OFFICE OF NAVAL RESEARCH 407-C

NAVAL RESEARCH

REVIEWS

JUNE 1975

PROFILES IN SCIENCE

Dr. Lazarsfeld

Dr. Lazarsfeld is Quetelet Professor, Emeritus, of Social Sciences at Columbia University and University Professor of Sociology at the University of Pittsburgh. He is renowned for his work in the field of mass communication with special interest in the field of changing opinions and market research.

When Dr. Lazarsfeld was President of The American Sociological Association in 1962, he organized a national meeting around the theme "The Uses of Sociology." This theme became the title of a book Dr. Lazarsfeld edited in 1965.

For many years the Office of Naval Research has supported Dr. Lazarsfeld's research in the application of social sciences to the institutional management of human resources. An important result of this work is Dr. Lazarsfeld's book an "Introduction to Applied Sociology" which will be published in the Fall of 1975.

Movement and Acoustic Influenced of Cyclonic Eddies*

The Navy's Interest

Embedded within the ocean are features which oceanographers call "eddies"; they are oceanic analogues to atmospheric high and low pressure systems. They have characteristic diameters of 100 km and they have vertical displacements of the main thermocline amounting to 100 m. Consequently, they represent a significant perturbation to the ocean's sound velocity field. Characteristic water current velocities associated with the eddies are larger by an order of magnitude than the velocities associated with the mean circulation of the ocean. So, in order to understand the mean circulation of the ocean, it is necessary to understand the eddies—their generation, propagation, and dissipation. Meteorologists found out, for example, that frequently in mid-latitudes the atmospheric eddies (highs and lows) completely dominated the mean atmospheric circulation.

The Naval Oceanographic Office has been locating and tracking eddies in the western North Atlantic for the past five years. These efforts were part of a broader program to study areas of anomalous thermal conditions under the assumption that the resulting anomalous acoustic conditions could create problems for sonar systems. On this basis it is important for the Navy to learn more about the impact of an eddy on various sonar systems, and to develop the capability of locating and tracking these features whenever desired.

The sound fixing and ranging (SOFAR) floats developed at Yale by Dr. T. Rossby under an Office of Naval Research contract are ideal to track and study ocean eddies (1). Originally these floats were used to study ocean circulation. Now the SOFAR floats are used for tracking cyclonic (cold-water) eddies, and as a secondary objective, to determine the impact of these eddies on acoustic surveillance in the western North Atlantic by monitoring the SOFAR signal from shore facilities. This project is being conducted by the Naval Oceanographic Office with the support of ONR's Ocean Science and Technology Division (Figure 1).

*Compiled with the assistance of LCDR Arthur Cecelski, Office of Naval Research from NAVOCEANO's July 17, 1973 research proposal "Investigation of the Movement and Acoustic Influences of Cyclonic Eddies," by M. Shank, CDR W. Matthews, and A. Crumpler; and "Preliminary Report on the Gulf Stream Eddy Tracking Experiment," November 1974 by Robert Cheney, NAVOCEANO Survey 702-75.

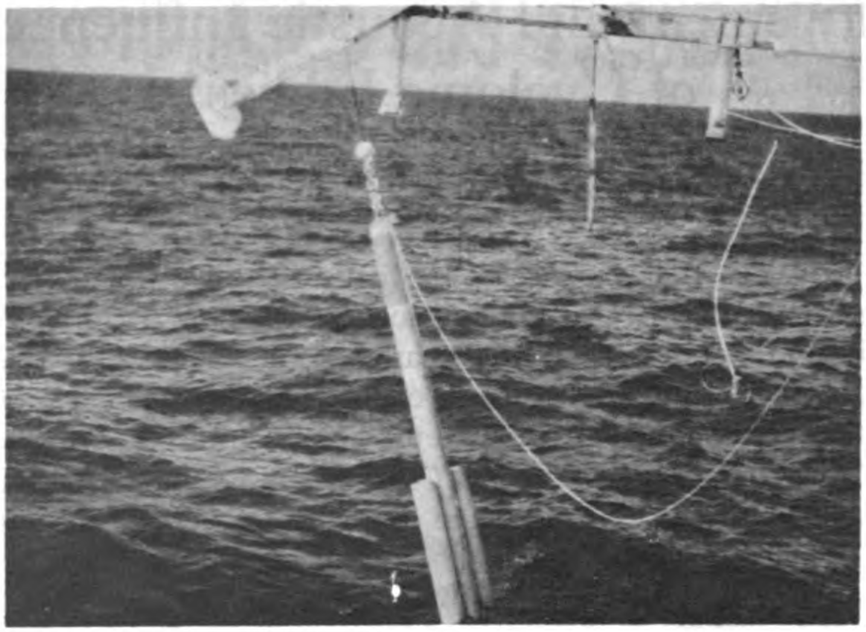


Figure 1 – Launching a SOFAR Float

Characteristics of Eddies

The existence of eddies has been known for some time, but only recently by use of oceanographic research aircraft could observations be made of the formation and movement of eddies. In 1968 the Naval Oceanographic Office mapped the formation and movement of a cyclonic eddy over a 15 day period using the airborne radiation thermometer (2). Since then over 26 eddies have been observed by NAVOCEANO using data collected from ship, aircraft, and satellites to study their physical characteristics and movements (3,4).

Circulation

The Gulf Stream generates eddies eastward of 70° West where meander amplitudes reach sufficient dimensions to spawn mesocale eddies ranging from 50 to 400 km in diameter. Eddies form as the meanders, often greater than 500 km in wavelength, completely surround large masses of water from north of the Gulf Stream (Slope) or water from south of the Gulf Stream (Sargasso water) leaving the neck of the meander closed while the Gulf Stream returns to a more direct path much the same as an ox-bow lake is formed on a meandering river. The newly separated eddy maintains an independent circulation through energy imparted by the Gulf Stream, rotating cyclonically or anticyclonically depending upon whether the southward-extending or northward-extending meander crest is isolated. Cyclonic eddies constructed of a cold core of Slope water surrounded by an outer Gulf Stream ring are often referred to as cold eddies or rings while their anticyclonic counterparts are referred to as warm eddies. Examples of the formation and movement of both types of eddies appear in the literature (4,5). According to F. C. Fuglister the estimated lifespan of a cyclonic eddy is 12 months, and 5 to 8 such eddies may form per year (6). Cyclonic eddies generally follow irregular paths toward the southwest at approximately 10 cm/sec (0.19 kts) average speed.

Figure 2 shows a typical isotherm pattern through a cold eddy as recorded by the USNS LYNCH. Three years of observation show that cyclonic eddies generally have diameters greater than 100 kilometers and extend to depths below 2000 meters. These eddies form a large volume of water with dramatically different properties than that of Sargasso water. Local circulation in the eddy varies between 50 and

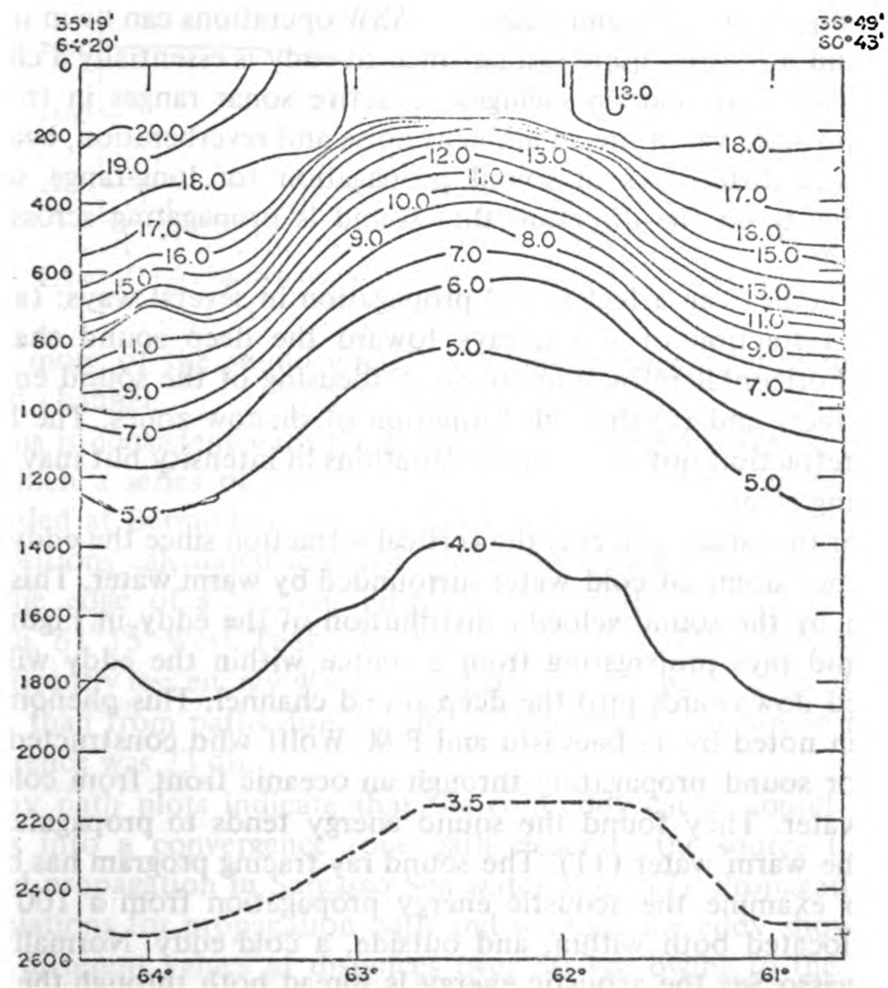


Figure 2 — Temperature profile through cold eddy — 4-7 February 1973

100 cm/sec (0.8-1.9 kts) and the cyclonic eddies gradually sink below the surface at a rate of approximately 1 meter/day.

Numerical models for predicting meanders of the Gulf Stream (8) and movements of eddies (9) are under development at NAVOCEANO. Recently, primary emphasis has been placed on developing a prediction model for cyclonic eddies. This model has been successfully used for short period predictions of cyclonic eddy movement in conjunction with observational studies. The model assumes a single-layered, homogeneous, viscous, and barotropic ocean. The prediction equation is the vertically integrated vorticity equation. Lack of proper initial conditions for these numerical models is the most serious limitation. Given the initial temperature observations and the flow characteristics of the Gulf Stream, eddies can be simulated and short period predictions made.

Acoustic Impact of Fronts and Eddies

The impact of fronts and eddies on ASW operations can be in many forms and are often quite similar since an eddy is essentially a closed front. There are sudden changes in active sonar ranges in frontal zones, possible variations in ambient noise and reverberation, bearing errors and differences in sound propagation for long-range sonar depending upon the direction that sound is propagating across the front (10).

Cold eddies can affect sound propagation in several ways: (a) by vertical refraction of sound rays toward the deep sound channel (b) by horizontal refraction to cause focusing of the sound energy (lens effect) and (c) through formation of shadow zones. The horizontal refraction not only causes variations in intensity but may lead to bearing errors.

By far the largest effect is the vertical refraction since the eddy is a bell-shaped dome of cold water surrounded by warm water. This can be seen by the sound velocity distribution of the eddy in Figure 3, the sound rays propagating from a source within the eddy will be refracted downwards into the deep sound channel. This phenomena has been noted by T. Laevastu and P.M. Wolff who constructed ray plots for sound propagating through an oceanic front from cold to warm water. They found the sound energy tends to propagate beneath the warm water (11). The sound ray tracing program has been used to examine the acoustic energy propagation from a 100 Hz source located both within, and outside, a cold eddy. Normally in the Sargasso Sea the acoustic energy is spread both through the surface duct and the deep sound channel. With the source inside the

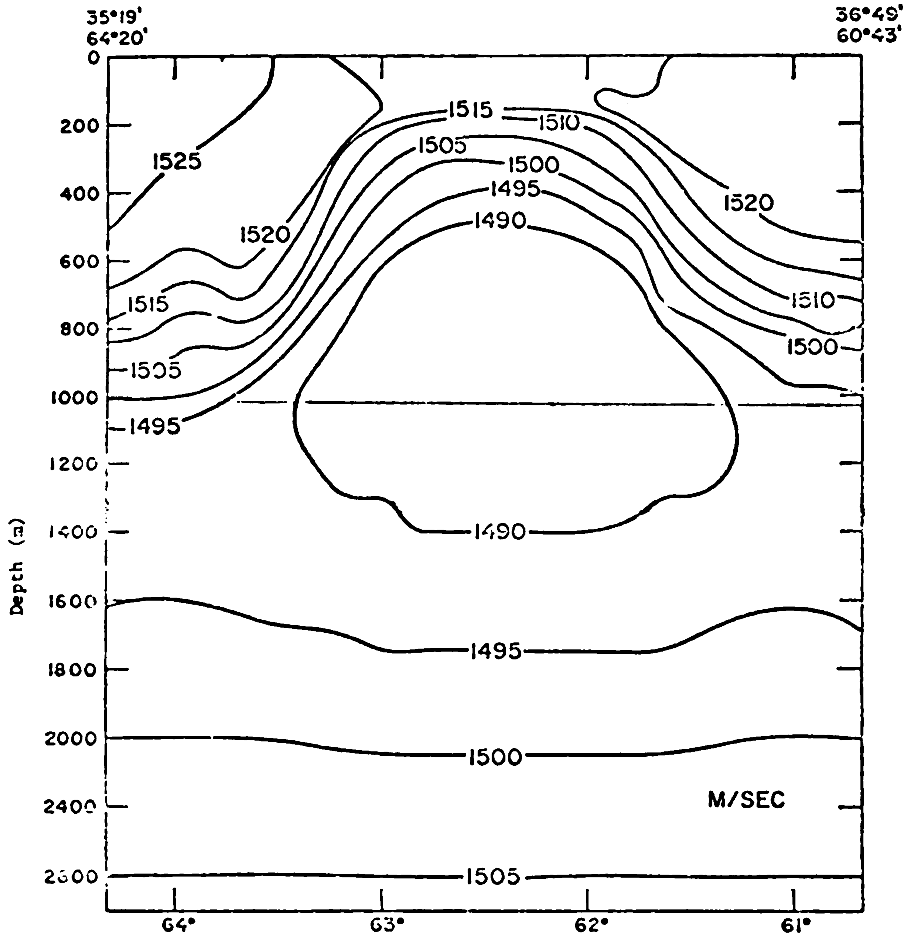


Figure 3 – Temperature profile through cold eddy – 4-7 February 1973

eddy more of the sound energy was bent downward into the deep sound channel.

This is consistent with the results of a NAVOCEANO experiment in which a series of explosives were dropped behind an eddy and recorded at Bermuda in December 1972. The charges were dropped at positions calculated so that sound paths would travel through, and on the edge of a cyclonic eddy with its center located at 36°25′ North, 61°15′ West. Peak sound levels recorded at Bermuda indicate significantly less energy was received from sound paths tangent to the eddy than from paths directly through the eddy. The largest relative difference was 23 db.

Ray path plots indicate that the cold eddy causes sound rays to focus into a convergence zone path closer to the source than for sound propagation in Sargasso Sea water alone (7). Propagation loss calculations for propagation with and without the eddy show markedly different values at distances over 50 km owing to the greater amplitudes and shorter wavelengths of the propagation loss curve for the former case. The differences between the peaks and troughs of the propagation loss curve were 25 db for propagation through the eddy and only 5-10 db with the eddy.

G. A. Gotthardt found similar results when he dropped signal underwater sound (SUS) charges across a Gulf Stream meander and measured sound intensities at hydrophones placed on both sides of the front. He found sound intensities received in the warm water from a source in the cold water 6 to 10 db higher than for the reverse case (3).

Although no quantitative evidence exists for it as yet, another possible cause for variations in sound propagation through eddies could be by the creation of a shadow zone. A sound ray passing through, but near, the edge of an eddy is refracted in such a manner to focus the rays behind the eddy. The next ray, just missing the eddy is not refracted and the resulting divergence between adjacent rays causes a zone of lesser sound intensity, or a shadow zone. If the sound source is moving along a path on the opposite side of the eddy from a receiver there could be times when the source is detected and periods when it is lost owing to the shadow zone.

The 1974 Survey

Objective

NAVOCEANO and ONR carried out a survey of cyclonic eddies from the USNS LYNCH (T-AGOR 7) between 17 September and 14 October 1974. The purpose of the survey was to locate cyclonic Gulf Stream eddies and conduct experiments dealing with eddy tracking and acoustics. The tracking experiment was performed by placing ten neutrally buoyant SOFAR floats in and around the eddies to study eddy movement with respect to the surrounding Sargasso Sea. The floats emit low frequency pulses (270 Hz) which allow them to be followed from land-based listening stations. Each float is designed to transmit for two years and is recoverable. By placing the floats within the eddy at selected depths and distances from the eddy's center, it is hoped to determine the nature of acoustic anomalies created by the presence of these large cold intrusions in the Sargasso Sea. Additional acoustic experiments were performed from an aircraft by detonating SUS charges along a series of arcs behind, through, and in front of each eddy being studied.

Ship Survey

The cruise track covered a distance of 6000 km. Four hundred eleven SXBT (Shipboard Expendable Bathythermograph) observations were collected during the survey to delineate the thermal structure of the region, and three cyclonic eddies were located (Figure 4). The isopleths in Figure 4 represent depth, in meters, of the 15°C isothermal surface. Normally 15°C is found shallower than 200 m in Slope Water and deeper than 600 m in the Sargasso Sea.

Eddy #1 was found adjacent to the Gulf Stream at 36°05′N, 71°15′W and was quite small, having a diameter (defined as 15°C at 500 m) of only 65 km. Because of this eddy's size and proximity to the Stream it was considered unsuitable for the experiment.

It had been hoped to study the cyclonic eddy that had formed in June 1974 near 37°30′N, 67°30′W (12). This eddy was tracked during the summer with the aid of SXBT data obtained from the M/S SEA VENTURE transiting between New York and Bermuda. On 19 August it was also surveyed by the R/V ATLANTIC II. Unfortunately, the initial survey of this region from LYNCH during 23-26 September indicated that the eddy (eddy #2) had merged with the Gulf Stream to form a large southward meander (Figure 3).

When the feature was resurveyed ten days later the neck of the meander had closed and eddy #2 appeared to have again separated from the Gulf Stream. Satellite infrared photographs, obtained after

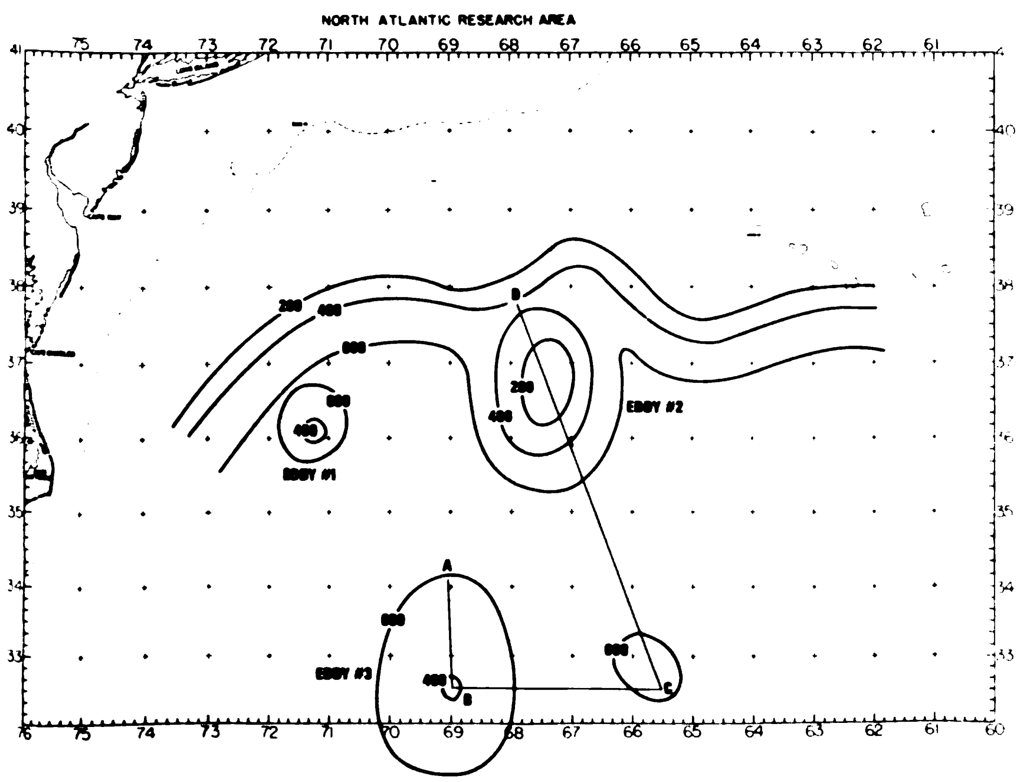


Figure 4 — Depth contours (m) of the 15°C isothermal surface over the survey area. (Three eddies are evident, one still partially attached to the Gulf Stream.)

the survey, indicate that the eddy was probably still partially attached to the Stream at that time. Figure 5 shows the newly formed eddy to be larger and colder than previously observed, having been renewed by an influx of Slope Water through the open neck of the meander. The lighter contours in this figure represent the position of the Gulf Stream as indicated by satellite imagery. The eddy is shown to be elliptical with an average diameter of about 200 km. The main thermocline was elevated 600 m at the center relative to the surrounding Sargasso Sea. Six SV-STD (Sound Velocity - Salinity/Temperature/Depth) stations were taken along a line from the eddy center to a point 150 km to the west.

Eddy #3, centered 375 km west of Bermuda, was also elliptical with an average diameter of 110 km. The eddy's temperature structure and size suggest that the feature is relatively old. Assuming isotherms at the eddy's center to have subsided at a rate of 0.5m/day (13) the eddy's age is estimated to be about a year. Nine SV-STD stations were taken in the eddy.

A small region of cooler water (15°C < 600 m) 100 km northwest of Bermuda (Figure 2) may have been a very old Gulf Stream eddy, or perhaps an intermediate scale, mid-ocean eddy of the type studied during the MODE (Mid Ocean Dynamics Experiment) program (14). This eddy was only partially surveyed.

Float Deployment

Three SOFAR floats were placed in eddy #3; two at the center and one 35 km to the west. The radial float and one central float were

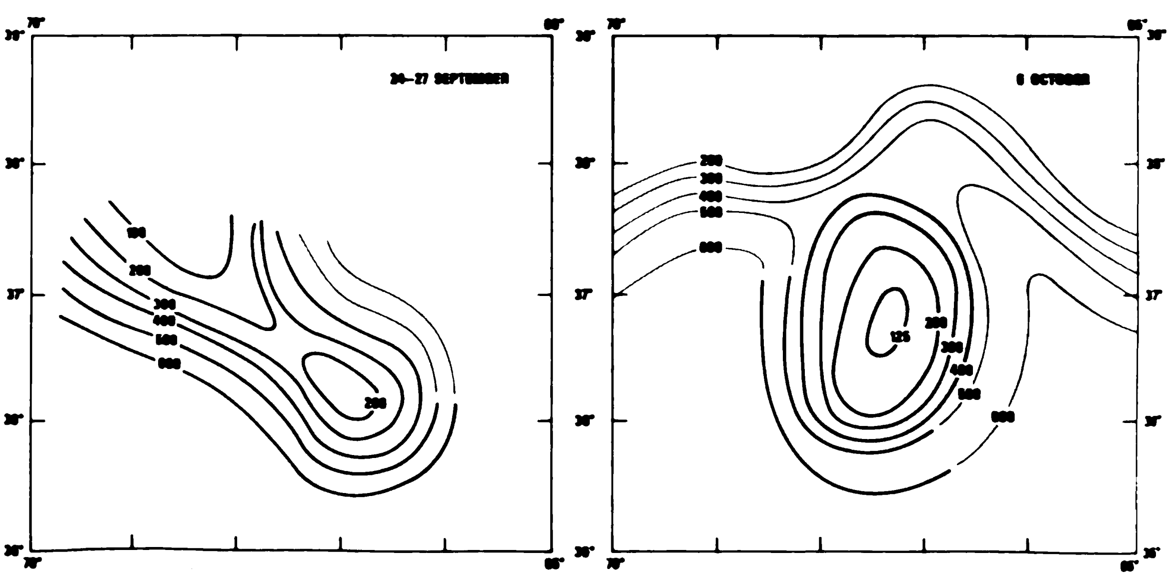


Figure 5 – Depth contours (m) of the 15°C isothermal surface. (Sequence shows evolution of elongated meander to an eddy, apparently separating from the Stream.)

ballasted for neutral buoyancy at the deep sound channel axis depth (1100 m). The third float was set for 700 m. All of these floats came to equilibrium within 100 m of target depth.

Six floats were placed in eddy #2. Two of the four floats launched in the center stabilized satisfactorily, coming to equilibrium at 530 m and 1130 m (both within 20 m of their preset depth). The other two floats were ballasted for 850 m but equilibrated at 230 m and 2100 m. Efforts to bring these floats to the surface for reballasting were unsuccessful. Two other SOFAR floats were placed 65 km and 85 km west of the eddy center at deep sound channel axis depths of 770 m and 990 m, respectively.

One additional float was placed halfway between eddies #2 and #3 to measure circulation in the Sargasso Sea. This float came to equilibrium in the deep sound channel at 1290 m.

The float released between eddies #2 and #3 is expected to sink about 0.5 m/day due to the gradual compression of its aluminum cylinder. Those floats placed in eddies may be expected to sink even faster (0.7 m/day) due to a combination of this creep effect with the subsidence of isopycnics within the eddy.

Initial Float Behavior

With the exception of two floats, #8 and #5 (the two deepest floats at the center of eddy #2), all are being successfully tracked. The signal from float *L*8 was lost after only 2-3 days, and the initial data from float #5 contained too many gaps for continuous tracking.

All four floats in eddy #2 began moving along cyclonic paths around the eddy at speeds ranging from 10-50 cm/sec. The outer float appears to be drifting out of the main flow and towards the south. Float #9, launched between the two eddies, began moving quite slowly, first to the northeast and then to the south. The movement of the three floats in eddy #3 is more complicated, with the two central floats moving in opposite directions and the radial float traveling in an anticyclonic loop. These results are, however, very preliminary since the floats will be allowed to drift for at least six months. Furthermore, little sense can be made of the float trajectories until more is known about the movement of the eddies themselves.

Recapture of Eddy #2

Since velocities are small at the center of an eddy the rapid (25-50 cm/sec) northward movement of the central floats in eddy #2 suggested that some change had occurred in the eddy's circulation. With the acquisition of additional ship data and satellite infrared photographs it became clear that the eddy had not broken away from the Gulf Stream as expected, but had, in fact, coalesced with the Stream. Figure 6 illustrates the sequence of events over a period of five weeks as indicated by all available data from ship, satellite, and aircraft. The eddy that formed in June and was tracked during the summer is believed to have coalesced with the Stream sometime between 19 August, when it was surveyed by ATLANTIS II, and 23 September, when the LYNCH survey revealed only a meander. Subsequent XBT data from the aircraft and LYNCH showed the meander to have closed off into an eddy. Satellite photos suggest, however, that the eddy was still partially attached to the Stream at this time.

Recent SXBT data from ATLANTIS II and satellite photos obtained on 23 October indicate that, rather than completely pinching off at the neck, eddy #2 was reabsorbed by the Gulf Stream, forming an open meander to the south. The resulting configuration is illustrated by the last drawing in Figure 6. A similar phenomenon occurred when a meander was observed to separate from the Stream only to be reabsorbed several days later (15). This process occurred twice over a period of ten days at which time the eddy separated totally and began to move to the south away from the Stream.

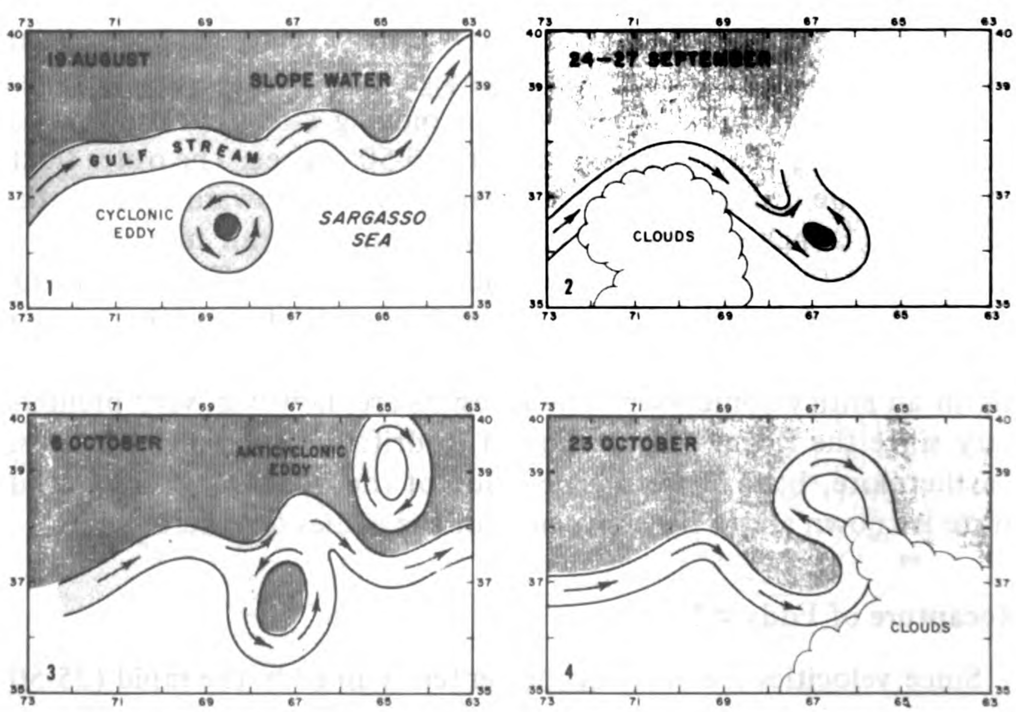


Figure 6 – Positions of Gulf Stream and cyclonic eddy during cruise as determined by satellite photoes, ship data (SXBTs), and aircraft data (AXBTs).

Conclusion

The floats are now being successfully tracked, with the exception of the float (8) in eddy #2 which has apparently stopped transmitting. The positions of the floats relative to the eddies will be determined during follow-up cruises by R/V TRIDENT and USNS LYNCH. Unfortunately, eddy #2 was believed to have coalesced with the Gulf Stream in mid October, returning to its original meander configuration. If the meander does not break off into an eddy, the floats will likely drift to the east with the Gulf Stream, eventually turning north towards the Norwegian Sea or south past the Canary Islands. Although not included in the original proposed study, such an event would add a new and potentially valuable facet to this experiment.

References

1. Rossby, T. and Webb, D. (1970), "Observing Abyssal Motions by Tracking Shallow Floats in the SOFAR Channel," *Deep-Sea Res.*, **17**, 359-365.
2. Bratnick, M., Wilkerson, J.C., and Athey, G.A. (1968), "Aircraft Observation of a Cyclonic Eddy South of the Gulf Stream," Abstract Trans., *Amer. Geophy. Union*, **48**, 123.
3. Gotthardt, G.A. (1973a), "Observed Formation of a Gulf Stream Anticyclonic Eddy," *Jour. Phys. Ocean.*, **3**, 237-238. "Gulf Stream Eddies in the Western North Atlantic," **NAVOCEANO TN 6150-16-73**, 42 pp.
4. Thompson, B.J. and Gotthardt, G.A. (1971a), "Life Cycle of a North Atlantic Eddy," Abstract Trans., *Amer. Geophy. Union*, **52**, 241. (1971b), "Movement of a Gulf Stream Eddy," **NAVOCEANO Gulf Stream Summary** 6 (1).
5. Gemmill, W. (1971), "Gulf Stream Meandering, April-June 1970," Abstract Trans., *Amer. Geophy. Union*, **52**, 241.
6. Fuglister, F.C. (1971), "Cyclonic Rings Formed by the Gulf Stream, 1965-66," Studies in Physical Oceanography–A Tribute to George Wust, Paper 10, 137 pp.
7. Khedouri, E.K. and Gemmill, W. (1974), "Physical Characteristics and Energy Distribution Observed in Gulf Stream Eddies," *NAVOCEANO TN 6150-22-74*, 24 pp.
8. Gemmill, W. (1971), "Numerical Methods of Predicting the Northern Edge of the Gulf Stream," **NAVOCEANO TR-225**.
9. Pickett, R.L. (1973), "Numerical Modeling Investigations of Cyclonic Gulf Stream Eddies," Thesis, Vir. Inst. Mar. Science, 79 pp.
10. James, R.W. (1972), "Criticality of Ocean Fronts to ASW Operations," *NAVOCEANO TN 7700-3-72*, 24 pp.
11. Laevastu, T. and Wolff, P.M. (1971), "Effects of Oceanic Fronts on Sound Propagation and Possible Implications for ASW Tactics," *NAVUSEACEN TP 226 (C), 17 pp.*
12. Gotthardt, G.A. and R.A. Doblar (1974), "Cyclonic eddies observed in the western North Atlantic, January-June 1974," *NAVOCEANO Technical Note 6150-29-74*, 21 pp.

13. Cheney, R.E. and P.L. Richardson (1974), "The observed decay of a cyclonic Gulf Stream ring," *University of Rhode Island technical report No. 74-2.* 132 pp.
14. Robinson, A.R. and H. Stommel (1974), "A Mode-1 overview," Abstract Trans., *Amer. Geophy. Union*, **55**, 289.
15. Fuglister, F.C. and L.V. Worthington (1951), "Some results of multiple ship survey of the Gulf Stream," *Tellus*, **3**, 1-14.

Mt. Wilson's Solar Telescope

The great 150-foot solar telescope that has watched the sun for 63 years from Mt. Wilson Observatory has been modernized with help from the Office of Naval Research so that it can make its daily 16,000 observations more precisely and automatically.

The instrument keeps track of solar activity as it is written in the ever-changing magnetic field patterns of the 864,000-mile-in-diameter sun. The telescope has been making these daily magnetic observations since 1959. The results are sent to observatories and universities throughout the world.

A major phase of the rebuilding program included installation of a computer that operates the instruments and collects and analyzes the data, reports Dr. Robert Howard, who is the astronomer in charge of the telescope. Mt. Wilson's solar telescope is a facility of the Hale Observatories, which are operated by the Carnegie Institution of Washington and the California Institute of Technology.

Atop the 150-foot tower is an observatory dome that protects two newly installed mirrors 15 and 19 inches in diameter that, when the dome is open, bring a beam of sunlight down the tower. A color-corrected 12-inch lens focuses a 17-inch-in-diameter solar image on a platform in the observing room at the base of the tower.

A small segment of the disk's light is projected on down to the bottom of an 80-foot pit. There a grating separates the light into its spectral lines and a lens projects this spectrum up to a magnetograph in the observing room. All of these lines are discarded except a green metallic spectral line of iron, which is sensitive to magnetic fields.

The sun's magnetic fields split this spectral line into two parts by what is known as the Zeeman effect. The greater the separation of the lines, the stronger the magnetic field. The Zeeman effect can be precisely measured in this unique telescope because it is enormously magnified as a result of the telescope's focal length of 150 feet, plus 80 feet to the bottom of the pit.

The telescope can magnify the Zeeman effect even more if Dr. Howard wants to concentrate on certain interesting regions. These are usually the more active regions on the sun.

(Continued on Page 23)

Blood Bubble Detection Prevents Decompression Sickness

Merrill P. Spencer*
Institute of Applied Physiology and Medicine

Bubbles forming in the blood of divers decompressing from underwater work can spell danger; however, detection of these bubbles with a new ultrasonic device may mean increased safety. Respiration, under increased pressures, of air or other mixtures of gases with oxygen, has allowed man to explore and work first-hand in the sea. A mixture is necessary to prevent the toxic effects of respired oxygen at increased partial pressure. Nitrogen in the air, as well as helium and other gases, are not metabolized but dissolve in the blood and body tissues under increased pressure breathing. During ascent these gases, which have been accumulated in the tissues during the "dive", must diffuse in the reverse direction, back into the blood and exit through the lungs. If ascent is too fast, the excess gas forms bubbles which, if an large numbers, or located in a critical position, block the local blood flow and produce a range of signs and symptoms collectively called decompression sickness. Decompression sickness may appear as mildly as itching in the skin, but more commonly pain in the bones, tendons and muscles occurs and is called "bends." "Chokes," a congestion of the lungs, may cause coughing, substernal oppression and reduced output by the heart. Loss of vision or hearing may develop if the bubbles form in sensitive areas of the eyes or the inner ear. Unfortunately, paralysis, convulsions and death also occur.

That bubbles of inert gas actually form in the bloodstream in divers and caisson workers with non-fatal decompression sickness has been suspected for many years. In 1942 Albert R. Behnke, then a Lt. Commander in the U.S. Navy, called them "silent bubbles" and other experts in the field agreed (1). They, like Behnke, had frequently seen their experimental animals loaded with uncountable bubbles throughout their veins, arteries and heart when they died during the experimental tests. Noninvasive methods of finding these gas pockets, when they were small and before serious problems developed, were limited to cumbersome surface microscopy of the eyes or nail beds.

---

*Dr. Spencer is Director of the Institute of Applied Physioloby and Medicine. He has published over 100 articles in his field of cardipulmonary physiology. Also he has developed many instruments, which measure the flow of blood, for clinical as well as research purposes.

In 1955 K. E. Schaefer drew blood from the arm vein of an experimental diver and reported many bubbles floating to the top of his syringe (2). Still, some thought these might have formed because of the suction he applied, or might have been air bubbles leaking around his needle junction.

High frequency sound was predicted by R. S. McKay in 1963 to be useful in finding tissue bubbles noninvasively, and many techniques for locating static bubbles sitting in the local tissues have been explored (3). These efforts have been worthwhile because it is felt that the local bubble lodged in a critical tissue is the one producing the serious symptoms. From a practical standpoint, however, a device which senses static bubbles will be limited to the local monitoring site. For practical diving situations, something is needed which is small, portable, easily operated, and monitors the entire body and gives a warning signal before symptoms of irreversible damage occur.

The best answer today for a decompression monitor which meets the needs of divers and other compressed air workers, is a variation of the doppler ultrasonic flowmeter. This device, first conceived in 1957 by S. Satomura in Osaka, Japan, was further developed by D. L. Franklin in 1961, who envisioned it as a device to transcutaneously measure the blood flow in the arteries and veins (4,5). As such, its popularity has grown with further refinements, but laboratory calibration of it was hampered by small bubbles inevitably present in calibration liquids, including milk, water, and blood, when outside the body.

The application of the doppler ultrasonic detectors to the problem of decompression sickness first occurred in our physiology laboratory which was active in the field of blood flow measurement. In 1966 the Institute of Applied Physiology and Medicine became interested in decompression sickness when Dr. Dennis Walder of New Castle-Tyne, England, and Dr. Leon Sealey of the Institute unfolded the problem of bone necrosis, "bone rot," long a plague of the tunnel workers in England. Many British scientists from the time of Haldane have studied this problem and provided insight into decompression problems of compressed air workers. Haldane's staged decompression stops to slow outgassing and to prevent bubble formation are still used today in the water and in tunnel work.

In 1967 the Institute, with the support of the Office of Naval Research, began work in the field of decompression sickness. We subjected one of our laboratory sheep to one hour of respiration in air at 200 feet of simulated water pressure in the medical recompression chamber of Seattle's Lake City Tunnel Project. Significantly, Washington State's new decompression schedules, now widely used, were in trial there for the first time. Our sheep had previously been surgically implanted with a doppler detector on the posterior aorta, which carries the blood to the lower one-half of the body from the heart. This allowed us to monitor all the blood flowing to those tissues. Presently recommended decompression schedules from the 200 ft. exposure call for stops at 10 ft. intervals, beginning at 60 ft., until the surface is reached. To determine whether bubbles could be detected by the doppler system, we skipped all decompression stops and brought the sheep directly to the surface. Sharp clicks, chirps and whistles were heard in the audio signal beginning at 80 feet and the animal simultaneously fell unconscious with convulsions. Recompression treatment was to no avail and the animal died. We had, however, given "voice" to Behnke's "silent" bubbles. We could detect bubbles in the arterial blood which produced serious brain damage, but we needed to know if they also occurred and could be detected in the venous blood, and further, whether or not they occurred before serious signs of decompression illness developed. We, therefore, implanted detectors on several veins of additional sheep and found many bubbles (venous gas emboli) occurring without apparent decompression sickness and during recommended diving procedures.

A flood of additional questions then came. Do venous gas emboli (vge) form in humans? Can they be used to develop improved diving tables? Do they occur before symptoms? Are they attended by effects on the blood? Can the diving supervisor, or physician, use them to prevent decompression sickness in the working situation? These are all questions that are now answered in the affirmative. In addition, we know they are produced by helium and neon, but sparse research funds have limited rapid extension of vge detection in deep diving.

Figure 1 illustrates the precordial transducer operated by continuous wave ultrasonic frequency at 5 MHz. Special characteristics of the system provide a wide range of impedance matching for large crystal transducers and a wide dynamic range for detection of bubble signals within the blood flow and cardiac motion signals. Piezoelectric transmitter and receiver crystals, with a 5 cm focal length, Figure 2, focus on the pulmonary artery where all the venous blood from the entire body passes after being pumped by the right ventricle on its way to the lungs. Headphones are connected to the same battery-operated electronics, Figure 3, for convenient listening to the audio signal. The source of vge detected with the precordial transducer can be localized to the regional body tissues by interchangeable detectors.

The device and its diagnostic information is indispensable during practical diving. Each year since 1968, a team of Seattle divers, led

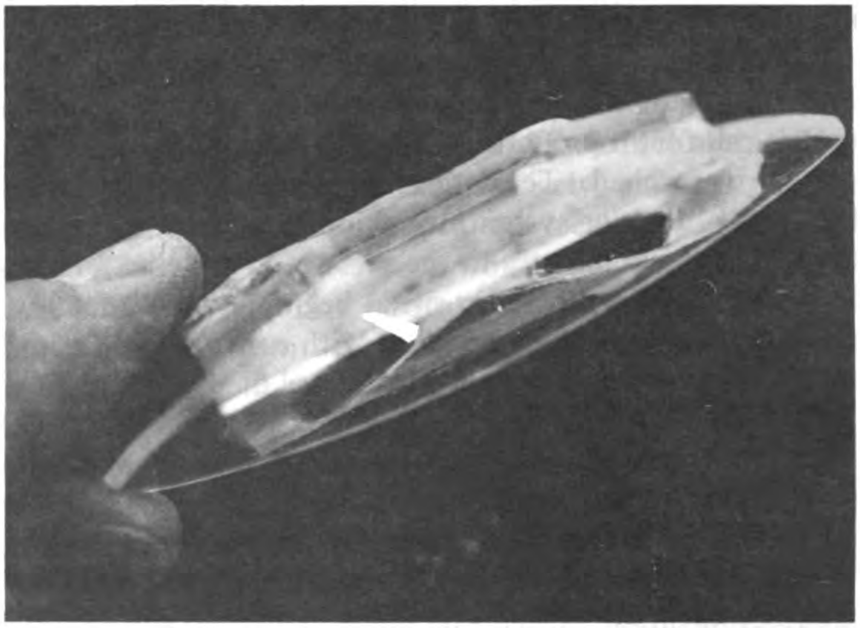


Figure 1 — Side view of the original Spencer precordial transducer showing the paried 1/2 cm² piezoelectric crystals angled at 13°. The air-filled chambers, which provide backing for the crystals, are vented to the top of the transducer thereby allowing the unit to be pressurized.

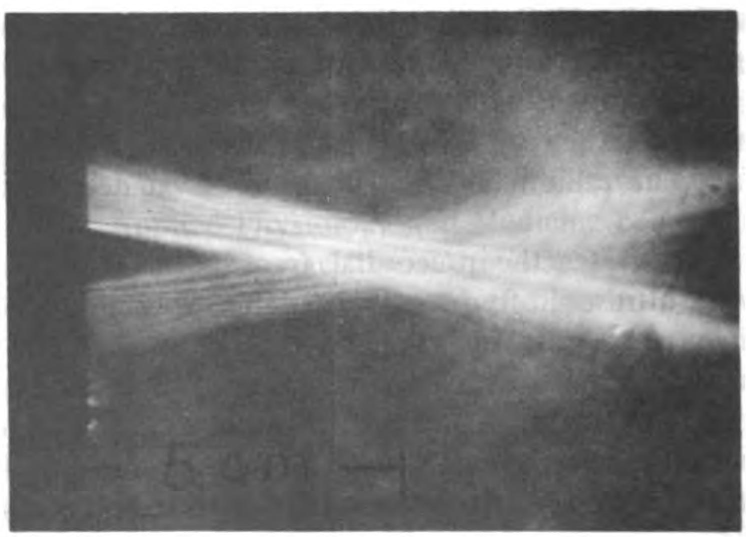


Figure 2 — Schlieren picture of the radiation pattern of the precordial transducer. Peak "focus" is achieved at 5 cm depth, although material close as 3 cm and as distant as 7 cm is also covered with adequate resolution.

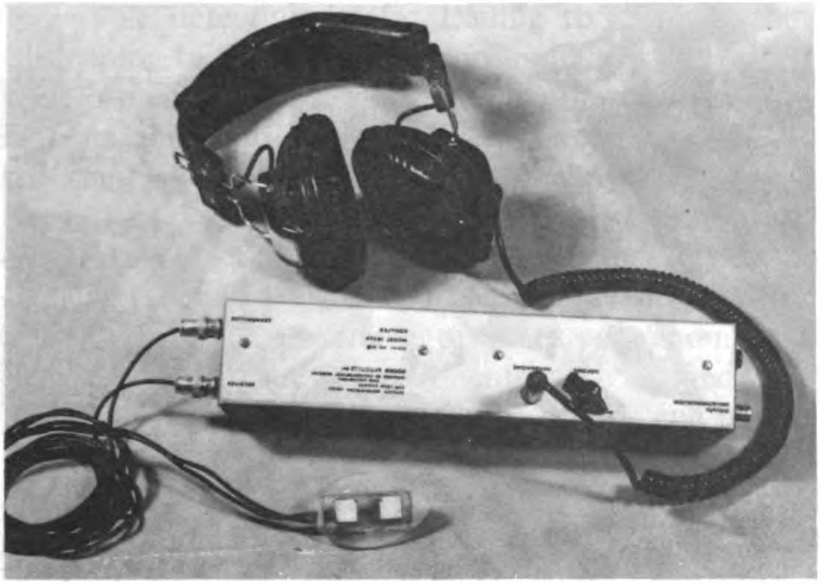


Figure 3 – The complete Doppler Ultrasound Blood Bubble Detector with precordial transducer and headphone connected. Additional transducers or headphones can be connected by simple detachment of and substitution for that connected at any time. The internal power supply for field use can be supplemented at any time by connection to a larger external power supply.

by Spence Campbell, have carried out oceanographic missions on Cobb Seamount in the Pacific Ocean, 270 miles off the Washington coast. Working on its pinnacle, between 120 and 165 feet, diving is stressful and dangerous.

"Before the use of the precordial detector," says diving physician William Postles, of The Dwyer Hospital, Portland, Oregon, "we always had one or two serious cases of decompression sickness affecting the nervous system of divers with severe pain. Since its use on the last three missions we have had no decompression problems. I monitor each diver soon after surfacing, (Figure 4) and if he has precordial vge grade I or more, we give him 100% surface oxygen to breathe. The bubbles usually go away within 20 minutes, but if not, we treat him preventively with the deck recompression chamber. I also forbid a bubbling diver to repeat his water exposure on the same day. As a direct result of the availability of the precordial ultrasonic detector, no decompression sickness has since developed at Cobb Seamount."

Studies in open water dives bring out important factors not present in experimental dives of the laboratory or hyperbaric chamber, but also reveal the special values of the chamber investigations. Six Cobb Seamount divers performed 165 ft. for ten minutes controlled dives, both in the open ocean and simulated in the hyperbaric chamber

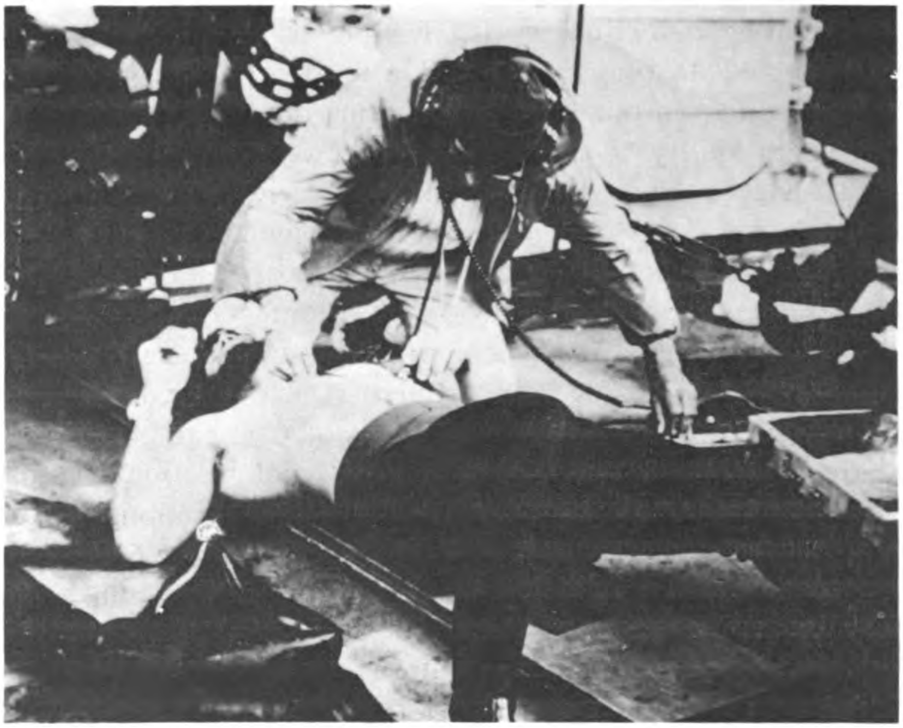


Figure 4 — On site (here shown on the deck of U.S. Coast Guard Cutter Iris) use of the Doppler Blood Bubble Detector by a trained operator can be fundamental in the prevention of decompression sickness by alerting the diving supervisor or medical personnel as to the advisability of recompression.

of the Institute of Applied Physiology and Medicine. The open water dives produced vge in five out of six subjects, while only two of these five bubbled in the laboratory chamber. The grade of bubbles in those two increased after the open water dives, with accompanying bends pain developing in both requiring recompression and oxygen treatment. Screening tests for professional diving trainees appear feasible and may eliminate the bubbles and bends susceptible individual.

The Maui black coral divers of the Hawaiian Islands represent a "naturally selected" group of commercial divers. A high incidence of paralytic bends has been sustained over the years. Studies on these men proved they routinely exceed recommended limits and produce a high incidence of vge. Their vigorous bottom exertion, as they search out and retrieve coral at 190 ft. plus, probably partially protects them during decompression. Reactive hyperemia increases the flow of blood through the lungs and other body tissues, probably hastening the elimination of excess nitrogen. This is suggested by the finding that the left arm of these right-handed divers produced most of the vge. The arms and legs in water or chamber have always been the most frequent source of vge, but in these working coral divers the less vigorously used arm appeared most susceptible to vge formation.

Blood bubble detection is also leading to safer decompression tables by helping to find the toleration limits of excess gas pressure. Studies performed in our laboratory during the past three years have resulted in an ability to accurately detect venous gas bubbles at a very early stage of their development. This early detection by means of the precordial detector, Figure 5, has provided additional time for safely conducting a peripheral site search to further identify vge as to regional source(s) and grade. Previous decompression schedules were tested by observing the occurrence of bends pain and making allowances for the critical tissue compartments, each defined by theoretical 1/2 times. To the subjective symptom of pain end point we now added the objective percentage occurrence and fractional grade of bubbles end point. By determining these end points along the time-pressure direct decompression limits, as shown in Figure 6, any allowable limit may be chosen. A 20% occurrence of precordial vge was found to be accompanied by less than 5% occurrence of mild bends pain. Providing that bends and bubbles susceptible persons do not push these limits, acceptable limits may be defined by Ft = 265 minutes$^{-0.51}$. Since these limits are more conservative than present U.S. Navy recommended No-D limits for most depths less than 100 ft., one should allow about one minute longer in the short deep

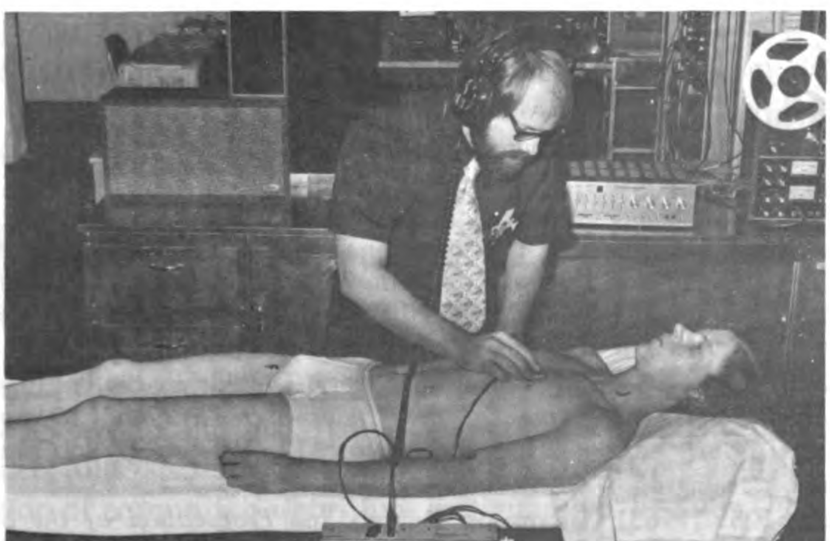


Figure 5 – Doppler monitoring of laboratory subject is a primary tool in the objective development of safe diving schedules and/or procedures. The precordial probe is shown correctly positioned along the left mid-sternal border. Preferred peripheral monitoring sites are illustrated by letters. J = Jugular vein, B = Brachial vein, and F = Femoral vein.

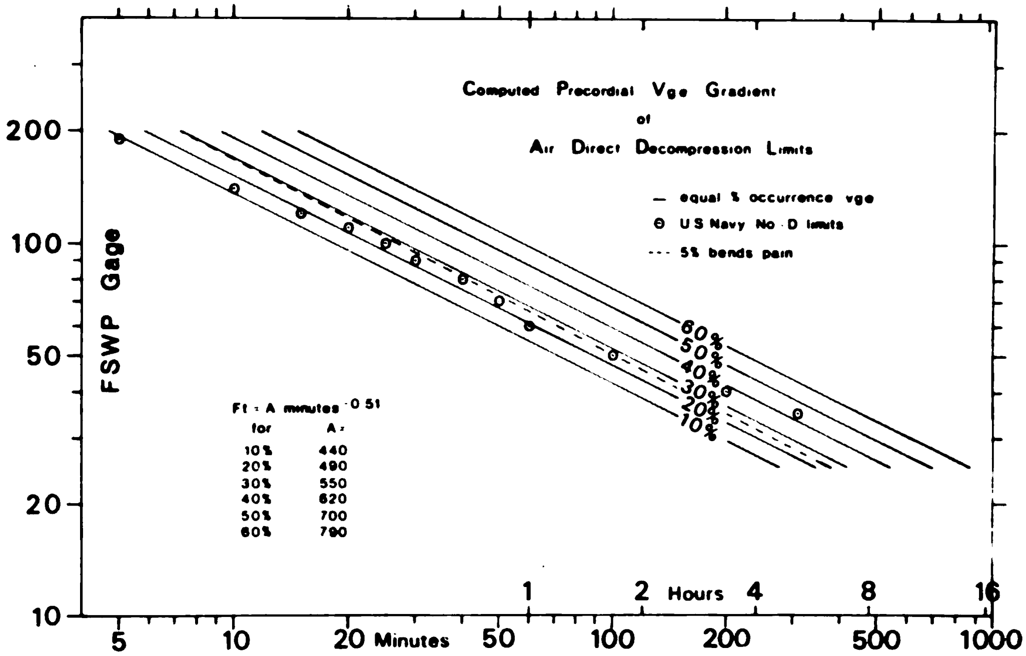


Figure 6 — Interpolated percentage occurrence lines for precordial vge as determined with the Doppler Blood Bubble Detector. Acceptable practical limits would probably include a 20% occurrence of vge accompanied by less than 5% mild bends pain.

dives greater than 100 ft. Further use of these limits is to calculate the maximum over-pressure which may be tolerated by each tissue 1/2 time compartment. By extension of this approach to dives requiring staged decompression, a complete model for decompression safety may be built up, and the tolerances for all tissues determined for all diving depths.

References

1. Behnke, A.R. (1942), "Investigations Concerned With Problems of High Altitude Flying and Deep Diving: Application of Certain Findings Pertaining to Physical Fitness to the General Military Service," *The Military Surgeon* 90 (1):9-28.
2. Schaefer, K.E. (1955), "The Role of Carbon Dioxide in the Physiology of Human Diving," *Proceedings of the Underwater Physiology Symposium* (Loyal G. Goff, ed.), pg. 135, Publ. No. 377, Nat. Acad. Sci. Nat. Res. Council, Washington, D.C.
3. McKay, R.S. (1963), Discussion Remark in *"Proceedings of the Second Symposium on Underwater Physiology,"* p. 41, Publ. No. 1181, Nat. Acad. Sci. Nat. Res. Council, Washington, D.C.
4. Satomura, S. (1959), "Study of Flow Patterns in Peripheral Arteries by Ultrasonics," Nahom Onkyo-gakkai Shi *J. of the Acous. Soc. of Japan*, 15: 151-158.
5. Franklin, D.L., Schlegal, W.A., and Rushmer, R.F. (1961), "Blood Flow Measured by Doppler Frequency Shift of Backscattered Ultrasound," *Science* 134:654-665.

"Hidden Line" Problem

Ivan Sutherland*
Rand Corproation, Santa Monica, California

The ability of computers to produce quite realistic pictures of three-dimensional opaque objects has only recently been developed. Since it is quite easy to program the computations of three-dimensional perspective, and the resulting programs run quite efficiently; it is easy to compute the positions on a simulated photographic film onto which a simulated camera would project parts of a simulated object were such parts seen by the camera. On the other hand, it has proven very difficult to write programs which will efficiently compute whether each particular part of the simulated object would be seen or whether the simulated camera's view of it would be obstructed by some other part of the simulated object. The task of computing which parts of an object will be seen and which will be obscured is known as the "hidden-surface" or "hidden-line" problem. This research will greatly benefit the Navy in the fields of computer aided ship design and photoreconnaissance.

Although the hidden-surface problem has been specifically identified as a difficult computing problem for over a decade, new solutions are still being sought. Until very recently, little real understanding of the fundamental nature of the problem was available. As a result, each new solution followed the intuition of its author rather than any guiding principle, and there has been considerable controversy over the merits of various approaches. In short, there has developed an "art" of hidden-surface programming with little scientific basis.

In a recently-published paper, Dr. Ivan E. Sutherland and two colleagues working under ONR support have set forth a rational basis for considering the hidden-surface problem. Their work is interesting not only for its results, a basis from which one can examine a hidden-surface algorithm and make some predictions about its probable performance, but also for its approach. It is relatively unusual for a collection of computing algorithms to themselves become the objects of study. It is perhaps a sign of our growing sophistication in computing that a study of computer programs can produce useful insights into the problems which the programs purport to solve.

*Dr. Ivan Sutherland who is a Senior Research Scientist at Rand Corporation, is a leading contributor to the field of computer graphics. He was Director of The Information Processing Technology Office at ARPA and was one of the founders of The Evans – Sutherland Corporation

In the publications of the past decade, Dr. Sutherland and his colleagues were able to find ten hidden-surface algorithms to be included in the study. Several other algorithms were not included because they use quadratic rather than linear data elements, or because insufficient detail about their operation was available. The ten algorithms studied span the decade in time and come from all over the United States. One algorithm of British and one of Italian origin were included.

The algorithms studied seem, at first glance, to vary widely in basic approach to the problem. Soon, however, a pattern began to emerge, and it became possible to categorize the algorithms by the methods of sorting used and the order in which various sorting steps are applied. The published result of the study, "A Characterization of Ten Hidden-surface Algorithms," describes the algorithms in common terminology and categorizes them according to the newly-discovered scheme.

What now seems a remarkably simple result, namely that the hidden-surface problem is essentially a sorting problem, is the principal technical contribution of the effort. That sorting techniques are basic to any solution of the hidden-surface problem is an irrestible conclusion in light of the ease with which the differences and similarities of the algorithms can be understood in sorting terms, and the simple categorization of the algorithms that the sorting view makes possible.

As a tutorial tool, the categorization of algorithms is naturally quite effective. It gives the student a framework into which to fit the various algorithms and tools by which to compare them. In addition, the categorization in this case also teaches the existence of new unknown algorithms as well, because there are unfilled positions in the categorization itself. Thus, the approach of studying and classifying algorithms has proven to be an effective research tool and not merely a tutorial device.

More important, taking the view that the hidden-surface problem is essentially a sorting task brings all of the theoretical knowledge on the performance of various kinds of sorting to bear on the hidden-surface problem. In retrospect it becomes easy to see places in each algorithm where its author violates the rules of good sorting technique. Performance predictions for the algorithms become possible on a theoretical basis because the performance of various sorting methods are quite well known. And finally, some theoretical insight into the probable performance of an optimum algorithm can be gained.

"We have found that what was seemingly a hard problem, the hidden-surface problem," reports Dr. Sutherland, "is in fact simply a special case of a well-understood problem, sorting. Though hidden-surface programs will still be complex, there need remain little mystery about their operation and expected performance. It is remarkable to me that what seems to be a tutorial simplification, i.e., looking at the hidden-surface problem as a special case of sorting, has such broad implications for future work in the area, but then I suppose that all of science is just a tutorial simplification for a pioneer without a tutor. We have greatly appreciated the flexibility of ONR's contracting procedures which enabled us to undertake this study on short notice."

(Continued from Page 12)

The 150-foot tower, completed in 1912, actually is two towers, one cleverly constructed within the other to prevent the mirrors from vibrating in high winds. The mirrors are mounted on the inner tower and the dome on the outer one. The inner tower is concealed because its girders are within the hollow girders of the outer tower. The two towers don't touch and each sits on its own foundation.

The 15-inch mirror atop the tower rotates back and forth in such a way as to allow the magnetograph to scan the sun, covering about 10,000 miles in a sweep and moving gradually from north to south. The 19-inch mirror provides the continuous tracking that keeps the image fixed as the earth rotates.

The entire solar disk can be scanned within 45 minutes. However, Dr. Howard prefers a longer scan time of 90 minutes because it accumulates less background noise. The observations are recorded on magnetic tape.

During the rebuilding process, which took several months, the telescope was inoperable only a few hours.

The big instrument was built originally by Dr. George Ellery Hale, founder of Mt. Wilson and Palomar observatories and one of the founders of modern Caltech. The magnetograph was developed by Dr. Horace Babcock, director of the Hale Observatories.

A great deal of what is known about the physics of the sun has been discovered at this telescope with the support of ONR. Over the years fundamental studies here of sunspots and their magnetic fields, solar rotation, the large-scale magnetic fields of the sun, motions in the solar atmosphere, and other topics have made important progress toward an understanding of the atmosphere of the sun and the nature of solar activity.

Solar activity, besides providing a clue to similar behavior in other stars, has practical importance because it is linked to a number of phenomena on the earth, including some aspects of weather.

The new mirrors and lenses were funded by the National Science Foundation. Other parts of the rebuilding program were assisted by the National Aeronautics and Space Administration, Office of Naval Research and Air Force Cambridge Research Laboratories.

Research Notes

Emergency Equipment Inventory Compiled for Undersea Operations

Two accidents in 1973 involving manned submersibles clearly demonstrated the need for quick response with appropriate equipment to effect emergency undersea rescue.

As a result of the JOHNSON SEA LINK and PISCES III accidents, in which two men died and four others nearly lost their lives, the Director of Navy Laboratories directed the Naval Undersea Center (NUC) to prepare a plan to provide emergency assistance from among Navy research and development assets in case of submarine/submersible disaster.

Two publications outlining emergency procedures and equipment available for rescue operations have been compiled by NUC.

The "Report of the Ad Hoc Interlaboratory Committee on Navy R&D Emergency Assets, July 1974" describes the efforts of that committee.

Consisting of members from Navy and private laboratories, and chaired by Howard R. Talkington, head of NUC's Ocean Technology Department, the committee met at NUC in October 1973 to discuss recommendations for Navy participation in undersea rescue and recovery attempts.

Development of new equipment for submersibles that will facilitate location and recovery during disasters was recommended.

The committee also recommended compilation of an emergency equipment inventory, which would be updated yearly.

NUC has compiled, as a result, "An Inventory of Navy Laboratory R&D Equipment Available for Emergency Undersea Operations."

The inventory presents, by category, ships, submersibles and equipment available at various Navy facilities for submarine search, recovery/rescue.

Contacts at the various Navy and civilian laboratories, as well as information on procedures for obtaining emergency assistance, are listed in the volume.

Copies of the publication are available from: Commander, Naval Undersea Center, Code 65, 201 Rosecrans Street, San Diego, California, 92132.

Ultrasound for Shipboard Waste Disposal

In response to the needs of the Fleet, the Naval Coastal Systems Laboratory has begun exploratory development of a flow-through sterilizer using the ultrasound principle which will permit safe overboard discharge of human wastes.

The compact, lightweight sterilizer would fit into the piping system of ships and sterilize fluid within these systems without adding heat or chemicals.

The device being developed for the system uses high intensity ultrasound (sound waves with a frequency above 20 kHz) for killing sewage organisms. At high intensities, exposure to ultrasonic irradiation results in destruction of cells, cellular organelles, and large molecules (e.g., DNA) which are critical to the life of microorganisms.

Scientists at NCSL feel that effective ultrasonic sterilizers could contribute greatly to shipboard or shore-based treatment of sewage and potable water. Used in combination with oxidizing agents such as ozone, ultrasound reacts synergistically to enhance disinfection by many orders of magnitude. At the same time, ultrasonic disinfection does not create environmentally hazardous waste material.

Chlorine, the most commonly used disinfectant, reacts with other compounds in sewage to form effluents which may be toxic to aquatic life and in some instances may cause cancer in man.

Spinning Currents Discovered in Arctic Ocean

Columbia University scientists have discovered swift, spinning currents near the center of the Arctic Ocean.

The oceanographers from Columbia's Lamont-Doherty Geological Observatory are scheduled to set up camp in the next week on the northern pack ice to study the large, whirling eddies and other ocean phenomena for a year.

The unusual disks of water ten miles in diameter and 1,000 feet thick spin just 100 feet or so beneath the great ice floes. The scientists have discovered four of them so far.

They believe the eddies influence the constant motions of the pack ice, affecting its patterns of breaking, buckling and refreezing, which, in turn, affect the world's weather.

Their work is part of AIDJEX (Arctic Ice Dynamics Joint Experiment), the most ambitious international study of the North Polar ice ever undertaken. This project is mainly funded by the Office of Naval Research and the National Science Foundation.

With the recent establishment of a base camp in the Beaufort Sea of the Arctic Ocean 250 miles northeast of Point Barrow, Alaska, marks the start of AIDJEX's largest and climactic phase.

Teams of American and Canadian scientists will study the air and ice as well as the ocean during the next 12 months, laying out instruments over a roughly circular area 500 miles in diameter. They hope to amass enough data to create an accurate "model" of the behavior of the Arctic ice so that changes in it can be predicted. Besides improving weather forecasting, the data would aid in laying out safe shipping routes for oil cargoes and even help improve the design of ships for travel in polar waters.

The Columbia scientists have been gathering evidence of the huge mid-ocean eddies since 1972, when AIDJEX conducted a two-month pilot study of the Arctic ice using simpler instruments over a smaller area. They are led by Dr. Kenneth L. Hunkins, adjunct professor of geology at Columbia and senior research associate at the Lamont-Doherty Observatory. He and Dr. Norbert Untersteiner of the University of Washington co-authored the plan for AIDJEX in 1969.

"These are unusual subsurface circular currents," said Professor Hunkins. "They turn at a speed of about one knot, which is relatively swift for a central area of the ocean." They are apparent about 150 feet below the ocean surface and display their strongest current about 500 feet down, he said. In the year of research ahead, the Columbia team will determine how energy from the currents may be transferred to the ice above.

"These large eddy motions are much like many air movements," he observed. "They show that the ocean, in a sense, has a weather of its own."

Through holes in the eight-foot-thick ice, Professor Hunkins and five Lamont-Doherty research assistants will lower sophisticated instruments to measure salinity, temperature, depth and current speeds. Their oceanographic findings, together with meteorological facts and ice-structure data obtained from other AIDJEX projects, will become a vast computerized bank of information that can explain the complex motions of the ice. Over the year, some 200 scientists, technicians and support personnel from nearly a dozen university and government organizations will man 50 buildings and tents at four camps and monitor instruments at ten additional stations.

AIDJEX, which is headquartered at the University of Washington in Seattle, is directed by Dr. Untersteiner. Other participating institutions include the University of Alaska, Oregon State University, McGill University, the Canadian government's Polar Continental Shelf Project and Bedford Institute, the Cold Regions Research and Engineering Laboratory in Hanover, N.H., the United States Geological Survey, the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration.

Ice On The Move

A team of scientists from the Geophysical Institute at the University of Alaska is trying to determine how near-shore sea ice moves and how strong the forces are that move this ice. For the third consecutive spring, members of the team are at the Naval Arctic Research Laboratory to monitor the spring break-up. In terms of ice movement this is the most interesting and dangerous time of year. According to Dr. Lewis Shapiro, a geologist at the University of Alaska, by spring the "shore-fast" ice has reached a thickness of about six feet. Therefore the forces against an offshore structure can be greater than at any other time of the year.

This research is jointly sponsored by the Sea Grant Project and the Arctic Oil and Gas Association. At a time when resources are being developed in the Arctic, industry is interested in the movements of shore-fast ice as it may affect offshore facilities.

A variety of instruments are used to measure strength and movement of ice. Stress transducers designed by Dr. Richard Nelson from the University of Alaska's Geophysical Institute record active forces in the ice. Once frozen into the ice these brass cylinders will monitor stress levels offshore at Barrow and in the Prudhoe Bay area. A radar site is maintained at NARL by Mr. Ron Metzner. The site consists of a 40 foot high tower with standard ship's radar equipment which receives signals from the natural reflectors on the surface of the ice – such as ice ridges and ice chunks. A 35mm camera is mounted facing the radar screen and set to photograph every 2-1/2 minutes around-the-clock.

The camera operates all year and provides continuous time-lapse films of the movements of the natural reflectors. Three seismometers have been installed on the ice to detect "ice quakes" which cause fractures in the ice and to monitor rates and locations of these fractures. Additional measurements will be taken on the creep qualities, salinity levels, thermal characteristics, and physical characteristics of sea ice.

As interesting phenomena occur at Barrow, such as the formation of a new ice ridge, Mr. Metzner notifies personnel at the Geophysical Institute in Fairbanks. If the phenomena merits further examination, researchers come to Barrow to look at the ice themselves. Researchers can learn a great deal about the forces in the ice by examining the fractures and fracture patterns after ridging has occurred. By knowing what circumstances are necessary before the ice will break or if there is a relationship between rate of cracking and stress, scientists might predict when the ice is unsafe for structures or personnel. The Naval Arctic Research Laboratory is the only logistical base in the United States where such field work on sea ice can be accomplished.

New Mother for Orphaned Bear

The Naval Arctic Research Laboratory was asked to assume responsibility for a polar bear cub which had been retrieved after the mother had been shot to provide meat for a group of Eskimos enroute to the village of Nuiqsut. After consulting with Mr. Jack Lentfer of the U.S. Fish and Wildlife Service, NARL agreed to keep the bear until it might be returned to its natural environment. Meanwhile, the 25 pound baby bear was made comfortable in NARL's Animal Research Facility and fed condensed milk which it lapped hungrily from a pan.

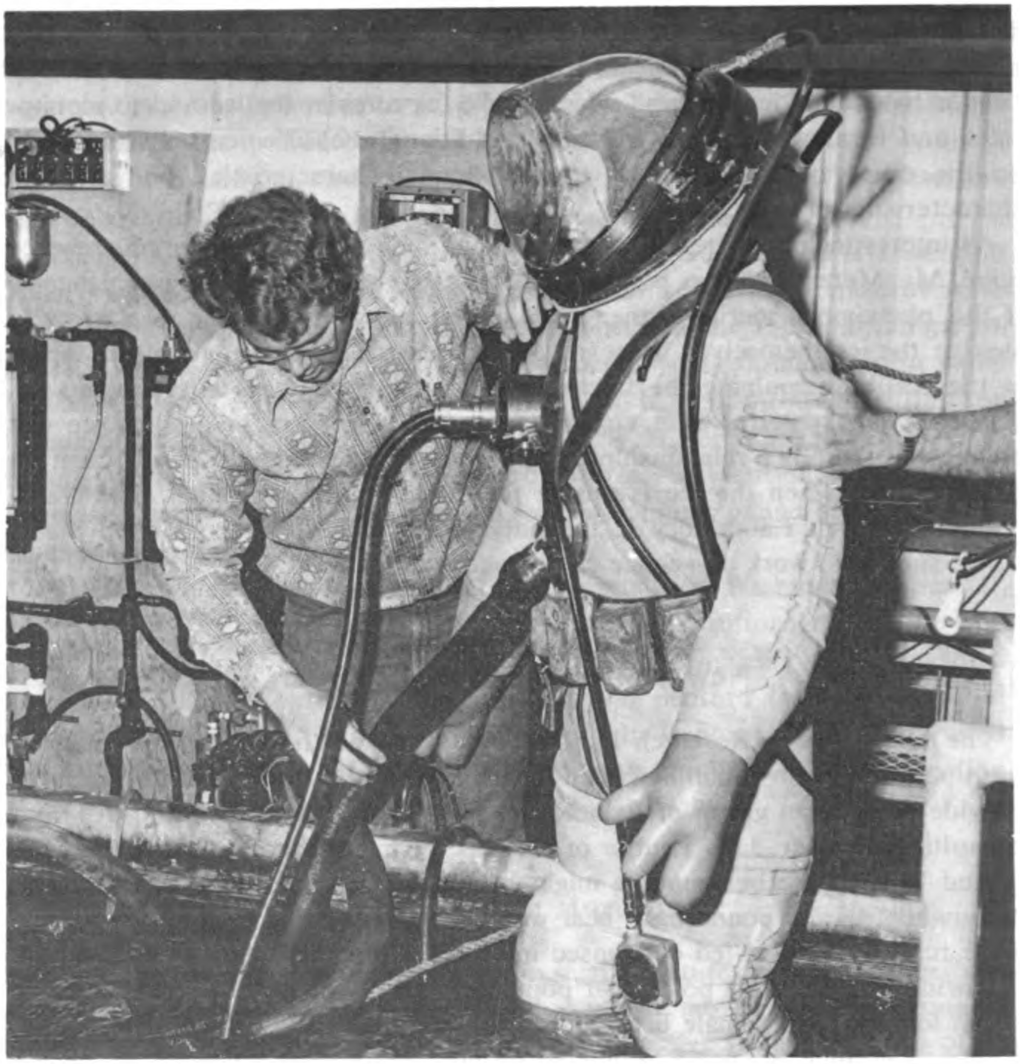
During Mr. Lentfer's polar bear population survey flights over the sea ice he began looking for a female bear with cubs who might be a prospective mother. Although nothing is known about the acceptance of orphaned cubs by female polar bears, personnel at the Laboratory felt that the bear would have a better chance in nature than in captivity.

A female bear with one cub was located about seven miles offshore. After the bear had been immobilized so that Mr. Lentfer could collect data and mark her for identification, a plane returned to NARL to pick up the cub. Soon after the cub was placed near the tranquil female she began to nurse. Mr. Lentfer spotted the female travelling with both cubs later that day and again saw the same female with both cubs two weeks later about five miles from the release site. Mother and cubs seemed to be doing fine.

Thermal Garment Successfully Tested at NCSL

A new thermal outer garment that offers better protection for the Navy diver in cold water has been successfully tested at the Naval Coastal Systems Laboratory.

The purpose of the task which began three years ago at NCSL was to find a technique to maintain a diver in extremely cold water—near 32 degrees Fahrenheit—for extended periods up to eight hours.



Outfitted in the thermal protection outer garment developed at the Naval Coastal Systems Laboratory, Jim Middleton prepares to enter the 34-degree water where he remained submerged for eight hours in comfort.

Trapped air provides insulation of clothing worn by man in a gaseous atmosphere. Once in the water, the trapped air is lost from the unclothed diver's bare skin. Since 32-degree Fahrenheit water has a thermal conductivity 24 times more than air at the same temperature, the immersed diver will lose body heat 24 times faster in 32°F water than in 32°F air. Thus the thermal insulation of the diver's garments must be much more effective than the best available for use in his normal gaseous environment.

The thermal protection garment is heated by an internal tube suit of conventional design through which warm water is circulated. The garment is inflated to provide an insulating gas layer.

A test subject suited with the garment was completely comfortable for eight hours in water nominally 34°F. The garment proved the concept that a diver can be sustained with supplemental heat under extreme conditions with a uniform insulation air gap between his body and the cold water.

Previous thermal garments have required from 70,000 to 10,000 BTUs of heat per hour. The test recently completed indicates the new equipment may require less than 2000 BTUs per hour.

Being developed concurrently at the Naval Civil Engineering Laboratory is a diver-carried heater to be used with the suit. Interface of the thermal protection garment and the diver-carried heater is projected for March 1975. This will make the system completely self-contained. A urine collection device originally designed for use in the Apollo pressure suits is used with the system.

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 730, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $6.50 per year in the U.S. and Canada; $8.15 per year, foreign; $0.55 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

Editor: WILLIAM J. LESCURE

NAVSO P-510

Associate Editors:

A. R. LAUFER, ONR PASADENA

A. R. DAWE, ONR CHICAGO

A. L. POWELL, ONR BOSTON

D. A. PATTERSON, NAVAL RESEARCH LABORATORY

U. S. GOVERNMENT PRINTING OFFICE : 1975 O - 577-934

IN THIS ISSUE

VOL. XXVIII, NO. 6

Cover Caption

SOFAR floats being transported to the sites where they will be placed to study eddie movements in the Gulf Stream. See page 1.

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
ARLINGTON, VA. 22217

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, $300.

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DoD-316

U.S.MAIL