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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

NRL's Deep Ocean Search System (DOSS) is a refinement of the system used to locate the lost submarine *Thresher* in 1963. It consists of shipboard electronics, the facilities used for launching, towing and retrieving the towed vehicle (fish), and the instruments and sensors of the fish.

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CONTENTS

NAVAL RESEARCH LABORATORY
DEEP OCEAN SEARCH AND INSPECTION SYSTEM

INTRODUCTION

The Naval Research Laboratory (NRL) has been engaged in towing unmanned vehicles from surface ships for many years. Various types and sizes of vehicles have been towed from the stern, from over the side, and from centerline wells. The first experience with a centerline well towing system dates back to 1954. At that time, the USS *Hunting* (EAG-398) was equipped to handle a 50,000-lb towed vehicle, or "fish" through a 12 ft by 28-ft centerline well (Figs. 1, 2). Experience gained from the use of various tow points system locations led to the design of the present centerline well towing configuration aboard the USNS *Mizar* (T-AGOR-11). The *Mizar* is the support ship used for NRL's search system.

THE *MIZAR*

The USNS *Mizar* (Fig. 3) is 266 ft long and 52 ft wide; it displaces 3800 tons at the design draft of 19 ft. Twin screws, powered by a 3200-hp diesel-electric propulsion plant, drive the ship at a top speed of 13 knots. The ship's complement consists of 30 men and 11 officers; quarters are provided for a scientific party of 19. The *Mizar* built in 1957, has an AK270-class hull which was modified for service as an ice breaker. The Marine Administration designation for this hull is C1-ME2-13a. The *Mizar* was modified and is operated by NRL as a general-purpose oceanographic research ship. The ship and its civilian crew are under the jurisdiction of the Military Sea-Lift Command.

CENTERLINE WELL

A major modification of the ship's hull was the construction of a centerline well. Symmetrically installed about the centerline and at the midlength point of the ship is a 10- by 23 ft well(Figs. 4, 5). The well extends from main deck to keel and is open to the sea and covered over by hydraulically actuated watertight doors at main-deck level. The forward and after bulkheads of the well are semicylindrical in order to break up wave action when under way. To further dissipate the energy of water in the well, baffle plates are mounted at the well ends, above and below the waterline.

A completely enclosed bridge-truss structure straddles the well. It has a 100,000-lb design load-carrying capacity. The carriage, an elevator-like structure (Fig. 6) riding four vertical guiderails through the well, provides the means for launching and retrieving towed vehicles or any other cable-suspended system. During a towing operation the carriage is locked at keel level and provides the towpoint for the cable streaming the towed vehicle (Fig. 7). Upon retrieval, the towed vehicle is nested to the underside of the carriage;

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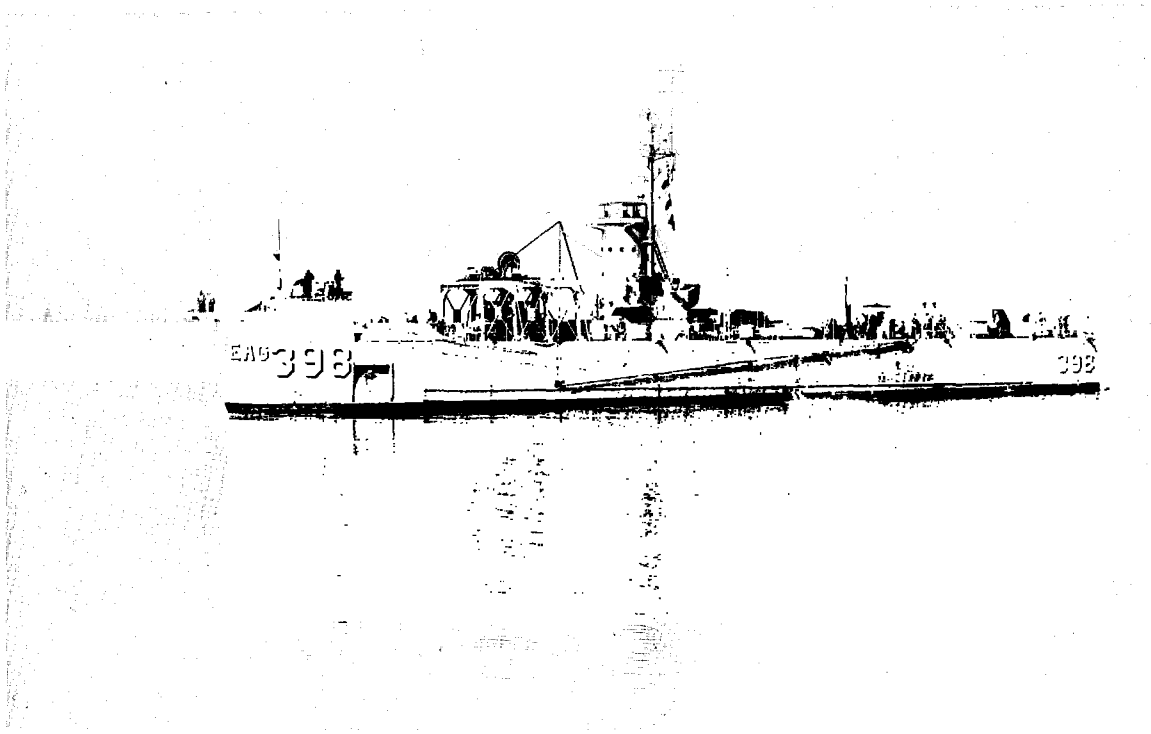


Fig. 1 — USS *Hunting* (EAG-398)

both are then hoisted through the well. The carriage is then locked at its uppermost elevation, the well doors are closed, and the vehicle is lowered to rest atop the well doors. The carriage steadies the vehicle and permits launching and retrieving in sea states of 5 or more without injury to personnel or equipment.

HOISTS

The principal hoist serving the centerwell has 22,000 ft of 0.68-in. armored coaxial cable stored on its drum (Fig. 8). Primary power for the hoist is obtained from a 75-hp electrohydraulic system. A 10-hp independent electric-drive backup system is provided for the deep sea winch; it is magnetically coupled to the main drive. Two 25-hp, variable-speed hoists, which normally stream their cable from an A-frame over the side, may also be rigged to stream from the centerwell; maximum load is 21,000 lb. Two remote operating stations allow control of the hoist at the well or in the main laboratory. All three hoists were designed and built at NRL.

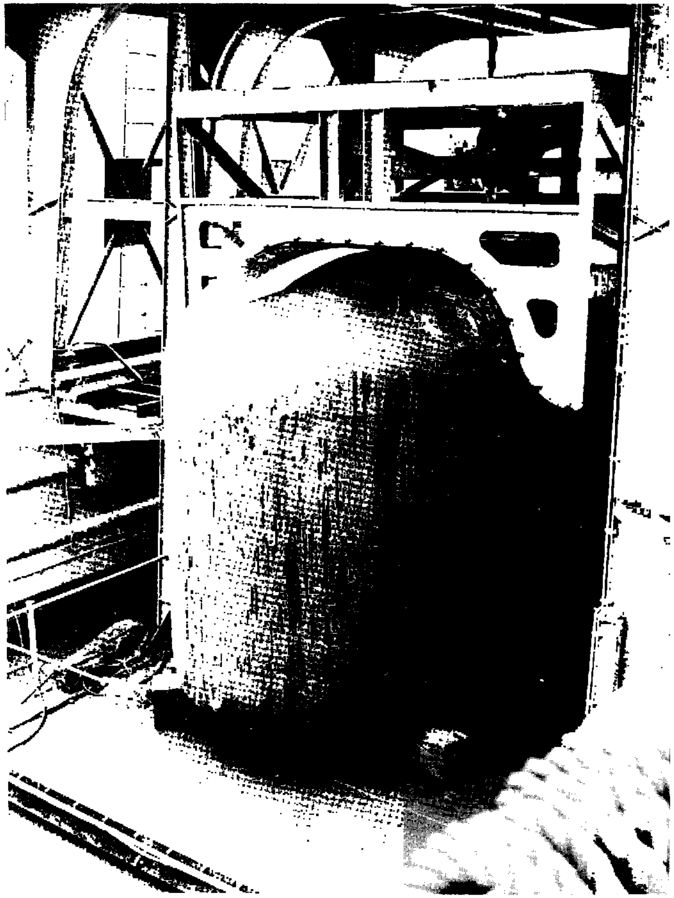


Fig. 2 — The 50,000-lb fish over the centerline well of USS *Hunting*

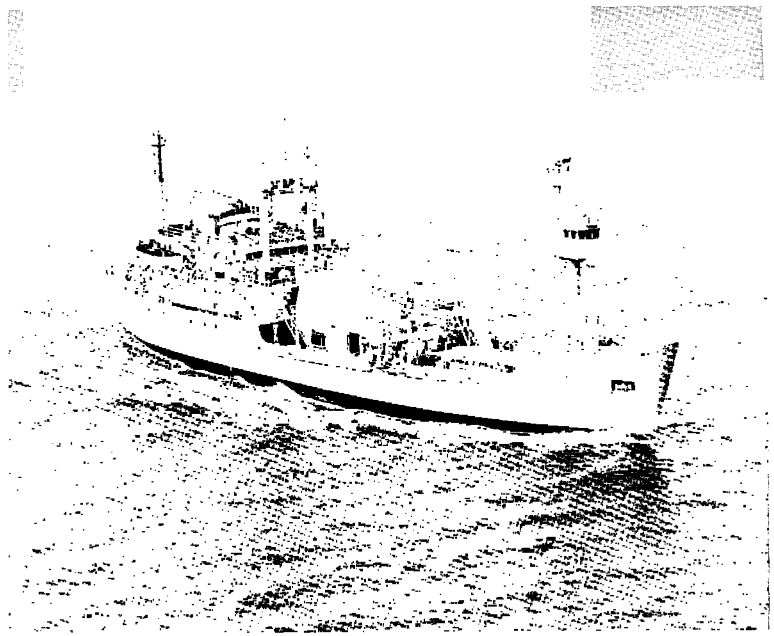


Fig. 3 — USNS *Mizar* (T-AGOR-11)

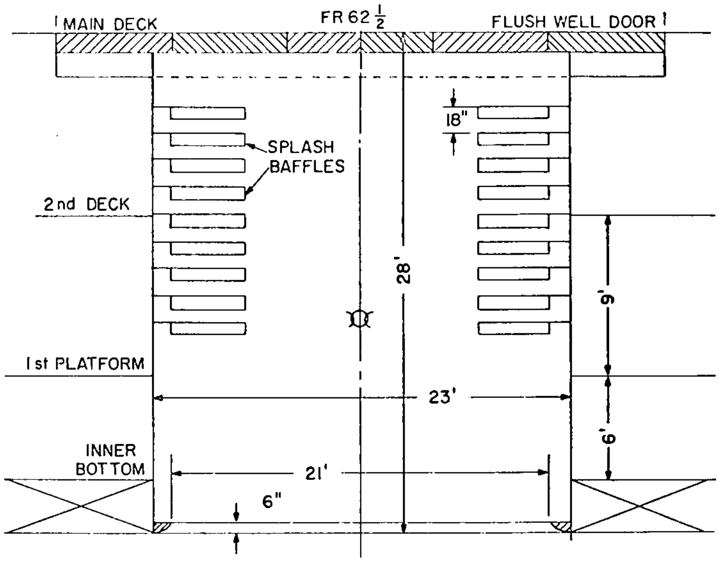


Fig. 4a — Centerline-well configuration (elevation)

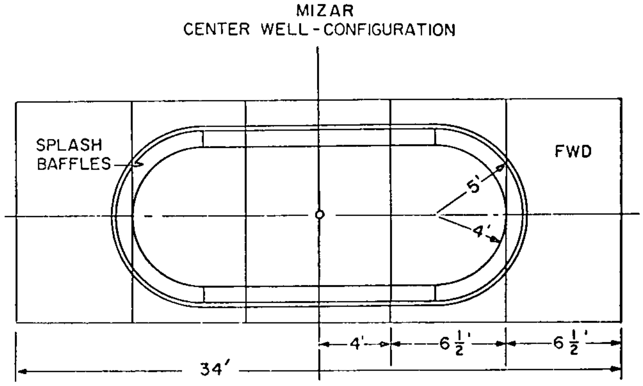


Fig. 4b — Centerline-well configuration (plan view)

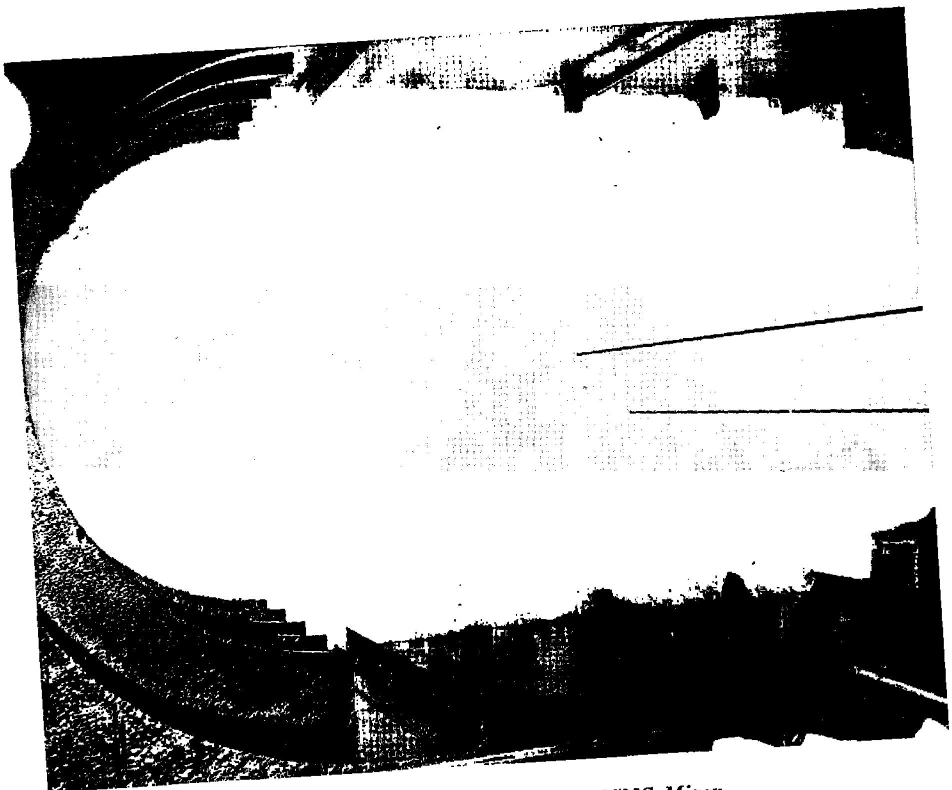


Fig. 5 — Centerline well of USNS *Mizar*

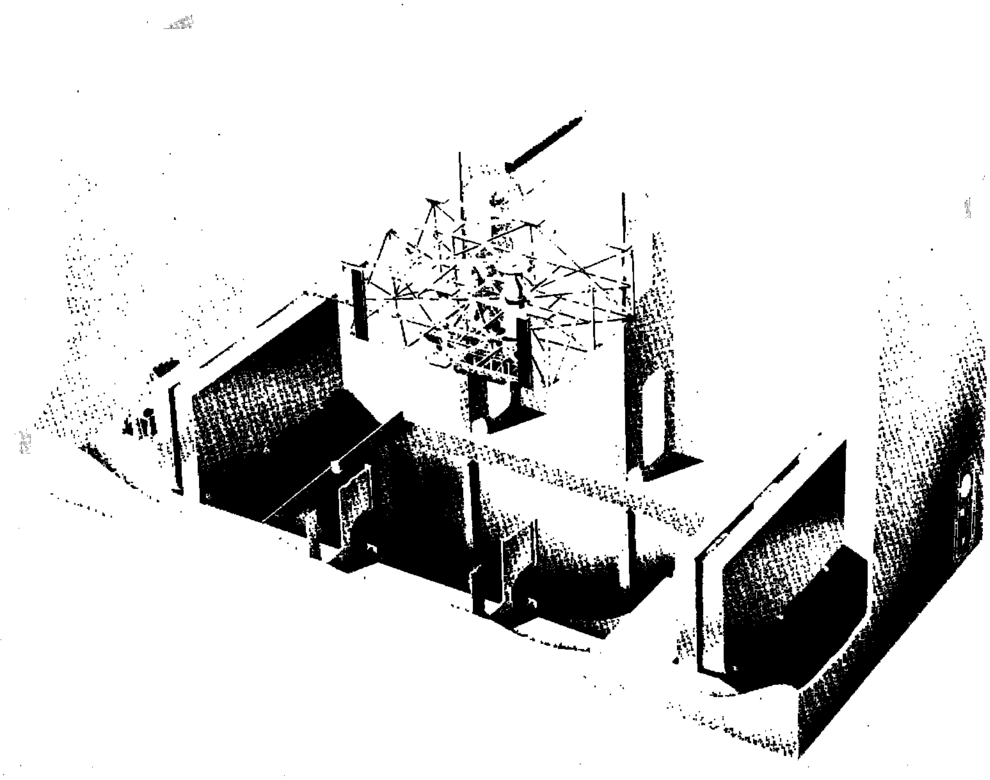


Fig. 6 — Enclosed centerline well

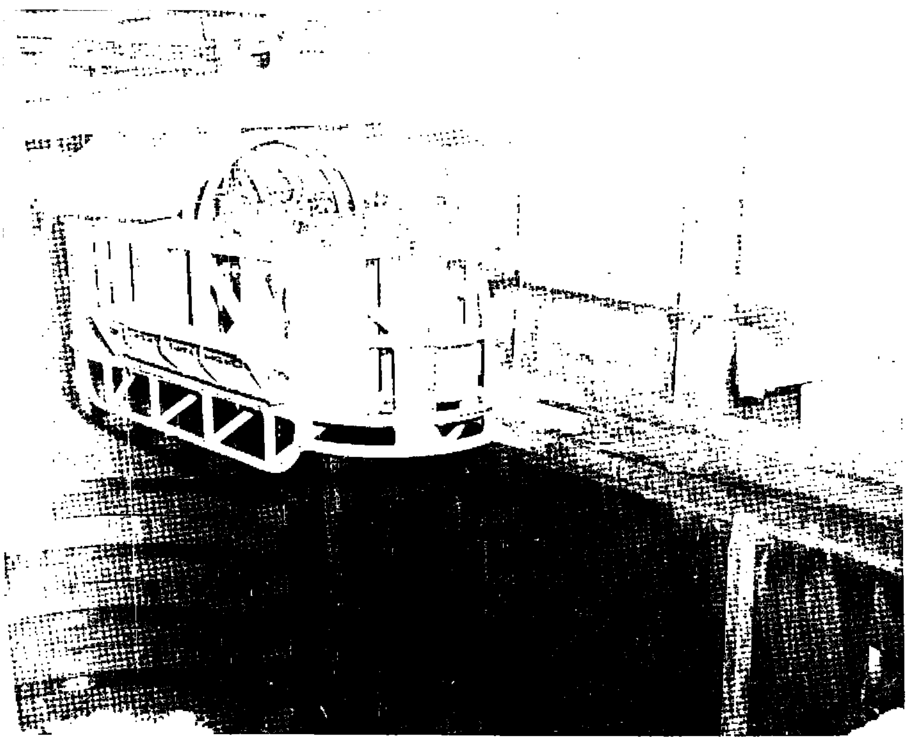


Fig. 7 — NRL fish nested in cradle entering centerline-well carriage

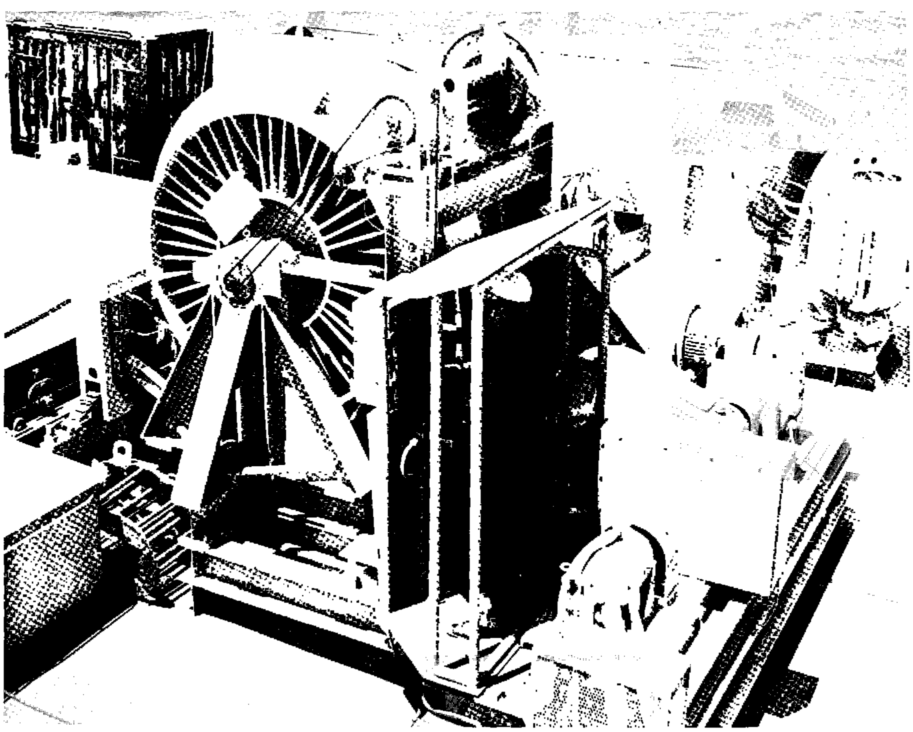


Fig. 8 — Deep-sea hoist with 22,000 ft of coaxial cable

ACOUSTIC NAVIGATION SYSTEM

To search an area effectively, one must know the location of the search vehicle relative to its towing ship, as well as the location of the surface ship relative to the area of search. For such purposes an acoustic triangulation system is employed aboard the *Mizar*.

Hydrophones

Permanently installed in the hull of the *Mizar* can three hydrophone wells, disposed at the apices of a right isosceles triangle (Fig. 9). The trunks extend from the second deck down through the ship's bottom. Hydrophones mounted on 4-in. tubular spars are lowered from the second deck through 12-in. I. D. trunks to a position about 2 ft below the hull (Fig. 10). Each transducer trunk is provided with a 60-in. streamlined sonar dome (Fig. 11). Installed in the aftermost trunk is an underwater telephone transducer (UQC), for use in underwater voice communication.

Vertical Reference Gyro

Since the tracking hydrophones are not inertially stabilized, a U. S. Navy Mark IV vertical-reference gyro is used. It provides information to compensate for tracking errors introduced by the roll or pitch of the ship. In the gyro used aboard the *Mizar*, the roll and pitch synchros have been replaced by digital shaft-angle encoders, to eliminate the errors inherent in synchro data transmission systems.

Towed Vehicle Location

The location of the towed vehicle (or fish) relative to the ship is obtained acoustically by the use of the ship's hydrophones and a responder mounted on the fish. The responder is triggered electrically via the tow cable. At the same instant, three time-interval counters on the ship are started. Each counter is stopped when the acoustic pulse from the responder is received by its associated hydrophone. An onboard computer accepts this timing information along with the signals from the vertical-reference gyro and the gyrocompass, performs the necessary calculation to provide a printout of the relative location of the fish. The precise measurement of the transit time of the acoustic signal is the most critical variable in the solution of the triangulation problem and is the source of the largest error.

Before a printout of the fish's location in a north-south or east-west reference to the ship is made, three corrections to the data must be undertaken. The first is necessary because the three hydrophones do not lie in a plane parallel to the ship's keel, and they are also not in an orthogonal relation with the ship's centerline. This requires that the timing data be translated and then rotated. Second, since the ship is not a stable platform, its position relative to the vertical must be accounted for. Corrective information for roll

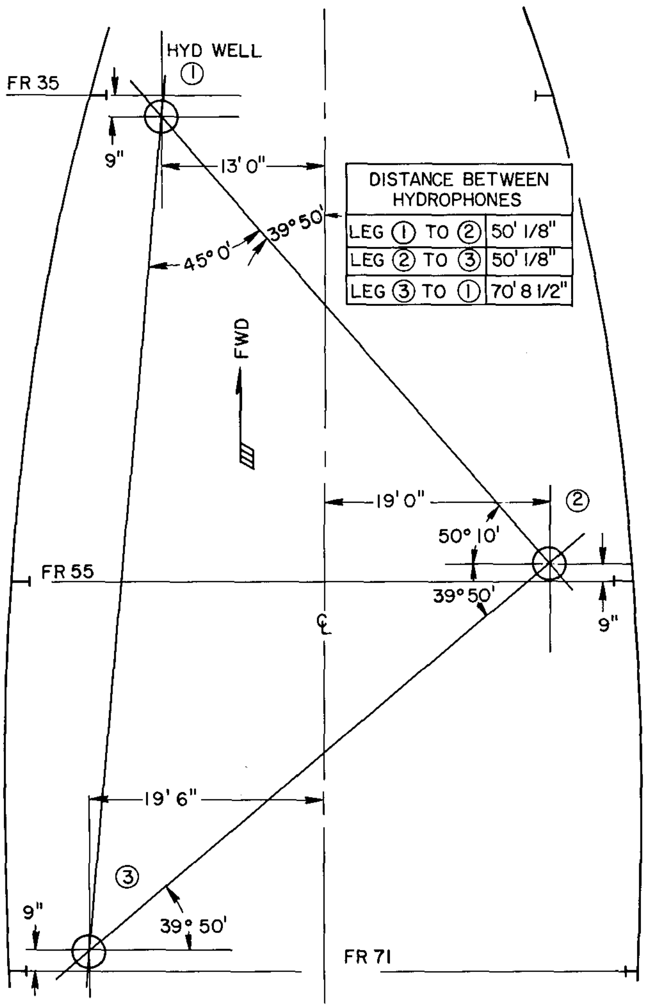


Fig. 9 — The *Mizar's* hydrophone layout

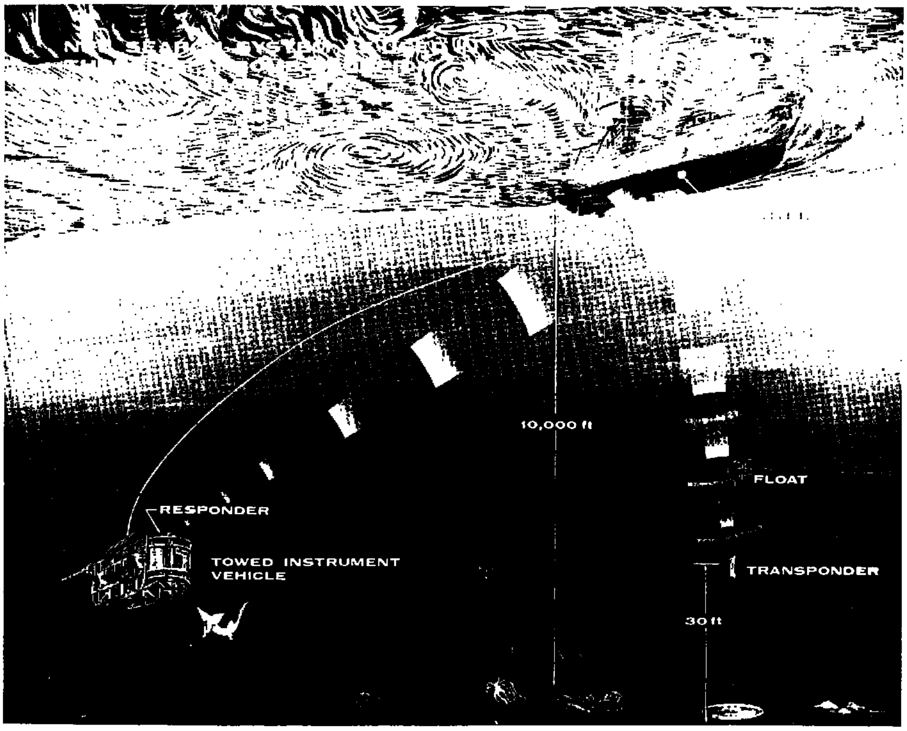


Fig. 10 — Acoustic navigation scheme

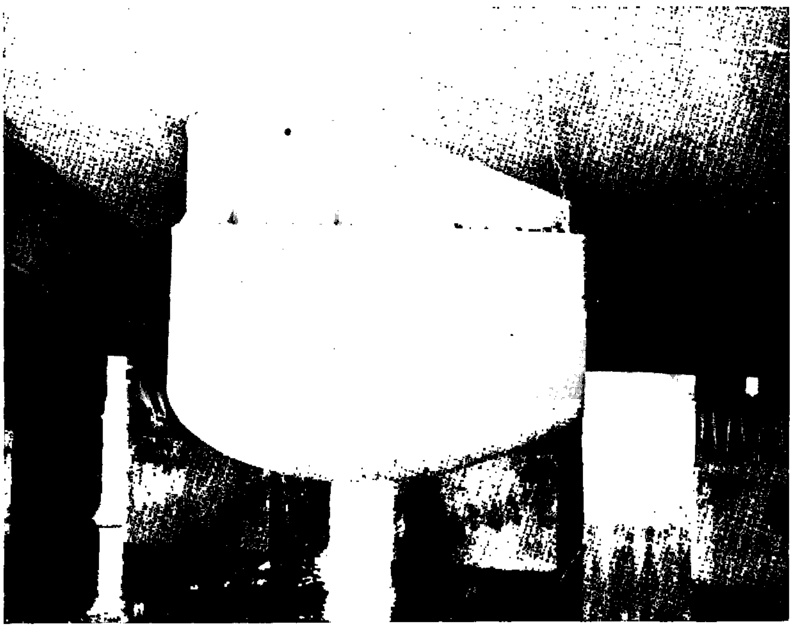


Fig. 11 — Sonar dome over port hydrophone

and pitch is obtained from a U.S. Navy Mark IV vertical-reference gyro. The third correction to the data is for convenience in plotting the fish's location relative to the ship. The location of the fish is plotted as being north-south or east-west of the ship rather than fore-and-aft or athwartships. The angular difference between the ship's heading and true north provides the needed data. This information is taken from a U.S. Navy Mark XIV ship's gyrocompass. Figure 12 is a typical printout of the location of the fish relative to the ship.

TIME	DIST(N-S)	DIST(E-W)	DEPTH	IDEN
10 36 29	1059 N	416 E	8229	F
10 36 45	515 S	188 E	8260	T
	1574 N	228 E	- 31	F-T
10 37 21	1626 N	698 E	8121	F
10 37 37	386 S	7 E	8253	T
	2011 N	691 E	- 132	F-T
10 37 58	1395 N	525 E	8182	F
10 38 14	476 N	468 W	8181	T
	918 N	993 E	0	F-T
10 38 35	1353 N	403 E	8201	F
10 38 51	437 S	35 E	8262	T
	1790 N	368 E	- 62	F-T
10 39 12	1332 N	478 E	8207	F
10 39 28	301 S	59 E	8250	T
	1633 N	419 E	- 43	F-T
10 39 49	1635 N	349 E	8166	F
10 40 05	283 S	46 W	8249	T
	1918 N	395 E	- 84	F-T
10 40 58	1583 N	435 E	8182	F
10 41 13	163 S	128 W	8288	T
	1745 N	563 E	- 105	F-T

Fig. 12 — Typical computer printout of location of fish relative to ship

Ship Location

The position of the towing ship within the search area must constantly be plotted. This position is fixed by radio navigation or by underwater acoustic systems. Radio navigation systems employed may be Loran C, Raydist, Decca Hifix, or any other similar system. The *Mizar* is equipped with Loran A and C.

When acoustic means are used for ship positioning, independent acoustic relay stations (transponders) are planted on the ocean bottom. These transponders are interrogated in a manner similar to that used with the responder on the fish, except that the transponder is interrogated acoustically by one of the ship's tracking hydrophones. The return signal received at the ship from the bottom-mounted transponder is processed by the computer in the same way as the signal from the fish's responder. From the fish's position relative to the ship and the ship's position relative to the bottom-mounted transponder, the fish's position with respect to the transponder is fixed.

The other variable required to calculate the location of an acoustic source is the underwater speed of sound. In short-base-line acoustic tracking systems, where the triangulation array is mounted on a surface ship, the ocean-surface speed of sound is used for establishing azimuthal position and the harmonic sound speed in the range calculation. In long-base-line systems, where an array of bottom-mounted transponders is used, only the harmonic speed of sound of the water column between the ship and the transponders should be employed. Equipment aboard the *Mizar* can be used for both short- and long-base-line triangulation modes.

Transponders

Transponders used with short-base-line tracking systems are interrogated individually at their uniquely assigned frequencies, and all respond at the same frequency. The inverse is true for long-base-line systems. The response frequency of NRL's system is 10.0 kHz. Interrogation may be done at any assigned frequency between 9 and 12 kHz. Some of the NRL transponders use a modulated 10 kHz for interrogation. Transponders are buoyed 30 to 100 ft off the ocean bottom, depending upon the terrain. They are retrieved when triggered by an acoustic command to release their anchors. Figure 13 shows a typical transponder-float assembly. Float and anchor sizes are selected to achieve a sink and rise rate of about 5 ft/s.

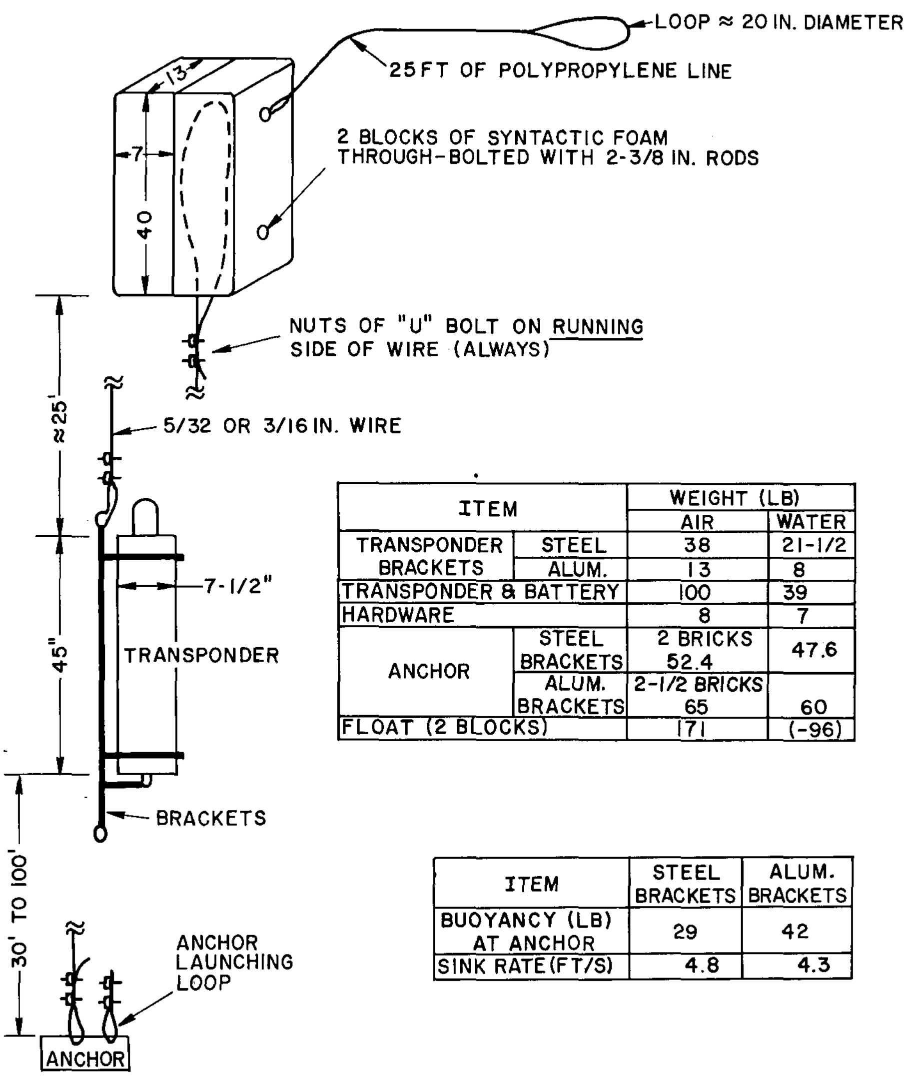
SHIPBOARD EQUIPMENT

The shipboard-installed subsystems listed below provide the necessary information-processing, display, or event-sequence controls during a search operation:

1. Tracking system
2. Surface navigation system
3. Timing equipment
4. Cable angle and tension indicator
5. Cable angles computer
6. Cable length indicators
7. Fish attitude indicators
8. Camera-control system
9. Film handling and processing equipment
10. Magnetometer receiver and recorders
11. Side-looking sonar (SILOS) receiver
12. Shipboard power supply.

Tracking System

One main electronic unit in the laboratory is the tracking system. It consists of instruments that process acoustic information for determining the locations of the fish and



ITEM		WEIGHT (LB) AIR	WEIGHT (LB) WATER
TRANSPONDER BRACKETS	STEEL	38	21-1/2
	ALUM.	13	8
TRANSPONDER & BATTERY		100	39
HARDWARE		8	7
ANCHOR	STEEL BRACKETS	2 BRICKS 52.4	47.6
	ALUM. BRACKETS	2-1/2 BRICKS 65	60
FLOAT (2 BLOCKS)		171	(-96)

ITEM	STEEL BRACKETS	ALUM. BRACKETS
BUOYANCY (LB) AT ANCHOR	29	42
SINK RATE (FT/S)	4.8	4.3

Fig. 13 — Acoustic-release transponder assembly

ship relative to some fixed ocean-bottom marker. The heart of the system is an 8,000-word, general-purpose digital computer. A digital magnetic-tape recorder is used to store part of the tracking program. The only input-output device is a typewriter. A three-channel sonar receiver and signal monitor and the transmitting system complete the system.

The responder on the fish and the bottom-mounted transponder are interrogated every 15 s. After each interrogation, the last five readings are averaged; erroneous readings are automatically discarded in the averaging process. Automatic range gating has been incorporated in the sonar receiver, allowing the system to run virtually unattended.

Surface Navigation System

A real-time plot of the ship's track is a basic necessity in any search. Two general methods are employed — relative and geographic navigation. When relative navigation is used, the position of the ship is based on the location of some fixed local reference point. This reference point may be a surface buoy or an ocean-bottom transponder. If it is necessary to know the geographic position of the ship's track, then the local reference must be tied to geographic coordinates before the operation begins.

Radio navigation can provide both relative and geographic ship positioning. Within 250 mi of land the short-range radio navigation systems, which are precise to about 50 ft, are employed. Beyond 250 mi from land, Loran can be used in most frequently navigated areas of the world, The *Mizar* is also equipped with a Transit satellite tracking system. However, the satellites passes are too infrequent to provide enough fixes for plotting a track. Fixes are needed every 5 or 10 min and Satellite navigation fixes are used only to verify the Loran positions.

Timing Equipment

Real time for indicating events on various sensor recorders is taken from a central clock and timing standard. This timing unit also has multiple outputs for frequencies of 1 to 100,000 Hz, in decade steps. All recording devices requiring a reference frequency source derive their reference from this central timer. Functions which must be performed sequentially at the fish are programmed by preset counters whose timing intervals are also derived from the central timer. Timing control for the pinger, camera trigger, and magnetometer polarizing are functions of this type. Once each day, the master clock is synchronized by radio with the WWV time standard to a precision and accuracy of 1 ms.

Cable Angle and Tension Indicators

Tension and angle (fore-and-aft) of the tow cable supporting the fish are obtained from outputs of two load cells. The cable-tension load cell supports one end of a fairlead sheave attached to the overhead in the well house, where the cable makes a 90-degree wrap around the sheave. By properly locating the sheave support points, the load cell can be made to read out tension directly (Figs. 14, 15).

The load cell used for sensing the load component of the fore-and-aft angle of the towline is positioned horizontally, in line with the strongback of a fairlead sheave. Three similar sheaves, 24 in. in diameter, are integrally mounted within the carriage framework in a vertical plane; the lowest of the three sheaves is the cable tow point. When the cable hangs vertically from the tow-point sheave, it makes a 90-degree wrap around this lowest sheave. Under this loading condition, the load-cell output for this sheave will read the same as the tension cell on the overhead. Any displacement of the tow cable from the vertical will add or subtract a horizontal component of loading to the lower load-cell output. Vectorially subtracting the outputs of the tension cell from the cable-angle cell will provide this horizontal component (Fig. 16).

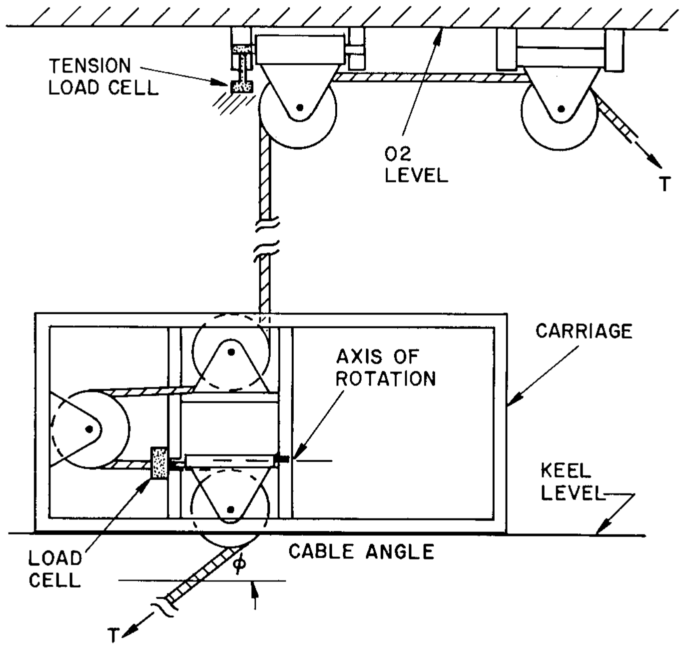
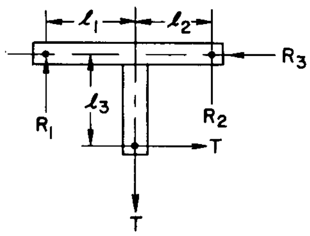


Fig. 14 — Load-cell locations



T = CABLE TENSION

$$\ell_1 = \ell_2 = \ell_3$$

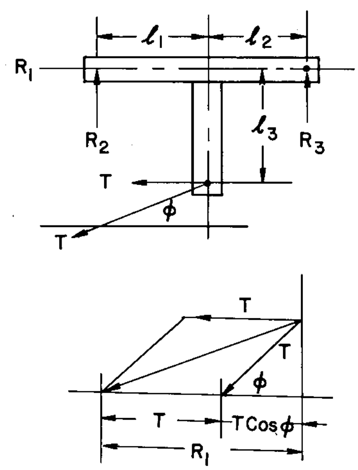
$$\Sigma M_{R_2} = R\,(\ell_1 + \ell_2) - T\ell_2 - T\ell_3 = 0$$

$$2R_1\,\ell_1 = 2T\ell_1$$

$$R_1 = T = R_3$$

$$R_2 = 0$$

Fig. 15 — Force diagram for cable tension



T = CABLE TENSION

$$\ell_1 = \ell_2 = \ell_3$$

ϕ = CABLE ANGLE

$$\Sigma F_X = R_1 - T - T \cos\phi$$

$$R_1 = T(1 + \cos\phi)$$

$$\cos\phi = \frac{R_1 - T}{T}$$

Fig. 16 — Cable-angle vectors

Cable Angle Computer

Fore-and-aft Cable Angle — the technique of converting the load-cell voltages to cable angles is novel and worthy of description. The idea is credited to Mr. Frank Heemstra of NRL. The electronic circuitry was designed and built by Mr. Lou Roudolf, also of NRL.

The method is based on the premise that an interval of time can be made to correspond linearly to the value of a trigonometric function. Selection for such an interval was set by assigning 180 μ s to be equivalent to 360 degrees. In order for the conversion to be useful, each microsecond must correspond exactly to 2 degrees. Since the outputs from the two load cells in the system that measures cable angle and tension are slowly varying dc voltages, rapid-sampling electronic circuitry can operate as if it were dealing with constant voltages.

From Fig. 16, the cosine of the cable angle is given in the expression

$$\frac{R-T}{T} = \cos \phi$$

or

$$T-R + T \cos \phi = 0$$

where

T is a dc voltage from the tension cell

R is a dc voltage from the cable angle cell

ϕ is the desired cable angle.

The first step is to convert the dc voltage T into a sinusoidal voltage whose maximum amplitude is equal to T and whose frequency has a period of 180 μ s. The voltage T is fed to a vibrator and to a filter which removes the undesired harmonics and dc components. The filter output is detected and amplified enough to restore the losses effected by the intervening circuitry. The output voltage from this circuitry may be expressed as

$$V = (\cos 2\pi)\ ft$$

where

$$f = 5555.5 \text{ Hz (period of } 180\ \mu s).$$

If in a circuit where T and R are differentially summed, the time-varying voltage T $(\cos 2\pi) ft_1$ is added, t_1 will be the time interval required for the amplitude of the generated sinusoidal wave to become equal to the dc value of T-R (Fig. 17). Also from Fig. 17, it is seen that

$$T (\cos 2\pi) ft_1 = T \cos \phi$$

where $\phi = 2\pi\ ft_1$. Electronically it is easier to measure the time interval t_3 (voltage null points) and take half of it rather than to attempt to measure t_1 directly. The time of

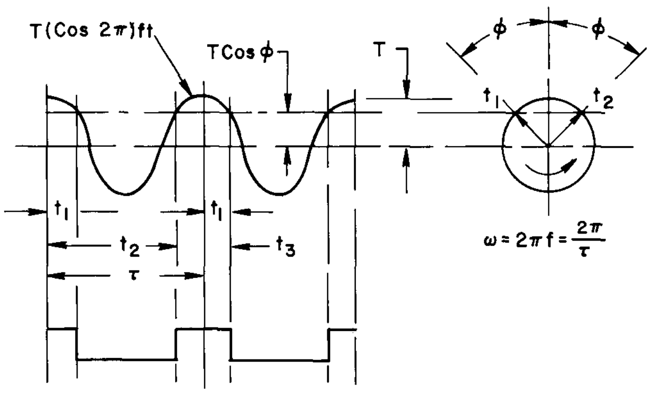


Fig. 17 — Comparing dc and sinusoidal voltage at null detection

origin of t_1 is more difficult to establish. The voltage equality points, which establish t_3, are sensed in a comparator circuit that starts and stops a counter at these null points. Since $t_3 = 2t_1$, $\phi = t_3/2$. The value of ϕ is displayed on a dial meter and on a digital printout.

Athwartship Cable Angle — The sheave acting as the tow point is fixed in the fore-and-aft direction but pendulously supported to allow rotation about a horizontal axis. Attached to a side of the sheave is mounted a highly damped pendulous potentiometer, from which is obtained the athwartship cable angle in voltage form.

Values of fore-and-aft and athwartship cable angles are displayed separately. If true cable angle (relative to stream direction) is desired, the above angles should be added together to obtain the true vector. This is not done aboard ship since the error for angles up to 15 degrees is small, and such precision is not required.

Cable Length Indicators

The length of cable supporting the towed fish is measured by three independent methods. The most reliable but least precise method measures cabledrum revolutions in feet. This first method uses a synchro generator chain-driven from the winch drumshaft. It has a sprocket ratio which gives each turn of the median layer of cable on the winch drum a "readout" directly in feet. For the outer layers the counter reads lower than actual value, and for the inner layers it reads higher. There are 34 layers of cable on the deep-sea winch.

A meter wheel 1 ft in circumference, bearing on the cable and coupled to synchro-driven counters, provides a more precise method of measuring cable length. The third method, still in the experimental stage, measures cable length by counting spots magnetically induced in the cable at intervals of 10 ft. Magnetization is accomplished automatically by using the pickup head to trigger the magnetizing head. Magnetization can be accomplished with the cable moving at 100 ft/min. One of the cable-length counters in the laboratory is coupled to a shaft encoder that provides a binary-coded decimal (BCD) output for use in digital systems.

Fish Attitude Indicators

Height of Fish Above Bottom — The 12-kHz signal from the pinger on the fish is triggered from the laboratory by gating a command oscillator once each second. The direct and bottom-reflected signals are received via the fathometer (UQN) hydrophone and recorded on a Precision Depth Recorder (PDR) or similar recorder. The reflected pinger signal is also received by the pinger transducer, which induces a signal into a secondary winding wrapped externally about the pinger transformer. This signal is telemetered to the ship via the cable and displayed on an oscilloscope at the winch operating station (Fig. 18). A third source of height information is an oscilloscope presentation of the cable-telemetered signal from a 102-kHz height-finder mounted on the fish.

While not intended for this function, fish height information is also available from the side-looking-sonar (SILOS) recorder. The Precision Graphic Recorder (PGR) is used to display SILOS information.

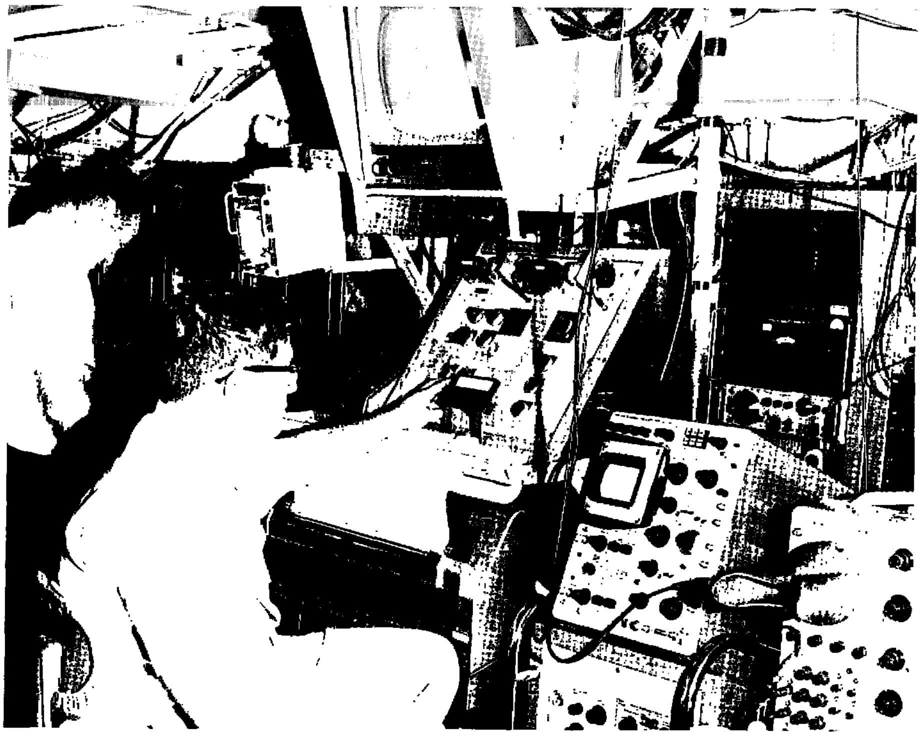


Fig. 18 — "Flying the fish" during an operation

Roll, Pitch, Heading, and Speed of Fish — The behavior of a towed vehicle is of sufficient interest to warrant its being monitored. The NRL fish is equipped to monitor roll, pitch, heading, and speed. These four variables are received aboard ship as a composite FM/FM signal on one of the information channels. After the carrier has been striped off, the composite signal is fed to a bank of discriminators. The discriminator outputs are recorded side-by-side on a six-channel strip-chart recorder.

Camera-control System

The operating rate of strobe lighting and cameras is programmed aboard ship by a dual preset counter. When separate control of narrow- and wide-angle cameras is desired, a second preset counter synchronized with the first and operating at one-third the rate of the narrow-angle camera may be employed.

A third counter displays the number of exposures taken by the cameras. The remote-controlled event markers on both the PDR and PGR are triggered whenever a photograph is taken. This allows constant monitoring of proper functioning of the camera and strobe control circuit and indicates the specific photographs related to any anomolous event which may have been sensed and recorded by the magnetometer or sonar recorders. When the counter reaches the predetermined number of exposures possible for the length of film in the cameras, the photographic operation is ended, and the towed vehicle is retrieved (Fig. 19).

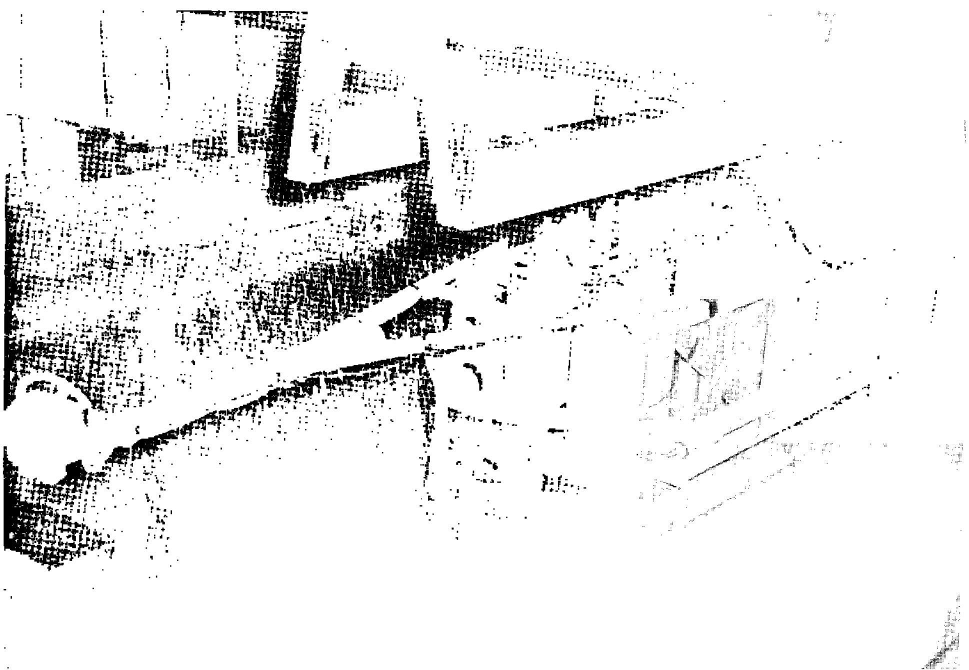


Fig. 19 — Fish being retrieved through centerline well

Film Handling and Processing

After the fish has been retrieved from a photographic run, the cameras and their pressure housings are removed from the fish and placed in a bath of warm water. This is done so the camera and film may be brought up to room temperature, thus preventing condensation from settling on and affecting the undeveloped film. The film rolls from several cameras are spliced, transferred to a large spool, and run through the "Processal," which completely develops and dries the film at a rate of 2-1/2 ft/min. Since the negative film is not used for viewing, a contact positive film is made. Viewing of the positive film is done with a variable-speed viewer having an 8-by-10-in. viewing screen (Fig. 20).

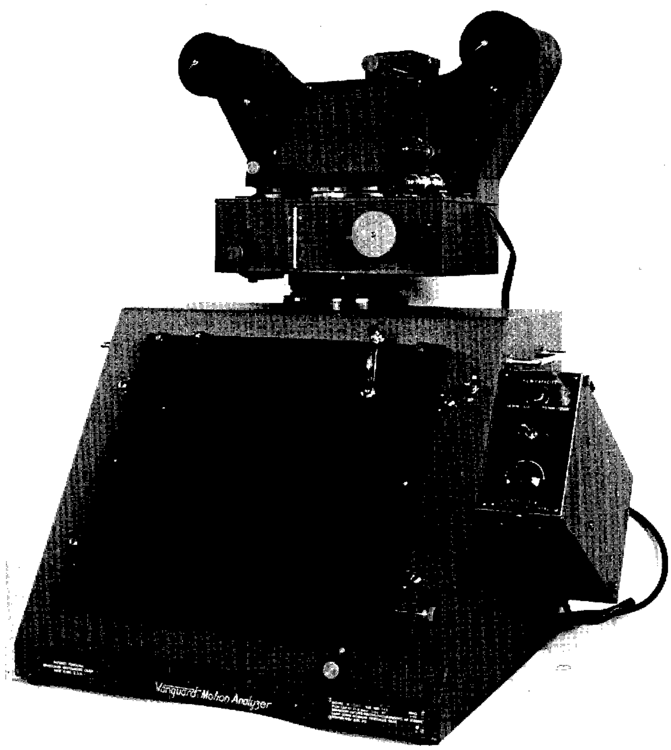


Fig. 20 — Film viewer

The film used in the cameras is Kodak's thin-based Linagraph Shellburst, type 2484. For developing, a two-bath solution of Kodak Diafine is used.

Magnetometer Receiver and Recorders

Detection of magnetic objects is performed by a pulsed, proton-precession magnetometer whose sensing head is suspended from the fish. The signal from the magnetometer sensing head is telemetered to the ship, stripped of its telemetry carrier, and fed to an audio receiver. The receiver is manually tuned to the frequency band related to the magnetic field for the particular geographical location in which the system is being used. For proton-precession magnetometers using hydrocarbon fluids, the output signal frequencies are in the 2- to 3-kHz range for normal terrestrial magnetic fields. Since the "ring" time of the signal is short, and since general-purpose instruments are used in the system, it is computationally easier to measure the period of the signal than the frequency. A digital counter counts the time interval for 100 periods of the frequency. The period is related to H (gammas) of magnetic-field intensity by the relationship

$$H = \frac{23487}{P}$$

where P is in microseconds.

The time-interval information from the digital counter, displayed in microseconds, is sent to a digital printer and to a recorder where "hard-copy" analog records are made of the signal.

Side-looking Sonar Receiver

Both types of side-looking sonars are triggered by the shipboard receiver-recorders. The present systems use commercial recorders and NRL-built receivers for processing sonar information. A 19-in. dual-stylus recorder displays the signals from the SILOS transducers in a "left-side" or "right-side" format. The signal from the transducer on the starboard side of the fish is displayed on the right half of the recorder paper (Fig. 21). The pulse repetition rate and the height of the fish above the ocean floor determine the effective scan (search) width of the side lookers. Object resolution is a function of pulse length and frequency.

Shipboard Power Supply

Electric power to maintain the 28-V, 20-A-hr battery on the fish is supplied from the the ship over the 22,000 ft of tow cable. The Ni-Cd battery is maintained at full capacity throughout a search mission for a full complement of sensors and control instruments. Four to 6 A, driven at 150 to 200 V shipside, supply the normal power needs of the towed system. The state of charge of the battery is constantly monitored and recorded aboard ship during a search operation by dial meters and a strip-chart recorder.

Figure 22 is a view of part of the shipboard electronics needed for operating NRL's search system.

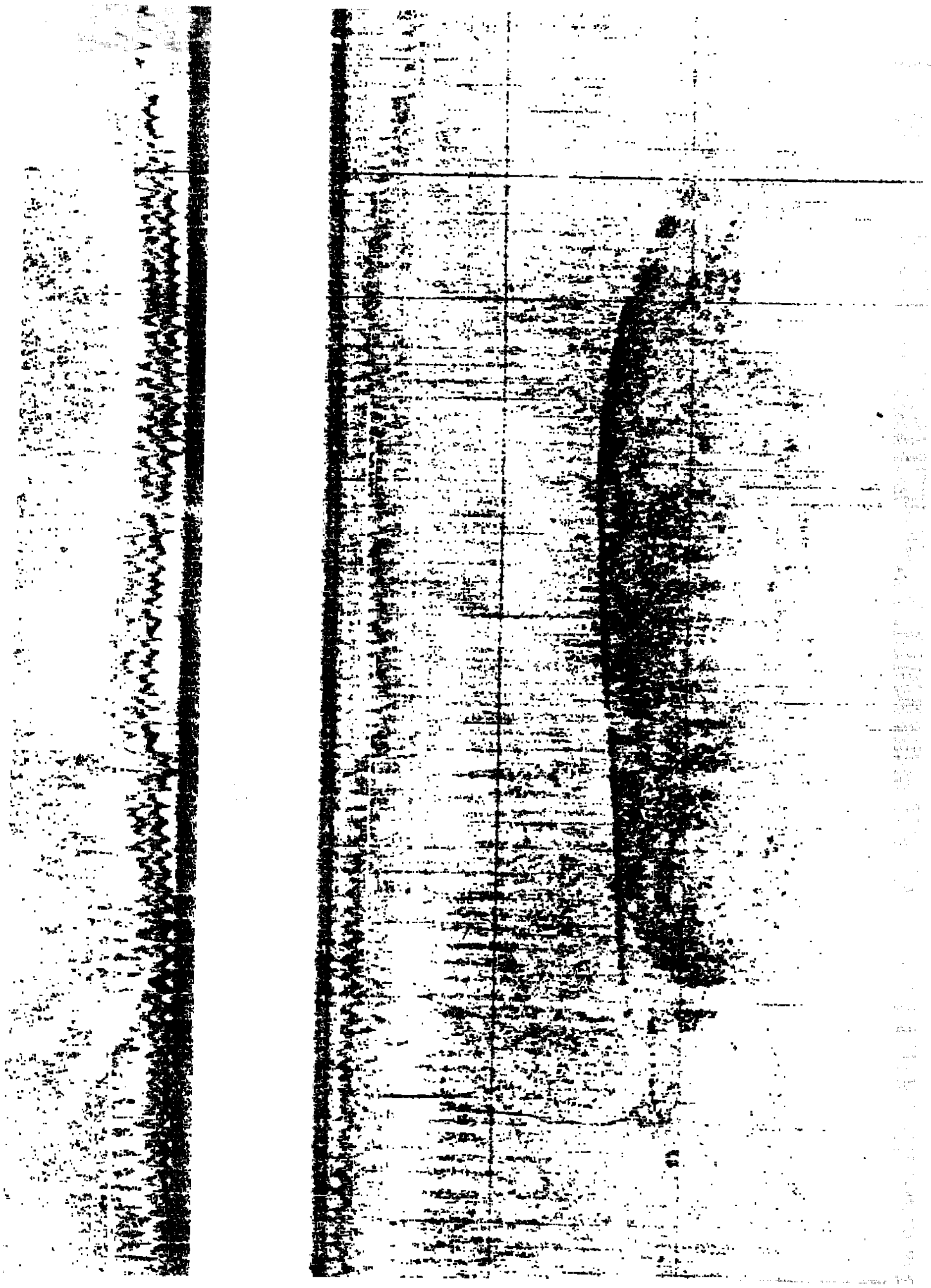


Fig. 21 — Acoustic picture of a ship's hull as seen by a 35-kHz, side-looking sonar in 16,000 ft of water

Fig. 22 — Part of instrumentation used for a search operation

TOWED VEHICLE EQUIPMENT

When fully instrumented for a major search operation the fish has the following equipment and sensor subsustems:

Vehicle support subsystems

- Power Supply
- Fish attitude equipment
  - Height above bottom
  - Roll
  - Pitch
  - Heading or yaw
  - Speed
- Navigation (acoutsic responder)
- Telemetry electronics

Sensor subsystems

- Photographic (still cameras)
  - Narrow-angle camera
  - Wide-angle camera

Narrow-angle survey camera

Wide-angle survey camera

TV, slow scan

Stroboscopic light sources

Magnetic proton-precession magnetometer

Acoustic side-looking sonar

Radiation detector

Miscellaneous sensors

Vehicle Support Subsystems

Power Supply — The fish power supply is a 20-A, nickel-cadmium, 28-V battery. An unregulated 28 V are provided to some units and a regulated 17 V to others. An inverter is used to develop a negative 18 V for the side lookers. The battery is maintained in a fully charged condition throughout the towing operation by supplying current from the ship through the 22,000 ft of cable. The battery-charging circuit makes use of the coaxial shield and the steel armor of the cable. The resistance of this circuit requires the cable to be driven with 180 V in order to deliver 5 A (normal current drain) to the battery.

Fish Attitude Equipment — The height of the fish above the ocean floor is indicated aboard ship on three displays whose signals are derived from two acoustic sensors. A 12-kHz (pinger) signal generated at the fish is received aboard ship on the UQN receiver via the direct and bottom-reflected paths. This signal is synchronously triggered at the fish via the tow cable each second and displayed on a precision graphic recorder. Through an additional winding around the pinger tuning transformer on the fish, the bottom-reflected signal is picked up, sent to the ship via the tow cable, and displayed on an oscilloscope. This system is capable of about 2- or 3-ft resolution. The second height-finding acoustic sensor on the fish uses a free-running 102-kHz signal at a 10-pps repetition rate. This signal is telemetered to the ship via the tow cable and also displayed on a scope. This second system has a potential resolution of about 3 in.

The roll and pitch of the fish is obtained from pendulous potentiometers feeding voltage-controlled oscillators (VCO). The heading or yaw of the fish is derived from a modified small-boat autopilot. The output from the autopilot is also fed to a VCO. The speed of the fish is determined by counting pulses initiated by the blade tips of a ducted impeller. These pulses are conditioned to operate another VCO. The above three VCO outputs are summed and fed to one of the telemetry channels. These FM/FM data are separated aboard ship and suitably displayed on multichannel strip-chart recorders.

Navigation (Acoustic Responder) — The location of the fish relative to the ship or any other acoustic reference marker is calculated by a shipboard computer. An acoustic responder mounted on the fish is triggered by the computer via the tow cable; the responder signal is received by the ship's three tracking hydrophones and processed to obtain the location of the fish.

The geographical position of the fish is obtained by determining the relationship of the fish to a bottom-mounted acoustic transponder. The transponder must, of course, have been previously fixed geographically by surface-navigational means.

Telemetry Electronics — Telemetry provides a multichannel command and data-link system between the fish and the shipboard control center. As many channels of information as required may be used simultaneously without degrading sensor signals. Any channel may be used for commands or for information. A set of band-pass (BP) filters is at each end of the 22,000 ft of tow cable. The two filter sets are physically and electrically identical. Each of the filters in each set presents an impedance of 32 Ω to the cable in the pass-band region and high impedance outside the pass band. Most of the pass bands are 4 kHz wide; others are 10, 20, 40, and 150 kHz wide. Sensor information or commands are fed to a balanced modulator associated with their respective channel band-pass filter. One side band is suppressed, and the carrier and one side band are transmitted. After passing through the matched set of BP filters at each end of the cable, the command or data signal is stripped from the carrier at the receiving end by demodulators. In order to assure that there is no deviation of frequency between any of the carrier frequencies used in the modulation-demodulation process, a master reference frequency is generated aboard ship and sent down the cable to the fish, where all carrier frequencies are developed harmonically from the reference frequency. Similarly, the reference frequency is fed to a set of harmonic generators aboard ship to develop the respective carrier frequencies required for demodulation. The 10-kHz reference frequency, whose amplitude is 2 V at the ship, arrives at the fish, after passing through 22,000 ft of cable, at 1.8 V.

Commands for effecting various functions at the fish utilize selected frequencies derived from a set of crystal oscillators aboard ship. Command frequencies match the center frequency of their assigned channels and may be initiated manually or automatically, in a gated or continuous mode. After passing through its set of BP filters at the fish, the command signals are stripped of their carrier frequency and amplified to actuate relay closures, which execute the desired functions. The complete telemetry system was designed and built at NRL (Fig. 23).

Sensors Subsystem

Photographic (Still Cameras) — The two types of still cameras used are similar except for film capacity. The smaller camera is designed for 100-ft film spools; the larger, for 400-ft spools. NRL has modified some of these cameras so that wide-angle lenses may be installed behind hemispherical windows (Figs. 24, 25). In air the narrow-angle camera lens has a 57-degree view angle, and the wide-angle lens has a view angle of 115-degrees. When wide-angle and narrow-angle cameras are used simultaneously, the wide-angle cameras are equipped with shutters and operate at one-third the rate of the narrow-angle cameras. Using thin-based film, about 140 ft can be wound onto a nominal 100-ft reel. On the larger spools, 500 ft of film is wound onto a 500-ft reel.

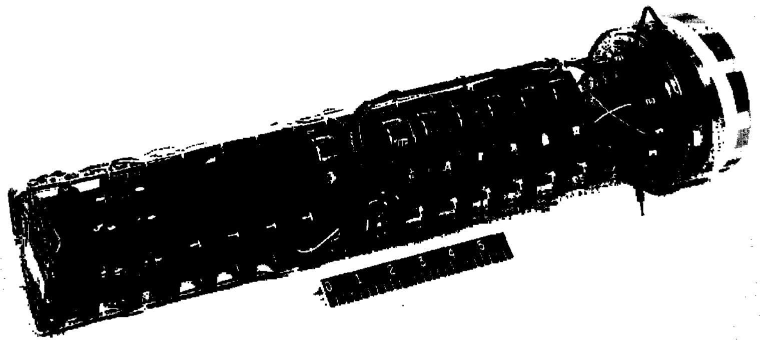


Fig. 23 — Fish telemetering electronics

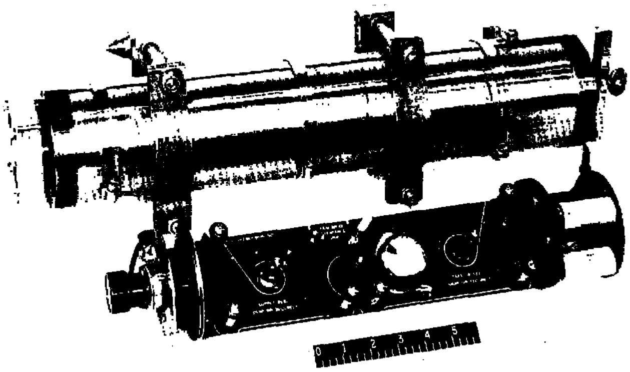


Fig. 24 — Normal-angle camera with 150-ft film-spool capacity

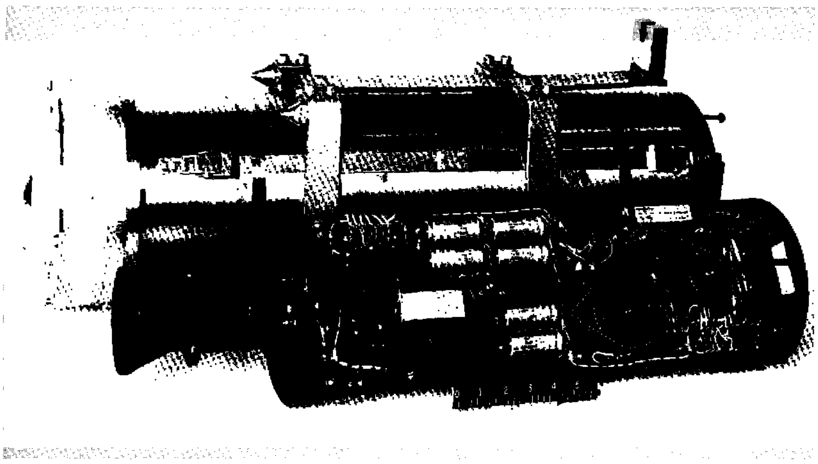


Fig. 25 — Wide-angle camera with 700-ft film-spool capacity

Stroboscopic Light Sources — Stroboscopic lighting, used to provide illumination for photography and TV, emanates from a pair of 250-ws flashes from xenon vapor lamps (Fig. 26). Maximum flash rate is approximately one flash every 3 s. During normal operation the strobes are flashed once every 15 s. This interval may be increased or decreased remotely, depending upon the type of search being performed.

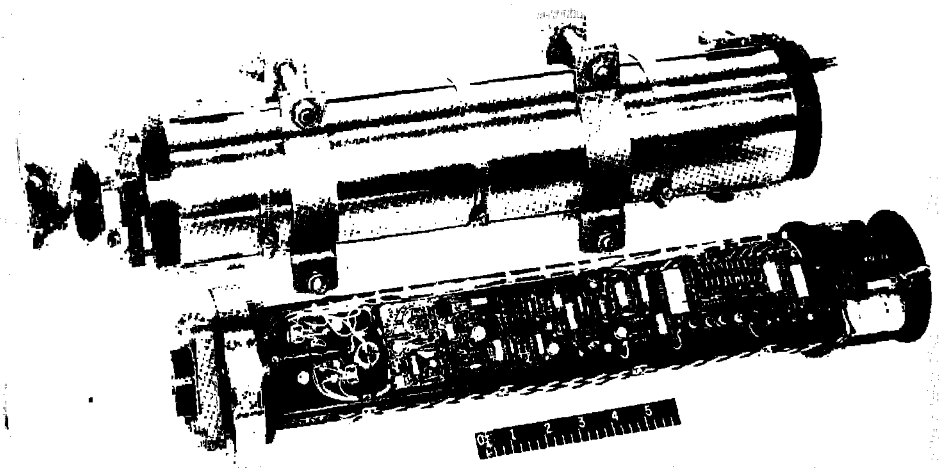


Fig. 26 — 250-Ws stroboscopic light source

Proton-Precession Magnetometer — The magnetic field sensor, or magnetometer, normally used on the fish is of the free, nuclear-precession, pulsed-field type. The sensing head is a toroidal wound coil, 3 1/2 in. in diameter, filled with a hydrocarbon liquid. The liquid is maintained in pressure equilibrium with its hydrostatic environment (Fig. 27). The sensing head is often mounted on a short tail-boom attached to the fish. When a better signal-to-noise ratio is desired, the sensing head is suspended about 12 ft below the fish. This arangement removes the sensing head from the local fields created by the steel in the tow cable and pressure bottles. These sensing heads are built at NRL.

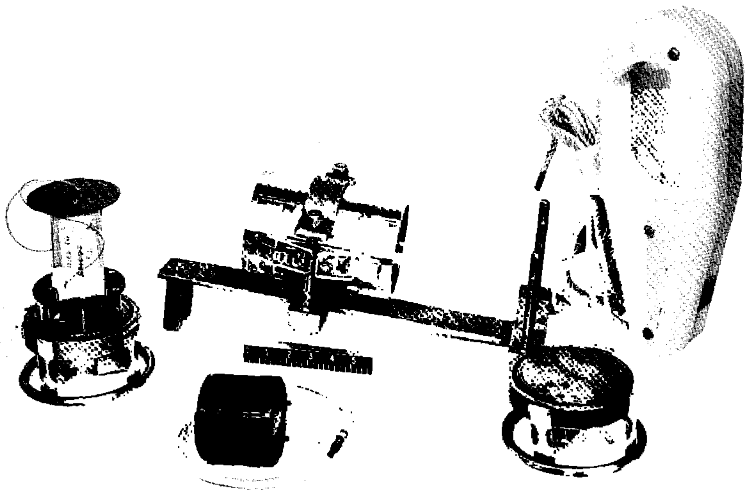


Fig. 27 — NRL-built proton-precession magnetometer (sensing head and preamp.)

Acoustic Side-looking Sonar — Two types of side-looking acoustic transducers are mounted on each side of the fish. The lower frequency units are pulsed twice each second and scan a range of 1200 ft to each side when operating 30 ft above the ocean floor. A 1-ms pulse is transmitted simultaneously, twice per second, and driven at 500 W at frequencies of 32.7 and 35.7 kHz. The higher frequency side-looking sonar operates at 225 kHz using 0.25-ms pulses at 6 pps on each side. At 30 ft above the bottom this unit has a search width of about 600 ft. The pulses for the high-frequency system are time-shared. Thus, the system operates using one frequency only. In the high-resolution mode, the sensor should be capable of defining a 1-ft target. In a low-resolution mode, the transducers are towed 225 ft above the bottom. At this height a 6 ft target should be resolvable in the sweep width of 2,400 ft.

Radiation Detector — An NRL-built sodium-iodide scintillation counter is used for detecting gamma rays. The photomultiplier output is conditioned to drive a VCO, which is in turn fed to one of the telemetry channels or sent unmodulated directly to the ship.

Miscellaneous Sensors — When required, the fish may be equipped with a velocimeter, a depth sensor, and a temperature sensor. Any or all of this equipment may be mounted on the fish and operated simultaneously.

TOWED VEHICLE (FISH)

The towed vehicle used by NRL during the successful searches for the lost H-bomb and the *Thresher*, *Scorpion*, *Alvin*, *Eurydice*, and *L.R. Briggs* is a skeletal, box-like structure measuring 30 in. X 31 in. X 75 in. (Fig. 28). Bumper guards have been added to all six sides of the vehicle, to protect it against accidental contact with ocean-floor obstructions. The box section of the fish is made of 2 in. X 2 in. X 1/4 in. 6061T-6 aluminum angles; the bumpers are 1-1/2 in. diameter rods. The aluminum structure was irridited and painted with two coats of Rustoleum, which provides the best protective coating we have found to date. The main frame is a welded structure with the bumpers bolted to it. Fully equipped, the fish weighs 2500 lb in air.

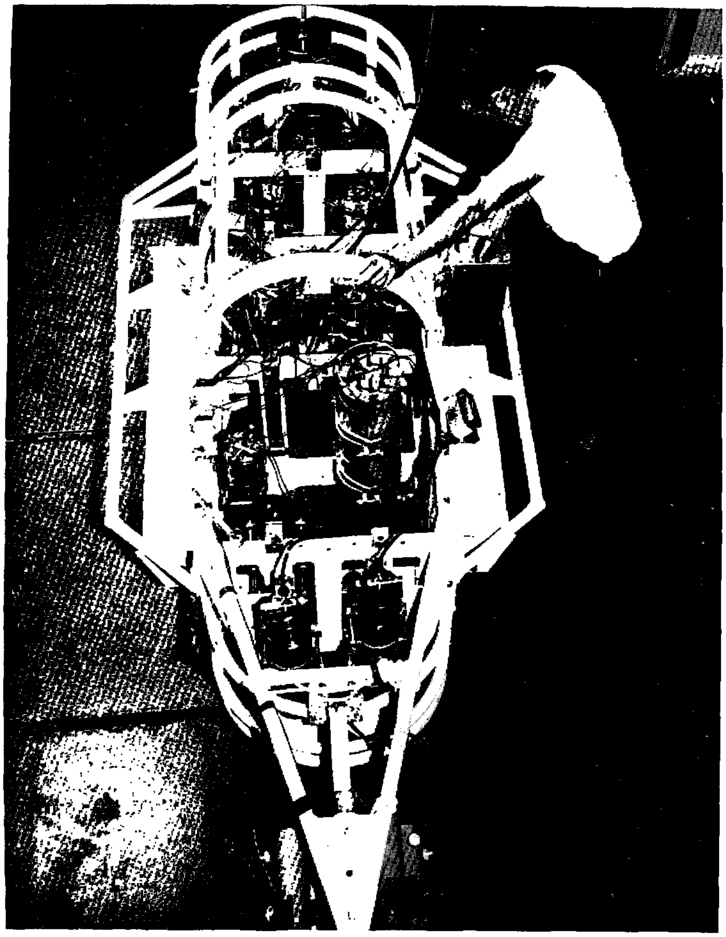


Fig. 28 — NRL towed fish with rosette water sampler attached to tail boom

A method for easy installation of instrumentation bottles has been devised. This consists of using two members, one permanently bolted to the main frame and the other bolted to the bottle. Only one bolt is required to mount the bottle securely in the frame. As many as 22 items — sensors or instrument bottles — may be mounted at one time.

TOW CABLE

A single-conductor, double-armored coaxial cable (Fig. 29) is used to tow the fish. Specifications for this cable are given below.

Specifications for Coaxial Cable

1. Nominal overall diameter: 0.68 in. maximum overall diameter: 0.690 in.

2. Center conductor: 10 AWG, annealed, tinned copper wire, stranded, 19 X 7 standard construction.

3. Core: Minimum wall thickness of 75 mils of H.D. polyethylene.

4. Shield: Tinned copper wire serving whose dc resistance value is equal to or less than the dc resistance value of the No. 10 AWG center conductor. The serving shall be laid up in the same direction and pitch angle as the outer layer of armor. The serving must have a minimum of 95% coverage of its core.

5. Jacket: Minimum thickness of jacket wall to be 50 mils of H.D. polyethene

6. Cushion: the jacket is to be cushioned from the armor with 3 or 4 mils of braided or taped Mylar, nylon, or rayon material.

7. Inner armor: 24 wires of 0.055-in. diameter, ± 0.003 in., made from galvanized, preformed, improved plow steel — right-hand lay with less than 20° pitch.

8. Outer armor: 24 wires of 0.070-in. diameter, ± 0.003 in., made of galvanized, preformed, improved plow steel — of opposite lay to the inner armor but of same pitch angle.

9. Length: 22,000 ft in one continuous length, wound on a steel cable reel.

10. Breaking strength: 32,000 lb minimum.

11. Nonflooding compound: The center conductor and shield will be solidly impregnated with a suitable filler compound to prevent ingress of water. The filler compound must remain flexible at 32° F and not flow at 200° F.

12. Compound retainer envelop: To impregnate the cable with the nonflooding compound, a suitable covering of rayon, nylon, or similar material may be used over the center conductor and shield.

13. Lubrication and Corrosion prevention: A suitable asphaltic-base lubricant having temperature characteristics similar to item 11 above is to coat both armor layers.

14. Insulation-resistance and high-voltage tests are to be conducted on the finished cable after the cable has been prestressed to 50% of its breaking strength. No breaking-strength tests are required.

The 22,000 ft of cable is wound onto the smooth-core drum of the deep-sea winch in 34 layers of 36 turns per layer. Considerable care must be exercised in laying down the first layer, since subsequent layers will magnify the faults of an imperfect first layer.

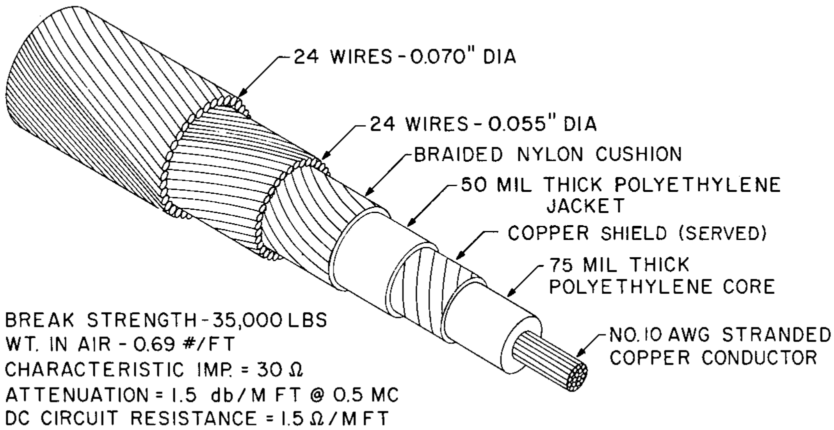


Fig. 29 — NRL 0.68-in. coaxial cable

Strain-member Terminal (Socket)

The strain-member terminal (socket) that transmits the load of the towed vehicle to the towline (Fig. 30) was developed at NRL. The socket is of the "potted" type, wherein the strength-member wire ends of the cable are potted in the cavity of the socket with either an epoxy compound or a metal alloy with low melting temperature. The alloy, Cerrobend is preferred to the epoxies because of longer shelf life (indefinite), reusability of the metal, and no need for curing time. Four 90-degree bends are made on each of the 48 wire strands within 4 in. of the cable end. This nest of bent wires is jammed into the socket cavity. The cavity is then filled with Cerrobend at a pour temperature of 160° F. During the pour, the socket body is kept heated and is vibrated so the melt fills all interstices between wires.

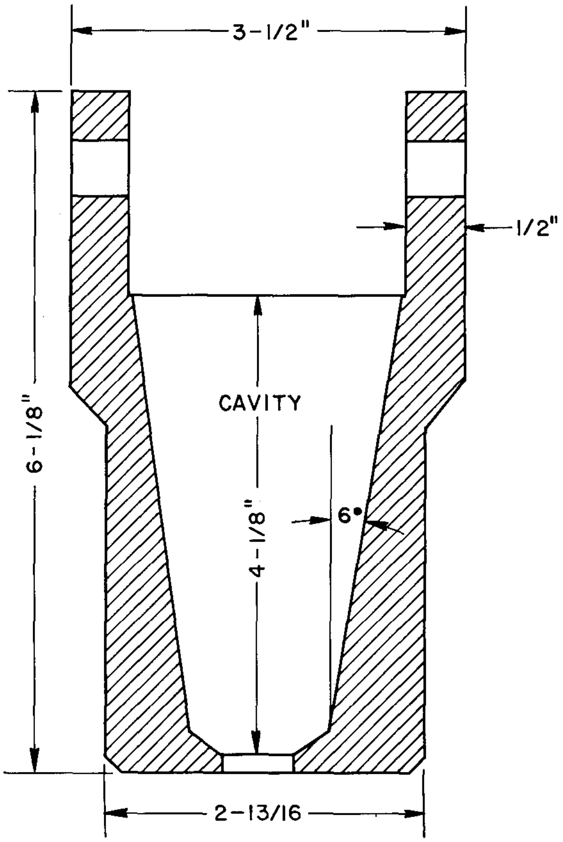


Fig. 30 — Cable socket

CONCLUSION

The search and inspection system described above has been used effectively in 30 operations since 1965. During that time more than half a million photographs of the ocean bottom have been taken. The negatives of all these photographs are stored at NRL. As better means of operating become available, they are incorporated into the search system, which is kept ready for any emergency search mission which may arise.