NASA Facts

Space Shuttle Solid Rocket Booster Retrieval Ships

To make space shuttle launches as economical as possible, the reuse of flight hardware is crucial. Unlike rocket boosters previously used in the space program, the space shuttle's solid rocket booster casings and associated flight hardware are recovered at sea. The expended boosters are disassembled, refurbished and reloaded with solid propellant for reuse.

The Ships and Crew

The two retrieval ships which perform the booster recovery, the *Liberty Star* and *Freedom Star*, are unique vessels specifically designed and constructed for this task. *Freedom Star* and *Liberty Star* are owned by NASA. They were built near Jacksonville, Fla., at the Atlantic Marine Shipyard on Fort George Island in 1980.

The ships are 176 feet in length, 37 feet in width, and draw about 12 feet of water. Each ship displaces 1,052 tons.

The ships are propelled by two main engines providing a total of 2,900 horsepower. The main engines turn two seven-foot propellers with controllable pitch. This provides greater response time and maneuverability.

A retrieval ship arrives at a half-submerged solid rocket booster after a shuttle launch. Divers will prepare the booster under water to float horizontally and be towed back to Port Canaveral.

The ships also are equipped with two thrusters. The stern thruster is a water jet system that allows the ships to move in any direction without the use of propellers. This system was installed to protect the endangered manatee population that inhabits regions of the Banana River where the ships are based. The system also allows divers to work near the ships at a greatly reduced risk during operations.

Improvements have been made to the ships since they first began service. Both vessels are now outfitted with highly precise Differential and WAAS Global Positioning System (GPS) navigational equipment, a Flume Tank System for increased stability, state-of-the-art communication systems, and man-rated, SOLAS-approved boat davits.

The ship's complement includes a crew of 10, a nine-person booster retrieval team, a retrieval supervisor and observers. The maximum complement is 24 people.

The Shuttle Solid Rocket Boosters

The typical shuttle flight trajectory takes the vehicle away from the continental United States and over the Atlantic Ocean. Power is provided by the combination of the orbiter's three main engines and the twin rocket boosters.

A pair of boosters, fully loaded with propellant, weigh about 2.8 million pounds apiece. They stand 149.2 feet tall, and have a diameter of 12 feet.

The boosters in use today are the largest solid propellant motors ever developed for space flight and the first to be used on a manned space vehicle. These boosters will propel the orbiter to a speed of 3,512 miles per hour.

The twin boosters expend their fuel at about two minutes after the space shuttle lifts off from the launch pad. The boosters separate from the orbiter and its external tank at an altitude of about 26.3 nautical miles above the Earth's surface.

After separation, momentum propels the boosters for another 70 seconds. They reach an altitude of 38.6 nautical miles before they begin their long tumble back to Earth.

SRB Descent and Splashdown

The nose cap of each booster is jettisoned at an altitude of 2.5 nautical miles. A pilot parachute is deployed. The pilot parachute immediately deploys the drogue parachute that is attached to the top of the frustum (the cone-shaped structure at the forward end of the booster).

At an altitude of 1.1 nautical miles, the frustums separate from the boosters. This action releases three main parachutes housed within the frustums. These chutes quickly slow the booster's speed from 230 miles per hour to a speed of 51 miles per hour.

The boosters impact the Atlantic Ocean approximately seven minutes after liftoff. The splashdown area is a square of about 6 by 9 nautical miles located about 140 nautical miles downrange from the launch pad.

The retrieval ships are stationed approximately 8 to 10 nautical miles from the impact area at the time of splashdown. As soon as the boosters enter the water, the ships accelerate to a speed of 15 knots and quickly close on the boosters.

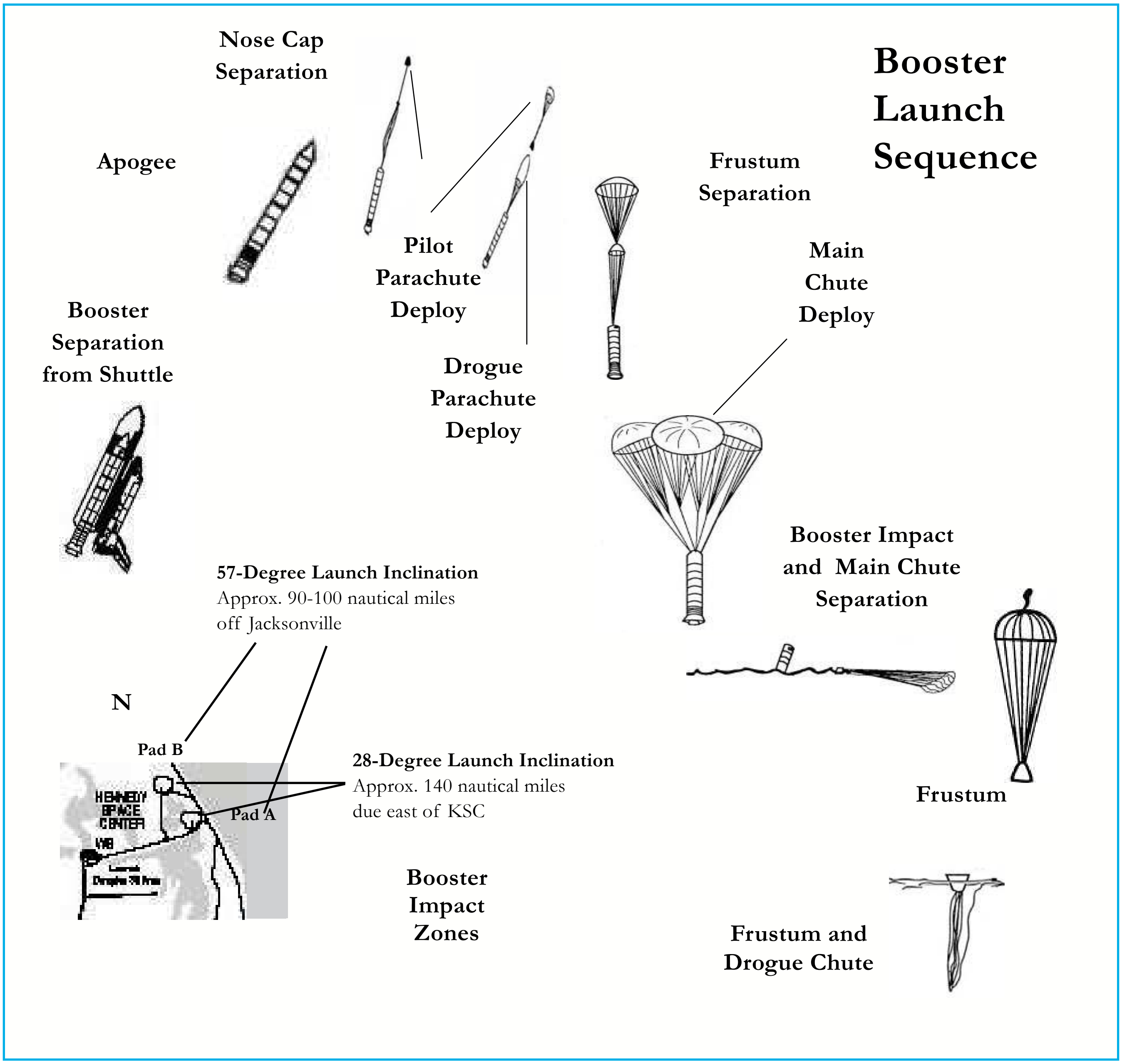
Retrieval

Each ship retrieves one booster. Upon arrival at the splashdown point, the recovery team first conducts a visual assessment of the flight hardware.

The pilot chutes and main parachutes are the first items to be brought on board. Their shroud lines are wound onto three of the four reels on the ship's deck. The drogue parachute, attached to the frustum, is reeled onto the fourth reel until the frustum is approximately 50 feet astern of the ship. The 5,000-pound frustum is then lifted from the water using the ship's power block and deck crane.

With the chutes and frustum recovered, attention

Mission Event	Elapsed Time After Liftoff	Height (feet/meters)	Speed (miles/kilometers per hour)
Booster separation from shuttle	124 seconds	156,000 feet (47,549 meters)	
Apogee (maximum height booster reaches after separation)	196 seconds	238,000 feet (72,542 meters)	
Nose cap separation/ pilot chute deploy	349 seconds	16,000 feet (4,877 meters)	360 mph (579 kph)
Drogue chute deploy	350 seconds	15,530 feet (4,734 meters)	
Frustum separation/main chute deploy	371 seconds	6,450 feet (1,966 meters)	250 mph (402 kph)
Booster impact and main chute separation	414 seconds		50 mph (81 kph)
Frustum/drogue chute impact	459 seconds		40 mph (64 kph)



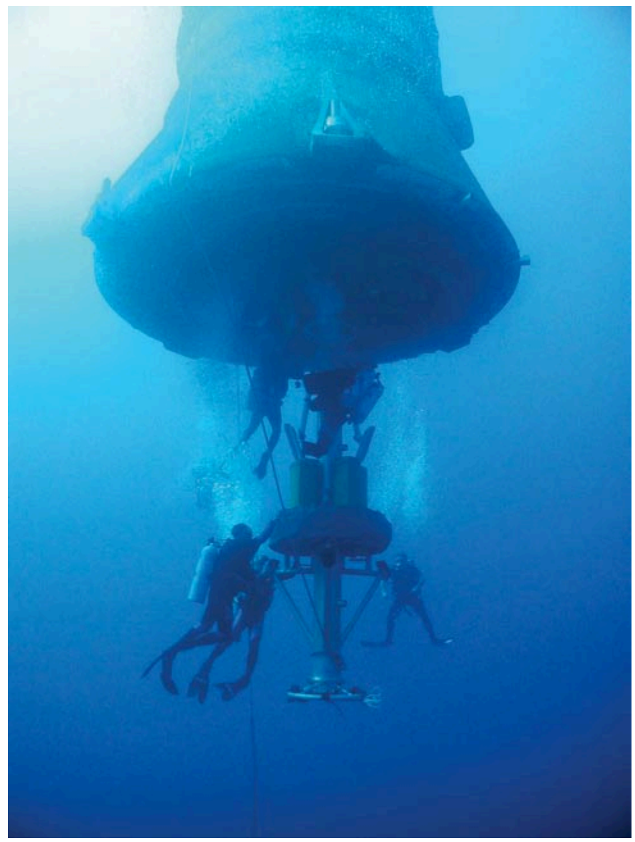
turns to the booster itself. The dive team prepares for booster recovery. Two small Ambar boats, with eight retrieval divers aboard, are deployed for each of the boosters.

The job of the first dive team is to install an Enhanced Diver-Operated Plug (EDOP) into the nozzle of the booster. The EDOP is launched from the ship and towed to the booster by one of the small boats. An air hose is then deployed from the ship. Once dive preparations are complete, the dive team enters the water for EDOP insertion. The EDOP is 15 feet long and weighs 1,500 pounds. It is neutrally buoyant in water, meaning it neither floats nor sinks. The divers guide the EDOP to the aft skirt of the booster, a depth of about 110 feet. They make a quick inspection of the nozzle. The EDOP is then inserted into the booster nozzle. An air hose is attached once the EDOP legs are locked in place and the nozzle is sealed.

The second dive team double-checks the aft skirt and EDOP installation to ensure there are no problems. Dewatering operations begin after the second dive is completed. Air is pumped from the ship through the EDOP and into the booster. This displaces water within the casing. As the process continues, the booster rises in the water until it becomes top-heavy. It falls horizontally, like a log in the water. Air pumping continues until all water is expelled from the empty casing.

The final step in the ocean retrieval procedure is to connect the ship's tow line. Once the tow connection is made, the divers return to the ship. The ship then begins

(Top left & right) The ship locates the booster, divers separate the chutes; (left) the ship retrieves the chutes.



(Above) Divers insert an Enhanced Diver-Operated Plug into the booster nozzle, displacing the water and causing the booster to assume a semi-log or horizontal position.

(Above left) The drogue chute is wound onto a reel on deck.

(Left) The frustum is lifted from the water by a power block attached to the ship's deck crane.

(Left) Divers attach tow lines to the floating booster.

With the booster now alongside in the hip tow position, the ship passes through a drawbridge and Canaveral Lock to the Banana River on its way to Hangar AF.

its return trip to Cape Canaveral Air Force Station (CCAFS).

The boosters are moved from the stern tow position to a position alongside the ship ("on the hip") after the ships arrive at Port Canaveral. This allows greater control of the tow. The ships then pass through a drawbridge, Canaveral Lock, and transit the Banana River to Hangar AF, at CCAFS. They are lifted from the water with Straddle-Lift cranes and placed on rail cars to begin the disassembly and refurbishment process.

Ships Provide New Service

In 1998 the solid rocket booster recovery ships took on new responsibilities for NASA. Space Flight Operations contractor United Space Alliance streamlined efforts for the Space Shuttle Program by taking over the towing of the shuttle's external tanks from Louisiana to Florida using the *Liberty Star* and the *Freedom Star*. The new service makes better use of the ships' downtime between shuttle launches.

The voyage begins near New Orleans at the Michoud Space Systems Assembly Facility, where the external tanks are manufactured. Five days later, the ship and tank arrive at Port Canaveral where a conventional tugboat takes over for the tank's transit upriver to the KSC Launch Complex 39 turn basin.

The ships were modified to meet the requirements of their new mission.

Enhancements included strengthening the decks and stern at critical points, installing bulwark fairings and towing H-bitts, and replacing the tow winch. The new hydraulic tow winch is referred to as a double-drum waterfall winch. It holds 2,000 feet of wire on each of its two drums. One drum supports booster recovery, while the second is devoted to towing the external tank.

The recovery ship *Freedom Star* made the inaugural tow on June 16, 1998. The second recovery ship, *Liberty Star,* was pressed into this service shortly thereafter.

Other Applications

The ships are well-suited for their role in supporting space shuttle operations. *Liberty Star* and *Freedom Star* also have proven themselves in other actions. Both vessels have seen service in side-scan sonar exercises, cable-laying,

At Hangar AF, the booster is released from the ship. It will be towed to a position where Straddle-Lift cranes can lift it from the water and place it on a rail car for disassembly.

underwater search and salvage, drone aircraft recovery, as platforms for robotic submarine operations, and numerous support roles for other government agencies. They have a proven record of reliability and performance.

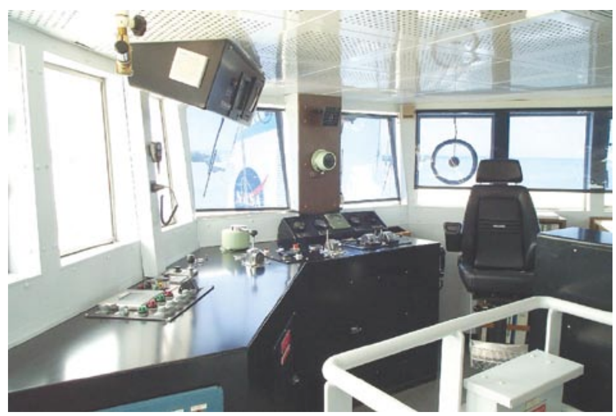
The retrieval ships played key roles in two rather unusual activities in 2002 and 2003.

On Sept. 11, 2002, the *Freedom Star* and its dive team were instrumental in rescuing a lobster diver in distress off Cape Canaveral The ship was on a certification exercise and near the location of a lobster diving boat that radioed the U.S. Coast Guard for help. One of the divers had experienced difficulty breathing on his return to the surface. Hearing the call for help, the captain of the *Freedom Star* offered to lend support.

Retrieval Dive Team personnel aboard *Freedom Star* treated the distressed diver in the vessel's recompression chamber until the ship reached Port Canaveral. A KSC Occupational Health doctor met the vessel upon its arrival in port. The diver was stabilized and taken to Florida Hospital in Orlando. A life was saved that day.

In the fall of 2002 and the spring of 2003, both *Liberty Star* and *Freedom Star* supported a National Oceanic and Atmospheric Administration-sponsored undersea expedition. The mission was to characterize the condition of the deep-sea coral reefs and reef fish populations in the Oculina Banks. The marine-protected area is located 20 miles offshore of the east coast of Florida. Equipment used for the research included an underwater robot, a seafloor sampler, and the Passive Acoustic Monitoring System, originally developed by NASA to monitor the impact of rocket launches on wildlife refuge lagoons at Kennedy Space Center.

Freedom Star tows a barge with an external tank into Port Canaveral for the first time.



(Left) The forward area of the bridge is for operation of the ship itself. Such state-of-the-art equipment as the Global Positioning System for precise navigation is located here. (Right) Booster retrieval operations are controlled from the aft bridge of the ship. Equipment located here includes hookups for communicating with the divers, forward deck and the other retrieval ship, along with a wind gauge, stern/bow thruster controls and radar.

A dive medical technician on the *Freedom Star* monitors a recompression chamber to help a lobster diver who suffered distress after a dive off Cape Canaveral.

The *Liberty Star* on the Oculina Banks, helping researchers who wanted to characterize the condition of the deep-sea coral reefs and reef fish populations on the banks, located 20 miles offshore of the east coast of Florida..

Ship Specifications

Length: 176 feet (53.6 meters)

Beam: 37 feet (11.3 meters)

Depth: 15 feet (4.6 meters) (From main deck to keel bottom)

Draft: 12 feet (3.6 meters)

Construction: Molded steel hull

Main propulsion: Two General Motors (EMD) 12-645E6A diesel engines, combined 2,900 horsepower, with Lufkin gears and LIPS controllable pitch propellers

Auxiliary propulsion: One 425-hp White Gill water jet stern thruster, driven by 8V71 turbo-intercooled (TI) Detroit diesel engine

Maneuvering: One 425-hp Schottel bow thruster, driven by 8V71 turbo-intercooled (TI) Detroit diesel engine

Ship's power: Two 166-kilowatt Kato generators and one 4-kilowatt Kohler emergency generator

Displacement: 1,052 tons (955 metric tons)

Towing pull: 60,000 pounds (30 tons, or 27,216 kilograms)

Top speed: 15 knots (28 kph

Normal cruising speed: 12 knots (23 kph)

Range: 6,000 miles (9,600 kilometers)

Endurance: Food and water for 30 days

Complement: 10 crew and 9-person retrieval team, plus observers. Total berthing: 24 people

Retrieval support equipment: Primary and backup Enhanced Diver-Operated Plug and associated dewatering gear; one Sullair Rotary air-cooled, air compressor (for nozzle plug operation); UHF, VHF, HF and SATCOM communications equipment; one North American deck crane, 5-ton (4.5-metric ton) capacity (for frustum retrieval); four parachute reels; one towing winch and one H-bit (for securing tow line) for towing one solid rocket booster casing with nozzle; one air hose reel.

National Aeronautics and Space Administration

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