AUGUST, 1926

Marine Engineering and Shipping Age

Marine Engineering

And Shipping Age

Vol. XXXI AUGUST, 1926 **No. 8**

Simmons-Boardman Publishing Company

30 Church Street, New York, N. Y.

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LONDON, England: 34 Victoria St., Westminster, S. W. 1.
Cable address: Urasigmec, London.

Subscription price: United States, Canada and Mexico, $3.00, foreign countries, $4.00 a year. When paid through the London Office, 34 Victoria Street, S. W. 1, 17s, 0d. Single Copies, 35 cents, or 1s. 6d.

their accomplishment, if the balance of the expense involved were to be met by the individuals or institutions conducting the tests. Again, it is not too much to hope that some "ship minded" capitalist may see his way clear to make such funds available, in short to establish a "foundation," if he pleases to call it such, whose sole purpose will be the investigation of the performance of actual, full-sized commercial vessels.

Raising the S-51

ELSEWHERE in this issue there is printed a description of the raising of the sunken submarine *S-51* from the ocean's bottom off Block Island. The story is plainly told by the officer who had charge of the work; just a description of one of the "odd jobs" which the navy is continually called upon to perform; another difficult situation which has been met and with all the hazards attendant upon one of the most trying of man's undertakings, the salving of a sunken vessel, successfully conquered.

One cannot read this simple and unvarnished story of work well done through months of successive discouragements and in the face of well nigh insurmountable difficulties without seeing between the printed lines a tale untold of the kind of courage and dogged "will to win" which has made our navy what it is; an additional example of the spirit which on the one hand guided Washington, Paul Jones, Farragut, Grant, Lee and a host of others in war, and on the other made possible the conquest of the Great West and built the foundations and structure of our country's economic strength as it stands today.

The salving of a damaged and sunken vessel under any cirmustances is a feat surrounded by difficulties of which but the faintest comprehension is possible without some knowledge of the sea and its ships, some knowledge of the physical laws which govern them. When the work has to be performed, as in the present instance, in open, unprotected waters and at a depth such as to make diving operations for all but the most skilled practically impossible these difficulties multiply and rise to a height where only the trained salvor can have any real knowledge or just appreciation of their magnitude.

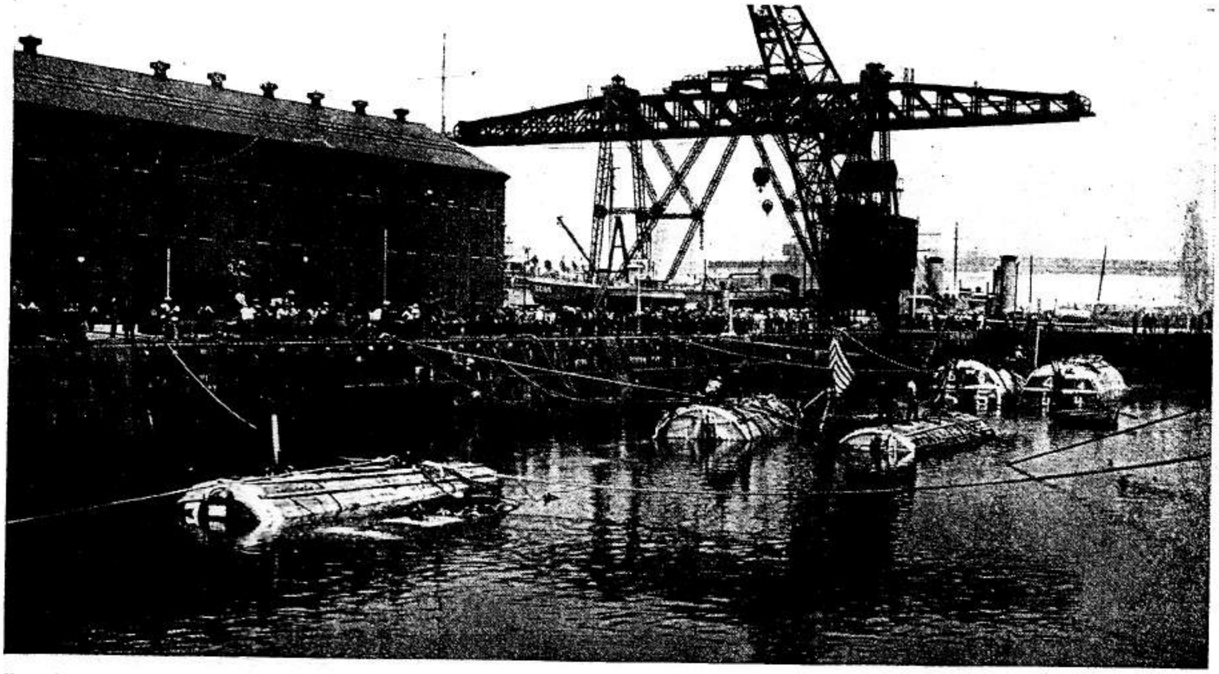
In the final analysis the test eventually comes upon the morale of those engaged, officers and men alike. Given all the power and moving force that a great government can supply, all the equipment which ingenuity can devise and unlimited resources provide; all is in vain if repeated failures, which from the very nature of the undertaking are bound to come, break down courage and undermine determination. To the uninitiated, the long months of preparation, of repeated and painstaking rehearsal, may seem a council of perfection, a devious road when direct action might have brought immediate results; but if the story proves anything at all it is the necessity of all that was done; first the devising of a reasonable and workable plan of campaign, then the preparation and training necessary to carry out that plan in its smallest details and thus insure its successful culmination.

The same spirit which navigated the *Johanne Dybwad* a thousand miles to port and safety and which rescued the crew of the *Antinoe,* put the *S-51* in the dry dock where she rests today. So long as this spirit continues there is hope for America on the sea and there she will be found.

High Pressure Steam

THERE can be but little doubt but that the next few years will see the very general adoption in marine steam machinery of certain engineering features which have been highly developed and are in general use in power house practice ashore. The enormous strides made during the past few years by internal combustion machinery in the marine field have naturally turned the attention of engineers to the study of increased economy in the marine steam plant and to an appraisal of the various methods by which economy has been increased in the field of stationary steam engineering.

The most obvious path to follow in attaining the end in view lies in the direction of increased steam pressure and superheat, but while this line of development is well advanced in shore practice, it is a path beset with difficulties when followed by the marine engineer. Two major obstacles lie in the way, obstacles which we believe are rarely if ever appraised at their full value by engineers without sea or shipyard experience. Their names are "reliability" and "salt water." We are by no means to be understood as implying that stationary or power house machinery is in general lacking in reliability; far from it, but the conditions and circumstances surrounding its operation are quite different from those obtaining on shipboard, the most important of these different conditions being salt water. Extreme high pressure makes necessary the use of watertube boilers and for continuous, efficient and safe operation these must be supplied with as nearly pure fresh water feed as can be obtained. The power plant ashore has, or usually has, a practically unlimited supply of fresh water to draw upon. Furthermore, in the majority of cases, fresh and not salt water is used for circulation through the condensers. In theory there may be no difference between the two forms of installation, land and marine. Both are operated on a closed circuit and if fresh water is originally available it should remain fresh and pure—provided no leaks occur. However, in practice it is next to impossible to prevent all leakage, particularly in a surface condenser. At sea this means salt in the feed water and boilers, not an insuperable difficulty with present pressures, but prohibitive, apparently, if the latter are greatly increased. Thus the marine engineer who seeks to adopt extreme pressures is faced at the outset with what, though it may be an old problem, assumes under the new conditions a major importance—the production of a practically tight and perfect surface condenser. Stationary plants have condenser troubles, but conditions at sea are such as to increase these troubles and make their effect on plant operation a far more serious matter. Again, the action of salt water has to be guarded against, not in this instance in the boilers or interior circuit of the plant but because of the often violent and destructive chemical or electrolytic action set up by it in condensers and their



Floating the S-51 into drydock, supported by 6 pontoons. The port bow pontoon is wholly submerged except for the hoses just showing above water. Note the absence of the second pair of pontoons, lost on Man of War reef

Salvaging the United States Submarine S-51

Through exceptionally heroic and skillful work naval officers and men raise 1250-ton submarine sunk in exposed position in 132 feet of water

By Lieutenant Commander Edward Ellsberg, C. C., U. S. N.

THE U. S. S. *S-51*, a submarine of post-war construction, with a surface displacement of 1,000 tons and a submerged displacement of 1,250 tons, was sunk on the night of September 25, 1926, about 15 miles east of Block Island in a surface collision with the merchant steamer *City of Rome*. A large gash in the port side of the *S-51*, about 30 feet forward of the conning tower, was made by the bow of the *City of Rome*, this opening coming into the battery room, the second main compartment from the bow. The *S-51* sank in less than one minute with the loss of 33 of her officers and crew, there being only 3 survivors picked up by the *City of Rome's* boat.

The wreck was located next morning by an oil and air slick. Divers went down and found the boat in 132 feet of water heeled over 11 degrees to port, heading about 350 degrees true. No signs of life inside were apparent then or later but, as a rescue measure, for about five days an endeavor was made to lift the stern with derricks. This failed.

After thorough consideration of all offers by commercial concerns, the Navy Department decided to undertake the work itself and the writer was placed in charge of the technical operations and the diving personnel.

Method of Salvage Determined

A study of the wreck lead to the conclusion that the battery room and the torpedo room forward were damaged by the collision and by the impact with the bottom to such an extent as to make their buoyancy irretrievable. It was decided to make the other compartments, which were found undamaged, watertight and thus obtain an internal buoyancy of about 450 tons, making reasonable allowances for bilge water. To make up the remainder of the buoyancy required, together with a safe margin for a reserve, 8 pontoons with a net lift of 80 tons each were to be employed. Two such pontoons, once used on the *F-4*, eleven years ago, were available at the Norfolk Navy Yard. The New York Navy Yard immediately commenced construction of the 6 additional pontoons required.

Construction of the Pontoons

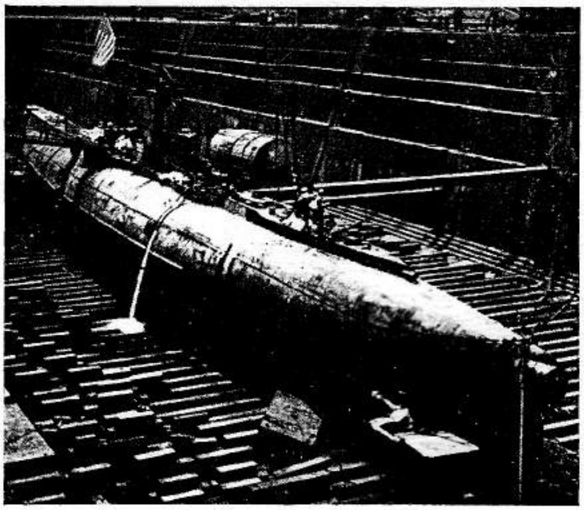
As the initial engineering problem, it was necessary to design the pontoons to withstand the pressures they were to work against. The water pressure at the depth of 132 feet was about 58 pounds per square inch. It was realized that the pontoons might be exposed to this as an internal bursting pressure in case of a rapid rise to the surface. They were therefore built to resist this pressure, and the two *F-4* pontoons were given additional internal stiffening, as they were originally built for use in only 45 feet of water. As an additional safeguard, all pontoons were fitted at the bottom with a simple spring loaded relief valve, 6 inches in diameter, set to lift at an excess pressure of 5 pounds.

The pontoons were steel cylinders, 32 feet long, 12 feet

6 inches in diameter, sheathed with 4 inches of wood to take external chafing. Each pontoon was in itself practically a section of a submarine, with internal frames, longitudinal stiffeners and heavy reinforced bulkheads at the ends and in the middle. A 12-inch hawsepipe ran vertically through each half of the pontoon 8 feet from the end, through which the chains which formed the cradle slings were passed.

While the pontoons were under construction, the salvage expedition sailed for Block Island and active work commenced about the middle of October. The first efforts were to cut away the rigging and radio antennae to avoid fouling the divers. That completed, the salvage work began.

The U. S. S. *Falcon*, a minesweeper fitted with extra air compressors, a recompression chamber for divers and some



S-51 in drydock, port side looking forward

others special apparatus, was the diving vessel. She first planted 7 anchors in a circle about the wreck, each secured to a surface mooring buoy, to which buoys the *Falcon* thereafter moored herself before diving.

The U. S. S. *S-50*, a sister of the *S-51*, was present for some time as a rehearsal vessel on which the divers practised before entering the *S-51*.

Difficulties Encountered in Making Flooded Compartments Airtight

The preliminary rehearsals over, the divers entered the engine room and proceeded to close all valves inside needed to make this compartment airtight. Some 30 valves were closed on the first dive, but trouble immediately developed. The largest valve, the main engine air induction, 25 inches in diameter, would close only about three-quarters of the way. After several dives on this valve, it was concluded that something had washed under the valve disk and was lodged there, preventing the valve from closing. The fight with the *S-51* had begun.

To clear this obstruction, it was necessary to remove the superstructure deck over the valve body and lift the valve bonnet. The bonnet weighed 300 pounds, was 39 inches in diameter and was secured by 40 bolts and nuts. It can be imagined what a task this presented to the divers. The work was immediately started, however, and proceeded for 5 days at the end of which time the bonnet was lifted and a piece of 1-inch steel pipe about 2 feet long was found under the valve disk. This was removed and the valve then closed easily.

The above instance, in which it took five days to close a valve which, it might confidently have been expected, should have been closed in 5 minutes was an example of what was found thereafter in the prosecution of the job.

The divers continued with the work of closing interior valves and doors and finally succeeded in closing all valves in the motor room aft as well as the door leading to that compartment. Compressed air was put on that compartment to force the water out, but the air was found to be escaping through a valve which was known to have been closed. Inquiry of the survivors showed this valve to have been defective. Nothing remained but to reopen the motor room, remove the defective valve and plug the pipe, which meant more work and more delay.

Special Hatches Built to Resist Internal Pressure

Meanwhile it was necessary to supplant the regular hatches to the intact compartments with special salvage hatches. The regular hatches were designed to seat under an external pressure only; even a light internal pressure would blow them open. In addition it was necessary to provide spill pipes reaching to the bottoms of the compartments to discharge the water, and air connections for blowing. These pipes and valves were made a part of the new salvage hatches, which were provided with strongbacks to keep them seated against a heavy inside pressure. These hatches were heavy, about 700 pounds each, and the long spill pipe attached made them cumbersome to handle but there was no easier method. Two hatches of this type were installed during the fall operations, one without pipes over the conning tower hatch, and one with pipes and valves over the gun access hatch, both leading to the central operating compartment under the conning tower.

To secure the pontoons to the submarine, it was necessary to run tunnels under her for the chain cables, about 70 feet from the bow and about 110 feet from the bow. In both these locations, the submarine was buried about 7 feet deep in hard clay and sand. Tunneling was started immediately, using a fire hose to cut through the clay, but progress was slow. It was interrupted by storms and after each enforced departure, it was found that the tunnel had filled up again and it was necessary to start afresh after each storm.

Stormy Weather Delays Operations

Meanwhile the weather was getting steadily worse and November was passing away. Storms increased in frequency and in intensity. The water grew colder and we ran into a stretch of weather which allowed only 1 working day out of 15 consecutive days.

Under these conditions work became impossible and operations were suspended until spring.

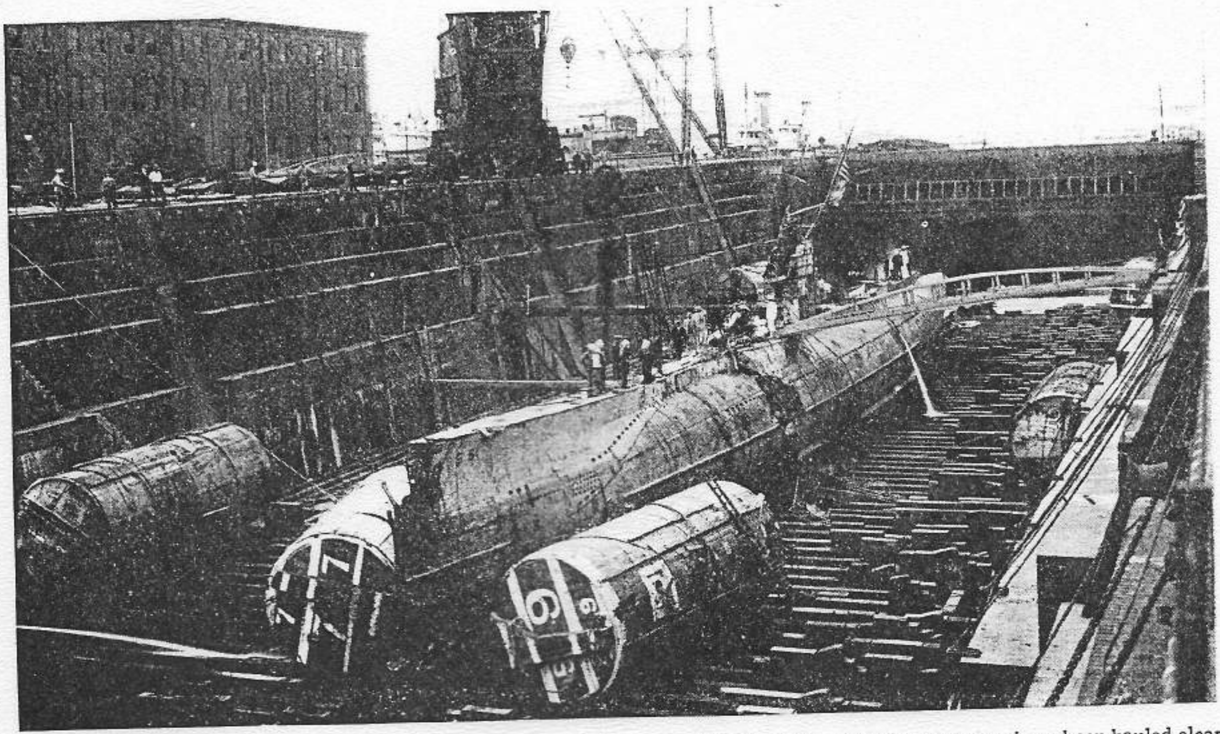
Additional Divers Trained During Winter

During the winter, a class for training new divers was started, experiments were undertaken with an underwater cutting torch which was developed into a successful instrument, and the necessary equipment was carefully overhauled.

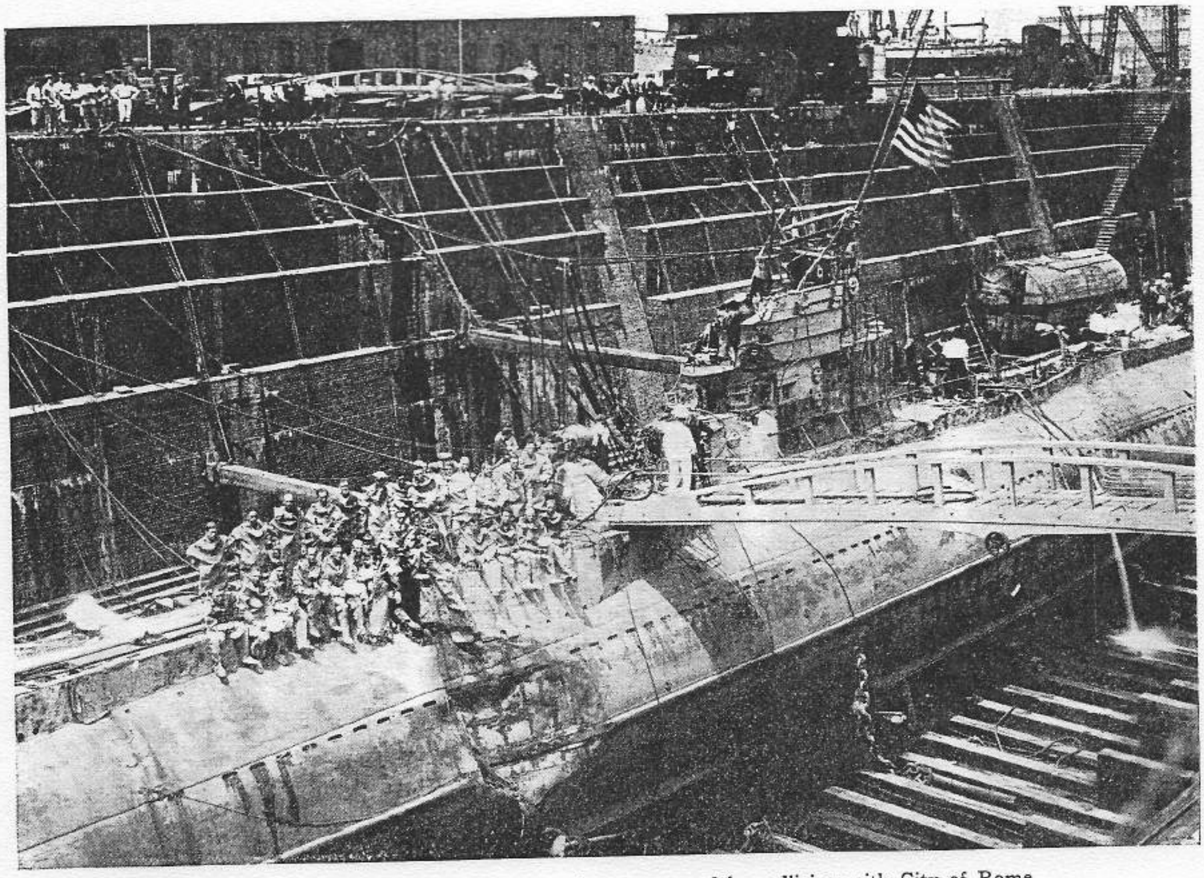
Diving operations were resumed on April 26, 1926, with a greatly augmented crew of divers, 24 men being available including the writer, who had also qualified as a deep sea diver during the winter.

Lowering and Securing the Pontoons

The first problem attacked was the proper method of lowering the pontoons. As this involved handling a bulky and heavy weight and correctly locating it 132 feet down, several rehearsals were carried out in deep water, but well clear of the submarine. It was finally determined that the only safe method was to flood the pontoon down until it just submerged, supporting each end of it on a 12-inch manila hawser. In its awash condition it was held with



S-51 in drydock, port side looking aft. The pontoons at the bow are still alongside, the other pontoons have been hauled clear



Port side of S-51 in drydock, showing damage caused by collision with City of Rome flood valves and vents open until it had reached a negative weight of about 8 tons, when the flood valves and vents were closed. This negative weight was found to be the minimum which would ensure longitudinal stability and prevent the pontoon from standing on end on its way down. With the valves closed, the pontoon was then lowered, its weight remaining constant all the way down.

Having made sure that the pontoons could be safely handled, the *Falcon* commenced securing pontoons to the stern which was clear of the bottom and required no tunneling. Two manila reeving lines were run under the stern and on these a pair of 1-inch wire lines was hauled through, from port to starboard. These wires were attached to the chains suspended through the hawsepipes of the first pontoon and were to be used to guide the pontoon down to its position. The pontoon was flooded as in rehearsal, but just as it went awash a 1-inch wire strap, holding the after 12-inch hawser to the pontoon, pulled apart in the splice and the pontoon tore away and sank, after end first. Fortunately the *Falcon* was holding this pontoon somewhat to port and it landed about 20 feet away from the submarine's stern.

An examination of the splice in the strap showed it had opened up without any special strain but, to prevent a recurrence, forged steel links were substituted and no more pontoons broke away in the lowering process.

The first pontoon was dragged over to the side of the submarine by hauling on the guide wires, after which these wires were threaded through the hawsepipes of the second pontoon. The second pontoon was successfully lowered to about 90 feet, held there while a diver checked its position, and then carefully lowered into position alongside the submarine. The chains from the opposite pontoon were hauled through the hawsepipes in this process. With the second pontoon on the bottom, the divers with the underwater torch burned out a stud in the chain link just above the top of the hawsepipe and inserted a 4-inch by 4-inch nickel steel toggle bar to lock the chain in position and take the load.

Looking directly into the hole torn in the port side of the S-51 by the Savannah liner

A pontoon was lowered with chains attached as at the stern, in the first instance, but the chains hung up on the box keel which was 1 foot lower than the hull, and refused to pull through. Some 2 weeks were spent in an endeavor to haul these chains through, but the net results were only broken hawsers, as a 6-inch manila line, an 8-inch manila line and a 1-inch wire line were successively parted and finally the stern winch was torn out of its foundations on the seagoing tug *Iuka* which was being used to haul on the lines.

Successful Method of Handling Pontoons Devised

After this last mishap, it was concluded that the method was wrong and the pontoon was blown free of water by compressed air and brought to the surface, chains and all. The chains were removed from the pontoon and lowered separately one chain at a time from starboard to port. The divers guided the hauling lines through the tunnel and, by giving enough slack to the chain, it was allowed to drag through the tunnel clear of the box keel and passed through without difficulty.

Having passed a pair of chains through in this manner,

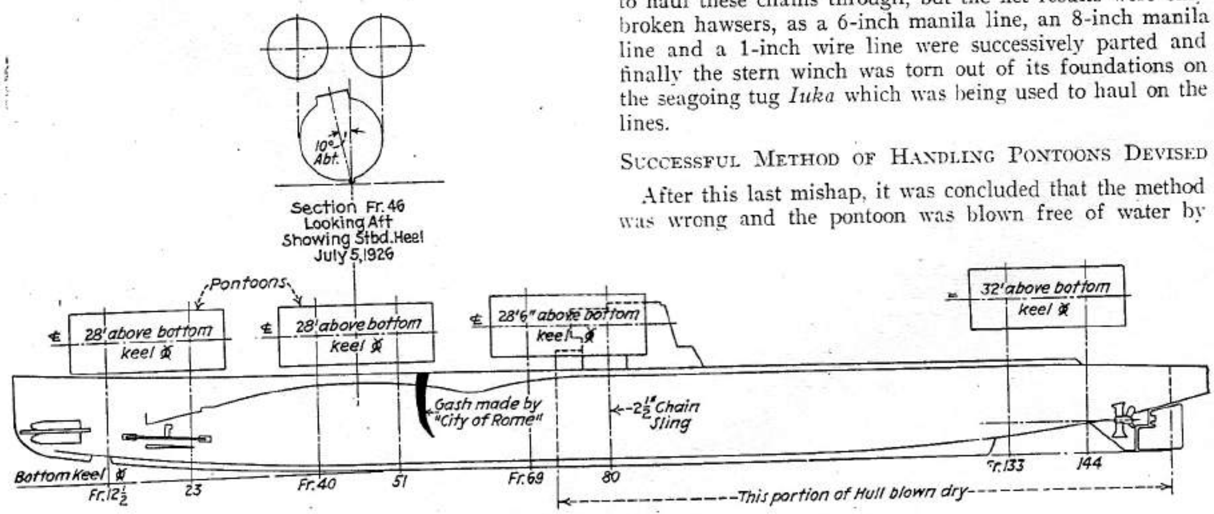
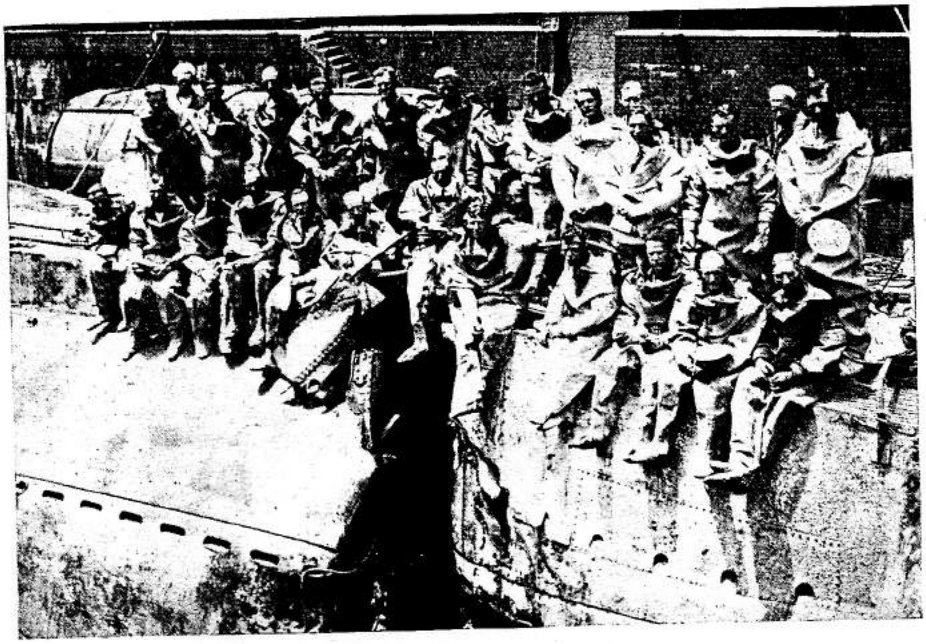


Diagram showing arrangement of pontoons for salvaging the S-51

These bars had previously been tested to a load of 235 tons over a span of 18 inches which was the distance across the top of the hawsepipe castings.

Having secured the first pair of pontoons, work was resumed on the tunnel at frame 46. After two weeks of dangerous and arduous work, the divers completed this tunnel and 2 manila reeving lines were run through it, followed by two 1-inch wire lines.



The divers who salvaged the S-51, with Lt. Comdr. Ellsberg in the middle of the front row, grouped just above the gash in the port side of the vessel made by collision with the City of Rome.

the 1-inch wires attached to the chains on both sides of the submarine were hauled taut and the chains held up vertically. The wires were threaded through the pontoon hawsepipes, and the pontoons lowered, port pontoon first, on the wires as guides. The pontoon was held suspended at a depth of 90 feet, when two divers went down on it, checked its position and reported everything clear. The pontoon was then slowly lowered with the divers riding down on it, until the chain showed through the hawsepipes, when it was again held while the divers inserted the toggle bars through the chain links. When this was done, the pontoon with divers aboard was lowered to the bottom, where the divers cast loose the 12-inch manila lowering lines, let go the 1-inch wire lines to the chains, opened flood valves, saw everything else secured and came up.

The mate pontoon was lowered in the same manner. The *Falcon* became so expert in pontoon handling that she was able to run a pair of chains and lower and secure completely a pair of pontoons in about 7 hours.

It now became necessary to dig a new tunnel under the submarine amidships. About this time, a machinist's mate on the *Falcon*, who had observed the action of the ordinary fire hose nozzle previously used in tunneling, turned out a new nozzle with balanced jets that enabled the divers to use about 5 times as much water pressure as formerly. With Waldern's nozzle, the diver could easily hold a 2½-inch fire hose under a water pressure of 200 pounds per square inch. As a result, the second tunnel was completed in two days instead of in the long number of weeks spent on the first one.

Lieutenant Commander Ellsberg testing his helmet just before going down to inspect the S-51 off Block Island

Leveling Pontoons Proves Difficult

The sealing up of the interior and the planting of all pontoons was completed about the middle of June. The next problem was to float up all pontoons alongside the submarine, level them off and lash them against sliding when the submarine rose. In this operation the cranky nature of the pontoons was demonstrated, because, as they became buoyant, one end or the other would always rise first and the pontoon would float on end and hardly ever horizontal. The end which rose first would drag the slack chain through under the submarine from the other side and make the leveling off of both pontoons above the submarine impossible.

After a few such experiences, a different leveling method was used. A 1-inch wire was attached to each end of the first pontoon of the pair to be leveled, the wires being taken through the bitts to the winches on the *Falcon*. The pontoon was then lightened by blowing and, during this process, a strain was kept on the wires until the weight was so reduced that the winches could haul the load. Blowing was then stopped and the pontoon, with perhaps 12 to 15 tons negative weight, was lifted from the bottom and hoisted up until it was held above the submarine at the height desired. The opposite pontoon was then blown until it floated up and, as one pontoon was already in proper position and held there, its mate was unable to run away with any slack chain. By blowing either end of the mate pontoon as necessary it was compelled to float horizontally alongside the first pontoon.

The above process worked very well and was regularly employed. However, owing to the heavy weights handled and the surging on the lines due to the *Falcon's* rolling in a seaway, it resulted now and then in breaking the 1-inch wires or the pelican hooks with which they were secured to the pontoons.

On the night of June 21, 1926, all work was completed, the pontoons partly blown down and some compartments partly emptied, in readiness for the final blowing the next day.

Storm Frees Bow of Submarine

June 22, 1926, brought a storm which made any attempt to raise the *S-51* on that day out of the question. Two of the pontoons and the engine room had been refilled the day before, to avoid a premature rise, and it was decided to await better weather. However, the storm took charge and rocked the lightened *S-51* on the bottom enough to break the suction grip forward and the bow rose. Quick work on the *Falcon's* part hauled her clear and prevented a disaster.

The bow and 4 forward pontoons showed above water. As practically the only thing to do, an attempt was made to lift the stern in spite of the storm and blowing was commenced on the after compartments and the after pair of pontoons. It should be remembered that it was always intended to raise the vessel stern first and the lashings and pontoon locations were selected with that in mind.

Stern Pontoons Break Away

When the stern pontoons were practically blown, but the after compartments still mostly full of water, the second accident of the day happened. The stern pontoons broke the 2½-inch chain cables holding them to the submarine and floated to the surface separately. It is now definitely known that they slipped forward bringing their chain cables successively in contact with the point where the vertical keel starts and thus breaking the chains under impact. This accident deprived the stern of its reserve buoyancy. As it further happened that all spill-pipes in hatches were located at the forward or high ends of each compartment, it was impossible to force out more than half the water in each compartment.

Under these circumstances, raising the stern was impossible, and nothing remained but to sink the bow before the storm should carry away the bow pontoons. Under conditions which sound more like fiction than fact, several seamen and officers from the *Falcon* boarded the pontoons and though many times swept off by heavy seas and thrown off by the erratic and tremendous hammering of the pontoons against each other and the submarine, these men stuck to the job until the flood valves were opened, and the bow, with the pontoons still attached, sank slowly from view.

Damaged Pontoons Raised and Repaired

The deep gloom which pervaded the salvage party after this accident can well be imagined. It is a high tribute to the spirit of the officers and men of the Navy to know that the next day all hands again turned to with a determination and a vigor far in excess of their previous efforts. The 4 damaged pontoons at the bow were found standing on end in a tangled heap. These were cast loose and brought to the surface for repairs. At the Harbor of Refuge, Point Judith, the repair ship *Vestal* and a 100-ton crane from the Navy Yard hauled these four and the two stern pontoons out of the water, and in 7 days had them completely repaired and ready for service again.

The pontoons were returned to the wreck, and the *Falcon's* men, working with redoubled energy, lowered and secured completely 3 pairs of chains and 3 pairs of pontoons on 3 successive days. The Fourth of July was celebrated by working all day and nearly all night; when July 5 dawned everything was again practicaly ready, and all vessels took their stations for raising.

The Submarine Raised and Towed to New York

At 12:17:30 p. m., the writer turned the air on the engine room and shortly afterwards on the stern pair of pontoons. At 2:06 p. m., the stern pair of pontoons with the stern rose to the surface. Air was then turned on the forward group of pontoons and, at exactly 3 p. m., the bow rose. All pontoons were noted to be spaced exactly as intended and the submarine's draft was found to be 32 feet as anticipated. There was a list to starboard of about 10 degrees.

At 4 p. m., the tow got underway for New York, 150 miles away. The *Sagamore* and *Iuka* were towing in tandem ahead, with the *Falcon* towing 150 feet astern of the *S-51* and maintaining a steady supply of air through 20 air leads to all pontoons and all buoyant compartments. The speed of the tow was at first 3 knots, which the next day was increased to 5 knots. The tow proceeded smoothly and steadily from the open sea into Long Island Sound and through it into the East River. Hell Gate was safely passed and the tow was within sight of the Navy Yard when a civilian East River pilot attempted to take it through a narrow passage between two reefs instead of sticking to the deep water channel on the Manhattan side. As a consequence, he stranded the *S-51* on Man-of-War Rock at high tide in about 24 feet of water and the impact of the keel with the reef carried away the chain cables of the second pair of pontoons from forward which happened to come where the reef hit the keel.

The *S-51* was thus left in a hazardous position, with one quarter of her pontoon buoyancy gone, hard and fast on a reef, and in a very strong tideway. Fortunately for all concerned, the original reserve buoyancy provided as a margin for towing was adequate. Working desperately for the remainder of the day, the salvage crew resank the 4 remaining forward pontoons until they were wholly awash and resecured the toggle bars. In this manner, the reserve buoyancy of these pontoons was brought into play for lifting purposes, and just overbalanced the effective buoyancy of the lost pair of pontoons.

When the evening high tide arrived, all pontoons were blown down again and the bow was lifted several feet higher than it had been when it struck. As a result, the *S-51* floated clear of the reef and was then towed stern first, with a list to starboard of about 25 degrees, the remainder of the way to the Navy Yard. Here, after a hard struggle against the tide, she was turned into the Navy Yard basin and the next day was safely landed in the drydock and straightened up.

Thus ended a salvage job which, for the size of vessel raised, the exposed location where the work had to be done, the depth of water worked in and the distance the submarine had to be transported, has no parallel in history. As an engineering feat, it is the pride of the officers who took part in it, but far above that in their minds stand the quiet, steadfast and heroic behavior of the men of the Navy who risked their lives in the depths and on the surface of the sea that the *S-51* might rise again.

Of the adequacy of the engineering appliances used, there never was any doubt. That the human element might crack under the strain was the ever present danger and the fact that in spite of peril and discouragement the officers and men involved came back and fought on until the job was done will always remain the brightest spot in the salvage history of the *S-51*.

Charles Albert Coffin, founder of the General Electric Company, Schenectady, N. Y., died on July 14 at his home in Locust Valley, Long Island. He was looked upon as the financial and industrial genius who translated the inventions of Thomas A. Edison and other pioneers in the electrical industry into workable machinery. Mr. Coffin was born in Maine in December, 1844, and began his business career as a shoe manufacturer in Lynn, Mass. Mr. Coffin was president of the General Electric Company for 21 years retiring from that office in June, 1913, and becoming chairman of the board, a post which he held until 1922.