program used a simulated SRB test vehicle designed by MSFC to be aerodynamically compatible with the B-52. The simulator weighed approximately one-third the actual empty SRB (about 50,000 pounds). The 11.5'-diameter pilot, 54'-diameter drogue, and three, 115'-diameter main flight-type parachutes were attached to the test vehicle, singly or clustered, and the vehicle was dropped from the B-52 at an altitude of approximately 19,000'. Several different parachute configurations were used to provide various conditions (e.g., reefed and full open canopy shapes).[1610]

The objective of the first drop test, conducted on June 15, 1977, was to measure drogue parachute performance under design load conditions. During this test, the drogue parachute, followed by the three main parachutes, were deployed successfully.[1611] The second test was designed to determine loads on the main parachutes. Test three of the series, conducted on December 14, 1977, focused on the integrity of the drogue chute under overload condition. Fins were added to the test vehicle to increase speed, improve stability, and produce less drag.[1612] During this test, the drogue parachute failed, as a result of insufficient reefing system design, and the test vehicle sustained severe damage.[1613] The successful fourth drop test in May 1977, which deployed the three main parachutes plus the pilot and drogue parachutes, tested the parachute recovery system to its full design limits.[1614] The fifth test, on July 26, 1978, successfully deployed the drogue and three main chutes. The parachute drop test program concluded on September 12, 1978, with the successful sixth drop test.[1615]

Physical and Functional Descriptions

Each SRB (Figure No. E-11) measured approximately 149' long, 12' in diameter, and weighed approximately 1,255,000 pounds fueled, with the propellant accounting for about 1,107,000 pounds, or roughly 88 percent of the total weight. Assembly items and attachments added approximately 1,230 pounds to the overall weight. With few exceptions, the left and right SRBs were almost identical and interchangeable.[1616] The boosters incorporated seven major subsystems (Figure Nos. E-12, E-13): 1) Structural; 2) Reusable Solid Rocket Motor (RSRM); 3) Separation; 4) Electrical and Instrumentation (E&I); 5) Recovery/Deceleration; 6) Thrust Vector Control (TVC); and 7) Range Safety System (RSS). A description of each follows.

[1610] "SRB Parachute Drop Tests Set," *Marshall Star*, June 8, 1977, 1, 4; "Agreement Reached on SRB Parachute System Testing," *Marshall Star*, May 19, 1976, 1, 2.
[1611] "SRB Recovery System Tested," *Marshall Star*, June 29, 1977, 1.
[1612] "Third Air-drop Set for SRB System," *Marshall Star*, November 30, 1977, 1.
[1613] George B. Hardy to Dr. Lucas, "SRB Parachute Drop Test # 3 Failure report," December 16, 1977, Drawer 28, File: SRB Quarterly Reviews 1977, MSFC History Office, Huntsville.
[1614] "Air Drop Test Set for SRB Parachutes," *Marshall Star*, April 19, 1978, 3; "Fourth SRB Parachute Drop Test is Success," *Marshall Star*, May 31, 1978, 2.
[1615] "Parachute Drop Test Successful," *Marshall Star*, August 9, 1978, 3; "SRB Parachute Recovery System Passes Drop Test," *Marshall Star*, September 20, 1978, 1, 4.
[1616] Among the differences were those in the E&I subsystem, the BSM locations, the SRB/ET attach ring orientations, and the forward skirts. USA, *Solid Rocket Booster Illustrated Systems Manual* (Huntsville: United Space Alliance, May 2005), 1.

Structural Subsystem

The SRB structural subsystem provided support for the Shuttle stack on the launch pad, held the vehicle on the pad during SSME thrust buildup and RSRM ignition prior to liftoff, and transferred thrust loads to the orbiter and ET. It also provided structural support for the SRB recovery, range safety, and TVC subsystems, as well for electrical components and the BSMs.[1617] Physically, the major structural subsystem components included the nose cap, frustum, forward separation ring, forward skirt, forward SRB/ET attach fitting, aft SRB/ET attach ring and struts, systems tunnel, and aft skirt (including the thermal curtain). The nose cap, frustum, and forward skirt collectively comprised the forward assembly.

The SRB structural subsystem components were protected by two primary types of thermal protection materials. These included cork and MCC, a spray-on ablative. MCC was used on the nose cap, frustum, forward and aft skirts, and on a portion of the systems tunnel. Cork was used on the SRB aft skirt, SRB/ET attach ring, booster separation motors, struts, and systems tunnel.[1618]

Nose Cap

The nose cap (Figure Nos. E-14, E-15) measured 68” in diameter at the base and 75” in overall length. This structure, made of 2024 aluminum sheet skins, was comprised of four formed ring segments, a spin-formed cap/dome, machined fittings, and an aft machined frustum separation ring.[1619] The nose cap housed the pilot and drogue parachutes, and typically was not recovered. The nose cap was separated from the frustum by three frustum-mounted thrusters.[1620]

Frustum

Also composed of aluminum (2219 forging and 7075 formed skins), the frustum measured 10’ in height, with a 68” minor base diameter and a 146” major base diameter (Figure Nos. E-14, E-15). It incorporated rings, fittings, separation motor housing, main parachute supports, and flotation devices for recovery. The frustum housed the three main parachutes, the altitude sensor, and the forward booster separation motors. The main parachute support structure was mechanically attached, but not considered part of the frustum structural assembly.[1621]

[1617] USA, *Solid Rocket Booster Familiarization Training, Revision K* (Florida: United Space Alliance, 2009), DVD, STR-2; USA, *Booster Manual*, 10.
[1618] USA, *Booster Manual*, 13.
[1619] Over time, there have been three different nose cap vendors, including USBI in Huntsville. James Carleton, interview by Joan Deming and Patricia Slovinac, June 29, 2010, KSC, Florida.
[1620] USA, *Booster Manual*, 10.
[1621] USA, *Familiarization Training*.

Forward Separation Ring

The forward separation ring, machined from 2219 aluminum forgings, was located between the frustum and forward skirt assemblies. It provided a mount for the linear-shaped charge used for separation of the frustum from the forward skirt assembly after the SRBs were jettisoned.

Forward Skirt

The forward skirt, made from 2219 aluminum, measured approximately 125” long and 146” in diameter (Figure No. E-16). It provided the necessary structure to react to parachute loads during deployment and descent, and also provided the hardpoint connection for parachute risers used during retrieval operations.[1622] The forward skirt included secondary structures for mounting components of the E&I subsystem, RSS panels, and the systems tunnel components.[1623] The left forward skirt and right forward skirt were not identical.

Forward SRB/ET Attach Fitting

The forward SRB/ET attach fitting (Figure No. E-17), manufactured from 2219 aluminum, was located on the external wall of the forward skirt. The forward separation bolt that held the ET to each SRB was fixed to this attachment point.

Aft SRB/ET Attach Ring and Attach Struts

The aft SRB/ET attach ring (Figure No. E-18) was comprised of four individual ring segments of steel construction. The segments were made from high strength nickel-chromium based alloys, 4130 and 4340, plus the high strength nickel-cobalt based alloy, Inconel 718. It measured 164” in diameter and 16” high. Located on the forward end of the aft motor segment, the aft SRB/ET attach ring housed the aft IEA and provided attachment points for the three aft struts. Protective covers for the struts and aft IEA encircled the entire ring assembly. The four ring segments were bolted to the motor case at 532 locations, and were joined by sixteen splices and eight angle caps including splice buildup over the systems tunnel.[1624] The attach ring/strut cavities were filled with silicone foam and a layer of silicone rubber was placed between the foam and covers to restrict the flow of hot gases.[1625]

The lower, diagonal, and upper SRB/ET aft attach struts physically attached the SRB to the ET. Each strut contained one bolt and one NASA standard initiator pressure cartridge at each end. The upper strut also carried the umbilical interface between the SRB and the ET, and that

---

[1622] USA, *Booster Manual*, 11.
[1623] USA, *Familiarization Training*.
[1624] USA, *Booster Manual*, 12.
[1625] USA, *Booster Manual*, 14.

extended on to the orbiter.[1626] The tubular struts, constructed of Inconel 718, were made in two halves and were held together by the aft separation bolt. At separation from the ET, the bolt was split by a pyrotechnic device, and the two halves of the bolt were caught inside the strut halves by honeycomb energy absorbers on each end of the struts.[1627]

Systems Tunnel

The systems tunnel (Figure No. E-19), located on the outside of each SRB, extended from the forward skirt to the aft skirt. It measured about 10" wide and 5" high, and housed electrical cables associated with the E&I subsystem, ground environmental instrumentation (GEI), heater system, and linear-shaped charge. The tunnel floor assemblies were bonded to the SRM case. Tunnel covers, made from 2219 aluminum, were attached to the tunnel floor assembly, and provided lightning, thermal, and aerodynamic protection.[1628]

Aft Skirt

The conical-shaped aft skirt, fabricated from aluminum, measured 90.5" long, with a minor diameter of 146" and a major diameter of 208.2" (Figure No. E-20). It featured integral stringer/skin construction welded to four forged hold-down posts with bolted-in rings. These rings, made of 2219 aluminum, provided structural support and attach points to the MLP. Bolted-in clips and gussets provided additional strength for water impact. The aft skirt provided both aerodynamic and thermal protection. It also provided support mounts for the TVC subsystem and the aft-mounted BSMs. The twin booster aft skirts supported the approximate 4.5 million pound Space Shuttle vehicle on the launch pad prior to SRB ignition.[1629] The thermal curtain assembly, installed circumferentially between the aft skirt aft ring and the SRM nozzle ring with mechanical fasteners, provided thermal protection. It was made from three layers of quartz cloth, fiberfrax insulation, and fiberglass cloth.[1630]

Reusable Solid Rocket Motor (RSRM) Subsystem

Each RSRM measured approximately 126' in overall length, 12.2' feet in diameter at the forward end and 12.72' at the aft (nozzle) end, and had a general wall thickness of 0.5". The major components of the RSRM subsystem were the segmented motor case loaded with solid propellant, and the movable nozzle with exit cone. Other elements of this subsystem included the igniter assembly and joint heaters. All of the RSRM major components were designed to be refurbished and used up to twenty times.

[1626] United Space Alliance (USA), *Shuttle Crew Operations Manual* (Houston: United Space Alliance, 2004), 1.4-7.
[1627] USA, *Familiarization Training*, STR-24, STR-25; NASA MSFC, *External Tank and Booster Camera Systems.*
[1628] USA, *Familiarization Training*, STR-29.
[1629] USA, *Familiarization Training*, STR-3, STR-32.
[1630] USA, *Booster Manual*, 14.

Motor Case Segments

Each RSRM contained four motor segments: forward, forward center, aft center, and aft. The forward motor segment measured 31.5' long and weighed up to 332,000 pounds fueled (Figure No. E-21). Each of the two center segments was 27' long and weighed a combined total of 593,874 pounds fueled (Figure No. E-22). The aft segment was 33' long and weighed 320,464 pounds. The RSRM segments were connected by pinned tang/clevis joints with O-ring seals (Figure Nos. E-23, E-24).

The motor case was of segmented construction to facilitate manufacture, shipping, assembly, and recovery. In total, eleven case segments (cylinders) comprised each motor. These manufacturing segments included the forward dome (3.88' total length), six cylinders (two forward segments, two forward center segments, and two aft center segments, each measuring 13.67' in length), the SRB/ET attachment segment (7.50' in length), two case stiffener segments (10.34' length each), and the aft dome (5.00' in length). The cylindrical segments had a nominal wall thickness of 0.506".[1631] The walls of the aft dome were 0.362" thick.

Each of the motor case segments was a weld-free cylinder produced by the joint efforts of Rohr Industries of Chula Vista, California, and their two subcontractors, the Ladish Company of Cudahy, Wisconsin, and Cal-Doran Metallurgical Services of Los Angeles, California. The metal components of the RSRMs began as ingots, procured from Latrobe Steel in Pennsylvania. The steel ingots, or billets, weighed approximately 31,000 pounds each. The Ladish Company forged the raw steel billets to make pre-forms, then "punched out the centers and formed case segments in a series of forging and roll-forming operations."[1632] Ladish shipped the cylindrical segments to Cal-Doran for tempering (heat treatment) to toughen the steel. The final machining was done by Rohr Industries. The clevis joints were machined and 180 holes were drilled in each joint for the retaining pins, which would couple the segments together.

The cylinders and domes, as well as the igniter chamber and adapter, were roll-formed from D6AC steel, a high strength, medium-carbon steel alloy. The cylinders were joined together with pins via a tang and clevis mechanical joint for a weld-free assembly. The pins were made from MP35N, a high strength multiphase alloy. The pin retainer band and shims were of Inconel 718, and the stiffener T-rings were of 4340 steel. For corrosion protection, the cylinders were painted with rust proof paint, and the bare metal areas were covered with HD-2 grease.

At Thiokol, the case segments were assembled into the forward, aft, and two center casting segments. These were then insulated, lined, filled with solid propellants, and cured.[1633] Rubber was vulcanized to the inside of the steel case segments to insulate them from the heat of propellant combustion (about 6,000 degrees F). The insulation was designed to partially burn

[1631] USA, *Booster Manual*, 156.
[1632] "First SRB Motor Case."
[1633] "First SRB Motor Case."

away during motor operations, but to leave enough material to protect the case. The rubber thickness was greatest in the aft dome (more than 5”) and least in the center segment cylinder sections (about 0.15”). Before propellant was cast into a case segment, a liner composed of liquid rubber with a curative added was applied to the insulation. This liquid also had “asbestos floats” in the mixture. The typical thickness of the liner was 0.060”. The propellant adhered to the liner better than it did to the insulation.

The forward cast segment was filled with 310,000 pounds of propellant, with 270,000 pounds each in the center forward and aft segments, and 260,000 pounds in the aft segment. The solid propellant was a mixture of ammonium perchlorate as the oxidizer (70 percent by weight; 1.1 million pounds), aluminum powder for fuel (16 percent), plus a polymer binder, PBAN (12 percent) that held the mixture together. An epoxy curing agent (2 percent) also was added, as well as a small amount of iron oxide powder (0.7 percent), which served as a catalyst to increase the burning rate. The solid propellant was a battleship gray in color and had the consistency of a hard rubber eraser. Each of the four motor segments for each pair was loaded with propellant from the same batches of ingredients to minimize any thrust imbalance.

Approximately 167, 600-gallon mixes were required to cast all four segments. Propellant was cast around a mandrel (spindle) inserted into the case, which gave the propellant surface inside the motor a specific shape. There was a different cast configuration for the forward segment, the two center segments, and the aft segment. The propellant was an eleven-point star shape in the forward motor segment and a double-truncated-cone in each of the center segments and the aft segment. The propellant was cured by heating in the cases at 135 degrees F for four days to achieve the desired mechanical properties, then cooled down to shrink back the propellant for core removal. The propellant was storable and stable.[1634]

The individual segments were connected by either a factory joint or a field joint. The field and factory joints prevented hot gas from reaching the O-rings. Factory joints were assembled at the Thiokol plant in Utah.[1635] The joints were located in seven places, mating the: 1) forward dome to the forward case segment (“Forward Y”); 2) the two forward case segment cylinders; 3) the two forward center segment cylinders; 4) the two aft center segment cylinders; 5) the SRB/ET attachment segment to the aft stiffener segment; 6) the two aft segment cylinders; and 7) the aft segment cylinder to the aft dome (“Aft Y”). Each factory joint was internally pressure sealed with dual V1115 fluorocarbon O-rings and full internal insulation. The forward dome featured a forward tang for skirt attachment with 195 pinholes, including eighteen extra pinholes in the thrust bearing attachment. The aft dome had an aft tang for skirt attachment with 177 pinholes and three alignment slots equally spaced around the circumference.

[1634] NASA MSFC, *A Primer on Propellants*, NASA Fact Sheet (Huntsville, AL: George C. Marshall Space Flight Center, no date), Folder: 35, MSFC History Office, Huntsville.

[1635] During stacking in the VAB, three field joints connected the forward segment to the forward center segment; the forward center segment to the aft center segment; and the aft center segment to the attach ring. Field joints were internally pressure sealed with three O-rings and bonded insulation.

Prior to shipment to KSC, Thiokol grit-blasted and installed the systems tunnel and handling rings to all segments, and installed the igniter in the forward segment, the nozzle in the aft segment, and instrumentation in the center segment.

Nozzle Assembly

The nozzle weighed roughly 24,000 pounds and had an approximate 54”-diameter throat and 146” exit diameter.[1636] It was built and shipped in two parts, the forward assembly and the nozzle aft cone (see Figure No. E-23). The forward assembly components were made from D6AC steel and 7075-T73 aluminum. The aft cone assembly housing was made of 7075-T73 aluminum. Metal components were fabricated by Kaiser Aerotech, while the ablative components and flexible bearing joints were made by Thiokol, who also subassembled and assembled the components. The nozzle was of modular-type construction with parts grouped into assemblies to facilitate reuse and refurbishment.[1637] The seven major nozzle subassemblies were: 1) nose inlet; 2) throat inlet; 3) flexible bearing; 4) cowl; 5) fixed housing; 6) forward exit cone; and 7) aft exit cone. The primary assemblies were bolted together, and the nozzle assembly was attached to the aft motor segment with 100 radial and 100 axial bolts.[1638]

The nozzle contained five sealing joints, each including dual redundant O-ring seals. A silicon rubber thermal barrier was used to protect the O-rings. The flexible bearing weighed about 7,000 pounds and measured almost 100” in diameter. It connected the fixed and movable portions of the nozzle, and allowed the nozzle to be moved eight degrees in any direction. Thermal protection for the flexible bearing core was provided by a multi-layer rubber boot and a silicon rubber bearing protector. The housing ablative liner was made from carbon cloth phenolic from North American Rayon Corporation/Cytec Engineered Materials. The structural over-wrap for the carbon cloth phenolic, boot and protector rings was made of glass cloth phenolic from Advanced Glass Fiber Yarns/Cytec Engineered Materials. The aft exit cone subassembly contained the severance system, designed to separate the aft 6’ of the aft exit cone prior to ocean impact. This was done in order to reduce splashdown loads on the nozzle flexible bearing.[1639]

Igniter Assembly

The igniter assembly, contained in the forward motor case segment, was comprised of the igniter, S&A device, and pressure transducers (see Figure No. E-21). The assembly was attached to the forward segment by bolts. The igniter was a small rocket motor measuring 48” long and 17” in diameter. It contained 134 pounds of solid propellant with a 40-point star grain. The S&A

[1636] T.L. Elegante and R.R. Bowman, “Nozzle Fabrication for the Space Shuttle Solid Rocket Motor,” in *Proceedings from the 14th American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, Las Vegas, Nev., July 25-27, 1978* (Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 1978).
[1637] USA, *Booster Manual*, 159.
[1638] USA, *Booster Manual*, 155.
[1639] USA, *Booster Manual*, 160.

device, mounted to the forward end of the igniter, ensured that the motor fired only when commanded. It provided the first ignition pulse via a pyrotechnic charge.[1640]

Electrical Heaters

Each of the three field joints and the igniter joint had an electrical heater which provided environmental protection during pre-launch countdown. The field joints and igniter joints were fabricated by Tayco Engineering of Cypress, California. The 40'-long field joint heaters were installed at KSC. The igniter joint heater was installed at the Thiokol plant. Field joint heaters were active between T-8 hours and T-1 minute. The igniter heater was active between L-18 hours or T-8 hours (if above 55 degrees F) and T-9 minutes. It was deactivated prior to the S&A arm command (barrier-booster rotor rotation).

Hardware

The three stiffener rings were fabricated in 120-degree sections, insulated, and bolted together with splice plates to encircle the case.[1641] A total of 180 high-strength pins were used to join one segment to another. These included three tooling pins, positioned at approximate 120 degrees around the case for case alignment, and 177 cobalt alloy pins for holding.

Separation Subsystem

The separation subsystem provided for the structural release of the SRBs from the orbiter/ET. The primary components of this subsystem were the total sixteen forward and aft BSMs on both SRBs, plus the forward and aft separation bolts.

Booster Separation Motors

Each SRB contained eight small BSMs. One four-motor cluster was installed on the frustum (Figure No. E-25) and another was located in the aft skirt (Figure No. E-26). The BSMs fired simultaneously and provided the force to move the SRB away from the orbiter/ET at separation during flight. Each BSM measured 31" long, 12.865" in diameter, and had a maximum weight of 167 pounds, inclusive of explosive devices and aeroheat shields or aft heat seals with mounting hardware.[1642] The BSMs burned solid propellant which had a sixteen-point star grain configuration. They fired only about one second each to accomplish the separation, with a thrust of about 20,000 pounds. The BSMs were designed to produce no debris that would be damaging to the orbiter tiles.

[1640] ATK Thiokol, *Reusable Solid Rocket Motor RSRM Design and Manufacturing Baseline, Revision C*, (Utah: ATK Thiokol, 2005), DVD.
[1641] USA, *Booster Manual*, 155.
[1642] USA, *Familiarization Training*, SEP-24.

Each BSM contained a motor case, nozzle, igniter, structured attach fittings and pyrotechnic connectors.[1643] The cylindrical-shaped motor case, made from 7075 aluminum, measured 25.83" in length and had a maximum wall thickness of 0.315". The forward end of the case had eight threaded holes and a guide pinhole to provide an alignment interface to the SRB.[1644] The BSM case liner material, specifically formulated for use with the propellant, served as a case wall insulator.[1645] The nozzle/aft closure assembly, attached to the motor case, was made from 7075 aluminum, and the exit cone part of the assembly was carbon steel.[1646] The nozzle was canted 20 degrees to permit installation in the frustum. The BSM igniter consisted of a simple perforated steel tube containing propellant. The small initiator charge was triggered by two (redundant) stainless steel confined detonating fuse initiators loaded with pentaerythrite tetranitrate charges.[1647]

Separation Bolts

Forward and aft structural attachment separation was accomplished with double-ended separation bolts. The forward and aft bolts were of a different size, but functionally identical. Pressure cartridges installed in each end of the bolts provided the explosive force to fracture and separate the bolts, which were designed to separate without producing debris.

The forward separation bolt measured 25" long, 3" in diameter, and weighed 70 pounds, and featured a groove about 11.5" from the top that allowed it to break when the pyrotechnic device fired. After separation, one-half of the bolt remained with the booster, secured within the forward skirt thrust post. The other half was retained with the ET. Although mounted on the ET, the bolt catcher was considered part of the SRB element design.[1648]

Electrical and Instrumentation Subsystem

The E&I subsystem, which connected the SRBs with the orbiter vehicle, controlled a number of functions during the prelaunch, ascent, ET/SRB separation, and deceleration phases. During the prelaunch phase, the data processing elements and cabling supported testing, calibration, and monitoring activities. The E&I subsystem's interconnecting cabling also was used for signal conditioning, power distribution, data processing, and operational flight sensors to support the

[1643] "Contractor Chosen for Shuttle Booster Separation Motors," *Marshall Star*, August 13, 1975, 1, 3.
[1644] USA, *Familiarization Training*, SEP-46.
[1645] USA, *Familiarization Training*, SEP-8.
[1646] USA, *Familiarization Training*, SEP-47; USA, *Booster Manual*, 101.
[1647] USA, *Familiarization Training*, SEP-37, SEP-50.
[1648] The bolt catcher was redesigned in 2005 and built by General Products of Huntsville, Alabama. It was changed from a two-piece welded design to a one-piece machined design to eliminate the weld and thereby improve the safety margin. Made from a stronger aluminum alloy, AL7050, the modified bolt catcher featured increased wall thickness (from .125 to .25 inches) and a more open cell texture. Thermal protection, provided by USA at KSC, changed from the original super lightweight ablator to a machined cork covered with a protective paint finish. NASA MSFC, *Bolt Catcher Modifications on the Solid Rocket Booster*, NASA Facts (Huntsville, AL: Marshall Space Flight Center, April 2005), http://www.nasa.gov/centers/ marshall/pdf/114018main_Bolt_Catcher_FS.pdf.

SRB during ascent. It also contained controllers used to regulate the speed of the TVC system's APUs. In addition, the E&I subsystem supported the initiation of the SRM nozzle extension severance and release of the nose cap and frustum during recovery functions.[1649] The primary components of the E&I subsystem included the IEAs and the rate gyro assemblies (RGAs); also included were the altitude switch assembly, the camera system, and the enhanced data and acquisition system.

Integrated Electronic Assembly

Each SRB had two IEAs which contained electronic circuits and wiring (Figure No. E-27). The forward and the aft IEAs were not interchangeable with one another.[1650] The aft IEA was cabled to the orbiter for power; the forward IEA was cabled to the aft IEA from which it received power.[1651] Designed and manufactured by L-3 Communications (formerly Bendix), each box-shaped IEA measured 45" long, 12" high, and 12" wide. The complete aft IEA with its internal components weighed 182 pounds; the complete forward IEA weighed 188 pounds.[1652] Both the forward and aft IEAs were fabricated from the same machined A356 aluminum casting. The top and bottom covers were made from 6061 aluminum sheet and were attached to the casting with ninety screws. The IEAs were hermetically sealed and watertight. The glass-sealed external connectors also were watertight.[1653] The IEAs processed signals for a variety of functions. Specifically, after burnout, the forward IEA initiated the release of the nose cap and frustum, jettison of the SRM nozzle, detachment of the parachutes, and turn-on of the recovery aids. The aft IEA, mounted in the ET/SRB attach ring, connected with the forward assembly and the orbiter avionics systems for SRB ignition commands and nozzle thrust vector control.[1654]

Each IEA had a MDM, an electronic device, which sent or received electrical signals from a sensor and inputted the signals to tape recorders on the SRB and in the orbiter. They were designed and manufactured by Honeywell (Sperry). Also housed in the IEAs was the dedicated signal conditioner, manufactured by the Eldec Corporation of Lynnwood, Washington. This component received an electrical signal from a sensor and changed it to ac or dc and raised or lowered the power level required to perform the intended function. [1655]

Rate Gyro Assembly

Mounted in a watertight compartment of the forward skirt were two RGAs, each containing two gyroscopes with auxiliary components. Each RGA measured 8.25" long, 7.6" wide, and 6.8" in height, and weighed 9.2 pounds. The external case material was aluminum alloy A356 class

[1649] USA, *Booster Manual*, 32.
[1650] USA, *Booster Manual*, 47.
[1651] USA, *Booster Manual*, 31.
[1652] USA, *Booster Manual*, 33, 38.
[1653] USA, *Familiarization Training*, E&I-11.
[1654] "Sperry Rand Gets Shuttle Contract," *Marshall Star*, July 23, 1975, 4.
[1655] "Signal Conditioner Modules Contract Awarded to Eldec," *Marshall Star*, December 24, 1975, 1

II.[1656] The RGAs, designed and manufactured by Northrop Grumman, provided vehicle angular rates (pitch and yaw) to the orbiter control system. The forward IEA powered one RGA, while the other received power directly from the orbiter.

Altitude Switch Assembly

The altitude switch assembly, mounted in the frustum, was designed and manufactured by Clifton Precision. It measured 5.5" high, 3.00" wide, 3.75" deep, and weighed about 2.8 pounds. The case was made of Monel QQ-N-281. The altitude switch assembly initiated the logic signals necessary for deployment of the drogue and main parachutes, and also initiated a timer for nozzle extension jettison.

Camera System

The camera system included the ET observation camera, aft-looking camera, and two solid state video recorders, all located within the forward skirt, as well as the forward-looking camera, housed in the ET attach ring.[1657] These components and interfacing cables were fabricated and assembled "in-house" by USA.

Enhanced Data and Acquisition System

STS-91 in June 1998, marked the first time that the Shuttle carried up to five enhanced data and acquisition system units, mounted on the SRB forward skirt ring. Beginning just after lift-off, these instruments recorded information from the ET and SRB sensors, including internal gas temperatures and pressures, skin temperatures, shock, and vibrations. After recovery, the units were disassembled, and the information uploaded and disseminated.[1658]

Recovery/Deceleration Subsystem

The Recovery/Deceleration subsystem included the assemblies required to "separate, deploy, disconnect, float, and retrieve all recoverable system components."[1659] This subsystem included elements of other SRB subsystems, such as the E&I subsystem altitude switch assembly, and the nose cap and frustum of the structural subsystem.[1660] The decelerator components, which provided attitude and terminal velocity control of the SRBs for water impact, included the pilot and drogue parachute pack assemblies located in the nose cap, plus the altitude switch and the three main parachute pack assemblies and main parachute support structure in the frustum. Collectively, the parachutes sequentially slowed the descent of the expended SRBs. Originally,

---

[1656] USA, *Familiarization Training*, E&I-25.
[1657] USA, *Familiarization Training*, E&I-33.
[1658] USA, *Booster Manual*, 29; USA, *Familiarization Training*, E&I-30.
[1659] USA, *Booster Manual*, 114.
[1660] USA, *Booster Manual*, 118.

all SRB parachutes and bags were manufactured by the Pioneer Parachute Company of Manchester, Connecticut, a subcontractor to Martin Marietta Corporation. More recent parachutes were made by Irvin Parachute. NASA had a total of sixty-eight large main parachutes built, fifty-six of which were still in active inventory at the end of the program. All were initially certified for ten flights and subsequently recertified for fifteen flights. Twenty-nine drogue parachutes were built and, as a result of attrition, thirteen were in active inventory at the end of the program. The drogue parachutes were initially certified for ten uses and then recertified for thirteen.

The SSP initially used smaller main parachutes, with a 115'-diameter. During the first few flights of the SSP, some single main parachute failures were experienced; the parachutes were impacting the water at higher velocities (109 feet per second versus 88 feet per second). This resulted in more damage to the boosters. NASA switched to a larger, 136'-diameter main parachute, first used on STS-41D, to mitigate this damage. If one large main parachute were to fail, the booster would impact the water at approximately 90 feet per second under two large main parachutes, about the same force as under three small mains.[1661]

The pilot parachute assembly (Figure Nos. E-14, E-15, E-28) included the chute canopy assembly with suspension lines, deployment bag, nose cap bridle, and an energy absorber. The pilot parachute measured 11.5' in diameter and weighed 55 pounds. It was of sixteen-gore, 20-degree conical ribbon construction with a 16 percent uniform porosity.[1662] The drogue parachute measured 54' in diameter and weighed 1,100 pounds, and was of the same sixteen-gore, 20-degree conical ribbon construction as the pilot parachute. The drogue parachute had sixty 102'-long suspension lines clustered in twelve suspension line groups. The retrieval line was 175' long. Each of the three large main parachutes measured 136' in diameter and weighed 2,200 pounds. They were of 160-gore, 20-degree conical ribbon construction with a 15.4 percent uniform porosity. Each main parachute pack assembly featured eight 40' risers, with four risers per deck fitting; eight 98.5' dispersion bridles with ten legs per bridge; and 160, 64' suspension lines with two suspension lines per bridle leg.[1663]

The three main parachutes were packed in deployment bags housed in individual compartments formed by the main parachute support structure within the frustum. This structure, designed to maintain separation of the main parachutes during installation and deployment, measured 62.06" in height by 92.0" in diameter.[1664] Each of the three panel assemblies, spaced 120 degrees apart, extended 54.965" out from the center of the structure.

Included in the main parachute assembly was the Salt Water Activated Release (SWAR). In the early days of the SSP, some of the SRB forward skirts were buckling because of the way the

[1661] Jack Hengel, personal communication with James M. Ellis, MSFC, August 31, 2011.
[1662] USA, *Familiarization Training*, REC-17.
[1663] USA, *Familiarization Training*, REC-27.
[1664] USA, *Familiarization Training*, REC-20.

motor splashed down when the parachutes were released at water impact. A solution to this was to keep the main parachutes attached at water impact and allow the boosters to lay down in the water without slapping down.[1665] The SWARs then separated the main parachute dispersion bridles from the risers. The SWARs were self-contained and required no electrical input from the SRB recovery subsystem electronics.[1666]

Thrust Vector Control Subsystem

The TVC subsystem (Figure No. E-29) controlled the direction of flight during the first two minutes of a mission through movement of the nozzles. Two complete TVC subsystems were housed in the aft skirt of each booster. Their primary function was to power the booster nozzle to aid the steering of the Shuttle during ascent. The TVC system for each SRB contained two separate hydraulic power units (HPUs), one to control nozzle position in the rock plane and the other to control nozzle position in the tilt plane.[1667] The HPU components were mounted on the aft skirt between the rock and tilt actuators. The HPUs were driven by the hydrazine-powered turbine, the APU. The APU drove the hydraulic pump through the gearbox to provide a pressurized fluid flow to the servoactuator.[1668] Rock and tilt systems supplied hydraulic power to the TVC electro-hydraulic servoactuators "to effect mechanical positioning of the SRB nozzle in response to steering commands."[1669] The dual action servoactuators were connected to the aft skirt attach point and RSRM nozzle by a clevis pin arrangement. They were hydraulically interconnected to each HPU for operating redundancy in the event of a failure of either HPU.[1670]

Each APU contained a fuel pump, gas generator and gas generator valve module, turbine, gear box, electrical controls, control valves, instrumentation, monitoring system, and the mechanical and electrical connectors required to interface with the other SRB subsystems. Each fuel tank contained twenty-two pounds of hydrazine.[1671] Two APUs, each driving a hydraulic pump, provided hydraulic power to the TVC subsystem of each SRB during the pre-launch and ascent phases of shuttle flight.

During prelaunch, the TVC subsystem was controlled by the APU controller assembly located in the aft IEA in each SRB. After lift-off, all command and control functions of the TVC subsystem originated in either the orbiter's GNC computers or the ascent TVC electronics of the orbiter.[1672] The TVC subsystem was designed to operate from approximately T-26 seconds through the

---

[1665] Jack Hengel, personal communication with James M. Ellis, MSFC, August 31, 2011.
[1666] USA, *Booster Manual*, 117.
[1667] USA, *Familiarization Training*, TVC-2.
[1668] USA, *Booster Manual*, 54.
[1669] USA, *Booster Manual*, 54.
[1670] USA, *Familiarization Training*, TVC-51.
[1671] Chris Bergin, "Shuttle Boosters to sport APU fuel pump safety redesign from STS-134," February 28, 2010, http://www.nasaspaceflight.com/2010/02/shuttle-boosters-sport-apu-fuel-pump-redesign-st.
[1672] USA, *Booster Manual*, 55.

powered flight of the SRB. The electrical power supplied to both of the HPUs was terminated at separation. The total operating time for each HPU was approximately 150 seconds.[1673]

Range Safety Subsystem

The RSS was designed as the shuttle destruct system in the event of a major malfunction or event. The RSS terminated flight by splitting the cases of the SRBs, which eliminated thrust.[1674] Dual (redundant) subsystems, A and B, were provided on each SRB, and these were "cross-strapped" to the opposite SRB through the ET. The RSS was active from T-10 seconds until approximately five seconds before ET/SRB separation.

Located in the forward skirt of each SRB, the RSS included a linear-shaped charge destruct assembly, two command receiver decoders, distributors, a directional and a hybrid coupler, two command antennas, two silver-zinc batteries, a S&A device containing two NASA Standard detonators, four confined detonating fuse assemblies, two confined detonating fuse assembly bulkhead connectors, and harness assemblies with all interconnecting cables.[1675]

The linear-shaped charge assembly, which measured approximately 80' long, was mounted along the SRB length in the systems cable tunnel. Six linear-shaped charge subassemblies were used in each SRB destruct assembly, including one forward, four intermediate, and one aft.[1676] The S&A device consisted of a longitudinal shaft with explosive transfer charges. Explosive leads at this device started the pyrotechnic reaction with the explosive transfer and ignition of the confined detonating fuses. The confined detonating fuse traveled through the forward skirt bulkhead and into the systems tunnel to the linear-shaped charge, which detonated, splitting the SRM case and terminating thrust.[1677]

Part of the RSS was the SRB Tracking System, which permitted tracking of the relative location of each SRB during shuttle ascent. It also provided interim tracking after liftoff, and served as a backup to the skin tracking radar by the Eastern Range. The SRB Tracking System data were used to determine the necessity of flight termination. Components of the tracking system, located on each SRB, included two C-band antennas, a power divider, a C-band transponder, and a C-band controller.

SRB/RSRM Process Flow

"The flow is always improving," noted Jim Carleton, USA's SRB Program Manager. After the *Challenger* accident, the flow changed considerably with a new focus on efficiency, and a

---

[1673] USA, *Booster Manual*, 56.
[1674] USA, *Booster Manual*, 141.
[1675] USA, *Booster Manual*, 141.
[1676] USA, *Familiarization Training*, RSS-27.
[1677] USA, *Familiarization Training*, RSS-23.