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SCIENCE

Search for the "Thresher"

Assistance to the Navy by the scientific community in this search effort proved to be essential.

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On the morning of 9 April 1963, the nuclear-powered attack submarine *Thresher* steamed out of Portsmouth Navy Yard toward a nearby submarine operating area. Her purpose was to conduct the usual series of check dives which follow any major overhaul period for submarines of our Navy. With her, to provide escort and communication contact, was the rescue ship *Skylark*. As soon as the *Thresher* was clear of the shipyard, the crew rigged for dive and check-dived the boat in shallow water, following procedures developed over many years of submarine operations. At 0745 the following day, she sent her routine diving message to *Skylark* and to submarine force headquarters, then shortly after disappeared into the sea on her dive to test depth. About an hour and a half later a routine report was made by sonic telephone to the escorting ship—all was going well except for some minor difficulty. Then there was a more hasty, garbled report indicating more severe trouble; this was followed by noises resembling, it seemed to the sonar man on the *Skylark*, sounds associated with the breakup of a sinking ship. The *Thresher*, with all hands, was lost.

This ship (Fig. 1) was the first of our Navy's newest class of attack submarines, the 15th nuclear-powered undersea craft of about 60 that have been in operation since the commissioning of *Nautilus* in 1954. The number of innovations which have been brought to reality in these boats is so great that experienced submariners of World War II would scarcely recognize these craft as related to the wartime submarines except for the cylindrical hull and ballasting principles common to both. Speed, endurance when submerged, operating depth, search capability, and weapons effectiveness all have increased by factors unimagined 20 years ago. With these great improvements has come, with much less fanfare, though it is of comparable significance, an increase in safety of operation. Through all of the second-guessing as to the cause of the loss of this beautiful piece of machinery and its human crew, much has been said of measures which could have been taken to increase its structural integrity or its ability to respond under conditions of extreme stress, and even of a need to install special emergency data-recording equipment. The remarkable reality, however, and the reason for shock within the submarine forces, is that this loss terminated a 14-year period in which not a single U.S. submarine had been sunk. This is the longest such period since the introduction of these craft into our Navy in 1900, with the commissioning of the U.S.S. *Holland*. There has been a tendency to forget that duty in submarines is considered hazardous in the same sense that duty in military aircraft is. The shock engendered by the *Thresher* accident, in contrast to our acceptance of the loss of more lives in 1963 alone in military aircraft accidents than were lost aboard the *Thresher*, is a tribute to this new standard of operational safety.

The purpose of this article is, however, not to recount the various theories as to why this unfortunate event occurred or to discuss the engineering and construction improvements which it has triggered. Rather, we describe the participation of marine scientists and their tools in the search for the wreckage of this ship, which must eventually have found its way to the floor of the sea. Clearly, such a discussion must start with some consideration of why one might want to make such a search at all. There are several answers, each of which was pertinent to a different phase of the operation as it developed. At the very first there was a hope that perhaps the boat had not really gone down but had surfaced in the rough seas and, though crippled, might yet be found, or that some survivors might have escaped. This hope rapidly faded and was replaced by a determination to learn as much as possible for the future from the accident by photography, or perhaps even recovery, of parts of the hulk. Finally, as overoptimistic piecemeal adaptation of techniques showed that the location problem itself was a difficult one and that the craft had been catastrophically damaged, the emphasis shifted to the long-term problem of developing specialized equipment for careful examination of objects on the sea floor. In this last context the *Thresher* has become simply a good specific case on which to test the effectiveness of newly developing systems.

The marine scientific community was actively involved from the beginning of the first phase of operations. *Atlantis II*, the recently completed research ship of the Woods Hole Oceano-

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graphic Institution, was at sea within 150 kilometers of the accident and immediately joined the destroyers, aircraft, submarines, and other Navy craft which responded to the emergency signals from the *Skylark*. The search initially was concentrated on effects observable at the surface, although the *Atlantis II* began use of its precision echo sounder early in the operation. The many ships plowed the area looking for slicks and debris, while the aircraft, in addition, surveyed the area with radiological monitoring equipment. Negative results with this equipment eliminated the fear that some reactor accident had occurred, with associated high-level contamination of the sea. As this phase developed it became clear not only that the boat was lost but that there was an uncertainty of several kilometers concerning the position of *Thresher* at the time of her last contact with the *Skylark*.

Determination to find the wreck in order to ascertain the cause of the disaster developed very quickly. During this same time the Navy began to realize that it had no operational techniques, in the conventional sense, adequate for the job. The Navy has, however, strongly supported research activity at sea, and thus had available a pool of interested scientists and research ships eager to assist with this new problem. Soon other research laboratories in the vicinity joined the search: Lamont Geological Observatory with its new (Navy-provided) ship *Conrad*; Hudson Laboratories with *Gibbs, Allegheny,* and *Mission Capistrano*; the Navy Research Laboratory, the Naval Oceanographic Office, and the Naval Ordnance Laboratory, working together, with another new research ship, *Gillis*, in addition to the *Rockville* and the *Prevail.*

Some organization of this effort was required, and for this purpose a seagoing unit was established—Task Group 89.7, under the command of Captain Frank Andrews, whose normal assignment was that of Commander Submarine Development Group Two, based at New London, Connecticut. Overall technical coordination was vested in the *Thresher* Advisory Group, under the direction of Arthur E. Maxwell, Office of Naval Research. This group included representatives from the laboratories mentioned above as well as from the University of Rhode Island School of Oceanography, the University of Miami Marine Laboratory, the Bureau of Ships, and the Office of the Chief of Naval Operations. The group met from time to time during the search to lay out plans and evaluate results. In addition, they were backed up by a full-time analysis staff assembled at Woods Hole and utilizing personnel from Woods Hole, the Navy Oceanographic Office, Submarine Development Group Two, the Naval Underwater Ordnance Station, and the Navy Electronics Laboratory.

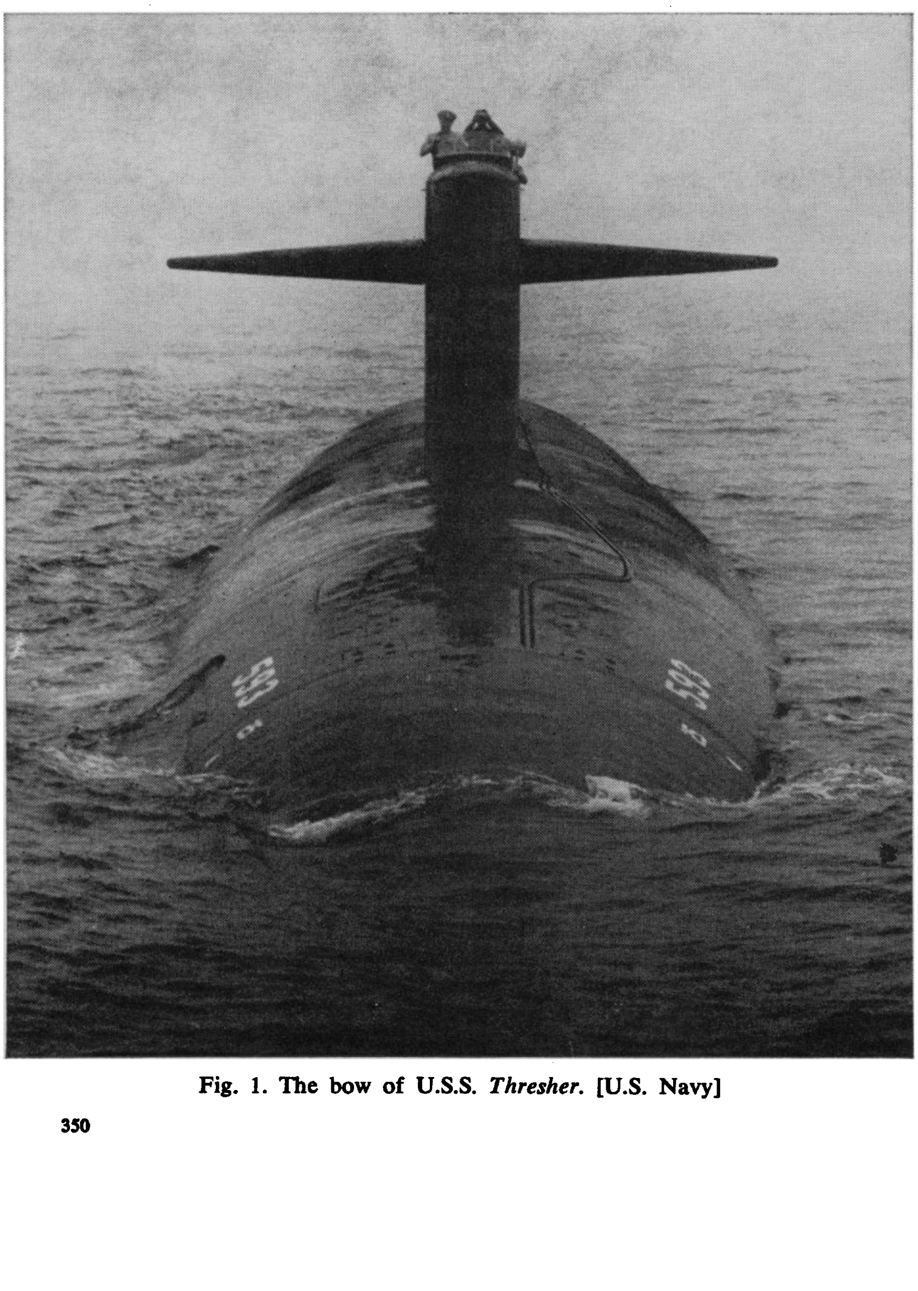
Fig. 1. The bow of U.S.S. *Thresher.* [U.S. Navy]

Throughout this phase of the search there was a sense of urgency. Initially this was a residue of the urgency that characterized the initial effort, when there was a true need for emergency action. Later on, the feeling of pressure continued because all the major participants had previous plans for research expeditions, to which they were anxious to return. As time passed and the difficulties became more apparent, there was pressure to bring the operation to a successful conclusion before bad weather set in, in the fall.

The individual techniques which were immediately recognized as potentially useful and which were already being employed in some fashion in exploration of the sea floor were use of acoustic echo sounders or near-bottom sonar; magnetic, electric, radiation detection; photographic detection; real-time optical detection, either direct viewing or viewing by closed-circuit television from deep-operating craft; and dragging or dredging. The group rejected the last alternative, primarily on grounds that it would disturb the site in ways which might confuse interpretation of the situation when the wreck was found. Direct observation could not be implemented initially, but the bathyscaphe *Trieste* was immediately transported by ship from San Diego to Boston and readied for use.

Of the techniques available, the one which was most immediately and widely applicable was use of the precision echo sounder. This device consists of a downward-looking broad-beam sound transmitter and receiver; the received signal is displayed on a facsimile-type recorder having a very stable time base. This display produces, on an expanded scale if desired, an analog record of the echo return times for successive sound pulses transmitted into the water as the ship travels along. In normal use, this system provides an approximate representation of the topography for the construction of charts or the study of shapes of naturally occurring features. For search purposes this technique would be useful only if the sea floor were relatively smooth. If this were the case, attention would be directed to search for a small crescent-shaped pattern superposed on the echo returns from the sea floor. Simple geometry shows that the return from a submarine will be the first echo, even if the hulk is 150 meters to the side of the search ship's track, for target height of 10 meters in water depth of 2500 meters (about that in the search area). Comprehensive application of this technique thus dictated a stringent requirement for a navigational capability not normally possessed by research ships in this area.

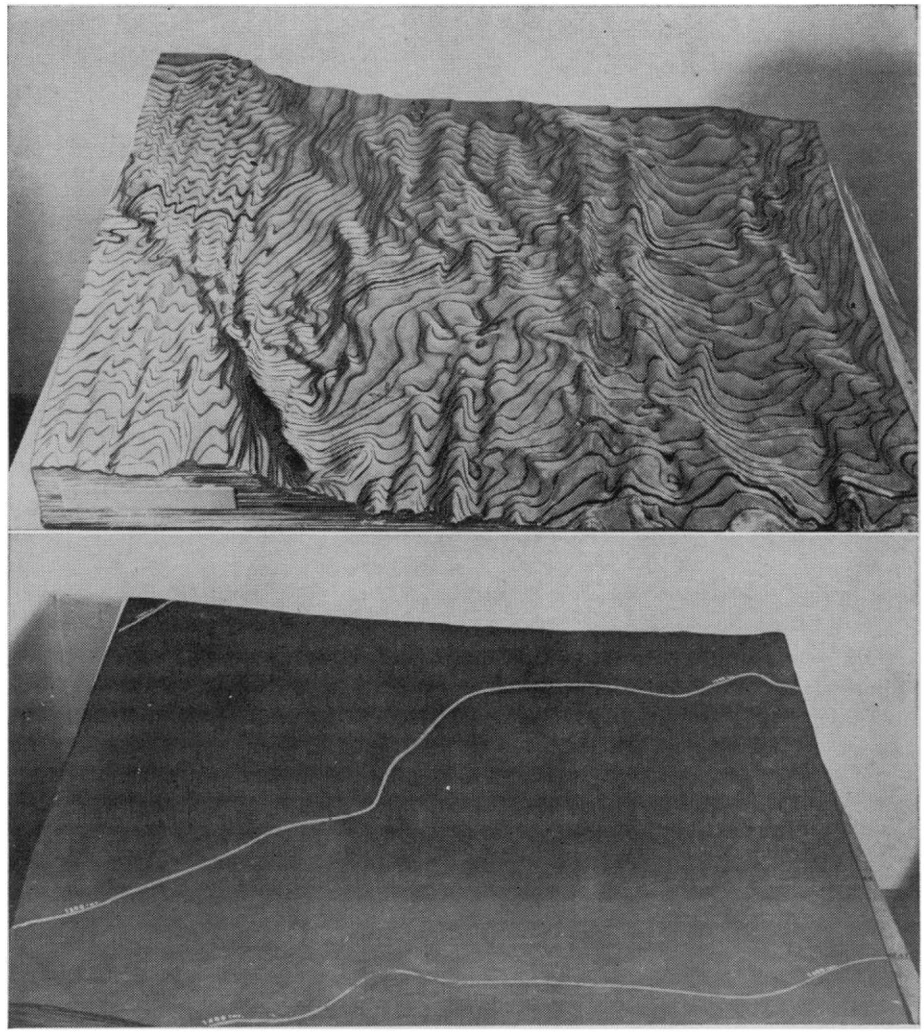

Fig. 2. Two models, prepared by the Hudson Laboratories from echograms, of the topography of the sea floor in the area of the *Thresher.* (Top) Model prepared from data obtained during last summer's search. (Bottom) Model prepared from data available before the search. The three light lines in the model at bottom correspond to the accented lines in the model at top. There are not only differences in detail but significant differences in the absolute depths. [U.S. Navy]

Search Areas and Accuracy

The navigational problem was first met by the use of the Loran C electromagnetic system. After difficult-to-obtain Loran C receivers were obtained, it became rapidly apparent that the shore station locations were such that only one coordinate was useful. Therefore, arrangements were made to utilize, in addition, a Decca system in the area, which provided another nearly orthogonal coordinate. Over a single weekend, new charts were prepared and receivers were provided for six ships. This system (combination Loran C and Decca), although it lacked accuracy at night, provided the primary navigational reference throughout the search. Reproducibility of position, as judged relative to bottom topography and moored buoys, was about 100 meters.

In the beginning of the operation the search area of 18 by 18 kilometers (10 by 10 nautical miles) was quartered, and one ship was assigned to each sector. With the availability of the improved navigational system it became apparent, however, that a more systematic approach was required. It was thus decided that four ships (*Allegheny, Mission Capistrano, Prevail,* and *Rockville*) would make a navigationally controlled, precision exploration of the entire area, with 250 meters between tracks, while *Conrad, Gillis,* and *Atlantis II* would move in to investigate possibly significant contacts. The systematic survey required 2 weeks of operating time in the area during which time the data were plotted and contoured aboard ship. The results provided the first quantitative indication of the difficulties of using the echo sounder for this purpose. A model showing the complexity of the topography is shown in Fig. 2, in comparison with a model based on previously available data. The result was the conclusion that in about half the area the sea floor was too rough for search by this technique. In the other half there were six possible target indications, one of which was point "delta," first observed by *Atlantis II.* Because "delta" was close to the location deduced from the rough navigational record provided initially by *Skylark,* and because the echogram (Fig. 3) was especially convincing, this point was given the highest priority for further investigation.

During the time the four ships were conducting their detailed sweep of the area, *Conrad, Atlantis II,* and *Gillis* had already begun investigation of the most likely locations. They relied principally on photographic equipment built over the years to solve the needs of submarine geologists. With such equipment it was possible to make stereo pair photographs of a strip about 7 to 10 meters wide, with over-

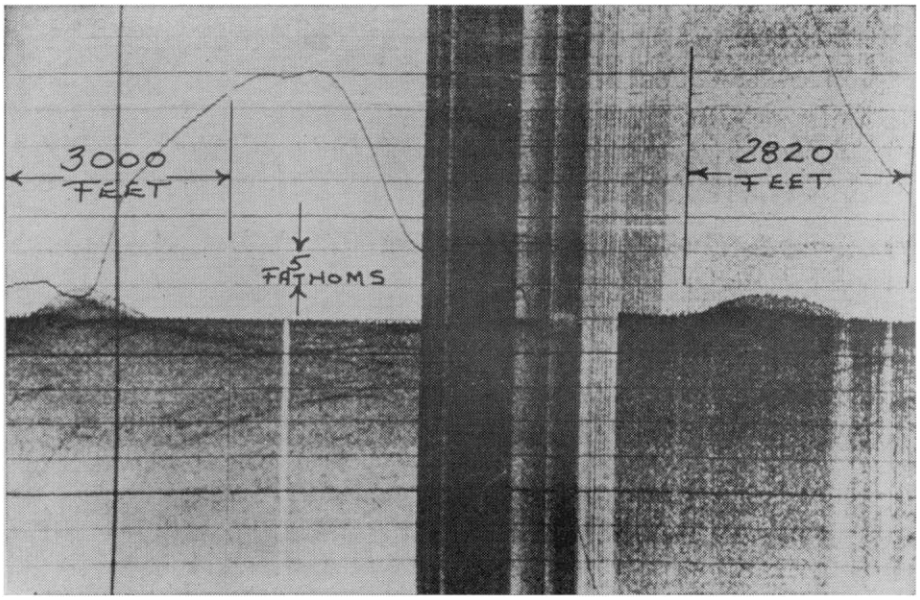

Fig. 3. Two PGR (precision graph recorder) records taken from *Atlantis II*, showing point "delta." Because of the size and shape of this contact an accelerated search for the *Thresher* was made in this area. The first photographs of debris were obtained about 1 kilometer to the north. [Woods Hole Oceanographic Institution]

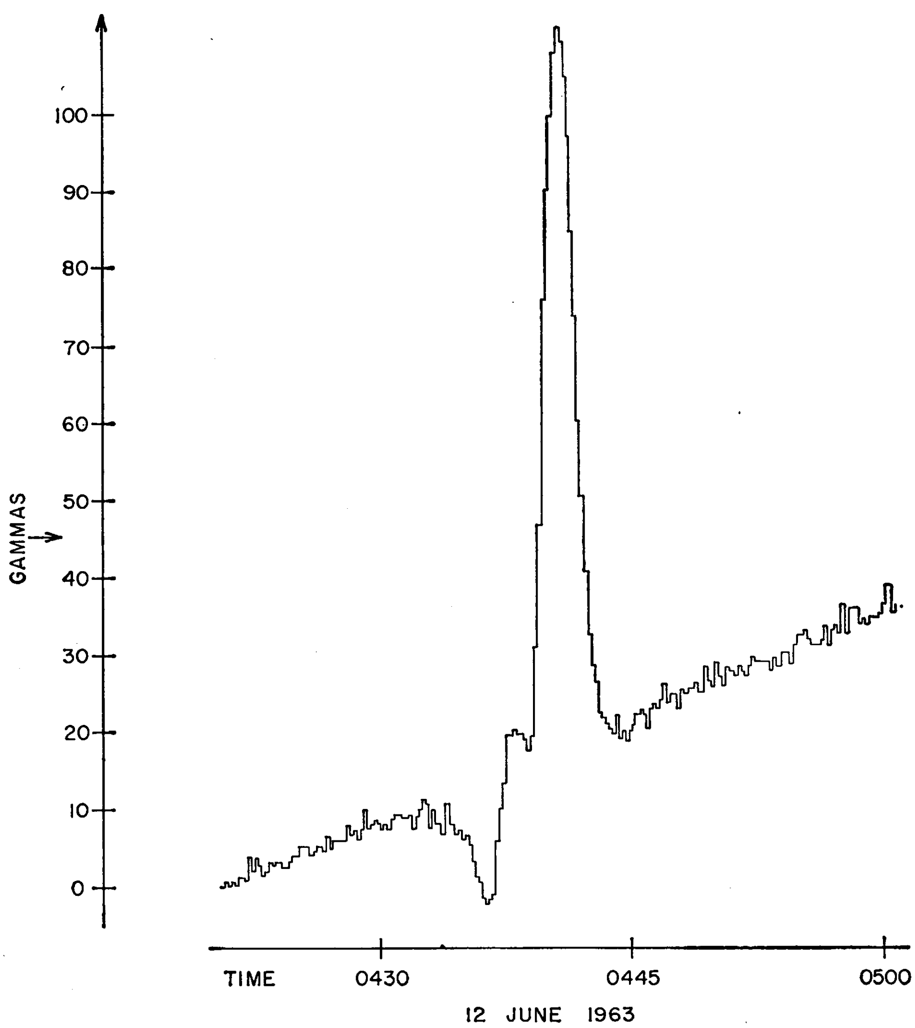

Fig. 4. Graph obtained with the deep-towed proton precession magnetometer, showing an anomaly of approximately 100 gammas in the intensity of the total magnetic field. This anomaly, first observed aboard the *Conrad*, was later confirmed by observers aboard the *Gillis* and the *Gibbs*. This single clue indicates that the hull, though badly torn, is still essentially in one piece. [Lamont Geological Observatory]

lapping coverage for successive exposures, while the vessel was traveling at speeds of 1 to 2 knots (1.8 to 3.6 km/hr). Aside from the resulting very slow search rate (about 2½ km^2 per week), this technique has the additional disadvantage of requiring a bottom-referenced navigation system accurate to within at least 5 meters to assure that there are no appreciable gaps in coverage. As an investigative tool in a restricted area, however, this is an essential method, since it can provide the detailed view of a wreck that is needed by investigators.

Underwater television was another device with similar restrictions that was available for optical investigation of the area. At the time of the *Thresher* sinking, the Navy Research Laboratory had under test a slow-scan underwater television system. It was being developed by the laboratory for direct observation of the bottom in real time, to correlate with acoustic reflection measurements, as well as for examination of instruments and structures emplaced on and in the bottom. The unit had been tested through 6700 meters of cable on the dock, but had never been to sea or even in the water. By accelerating the development program, the system was readied for use aboard the *Gillis* in May. Although the television had an advantage over photography in providing real-time observations (one picture every 2 seconds), it had a relatively poor 600-line resolution. Fortunately, the cameras could be activated to give pictures of better resolution when interesting objects came into view on the tube. Many thousands of "looks" at the bottom were obtained by this technique, complementing the results obtained by photography.

Debris Is Photographed

In spite of lack of knowledge of the exact location of the photographic or television camera (on the end of 2500 meters of wire) relative to a lump on the sea bottom that had been found by the echo sounder at the surface, the ships criss-crossed the area with some success. Using combined photographic, echo ranging, electric potential, and radioactive equipment, part of which was loaned to Woods Hole by Schlumberger, the *Atlantis II* searched in a predominantly north-south pattern based on *Thresher*'s last known course of 090 degrees, in the hope that some evidence of her passage might be detected. This strategy paid off with the receipt of the first pictures of fresh man-made materials on the sea floor, and was used by other ships to build up, gradually, sufficient evidence to indicate a streak of debris about 1000 meters wide and at least 4000 meters long. However, none of the pieces of debris photographed at this stage showed any item clearly identifiable as belonging uniquely to *Thresher*.

At this time the need to identify the debris streak with *Thresher* became strong enough to override, temporarily, the earlier restriction against dredging. *Conrad* had on board equipment normally used to gather rock samples from the sea floor. She dragged this across the debris area and, in several passes, recovered some envelopes containing spare gaskets. These were identified, from notes on the envelopes, as being definitely from the interior of the *Thresher*. Similarly, the *Atlantis II* dredged up pieces of battery plates that were later identified, by chemical analysis, as being of the type carried on nuclear submarines.

Dredging, photography, and echo sounding were three techniques which could be used in this search without any modification. Magnetometers [obviously applicable in a search for a 3000-ton (2700-metric-ton) lump of iron] had been used for geophysical exploration both on land and at sea, but usually as airborne or shallow-towed instruments. Only the geophysical group at Cambridge University, England, had a magnetometer capable of being towed at great depth, and this particular instrument was then in use in the Indian Ocean. Several laboratories (Lamont, Scripps Institution of Oceanography, and the Naval Ordnance Laboratory) thus began packaging the available magnetometers for use at depths which would give the required proximity (about 200 meters) to the hulk during search. More was involved than simple provision of a pressure-proof case; also required were a strong towing wire having good capability as a conductor of an electrical signal and proper telemetering circuitry to make the signal available on the towing ship. In early attempts there were many electrical problems. Nevertheless, one credible anomaly was found, at about the time of the dredging operations, but it was apparently remote from the debris area by more than a kilometer. Somewhat later, another signal (Fig. 4) was found, several times, by *Conrad*. Still later

Fig. 5. Photograph of debris from the *Thresher*, taken by the Navy Electronics Laboratory bathyscaphe *Trieste*, on 24 August 1963 at a depth of 2600 meters. [U.S. Navy]

this magnetic signal was confirmed by both *Gibbs* and *Gillis* (with equipment from Scripps and the Naval Research Laboratory). In each instance, navigational uncertainty and lack of ability to make photographs or view by television at the time the signal was obtained precluded the possibility of identifying these signals with *Thresher*, or even of being sure that they were all generated by the same object. The amplitude and dimensions of the signals were such that it is highly probable that they were generated by a mass of iron of the approximate dimension of a submarine, but whether this was *Thresher*, some other wreck, or even natural background is as yet not known.

High-resolution acoustic techniques, used near the sea floor, were regarded from the start as providing a most promising type of search. Two units were assembled through modification of existing equipment (by Marine Physical Laboratory and Woods Hole Oceanographic Institution), but these units lacked adequate resolution in angle. Westinghouse, under contract with Hudson Laboratories, built a unit specifically designed for the purpose, and it was operating effectively by July. This unit was towed near bottom, by means of a cable similar to that used with the magnetometers; it had an acoustic transmitter and receiver whose two narrow beams were directed one to each side. The variation in amplitude of the nearly continuous sea-floor reverberation from each transmitted pulse was plotted on a facsimile-type recorder. In this way, for each pulse a high-intensity mark was made at the ranges of highly reflecting sea-floor features and virtually no intensity was recorded at ranges corresponding to shadows. Thus, as the towed unit moved along, from successive pings it created a picture of the sea floor similar to that used by cartographers to show roughness of terrain, or similar to the "PPI" (plan position indicator) display from a radar installation looking out at a flat angle over the land. Many informative pictures were obtained with this unit, but none could be positively identified with *Thresher*.

Trieste Aids the Search

As additional evidence from photography, television, magnetometers, and side-looking sonar was accumulated, it became evident that the most promising region, where search should be concentrated, was the small area directly to the east of the strip of debris charted by *Atlantis II*, *Gillis*, and *Conrad*. This was the area in which the magnetometer contacts were obtained, as well as the photographs of the larger pieces of debris. Because this area was sufficiently restricted in size to allow effective use of *Trieste*, the bathyscaphe was brought to the scene. She is one of the few craft in the world (and the only one belonging to the United States) which can operate to the depth necessary for observing the

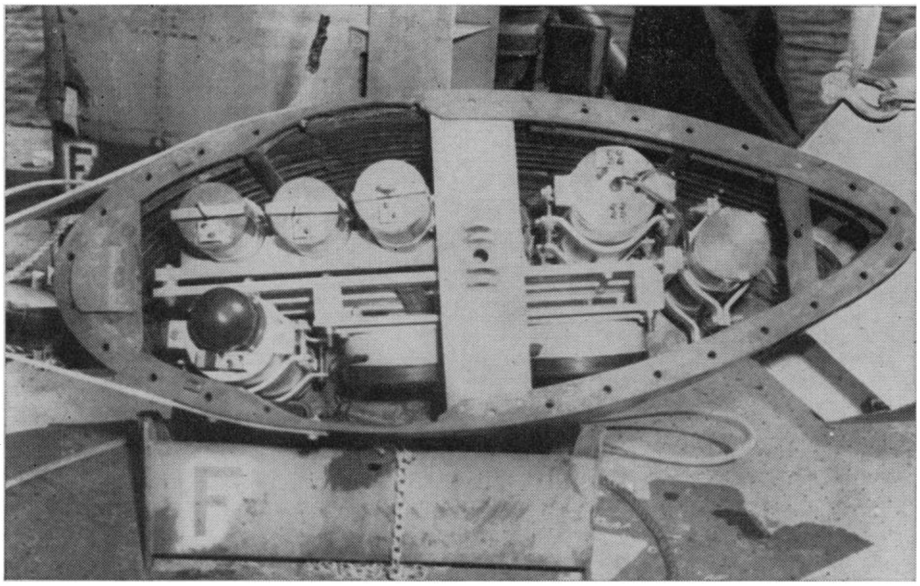

Fig. 6. An attempt was made by the Navy Research Laboratory to integrate several sensors into a single streamlined package. This unit contained a side-looking sonar, a television camera, a photographic camera, a proton precession magnetometer, and a pinger to determine the depth of the unit above bottom. [U.S. Navy]

bottom in this area. Like all the others (French and Japanese craft), *Trieste* lacks the cruising range and maneuverability necessary for an extensive search operation, but her observational capability makes her a useful investigative adjunct, once an area of high probability has been established. Operation of this craft is time-consuming and provides a good example, for the non-seagoing scientist, of the slow pace at which many seagoing experimental activities must be conducted. *Trieste* must be towed from port to the operating area at a speed set by the conditions of wind and sea, at best not in excess of 5 knots. She is essentially a fair-weather vehicle and is very vulnerable if caught under tow in a storm; thus, she is not taken out of port unless there is a prediction of good weather for the entire operation period.

In the present case, the tow from Boston took about 3 days. Once on station, it is necessary to transfer personnel from the towing ship to *Trieste* in small boats, and to maintain divers in the water until she has started her descent. This portion of the operation typically takes more than an hour. Once on her way, *Trieste* sinks at a rate of less than 1 meter per second, requiring some 60 minutes to reach bottom in the *Thresher* area. After *Trieste*'s arrival on the bottom (and possibly after oscillating maneuvers to free her from mud, if her descent was not checked in time), her ballast is adjusted and she can begin to cruise horizontally at speeds of ½ to 1 meter per second at an elevation of about 10 meters above the sea floor. From this position, one of the three men in the sphere (2 meters in diameter) can observe a patch of sea floor a few meters wide and 10 to 15 meters long, ahead of the vehicle. Her turning circle is about 20 meters in diameter, and thus a 180-degree turn takes about 2 minutes and no single spot on the sea floor can be kept in view during that time. When the battery supply is exhausted, after she has been at the bottom for 4 or 5 hours, ballast is released and she ascends to the surface. Once the *Trieste* is at the surface it is necessary to check out all equipment, recharge batteries, and load ballast before she can make another dive. One dive per day is her maximum capability under good weather conditions in this area.

Trieste made two series of five dives each in connection with the *Thresher* search. Because of navigational difficulties and minor malfunctions of equipment, only two out of each five dives were highly successful. The remaining three dives per series, while useful, provided essentially negative evidence, such as evidence on where *Thresher* was *not*. During these dives, personnel of the *Trieste* were able to plot the limits of debris on the bottom, obtain photographs (Fig. 5) of many parts of the hulk (including draft markings from the bow), and recover pieces of the debris. The debris area has been described by the *Trieste*'s pilot, Lieutenant Commander Donald Keach, as "resembling an automobile junk yard." Unfortunately, a magnetometer aboard the *Trieste* did not operate properly and the magnetic anomaly observed by the surface ships could not be positively associated with the debris. Radiation detectors, both total-count and pulse-height analyzers, showed the radioactivity in the area to be normal and to be attributable primarily to the potassium-40 in the sediments.

Results from the *Trieste* operations showed the microstructure of the bottom to be sufficiently complicated to make further use of surface echo sounders impractical. As a consequence, considerable effort was expended to improve deep-towed instrument packages. The Navy Research Laboratory combined their television camera unit with a proton precession magnetometer and a side-looking sonar (Figs. 6 and 7). Although there was interference between the various components, nonetheless, the advantage and practicability of multiple sensors was amply demonstrated. Even with this increase in capability there remained the problem of accurate navigation with respect to the bottom, which hampered all phases of the search operation.

New Tracking System

As the difficulties in finding *Thresher* became more apparent it also became clear that a major requirement would be the ability to keep a record of the tracks of various instrument packages and of *Trieste* in their traverses across the area. Initial estimates of the positions of deep-towed instruments relative to the towing ships were made from knowledge of the ship's speed, the amount of towing wire used, and the angle of the towing wire at the ship. However, the currents in the area are not constant, either as a function of time or as a function of depth; thus, particularly at the low towing speeds which were necessary, the 3000 meters of wire allowed a considerable position uncertainty. It was known from other work that acoustic methods could be used to determine the position of the tow relative to the tending ship.

Thus, the Woods Hole group on *Atlantis II* put into operation a tracking system in which a sound source on the towed package transmitted a signal picked up by three elements, two mounted (fore and aft) on the ship and the third mounted on an outrigger to provide a 15-meter athwartship separation between the receivers. With this arrangement and with knowledge of the water depth from echo sounding, it was possible to compute the approximate position of the sound source. By the time the *Trieste* made her second series of dives, a more elaborate tracking system, assembled by the Applied Physical Laboratory of the University of Washington, had been installed on the research ship *Gillis*. In this system a short pulse signal is transmitted from the ship and answered automatically by the sound source (transponder) on the tow. Three receivers are mounted on the ship, and their outputs are fed to a computer which produces all three coordinates of the transponder relative to the ship for each pulse.

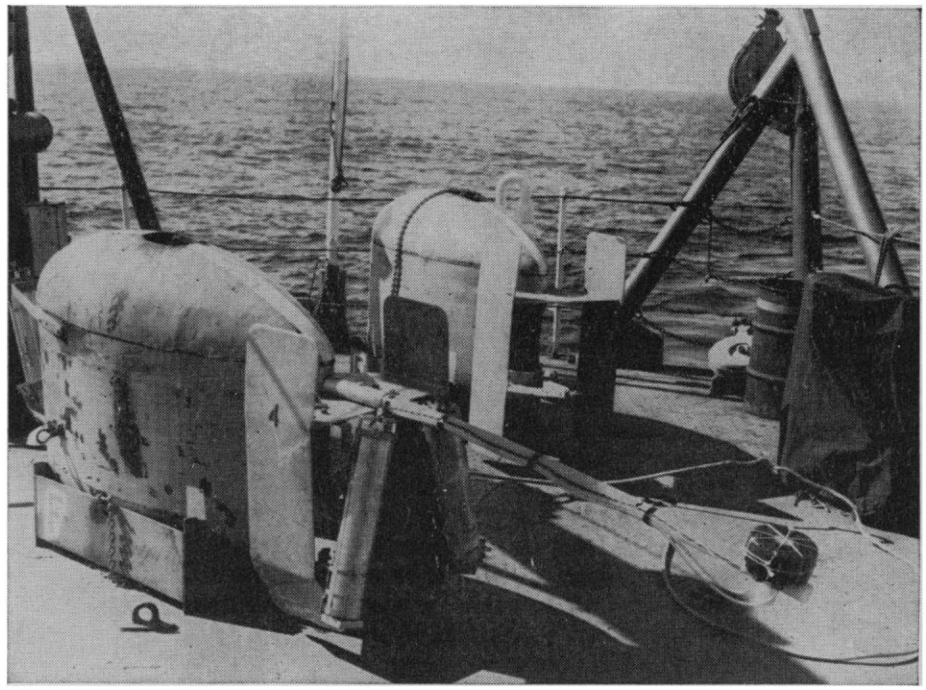

Fig. 7. Exterior of the unit described in Fig. 6, showing the sensing element of the magnetometer mounted on the extended boom. [U.S. Navy]

This system was used to track *Trieste* in her second series of dives and to navigate *Gillis* relative to a transponder fixed to the sea floor. Throughout the entire operation consideration had been given to the use of acoustic transponders or beacons to mark various reference points, but erratic performance and fear of overloading the area with confusing noisemakers made the Advisory Group reluctant to use them extensively.

While acoustic methods seemed appropriate for use with most instrument packages, there was also a realization on the part of some participants that even simple, after-the-fact, knowledge of the position of photographic equipment relative to the sea floor would be useful. This led to the use of "fortune cookies"—plastic sheets (40 by 55 cm) numbered sequentially, rolled, tied with a soluble band, weighted, and dropped into the sea by one of the ships. This provided strings of spots on the sea floor which were then used for correlating different photographic sequences traversing the same area. This system also proved useful in orienting observers during bathyscaphe dives.

Following the second series of *Trieste* dives the weather began to worsen, and the decision was made to terminate the entire operation, at least for 1963. By that time the debris area had been well determined and convincing photographs and pieces of material from within the submarine had been obtained; there no longer remained any doubt that the site of the accident had been found and that any properly equipped ship could return to the debris area at will. The evidence clearly indicated that some catastrophic event had occurred as the eventual result of loss of buoyancy and control by *Thresher*. It did not appear that any direct information on the chain of events leading to the violent hull failure could be reconstructed from the debris thus far found. Some questions still remain, however, which make the area an interesting one for testing new and improved systems for sea-floor search. Specifically, the location and condition of the remains of the pressure hull and the reactor are of considerable interest, particularly in view of the variety of credible hypotheses as to their behavior that have been proposed. These range from a hypothesis of complete burial in the sediment, due to high sinking speed, to one of possible temporary surfacing of a portion, resulting from a diesel-engine-like explosion following rapid flooding from one end.

Further activity in the search area this summer is already under way. Complete systems combining acoustic, magnetic, and photographic techniques are being used, in connection with careful sonic navigation. *Trieste* has been extensively rebuilt (this work had been started prior to the *Thresher* accident) and has returned to the scene as a far more rugged piece of seagoing machinery. Concurrently, the Navy is preparing to implement a long-term development program, based on work of a special study group (the Deep Submergence Systems Review Group), which will give it capability in locating, examining, and (in special instances) recovering objects on the deep sea floor. This program will include the construction and outfitting of small submarines having greater mobility, cruising range, and work capability (though not greater operating depth) than *Trieste*. Many marine scientists have long desired development of craft with the observational, instrument-planting, and recovery capabilities that these small submarines will have. It is unfortunate but true that it has taken the *Thresher* tragedy to awaken many to our lack of ability to investigate the deep sea—a lack not of basic knowledge of fruitful techniques but of experience and equipment in being. Such capabilities as we had a year ago grew directly out of our existing marine research effort. The new capabilities which are being brought into being as a result of last summer's work will help push forward our ability to make even more fruitful exploration of the depths of the sea.