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SPACE SHUTTLE SOLID ROCKET BOOSTER RETRIEVAL SYSTEM. FIVE NOSC --ETC(U)
JUL 80 A J SCHLOSSER, S D HULTBERG, R L WATTS
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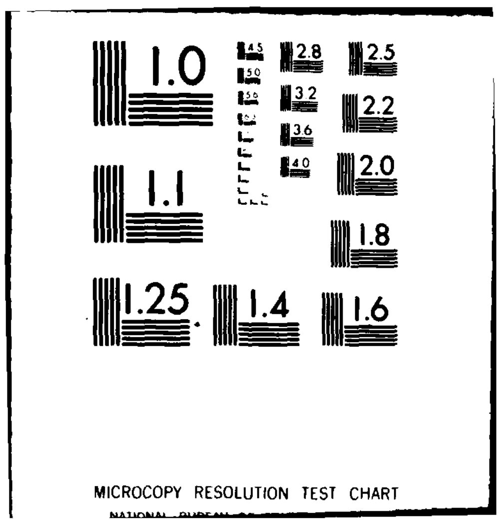
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Technical Document 355

# SPACE SHUTTLE SOLID ROCKET BOOSTER RETRIEVAL SYSTEM

## Five NOSC papers on Space Shuttle support, presented at OCEANS '79, San Diego CA, 17-19 September 1979

AJ Schlosser et al

10 July 1980

Prepared for

Space Shuttle Solid Rocket Booster Recovery Program

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NAVAL OCEAN SYSTEMS CENTER
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Released by
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## METRIC CONVERSION

| To convert from | to | Multiply by |
|---|---|---|
| inches | millimetres (mm) | 25.4 |
| cubic inches | cubic metres ($m^3$) | ~ 1.64 E-05 |
| feet, feet per second | m, m/s | ~ 3.05 E-01 |
| cubic feet | $m^3$ | ~ 2.83 E-02 |
| miles | kilometres (km) | ~ 1.61 |
| nautical miles (nmi) | km | ~ 1.85 |
| knots | metres per second (m/s) | ~ 5.14 E-01 |
| pounds (lb) | kilograms (kg) | ~ 4.54 E-01 |
| pounds of force (lbf) | newtons (N) | ~ 4.45 |
| pounds of force per square inch (psi) | pascals (Pa) | ~ 6.89 E+03 |
| horsepower (550 ft·lbf/s) | watts (W) | ~ 7.46 E+02 |
| gallons per minute (gpm) | $m^3/s$ | ~ 6.31 E-05 |
| °F | °C | Subtract 32, then divide by 1.8 |

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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| Frustum | Parachutes |
| Retrieval equipments | Abnormal conditions |

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A compilation of five papers on space shuttle support: Space Shuttle Solid Rocket Booster (SRB) Retrieval Equipments, by AJ Schlosser; The Solid Rocket Booster Dewatering Set, by KR Fishel; The SRB Parachutes and Frustum Retrieval Equipments, by SD Hultberg; The SRB Retrieval Support Craft, by RL Watts; and Contingency Plans and Equipments for SRB Retrieval for Abnormal Conditions, by RE Jones. Authors are members of the NOSC Applied Technology Division, Code 522.

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## CONTENTS

# SPACE SHUTTLE SOLID ROCKET BOOSTER (SRB) RETRIEVAL EQUIPMENTS, AN OVERVIEW

**AJ Schlosser**

*Abstract*

*A cost-effective recovery system for the Solid Rocket Booster (SRB) and associated hardware has been established to provide significant cost savings for the Space Shuttle Program.*

*On each flight of the Space Shuttle Orbiter, two SRBs are separated from the orbiter after expending their fuel. They are decelerated by three main parachutes. The SRB frustum and drogue separate from the booster upon deployment of the main parachutes and descend to the ocean. Upon impact, the main parachutes separate from the SRB and float suspended from flotation units attached to the apex of each parachute. The frustum floats with the apex of its truncated cone pointing downwards, with the drogue parachute still attached. The SRBs ingest water until they stabilize in the "spar" mode.*

*For each flight mission there are a total of twelve elements subject to retrieval, consisting of two SRB casings, six main parachutes, two frustums, and two drogue parachutes. Each of these elements is equipped with location aids. Following splashdown, retrieval vessels enter the area and recover all the reusable components.*

The National Aeronautics and Space Administration (NASA) has provided for the Space Shuttle Program the first reusable space hardware. The Space Shuttle concept features a fly-back orbiter and two recoverable Solid Rocket Boosters (SRB). This paper concerns itself with recovery of the SRBs and their return to the refurbishment facility.

The SRBs are used to perform the lift-off and boost functions for the Space Shuttle Orbiter, then are separated from the orbiter and parachuted to the ocean surface. The SRBs and the SRB frustums and parachutes are then recovered and transited 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 these equipments, NASA has baselined two off-shore supply vessels outfitted to retrieve the hardware and to transport it to the refurbishment facility for off-loading. The impact area projected in the recovery plan has an elliptical footprint of 6 X 9 miles. Each vessel has the capacity to retrieve one SRB and its associated equipments.

The launch schedule for the first shuttle craft is anticipated for early 1981 and will build to a maximum of 40 launches per year, and the retrieval equipments must be sufficient to maintain recovery at this rate. It is anticipated that an SRB can be reused on 20 launches, effecting a considerable cost savings over the life span of the program.

## THE SOLID ROCKET BOOSTER SEPARATION

Each SRB is approximately 149 feet long and 12 feet in diameter. Upon separation from the orbiter, the nose cone separates from the frustum and is jettisoned and not recovered. The frustum, a truncated cone approximately 10 feet in height, is also separated

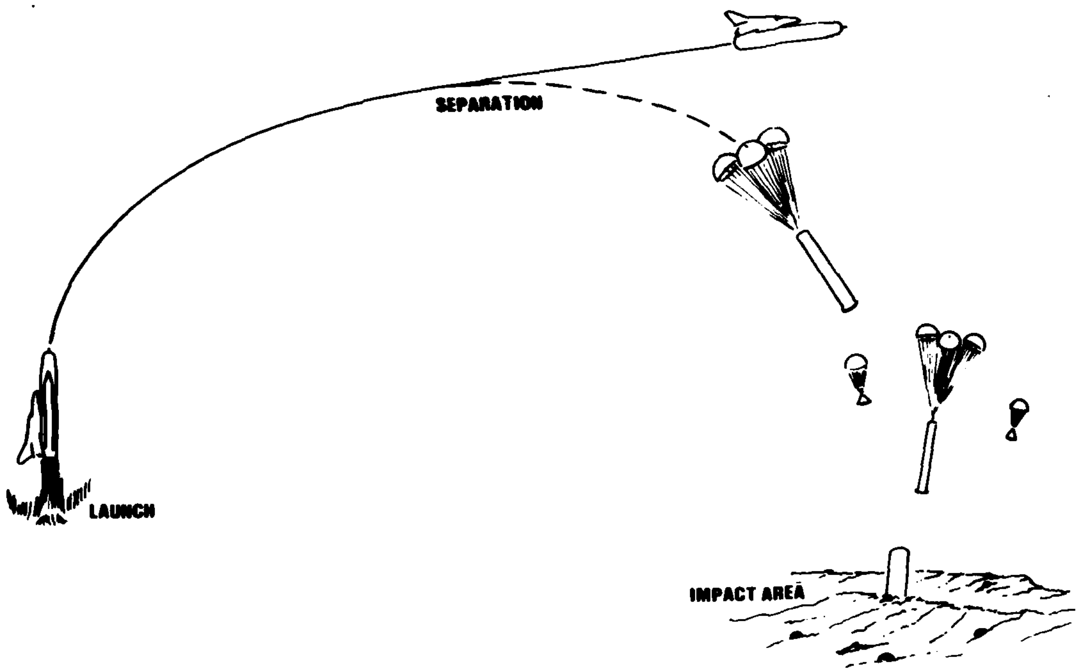


Figure 1

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 feet long.

The SRB has the three parachutes separate at water impact. It lies on its side (log mode) at first but ingests water through the nozzle opening until it assumes a vertical attitude (spar mode). The frustum, upon water impact, takes an inverted attitude and floats with its parachute attached. A surface float attached to the parachute tends the chute. All parachutes are equipped with a radio-frequency beacon to aid in their location for recovery.

## RETRIEVAL BASELINES

Under the assumption of normal splashdown of the SRBs and associated equipments, the following baseline has been established for retrieval:

a. Ocean retrieval is accomplished through sea-state 4 (4- to 8-foot waves).

b. The tracking/locating functions are capable of all-weather, around-the-clock operations.

c. Retrieval is accomplished as soon as possible after impact.

## RETRIEVAL EQUIPMENTS

The three main parachutes of the SRB are supported in the water by an apex float, as shown in figure 2. Capture is made by attaching to the float. The retrieval equipment consists of a powered reel and rolling chocks. The reel provides the necessary pull to allow

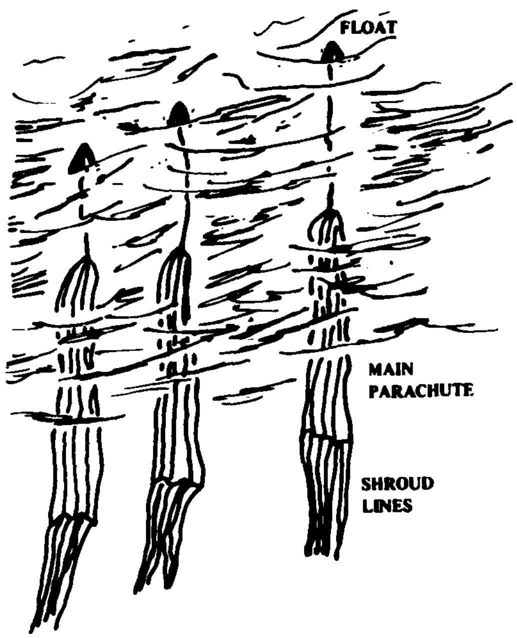


Figure 2

egress from the sea. The rolling chocks prevent damage to the parachute and act to remove a considerable quantity of salt water, which is damaging to the nylon construction. The main parachutes, including the risers, are 230 feet long.

The frustum and parachute are attached, and flotation of the parachute is accomplished by a flotation unit. Since the frustum, being inverted, has no lift points on the large end, the flotation is the only lift point readily accessible from the surface, as shown in figure 3.

The retrieval vessel is maneuvered close to the floating hardware, and a long-handled boat hook with a snap is used to attach the messenger line to the flotation unit. A power block is used to feed the shroud lines of the parachute to a stowage reel. The frustum, when almost clear of the water surface, is then attached to the articulated crane and brought on deck to its storage pallet. The parachute and shroud lines are stowed on a storage reel with a removable spool for further processing at the refurbishment facility.

The SRB casing at float in the spar mode must be reoriented to the log mode for the tow back to port, as shown in figure 4. The Dewatering System (ref 1) was developed by NOSC under a contract by NASA. 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 by means of an articulated crane. The pneumatic and electrical cables form a common umbilical from the vessel to the NP. After the NP has inspected the SRB casing, docking maneuvers begin. The NP is positioned beneath the SRB nozzle, then is maneuvered into the nozzle by upward thrust. When the NP is firmly seated, locking arms are deployed and the NP is docked.

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1. NOSC TR 144, A Remote, Unmanned Dewatering System for Recovery of the Solid Rocket Boosters of the Space Shuttle Program, by AJ Schlosser, 1 August 1977.

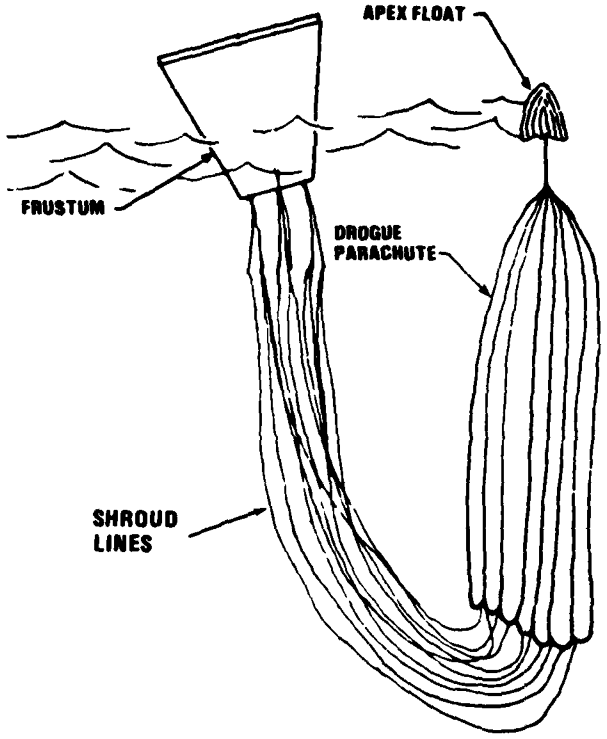



Figure 3

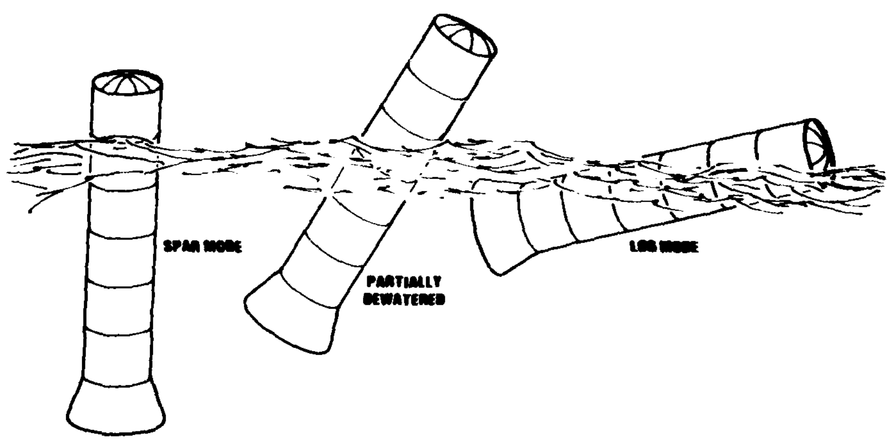



Figure 4

First stage dewatering is done while the SRB is in the spar mode. Compressed air from the retrieval vessel is forced through the umbilical hose into the SRB, forcing water out until the SRB becomes unstable and pitches over, assuming the log mode. At this time a bag on the NP is inflated, sealing the SRB nozzle. Final dewatering is accomplished in the log mode. The umbilical is disconnected and the SRB casing is towed back to port.

NASA has specified that off-shore supply vessel boats (fig 5) are to be employed to retrieve the spent SRB hardware. This type of vessel provides the necessary deck space to accommodate all the retrieval equipments. Two vessels are used during a normal retrieval operation. Each vessel has the responsibility to recover the associated hardware for one SRB and to dewater the SRB and tow it to port. In the event one vessel becomes disabled, the remaining vessel has the capability to recover the hardware from both SRBs 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.

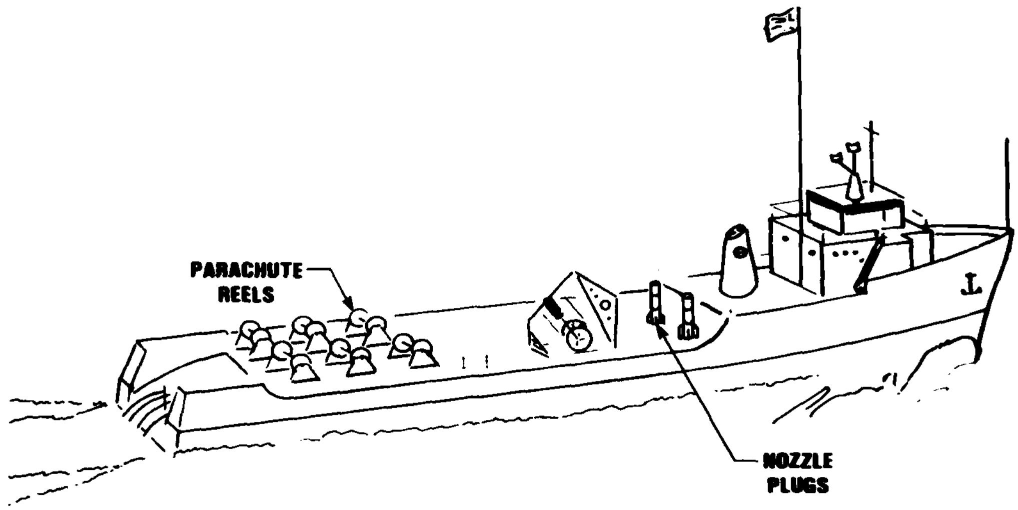



Figure 5

# THE SOLID ROCKET BOOSTER DEWATERING SET

**KR Fishel**

*Abstract*

*After launch of the Space Shuttle, the Dewatering Set is used to expel the water from within the Solid Rocket Booster (SRB) casing to enable it to be towed back to port for refurbishment.*

*The SRB assumes a vertical or spar floating condition after impact, but must be brought to a horizontal or log mode for towing. The Nozzle Plug of the Dewatering System docks and locks itself into the nozzle of the booster.*

*The heart of the Nozzle Plug (NP) Vehicle is its extremely lightweight pressure-compensated electro/hydraulic power supply developed for the airline industry. The system uses two 15 hp motor-pump units to provide a total of 17 gpm at 2900 psi. Each motor-pump unit weighs only 44 pounds in air. The hydraulic system and its functions, the thrusters, and the locking arms are described.*

*The controls used to operate this system and some of the unique subsystems developed, such as the automatic heading device, are described.*

The prototype Solid Rocket Booster (SRB) Dewatering System was developed by NOSC to inspect and dewater the expended SRBs of the Space Shuttle. Following the boost phase of the trajectory, the SRBs are parachuted into the sea where they float in a spar (vertical) mode with the rocket nozzle down. The SRBs are dewatered, sealed, and made to float in a log (horizontal) mode so that they can be towed back to the shore facility and refurbished for reuse.

Several methods for dewatering the SRBs 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 (4-1/2 feet diameter at the throat), the working depth (120 feet), and the recovery conditions (up to sea-state 4) would present conditions too hazardous for a manned recovery.

Because of NOSC experience with unmanned work vehicles such as CURV, RUWS, Snoopy, etc, NOSC proposed and was contracted to develop a prototype remote-controlled vehicle to plug the nozzle and dewater the SRB. Figure 6 shows the resulting Nozzle Plug (NP) Vehicle. Other (shipboard) portions of the system (fig 7), 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.

## OPERATIONAL DESCRIPTION

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

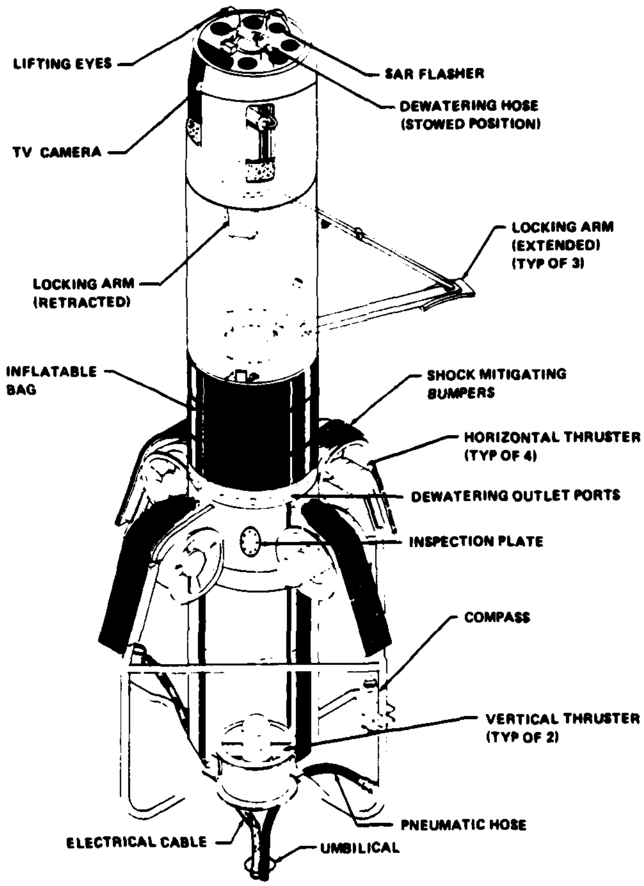



Figure 6. Nozzle Plug Vehicle.

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 overpressure 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 refueled for its next mission.

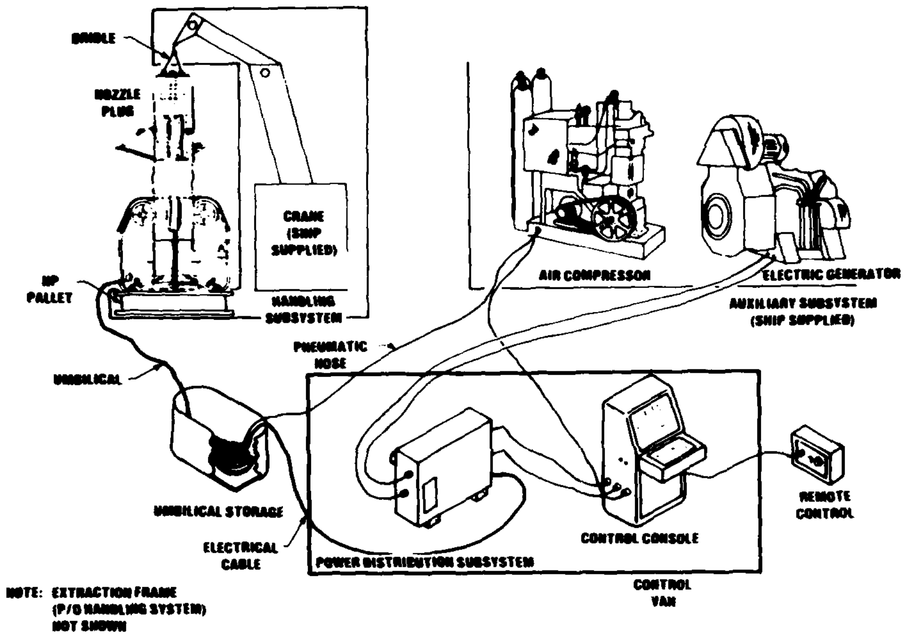



Figure 7. SRB Dewatering System.

## SYSTEM REQUIREMENTS

The system must be capable of accomplishing the mission to complete dewatering of the SRB in less than 3 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, and it must operate from a platform with a standoff range of up to 300 feet. 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 electro-hydraulic 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 on-board pump or force it out with compressed air. On the basis of trade-off 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, due 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. This approach 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 balance is required.

### 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/cu ft). With the center of buoyancy 9 inches 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 through a Control Console located on board the support ship. The Control Console is equipped with a joy stick 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 figure 8. Moving the joy stick in any direction provides proportional control to the four horizontal thrusters to move the vehicle in the same horizontal direction as the joy stick relative to the vehicle's forward. Twisting the joy stick 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 with servo control valves.

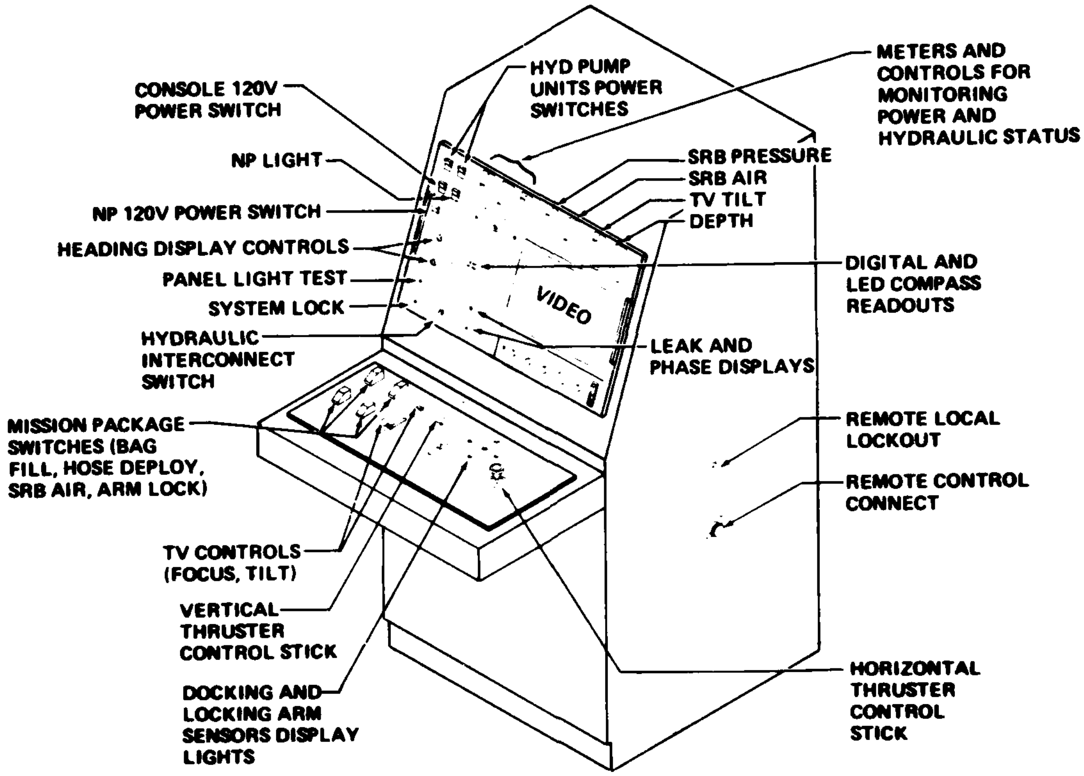



Figure 8. Dewatering System Control Console.

### 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 joy stick, the automatic heading hold is deactivated and the vehicle yaws in the commanded 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

Information feedback from the vehicle to the operator is primarily through the video system. Since no sonar system is employed, noise was not a factor in the selection of the hydraulic power supply. System weight, cost, and reliability were the major factors governing this selection. 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 units of 15 hp hydraulic power output each are used for redundancy. The mission can be accomplished (over a longer period) with only one motor-pump unit operating. Each unit weighs only 44 pounds and, in the aircraft environment, has demonstrated a 15000-hour mean time to failure. The output capability of each is 8.5 gpm at 2900 psi. Prime power for the motor-pumps is 3-phase, 400 Hz, 400 V transmitted from the shipboard 50 kW generator to the NP through six number-8 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 was also believed desirable to provide a slight overpressure (above ambient) to the compensated system because of the vehicle's 14-foot 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 diaphrams. 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-cubic-inch displacement. They provide 5.5-hp output at 900 rpm. Each thruster provides a maximum static thrust of 300 pounds of force forward, 290 pounds of force reverse.

## BUOYANCY

As mentioned earlier, vehicle envelope constraints made vehicle weight (and buoyancy) a critical design parameter. Buoyancy materials selection and design therefore required more than normal effort. Fortunately, the vehicle design depth of only 200 feet allowed the use of very lightweight (15 lb/cu ft) 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 percent of its buoyancy through compression at the NP design depth. Therefore, regular syntactic foam with a density of 32 lb/cu ft 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.

## 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. The NP is now cantilevered from the forklift, which backs the NP out of the SRB (figure 9), 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.

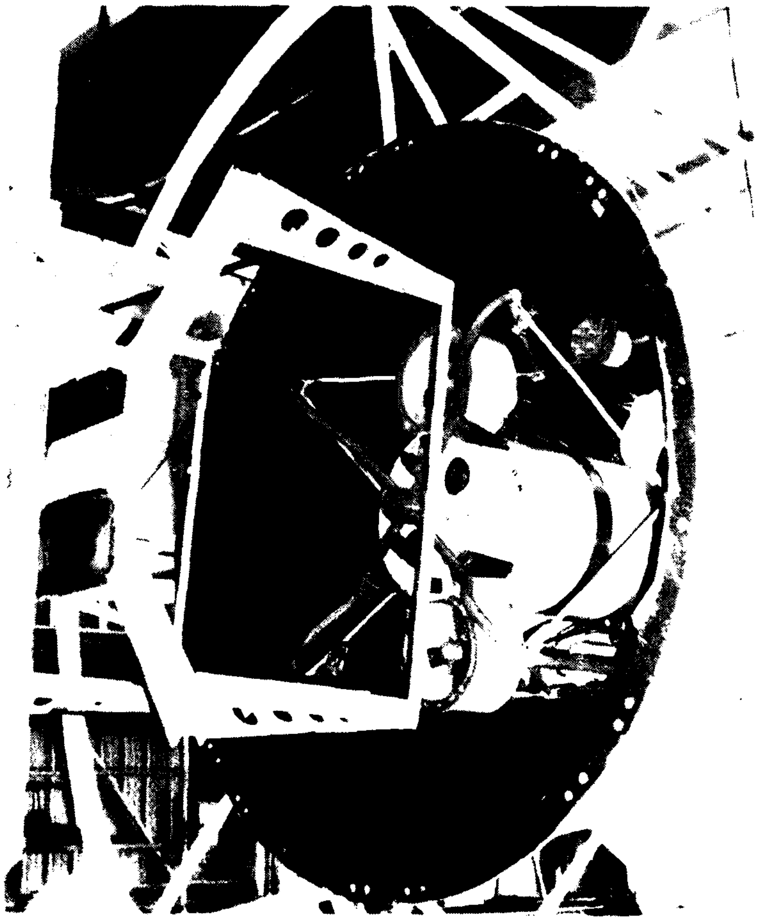


Figure 9. Nozzle Plug extraction.

# THE SRB PARACHUTES AND FRUSTUM RETRIEVAL EQUIPMENTS

**SD Hultberg**

*Abstract*

*Upon completion of the initial boost of the Space Shuttle Orbiter, the Solid Rocket Booster (SRB) system components are jettisoned into the ocean. Recovery of these components required the development of specialized equipment and recovery techniques. Equipments and procedures for component recovery and stowage aboard a specially equipped surface support craft are discussed.*

*Upon impact, the three main parachutes of the SRB case separate and are supported by individual floats with location aids. The frustum, separated from the SRB case while descending, upends upon impact and floats on the surface along with its parachute, support float, and location aids. A unique recovery method is required for the frustum since there are no lift or tie-down points.*

*The chosen equipments and techniques were formulated through a series of systematic tests and trade-off studies.*

On each flight of the Space Shuttle Orbiter, two Solid Rocket Boosters (SRB) are separated from the orbiter after expending their fuel. The SRB is decelerated by a drogue and three main parachutes. The SRB frustum and drogue separate from the main body of the booster upon deployment of the main parachutes. On water impact, the main parachutes separate from the SRB and are supported by a float attached to the apex of each parachute. The frustum floats with its apex down, with the drogue parachute still attached. Each of these elements is equipped with location aids such as flashing lights, acoustic pingers, and radio-frequency beacons.

The first items to be retrieved are the main parachutes. The retrieval vessel captures the apex float of one of the parachutes. A line is then attached to the apex of the parachute and the parachute is reeled aboard the retrieval vessel by a hydraulically operated stowage reel. The other parachutes are likewise reeled onto their stowage reels, one main parachute per reel.

The drogue parachute and frustum are retrieved next. The drogue is brought aboard the retrieval vessel in the same manner as the mains. When its suspension lines are aboard, they are fed into a powered snatch block and power grip attached to a crane. The frustum is lifted from the water by the drogue suspension lines, swung by the crane boom to position it on dunnage, and secured.

The SRB equipment retrieval was formulated on the basis of a systematic series of tests and trade-offs. The requirements imposed on the design by NASA and the environmental and operational factors were analyzed, and candidate concepts were developed.

## OPERATIONAL REQUIREMENTS

The following operational requirements were identified during system design:

a. Retrieval is to be accomplishable through sea-state 4.

b. The parachutes must be protected from the deteriorative effects of salt water and sun following retrieval. The frustum must be protected from the corrosive effects of salt water.

c. Delays in retrieval will probably result in dispersion of the SRB elements; therefore, retrieval must be accomplished as soon after impact as possible.

d. Off-the-shelf hardware and designs, with a proven operational and reliability history, should be used wherever possible to ensure the reliability and cost-effectiveness of the concept.

e. Parachutes are to be stored on reels.

f. No workboats or swimmers are to be used.

## MAIN PARACHUTE

### Main Parachute Description

Three main parachutes are used to slow the descent of each SRB. On impact, each main parachute separates from the SRB casing and is supported by a float attached to its apex. A satellite float containing a radio-frequency beacon and a flashing light for location is attached to the apex float.

Figure 10 illustrates the main parachute configuration. The maximum girth of the parachute, deployed but not blossomed, is 11.8 feet. The dry weight is 1507 pounds. The nylon parachute is of ribbon-type construction.

### Main Parachute Capture

Since each main parachute is supported by an apex float (figure 11), it is advantageous to capture the float at standoff ranges from the retrieval vessel to avoid damaging the parachutes. The tool used to capture the float is a long pole equipped with a snap hook and a detachable handle (figure 12), manipulated from the deck of the retrieval vessel. The long pole requires the retrieval vessel to approach to within 15 feet of the float.

### Main Parachute Retrieval

Four candidate concepts for main parachute retrieval were investigated, as follows.

POWERED REEL AND ROLLING CHOCK. The reeling concept (figure 13) requires the use of a powered reel to pull the parachute over a rolling chock mounted on the side or the stern. The parachute is reeled in, apex first, and each loaded reel is then detached for handling and stowage of the parachute wound on it.

WRINGER. The wringer concept (figure 14) requires the use of two spring-loaded powered horizontal rollers mounted outboard, through which the parachute is winched (apex first). The wringers provide the force required to pull the parachute onto the deck, where it is then stowed on a reel.

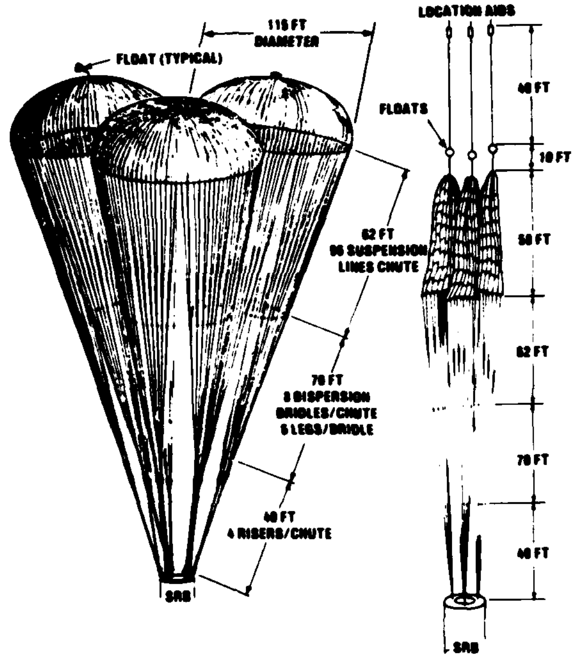



Figure 10. Main parachute configuration.

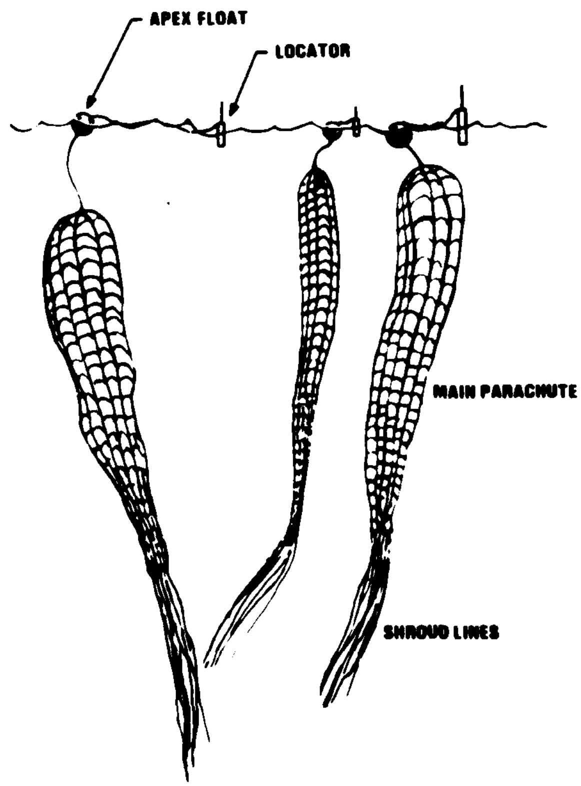



Figure 11. Main parachutes supported by floats.

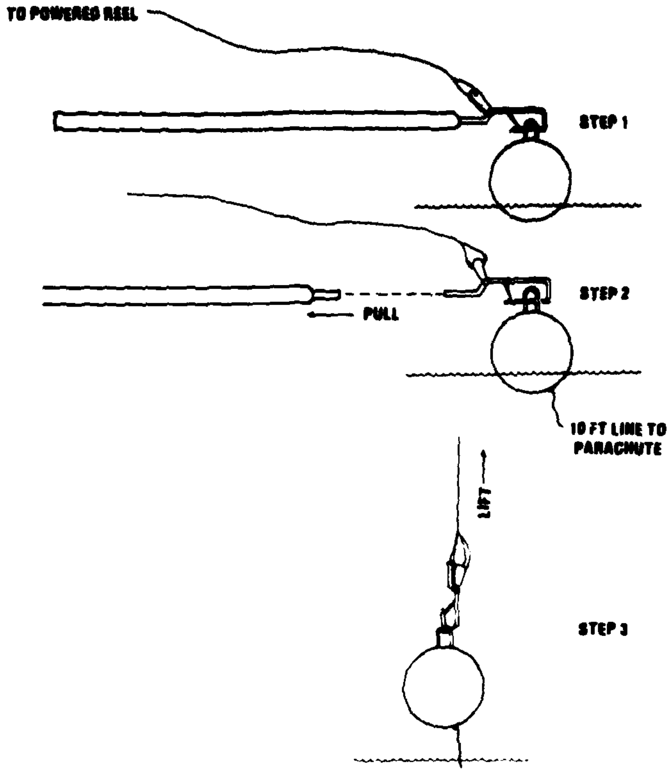



Figure 12. Long-handled Snap Hook.

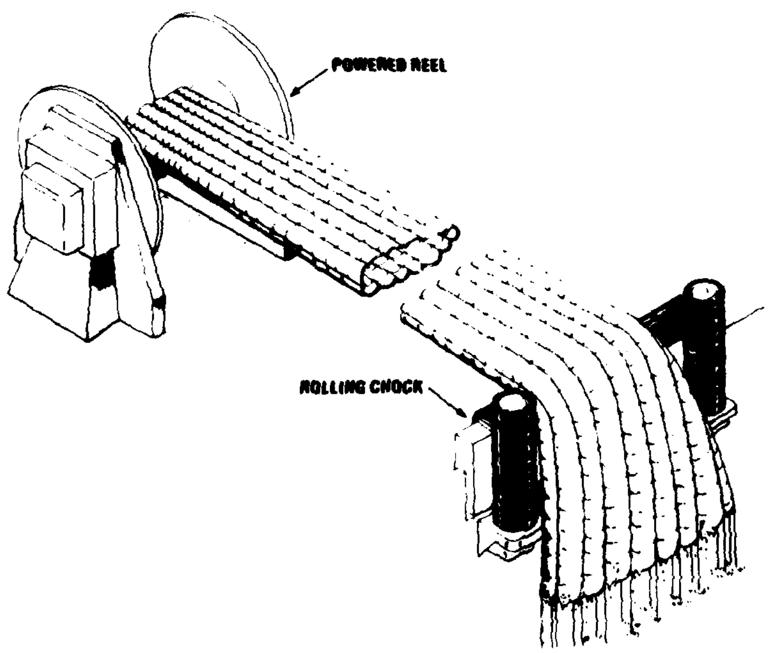



Figure 13. Powered reel and rolling chock.

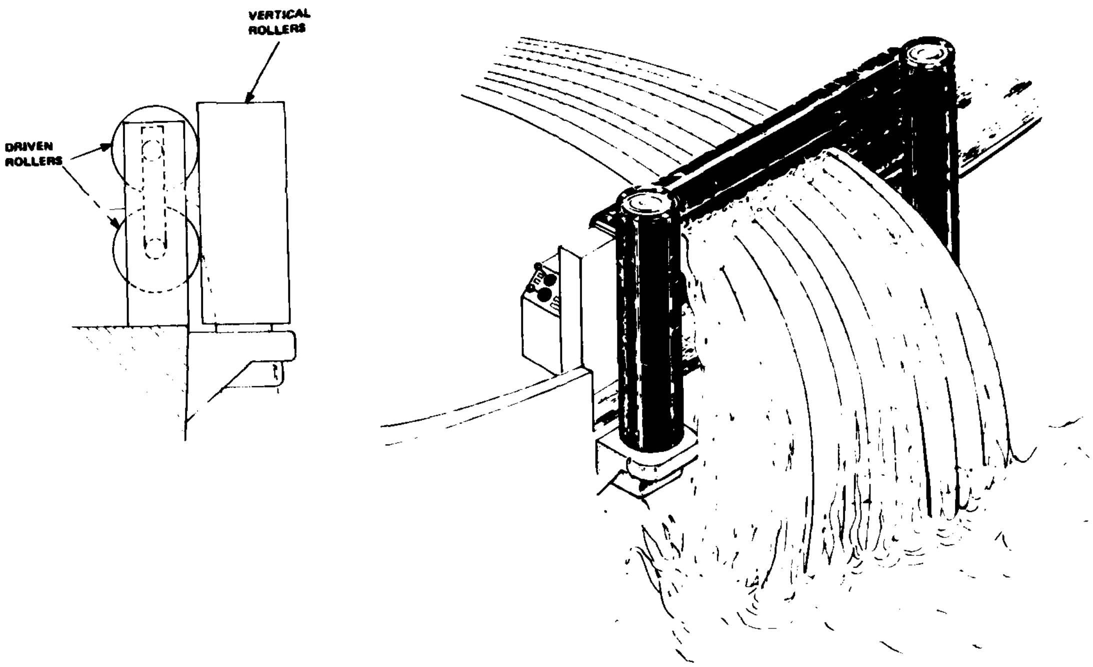



Figure 14. Wringer.

UNPOWERED BLOCK AND POWERED REEL. This concept (figure 15) requires the use of a block suspended from a crane in conjunction with a powered reel. The primary advantage of this concept is that it permits the retrieval of the parachute at standoff ranges rather than by pulling the parachute directly over the side or stern. This is accomplished by pulling the parachute through a freewheeling block and fairlead, with power supplied by a stowage reel.

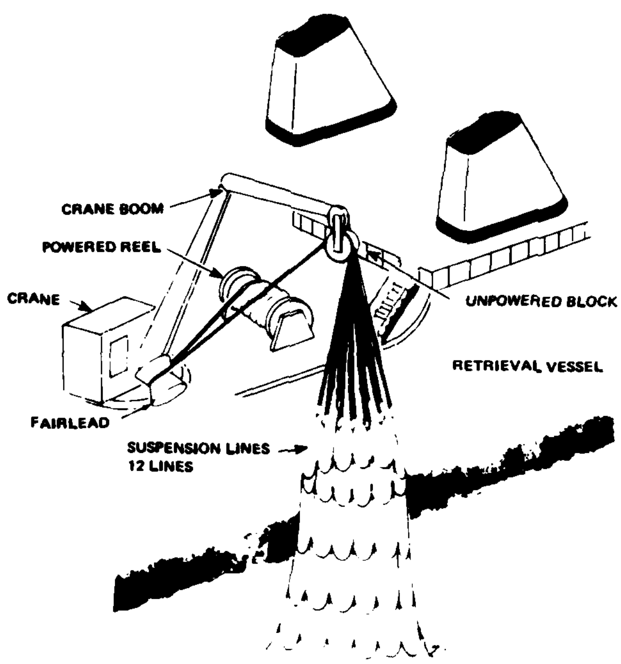



Figure 15. Unpowered block.

POWERED BLOCK WITH POWER GRIP. The powered block with power grip concept (figure 16) is similar to the unpowered block concept except that the retrieval force is furnished by the block and grip rather than the reel.

Powered blocks are used in the fishing industry to retrieve nets. Using the concept illustrated in figure 17, a 36-inch diameter block with a power grip would be adequate.

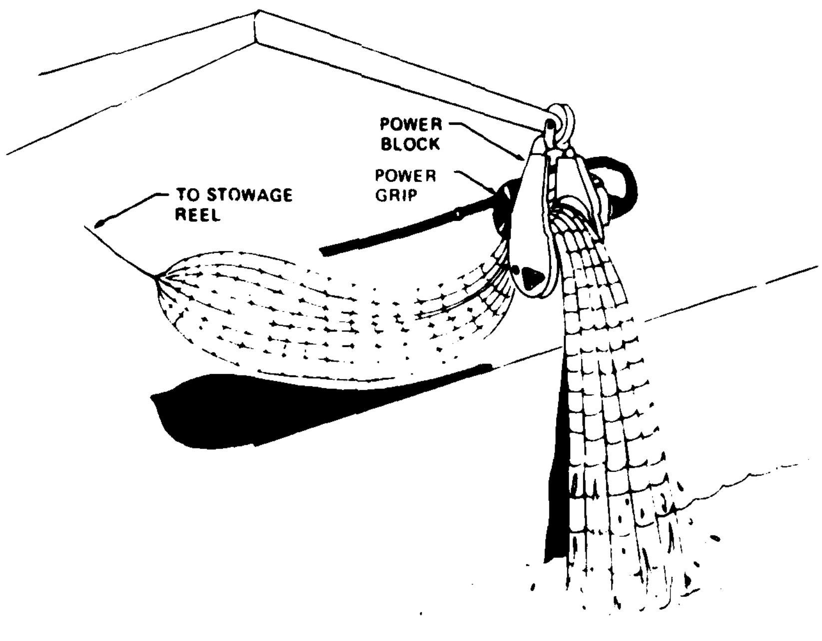



**Figure 16. Powered block with power grip.**

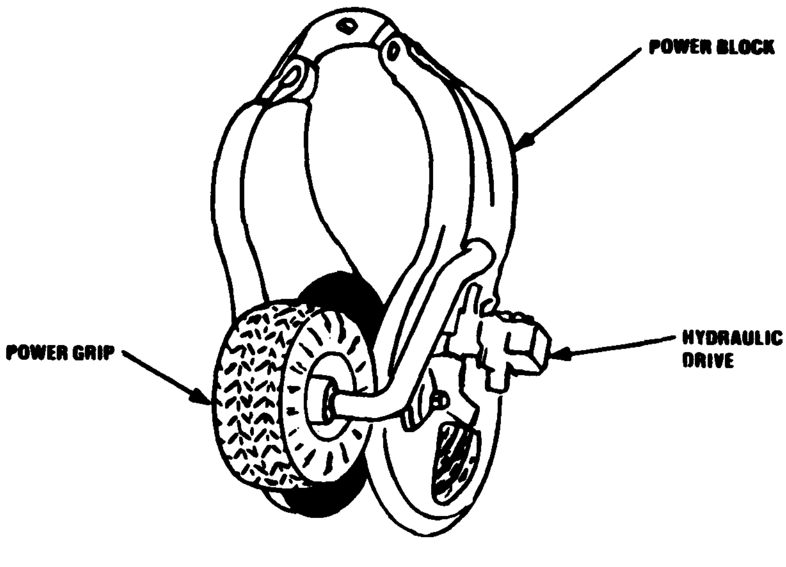



Figure 17. Power snatch block.

Of these four concepts, NASA has chosen the powered stowage reel and rolling chock (figure 13).

**Main Parachute Stowage**

Parachute retrieval requires the use of three powered reels. These same reels are used to stow the parachutes. The reels themselves can be detached from the support base power drive assembly for off-loading and transporting to the parachute refurbishment facility. The reels are constructed of aluminum to avoid rust damage to the parachute fabric.

It is desirable that the parachutes be washed down with fresh water prior to stowage (to remove salt) and mandatory that they be kept wet during stowage. Furthermore, the parachutes must be protected from sunlight, since ultraviolet radiation causes deterioration of the material. The process of winding the parachutes on reels removes most of the salt water. The residual water serves to keep the parachutes wet if an appropriate cover (sun shield) is provided for each reel. Fresh water used for washing the frustum can be used to wet the parachutes.

The decision to use reels that each accommodate only one parachute is based on the fact that this simplifies handling at the parachute refurbishment facility. This stowage scheme implies a necessity for four parachute reels: three to stow the main parachutes and one to stow the drogue parachute. In a contingency such as in a one-ship retrieval situation, there is room for the extra parachutes to be reeled, one per reel, on top of the first parachutes. Even though the drogue parachute volume differs from that of the main parachutes, it would be ideal for purposes of standardization to make all parachute reels the same size and interchangeable. Figure 18 illustrates the basic elements of the reels.

## FRUSTUM AND DROGUE PARACHUTE

After the SRB separates from the Space Shuttle Orbiter, it is stabilized by a drogue parachute attached to its frustum. The frustum is then separated pyrotechnically from the SRB and is decelerated by the drogue to moderate the water impact.

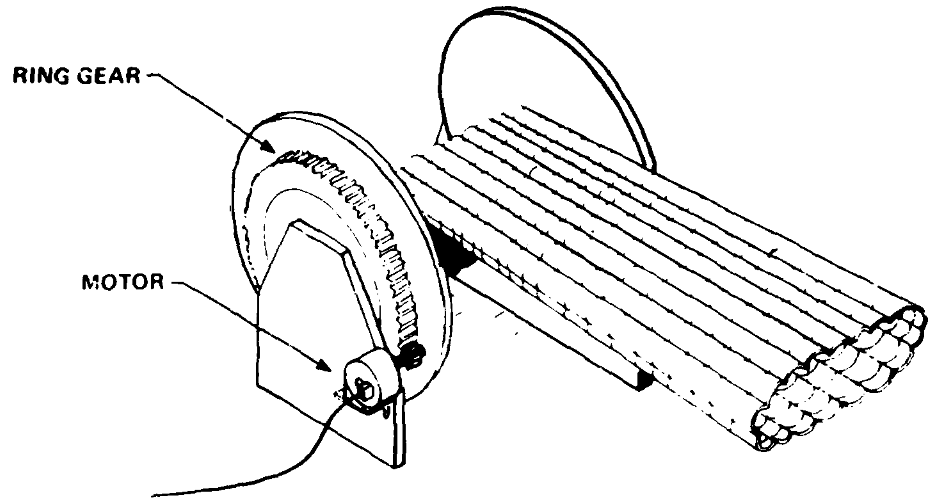



Figure 18. Powered parachute reel.

### Drogue Parachute Description

The drogue parachute is a ribbon-type parachute weighing approximately 1000 pounds in air. The dimensions of the drogue are illustrated in figure 19. It has a float attached to its apex to keep the drogue from sinking and to assist in recovery.

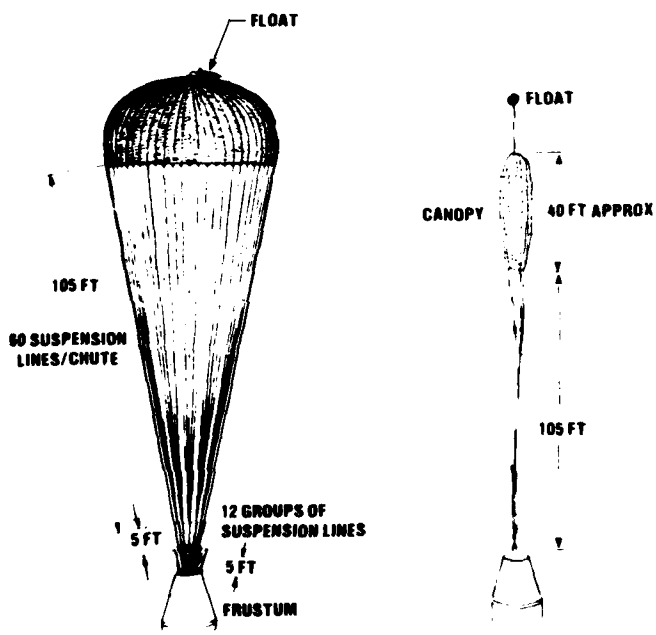



Figure 19. Drogue parachute dimensions.

## Frustum Description

When attached to the SRB, the frustum (including the three main parachutes) weighs almost 5000 pounds. Separation of the frustum from the SRB deploys the main parachutes. The frustum is decelerated by the drogue parachute. After impact, the frustum is upended by the weight of the separation motors and the attached drogue parachute, and it floats by virtue of built-in flotation material.

Figure 20 illustrates the approximate dimensions of the frustum. The drogue suspension lines are attached to its small end. The location aids, consisting of an rf beacon and flashing light, are located on the large end. Deployment of the location aids from their stowage locations follows upending of the frustum after splashdown. Each drogue/frustum floats bottom up with the location aids exposed, tilted at approximately 15 degrees (figure 21). The tilt is caused by the off-center weight of the separation motors.

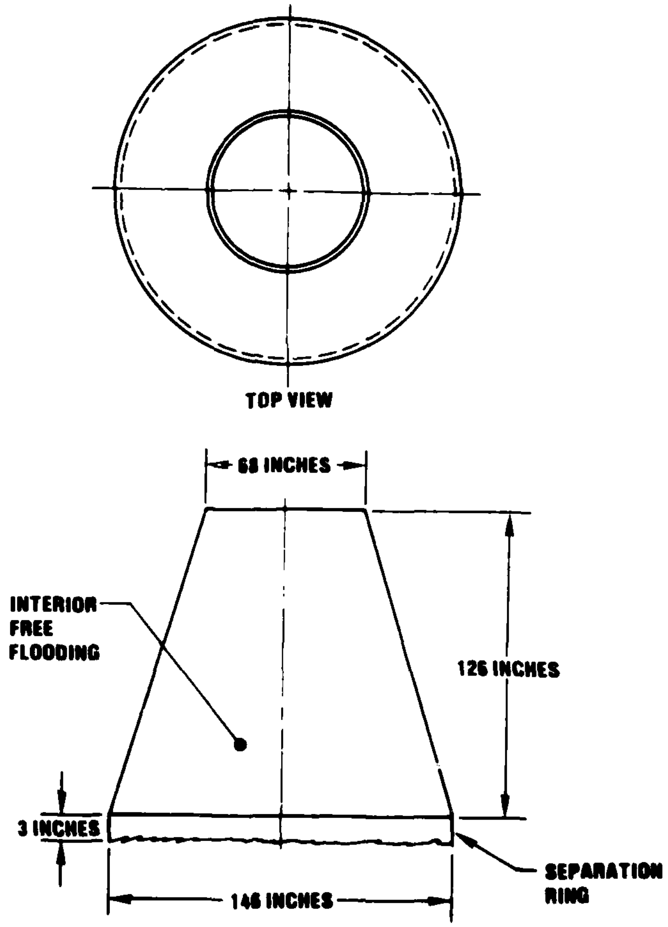



Figure 20. Frustum dimensions.

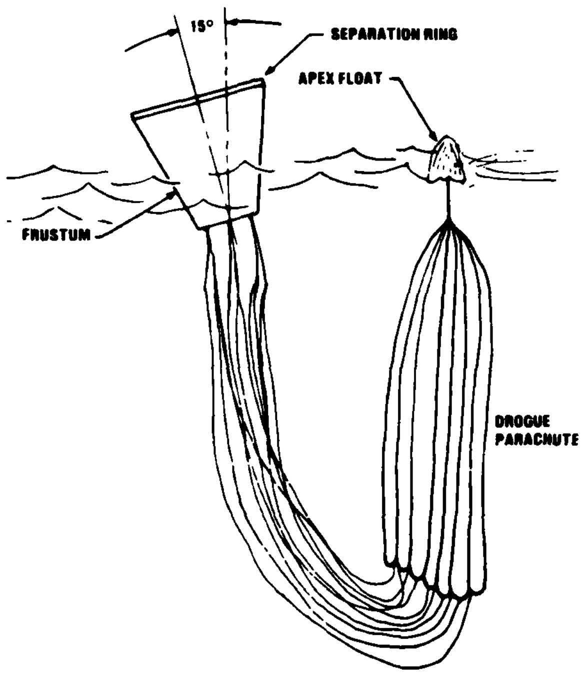



Figure 21. Drogue/frustum flotation configuration

Note that there are no lift or tie-down points on the large end of the frustum. The frustum is separated from the SRB by a pyrotechnically frangible ring (separation ring) at the base of the frustum. Half this ring remains with the frustum while the other half remains with the SRB. The separation ring is expendable: when the frustum is refurbished for reuse, this ring is removed and replaced.

**Frustum/Drogue Capture**

Capture of the frustum/drogue combination is done by attaching a line to the apex float of the parachute, using the same long pole and snap hook required for main parachute capture.

**Frustum/Drogue Retrieval**

The frustum has no suitable projections to which attachments can be made while it is inverted in the water. For this reason, it is removed from the water and stowed by lifting the drogue suspension lines attached to its top. This approach restricts the candidate concepts to those which provide both for handling the drogue and for lifting the combined drogue and frustum. Four candidate concepts for retrieval were investigated, as follows.

UNPOWERED BLOCK WITH POWERED REEL. This concept (figure 22) uses a large unpowered block suspended from a crane boom over which the parachute is reeled onto a powered reel, apex first. The drogue is thus reeled until the frustum is above the level of the deck. The frustum is then brought aboard by inboarding the crane.

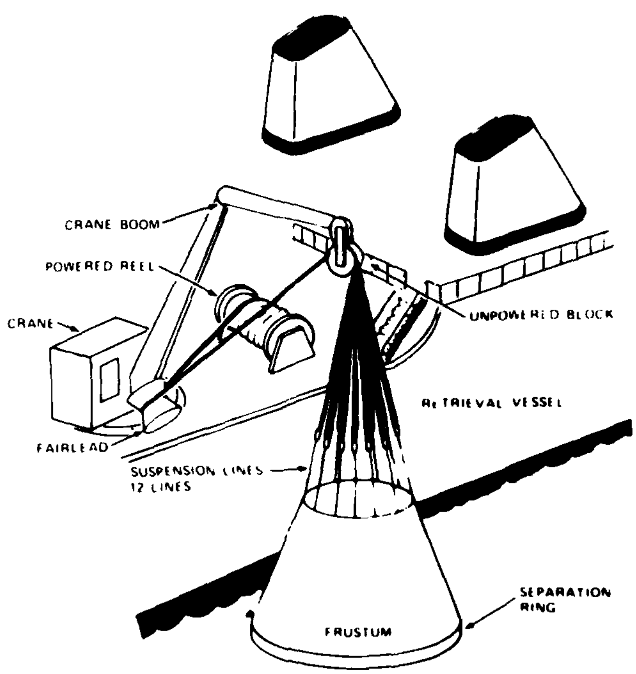



Figure 22. Unpowered block with powered reel.

UNPOWERED BLOCK WITH GRABBER AND POWERED REEL. This concept (figure 23) is very similar to the unpowered block with powered reel except that a grabber located on the shipboard side of the block is used to secure the drogue parachute suspension lines. The force to lift the frustum, once the grabber is engaged, comes from the crane boom rather than the powered reel. Thus, since the powered reel is not required to lift the frustum, the reel can be somewhat smaller, lighter, and less powerful than the unpowered block without the grabber. The crane boom is then raised to lift the frustum from the water sufficiently to swing it onto its stowage pallet on deck.

POWERED BLOCK WITH POWER GRIP. This concept (figure 24) has been used widely by the fishing industry for some years to retrieve large, bulky fishing nets with attached floats. Tests conducted with power blocks at the manufacturer's facility indicate that the concept is well suited to the retrieval of parachutes. This concept is very similar to the unpowered block concept with one major difference: the powered block, instead of the powered reel, provides the pulling force and guiding capability. The reel is used only to take up the slack and stow the drogue.

The powered grip element assists in gripping the parachute and guiding it through the block. Furthermore, the power grip provides the necessary gripping force for gripping the risers and lifting the frustum.

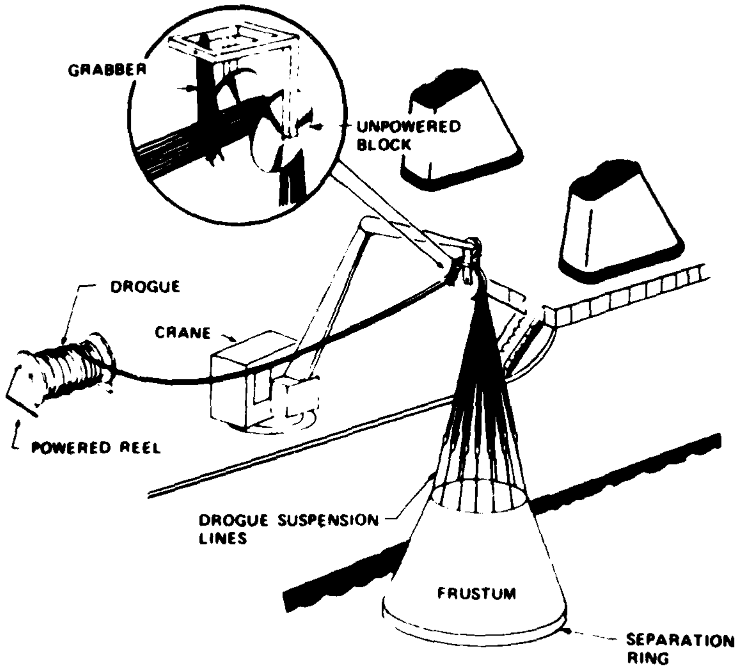



Figure 23. Unpowered block with grabber and powered reel.

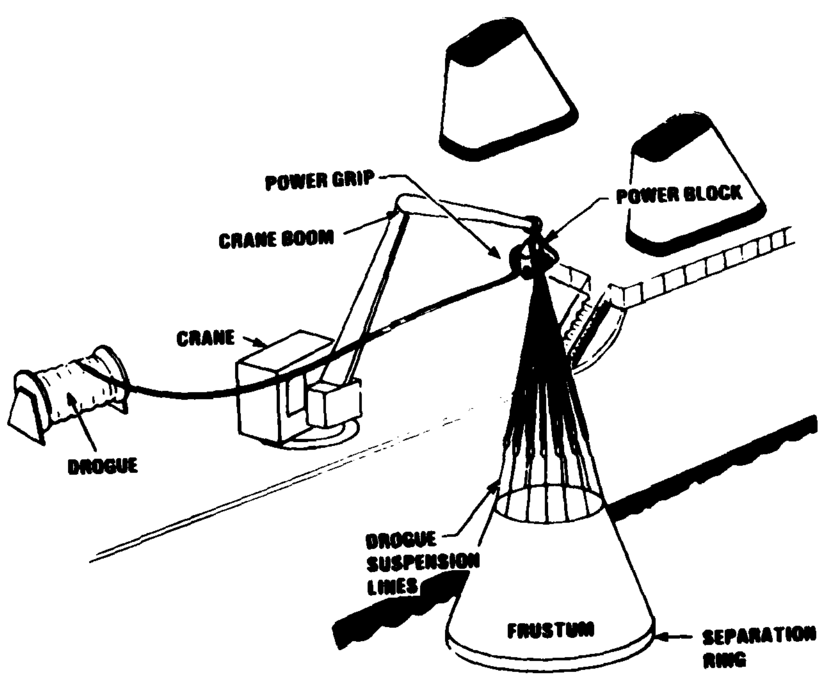



Figure 24. Powered block with power grip.

ROLLING CHOCK WITH POWERED REEL AND CRANE. This concept (figure 25) employs a powered reel, a rolling chock located at the deck edge or stern, and a crane to lift the frustum from the water. A large fender or similar device is used to protect the frustum from the effects of collisions with the hull of the retrieval vessel. The crane, using a gripper, grasps the bundle of drogue suspension lines and lifts the frustum on board.

The concept chosen from these four is a combination: a rolling chock with powered reel, to reel and stow the drogue (as in figure 13); and the crane with a powered snatch block and power grip, to lift and stow the frustum. After the drogue is reeled in, its suspension lines are placed in the snatch block and the frustum is two-blocked and lifted aboard.

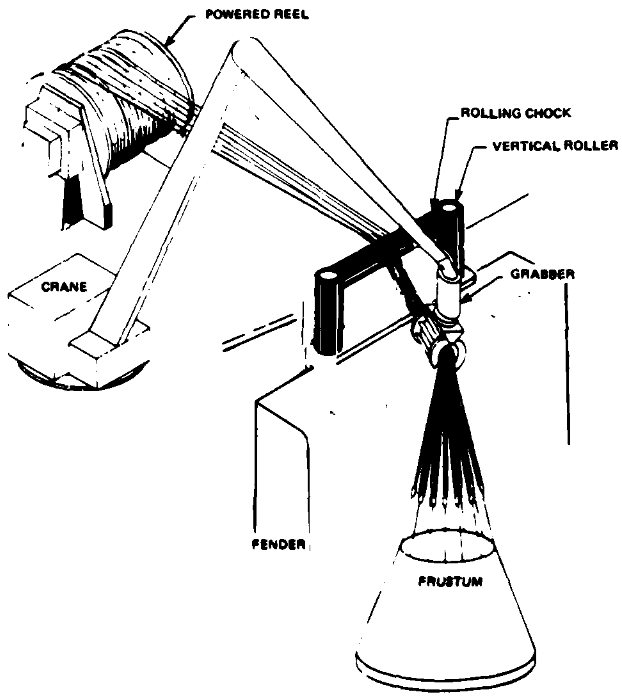



Figure 25. Rolling chock with powered reel and crane.

### Drogue/Frustum Stowage

Since all retrieval concepts that were considered require retrieval of the frustum by reeling in the drogue, the drogue is detached from the frustum after the frustum is stowed aboard the retrieval vessel. The drogue is stowed on the powered reel.

Because the lower edge of the frustum is protected by the expendable separation ring, no special pallet is necessary except to protect the deck. Plywood or dunnage is adequate. The frustum must be securely tied down to withstand the forces involved in transit to port. Capability must be provided to off-load the frustum in port.

The frustum does not have any tie-down points to secure it to the deck. Tie-down can be accomplished by using a stud gun or similar device to insert studs into the separation ring at the base of the frustum, then lashing the studs to deck tie-downs. Alternately, a net or harness can be placed over the frustum and attached to deck tie-downs.

Once the frustum is secured, it must be rinsed with fresh water to remove the salt so as to minimize corrosion. It is then covered.

## HANDLING

### Parachute Reel Handling

The parachutes (main and drogue) are stowed on reels after retrieval. The reels are dismountable from their drive pallets but normally remain attached to the drive pallets for handling and transporting to the refurbishment facility. These pallets are provided with pad-eyes for lifting by crane and have slots for the blades of forklift trucks. However, the parachute reels are easily separable from the reel drive pallets to minimize the number of pallets to be fabricated. The reels and pallets with parachutes loaded weigh approximately 5000 pounds each and can be handled by crane or forklift. The parachute reels must be interchangeable.

### Frustum Handling

The frustum requires a sling secured to the attachment points of the drogue parachute and is lifted off by a crane. A truck with dunnage is used for transporting it to the refurbishment facility.

## SUMMARY OF CONCEPTS

### Capture of Parachutes

Long-handled releasable snap hooks are used, with lift line fairleaded through the crane block. Snap hooks are attached to the apex float.

### Retrieval/Stowage of Parachutes

Apex of chutes go over outboard roller chocks to powered storage reels, one parachute per reel.

### Retrieval/Stowage of Frustum

Suspension lines from the drogue parachute are placed in a powered snatch block/ power grip on a crane. The crane lifts the frustum from the water and places it on wooden cribbing on deck. The frustum is secured by inserting studs into the separation ring and attaching them to deck tie-downs. Or a harness can be placed over the frustum and attached to deck tie-downs.

# THE SRB RETRIEVAL SUPPORT CRAFT

RL Watts

*Abstract*

*This paper is limited to the recovery of the Solid Rocket Boosters (SRB) and accessory hardware and specifically addresses the development of operating platforms to support at-sea retrieval.*

*NOSC provided to NASA an operational scheme and retrieval vessel specifications for SRB retrieval. Subsequent to this, NOSC was tasked by the Air Force Space and Missile Systems Organization to analyze their SRB recovery needs and to recommend a retrieval vessel approach suited to their particular needs, which are distinctly different from those of NASA.*

*The NASA recovery port facility near Cape Kennedy imposes some unique operational requirements on the retrieval vessels and dictates certain approaches to developing a platform capability.*

*The Air Force recovery requirements are based on a less frequent launch schedule and a different port facility arrangement that allows a more economical approach in providing a retrieval platform.*

*The requirements of both retrieval situations are discussed, and the development of retrieval vessel configuration and operating methods tailored to the two unique environments are compared and contrasted.*

Within the Space Shuttle Program there are two independent SRB recovery environments, each of which imposes its own unique requirements. East coast launches conducted by NASA from Kennedy Space Center (KSC) are expected to reach a peak launch rate of 40 per year, while the Air Force operation conducted from Vandenberg Air Force Base (VAFB) on the west coast is anticipated to have a maximum launch rate of 20 per year.

The platforms for either environment must be able to operate in the open ocean day or night and to provide a safe and reliable base of operations for all SRB recovery equipment and towing evolutions up through sea-state 4.

Because many of the requirements imposed by the two operating areas are appreciably different, the support platform configurations and operating scenarios are discussed separately.

## NASA SRB RECOVERY BASELINE

Since the first launch of NASA will precede that of the Air Force by almost 2 years, the recovery system and operational plan for it was necessarily developed first. A guideline established by NASA was that the at-sea recovery operations be developed around the use of commercially available offshore tug supply vessels. Under this guideline, no engineering effort was required to develop a seagoing platform configuration. Instead, the design task was first to investigate available tug supply vessels suited to SRB recovery operations, then to develop a plan for adapting and modifying these types of vessels to accommodate the recovery and towing hardware for meeting both routine and contingency recovery operations. An additional constraint is that these vessels must negotiate the canals, locks, and shallow-draft harbor entrances to the refurbishment facility on the Banana River.

**Environmental Restrictions Unique to KSC Recovery Area**

The environmental factors of sea-state and weather at the splashdown site are relatively mild. Conditions are generally sea-state 4 or less, with conditions above sea-state 4 occurring only about ten percent of the time and lasting an average of approximately 15 hours. Winds of 9 to 14 knots can be expected out of the southeast during summer and out of the northeast/northwest during winter. (See table 1.) These conditions pose no particular challenge for a vessel of the type recommended. However, the Gulf Stream creates northerly currents of up to 3 knots (greater than 6 knots is possible) throughout the year as well as a sharp velocity gradient normal to that flow of up to 0.5 knots per nautical mile.

| Factor | | KSC Splashdown Areas |
|---|---|---|
| Sea state[1] | $>$ SS4 ($>$ 8 feet) | 9.7% of time – (2-14%)[2] |
| | $>$ SS3 ($>$ 4 feet) | 47.4% of time – (22-68%)[2] |
| | Persistence $>$ 4 | ~ 15 hours (average) |
| Winds | Average speed | 13-14 knots north sector<br>9-10 knots south sector |
| | Direction | SE in summer<br>NW/NE in winter |
| Currents | Speed | Up to 3 knots[1]<br>(6+ knots possible) |
| | Direction | Generally N and NE with weaker S along coast |
| Visibility | Distance/occurrence | $<$ 2 nmi = 1%<br>$>$ 5 nmi = 95% |
| Temperature[1] | Air | 41-97°F |
| | Surface water | 72-83°F |
| Depth | | 800-3300 feet<br>(12 feet in canal to VAB) |
| Manmade | | Active shipping lanes<br>Submerged submarine operations area |

Notes:

1 Taken from addendum to NASA TM X 64589 (1971 Revision)

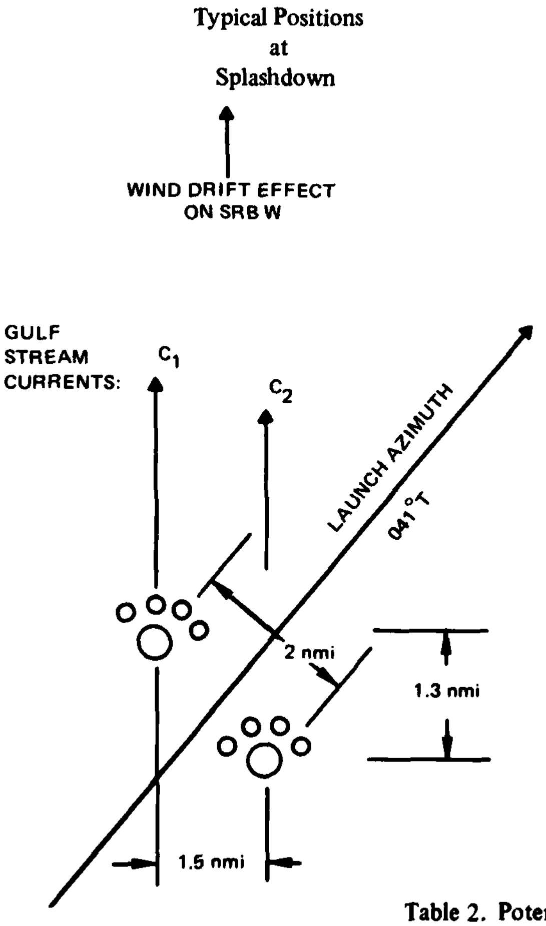
2 Depending on month

Table 1. Environmental characteristics of surface operations.

**Operating Requirements Support the Use of Two Platforms**

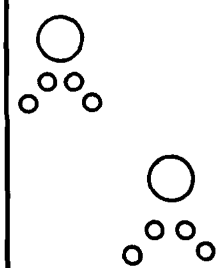
This condition strongly supports the use of two recovery vessels independently configured to perform all recovery and towing phases. During any delay in recovery, the SRBs, parachutes, and frustums can drift to dispersion distances, taxing the capability of a single ship to maintain proper contact. Significant dispersal can be caused by differences in drift rates between points in the ocean where each item is located, wind/sail effects on SRBs and frustums, and weather "holds" if the sea-state is greater than 4. A 15-hour hold with winds of 20 knots and a current gradient of 0.3 knots per nautical mile increases the 2-nmi SRB splashdown separation to 24 nautical miles, with the farthest unit 52.5 nautical miles from the splashdown area. Additional study shows that an average 15-hour hold with maximum current velocity (6.4 - 6.8 knots) and a 0.5-knot wind-drift effect on the SRBs results in a maximum unit separation of 14.8 nautical miles and a distance of 251.8 nautical miles from port. Under worst conditions (48-hour hold, 1-knot wind drift and 6.0- to 6.8-knot current), these distances increase to 87.7 nautical miles separation and 516.7 nautical miles from port (table 2). The continuing drift of retrievable hardware throughout the retrieval operation further increases these separation distances.

The availability of a second ship equipped for independent recovery operations greatly reduces this contact problem. It also decreases the total time required to retrieve the parachutes and frustums, dewater both SRBs, and rig them for tow. Another important consideration is a need for a backup system in case of a casualty at dockside or at sea that disables a retrieval vessel; the second vessel satisfies this requirement. Scheduled ship maintenance also results in downtimes of up to 30 days per year per vessel. A major reason for this long downtime is that these vessels are of standard ship construction, and propulsion and main machinery are integral parts of the vessel structure. This point is examined further in discussion of the VAFB support platform baseline.




(Worst Case)
Splashdown Range = 141 nmi
Weather hold for 48 hours
W = 1 knot
$C_1$ = 6.8 knots: $C_2$ = 6.0 knots
$\Delta C$ = 0.5 knots/nmi

POSITIONS AFTER 48-HR HOLD:



| Rel Dist, nmi | Dist from Splash-down, nmi | Dist from Port, nmi |
|---|---|---|
| 87.7 | 375.7 | 516.7 |

Table 2. Potential dispersion.

**Retrieval Vessel Configuration Requirement**

The operational requirements limit the configuration of the retrieval vessel hull to a very large degree. The deck space and layout requirements of the other retrieval-system subsystems also constrain the hull configuration.

Vessels of a large variety originally were considered as candidate concepts. The maximum draft of 12 feet and the requirements for an expanse of deck space precluded all but a few of the early candidates, however, and these were further reduced by cost considerations and availability to one type: the oil field offshore support class vessels.

The oil field offshore support class vessels are of two basic categories:

Tug/supply vessels

Supply vessels

The tug/supply vessels are generally larger vessels with more horsepower and a greater draft than the supply vessels. Tug/supply vessels are generally equipped with towing winches, while supply vessels are not. Tug/supply vessels generally (but not always) have twin stacks located forward; supply vessels generally have twin stacks located aft. Tug/supply vessels range in length from 150 to 180 feet with 32- to 38-foot beams. Tug/supply vessels have a maximum draft ranging from 12 to 17 feet, while supply vessel maximum drafts range from 9 to 12 feet.

Hulls of both categories generally are of welded steel construction, meet ABS class "Maltese Cross" A1 requirements, and are US Coast Guard approved for unrestricted ocean operation. Table 3 illustrates typical characteristics of tug/supply and supply vessels considered appropriate for the intended recovery scenarios.

| | Tug/Supply Vessels | Supply Vessels |
|---|---|---|
| Length overall | 176 feet | 194 feet |
| Beam | 38 feet | 40 feet |
| Draft (minimum) | 9 feet | 13 feet |
| Horsepower | 3080 | 6325 |
| Stack location | Forward | Forward |
| Screws | Twin, opposed rotation | Twin, opposed rotation |
| Bow thruster | Yes | Yes |
| Stern roller | Yes | Yes |
| Open deck (without towing winch) | 114 x 30 feet | 134 x 32 feet |

Table 3. Ship subsystem eligible candidate characteristics.

The final baseline configuration specifies two tug/supply vessels (figure 26), each outfitted similarly and with trained retrieval crews. Each vessel operates independently. Under average conditions, each should complete its recovery at about the same time and consequently return the SRBs to the shore facility at about the same time.

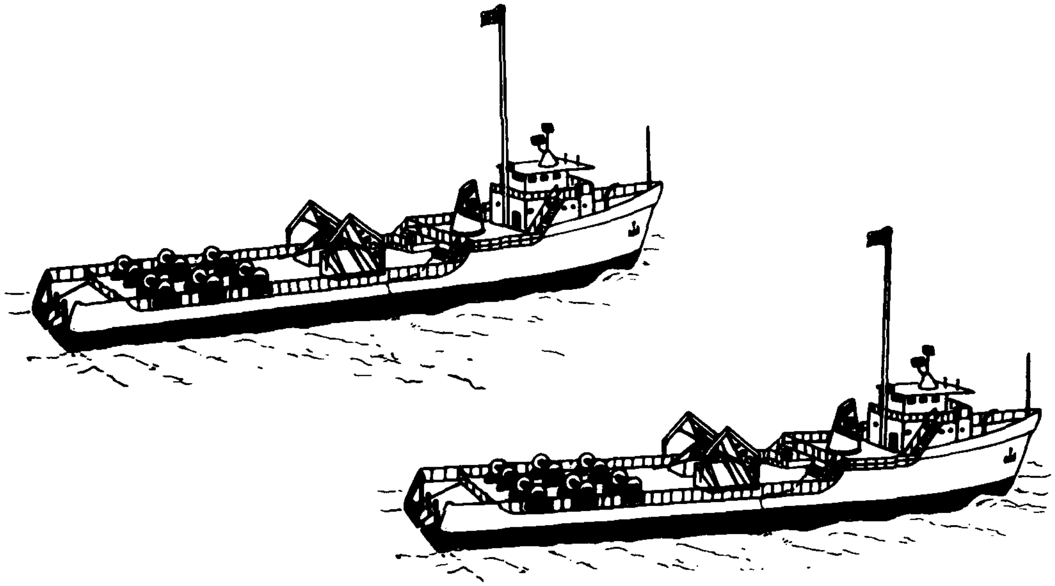


Figure 26. NASA SRB recovery vessels.

## A POWERED BARGE/LEASED TUG CONCEPT FOR VAFB RECOVERIES

The reduced launch frequency and an innovative approach to platform maintenance allow the consideration of an alternate baseline approach to the VAFB recovery platform specifications and operating scenario. It will be shown that this alternate baseline results in significant cost savings to the overall recovery program through reduced operating cost and lower initial capital investment in recovery systems hardware. These savings are achieved with no sacrifice in reliability and only minor impact on the recovery operations schedule.

The alternate baseline differs from the original NASA scheme mainly in the surface support platform configuration and attendant reduction in quantity of retrieval systems hardware. A single powered barge carrying retrieval hardware and backup systems for retrieval and dewatering of two complete SRB sets is assisted by a commercially leased tug for towing the units back to port. Reliability is maintained by using the same retrieval systems employed in the NASA system; but because VAFB operations do not contend with the potentially high dispersion of the units, retrieval and dewatering of SRB hardware is accomplished serially. Upon completion of the first retrieval and dewatering, the first SRB is handed off to the tug for tow to port and the powered barge begins retrieval and dewatering of the second set of SRB hardware. Upon completion of the second dewatering, the powered barge tows the second SRB to port.

### Powered Barge Design Requirements

The objectives of the powered barge platform are to provide all the sea-keeping, transit, and towing capabilities of the NASA baseline and to provide for safe and reliable operation of all the necessary hardware for two complete SRB recoveries, including required backup systems. It may be seen from table 4 that sea-state conditions in the VAFB splashdown area are roughly similar to those of the KSC area but lack the strong current gradient caused by the Gulf Stream. Thus all the seaworthiness, safety certification, and maneuvering requirements imposed on the KSC recovery vessels apply to the powered barge system.

| Factor | | VAFB Splashdown Areas |
|---|---|---|
| Sea state | > SS4 (≥ 9 feet) | 7.6% of time – 5-13% * |
| | > SS3 (≥ 5 feet) | 43.3% of time – 34-51% * |
| | Persistence 4 | ~ 20 hours average;<br>~ 70 hours max* |
| Winds | Average speed | 13-14 knots |
| | Direction | Generally SE |
| Currents | Speed | Up to 0.4 knots (1 knot possible) |
| | Direction | Generally SE |
| Visibility | Distance | < 2 nmi < 1.5% of time |
| | Occurrence | > 5 nmi > 95% of time |
| Temperature | Air | 40-84°F |
| | Surface water | 57-65°F |
| Depth | At splashdown<br>(harbor and inland) | 120-14000 feet<br>(30 feet in Port Hueneme) |
| Manmade | | Active shipping lanes<br>Submerged operations area |

*Depending on month

Table 4. Sea conditions, VAFB splashdown area.

An additional requirement of this system is that since it is the only primary recovery platform, it must be maintainable throughout a program that allows for a maximum yard period of 20 days, and some scheme must be developed to accommodate recoveries in the event of catastrophic failure of the platform. Since all the recovery hardware is essentially portable, recovery operations could be conducted from two leased offshore tug/supply boats by transferring the recovery hardware. This could be accomplished on short notice and is recommended only in the event of unavailability of the powered barge.

**Candidate Platform Approaches for Alternate Baseline**

With the aforementioned constraint in mind, several approaches to developing the required platform were investigated. In-depth consideration, with emphasis on performance and economy, was given to both new construction and conversion alternates. The conversion of existing barges was limited to hulls at least 140 feet long, which would provide necessary deck space. Of the military barges available, only six were large enough. Because of extensive installations already on these barges, however, conversion was determined to be prohibitively expensive. Several commercial barges were available that were of the proper size, but adding the purchase price to conversion costs again ruled out this method. In addition to barges, a survey of available assets within the tug/supply vessel fleet was made. Several vessels in the 206- to 226-foot class are now available. (Earlier studies showed that the smaller 150- to 190-foot boats would be unable to accommodate equipment for two full recoveries safely and with adequate contingency, on a continuing basis.) But these vessels have an extended superstructure and towing winch installation that limits usable open deck space to an area not adequate to meet the needs of routine dual-recovery operations. It was concluded that if any tug/supply vessels were used, at least two of them probably would be needed. It should be remembered that to use these vessels still implies a yard period of approximately 30 days for major maintenance and overhaul cycles.

A new-construction powered barge provides the best cost benefit, both initial and long-term, and meets or exceeds all operational requirements. In developing the concept of the powered barge, much information on the projected operational capabilities and the conversion costs of existing barges was developed from NAVFAC CHESDIV experience with SEACON.* The SEACON (figure 27) is a converted YFNB Navy barge that was designed to support a number of at-sea construction, salvage, submersible, and diving operations. SEACON displaces 2300 tons and is 260 feet long with a 48-foot beam. She has extensive covered work space, shops, and accommodations for 50 underwater construction team personnel. Therefore, her usable deck space is limited to only 130 by 48 feet. To convert a similar hull for SRB recovery would be not only extravagant in terms of capability but costly compared to new construction designed specifically around the task at hand.

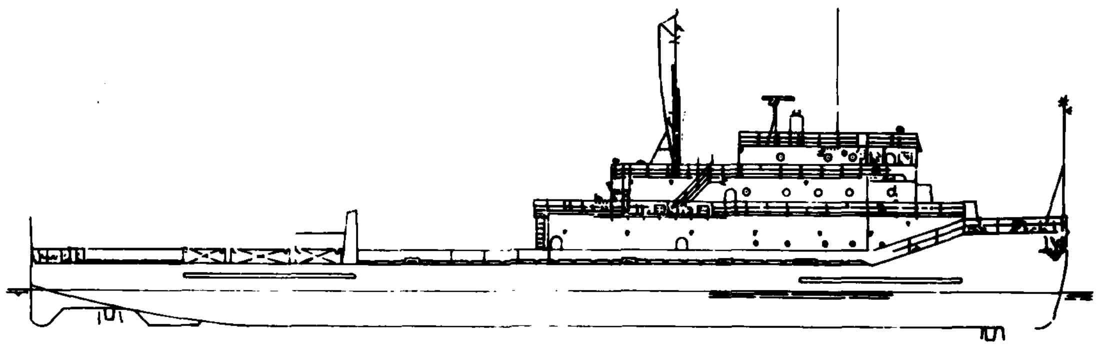


Figure 27. SEACON outboard profile.

**Powered Barge Design Specifications**

Since only limited superstructure is required for navigation and ship husbandry functions, and since crew accommodations, machinery spaces, and stores can be accommodated below decks easily, a powered barge 180 feet long with a 55-foot beam provides adequate platform area to support recovery, dewatering, and towing equipment. The basic design is similar to tug/supply vessels in that all main superstructure is located far forward, leaving a large open afterdeck for easy access to the water while providing protection from prevailing seas when the barge is headed into those seas.

The method of installing all the main machinery, including propulsion, is a definite departure from standard ship construction. These units are designed to be installed or removed as a complete system without the need of drydocking. To maintain ABS certification of the platform and assure a reliable and safe operating system, however, drydocking for the purpose of bottom maintenance and preservation is required every 5 years. Zinc anodes below the waterline are of bolt-on type to allow for diver replacement, since typical service life of these units is approximately 2 years. Drydocking of this sort of platform for sandblasting, inspection, painting, and replacement of zinc anodes can be accomplished in a minimum of 5 days. Or, if 100 percent bottom coverage is desired, the drydock period is more likely to be 10 days. All other major and minor maintenance is designed to be accomplished pier-side. The main propulsion units for instance, including engine and lower drive units, can be removed from or replaced in their pedestal mounts while the vessel is in the water.

*SEACON is a YFNB barge hull (260 feet long) converted to a self-propelled ocean construction platform. It is powered by three 350-hp Voith Schneider thrusters and has a speed of 7 knots.

Requirements for the powered barge concept include a bow thruster to aid in ship positioning during the retrieval operation and to assist in general station keeping. The projected main thruster horsepower requirement is 2000, for towing SRBs successfully at 7 knots and to provide needed maneuverability. It is a complex task to predict platform performance characteristics. Analytical studies, experience with the SEACON operations, and various towing contractors' experience support a predicted cruising speed for the powered barge of approximately 10 knots. The following organizations also provided supporting data: NAVFAC, CHESDIV, Washington Navy Yard, Wash. D.C.; Globar Marine, Newport, CA; National Steel and Shipbuilding Co., San Diego, CA; and Pacific Towboat & Salvage, San Diego, CA.

Dual engine control stations, on port and starboard bridge wings, are recommended to give the master an unobstructed view of the SRB, Nozzle Plug, parachutes, and frustum.

The propulsion system is tailored to meet the specific operational requirements for minimum system cost and maximum fuel economy. The engine thruster combinations considered for platform propulsion are described here by order of preference.

Option 1. Two diesel-driven open propeller main thrusters of 1000 hp each and one 200- to 500-hp electric-driven ducted bow thruster. All are 360-degree trainable with fixed-pitched propellers. (No drydocking required on any servicing.)

Option 2. Two Voith Schneider cycloidal thrusters, each with a 1000-hp direct-drive diesel. One system is mounted forward, the other aft. (Requires drydocking for service to thruster head.)

Option 3. Two main thrusters of 1000 hp each, fixed shaft and variable-pitch propellers, and one 200- to 500-hp trainable bow thruster with ducted fixed-pitch propeller. (Requires drydocking for major servicing.)

TOWING CAPABILITIES. The SRBs must be able to be towed to the shore facility with a dynamic pull on a single line of less than 40000 pounds. Capability for a tandem tow must be provided in the event of a breakdown of the tug.

MOORING EQUIPMENT AND GROUND TACKLE. The barge should be equipped with bow anchor, chain, and an anchor windlass with gypsy heads for line handling. Standard mooring hawsers for tying up at dock are included.

ACCOMMODATIONS. The dedicated barge should accommodate at least 20 persons in four-person cabins. Messing facilities are also included.

**Powered Barge Acquisition Plan**

Procurement of the powered barge is planned to be accomplished in two phases. The first phase provides a detailed system design and procurement specification. Phase two is a fixed-price construction contract to provide an operational powered barge system. It is expected that from initiation of phase one, a completed system can be delivered in slightly less than 3 years.

# CONTINGENCY SITUATIONS AND PLANS FOR RETRIEVAL OF SOLID ROCKET BOOSTERS OF THE NASA SPACE SHUTTLE

**RE Jones**

*Abstract*

*Implementation of the normal modes of retrieval of Solid Rocket Boosters and their associated hardware may not always be possible. It is therefore necessary to plan, design, and fabricate systems to provide an alternate method of retrieving recoverable items that fall into the sea.*

*Currently, NASA has elected to confine itself to providing telescopic harpoons for operation either from a slightly modified Nozzle Plug or by divers.*

*During the studies conducted at NOSC, many contingency situations were identified and solutions for them were conceptualized. Selected examples with appropriate illustrations are presented herein.*

At the request of the National Aeronautics and Space Administration, Kennedy Space Center, NOSC conducted studies to identify contingency situations that may have significant impact on the retrieval of Solid Rocket Boosters (SRBs) and their associated components. In addition, NOSC was requested to propose alternate retrieval techniques and equipment to increase the probability of successfuly recovery of SRB components. The contingencies identified included main parachute entanglement with the top of the SRB, parachute blockage of the SRB nozzle, entanglement of two or three main parachutes with one another, and parachute sinking. Also identified were frustum and drogue entanglement, frustum sinking, and loss of the drogue apex float. Several contingencies were anticipated that directly affect the SRB, including failure to achieve a vertical attitude, suspected and confirmed leaks in the SRB casing, partial or total nozzle blockage, and SRB sinking.

The probability of occurrence of the several contingency situations does not readily lend itself to analysis. No empirical data of significance are available because no precedent exists. Therefore, the determination of contingency situations has been approached intuitively.

## SPACE SHUTTLE RECOVERY SCENARIO

Following the initial acceleration phase of the Space Shuttle Orbiter launching, the two spent Solid Rocket Boosters, each about 140 feet long and 12 feet in diameter, are explosively jettisoned. On each, the nose cap is separated and a pilot parachute emerges that pulls a drogue chute out of the frustum. The frustums are then separated from the SRB. Each SRB deploys three ribbon-type parachutes and descends to the ocean, impacting at about 80 feet per second. Ordnance devices separate the parachutes from the SRBs on impact. One parachute deploys a towing pendant attached to the top of the SRB. The SRB soon float stabilizes in a vertical attitude (spar mode). The frustum, suspended from its drogue, impacts nearby. As the drogue collapses and sinks, its weight overturns the frustum; the drogue apex is supported by a float for easy recovery. The three main parachutes hang in the water, suspended from apex floats, until retrieved. Location assistance is provided by sonar beacons, flashing lights, and rf transmitters attached to the various components.

## DISCUSSION

Since the most critical items for recovery – from an economic standpoint – are the SRBs, the contingency plan currently adopted by NASA is concerned primarily with situations that could impact SRB case retrieval. For the situation of a partially blocked nozzle (precluding the use of a Nozzle Plug in the normal mode), a preliminary design and an operational plan have been completed in which a strap-on telescopic harpoon equipped with retaining toggles can be deployed from a very slightly modified Nozzle Plug.

The harpoon (figure 28) uses a telescoping mechanism (figure 29) for reduced overall length until it is actuated and inserted into the SRB. Initial calculations determined that the harpoon must extend 18 feet above the NP (24 feet overall) to allow sufficient clearance inside the SRB for toggle arm deployment (assuming NP positioned about 3 feet below the nozzle). In the stowed position, the harpoon extends 2 feet above the NP. The extended and stowed positions relative to the NP are illustrated in figure 28. The small size of the harpoon when stowed alleviates many of the problems associated with launching and operating the NP with the device attached to it. Because the harpoon in the stowed position extends only 2 feet beyond the NP, crane attachment to and launch of the NP follow standard procedure. Operation of the NP is unaffected by the attached telescopic harpoon. The light weight of the harpoon and short extension beyond the NP allow unobstructed operation throughout the traverse and positioning phases of the dewatering procedure and do not significantly affect CG.

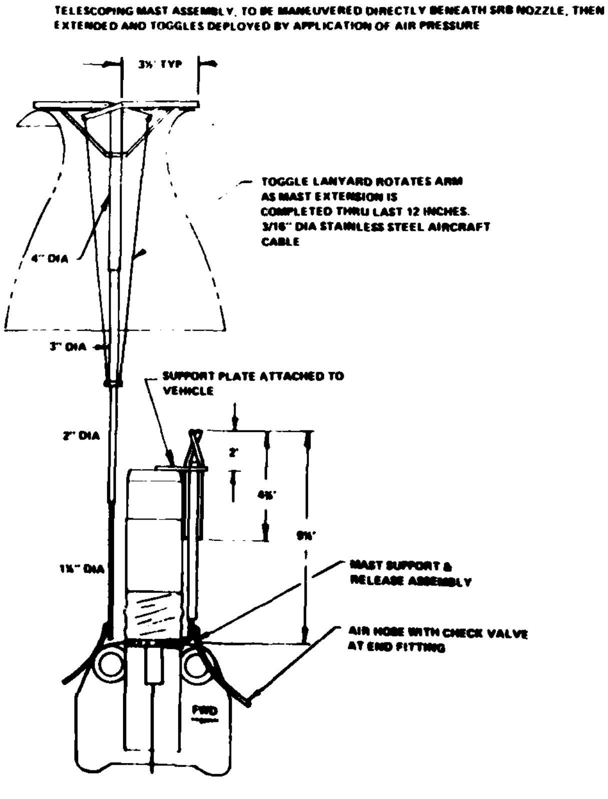



Figure 28. Telescopic harpoon on NP, showing position of extended and stowed mast relative to SRB nozzle.

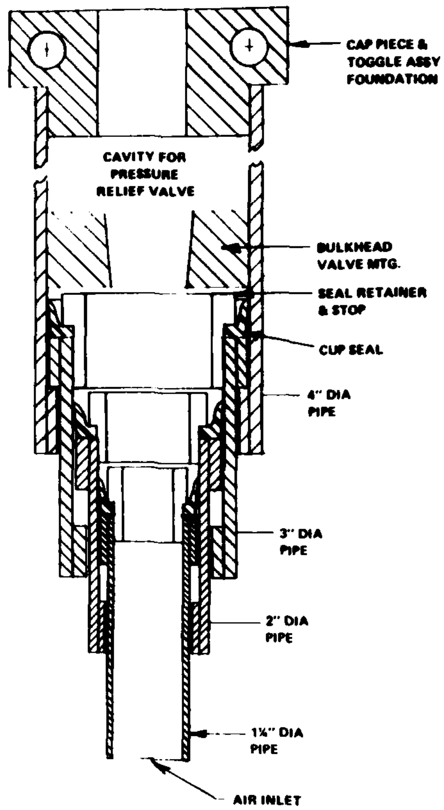



Figure 29. Telescoping mechanism.

Actuation of the harpoon mechanism for insertion into the SRB casing is effected by air pressure sufficient to overcome both the relief valve between the hose and harpoon and frictional forces within the mechanism but not sufficient to open the harpoon relief valve. Increased air pressure opens the relief valve and allows air to enter the SRB casing. The use of an adjustable relief valve allows the extension force to vary as required to overcome any changes in friction caused by changes in the material properties of the harpoon mechanism as it ages.

As the harpoon extends through the last foot of travel, the toggle arms deploy automatically, activated by lanyards fixed to the preceding section of the harpoon. Preliminary design of the toggle arms indicates that a minimum arm length of 5 feet is required to insure positive retention in the event one arm fails to deploy properly.

The telescopic harpoon is attached to the NP in two places. The primary attachment point connects the base of the harpoon to the NP by a baseplate that is affixed to the NP by anchor bolts inserted into the water drain holes of the NP transition section. The baseplate supports the weight of the harpoon and carries the harpoon release mechanism. The release mechanism consists of a redundant shear pin system in which the NP thrusts down against the deployed toggle arms to break the shear pin and release the harpoon. The release requires only that the harpoon be extended into the casing, which is visually verified by video feedback from the NP TV camera. Once extended, the NP can immediately thrust down from the nozzle, bringing the toggle arms against the nozzle and breaking the shear pin.

Thus only for a minimum time are the NP and harpoon vulnerable to collision with the SRB. The undersides of the toggle arms have reflective tape attached for improved visibility. The operation sequence is shown in figures 30A and 30B.

Furthermore, this release system provides a positive test for toggle arm deployment. Should the toggle arms fail to deploy, the harpoon is withdrawn when the NP backs away, allowing convenient recovery of the harpoon for failure analysis and repair. When the SRB is under tow, the towing forces on the air umbilical might pull the harpoon out of the casing without the toggles. The result of this occurrence could be damaging if the SRB should ingest enough water to go into the spar mode in shallow water.

The secondary attachment point is simply a plate with a cut-in slot to capture the larger diameter pipe of the harpoon. This plate provides lateral support of the harpoon until it is extended, whereon the smaller diameter pipe and air hose pass through the slot, releasing the harpoon when the shear pin is broken.

This same harpoon system can be diver deployed and operated with very simple modifications to provide reaction for the resisting forces that may be encountered when it passes through the nozzle. A manually operated valve replaces the hose end check valve.

A preliminary design has also been completed for a lightweight buoyancy system consisting of air-filled buoyancy bags and harnesses for attachment to an SRB that cannot be adequately dewatered. Figures 31, 32, and 33 illustrate the system. The buoyancy bags are commercially available off-the-shelf products with minor modifications required for this application.

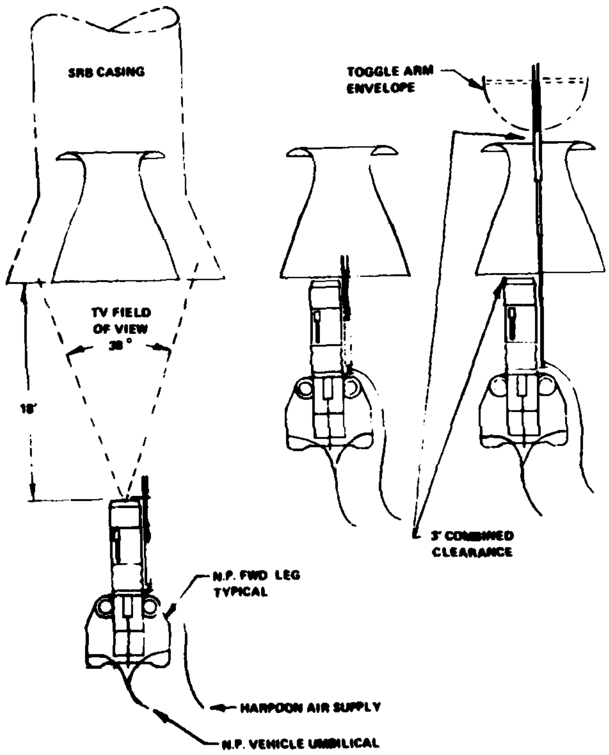



Figure 30A. Telescoping harpoon operation sequence.

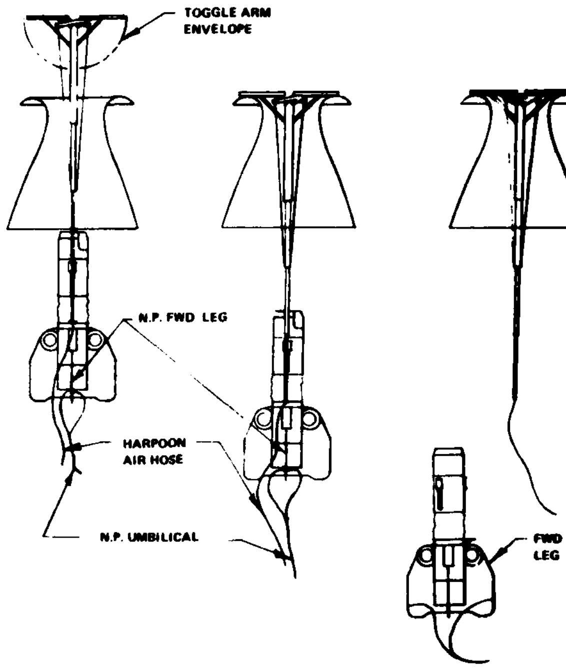



Figure 30B. Telescoping harpoon operation sequence.

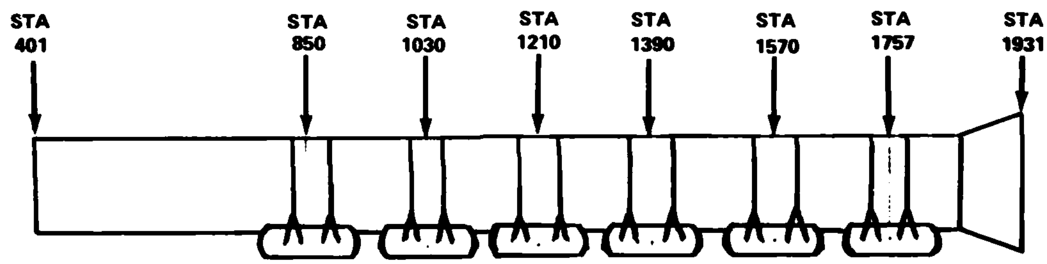



Figure 31. Buoyancy bag stations.

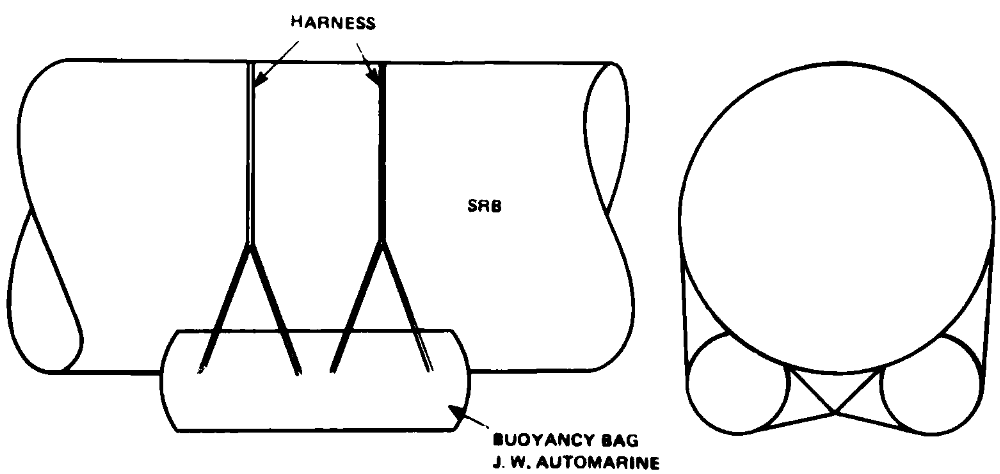
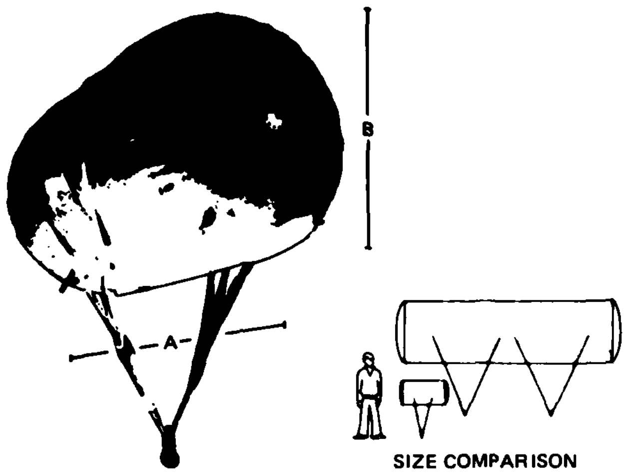



Figure 32. Bag arrangement.




| Model | Lift capacity (kg) | A | B | Weight |
|---|---|---|---|---|
| T7 | 7000 | 4.25 m | 1.5 m | 63 kg (140 lb ) |

Figure 33. JW Automarine lift bag.

Studies and conceptual designs were performed in several areas to plan for the many anticipated contingencies. A series of Nozzle Plug replacement modules was developed to provide the undersea vehicle with a work capability that would be useful in many situations. For example, replacement of the upper modules with an arm having a claw or cutter and an arm having a hook and a reel were conceptualized to assist in parachute removal from the SRB nozzle and for handling harpoons for dewatering through a damaged nozzle. These are illustrated in figures 34 A, 34 B, and 34 C. An inflatable bladder module carried aboard the Nozzle Plug for dewatering an SRB casing was considered for use where the SRB was incapable of holding air and therefore of pitching over to the log mode. NASA studies indicated a very low probability for this occurrence. The concept is illustrated in figure 35.

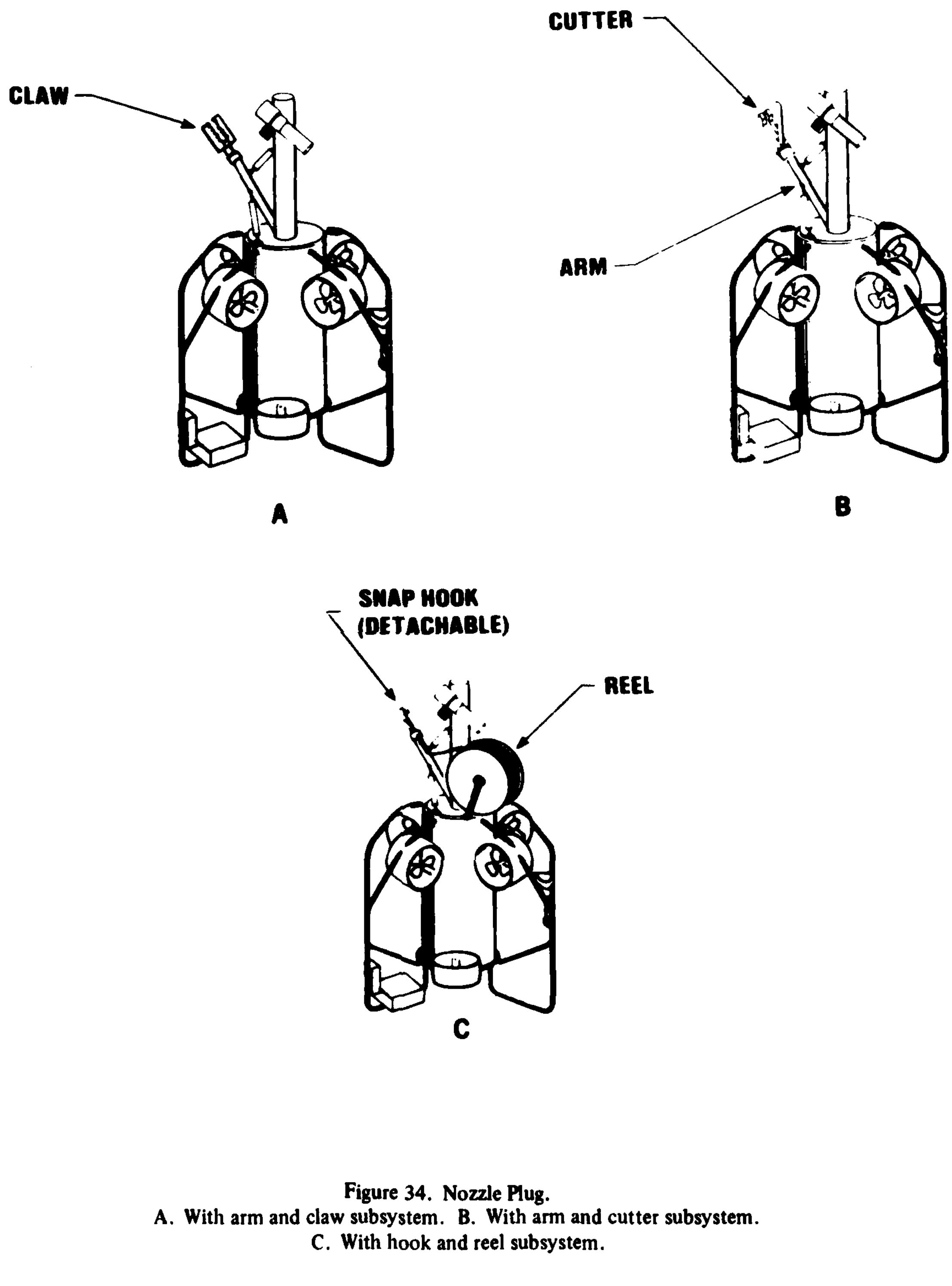



Figure 34. Nozzle Plug.
A. With arm and claw subsystem. B. With arm and cutter subsystem.
C. With hook and reel subsystem.

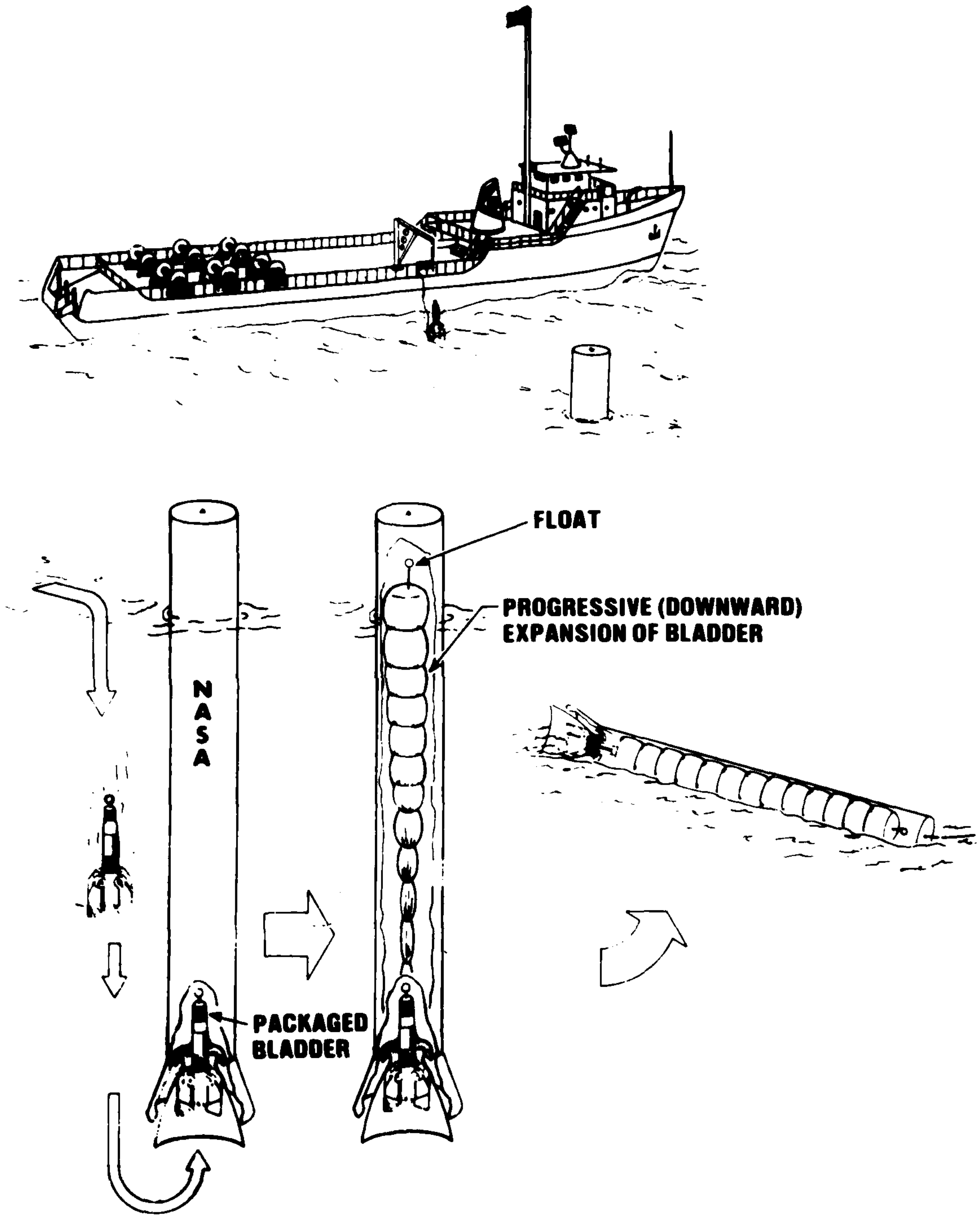



Figure 35. Inflatable bladder module.

A procedure using swimmers or an arm-and-claw-equipped Nozzle Plug was developed to "de-air" an SRB that fails to assume the vertical attitude following water impact. Figures 36 and 37 illustrate the technique.

Two procedures for retrieving an SRB with a totally blocked nozzle were submitted. The first contemplates a series of "life rings" or flotation collars attached to each other, as shown in figure 38, to put the SRB in the log mode. These are lowered, before inflation, over the top of the SRB. The upper collar is attached to the top of the SRB and the lower collar to a ring carrying arms which, when actuated, hook under the SRB skirt. Sequential inflation of the rings by a hose from the attendant ship raises the SRB and pitches it over to the log mode. Adequate sizing of the flotation collars causes some dewatering of the SRB as it changes to the log mode, decreasing its draft. Similar collars have been built and successfully used in the Apollo program to keep the spacecraft safely floating during recovery. The second concept uses a large valved penetrator attached to the SRB above the waterline, as shown in figure 39. After the penetration of the hull is made, a second valve chamber containing a tightly packed bladder is attached to the penetrator. The inner valve is opened and

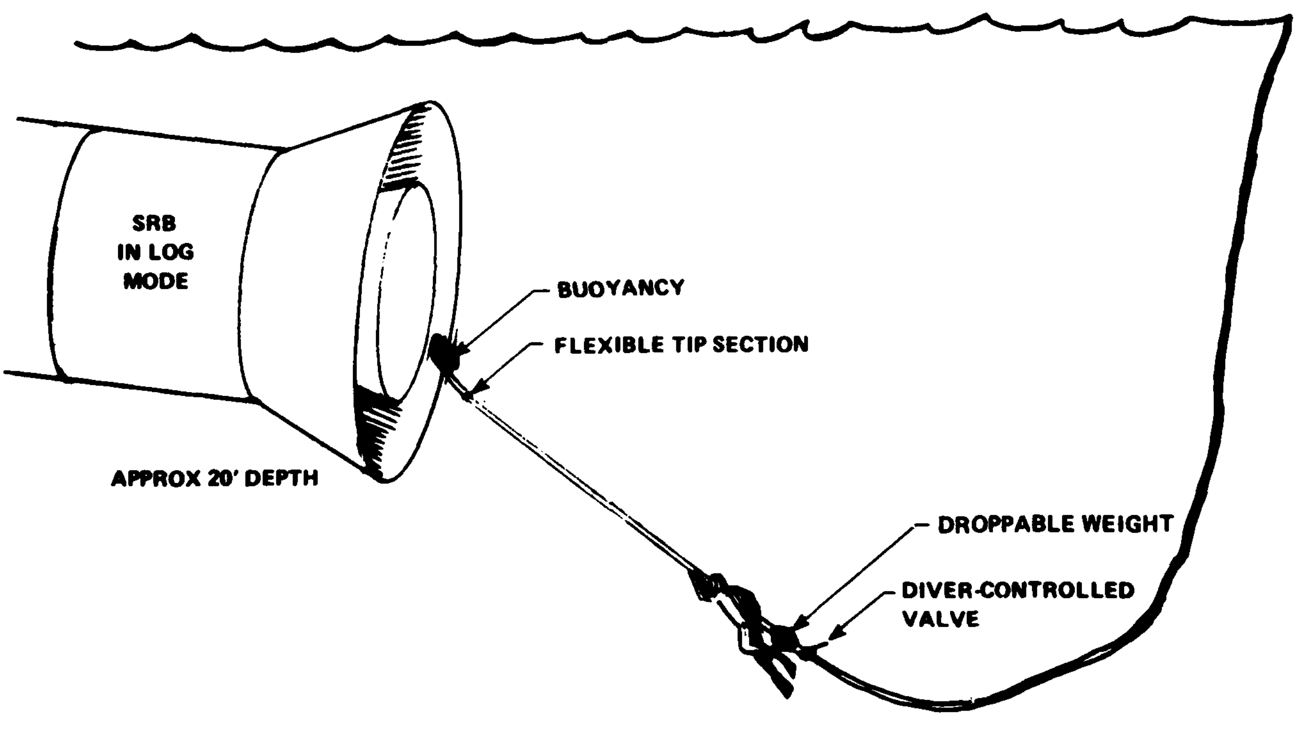



Figure 36. Diver-handled harpoon for uprighting SRB.

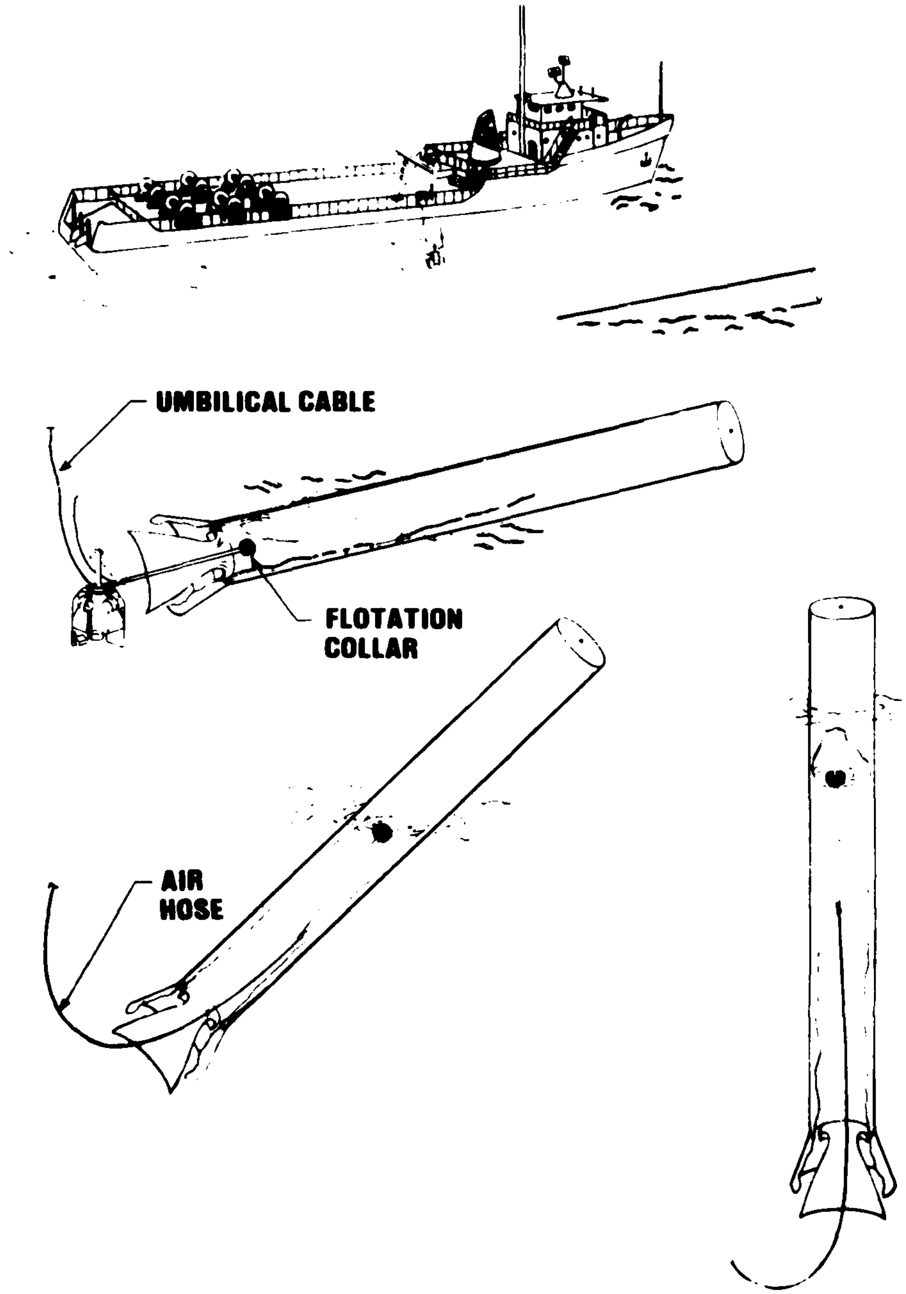



Figure 37. Procedure for uprighting SRB by use of the arm- and-claw-equipped Nozzle Plug.

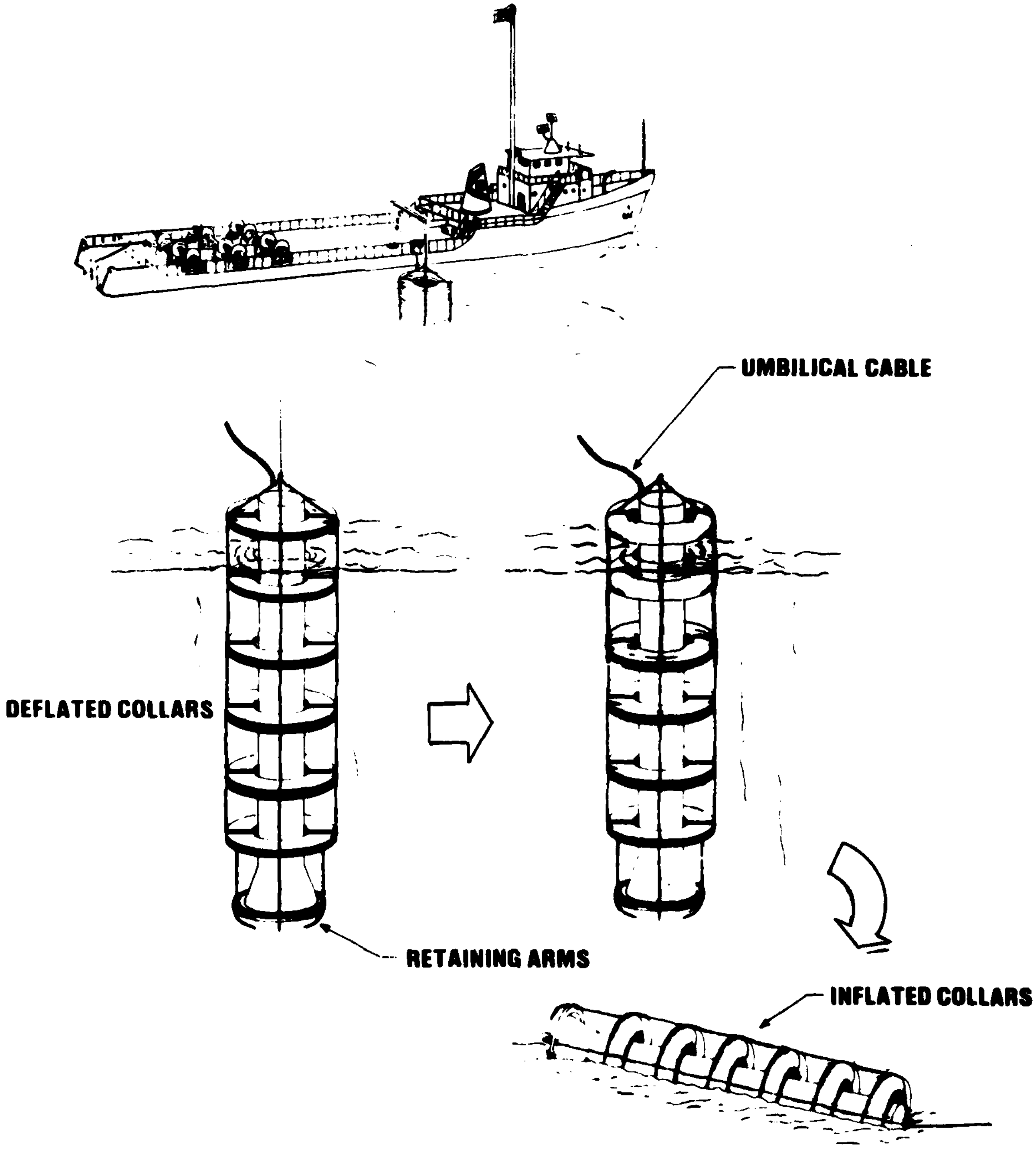



Figure 38. Flotation collar assembly.

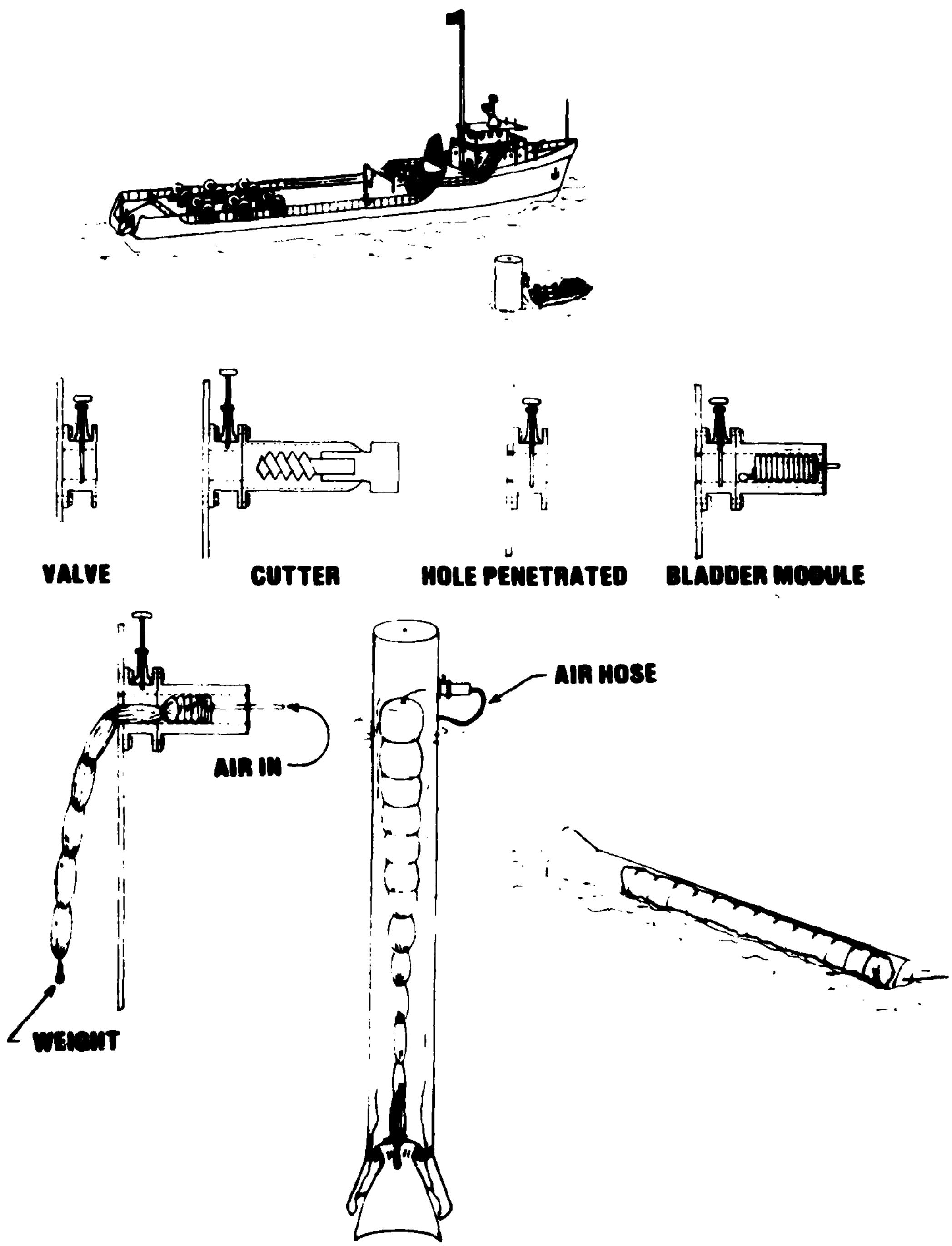



Figure 39. Bladder and penetrator.

the bladder, weighted at the end, is pushed into the SRB by air pressure. On inflation, it pushes the water downward and out, which allows the SRB to attain the log mode. This method has the obvious disadvantage of damaging an SRB segment and is considered only as a last resort. Many other systems and procedures were developed but have not been included in the contingency plans. Space limitations prevent their inclusion in this paper.

## CONCLUSION

Contingencies and associated solutions and techniques have been presented to provide some indication of the magnitude and diversity of what can go wrong. Many details have been omitted in the interest of brevity.