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Space Shuttle Solid Rocket Booster Dewatering System

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After the launch of the Space Shuttle, the two solid rocket boosters (SRB's) are jettisoned into the ocean where they float in a spar (vertical) mode. It is cost effective to recover the SRB's. A remote controlled submersible vehicle has been developed to aid in their recovery. The vehicle is launched from a support ship, maneuvered to the SRB, then taken to depth and guided into the rocket nozzle. It then dewaters the SRB, using compressed air from the ship, and seals the nozzle. When dewatered, the SRB floats in a log (horizontal) mode and can be towed to port for reuse. The design of the remote controlled vehicle and its propulsion system is presented.

Introduction

THE National Aeronautics and Space Administration (NASA) has provided the first reusable space hardware for the Space Shuttle program. The Space Shuttle concept features a flyback orbiter and two recoverable solid rocket boosters (SRB's). This paper describes the system for the recovery of the SRB's and their return to the refurbishment facility.

The SRB's are used to augment the liftoff for the Space Shuttle orbiter, then they are separated from the orbiter and parachuted to the ocean surface. The SRB's and the SRB frustums and parachutes are then recovered and transported to the refurbishment facility for processing and reuse in the Space Shuttle program.

Figure 1 depicts the launch, booster separation, and frustum and parachute deployment to water impact. For recovery of this equipment, two offshore supply vessels are outfitted to retrieve the hardware and to transport it to the refurbishment facility. The impact area projected in the recovery plan has an elliptical footprint of 6×9 miles. Each vessel has the capability to retrieve one SRB and its associated equipment.

The launch schedule for the Shuttle is anticipated to build to a maximum of 40 launches per year. The retrieval equipment must be sufficient to maintain recovery at these rates. It is anticipated that an SRB can be reused on 20 launches, effecting a considerable cost savings over the life span of the program.

Solid Rocket Booster Separation

Each SRB is approximately 149 ft long and 12 ft in diameter. Upon separation from the orbiter, the nose cone separates from the frustum, is jettisoned and not recovered. The frustum, a truncated cone approximately 10 ft in height, is also separated and is parachuted to the sea. The frustum, upon separation from the main body of the SRB, releases the three main parachutes for the SRB. The recoverable SRB casing is approximately 127 ft long.

Upon water impact, the three parachutes separate from the SRB. The SRB lies on its side (log mode) at first, but ingests water through the nozzle opening until it assumes a vertical attitude (spar mode). It floats in this attitude with the nozzle down. All parachutes are equipped with a radio-frequency beacon to aid in their location for recovery.

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Retrieval Baselines

Under the assumption of normal splashdown of the SRB's and associated equipment, the following baseline has been established for retrieval: 1) Ocean retrieval is accomplished through sea-state 4 (4-8-ft waves). 2) The tracking/locating functions are capable of all-weather, around-the-clock operations. 3) Retrieval is accomplished as soon as possible after impact.

Retrieval

The retrieval vessel is maneuvered close to the floating hardware. A power block (a deep V power-driven sheave often used for retrieving large fishing nets) is used to feed the shroud lines of the parachutes to stowage reels. The frustum is then brought on deck to its storage pallet. The parachutes are washed down with fresh water and stowed on reels with removable spools for further processing at the refurbishment facility.

The SRB casing at float in the spar mode must be dewatered and reoriented to the log mode for the tow back to port. The dewatering system consists of seven subsystems: auxiliary support element, power distribution element, control console, remote control unit, nozzle plug, umbilical cable, and handling element.

The nozzle plug (NP) is launched over the side of the retrieval vessel, maneuvered into the nozzle, and locking arms are deployed. The NP is now docked in its dewatering position in the SRB nozzle.

Compressed air from the retrieval vessel is forced through the umbilical hose into the SRB, forcing water out past the NP until the SRB becomes unstable and pitches over, assuming a horizontal or log mode. At this time, a bag-like seal on the NP is inflated, sealing the SRB nozzle. Final dewatering is accomplished by deploying a weighted hose from the top of the

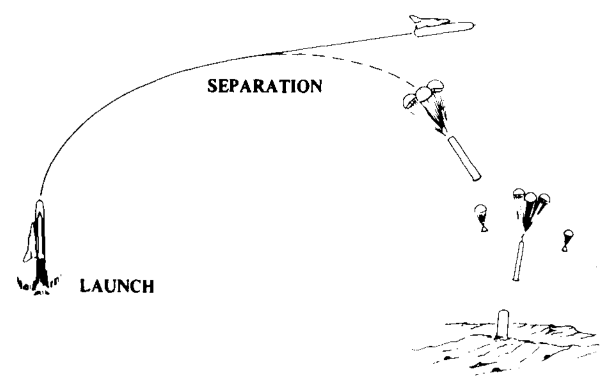

Fig. 1 Launch sequence.

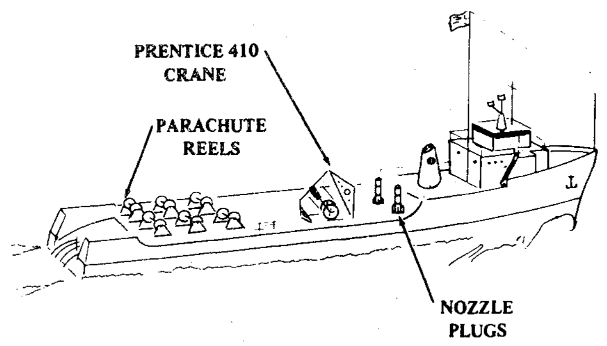

Fig. 2 Support ship.

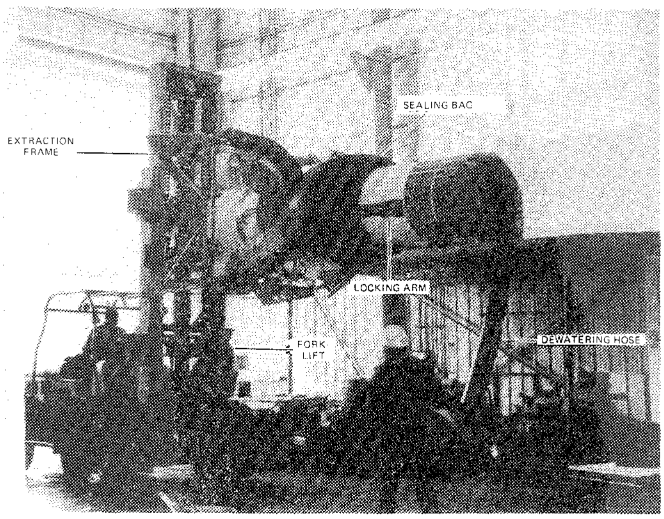

Fig. 3 Nozzle plug extraction.

NP, overpressuring the SRB to 10 psi, and forcing the remaining water out through the NP. The umbilical is disconnected and the SRB casing is towed back to port.

NASA has specified that offshore supply vessel boats (Fig. 2) are to be employed to retrieve the spent SRB hardware. This type of vessel provides the necessary deck space to accommodate all the retrieval equipment. Two vessels are used during a normal retrieval operation. Each vessel has the responsibility to recover one SRB and its associated hardware. In the event one vessel becomes disabled, the remaining vessel has the capability to recover the hardware from both SRB's and to dewater and tow the two boosters. The vessels are fully equipped to search for and locate the hardware, and to maintain recovery operations in sea-state 4.

Postmission Nozzle Plug Removal

After the SRB is returned to the shore facility and removed to the refurbishment building, the nozzle plug vehicle must be removed from the SRB. For this purpose, an extraction frame was developed which fits onto the lift bar of a forklift. The extraction frame slides onto the parallel segments of the lower NP leg structure and is securely clamped so that the extraction frame takes most of the bending forces resulting from horizontally cantilevering the NP from the forklift. The extraction frame is provided with a large roller bearing between the frame and the forklift mount to allow the frame to be rotated and indexed to the NP legs. Alignment is provided by forklift elevation, tilt, and steering.

After the SRB is recovered, it is positioned horizontally inside the refurbishment building. The forklift operator positions and indexes the frame, then moves forward until the frame is fully engaged with the NP legs. An assistant clamps the frame to the legs. By means of auxiliary equipment, the NP sealing bag is deflated and the locking arms are retracted.

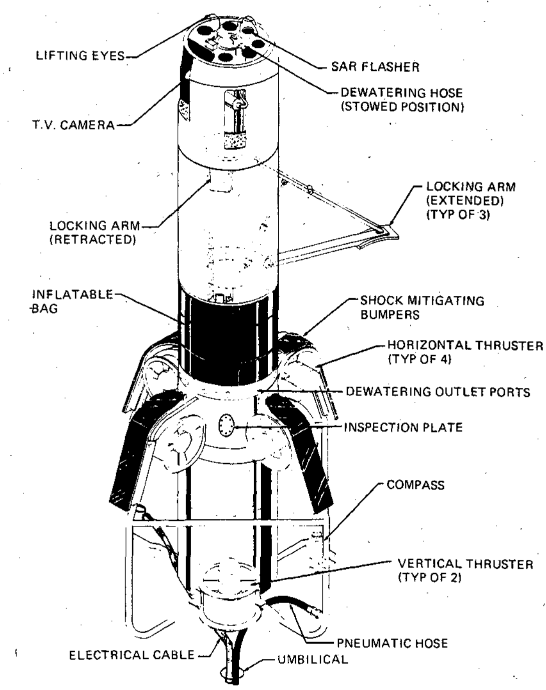

Fig. 4 Nozzle plug vehicle.

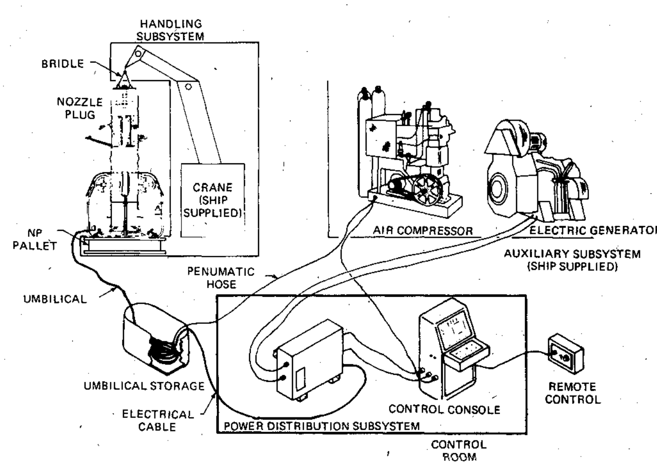

Fig. 5 SRB dewatering system.

The NP is now cantilevered from the forklift, which backs the NP out of the SRB (Fig. 3), and the NP and extraction frame are lowered to the deck. A crane is attached to the top of the NP, raises it to the vertical position, lifts it out of the frame, and sets it back on its storage pad, completing the mission.

Operational Description

Several methods for dewatering the SRB's were studied, including the use of divers to insert an inflatable sealing bag into the rocket nozzle. However, it was concluded that the size of the SRB nozzle (4½ ft in diameter at the throat), the working depth (120 ft), and the recovery conditions (up to sea-state 4) could present hazardous conditions for a manned recovery.

Because of NOSC experience with unmanned work vehicles such as the cable-controlled underwater recovery vehicle (CURV), remote underwater work system (RUWS), SNOOPY, etc., NOSC proposed and was contracted to develop a prototype remote-controlled vehicle to plug the nozzle and dewater the SRB. Figure 4 shows the resulting nozzle plug (NP) vehicle. Other (shipboard) portions of the system (Fig. 5) include a control console, the air and electrical umbilical, an electrical power generator, a power distribution unit, and an air compressor.

Vehicle subsystems include hydraulically powered thrusters and locking arms, inflatable nozzle sealing bag, TV camera and lights, and deployable dewatering hose.

After the vehicle is launched, it is guided on the surface to the target vicinity until the SRB is acquired on the vehicle's video system. The vehicle is then used to perform a video inspection of the submerged portion of the SRB. Following the inspection, and assuming no damage has been incurred by the SRB, the operator guides the NP into the nozzle of the SRB. The inherent shape of the NP allows it to dock in the nozzle skirt with the inflatable sealing bag properly positioned inside the nozzle throat. After the NP is docked, locking arms are deployed to lock the NP into the SRB nozzle. Compressed air is then forced into the SRB to displace the water inside the casing, forcing it out past the nozzle plug. When sufficient water has been displaced, the SRB becomes unstable in the spar mode and pitches over to the log mode. When this occurs, the sealing bag is inflated, sealing the space between the NP vehicle and the nozzle throat. The dewatering hose is deployed from the top of the vehicle, the weighted end dropping into the remaining water in the SRB. Air continues to be forced into the SRB until an over-pressure of 10 psi above ambient is achieved. This is sufficient to force the water up the dewatering hose, through the NP, and out through holes below the sealing bag, completing the dewatering of the SRB. The SRB is next rigged and towed to the shore facility where it is brought ashore. The NP is removed and the SRB is then refurbished and prepared for its next mission.

System Requirements

The system must be capable of accomplishing the mission, including the complete dewatering of the SRB, in less than three hours from the time the nozzle plug vehicle is launched from the support ship. It must be operable day or night in sea conditions up to sea-state 4 (4-8-ft waves), and it must operate from a platform with a standoff range of up to 300 ft. After dewatering is completed, the NP must remain locked into the nozzle, and the sealing bag must retain its inflation with the umbilical disconnected during the tow to shore. There must be no damage to the nozzle or the NP during docking, towing, and extraction.

Design Approach

Hydraulic vs Electrical Propulsion

To dock the NP into the nozzle of the SRB, the operator must be able to follow the motions imparted to the target by the sea. These motions and the response of the vehicle with various candidate propulsion systems used were modeled on an analog computer. These studies showed that the slower response times of thrusters that are driven by electric motors would not be adequate. Therefore an electrohydraulic prime power system was selected for the NP vehicle, with hydraulic motors driving the thrusters.

SRB Dewatering Method

Two approaches were considered for removing the water from the SRB: pump it out with an onboard pump, or force it out with compressed air. On the basis of tradeoff studies of vehicle weight and system reliability, the use of compressed air was chosen as the means of forcing the water out.

Single Hull Design

Unmanned submersibles developed at NOSC have used the individual bottle concept for packaging electronics, servo valves, etc.: most of the vehicle is free-flooded and the dry components are packaged inside individual pressure resistant bottles, interconnected by oil compensated cables. For the nozzle plug, however, owing to the envelope constraints imposed by the SRB nozzle and the relationships of the sealing bag, locking arm, and thruster location, vehicle density-to-volume ratios dictate a single-hull construction; i.e., all dry components are packaged inside a single pressure hull, providing a more compact envelope. This approach also provides fewer leak paths and more flotation for a given vehicle volume. Since these physical constraints do not permit the addition of flotation materials outside the basic vehicle envelope, precise control of vehicle weight and stability is required.

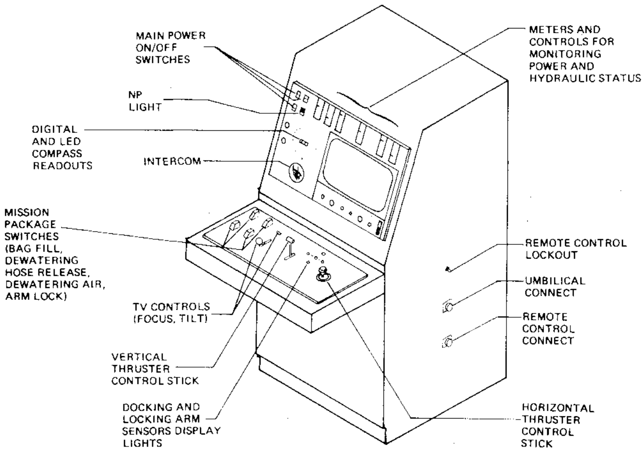

Fig. 6 Dewatering system control console.

Vehicle Stability

Static stability is achieved by placing the heavier components such as the hydraulic power supply in the lower portion and lighter subcomponents such as the electronics nearer the top, where possible. Buoyancy requirements are achieved by filling the upper portions of the vehicle with very lightweight foam (15 lb/ft^3). With the center of buoyancy 9 in. above the center of gravity, excellent static stability is achieved.

To allow the operator to position the NP under the SRB and follow its wave induced motions, the NP is designed to remain in the vertical attitude. Providing dynamic stability when thrusting in the horizontal direction requires accurate positioning of the horizontal thrusters near both the center of drag and the center of gravity. Allowances are made for the umbilical, which is suspended below the vehicle. Using the above techniques, good vehicle stability—both static and dynamic—is achieved.

Control

Thrusters

System control is accomplished through a control console located on board the support ship. The control console is equipped with a joystick control for operating the horizontal thrusters, and a separate two-way control for the vertical thrusters. A small hand-held remote control unit, equipped with an extension cable, can be connected to the control console. The remote control contains only the thruster controls and has no video or other readouts. When the NP vehicle is operating on the surface, the remote unit can be used to control it visually from the deck of the support ship. Layout of all system controls and sensor readouts is shown in Fig. 6. Moving the joystick in any direction provides proportional control to the four horizontal thrusters to move the vehicle in the same horizontal direction as the joystick relative to the vehicle's front end. Twisting the joystick in either direction controls two of the horizontal thrusters, causing the vehicle to yaw in the same direction. Hydraulic power to the thrusters at the vehicle is controlled by servo control valves.

Automatic Heading Hold

The vehicle control system is equipped with an automatic heading hold circuit slaved to a magnetic compass on the NP vehicle. When activated by the operator, this circuit holds the vehicle at whatever compass heading the vehicle had when the circuit was activated. However, the manual yaw control overrides the automatic heading hold circuit. That is, when the operator twists the yaw control on the joystick, the automatic heading hold is deactivated and the vehicle yaws in the command direction until the operator releases the control to return to its null position. The automatic heading hold then reactivates and holds the vehicle in its new heading.

Other Subsystem Controls

Camera tilt is also hydraulically powered and a servo valve is used for control. The locking arms are hydraulically powered and controlled with a solenoid valve. Their speed of operation is controlled with a fixed orifice in each of the three actuator circuits. (The arms are locked into their extended positions with over-center mechanical linkages.)

Hydraulics

Motor-Pump Units

Since no sonar system is employed, acoustic noise was not a factor in the selection of the hydraulic power supply. System weight, cost, and reliability were the major factors governing this section. Lightweight, highly reliable motor-pump units were found to exist in the aerospace inventory. The system selected is pressure compensated and is cooled by passing part of the hydraulic system fluid internally through the electric drive motor. Thus this unit is able to be mounted immersed inside the hydraulic reservoir, providing a compact, lightweight system isolated from the ocean environment. Two redundant units of 15-hp hydraulic power output each are used for reliability. The mission can be accomplished (with reduced thrust) with only one motor-pump unit operating. Each unit weighs only 44 lb and, in the aircraft environment, has demonstrated a 15,000-h mean time to failure. The output capability of each is 8.5 gpm at 2900 psi. Prime power for the motor-pumps is three-phase, 400-Hz, 400-V transmitted from the shipboard 50-kW generator to the NP through six No. 8 A.W.G. copper conductors.

Hydraulic Reservoir

During the early phases of the design it was decided to provide the operator with data concerning reservoir oil volume so that if a leak develops and fluid is pumped overboard, this information can be discerned and the pumps shut down before the system incurs damage. It is also believed desirable to provide a slight overpressure (above ambient) to the compensated system because of the vehicle's 14 ft height. Otherwise, a negative head would result at the top of the vehicle (in air). The overpressure also helps to prevent air or saltwater intrusion into the hydraulic system. Because of these considerations and for better heat transfer, a hard reservoir made of aluminum is used, along with two spring-loaded piston compensators sealed with rolling diaphragms. Fluid volume is measured with a potentiometer linked to the pistons, providing direct fluid volume data for display at the control console. A soft-bag self-compensating reservoir was considered, but it was rejected because the above features could not be incorporated and because without reinforcement the bag type reservoir could not contain the pressure head imposed by the vehicle's height.

Hydraulic Thruster Motors

The hydraulic motors used to drive the thruster propellers are the bent axis piston type, with 0.95-in.^{3} displacement. They provide 5.5-hp output at 900 rpm. Each thruster provides a maximum static thrust of 300 lb forward, 290 lb reverse.

Buoyancy

As mentioned earlier, vehicle envelope constraints made vehicle weight (and buoyancy) a critical design parameter. Buoyance materials selection and design therefore required more than normal effort. Fortunately, the vehicle design depth of only 200 ft allowed the use of very lightweight (15-lb/ft^3) syntactic foam in the upper dewatering section of the vehicle. However, this foam does not have the structural strength of the heavier syntactic foams commonly used for flotation. It also is slightly resilient, losing about 5% of its buoyancy through compression at the NP design depth. Therefore regular syntactic foam with a density of 32 lb/ft^3 was used in the remaining lower sections of the vehicle. By machining and hand carving the foam into intricate shapes, every possible void was taken up with syntactic foam. Even voids inside the dewatering portions (flooded portions) and around the thruster shrouds were fitted with foam shapes. This by-hand approach was feasible for a first prototype. Future production can use these original pieces as patterns for molds.

Conclusion

At-sea tests off the coast of California and off the east coast of Florida, using a full-scale simulated SRB, demonstrated the capability of the nozzle plug vehicle to perform as required, and resulted in acceptance of the system by NASA. The system was used to recover the actual SRB's following the first launch of the Space Shuttle. Design requirements for the NP specified that there would be no damage to or distortions of the SRB nozzle upon water impact. However, there was, in fact, dimensional distortion on one of the SRB's, resulting in binding of the locking arms in one SRB nozzle. Subsequent to the flight of STS-1, the decision was made to use divers to accomplish SRB dewatering.

Divers were used to recover the SRB's following the second Space Shuttle launch, but again, difficulties were experienced. The entire dewatering concept is presently undergoing review.

Acknowledgment

The dewatering system[1] was developed by the Naval Ocean Systems Center (NOSC) under a contract by NASA.

Reference

[1]Schlosser, A.J., "A Remote Unmanned Dewatering System for Recovery of the Solid Rocket Boosters of the Space Shuttle Program," NOSC TR 144, Aug. 1977.