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REPRINT R140

UNDERSEA TECHNOLOGY®

THE MAGAZINE OF OCEANOGRAPHY, MARINE SCIENCES, AND UNDERWATER DEFENSE

Practical Depth Determination For Multi-Sensor Towed Systems

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Practical Depth Determination For Multi-Sensor Towed Systems

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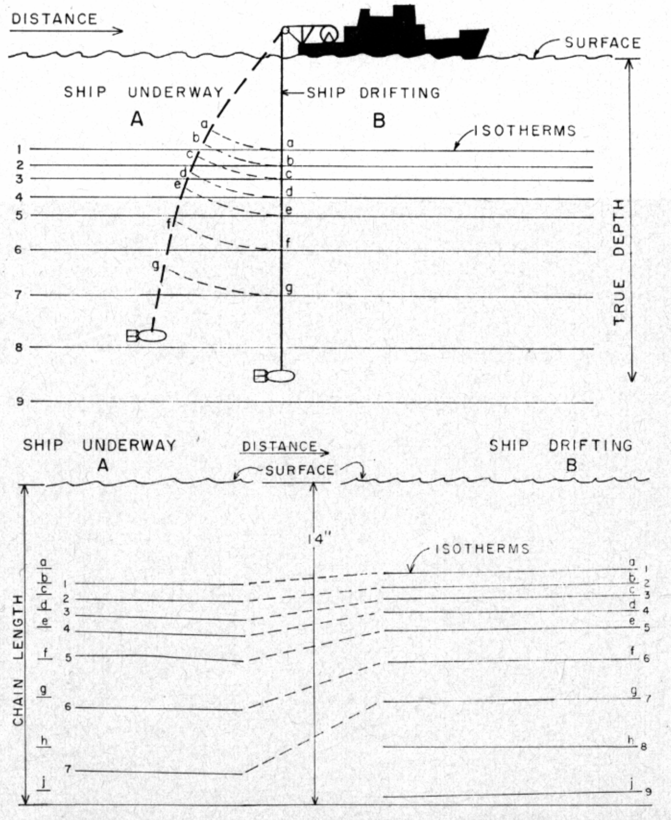
Rather, Hersey, et al, 1965, have discussed basic problems associated with improved towline design for oceanography. One important piece of scientific equipment, heavily dependent upon such design and now in use on oceanographic vessels, is the thermal-tow. This is an instrument which may utilize a faired cable with thermistors attached at intervals and with a pressure (or depth) transducer at the end of the chain. The cable may be towed at speeds up to approximately ten knots. Data are recorded automatically in several forms in the ship laboratory. As ship speed, wind, ocean current, sea state and other conditions change, the depth attained by the cable changes. Thus, the thermistors (or other sensors) affixed to the chain also change depth and a way must be found to determine the true depth at which each is functioning.

As stated by Rather, Hersey, et al, no valid, generally accepted theory exists for the practical solution of this problem.

The Texas A&M Research Vessel *Alaminos* has a faired cable 267 meters long with thermistors attached at 7.6 meter intervals. On a cruise in the Gulf of Mexico in May 1964, data were collected from which a depth determination chart was prepared. The nature of this chart, its development and its application are the subject of this presentation. In brief, the chart is a set of scales such that, given the single depth reading from the chain end, the depth associated with any particular point along the chain length may be read off. Such a chart may readily be developed for any towed system. It provides an empirical approach which is the type of approach indicated by Rather, Hersey, et al, to be the only feasible one.



shows the true thermal-tow position, and depth section of isotherms. Lower drawing shows isotherms as they appear on contour chart. chart contours. Upper drawing Figure 1. Sketch showing the relationship between the ship,

Instruments somewhat similar to the Texas A&M thermal-tow (TT) have been described by Richardson and Hubbard, 1960, and by La Fond, 1963. On the *Alaminos*, TT temperature is recorded on punched tape, in typewritten form, and as isotherms on a contour chart having chain length and time as coordinates. Chain-end depth is a part of the typed record. On the May cruise the pressure transducer attached to the lower end of the chain showed depths from 185 to 243 meters with constant engine speed of 580 revolutions. The indicated depth changes were not random but occurred with noticeable changes in environmental conditions.

The determination of the depth of a particular sensor attached to a towed chain is difficult under such circumstances because the shape of the chain is complex. When a current exists, the shape may change not only in the vertical plane in which the ship is moving, but in the third dimension also, as in the common case when a ship is traveling across the current system.

For practical reasons in using the TT, it seems desirable to tow it at a speed which allows the TT to attain a depth greater than 200 meters. This provides information throughout the layer in which most of the seasonal effects on temperature, other than those related to the general circulation, are observed. Although turbulence around the chain remains low, it allows the ship to travel at 6 to 9 knots.

After an initial period of experience, the engines on the *Alaminos* were turned at a number of revolutions such that the pressure transducer attached to the chain end varied in depth between about 215 and 225 meters. Engine speeds were changed as few times as possible as long as the chain end could be kept within this range.

In the depth determination method which was adopted, the transducer reading at the time of observation determines for that observation, the depth scale with which the isotherm depth is read from the contour chart.

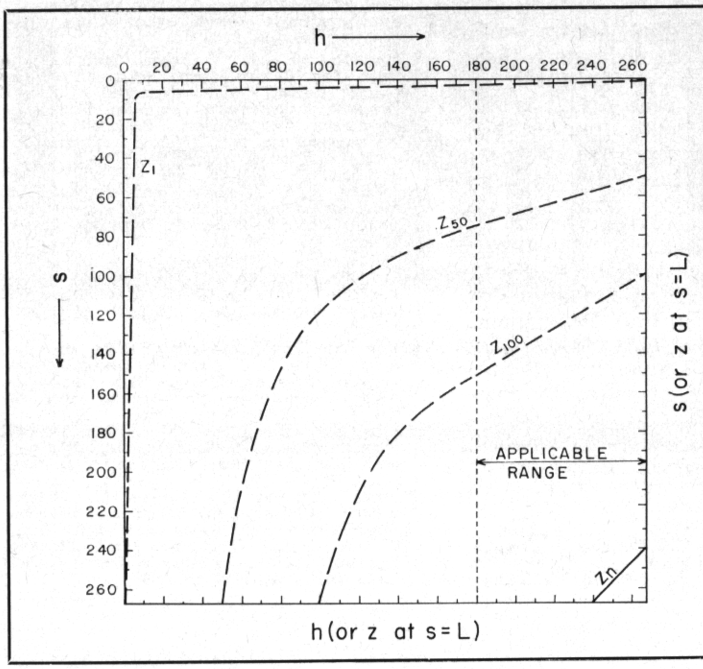


Figure 3. Characteristics of lines under constant Z.
L = total length of cable submerged.
h = depth of chain end.
Z = depth below surface at which temperature is measured or interpolated.
S = cable length below the surface required to reach the depth Z.

The nature of the contour chart plays an important role in the establishment of a method for depth determination. On this chart the horizontal scale indicates time with 15 inches being an hour at the setting used on the May cruise. When the ship is underway at a given speed, this scale also represents distance. Figure 1 is a sketch indicating the relation between the ship, the thermal-tow position, and chart contours. Figure 2 is a photograph of an actual record.

The depth of vertical range on the contour chart paper is 14 inches. Since the vertical scale is a linear scale of chain length, each thermistor on the chain is represented by the temperature value at a fixed vertical position on the chart, regardless of the depth of the thermistor in the water. The surface thermistor records at the top of the vertical scale and the deepest one records 14 inches lower at the bottom of the sheet. The intermediate thermistors are equally spaced along the chain and the isotherms, which are linearly interpolated between thermistors, appear at the proper proportionate distances along the chain between the surface and bottom thermistors. Since typed temperature readings may be obtained for all thermistors, these readings may be entered on the contour chart at appropriate chain lengths and used as references for labelling isotherms on the chart.

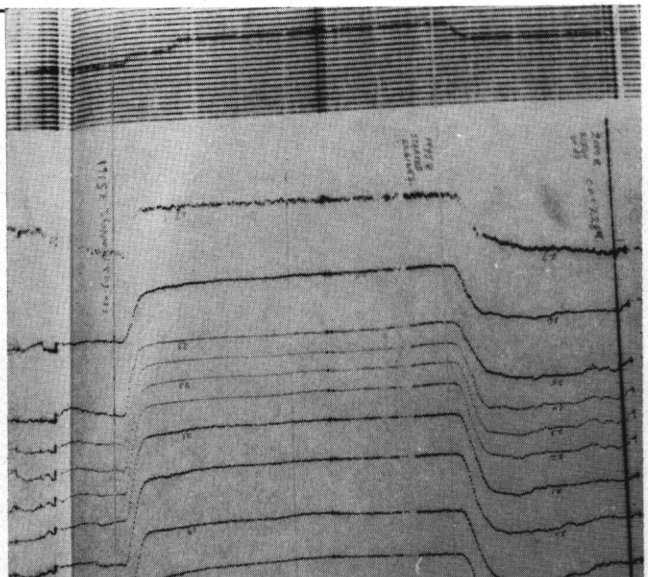
Whatever the total depth range of measurement by the chain may be, the full depth extent of the associated temperature field is equal to 14 inches on the contour chart. Thus, when the *Alaminos* is drifting and the chain is hanging vertically, 14 inches represents 267 meters of depth. The vertical scale then is linear in depth as well as in chain length since, under these circumstances the chain, for all practical purposes, hangs vertically due to its weight of some 6300 pounds. When the ship is underway the chain drags and its lower end comes to a shallower depth. At some eight knots the chain end usually will be at about 220 meters depth. At this time the 14 inch chart represents 220 meters and the scale, although still linear in chain length, will no longer be linear in depth because of the curvature in the chain.

It does appear that curvature is introduced when the chain is under tow. As the chain rises, the chain takes a catenary-like shape. If tension alone is considered, the greatest curvature is at the bottom where the tension is least. There are, however, some indications that the greatest curvature is nearer the surface. If true, a possible explanation might lie in the fact as expressed by Rather, Hersey, et al, that "resistance of the tow line appears partly as lift."

The greatest deviation of the towed chain from the vertical is observed in the upper layers of the ocean. In these upper layers, because of the chain slope, the thermistors are at reduced true depth intervals from each other but they still are represented at the same vertical positions on the contour chart. Thus, the isotherms on the contour chart appear at wider spacing in the upper layers as the ship speed is increased and the chain rises. In the opposite case, as the chain end lowers, the isotherms in the shallow layers move together on the contour chart.

Chain depth affects the isotherms appearing on the contour chart in other ways. As ship speed decreases, the bottom of the chain falls deeper and isotherms not previously observed will be recorded on the lower portion of the contour chart. Also, all other isotherms on the chart will move upwards as the greater depth ranges covered by the descending chain must be compressed into the 14 inch vertical recording space on the chart. When the ship speed is increased, a reverse change in position of isotherms occurs and each isotherm appears at a lower position (greater chain length) on the contour chart.

Figure 2. Photograph of contour chart for thermal tow showing (left to right) the depth of isotherms with ship underway, drifting, and underway again.

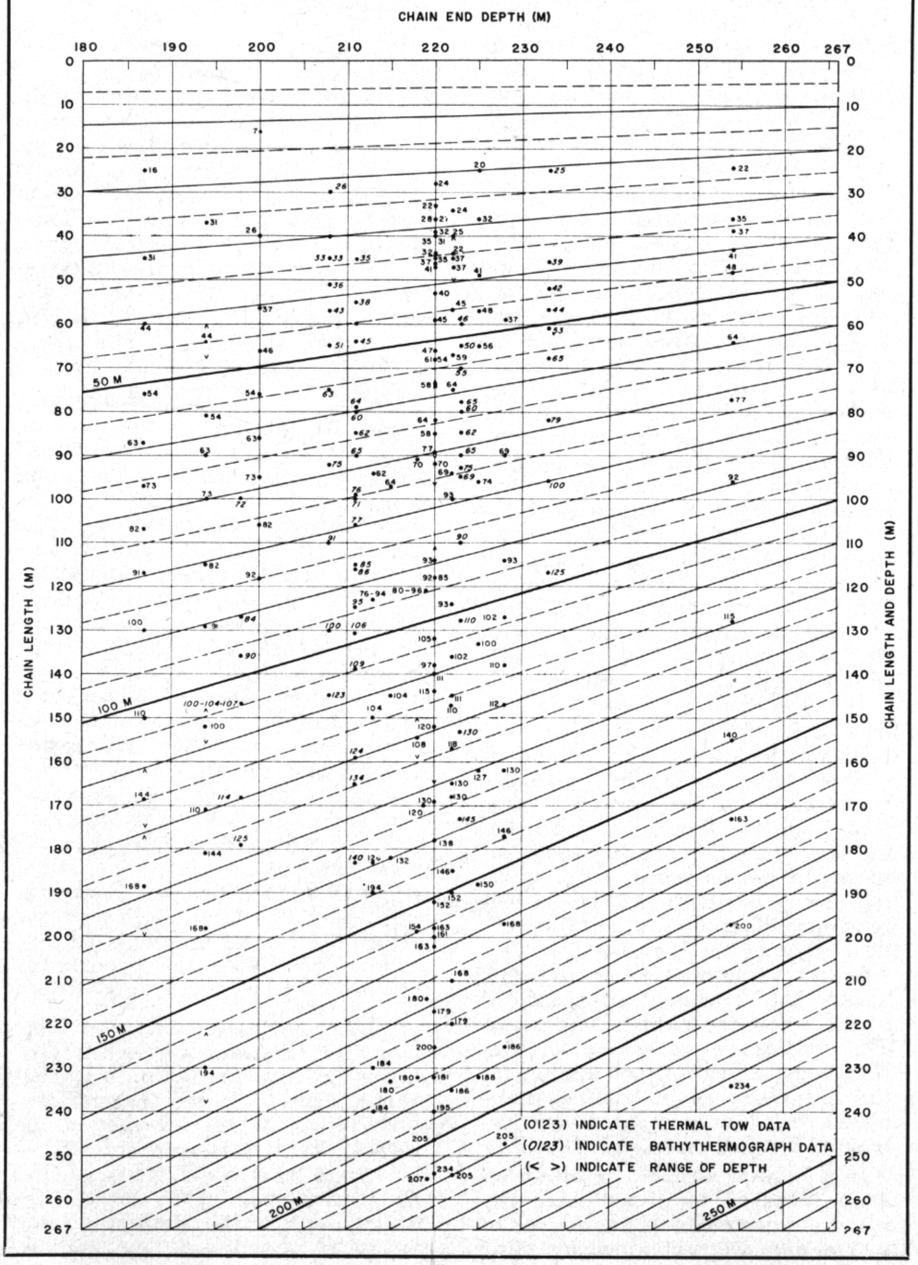


Consideration Of An Analytical Approach

It would seem logical that analytical approaches be the first to be tried. The simplest of these is the assumption that the chain is straight between the ocean surface and the chain-end depth. When the ship is underway and when the readings derived using the linear assumption are compared to the best data on true depth available from bathythermograph observations and from thermal-tow records made while the ship was drifting, there seems to be considerable deviation from linearity. Errors at the surface and at the lower end of the chain are zero by the nature of the linearity assumed. At intermediate depths the errors vary depending upon the total depth reached by the 267 meter chain. For the common chain-end depth of 220 meters the error due to use of the linear assumption apparently would be approximately 6 meters at 50 meters depth, 10 meters at 100, and 6 meters at 150. When the chain end is at shallower depths the error would be larger. Not only does the use of the linear assumption appear to give considerable error at intermediate depths but, when conditions are such that the end of the chain may rise and fall, the errors are systematic and distortions introduced on the contour chart as previously described go uncorrected.

A second and better analytical representation of the towed chain would be a catenary-like curve. Some idea of the complexity of the analytical approach in this case may be obtained by reference to Pode, 1951, Ellsworth, 1960, Thorne, Blackshaw and Claasen, 1962, and Claasen and Thorne, 1963. Rather, Hersey, et al., say, "Unfortunately, no simple relations (between speed, instrument weight, length of cable and depth) exist and untrained intuition may turn out to be a fickle guide." At the present time it would appear that a theoretical approach assuming catenary-like curves is not the most practical one for determining the depths of the thermal-tow observations. First, there is difficulty in obtaining representative equations for the curve which take into account all of the pertinent variables, and second, certain of the assumptions which must be made are such that they do not apply well to the thermal-tow situation.

Figure 4. True depth of temperature readings with 267 meter chain. Data is empirical.



In obtaining representative equations the variables involved would be: (1) the drag characteristics of the faired-cable including the ratio of normal and tangential drag coefficients, (2) the relative speed of the ship, (3) the chain weight per unit length, (and total weight), and (4) the weight of the towed fish. The drag characteristics are not now available and could be obtained only through experiment. Without these, calculation of depth would be subject to large errors. Even with them, the calculation would be difficult.

The effects of the above variables upon the shape and position of the chain are indicated by several observable features. Among these are the total tension at the tow point, the wire (or chain) angle, the depth of the chain-end, and the horizontal distance of the towed fish from the surface tow point. (Of these only the depth of the chain-end is available from the May cruise.) The wire angle may be computed at the surface from recorded data. Although they were not available on this cruise, it is possible that arrangements might be made for measuring the tension and the horizontal tow distance on future cruises. If this were done, these measurements might make it possible to deduce the drag characteristics of the chain and thus to compute depths analytically.

As to the applicability of the assumptions which are made in calculating the catenary-like curves, the greatest deviation in the case of the thermal-tow is probably that from the apparently universal assumption that the cable lies in a vertical plane parallel to the direction of the motion. If the ocean waters were not moving or if the ship moved only along the path of ocean currents this assumption might be valid. However, most oceanographic cruises are planned to measure the gradients of the different variables and these are nearly always perpendicular to the flow. For example, the gradient of density is at right angles to the common geostrophic flow. Thus, research vessels often move across the current and the flow of the waters, unless it is the same at all depths, acts to move the towed chain out of the vertical plane defined by the ship's path. Indications are that such cross currents in the Gulf of Mexico were responsible for vertical shifts of thermistors of 10 meters or more. The assumption of a plane curve parallel to the ship's motion is therefore not a good one for this application.

Usually assumed too is that "equilibrium conditions in a uniform stream" prevail. In actual practice, the thermal-tow may be used on long cruises encountering a wide variety of conditions and, as mentioned, the depth of the chain-end and thus the shape of the cable varies considerably, greatly weakening the applicability of this assumption.

Only after considerable effort to find a completely workable analytical approach to the determination of depth of isotherms was it decided that an empirical one would be more adaptable to the thermal-tow problem at the present time.

Preparation Of A Depth Aid

For practical use in determining the true depth of isotherms printed on the contour chart, a simple overlay scale of depth would be desirable. Thus, at any given time the depths could be read off. If the chain elements remained at fixed depths only one scale would be needed but, as previously described, the depths do change significantly. The chain-end depth is the most readily available indicator of these changes. Therefore, this quantity provides a good index of depth scales to be used. It is convenient to assume that for a given chain-end depth each element attached to the chain has a unique depth at which it is found. Under this assumption, which seems applicable in many situations, a large number of empirical depth scales might be made up, one for each value of the chain-end depth. However, it is more convenient to place these scales side by side and to prepare from them a graph which would serve for any value of the chain-end depth.

Consider on rectangular coordinates a graph having the elements of Figure 3. On this figure several relationships may be indicated. First, $z = s$ when $h = L$ since, under these circumstances, the chain must be hanging vertically. Further, $z = h$ when $s = L$, $z = 0$ when $s = 0$ and $z = 0$, when $h = 0$. These facts permit the general character of lines of constant z to be determined.

In Figure 3 the line indicated z_1 is drawn to show the nature of the z contours when the conditions are approached where $z = 0$ when $s = 0$ and where $z = 0$ when $h = 0$. On the lower right-hand portion of the chart the line indicated z_n connects equal values of z and probably does not deviate significantly from a straight line. The lines such as those indicated by z_{50} and z_{100} must join equal values of z on the right-hand and bottom scales, 50 and 100 m respectively. Their slopes would be intermediate between the slopes of line z_1 and line z_n — somewhat as indicated.

Since, on the May cruise, the range of h was limited between 180 meters and 267 meters and since the chain-end will usually be kept deeper than 180 meters, attention may be confined to that range. Figure 4 has been drawn to cover this range only. Within this range the field of z was plotted from field data in the following manner:

First, at a given ship position the true depth of each isotherm was determined. This was done by allowing the ship to drift so that the chain would hang vertically and s would equal z. The depth could then be read off the contour chart since, as above, s and z are equal under these circumstances. The depth of isotherms or other values of temperature at this ship position could be checked in other ways as with a deep bathythermograph or with a hydrographic cast.

Next, to determine a depth scale for use at a particular chain position, the ship's engines were started and the chain-end came up to a new and shallower depth h_n. The assumption was made that the isotherms in the ocean remained at the same depth over a short period of time (roughly 15 minutes) and within a limited area (a 2-mile radius) of the position where the drifting observation was made. This assumption can be checked by observation when it seems desirable to do so. Since the thermistors moved vertically when the ship got underway and since the contour chart is drawn using a vertical scale of chain length, the isotherms with the ship underway appear at different vertical positions on the chart than they did when the ship was drifting. Now, each new vertical position has associated with it a true depth z for the particular isotherm or temperature value which appears there, this depth being the one observed for that isotherm or temperature value while the ship was drifting. These values of z may be entered along the vertical scale of the contour chart beside the appropriate value of s where the pertinent isotherm is found when the ship is underway. This vertical set of values of z defines a depth scale which applies for the particular chain position associated with that ship speed and designated by that chain end depth h_n.

In a similar fashion depth scales were prepared for other chain positions indicated by other values of h. The data were obtained by going from the ship drifting situation to different underway ship speeds, bringing about different chain-end depths for comparison. The depth or z scales obtained in this way for the various values of h were then transferred to Figure 4 and plotted along the ordinate having the appropriate value of h. These plotted values indicate the field of z on the h, s coordinates.

Recalling the general features of lines of equal z value as indicated on Figure 3 and observing the data in Figure 4 it is apparent that, over the range of h covered in Figure 4, the curves of equal value of z may be assumed to be straight lines to a good approximation. Thus, such lines were drawn to fit the data. These are the sloping lines in Figure 4 which are marked with values z.

Finally, to simplify the depth determination chart, the s scale and grid lines may be removed, since no reference to them need be made in application of the chart.

The manner in which Figure 4 was prepared is such as to incorporate several types of corrections. If, for example, a given thermistor changes temperature calibration as it moves vertically from one pressure range to another, the effects of this change upon the temperature would be reflected as a change in depth of isotherms upon the contour chart and would be removed when the true depth was read from this chart. The thermistor calibration problem then is one only for the drifting position.

Data for the depth determination chart, (Figure 4) may be obtained in other ways. One is by obtaining simultaneous observations with the deep bathythermograph and the thermal-tow while the ship is underway. This method eliminates the necessity for assuming that the depths of isotherms remain constant for any significant period of time or over any significant area. However, it introduces difficulties such as the difficulty of lowering another cable while the thermal-tow is down and the ship is underway. This can be done but requires great care and some luck. On the May cruise bathythermograph observations were taken every two hours without incident. The lowerings were only to depths of approximately 140 meters but they were of value in preparing the upper portion of Figure 4.

Another method consists of lowering the thermal-tow while the ship is drifting and taking a hydrographic cast while the thermal-tow is operating. When the cast is retrieved, the ship is then gotten underway at its cruising speed, raising the thermal-tow chain to its operating depth. After a suitable time, say 10 to 15 minutes, the engines are stopped and a second hydrographic cast is taken while the thermal-tow is operating (ship drifting). Interpolation between the two casts provides temperatures and depths for comparison to thermal-tow contour chart readings obtained between the two casts while the ship was underway.

Use Of The Depth Determination Chart

For practical use, a reproduction of Figure 4, less the data points, is made on transparent paper with the full vertical scale being 14 inches, thus matching the full vertical scale on the contour chart. To read isotherm depth from the contour chart at a particular time, the recorded chain-end depth for that time is noted. Then the ordinate of Figure 4 bearing this label is superimposed upon the contour chart at the time for which the readings are desired. The position where each isotherm crosses the ordinate is then noted and the true depth of the isotherm may be read off. It is the value of the sloping line on the overlay which crosses the ordinate at that position.

This research was sponsored by the Geophysics Branch of the Office of Naval Research through the Texas A&M Research Foundation. It was conducted in the Department of Oceanography and Meteorology of Texas A&M University. Helpful suggestions were provided by Professor R. O. Reid and technical assistance by Larry L. Brennan and John Hutchins. Lydia Fenner served as Secretary.

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Reprinted from Undersea Technology, February 1966

R140 2/66 Printed in U.S.A.