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.

dramatic reduction in the size of the workforce.[1678] The completion of the Solid Rocket Booster Assembly and Refurbishment Facility (SRB ARF) complex at KSC, officially dedicated on August 1, 1986, facilitated such improvements. The SRB ARF Manufacturing Building was specially designed and constructed to support the fabrication and processing of Shuttle SRB non-motor components. Some of this work had historically been completed at the VAB, Hangar AF, and other facilities.[1679] Operations began in 1987 at the SRB ARF, designed to process up to eighteen flight sets of forward skirts, aft skirts, frustums, nose caps, and various smaller components per year. In addition to the fabrication of non-motor SRB components, other activities included the replacement of thermal protection materials, installation of electronic and guidance systems, integration of SRB recovery parachutes into the forward skirt, assembly and testing of steering elements of the TVC system, installation of explosive devices (ordnance) for booster separation, and automated checkout.[1680]

From recovery of the SRBs after splashdown in the Atlantic Ocean through refurbishment, subassembly, and final preparations for the next mission, the SRB/RSRM process flow activities occurred not only at the SRB ARF, but also in multiple contractor-run facilities at KSC, as well as the Thiokol facilities in Utah. An overview of the process flow follows.

Recovery

Parachute Deployment Sequence

About five and one-half minutes after lift-off, and approximately 215 seconds after the SRBs detached from the ET, the pilot, drogue and main parachutes began the process of decelerating the boosters to water impact, about one minute later (Figure No. E-30). Working sequentially (Figure No. E-31), the parachutes slowed the fall of the SRBs from about 360 mph to 50 mph at splash down in the Atlantic Ocean (Figure No. E-32). Water impact occurred approximately 122 nautical miles down range of the launch site.

First, the nose cap separated from the frustum and the pilot parachute was extracted from the nose cap and released. Deployment occurred at an altitude of about 15,200' and a speed of 364 mph. Next, the pilot chute extracted the drogue chute, and pulled the drogue pack away from the SRB. The drogue parachute was attached to the top of the frustum. Inflation of the drogue parachute provided the initial deceleration and proper orientation for the SRB to hit the water. The drogue parachute inflated in stages; this process is known as "disreefing."[1681] Initial

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[1678] Carleton, interview.

[1679] ACI, *Survey and Evaluation of NASA-owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program, John F. Kennedy Space Center (KSC), Brevard County, Florida* (survey report, NASA KSC, October 2007), Appendix C.

[1680] The forward and aft skirts, separation motors, frustum, parachutes, and nose cap were originally manufactured by USBI in Huntsville, Alabama, with other parts made in-house at MSFS. Beginning in October 1999, the USBI functions were absorbed by USA at KSC.

[1681] During the disreefing process, each of the inflation stages was accomplished by pyrotechnically-actuated cutters deployment to 60 percent occurred at an altitude of approximately 14,500' and speed of 360 mph. The first stage reefing line cutters fired after a seven second delay from deployment and first inflation. This allowed the canopy to grow from 60 percent to 80 percent of full inflation. At this point, approximately 363 seconds after separation, the altitude was roughly 11,400' and the velocity was 320 mph. The second stage reefing line cutters fired after a twelve second delay from deployment, or five seconds after the first disreef. As a result, the canopy enlarged from 80 percent to 100 percent of full inflation.[1682] The drogue parachute opened to 100 percent at an approximate height of 9,200' and speed of 292 mph.

Roughly eleven seconds later, at a height of 5,500' and velocity of 243 mph, the drogue parachute pulled the frustum away from the SRB and deployed the three main parachutes from the frustum. Like the drogue parachute, the main parachutes went through a "disreefing" process involving their gradual opening to slow down the fall of the SRB. Approximately five seconds after deployment, the main parachutes were at 20 percent inflation. Altitude was now 4,110' and velocity was 238 mph. The first stage reefing line cutters fired after a ten second delay, allowing the canopy to grow from 20 to 40 percent at an altitude of 2,100' and velocity of 115 mph. The second stage disreefed after a seventeen second delay allowed the canopy to increase to 100 percent. At full inflation, the altitude was 1,115' and speed was 73 mph.

The SRB nozzle extension was jettisoned just before splashdown, in order to prevent damage to the TVC hardware, located inside the aft skirt, from water impact forces.[1683] This occurred about the time the canopies reached 100 percent of inflation.[1684] The dispersion bridles of the main parachutes separated from the risers via the SWAR, and the main parachutes remained attached to the booster via their 50'-long Kevlar retrieval lines. Air trapped in the motor casing of the booster allowed it to float vertically, with the forward end about 30' out of the water (Figure No. E-32).

The frustum impacted the water at 60 feet per second after being decelerated by the drogue parachute. The frustum floated apex down, with the drogue parachute attached and submerged. The frustum was self-buoyant because of its foam content. The pilot parachute remained attached to the drogue bag. The pilot parachute and drogue bag were recovered, if located. The SRB nose cap and nozzle extension typically were not recovered.

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that servered a reefing line that keeps the skirt of the parachute gathered until the line was cut.

[1682] USA, *Familiarization Training*, REC-8.

[1683] USA, *Booster Manual*, 117.

[1684] Early in the SSP, when the frustum was separated at a higher altitude, the main chutes reached full inflation before the nozzle was jettisoned (about 13 seconds prior). Later, to allow more time for the drogue to dampen SRB oscillation, the frustrum separation was set to occur at a lower altitude and the nozzle jettison occurred about the same time as the main chutes disreefed to full inflation. Jack Hengel, personal communication with James M. Ellis, MSFC, August 31, 2011.

Recovery at Sea

The expended SRBs, pilot/drogue parachutes, and main parachutes were recovered at sea after each launch by the ships *Liberty Star* and *Freedom Star.* Twenty-four hours prior to launch, the *Liberty Star* and *Freedom Star* travelled to their stations in international waters about 135 miles downrange of the launch site. Both vessels, positioned about 1 mile apart, had to be at their stations four hours prior to launch.[1685] At the time of splashdown, the ships were positioned about 8 to 10 nautical miles from the SRBs' impact area. Each ship was designed to recover one SRB, including its parachutes and frustum (Figure No. E-33).[1686]

According to Joe Chaput, Captain of the *Liberty Star* and manager of USA's Marine Operations at KSC, prior to retrieval, the dive team conducted a search and recovery (if found) of the pilot parachute and drogue bag, and an above water and below water visual/photographic damage assessment.[1687] Divers installed floats and cut the main parachute retrieval lines.[1688] The three main parachutes were wound onto three of the four reels on the ship's deck. The frustum and attached drogue chutes were reeled in next.[1689] The frustum was lifted from the water by the ship's 10-ton crane. The SRBs were recovered last. Two dive teams, of nine persons each, were deployed from two inflatable boats to recover the boosters. An Enhanced Diver-Operated Plug was launched from the ship and towed to the booster by a small boat. The first team, comprised of five divers, inserted the plug into the booster nozzle and pumped air from the ship into the booster. The second team double-checked the aft skirt and plug installation to ensure there were no problems. After inspection, the dewatering process began. This operation, which took approximately twenty minutes, forced out all the water, causing the booster to shift position from vertical (spar mode) to horizontal (log mode). During the final step, a tow line from each ship was connected to a booster, and each booster was towed about 1,800' behind the respective ship. At Port Canaveral, each booster was brought from the stern tow position to the hip tow position alongside the ship for the remainder of the trip to the dock near Hangar AF at Cape Canaveral (Figure No. E-34). The tow was shortened before entering Port Canaveral. The return to Hangar AF typically took twenty-six hours.

Disassembly

At the Hangar AF SRB recovery slip, an approximate twenty-two-day disassembly workflow began with the lifting of the left-hand and right-hand SRBs out of the water by a 200-ton straddle lift crane (Figure No. E-35). After the saltwater was washed off, the SRBs were placed onto

[1685] Joseph Chaput, interview by Joan Deming and Patricia Slovinac, KSC, June 29, 2010.
[1686] Typically, *Liberty Star* retrieved the right-hand booster and *Freedom Star* the left-hand booster (USA, *Booster Manual*, 119). Features on the exterior of the SRB, such as the ET attach struts, required that the right-hand SRB be hipped on the starboard side of the towing ship, and the left-hand SRB on the port side.
[1687] Chaput, interview.
[1688] USA, *Booster Manual*, 33.
[1689] The pilot/drogue chute deployment bag assemblies were not always recovered. Replacements were fabricated at KSC's Parachute Refurbishment Facility. ACI, *Kennedy Space Center*, Appendix C.

parallel rail dolly trains. The frustum and parachutes were off-loaded from the ship deck (Figure No. E-36). A two-week open assessment period preceded the start of disassembly operations. During assessment, the SRBs were thoroughly inspected and checked to see if large pieces of TPS or other materials had come off that might have damaged the orbiter. The main parachutes were moved and transported to the Parachute Refurbishment Facility (PRF) at KSC for cleaning and refurbishment.

The frustum was moved into the Hangar AF high bay for assessment and disassembly. It was rinsed with water, and the drogue and pilot parachutes removed and kept wet prior to their transfer to the PRF. The BSMs were inspected for residual propellant and then removed for further disassembly and inspection. The frustums were verified as “safe” by inspecting and removing the confined detonating fuses. All remaining frustum components were removed and staged for refurbishment, reuse, or scrap.

The forward skirt was initially safed, and the data acquisition system, solid state video recorders, S&A device, related ordnance, and batteries, as well as the operational pressure transducer, and ET ball fitting from inside the forward skirts, were removed and cleaned (Figure No. E-37). The TPS materials were removed by hydrolasing.[1690] The TVC system was depressurized, and the IEAs were flushed, washed, and rinsed. The TVC components were removed and refurbished at several places, including the suppliers Hamilton Sundstrand (APUs), Moog (actuators), and Parker Abex (hydraulic pumps).[1691]Also removed were the blast container, struts, nozzle exit cones, ground electrical and instrumentation cables, and linear-shaped charge. The RSS command receivers/decoders were returned to the manufacturer (L3 Cincinnati Electronic, Ohio) for testing and analysis before reuse.

During the second week of operations, the aft skirt and ET attach/stiffener ring were removed; the forward skirt was demated; and the nozzle and igniter were removed, inspected, and prepared for shipment to Thiokol. The demated forward skirts were prepared for further disassembly, inspection, and refurbishment.

Typically during the second and third weeks of processing at the Hangar AF complex, the four RSRM case segments of each booster were separated, inspected, assessed, and cleaned. Joints were assessed, washed, and cleaned, and live propellant was removed. The nozzle-to-case joint was examined for overall erosion and the condition of the joint insulation. The internal insulation was checked for overall performance, remaining liner patterns, debris hits during splashdown (which may have punctured the insulation and led to case hardware corrosion), and unburned propellant in the center forward segment. The joints were preserved immediately after inspection. All corrosion was addressed immediately. Each segment was cleaned out and washed to remove debris, propellant by-product, and nozzle phenolics. The insulation was pressure

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[1690] Hydrolasing is a pressure cleaning process, which uses water, sprayed at 17,000 pounds per square inch, to strip off insulation and other materials.
[1691] Carleton, interview.

washed 6' back from both ends to prevent joint corrosion during shipment to Thiokol. Handling rings were installed to prepare the segments for transport to Utah. The segments were then moved from the rail dollies to trailers, and subsequently moved by trailer to the railhead where they were loaded onto special rail cars, covered, and prepared for overland travel back to Utah (Figure No. E-38).[1692]

In the High Pressure Wash Facility at the Hangar AF complex, high pressure cleaning (hydrolasing) of the frustums, forward skirt and aft skirt was performed by a robot to strip off the TPS. The nose cap, almost always lost, was not part of the process. Next, the non-motor components were moved to the explosion-proof Multi-Media Blast Facility where high-pressure impact with glass beads removed paint coatings, primer and sealants, stripping them down to bare metal. After a water-break test and the application of alodine, the components were taken to Hangar N, also in the Industrial Area of CCAFS, for inspection and non-destructive evaluation, including the inspection of welds. The parts were returned to the Hangar AF complex where protective finishes were applied in the SRB Paint Building. Frustum processing was completed with periodic phenolic island replacement and the installation of baro-tube and drain tubes.[1693] In the words of Jim Carleton, at the completion of processing at the Hangar AF complex, the frustums, forward skirts and aft skirts looked "like a new car."[1694]

Refurbishment and Subassembly

Following completion of disassembly and initial cleaning at the Hangar AF complex, during separate but parallel processes, the RSRM segments were returned to Thiokol's refurbishment facility in Clearfield, Utah, for processing, the parachutes were moved to the KSC PRF for cleaning and refurbishment, and the inert or non-propellant SRB elements, including the forward and aft skirts and frustums, were moved to the SRB ARF for refurbishment and subassembly by USA. During the refurbishment process, any outstanding modifications and structure repairs were made. Refurbishment operations at Hangar AF for each flight set of hardware typically required forty-five days for disassembly; 120 days for aft skirt processing; sixty days for the ET attach rings; fifty-five days for the frustums; sixty-five days for the forward skirts; and 300 days for component small parts.[1695]

RSRM Segments

The four motor case segments, igniter components, and nozzle were returned from KSC on railcars and trucks to the Thiokol facilities in Clearfield and Promontory, Utah, for cleaning, inspection, refurbishment and reloading with solid propellant. The components shipped by truck

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[1692] USA, *Familiarization Training*, DRO-19 through -24.
[1693] USA, *Familiarization Training*, DRO-28.
[1694] Carleton, interview.
[1695] USA, "STS Recordation, Phase I SRB Hardware Process Flow," (presentation to Joan Deming and Patricia Slovinac of ACI, KSC, June 2010), SRB-6.

were received at the Clearfield facility. Following inspection, further disassembly, and processing, they were shipped by truck to Thiokol's main plant in Promontory. The metal parts were surface cleaned and prepared for coating and bonding. Nozzle refurbishment included phenolic tape wrap and machining. Following reloading with propellant, final assembly operations were performed. This entailed installation of the nozzle and igniter, the aft exit cone linear-shaped charge, S&A processing, systems tunnel bonding, and installation of flight and shipping instrumentation.[1696]

The propellant-loaded RSRM segments were returned to KSC via special 200-ton fiberglass-covered railcars (Figure Nos. E-39, E-40). During overland travel, environmental data recorders monitored shock and vibration, as well as the temperature, of the RSRM exit cones and segments. The nozzle components, igniters, stiffener rings and other smaller components were shipped by truck. The joint pins remained at KSC and were refurbished by Thiokol personnel.

At KSC, the reloaded RSRM segments arrived at the Rotation Processing and Surge Facility (RPSF) where they were inspected and rotated (Figure No. E-41).[1697] Processing at this facility included the installation and/or close-out of the stiffener rings, tunnel cables, tunnel covers, thermal curtains, rain curtains, and aft exit cone. In addition, foam was applied to the stiffener, aft skirt and internal rings, and the field joints were closed out. Completed aft skirt assemblies from the SRB ARF were mated to the aft RSRM segment. Left and right aft booster assembly operations in the RPSF required approximately forty-five work days.[1698] Once this work was completed, the booster segments were placed on transporters, and moved to one of the ancillary surge buildings for storage. Sometime thereafter, they were moved to the VAB for integration with the other flight-ready booster components.

Parachutes

The deployed pilot, drogue and main parachutes recovered from the Atlantic Ocean arrived at the PRF from the Hangar AF complex on eight reels. The parachutes were kept wet to prevent ocean salt from crystallizing on the fabric. They were unrolled and untangled in the "defouling" area (Figure No. E-42), then hung on an overhead monorail system and conveyed to the 30,000-gallon capacity washer, where a water wash removed the salt (Figure No. E-43). Each parachute was backed out of the washer and moved into the dryer, where 140-degree F hot air dried it over an average period of five to seven hours. Next, the cleaned and dried parachute was moved to the refurbishment area inside the PRF (Figure No. E-44). Here, all parachutes were hand-inspected, and red flags were placed on damaged areas. An inspector decided whether to make the repair, or to use as is. Typically, each main parachute required hundreds of repairs. The smaller parachutes and deployment bags also were repaired. Following repairs, inspection, and acceptance, all

[1696] ATK, "RSRM Overview," 13-17.
[1697] Rotation of the RSRM segments, a critical component to the preparation of the space shuttle vehicle for launch, originally was performed in High Bays 2 and 4 of the VAB. ACI, *Kennedy Space Center*, Appendix C.
[1698] USA, "STS Recordation, Phase I SRB Hardware Process Flow," SRB-5.

performed at the PRF, the parachutes were folded and placed in canisters. The packing process began with a deployment bag, which was placed into a wood or metal container. The parachute was folded into this bag, and compacted with a hydraulic press. The suspension system was placed on the bottom and the parachute went on top. On average, it took four people five days to pack a main parachute (Figure No. E-45). The three main parachutes were placed into a single parachute support structure.[1699] Overall, parachute refurbishment operations at the facility typically required sixty workdays.[1700]

The processed main parachutes were transported to the SRB ARF via flatbed truck; the drogue and pilot parachutes were moved to this facility separately. Replacement pilot parachutes and pilot/drogue chute deployment bag assemblies, or replacements for non-recoverable items, were made at the PRF. Typically, there was about a 50 percent loss of pilot parachutes in use. They were then delivered to the SRB ARF for further processing and integration. Each flight set was typically stored for six months to one year before its next use. Nine parachute flight sets were maintained in the PRF.[1701]

SRB Non-motor Segments

Refurbishment operations for the non-motor segments were performed in the SRB ARF (Figure No. E-46). These included the application of thermal protection; painting; installation of electronic and guidance systems; integrated assembly of the refurbished parachutes; rebuilding of the TVC system; and the installation of explosive devices (ordnance) for booster separation.[1702] Following processing, the SRB components underwent final automated checkout before they were moved to the VAB for integration. The amount of time required for assembly and check out operations performed in the SRB ARF varied by component. Typically, the left and right aft skirts required 190 workdays; the forward skirts/forward assemblies, 160 days; the frustum, ninety-eight days; the ET attach rings, thirty-four days; and the struts, twenty-two days.[1703]

At the SRB ARF, the initial step was to test the critical dimension of the aft skirt before processing started. Next, the TPS, MCC was applied to the aft skirt.[1704] This mixture of small glass spheres, cork, and epoxy was mixed right in the gun at the time of application. Curing of the TPS took twenty-four to forty-eight hours. After the TPS was cured, a coat of exterior paint was put on the TPS to seal the aft skirt and keep moisture out of the cork. Thus, the aft skirt was

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[1699] ACI, *Kennedy Space Center*, Appendix C.
[1700] USA, "STS Recordation, Phase I SRB Hardware Process Flow," SRB-5.
[1701] NASA KSC, *Parachute Refurbishment Facility*, NASA Facts, (Florida: Kennedy Space Center, no date), http://www-pao.ksc.nasa.gov/kscpao/nasafact/pdf/PRF.pdf.
[1702] "Inside SRB Refurbishment," *Spaceport News*, July 20, 2001, 4-5.
[1703] USA, "STS Recordation, Phase I SRB Hardware Process Flow," SRB-5.
[1704] Following a trend towards the use of more environmentally friendly materials, three different types of TPS have been used over time, originating with Marshall Sprayable Ablative (MSA) and followed by MSA-1. MCC was first used ca. 1988-1990. The most recent solvents were all water-based. Carleton, interview.

painted twice: once on the bare metal and once on the TPS.[1705] After painting, the aft skirt went to the high bay for subassembly installation, including the TVC system. Following aft skirt build up, it was hot-fire tested at the SRB ARF.

Build-up and testing of the forward assembly, including the forward skirt, frustum, and nose cap, plus attachments, followed a TPS application and painting process similar to the aft skirt and aft assembly. In addition, parachutes brought over from the PRF were installed in the frustum. Prior to installation, the main parachute support structure also underwent hydrolasing to remove sealant, and media blasting to remove the protective finish. Mechanical operations included shim fabrication and fairing assembly installation, nut plate replacement, and helicoil installation. The process was completed with a finishing touch-up, sealant application, and part marking.[1706]

SRB Integration

The four RSRM segments were joined with the SRB forward and aft assemblies to form the flight configuration boosters. This integration process was conducted in three phases. The first phase of the "buildup process" began in the RPSF with the aft and forward segments. Each SRB aft booster assembly consisted of one SRB aft skirt, one RSRM aft motor segment, three RSRM stiffener rings, one RSRM aft exit cone, one ET attach ring, several aft skirt electrical cables, aft system tunnel covers (including covers commonly known as a "rooster tail"), ancillary attach hardware, and several different thermal protection systems. The aft skirt clevis was mated to the aft motor segment tang. The joint was held together using 177 stainless steel pins. After pin insertion, the steel pin retainer band was installed and covered with cork and TPS materials, and the valley of the aft skirt kick ring was filled with RT-455.[1707] Next, the transition floor plate assembly was installed between the aft motor segment floor plates and the rooster tail.[1708] This buildup process took approximately four to six weeks.[1709] The assembled aft boosters were stored in the surge buildings at the RPSF until their transport to the VAB High Bay 1 or 3 integration cell. All segments remained vertical on their pallets until they were transferred to the VAB for stacking (Figure No. E-47).

The second phase of integration entailed SRB stacking operations and Space Shuttle buildup in the VAB. The aft booster assemblies, transported from the RPSF, were mated to the MLP hold-down posts and bolted down (Figure No. E-48).[1710] After installation of hold-down post hardware, the aft center, forward center, and forward motor segments, followed by the forward

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[1705] Carleton, interview.
[1706] USA, *Familiarization Training*, DRO-33.
[1707] RT455 is a trowelable thermal ablative compound.
http://rtreport.ksc.nasa.gov/techreports/2002report/700%20Process%20Human%20Fac/701.html.
[1708] USA, *Familiarization Training*, INT-3, INT-4.
[1709] Until 2004, this process was done in the VAB High Bay 4. Bartolone, interview.
[1710] Since 1984, following transport from Utah, the fueled SRB segments have been received at the Rotation, Processing, and Surge Facility. Here, they are rotated to vertical, inspected, processed, and stored until their turn in the Space Shuttle stacking process. ACI, *Kennedy Space Center*, Appendix C.

assembly, were brought in to build up the SRB from bottom to top (Figure Nos. E-49, E-50). The stacking process typically alternated left- and right-hand boosters, rather than completing the buildup of one SRB before beginning the other. The forward assembly was connected to the forward motor segment with 195 stainless steel pins. The last step was the installation of the forward skirt access kit, a "pie-shaped flooring to prevent damage to the RSRM igniter and associated cables."[1711] The S&A device was installed after the forward skirt was installed.

During shuttle vehicle mating, the ET was attached to each SRB aft frame by two lateral sway braces and a diagonal attachment. The forward end of the ET was attached to each SRB forward skirt.[1712]

Operations in the VAB typically required about forty-four workdays. This period included nineteen work days for stacking of the left and right boosters, eighteen days for mating with the ET and integrated close outs, and seven days for mating to the orbiter, followed by systems tests.[1713]

Launch

The launch countdown for the SRB/RSRM began about three days prior to launch. RSRM systems became operational approximately eighteen hours prior to launch with activation of the igniter heater. The operational pressure transducers and the joint heaters were powered up at nine hours and eight hours before launch, respectively; the transducers were checked out at T-90 minutes. At T-5 minutes before launch, the igniter heater was deactivated and the S&A device was armed. The SRBs came to life when the TVC system was activated at T-28 seconds before launch.

At T-0, or liftoff, the SRBs were ignited by an electrical spark that sent flames from the igniter down the center of the propellant. The boosters went to full power in two-tenths of a second. At the same time, the frangible nuts on each of the four hold-down bolts were exploded, freeing the Shuttle for lift-off. Operating in tandem with the SSMEs for the first two minutes of flight, the SRBs provided about 80 percent of the thrust to escape the Earth's gravitational pull. Propellant in the forward segment of the RSRM, designed to provide fast acceleration, burned out fifty seconds after launch. The remaining propellant, shaped to burn at a slower rate, was all consumed after about two minutes. Exhausted of their fuel, the boosters burned out and separated from the orbiter and ET. Momentum continued to carry the SRBs upward for another 70 seconds to an altitude of about 43 miles (apogee) before they began their controlled descent back to Earth and splashdown into the Atlantic Ocean. At an approximately 1,100' altitude, firing of a pyrotechnic initiator card activated a linear-shaped charge on the RSRM nozzle to jettison the nozzle extension. This prevented water impact damage to the TVC hardware located inside the

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[1711] USA, *Familiarization Training*, INT-15.
[1712] NASA, "SRB Overview," 2002, http://spaceflight.nasa.gov/shuttle/reference/ shutref/srb/srb.html.
[1713] USA, "STS Recordation, Phase I SRB Hardware Process Flow," SRB-5.

aft skirt. The timing of the nozzle extension jettison served several purposes. It prevented detonation of the thrust vector control system hydrazine fuel during reentry. Also, it minimized heat and flame damage to the aft skirt heat shield curtain (caused by booster exhaust gas), and prevented contact between the SRB and the severed nozzle extension at water impact.[1714]

[1714] USA, *Familiarization Training*, REC-12.