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SOLID ROCKET BOOSTER RETRIEVAL OPERATIONS

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ABSTRACT

The Solid Rocket Booster Retrieval Program operates with one primary objective, the recovery of expended boosters and associated hardware without damage attributable to retrieval procedures. This is accomplished by a retrieval force consisting of ship's personnel and retrieval team members, each of whom has been trained and is highly skilled in multi-faceted operations. The retrieval force is equipped with two specially-built, highly maneuverable ships outfitted with parachute reels, retrieval cranes, towing winches, large volume-low pressure air compressors, SCUBA diving gear, inflatable boats with outboard motors and diver-operated SRB dewatering devices.

The two ships are deployed in sufficient time to conduct an electronic and visual search of the impact area prior to launch.

Upon search completion, each ship takes station a safe distance from the predetermined impact point initiating both visual and electronic search in the direction of flight path, ensuring SRB acquisition at splashdown. When safe, the ships enter the impact area and commence recovery of all floating flight hardware which is subsequently returned to the Disassembly Facility for refurbishment and reuse.

INTRODUCTION

NASA's commitment to Retrieval Operations began with and paralleled Shuttle development. Several feasibility studies were conducted after which contracts were initiated for Solid Rocket Booster Retrieval System final design concept. The following extracts, NUC TN 1822, describe the final design concept.

"The Naval Undersea Center, San Diego, and the U.S. Navy Supervisor of Salvage formulated and developed the final design concept.

For each flight mission there will be a total of fourteen elements subject to retrieval consisting of: two SRB casings, six main parachutes, two frustums, two drogues and two pilot parachutes. Each of these elements is equipped with location aids such as flashing lights, acoustic pingers and radio-frequency beacons, or are attached to elements equipped with these devices. All of the elements impact in a tear-shaped footprint 62 nautical miles long by 16 nautical miles wide.

Retrieval vessels will be stationed outside the impact area until splashdown. Following splashdown two fully-equipped vessels will deploy and transit to the impact area. These vessels will be oilfield tug/supply vessels with all retrieval equipment installed. The vessels will be at least 170 feet long with a beam of not less than 30 feet and engines that will develop at least 3500 h.p., twin screws and a bow thruster for station-keeping.

The first items to be retrieved will be the main parachutes. The retrieval vessel will capture the satellite float and apex float of the parachute. A line will then be attached to the apex of the parachute and the parachute will be reeled aboard the retrieval vessel by a hydraulically operated power block with a power grip. The power block and grip will be suspended outboard of the retrieval vessel from the boom of a deck-mounted crane. The parachutes will then be reeled onto stowage reels, one main parachute per reel. The stowage reels will be covered to protect the parachutes from sunlight.

The drogue and frustum will be retrieved next. The retrieval vessel will snare the pilot parachute and attach a line to the apex of the drogue. The drogue will be brought onboard the retrieval vessel using the power block and grip and stowed on the remaining parachute stowage reel. The frustum will be lifted from the water by the drogue suspension lines; the crane boom will then be swung to position the frustum over dunnage on the deck of the retrieval vessel. The frustum will be lowered onto the dunnage and secured to cleats on the deck.

The last items to be retrieved are the SRBs.

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A Nozzle Plug (NP) is used to dewater the SRB casing so that the casing will float in a log mode, after which it can be towed to port by the retrieval vessel. The NP is an unmanned, umbilical-cable-controlled submersible vehicle and is controlled from a console located aboard the retrieval vessel. The NP is launched by the deck-mounted crane.

The NP docks with the SRB and is locked into place by three locking arms. Dewatering of the SRB is accomplished when air from the retrieval vessel is forced through the pneumatic hose of the umbilical into the SRB. The air pressure forces the water out through the SRB nozzle (past the NP). When sufficient water has been removed from the SRB, the booster will become unstable and float in a log mode.

An inflatable bag on the NP will be inflated, once the SRB assumes a horizontal mode and a dewatering hose will be deployed. Additional air is then forced into the SRB to achieve a pressure differential which will force the remaining water out of the SRB through the dewatering hose. The umbilical is then detached prior to towing operations. A towline is attached to a towing pendant on the nose of the SRB and transit to the refurbishment site is begun."

STS-1 flight delay allowed delivery of specially built retrieval vessels and provided time to fully evaluate final design concepts. Extensive training resulted in a cohesive retrieval organization which immediately demonstrated Shuttle cost effectiveness.

It must be noted that the first retrieval mission paid for the Parachute Development Program, SRB Water Impact Testing and cost of two retrieval vessels. Replacement value of hardware retrieved from STS-1 thru STS-5 would exceed $216,000,000.00. (Table 1)

RETRIEVAL SHIP OPERATIONS

Effective ship operations require proper interfacing of ship, ship's crew, retrieval team members and procedures bonded through extensive training and observance of safety procedures.

The dedicated retrieval vessels with controllable pitch propellers, transverse bow and trainable stern thrusters afford unmatched maneuverability and station-keeping accuracy. The vessels were constructed and documented in accordance with strict U.S. Coast Guard, American Bureau of Shipping and Federal Communications Commission regulations. The vessel crews are dictated by the U.S. Coast Guard and must possess appropriate licenses demonstrating proper experience and education levels. Basic ship handling techniques require fine honing to provide station keeping and close in maneuvering expertise essential for safe, efficient retrieval activities.

The camaraderie between ship's crew and retrieval team members, created by individual respect and personnel cross-utilization, has instilled a 'team' spirit. This 'team' spirit has provided a broad information exchange system providing coordinated operational inputs. The retrieval force operational capabilities are clearly illustrated by success rates under diversified conditions.

RETRIEVAL EQUIPMENT IMPROVEMENTS

Retrieval Operations have undergone rapid change. The major changes have occurred in the area of equipment improvements and as a result, technical developments have enhanced overall mission effectiveness.

Prior to STS-1

Prior to STS-1, the final design concepts were thoroughly tested during at-sea training using a full scale Ocean Test Fixture simulating the SRB, a full scale model frustum, and full sized parachutes. During these at-sea training missions, procedures were developed to retract the frustum location aid antenna, thereby eliminating the large wooden beams (79K12931 - KSC DWG) which were provided to eliminate antenna damage. Plywood was substituted as a base in frustum landing area which substantially eliminated potential frustum damage. The parachute retrieval concept required use of two heavy idler rollers (79K12922 - KSC DWG). Parachute retrieval operations demonstrated that a parachute slide (nylon) on the deck could be utilized effectively, thereby eliminating personnel handling hazards. The Ballast Aerating Retrieval Boom (BARB) (79K20974 - KSC DWG) was developed for use if SRB nozzle damage prevented use of the NP and associated telescopic harpoon. Additionally, the BARB could be utilized in a dual role for open nozzle towing. The BARB is a simple, efficient device constructed from aluminum pipe and tubing. The main member is 20 feet long and 1 1/4 inches in diameter. The upper end is fitted with an aluminum cap and "O" ring seal. The lower end is threaded to accept a 2 inch ball valve and 1 1/2 inch quick-disconnect fitting. The cross member is 10 feet long, 2 inches in diameter with welded ends. The units are attached with a swivel fitting, approximately 5 feet from the main member upper end. Bungee cord is secured around the swivel fitting placing the unit under tension when the cross member is parallel to the main member. A cable lanyard attached to the main member cap and cross member retains the device in a cocked position.

Air applied through the ball valve deploys the main frame cap allowing the tensioned cross member to re-position perpendicular to the main member, effectively retaining the unit in the SRB nozzle.

Prior to STS-2

The nozzle plug (79K15557 - KSC DWG) failed to operate satisfactorily during STS-1 operations. From a conceptual viewpoint, the remote-control plugs designed and constructed for NASA fulfilled the requirements for a positive and hazard free retrieval of SRBs from the ocean. In actual use the plugs proved to be maintenance intensive, hazardous to launch, and unreliable in performance. Close tolerance, interlocking segments and general 'layer cake' design prevented minor maintenance unless the total system was desegregated. The basic design would not lend itself to adjustment or modification that would allow for tracking the learning curve; therefore, the nozzle plugs remained inflexible from intended design use and application. Based upon this conclusion, the Ballast Aerating Retrieval Boom and divers were baselined for SRB dewatering. Additionally, an in-port Diver Operated Plug was developed and brought into service to provide final SRB dewatering at Port Canaveral, thereby facilitating transit through the Banana River to the refurbishment facilities. The frustum landing area was modified and standard dunnage (double thickness 2 x 12 planks) installed.

Prior to STS-3

Considerable problems had been encountered with the final concept design weak link (79K19967 - KSC DWG), which was placed in series between the SRB and towing vessel alleviating damage to the forward skirt. NASA analyzed the problem area and designed a weak link that would fail in tension and bending modes while providing higher breaking strength, ease in handling, and low maintenance.

Prior to STS-4

Evaluation of parachute retrieval operations clearly illustrated that the existing parachute deck edge roller (79K12922 - KSC DWG) caused additional and unnecessary damage to the parachutes. At this time, the deck edge roller was replaced with a permanent deck edge guide consisting of a 3/4 round stainless steel pipe with vertical guides. This resulted in a drastic reduction in damage and provided for an overall smoother, safer parachute recovery. Decelerator sub-system problems required parachute flotation removal; therefore, procedures were developed for detaching main parachutes from the SRBs at the 40 foot release links. To aid divers with detaching, two Avons, rigid hull inflatable boats and five diver propulsion vehicles were added to the retrieval equipment inventory. SRB and frustum location aids had proved to be marginally effective or had intentionally been deactivated; therefore, 12 commercial emergency radio indicator beacons with lights were purchased for severe weather and night station-keeping operations. The accelerated use of divers required by BARB and parachute operations mandated additional safety equipment. A recompression chamber was obtained from the Navy and installed on-board one retrieval vessel for use in the event of diving accidents. At-sea operations in various weather conditions had demonstrated the concept design hawser was of insufficient length creating situations that could potentially impart snap loads upon the SRB forward skirt. After careful evaluation, the nylon tow hawsers were replaced with 2000 foot plastic covered tow wire. These provided a longer life use cycle, catenary in the tow line to eliminate snap loads and additional safety to deck personnel.

Prior to STS-5

Projected SRB modifications and future filament wound casing information indicated the center of gravity would shift aft on the casing necessitating at-sea dewatering capabilities. Response to future requirements resulted in design and construction of an at-sea prototype Diver Operated Plug. The prototype utilized a smaller, less expensive bag seal, check valves in the mandrel and was streamlined to facilitate diver handling. In-water testing verified bag seal design and provided sufficient information to verify check valve utilization.

RETRIEVAL TECHNIQUE DEVELOPMENT

Retrieval techniques have evolved in parallel with equipment and flight hardware configuration changes. Additional changes have been initiated to improve personnel safety.

Prior to STS-1

Prior to STS-1, extreme emphasis was placed upon crane operations training. This was mandated by the requirement to develop safe procedures for deploying the nozzle plug and to develop operator techniques which would preclude damage to the frustum during retrieval operations.

At this time, it became evident that a diving contigency would be desirable. To this end, a basic five-man dive team was formed, trained and with the advent of the BARB, developed preliminary insertion techniques.

Prior to STS-2

NASA's decision to suspend NP operations on STS-2 placed heavy emphasis on additional diver training and BARB techniques had to be fully operational. STS-1 operations demonstrated that the SRB would return to the spar mode in various sea states. To eliminate this potential hazard in shallow waters, an astern air supply technique was developed and utilized. Upon initial rotation to the semi-log mode, the SRB air hose was disconnected and capped 200 feet aft of the BARB. Additionally, a 100 foot positively buoyant polypropylene line was attached to the free end. This allowed a retrieval vessel to work astern of the distressed SRB, retrieve the airline and resupply air without interrupting the tow of either vessel.

Prior to STS-3

Towing procedures had proven to be a continuous problem. Elimination of these problems was analyzed with subsequent equipment change. The final design concept H-Bitt and capstan towing equipment was removed allowing the towline to be deployed directly from the towing winch. This change required two seamen versus five for handling the towline and eliminated towline chafing problems. It also allowed for easy variance in towline lengths as dictated by changing sea states.

Prior to STS-4

Decelerator subsystem problems necessitated removal of the parachute flotation which, in turn, mandated that parachutes remain attached to the SRB. Various parachute removal techniques were investigated and detachment at the 40 foot release links was elected as the preferred mode.

Parachute removal utilizing this mode requires the attachment of two 180 pound positive floats to each leg of the parachute. This is accomplished by divers passing a nylon line through the center of four dispersion bridles above the 40 foot release links. The line is attached to the floats effectively transferring the parachute weight from the SRB to the floats allowing the divers to disassemble the release links. Once released the parachute floats free and vessel retrieval can commence.

When parachutes are detached in this mode, the apex is approximately 200 feet beneath the ocean surface. Parachutes can be retrieved in three basic modes, i.e., apex first, one leg or two leg. Retrieval and refurbishment operations prefer the apex first recovery, sea conditions permitting. This is accomplished by towing the parachute, with one leg, into the current until the apex is floating 15 to 25 feet below the surface. Divers from a following boat enter the water and attach a nylon messenger line through the apex suspension lines. This messenger is passed to the retrieval vessel and the parachute is reeled onboard.

Prior to STS-5

Extensive testing of the prototype At-Sea Plug was conducted in a water environment. Divers established handling and docking techniques which impacted design criteria.

PLANNED FUTURE DEVELOPMENTS

At-Sea DOP development has continued on schedule with the first devices to be operational for STS-7. The device will be inserted manually at depth, permit SRB dewatering to the full log mode, thereby improving towing characteristics and subsequently reducing corrosive in-water time.

The DOP's primary structure element is constructed from 12' of 10" diameter aluminum pipe. It contains a one-way valve and has an "O"-ring seal and end cap at each end. The forward half of the pipe houses an 8" diameter dewatering hose. A sliding collar is fitted outside the forward end of the pipe which moves three folding arms into open or closed positions. A 1/2" ball valve penetrates this pipe forward of the one-way valve and is used to add ballast water on the surface, and equalize the pipe after the DOP is locked into place at depth allowing the two end caps to fall free.

A 52" diameter mandrel is flanged around this pipe with an inflatable neoprime bag seal bolted around the rim. Three hinge points are welded to the top outer edges of the mandrel as supports for the three folding arms. The bag air supply and valve are attached to the lowerside of the mandrel. Three attachment points are welded to the bottom of the mandrel supporting three rigid legs that are welded to the after 10" pipe section.

The DOP utilizes a chain and cable system for opening and restraining the locking arms during insertion. A rod, chain and ratchet system closes and locks the arms after docking.

A 1 1/2" pipe with a quick-disconnect and check valve passes through the mandrel and is attached to each end of the 10" pipe providing a means for pressurizing the SRB.

Plans are currently being formulated to establish procedures, equipment and time lines required to support retrieval operations in the Pacific area.

This author believes labor intensified diving requirements and increased launch rates will require a review of the original baselines; i.e., remote-controlled dewatering devices and detached parachute with subsequent reduction of diver requirements.

TABLE I.- RETRIEVED FLIGHT HARDWARE - REPLACEMENT COSTS*

MISSION STS	SRB		MAIN PARACHUTES								FRUSTUM		
	RIGHT	LEFT	1	2	3	4	5	6	RIGHT	LEFT	RIGHT	LEFT	
1	25M	25M	65K	65K	65K	65K	—	—	50K	50K	1.5M	1.5M	53.36M
2	25M	25M	65K	65K	65K	65K	65K	—	50K	50K	1.5M	1.5M	53.425M
3	25M	25M	65K	65K	65K	65K	65K	—	50K	50K	1.5M	1.5M	53.425M
4	—	—	—	—	—	—	—	—	50K	50K	1.5M	1.5M	3.1M
5	25M	25M	65K	65K	65K	65K	65K	65K	50K	50K	1.5M	1.5M	53.49M
TOTALS	100M	100M	260K	260K	260K	260K	195K	65K	250K	250K	7.5M	7.5M	216.8M

* COST DATA PROVIDED BY MSFC, APRIL 1983

REFERENCE MATERIAL

Technical Report - Naval Undersea Center, San Diego, California: Solid Rocket Booster Retrieval System Final Design Concept. NUC TN 1822, 1977.