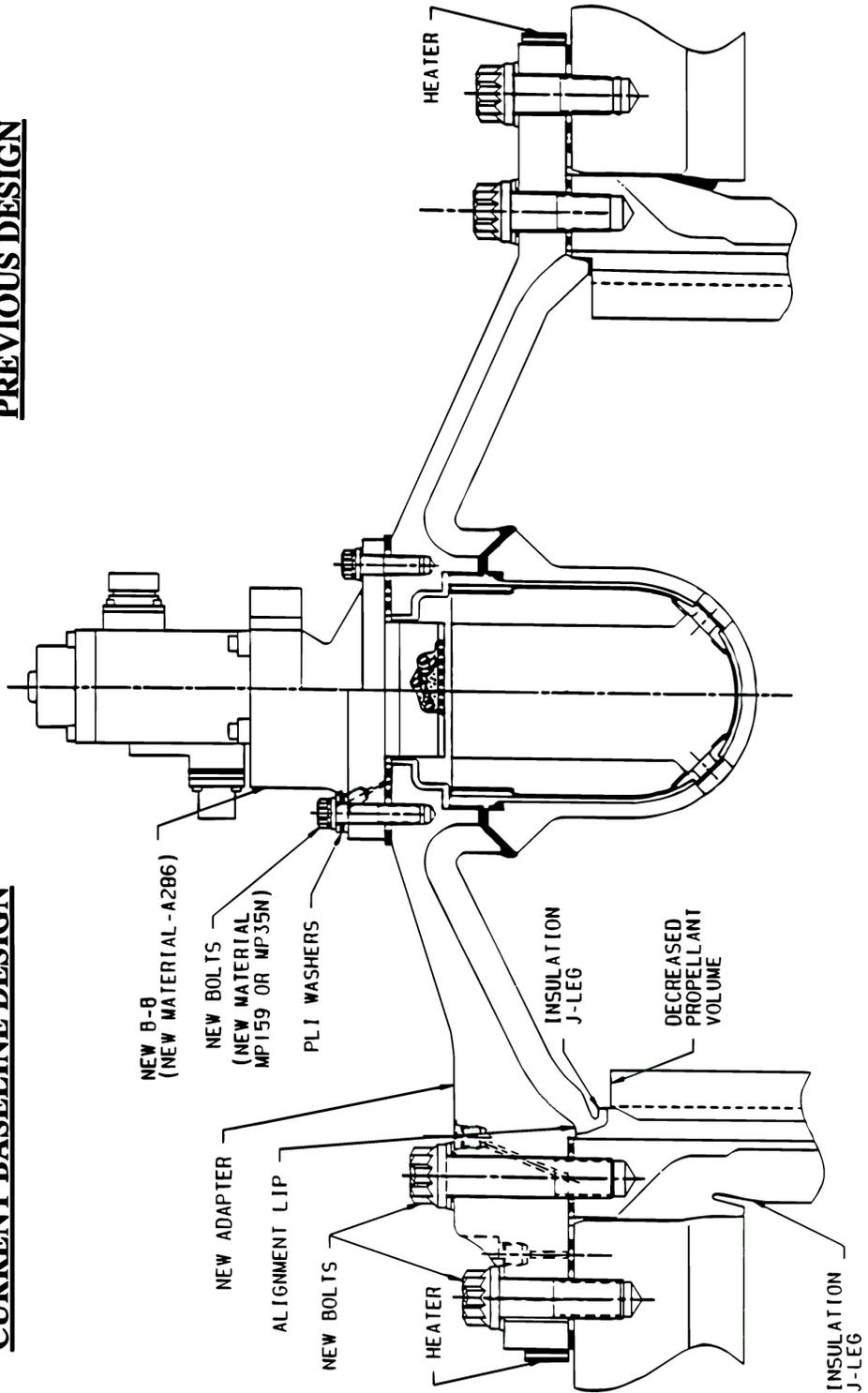


Figure 4.5-IV.- RSRM igniter adapter design comparison.

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4.6 SRB HYDRAULIC POWER UNIT AND TVC SYSTEM

4.6.1 Introduction

The SRB thrust vector control (TVC) system is located on the aft skirt and consists of two hydraulic power units (HPUs) and two servoactuators per RSRM. The HPUs supply the hydraulic pressure which drives the servoactuators to gimbal the solid rocket motor nozzles in response to the TVC steering commands. This action provides ascent control authority in roll, pitch, and yaw. The two auxiliary power units (APUs) provide power for the hydraulic pumps.

The actuators are oriented at 45° outboard to the vehicle pitch and yaw axes; therefore, the SRB axes are called tilt and rock. Each HPU is connected to both actuators. One HPU serves as the primary hydraulics on an actuator; the other HPU is the secondary hydraulics on that actuator. HPU A is the primary hydraulics for the rock actuator, and HPU B is the primary hydraulics for the tilt actuator. If one HPU fails, the surviving HPU can increase its hydraulic pressure output and power both actuators at a slightly degraded nozzle gimbal velocity. With both HPU's running, the system is certified to support a gimbal rate of 5° per second per actuator. One HPU running at higher (110%) output is certified to support a gimbal rate of 3° per second per actuator. A Monte Carlo analysis of early engine failures and high wind shear showed that guidance only rarely demanded more than 3° per second, and control authority was not compromised when system response for those cases was limited to 3° per second. The gimbal capability in both axes is +5°.

The SRB TVC system is similar to the orbiter TVC system. Table 4.6-I shows some of the basic differences.

The components of the SRB TVC system will be described in this systems brief in detail. Figures 4.6-I through 4.6-III show an overview of the SRB HPU. The SRB drawing in the SSSH (Space Shuttle Systems Handbook) should be referred to when studying this systems brief in detail. The zone codes in the following pages refer to SSSH Drawing 10.2 (Ref. 2).

4.6.2 Auxiliary Power Unit **LZ³**

The purpose of the APU is to convert chemical energy stored in liquid hydrazine (N₂H₄), into mechanical shaft power to drive the hydraulic pump. Each APU contains the following components:

- A. Fuel supply module (FSM)
- B. Fuel tank isolation valves and feedlines
- C. APU assembly
 1. Fuel pump
 2. Fuel control valves
 3. Gas generator

4. Gas generator heaters
5. Dual pass, reentry turbine
6. Gearbox

D. APU controller

Filtered, liquid hydrazine at an initial pressure of 300 to 425 psia is supplied to the fuel pump inlet from the FSM. During APU startup, the pressurized fuel flows through the isolation valve to the start bypass line and directly into the gas generator. As the turbine speed increases and the integral fuel pump output pressure exceeds the FSM supply pressure, the fuel pump begins to deliver N_2H_4 to the gas generator. At nominal APU operating speed, the fuel pump output is 1270 psi. The fuel is decomposed over a catalytic bed in the gas generator into a hot gas. The hot gas enters the turbine through the primary turbine inlet for the first pass and then re-enters the turbine through the secondary inlets for the second pass. The expanded gas, primarily nitrogen, ammonia, and hydrogen, is then dumped overboard through the turbine exhaust ducting. Under normal operation (100 percent) the turbine operates at a constant nominal output of 72000 rpm. When in backup mode, the turbine operates at 110 percent of nominal, which is 79,200 rpm. A second backup mode operates the turbine at 112 percent (80,640 rpm). The turbine is linked to the hydraulic pump through a fixed ratio (18.93:1) gearbox that reduces turbine speed to that required for hydraulic pump operation. Other reduction gear trains in the gearbox power the fuel pump and lubrication pump.

4.6.2.1 Fuel Supply Module sZ^2

The FSM stores the liquid N_2H_4 . The tank has a volume of 1950 in³ and stores approximately 22 lbs of N_2H_4 . The FSM is pressurized to about 400 psi with 1.3 pounds of GN_2 , which delivers the N_2H_4 to the APU fuel pump inlet. The tank contains a diaphragm to separate the pressurant from the fuel. Temperature and pressure sensors are mounted on the tank.

4.6.2.2 Fuel Tank Isolation Valves and Feedlines RZ^2

The fuel feedline from the FSM has a 25 μ fuel filter at the FSM exit, a fuel isolation valve, a pressure relief valve set at 50 psid, and a 25 μ fuel filter between the fuel pump and gas generator control valves.

The fuel isolation valve (FIV) ensures positive isolation of the fuel in the FSM from the APU assembly during non-operational periods. This normally is a closed valve. The FIV is opened at APU startup and will remain open until power is removed as part of the HPU power deadfacing at SRB separation.

The pressure relief valve allows reverse flow to the FSM in the event of fuel expansion due to heat soakback.

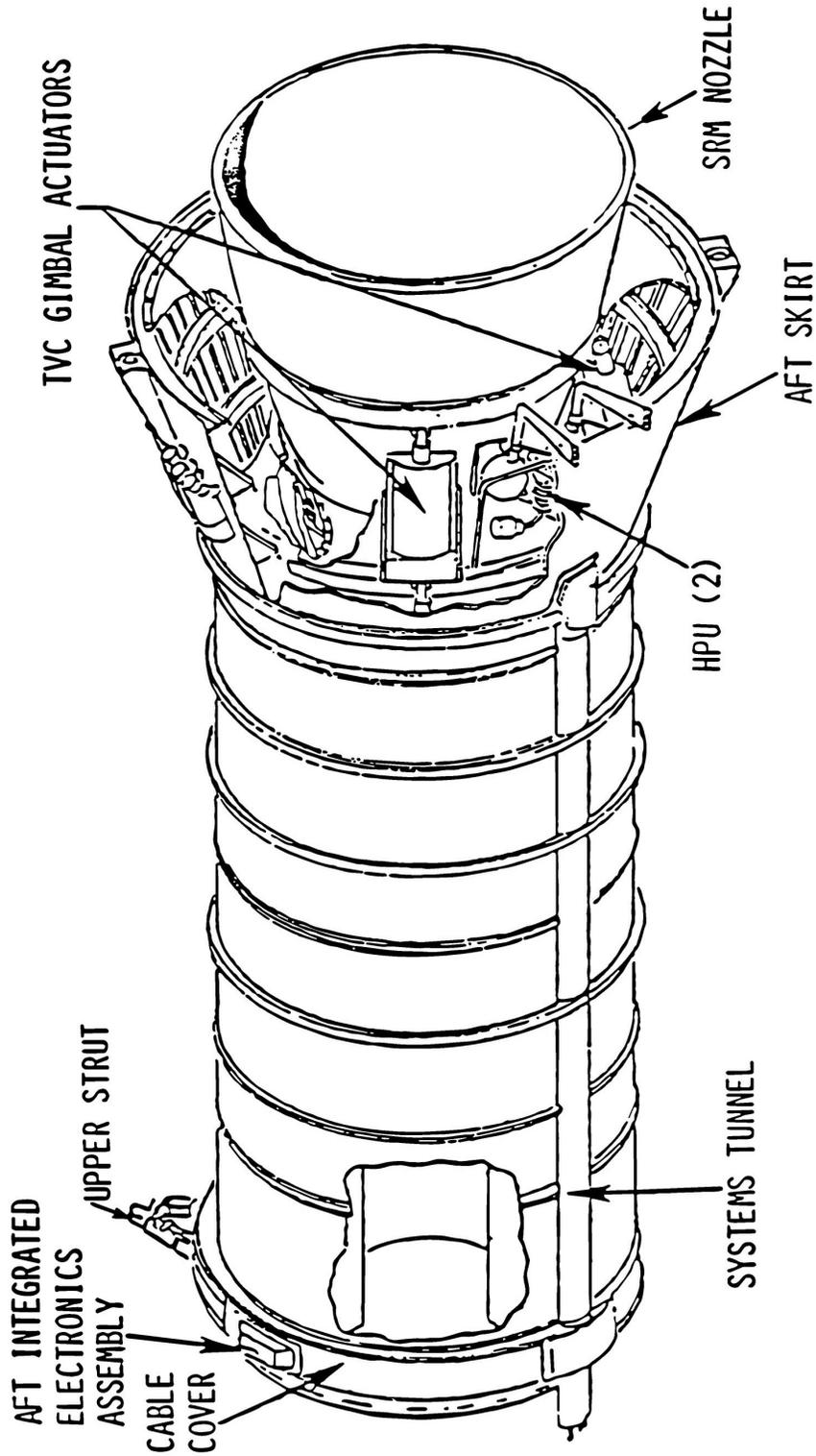
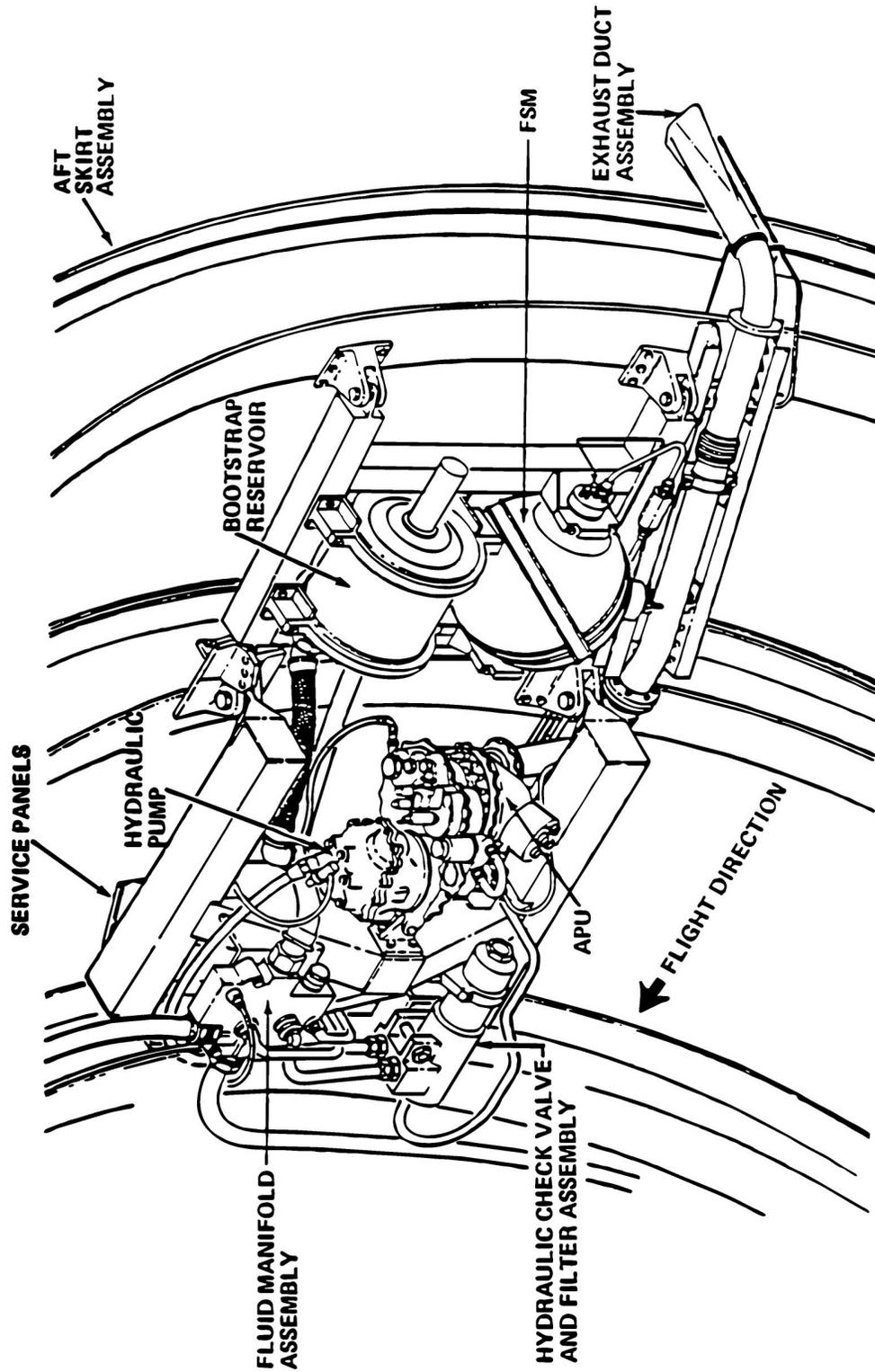


Figure 4.6-I – SRB TVC Components Location



NOTE: FUEL ISOLATION VALVE, SERVOACTUATOR, WIRING, AND INSTRUMENTATION NOT SHOWN.

Figure 4.6-II – SRB TVC Panel Detail

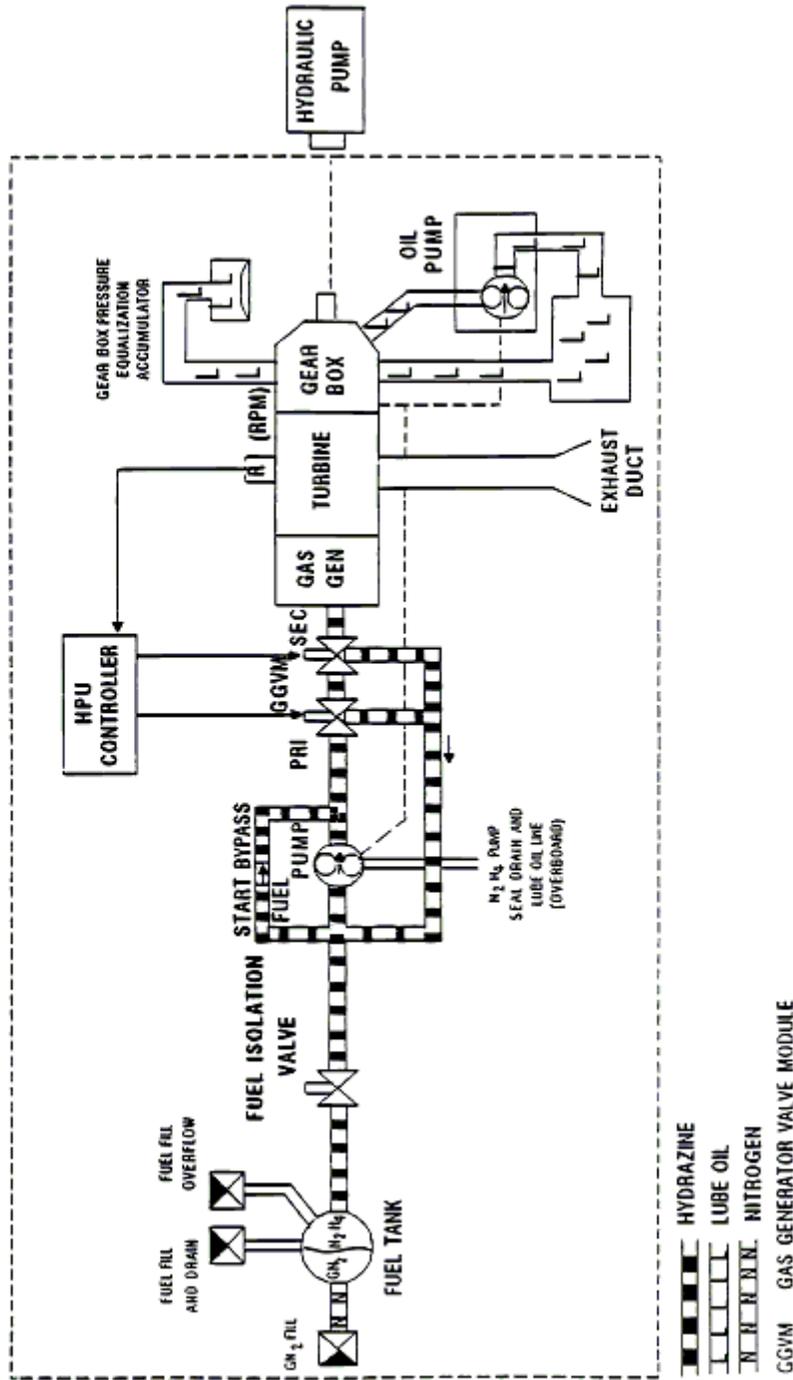


Figure 4.6-III – HPU System Schematic

4.6.2.3 Fuel Pump Assembly ^PZ²

The fuel pump maintains the fuel pressure at 1270 psi to the gas generator once the APU is started. Each assembly has a start bypass valve, which allows fuel to bypass the pump to the gas generator for initial APU start before the fuel pump is activated. As the APU comes up to speed, the pressure output of the fuel pump becomes greater than the initial FSM pre-pressurization pressure. Then the startup bypass line check valve closes. For the remainder of APU operation, the fuel pump supplies all of the fuel to the APU.

The fuel pump assembly also has a relief valve which is set at 1725 ± 25 psid to relieve fuel overpressure between the fuel pump and the gas generator.

4.6.2.4 Fuel Control Valves ^OZ²

The two control valves are solenoid-operated, three-way, two-position valves controlled by an APU controller. The controller regulates the APU turbine speed by rapidly cycling a control valve (full open or full closed) to regulate the fuel flow to the gas generator. One valve is called the primary (PRI) valve and the other, the secondary (SEC) valve. The PRI valve is a normally open valve and is controlled by either the 100 percent or the 110 percent control circuit. Nominally, the PRI valve is opened and closed by the 100 percent speed control circuit. At the same time, the SEC valve, which is a normally closed valve, is powered open. If the primary hydraulic pressure drops between 1900 and 2200 psig, a pressure sensing, spring actuated switching valve in the actuator will allow the secondary hydraulics to power the actuator. A signal is sent to the APU controller of the hydraulic system now in control. This signal comes from the sick actuator through the SRB aft LL (LR) MDM. This signal inhibits the 100 percent circuit and enables the 110 percent circuit. This increased APU speed provides extra hydraulic flow needed to drive two actuators instead of one.

If the pressure in the primary system returns to normal, the HPU can revert to 100 percent speed operation, and then both HPUs will resume powering the TVC system.

If the PRI valve or control logic fails to the open state, the valve can no longer be operated to maintain the turbine speed at 100 percent. Instead, the APU turbine speed will continue to increase. When the speed reaches 112 percent, the 112 percent control circuit will close the SEC valve. Then the SEC valve will be used to control the turbine speed at 112 percent. Once the 112 percent operation is initiated, the affected APU will operate at 112 percent for the duration of SRB powered flight.

There is no overspeed protection if the control logic for the SEC valve fails to the open state. The turbine speed would continue to increase until blade failure occurs. The SRB APU turbines are surrounded by a containment ring, but this ring will only contain blade failures if the blades

fail below 126 percent nominal speed. (90,700 rpm). Ground tests indicate a turbine without blades will breakup and fail at speeds of 105,000 to 115,000 rpm.

4.6.2.5 Gas Generator ^MZ²

The gas generator consists of a catalytic bed with a granular catalyst (Shell X-405) within a pressure chamber mounted inside an exhaust chamber. Hydrazine propellant decomposes when it contacts the catalyst and hot gases are produced. The hot gases are directed to the turbine. Gas generator heaters are provided to preheat the catalyst bed for smooth decomposition. Only one heater will be used at any one time and will be powered off prior to launch. The design operating gas generator temperature is 1700° F.

4.6.2.6 Dual-pass, Reentry Turbine ^LZ¹

The hot gas from the gas generator is routed to the turbine. The turbine converts thermal energy from the hot gas into mechanical energy. The hot gas enters the turbine through the primary inlet and is cycled to reenter the turbine secondary inlet before being exhausted overboard.

The normal operating speed is 100 percent (72,000 ± 5760 RPM). The backup speeds are 110 percent (79,200 ± 5760 rpm) and 112 percent (80,640 ± 5760 rpm). The turbines are designed to reach their nominal speed within a maximum of 4 seconds after initial fuel flow.

4.6.2.7 Gearbox ^JZ²

The gearbox consists of a cluster of speed reduction gears and a lubrication system. The gearbox provides shaft power to drive the gearbox lube oil pump, APU fuel pump, and HPU pump. The speed ratios are as follows:

Turbine to HYD pump	18.93:1
Turbine to lube pump	6.07:1
Turbine to fuel pump	18.93:1

The nominal rated shaft output is 135 hp. Lubrication of the gearbox is provided by an internal oil pump. The oil returns through a filter, then to an accumulator, which is used to compensate for thermal expansion and leakage.

4.6.2.8 APU Controller **JZ**⁶

There is one controller for each APU. A controller provides speed control, logic for APU startup and shutdown, and signal conditioning. The controller electronics are located in the aft integrated electronics assembly (IEA).

Power, command, and data lines for the HPU/TVC systems are channeled to the SRB aft IEA from the orbiter via connecting cables which pass through the orbiter / ET LH2 and LO2 monoball located adjacent to the 17-inch disconnects. From this location, the cables all pass through the SRB/ET upper aft strut.

There are two magnetic pickups (MPU) on the APU drive shafts that are used to sense APU turbine speed. The output from MPU 1 is sent to the 100 and 110 percent circuits, and the output of the other MPU 2 is sent to the 112-percent circuit. The output is a train of pulses, which have a frequency that is directly proportional to turbine speed. This train of pulses is changed to a rectangular wave by the waveshaping circuit. The shaped pulses are then applied to a one-shot multivibrator. The output of the multivibrator is filtered and then compared with a reference voltage in the comparator. The signal from the comparator is amplified and sent to the valve.

The 110-percent speed circuit is enabled when the pressure indication of an actuator pressure O.K. pressure switch is lost. When the APUs are first started, the 110-percent speed circuit will be enabled until the hydraulic pressure builds up higher than between 1900 and 2200 psig.

4.6.3 Hydraulics

4.6.3.1 Hydraulic Pump **HZ**¹

Hydraulic power is generated by a variable displacement hydraulic pump. The APU drives the pump at 3800 rpm \pm 8 percent nominal speed to produce a full-flow pump output of 2800 to 3486 psig at a flow of 55 gpm. The speed is controlled to an accuracy of \pm 8 percent of the selected speed due to the inertia of the turbine wheel. Hydraulic fluid from the hydraulic reservoir is supplied to the hydraulic pump inlet at 55 to 75 psig.

Each pump will provide hydraulic power to move the SRB TVC actuators. HPU A and HPU B supply redundant hydraulic power to each of the actuators.

4.6.3.2 Reservoir **FZ¹**

Each HPU has a hydraulic fluid reservoir, also known as the Bootstrap Reservoir. The reservoir provides pressurized fluid to the hydraulic pump inlet by means of a differential area piston and a mechanical spring, which will compensate for fluid volumetric changes resulting from temperature and/or system operating conditions.

The reservoir has a high pressure chamber, a low pressure chamber, and an air chamber. The fluid from the high pressure chamber has a pressure of 2800 to 3486 psig and is routed to the servoactuators. Low pressure (55 to 75 psig) fluid is returned from the servoactuators to the low pressure chamber. During flight operations, the high pressure chamber uses flow tapped off the output of the pump to actuate the differential area piston, which maintains the low pressure chamber operating pressure required for the pump. The mechanical spring regulates the response to system pressure changes. The air chamber is enclosed and vented to the atmosphere to eliminate a positive or negative back pressure reaction against the piston. The vent port fitting has a 100 μ filter to protect the piston seal from contamination. Bleed valves are located on the high point of the low pressure and high pressure chambers to allow removal of trapped air prior to flight.

A low pressure relief valve is provided to protect against GSE overflow/ overpressurization. Overpressurization (3650 psig or greater) in the high pressure chamber is relieved by a relief valve, which will open and permit fluid to flow to the low pressure chamber.

The fluid quantity indicator is a hermetically sealed unit, which senses fluid quantity as a function of the reservoir piston position. The indicator provides an electrical output signal that is directly proportional to the fluid level in the reservoir.

4.6.3.3 Accumulator **GZ³**

The hydraulic pressure accumulator dampens subsystem pressure impulses and minimizes pump supply pressure ripples. The accumulator has a volume of 49 in³ for hydraulic fluid, and 98 in³ for GN₂.

4.6.3.4 Hydraulic Fluid Check Valve and Filter **HZ³**

A check valve and filter are located in the hydraulic line between the hydraulic pump and the servoactuators. The check valve blocks backflow into the hydraulic pump during system bleed and fill, and the filter removes nonsoluble pollutants that are larger than 5 microns from the hydraulic fluid.

Table 4.6-I.-OPERATIONAL COMPARISON OF SHUTTLE APU TO SRB HPU

	<u>Orbiter APU</u>	<u>SRB HPU</u>
Nominal power	135 HP	135 HP
Mission length	75 minutes - EI-13 start 95 minutes - TIG-5 start	166 seconds
Mission fuel consumption	175 lb. - EI-13 start 200 lb. - TIG-5 start	6.6 lb - normal mission 10.0 lb - back-up mission
Operational environment	-65 degree Fahrenheit to space ambient	-salt water exposure -increased vibration loads -water entry at pressure loads -limited soakback time
Handling differences	Requires refurbishment after 20 hours Oil and oil filter changed after every flight	-requires refurbishment between missions -simplified controls -reduced instrumentation -N2 checkout capability
Thermal	-oil and water coolers -thermally insulated	-no oil cooling -no water coolers -uninsulated -eliminated fuel pump heater
Fuel isolation valve	Two parallel valves	One valve
<u>APU speed control</u> normal backup secondary backup overspeed protection underspeed shutdown	-103 percent -113 percent -115 percent -Yes (will AUTO-SHUTDOWN) -Yes (will AUTO-SHUTDOWN)	-100 percent -110 percent -112 percent -No (containment ring only) -No

4.6.4 References

1. Solid Rocket Booster Thrust Vector Control Subsystem Description, NASA TM-82546, September 1983.
2. Space Shuttle Systems Handbook, NASA-JSC-11174, Revision F, November 15, 2002.
3. Space Shuttle Probabilistic Risk Assessment - APU/HPU VOLUME III, MDAC WORKING PAPER 1.0-WP-VA88004-03, December 18, 1987.

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