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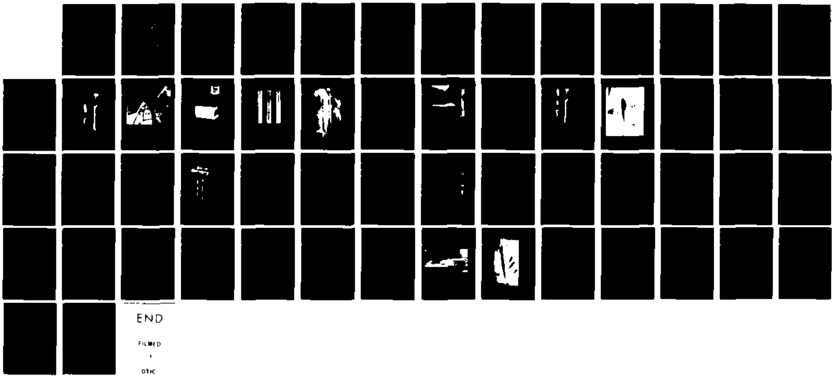

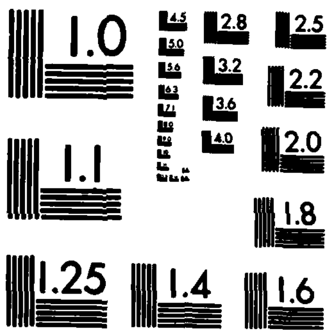
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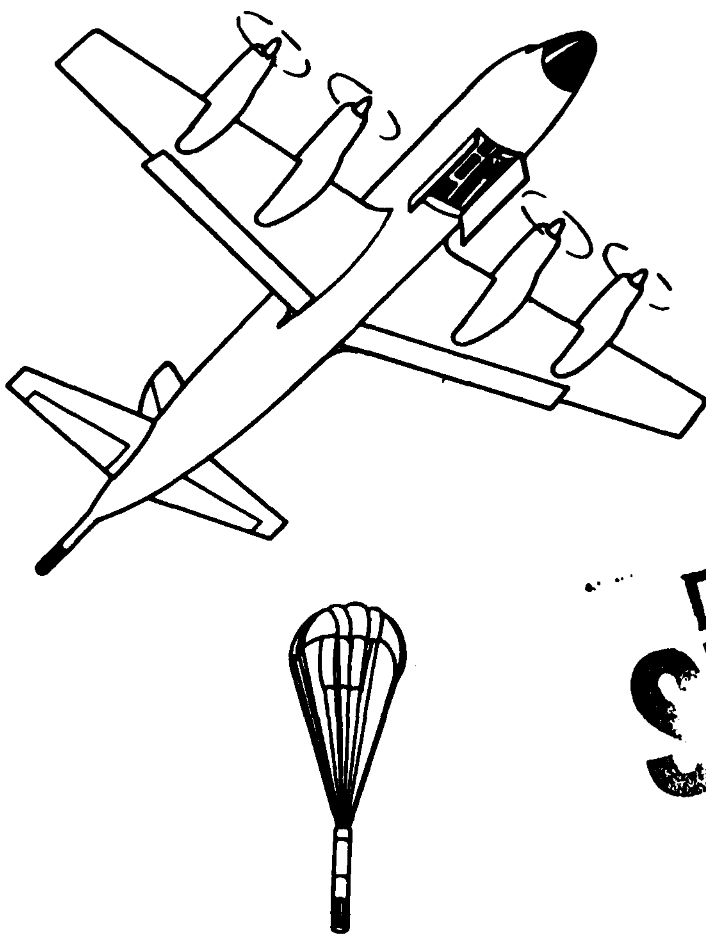

ARCTIC EXPENDABLE TECHNOLOGY

ONRDETPAS Report 8

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

A workshop was held in December 1981 during the Annual Fall Meeting of the American Geophysical Union. Scientists and engineers concerned with polar oceanography meet with scientists and engineers concerned with oceanography in warmer regions to discuss the state of knowledge in expendable technology. The objective was to access the transferability of expendable technology to applications in polar regions. An emphasis was given to research in the ice marginal zones. This report summarizes the information discussed and the opinions and conclusions expressed.

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ONRDETPAS REPORT 8

ARCTIC EXPENDABLE TECHNOLOGY

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September 1982

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Acknowledgements: The roots of this report are in the recorded discussions of participants in the planning meeting. Their names are in the Appendix. After reorganizing and rewriting the recorded material, this report has benefited greatly by the editorial advice and corrections contributed by Mr. J. M. Hannon, Dr. K. M. Ferer, Dr. T. B. Sanford, Dr. W. W. Denner, Dr. J. Morison, Mr. A. Hanson, Mr. J. R. Lovett, Dr. G. L. Johnson, Dr. K. Hunkins, Dr. R. Corell, and Mr. R. McGregor. Much detailed editing and suggestions were contributed by Dr. John Newton. The several drafts and many typed changes were made by Mrs. Barbara Brown. Figures have been contributed by several participants and are credited on their figures.

FOREWORD

In the ice-covered Arctic Ocean and the marginal ice zones the temperatures are low and frequently close to freezing. The density, a most important physical parameter used to determine circulation, acoustical conditions, stability, and mixing, is mainly determined by salinity as a function of depth.

In cases where a strong temperature-salinity correlation exists, a qualitative concept of the salinity structure (and thereby the density structure) may be based on temperature measurements. However, the usefulness of this approach is open to question in the marginal ice zones (where the temperature range is small and the temperature-salinity relationships are such that salinity may vary widely over a narrow temperature range).

There is a well-developed non-expendable technology for the measurement of temperature and conductivity (from which salinity can be calculated) as a function of depth. Unfortunately, at the present time, no accurate reliable expendable conductivity and temperature instrument exists. An attempt was made several years ago to marry the Expendable Sound Velocimeter (XSV) with a thermistor as a means of calculating density (by backward calculation from temperature and sound velocity) but the results were disappointing.

The remoteness and severity of the arctic environment are strong motivations for the use of expendable technology, as evidenced by the expressed interest among scientists and engineers in mutual discussions of the technology. Many such discussions have been held, and this report contains results of a planned discussion meeting. Many applications for presently developed expendable technology in Arctic regions exist and their uses are increasing. No comprehensive survey of these applications is known, but the interests of many Arctic Ocean research personnel are summarized herein.

FOREWORD

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SUMMARY

A planning meeting was held in December 1981 during the Annual Fall Meeting of the American Geophysical Union in San Francisco.

Oceanography in polar regions has been the purview of a hardy community of scientists and technicians who have faced the problems of a remote and severe environment in efforts to collect vital data. The much larger community of scientists and engineers working in warmer ocean regions has developed the technology of expendable instrumentation to a high state.

The purpose of this meeting was to clarify and articulate possibilities for the effective use of expendable instruments in the study of the oceanography of polar regions, primarily in marginal ice zones, but including the transitional regions from the completely ice-covered ocean to the completely ice-free ocean. Implicit in this purpose was the transfer of technology developed for temperate and tropical ocean regions to the polar oceans. It was achieved by assembling scientists and engineers, both those studying the polar regions and those whose work has been in temperate and tropical regions, for organized discussions. The contributions of this report were made possible by the interactions and oral exchanges among these communities of technical people.

The primary conclusion from this meeting was that expendable instrumentation technology offers both scientific effectiveness and cost-effective advantages to future programs aimed at understandings of the ocean structure and dynamics, especially in the marginal ice zones. Because of the hazardous nature of obtaining data from conventional platforms in these areas, expendable instruments can provide a safer approach. Difficult logistics lead to a reluctance or an inability to adequately sample an area; thus expendable instrumentation can provide better area coverage. A reconnaissance strategy, based on a rapid survey using expendable instruments, may be useful in determining the most effective deployment of ships and ice camps for obtaining the basic oceanographic data. Improved delivery systems for aircraft-deployed instruments are necessary to fully take advantage of the safety and survey aspects of expendable instruments.

The primary recommendation from the meeting was for the development of expendable instrumentation which could be used to determine salinity structure in the ocean.

A review of engineering specifications for expendable instrumentation is also included.

INTRODUCTION

When one considers the difficult scientific questions of the marginal ice zone in light of the available instrumentation technology, a severe challenge is perceived to obtain adequate data. For this reason an effort was made in the meeting to clarify the scientific questions and attendant hypotheses pertinent to the transition and interaction regions between the completely ice-covered ocean and the completely ice-free ocean. For perspective, ideal instrumentation which would most appropriately measure the basic parameters in the time and space scales needed for scientific objectives was discussed, and the instrumentation utilized and being developed for less severe and warmer oceanographic regions was reviewed. Field experiences with instrumentation in polar regions were described in discussions on the adaptability and unique problems of transferring technology developed for warmer environments to the polar oceans. The many possibilities discussed were distilled into a few conclusions and recommendations for the development of instrumentation to support current and future scientific programs for understanding the structure and dynamics of the ice and ocean in marginal ice zone regions.

Philosophically, scientists working in polar regions have been conditioned, to some extent, to think in terms of available technology for planning scientific field experiments. In this meeting they were encouraged to think more broadly in terms of potentially available technology. Conversely, the engineers were encouraged to think more broadly in terms of scientific needs and technical possibilities in order to avoid the limitations of directed thinking normally employed between scientists and engineers. To discuss engineering developments based on scientific need, guideline questions were asked. For example, the question was addressed, "Is present expendable technology adequate for polar scientific applications?" In several aspects the answer was found to be "Yes," and the meeting served to clarify the polar applications of this available technology.

The harsh Arctic environment and difficult logistics have led Arctic scientists to encourage the development of automated data systems and of labor-saving approaches to the measurement of environmental parameters. Instruments which supply data but do not need to be retrieved save a lot of effort and often reduce the risk involved in staying on-station to complete the data record. High-cost complex instrumentation is often not deployed in high risk areas because of potential loss or damage. Substantial logistics effort involving some risk to personnel is often required to deploy instrumentation. An unwillingness to risk people, platforms, and instrumentation in the Arctic region is a deterrent to obtaining adequate scientific data. The use of expandable instruments could permit simpler and less hazardous data collection.

It is often said that Arctic regions are the crossroads for most of the nations in the Northern Hemisphere. Not only do these regions influence transportation and communications, but also they are reservoirs for weather and climate dynamics on a global scale. The marginal ice zones exert strong influences on both the atmosphere and the oceans. Substantial scientific projects are planned for the decade of the 1980's to obtain an understanding of the major marginal ice zones in Arctic regions. "What determines the location of the ice margin?" and "What factors irfluence its characteristics and seasonal migration?" are fundamental scientific questions. The determinations of space and time scales of these structural characteristics of the marginal ice zones are major scientific objectives. An understanding of the physical processes which control the edge of the ice is necessary in any attempt at modeling and eventual parameterization, both for predicting the locations of ice margins and for judging their impact on the global weather and ocean circulation. Since there are complex interaction processes involving the atmosphere, ocean, and sea ice, both the scientific questions and appropriate measurement technology are correspondingly very complex. Large seasonal migrations of the ice margins compound the air-ice-ocean interaction by passing over highly varying bottom topagraphical features, such as shelf breaks, which, in turn, affect the mesoscale structures.

It appears that horizontal space scales of dynamically important structures may be smaller in ice marginal regions than in the major frontal areas of more temperate or tropical oceans. In particular, the Rossby radius of deformation along the ice edge east of Greenland is about five kilometers. Eddies and frontal features in this region tend to be much smaller in horizontal dimension than eddies and frontal structures commonly associated with the Gulf Stream or the Subtropical Front in the Pacific Ocean. Smaller horizontal scales, coupled with the existence of significant small-scale processes further increase the complexity for designing adequate scientific field experiments to obtain necessary data sets.

Knowledge of the density structure in the ocean is fundamental to the scientific descriptions of ocean structure and dynamics in the marginal ice zones. There is a strong salinity signature in the Arctic Ocean. In the marginal ice zone regions there is often both a strong salinity signature and a strong temperature signature. Density is a function of both temperature and salinity but there is, at present, no satisfactory general purpose expendable conductivity probe. The development of a suitable expendable conductivity cell and instrumentation (which must include a temperature sensor for conversion of conductivity to salinity) would be a major contribution to the success of field experiments in polar oceans and probably in the more temperate and tropical oceans.

Expendable instruments include not only probes which last for periods of tens of seconds but also more complex automatic instrumentation, which may be deployed to yield data over a period of several months or years. Such instrumentation includes drifting buoys, which telemeter their data, and packages which may be revisited from time to time but are ultimately abandoned. Perhaps the most complex expendable instrument discussed at length was the Air-Deployed Oceanographic Mooring (ADOM) which can record and transmit data from a chain of sensors suspended in the water column, both in ice-covered oceans and ice-free oceans. A summary of all expendable instrumentation known to the participants is contained in this report.

In general, expendable instruments were developed to reduce platform costs associated with the survey of a large ocean area, and since the ability to deploy instruments without stopping simplifies the delivery system, an aircraft is the ideal platform; it offers minimal risk in delivery of instrumentation and permits quicker spatial coverage. However, aircraft delivery systems are primitive and need to be improved to be cost-effective and adaptable to scientific requirements. Poor visibility and lack of accurate navigation further limit present aircraft delivery systems. Most instrumentation must still be placed on the ice or in the water by persons on the ice or on ships. This leads to the primary reason for instrument expendability in the Arctic; it may be hazardous to reach the optimum location or there may be a high risk of not being able to retrieve instrumentation planted there - a scientist could deploy expendable instruments rather than placing his instruments in a less scientifically desirable though safer location. Considerable effort to improve aircraft delivery systems have been implemented to meet tactical Navy requirements. These improvements and skills if adapted by the scientific community will go a long way toward eliminating past aircraft delivery problems.

Inherent in considerations of instrument risk is the recommendation that data telemetry systems be utilized whereby the data are obtained even though the instrument may ultimately be lost. Some discussion in the meeting centered around possibilities for telemetering data from non-expendable instrumentation through satellite links, which permits one to risk the instrumentation a bit more without risking the data. Data telemetry by satellite link is also used with expendable instruments, such as drifting buoys. The principle of separating the sensing system from the recording system, in this case by telemetry, offers advantages in the Arctic where remoteness and severity of the environment are dominant factors, and the impact of losing the information is often more damaging than the effect of losing the sensing system.

A potentially important application of expendable instruments is in reconnaissance. The most desirable position for a manned camp or ship for the study of mesoscale features along the ice margin, would be in the location of strong features. A more cost-effective use of ships and camps may be achieved by implementing a survey technique that reconnoiters the area and produces a qualitative mapping of horizontal structures in order to vector the ship or locate the camp in the most interesting portion of the structure. Although a relatively large number of expendable probes may be used during an aerial survey or a ship transit for reconnaissance purposes, it still is cost effective with respect to a search pattern of oceanographic stations made with a ship. Some degradation in the accuracy of the sensors may be permissible when used in the reconnaissance survey operation.

Coordination of expendable instrumentation with remote sensing instrumentation is desirable. If an aircraft is used as a launch platform for expendable instruments, it may also be a suitable platform for simultaneous remote sensing instrumentation. Remotely sensed data tend to give nearly synoptic patterns of the ocean surface characteristics and may be used to assist in the interpretation of the data from expendable instruments. Expendable probes provide for some depth correlation of the remotely sensed surface data, and the use of remote sensing permits a more generalized interpretation of data from expendable instruments. Because of severe moisture contamination in the atmosphere of marginal ice zone regions, the employment of remote sensing, especially that of visible and infra-red, has severe limitations. On the other hand, radar and microwave radiometers are less subject to atmospheric contamination but more difficult to interpret for mesoscale features. The point is made that expendable instruments are not stand-alone instruments but are best used in coordination with other data systems.

In summary, the use of expendable instrumentation provides a method of performing cost-effective and rapid area surveys. Uses of expendable instrumentation to reduce the danger to personnel in hazardous areas and to reach very remote areas are distinct advantages. Thus, expendable instruments may offer a means of obtaining data not available by conventional oceanographic methods. In addition, the severe environment and remoteness of the polar regions places heavy requirements on delivery platforms for all instrumentation. The marginal ice zone is probably the most difficult of all such areas and, as sometimes occurs, it is there that the highest scientific interest exists. Both the contributions to global climate studies and the importance to national interests are emphasized in the marginal regions and deserve the full application of latest technologies, including that of expendable technology.

READILY AVAILABLE EXPENDABLE INSTRUMENTATION

The most common expendable instrument is the bathythermograph probe (XBT, Figure 1) such as made by the Sippican Ocean Systems, Inc. This instrument has been used by the hundreds of thousands in the past 15 years. It has been launched (Figure 2) from almost every conceivable platform, including ships, submarines, helicopters, and fixed-wing aircraft. A three-conductor wire is used for the return signal when it is launched from a platform that does not have an electrical contact with ocean, such as a helicopter; otherwise a two-conductor wire is used with a sea-water ground to provide the path for the return signal. The XBT has been used in ice camps, both by launching directly through holes in the ice and/or through special plastic tubes. The unique aspect of the XBT is the wire system. The fine wire is actually two filaments, individually coated and married together in the production system. The breaking strength is about 1/2 lb. Sippican's very elaborate production facilities for the small, coated wire are not duplicated elsewhere, and its wire-related products are often incorporated in other instrumentation. For example, the Plessey (Grundy) expendable conductivity probe uses the Sippican wire system. The standard strip chart recorder (Figure 3) built by Sippican is normally used on a ship to record the temperature signal from the falling XBT probe. Various modifications and innovations have been made to this recorder for use on other platforms. Sippican has recently introduced a digital XBT/XSV system (Figure 4) designed especially for the scientific community.

The shipboard XBT, a very versatile probe, is available in quantities for prices beginning at about $30 apiece. Sippican has supplied about 3,000,000 of these standard probes; about 10,000 per year are used for scientific purposes by the Navy. Versions can be obtained which reach depths from 600 ft to 6,000 ft. The only sensor contained in the probe is a small thermistor coated with a thin layer of paralene. The thermistor has a 120 millisecond time constant. Probes fall at about the rate of 20 fps. The rate of fall varies with depth, primarily because, as the probe falls, it pays out wire, causing a loss of mass in the probe. Tensionless dereeling preserves the wire until the probe reaches the end. There is a spool in the probe and a spool in the cannister which remains in the launcher, so that they act as a wire deployment system both from the ship and from the falling probe. Probes have been launched from ships at speeds up to 30 knots. Experience indicates that the temperature accuracy is approximately 0.1°C. Special thermistors can be provided which give an accuracy of approximately 0.03°C. A more complex version of the XBT is available for submarine operations.

The air-launched expendable bathythermograph (AXBT), designated in the supply category of sonobuoys (Figure 5) by the Navy, bears little resemblance to the ship-launched XBT. The aircraft-launched instrument was designed for launch from Navy patrol aircraft (Figure 6). It has been supplied in large quantities by several companies including Magnavox, and more recently, Hermes. In these instruments, the configuration which falls away from the aircraft includes an aerodynamic drag device, usually a parachute or rotorchute, and a buoy. When the buoy is stabilized in the water, a falling probe containing a thermistor is deployed. As in the XBT, the assumed speed of fall is related to the depth. The buoy contains a radio to transmit the temperature signal back to the aircraft.

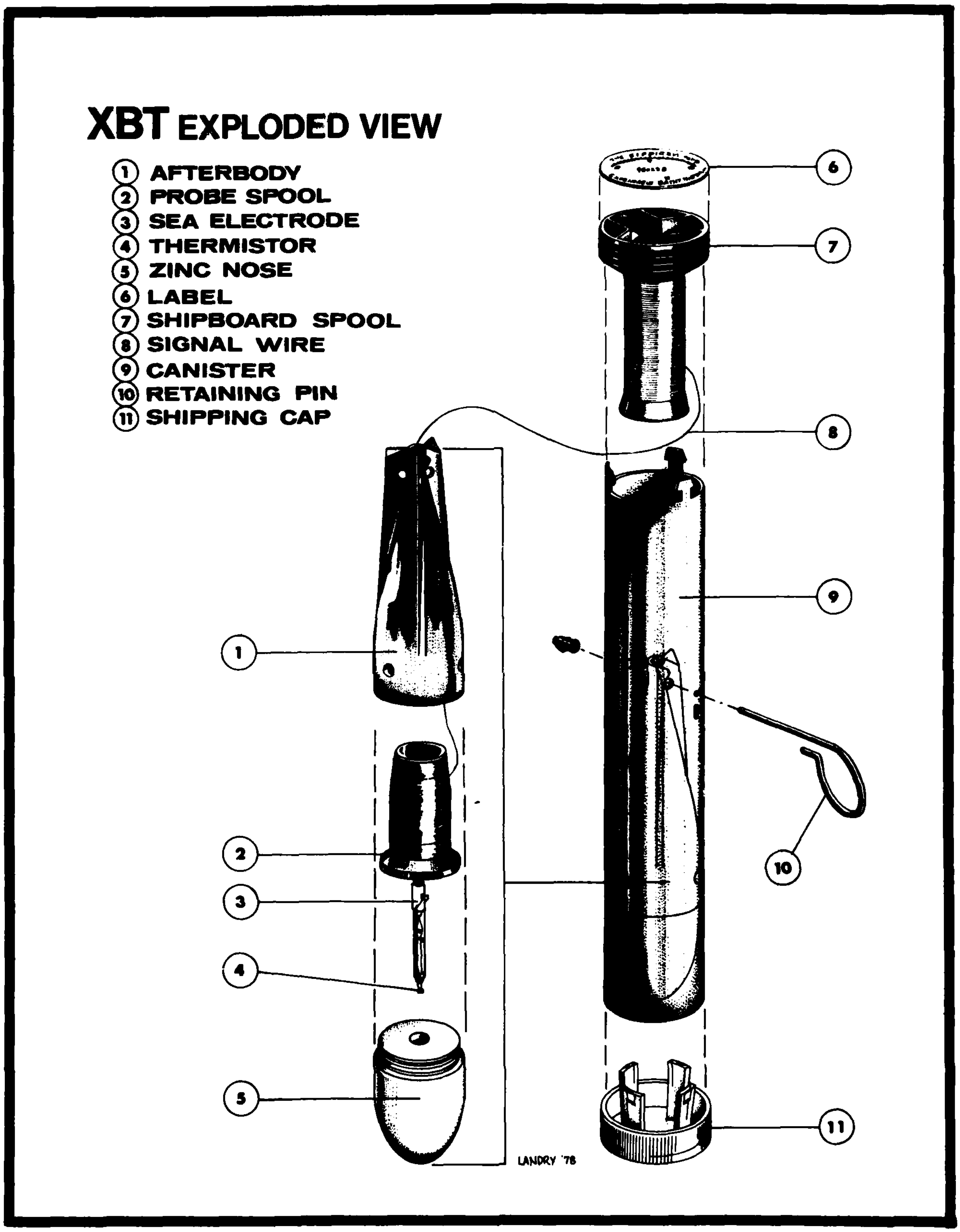


FIGURE 1. THE EXPENDABLE BATHYTHERMOGRAPH PROBE, XBT, SHOWING BASIC COMPONENTS. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

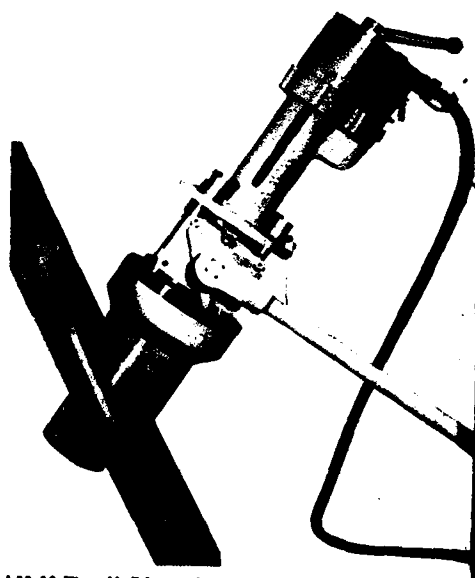
Launchers

Sippican XBT launcher systems are compatible with all recorder systems and XBT's. The LM-2A Deck Mounted Launcher is easily installed on the quarter of any vessel.

The LM-4A Thru-Hull Launcher employs the same basic assemblies as the Deck Mounted Launcher but is installed below deck to improve crew safety and operating convenience at sea.

The LM-3A Hand Held Launcher is designed for use where maximum portability and flexibility are required. A probe may be launched from any position of the vessel to avoid interference with other equipment.

LM-3A Hand Held Launcher



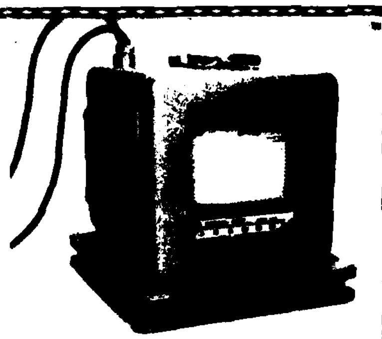
LM-4A Thru-Hull Launcher

FIGURE 2. TYPICAL METHODS OF LAUNCHING THE EXPENDABLE BATHYTHERMOGRAPH PROBE, XBT. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

recorders have proven a reliable means of obtaining a graphic display of temperature versus depth from the Sippican family of XBT's. It is available in metric or english scales.

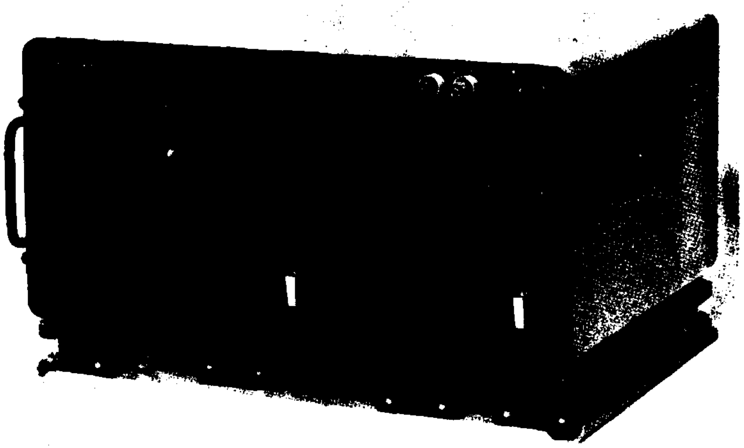
Specifications:

Temperature Range: −2° to 35°C
Temperature Accuracy: ±0.2°C
Resolution: 0.1°C
Depth Range: 0 - 1830 meters
Accuracy: ±2% of depth
Power Requirements:
115 VAC, 60 Hz, 35 Watts
Installation Data: 17" x 15" x 15" — 45 lbs.



MK-2A

FIGURE 3. A COMMON TYPE STRIP CHART RECORDER FOR THE EXPENDABLE BATHYTHEMOGRAPH PROBE. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)



MK-8

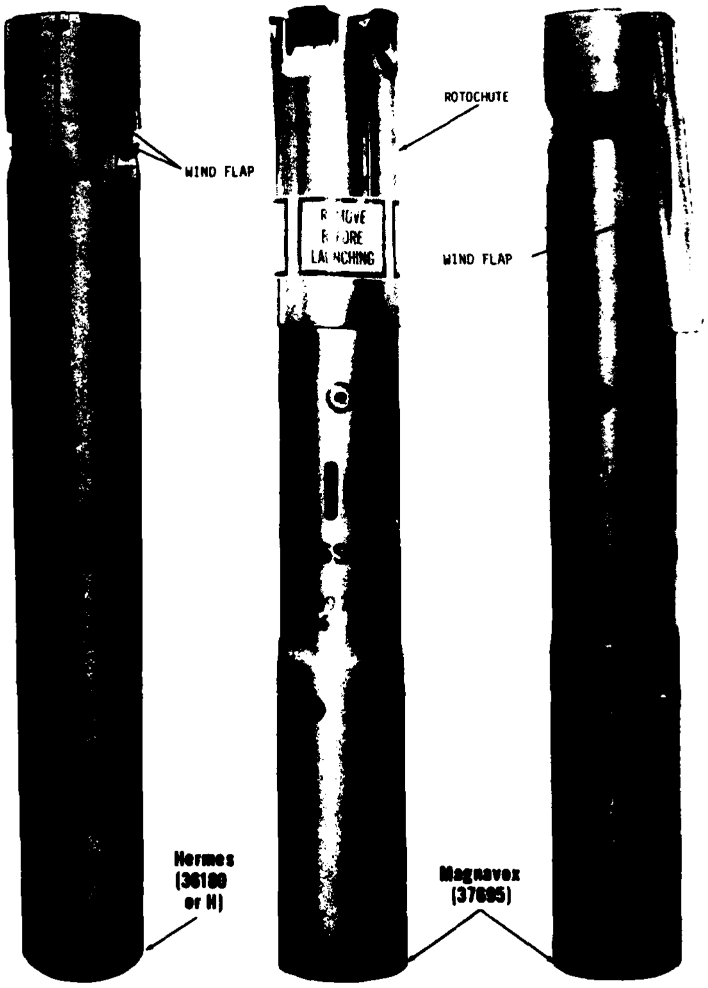
SIPPICAN'S MK-8 AND MK-9 XSV/XBT DATA SYSTEMS WILL INTERFACE WITH ANY SIPPICAN XBT OR XSV.

The MK-8 processor/recorder is a microprocessor based, stand alone system with three independent functional outputs; sensor data stored on magnetic tape cassette, an analog chart paper trace, and an RS-232 interface to external data systems. The MK-8, built to meet U.S. Navy requirements, performs automatic, prelaunched tests and self test functions to aid in rapid fault isolation.

The MK-9 system was designed to meet the exacting standards of scientific and commercial applications. The MK-9 interface outputs digital data thru an IEEE-488 (G.P.I.B.) bus which is compatible with most computers. Complete systems, including the HP-85 and software are available.

The XSV systems utilizes standard XBT Launchers. Choice of the LM2-A deck mounted launcher, LM3-A hand-held launcher or LM4-A thru hull launcher, depends upon ship type and specific application.

FIGURE 4. DIGITAL RECORDING SYSTEM FOR EXPENDABLE BATHYTHERMOGRAPH OF SOUND VELOCITY PROBES. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)



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AN/SSQ-36 Sonobuoys

FIGURE 5. AIR-LAUNCHED EXPENDABLE BATHYTHERMOGRAPH SONOBUOY.

FIGURE 6. U. S. NAVY P-3 TYPE PATROL AIRCRAFT. (PHOTO COURTESY OF R. F. LAWSON CDR, USN RET)

There is a new version of the AXBT (Figure 7) being manufactured by Sippican. Some simplification has been made in design and the falling probe resembles the probe in the shipboard XBT. In principle, this design will permit modifications to incorporate various probes with additional sensors. The current contract with Sippican is to deliver some 40,000 AXBTs to the Navy at a price of approximately $127 each. These probes have the 1,000 ft depth specification of previous AXBTs delivered by other companies. However, the Navy is also contracting with Sippican for approximately 5,000 AXBTs with probes capable of reaching a depth of 2,500 ft. These deep probes sell for an approximate cost of $145 each. The early purchase of deep probes is primarily for use by the Office of Naval Research (ONR), the Naval Ocean Research and Development Activity (NORDA), and the Naval Oceanographic Office (NAVOCEANO). This new AXBT uses an ac frequency signal so that it lends itself to both frequency modulation and digital recording.

The initial requirement of the Navy was to simply determine the depth of the mixed layer. This led to a simple recording system for both the XBT and the AXBT. Specification for the AXBT was that output should be within some frequency range and a linear relationship should exist; this led to an approximately $\pm 0.5^{\circ}C$ accuracy in the instrument. If probes are stored for long periods of time and used indiscriminately, then this is about the accuracy one might expect. However, by careful attention to manufacturing, and by suitable calibrations, it is possible to achieve an accuracy of about $\pm 0.1^{\circ}C$. This enables AXBTs to be used for scientific purposes, such as making heat content measurements in the ocean.

The AXBT recorder on Navy patrol aircraft is not of recent vintage, and new recorders are desirable for scientific data. The AXBT transmission is fm modulated. On the aircraft, the signal is demodulated and put on a strip chart recorder containing a small paper tape with a grid of poor resolution. This resolution is not improved by using the on-board magnetic tape recorder for post-flight analysis. A recorder was designed at the Scripps Institution of Oceanography and flown on many flights. It was duplicated at the Hawaii Institute of Geophysics and used on shuttle flights across the Equator. It records frequency out of the aircraft radio receiver. Thus, the actual frequency data transmitted from the AXBT is recorded for later analysis. From these fundamental units one may achieve resolutions of the order of $0.03^{\circ}C$.

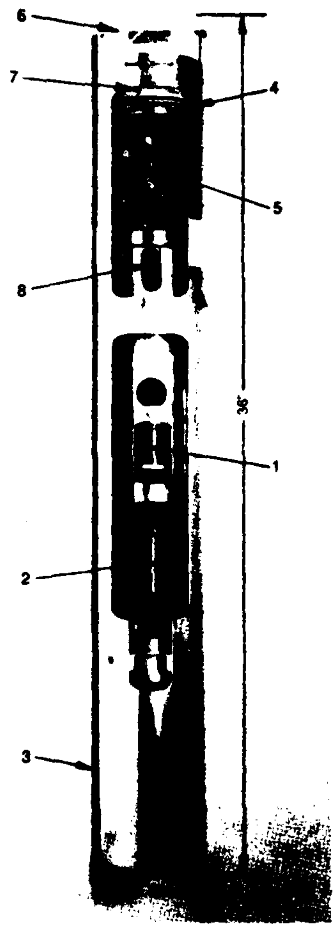
New recording systems are becoming available. Sippican has produced approximately 100 recorders to military specifications for submarines at a cost of about $40,000 each. This recorder provides digital data both in cassette tape and on strip chart. It is used both for the XBT and for the expendable sound velocimeter. Many organizations have produced variations of the old recorder for the XBT, and some are producing recorders which provide a digital record of data. Sippican's new MK-9 recorder interfaces with the Hewlett-Packard (HP)-85 desk top computer. With the addition of two cards in the recorder, it will accept all varieties of XBTs for depth from 600 ft to 6,000 ft. With other cards, it will accept the expendable sound velocimeter (XSV); the concept is adaptable to expendable conductivity, temperature, and depth sensors. An effort is underway to incorporate AXBT recording capability into the MK-9 System. The MK-9 System is IBM compatible and can be expanded to accomodate newly designed probes. Complete with H-85F and software it sells for about $9,500; less the HP-85F it is about $5,500.

Aircraft Launched XBT Development

Sippican AXBT Launched from U.S. Navy P-3C aircraft, St. Croix Test range

Sippican has completed the development of an Air-launched Expendable Bathythermograph (AXBT) which combines the depth capability and accuracy of the T-7 XBT probe and the fine grain structure of the T-11 probe. This program represents the culmination of over 4 years of effort at Sippican, beginning with a study sponsored by the Office of Naval Research in 1976. To date over 400 buoys have been tested with the results supporting the original design objectives. Although this system was designed to meet the requirements for the Navy's AN/SSQ-36 Bathythermograph Transmitter Set (BTS), it also provides improved performance to the scientific community. Table 1 compares the performance specifications of the standard Navy BTS, the Sippican AXBT and Sippican T-7 and T-11 XBTs.

TABLE I	*Sippican AXBT*	*Navy BTS*	*T-11*	*T-7XBT*
Probe Operating Depth	2500 Ft.	1000 Ft.	1500 Ft.	2500 Ft.
Probe Drop Rate	5 Ft/Sec.	5 Ft/Sec.	6 Ft/Sec.	21 Ft/Sec.
Thermal Time Constant	100 Ms.	1 Sec.	100 Ms.	100 Ms.
Spatial Resolution (Time constant × Drop rate)	0.5 Ft.	5 Ft.	0.6 Ft.	2.1 Ft.
Depth Accuracy	± 2%	± 5%	± 2%	± 2%
Temperature Accuracy	± .18°C	± .55 C	± .2°C	± .2°C



Sippican AXBT

1 Sea Keeping Spool
2 Probe
3 Housing
4 Wind Flap
5 Transmitter
6 Parachute
7 Antenna
8 Seawater Battery

FIGURE 7. THE SIPPICAN DESIGN OF AIR-LAUNCHED EXPENDABLE BATHYTHERMOGRAPH. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

Several other recorders are on the market. For example, the Grundy Corporation has a recorder which is microprocessor based with a digital display. In addition to the recorder, Grundy is developing an onboard calibrator so that both temperature and conductivity can be calibrated just before a probe is launched. This approach may offer increased accuracy. Grundy markets an expendable probe based on the Sippican wire system. Early tests by the Navy of a Grundy expendable temperature and conductivity probe indicated that the prototype electronics were pressure sensitive, but it may be possible to compensate for this characteristic. The costs of the Grundy expendable instrumentation components are not known at this time.

Some expendable instruments are relatively new in the community and some are expected to be available in the near future which measure parameters other than temperature. One currently available is the expendable sound velocimeter (XSV, Figure 8). The expendable sound velocimeter has been used in the Arctic. For example, the Canadian Geological Survey has used it several times since 1978. Another new instrument is an expendable current probe (XCP), which may be obtained on an experimental basis. This probe, developed by Dr. Tom Sanford and Mr. Bob Drever of the University of Washington, measures horizontal water velocity versus depth. Sometimes erroneously thought of as a shear probe (shear is the vertical derivitive of velocity), the XCP measures velocity, the integrel of shear, relative to an origin of offset that is independent of depth. It is a velocity profiler.

Of course, the expendable most highly desired is a salinity instrument. This usually translates into an expendable conductivity cell together with a temperature sensor. An effort has been made to calculate salinity backwards from the expendable sound velocity probe measurement by incorporating a thermistor in the probe. The problems with backward computation to salinity are discussed later.

NORDA has an instrumentation program with an objective of developing general classes of instrumentation. These include expendable shipboard instruments and moored instruments; an emphasis in the last few years has been on expendable instruments. One reason is cost effectiveness. Because they are easier and cheaper to use, on a unit basis, a data profile obtained in the ocean can be thought of as being obtained at less cost. In addition to expendable instruments discussed so far, the program also includes development of an expendable dissipation profiler (XDP, Figure 9). It is designed to measure microscale shears relating to turbulent energy dissipation in the ocean. The NORDA program also includes an interest in producing semi-expendable instruments. One is the automatic microstructure profiler which may be available at an acceptable cost for high risk Arctic deployments in the future. One program objective is to produce a more manufacturable type instrument in any expendable probe. There is a recent effort with Sippican to adapt the expendable sound velocity probe to the new AXBT delivery system; this is intended to produce profiles to 800 meters depth. Along with the emphasis on expendable instrumentation is a study on accurate prediction of vertical position of the sensor. Improvements in the equation for computing depth from time of fall are being developed and verified by acoustic trials in the Tongue of the Ocean. A table illustrating the suite of sensors being considered in the NORDA program is presented in Figure 10.

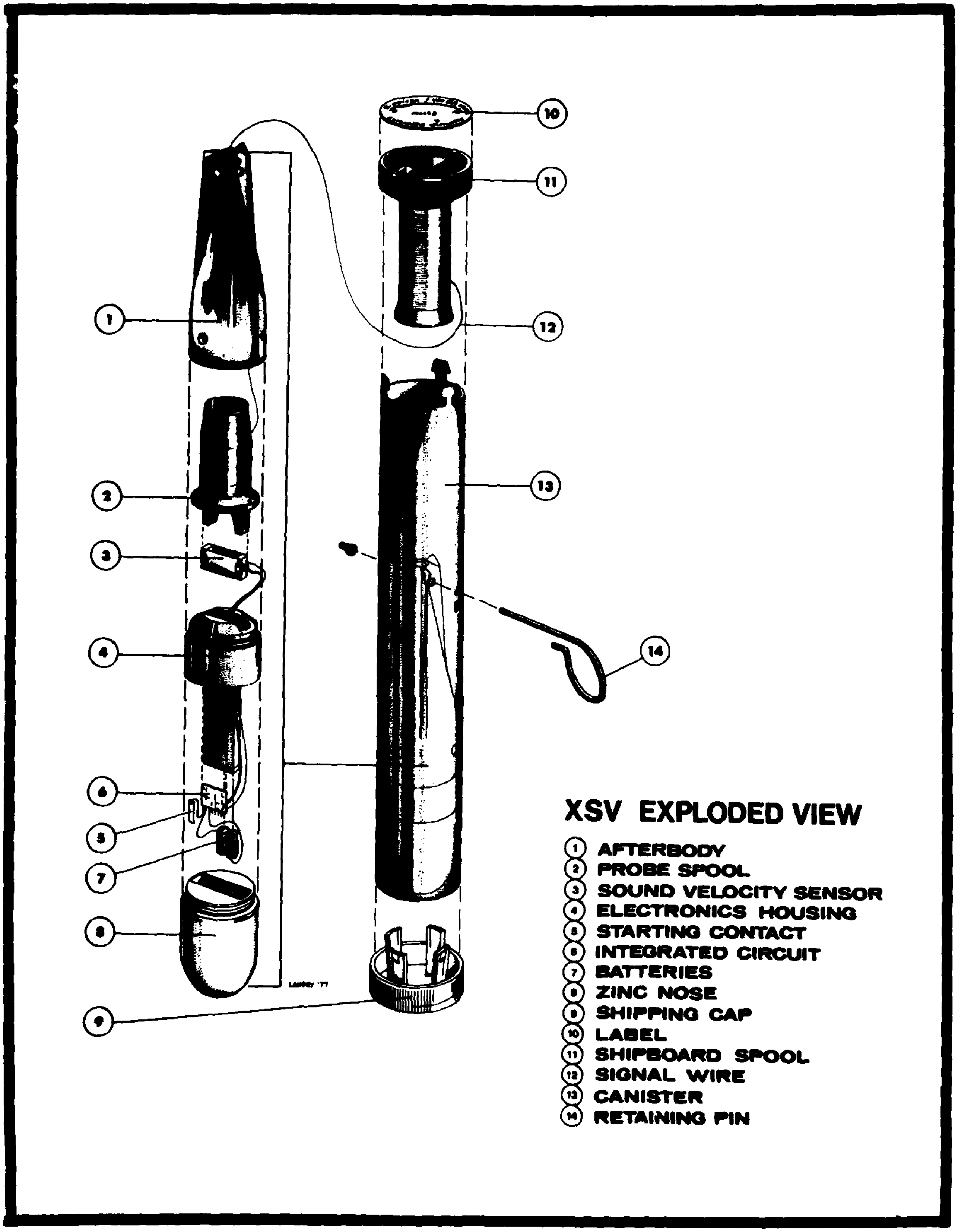


FIGURE 8. THE EXPENDABLE SOUND VELOCITY PROBE. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

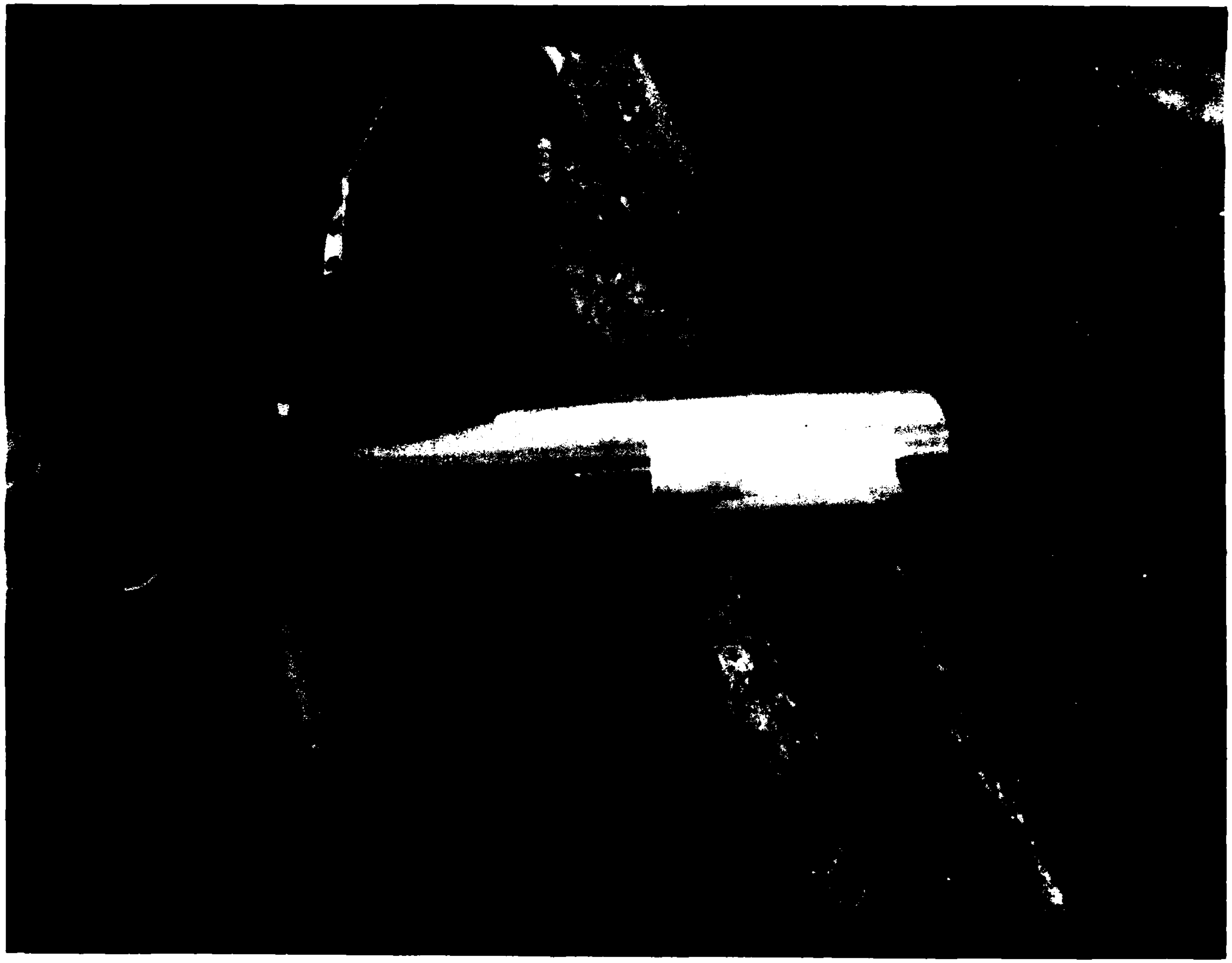


Figure 9. Expendable Dissipation Probe (the plastic cylinder protects the extended nose-mounted sensor until launch). (Photo courtesy of K. Ferer of NORDA)

OCEAN INSTRUMENTATION SYSTEMS
EXPENDABLE OCEANOGRAPHIC PROBES

	In Use		Under Development			Proposed		
	XCP[1]	AXBT[2]	AXSV	XCTD[2]	XDP	ASM	XSI	AXCP
Parameter Measured	Shear-Current-Temp.	Temp.	Sound Velocity	Temp.-Conductivity	Shear-Energy	Magnetic Field Variations	Specifications	Shear-Current-Temp.
Launch Speed (kts)	10	*	*	15	---	*	---	*
Depth Range (m)	800	800	850	760	450m	near surface	760m	760m
Fall Rate (m/sec*)	4.5	1.5	6.1	1.5	2.5	stationary	1.5	4.5
Package Size dia. (cm)	7	12	12	7	7	---	---	12
length (cm)	64	92	92	36	76	---	---	92
Package Weight (kg)	3	6.8	5.9	1.0	2.0	---	---	---
Approx. Unit Cost ($)	600	140	**	180	---	---	---	---
Accuracy/Resolution	1 cm/sec	.18°C	.25m/sec	0.05°C	$10^{-6}W/m^3$	1 gamma	ppt	1 cm/sec
Salinity (0/00) Calculated	---	---	0.3	0.05	---	---	---	---

1. Existing design being modified to incorporate R.F. link.
2. Joint ONR/NORDA development.

*Altitude dependent
**Quantity dependent

FIGURE 10. EXPENDABLE INSTRUMENTS BEING CONSIDERED IN A NORDA OCEAN INSTRUMENTATION PROGRAM. (TABLE COURTESY OF K. FERER OF NORDA)

ACCURACY LIMITATIONS ON EXPENDABLE XBT AND AXBT

There are, sometimes, unacceptable limits to the accuracy, resolution, and reliability of expendable instruments. In general, the expendable instrument is used where relative values, spatially or temporally, are of significance in understanding the ocean structure. The usual expendable instrument does not have an accurate pressure sensor because of the high cost of such a sensor. Depth is obtained by a time of flight technique which is usually inadequate for accurate determination of microstructure. A typical example of depth error has been provided by Mr. Jack Lovett (Figure 11). Generally, all probes produced of a given type (T-4's, T-7's, T-5's, etc.) have highly repeatable fall rates. Considerable effort has been expended to improve the absolute value of the drop rate.

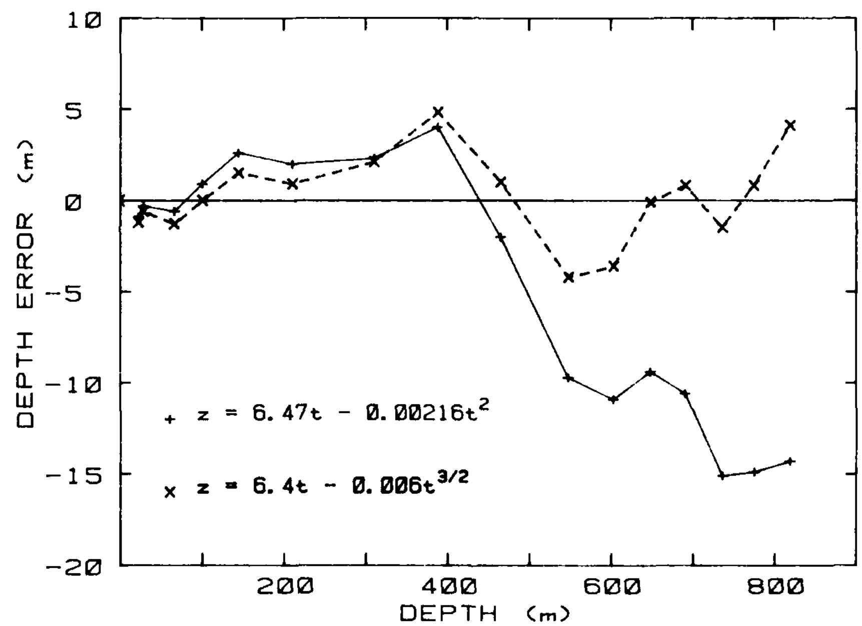


Figure 11. Typical depth error for an expendable bathythermograph probe. (Data courtesy of J. Lovett of NOSC)

A common feature in Arctic regions is the formation of tiny crystals of ice on or near the sensor in any expendable probe. A small amount of ice on the water may not be noticed; yet it may cause spikes in the data from small cuts (leaks) in the fine wire. This is a problem in launching from shipboard as well as from aircraft. In one lot of 150 XBTs dropped from an icebreaker, almost half produced erratic data, some of which was thought to be due to tiny crystals of frazzle ice. On that cruise, good data were usually obtained in open water but drops in a polynya with just a whisper of ice on it produced erratic data. None of the expendable temperature probes in current use were designed for Arctic regions. Except for the new Sippican AXBT, the probe which falls away from the AXBT has a heavier wire than the ususal ship-launched XBT. Since the probe falls away from the buoy, the interface problems due to ice crystals are reduced. The heavier wire offers some advantages in remote severe environments.

The standard AXBT sonobuoy has been used successfully for obtaining scientific data in several areas, including the tropical Pacific. Here, much effort went into selecting AXBTs. Records were kept on lot numbers and any changes in manufacturing technique. Working relations were developed with the manufacturers in order to anticipate changes which might affect data. As a result, data from the Sippican AXBT is probably more accurate than the Navy specifications require for operational use. In the early days, it was necessary to calibrate every instrument to achieve $\pm 0.1^{\circ}C$ accuracy. However, manufacturers have improved the product. Now it may be sufficient to simply follow lot numbers and manufacturing practices and calibrate samples from a given production group. Samples calibrated for temperature vs. output frequency may provide an accuracy of about $\pm 0.15^{\circ}C$ for the group.

Thousands of AXBTs have been used in research. Few are known to have been dropped for scientific data in winter further north than 50 deg latitude. However, Navy operational patrol aircraft deploy them at high latitudes. Since the AXBT is usually carried externally at high altitudes, it may be at a temperature of $-20^{\circ}C$ to $-30^{\circ}C$ when dropped. The probe may be cold enough to ice up before or when released from the buoy, but these effects have not been seen in the Pacific.

It should be noted that there is quite a bit of field experience in using AXBTs and laboratory experience in calibrating them, but laboratory calibrations are for static behavior. Dropping them alongside the CTD or STD is the best way to determine lag time in the sensor or other dynamic behavior of the instruments. Many AXBTs were used in the Pacific Ocean for which it was later determined that the thermistors had been more heavily coated than usual. About a dozen AXBTs containing small pressure sensors were dropped alongside good CTD stations and thermal lag in the thermistors was uncovered. The thicker coating on thermistors was traced to a change in manufacturing technique. The time response was large, although the data traces looked reasonable until the comparison was made. In the analysis of data it was necessary to go back and change the sign of the calculated heat content at mid-depth. Fortunately, this was found before publication.

It is possible that Arctic applications require a much faster response in a sensor. This may be necessary because of the extreme temperature change that often occurs at the water surface or in the first few meters. The instrument may be much colder than the water when it enters the water. Sometimes there is a small lens of fresh water on the sea water surface so the sensor can freeze up while passing through it. Conversely when instruments are dropped from warm huts the sensor is much warmer than the water it enters.

One difficulty encountered is the formation of ice crystals. If the instrument is allowed to become cold before being dropped into the water, it can form ice crystals over the sensor. These probes have been used in holes in the ice kept ice-free with the instrument itself slightly warmer than the water. Spikyness in the signal output will occur when there is any damage to the wire system, such as might occur when the wire is swept to one side at the bottom of the hole. A warm hut over an open hole, well lighted to the bottom of the ice, is an ideal location to drop an expendable instrument.

LESS-COMMON EXPENDABLE INSTRUMENTS

The expendable sound velocimeter (XSV, Figure 12) represents a class of expendable instruments which may have increasing use. This instrument contains the Sippican delivery and wire system. The sensor and electronics are obtained from a company in the Netherlands. This sensor is a sing-around type, and the probe contains hybrid chip electronics and battery power. The sensor is pulsed at about 6 MHz and it sings around at approximately 30 kHz. The signal frequency is counted down for wire bandpass considerations and recorded for measurement in the deck recording equipment. Probes are available for 750 and 2,000 meter depths. The instrument has been on the market for about three years and costs about $180. It has not been used in large quantities. The aircraft-launched version of this sound velocimeter will probably sell for about $500, based on limited quantities.

An expendable sound source instrument, the SUS MK-84, includes a two-frequency acoustic sound source at roughly 3.2 and 3.5 kHz. Each has five coded tones in short and long bursts. This instrument is used as a very limited signaling device between aircraft and submarines. When dropped in the water, the probe becomes active and free falls. The Navy purchases about 10,000 per year at a price of about $100.

Another expendable instrument being developed by Sippican measures gross conductivity. It is launched on a wire link from a helicopter equipped with an automatic launching system. It also contains a pressure transducer, because the depth measurement is used for bathymetry. The application is in mine warfare applications where it is desirable to know the conductivity at the water-bottom interface in shallow water. The conductivity sensor uses a resistivity-type measurement, which if combined with a thermistor, might produce an equivalent accuracy in salinity of about $\pm$0.35 parts per thousand. However, for use in research a conductivity device should achieve an equivalent salinity accuracy of approximately $\pm$0.05 parts per thousand.

Studies have been made on a penetrometer to indicate the possibility of an aerially-deployed mine getting buried in a muddy bottom. An accelerometer is used to measure bottom penetration. This concept has possible applications in polar regions where it is necessary to determine the ice thickness before landing an aircraft. One concept proposed by Sandia Corporation was a penetrometer with accelerometer and radio link. The changes of acceleration as the probe impacts the ice and as it exits the ice into the water below give two marks, which when calibrated, could be equated to ice thickness. Since the ice seldom has a simple structure, there were many questions about the calibration. An even simpler concept has been discussed in Canadian applications. No radio link is needed, but the pilot needs to have sufficient visibility to see the surface where the probe strikes the ice. The probe contains a quantity of highly visible dye. If the probe passes through the ice, the dye is lost in the water beneath, but if the probe fails to pass through the ice, the ruptured container of dye simply leaks and dye spreads upwards and outwards on the ice surface. Again, calibration would lead to an assumed ice thickness that would always stop the probe and a lesser thickness which would always pass the probe. Of course, if the dye is not visible, one might think the ice too thin when in fact the probe might have failed to operate or the visibility might be too poor. Such fail-safe features are desirable.

It is likely that the third most measured parameter in the world's oceans is the value of dissolved oxygen. The need for an expendable instrument to measure dissolved oxygen has been discussed for many years. None has been developed for quantity production, but there has been some laboratory testing. One approach has been to simply transfer the technology in the medical profession for a dissolved oxygen probe in the bloodstream. This is thought to be feasible, but there are many questions. One concerns shelf life. Two electrodes are used in which the process plates metal from one to the other. This is simpler than the usual membrane approach. It is expendable because it can only be used once without recalibrating and it has a very short life once it is activated. Studies indicate that, once activated, the expendable device would be reliable for between 90 and 120 sec. Since there is no membrane, the electrodes are poisoned very quickly. Response time can be very short. There has not been sufficient interest to bring this potential product into a marketable situation. However, some studies indicate that, in quantities, the probe might sell for about $125.

Probe and Wire Link

The afterbody and wire link used in the XSV are nearly identical to those used successfully in the more than 2,000,000 XBT's manufactured by Sippican. The only real difference in this portion of the probe is in the fact that XSV's require only one transmission wire in the wire link; whereas, XBT's require two wires, one for each leg of the modified wheatstone bridge used to determine thermistor resistance.

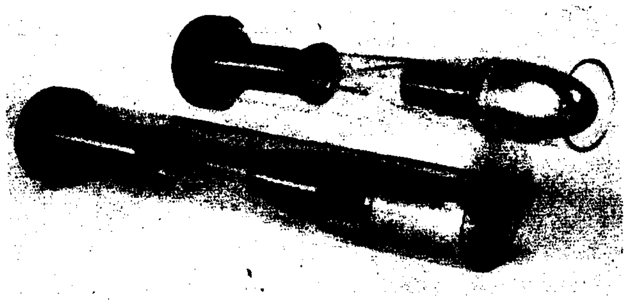
Forward of the afterbody, a 28mm extender has been inserted as a compartment for housing the sing-around sound velocimeter and associated electronics.

The zinc nose of the XSV is slightly heavier than the standard XBT in order to maintain the proper center of gravity. The nose has also been modified by flattening the front to provide descent stability and by replacing the round water-flow channel of the XBT with a rectangular channel to accommodate the geometry of the sing-around sensor.

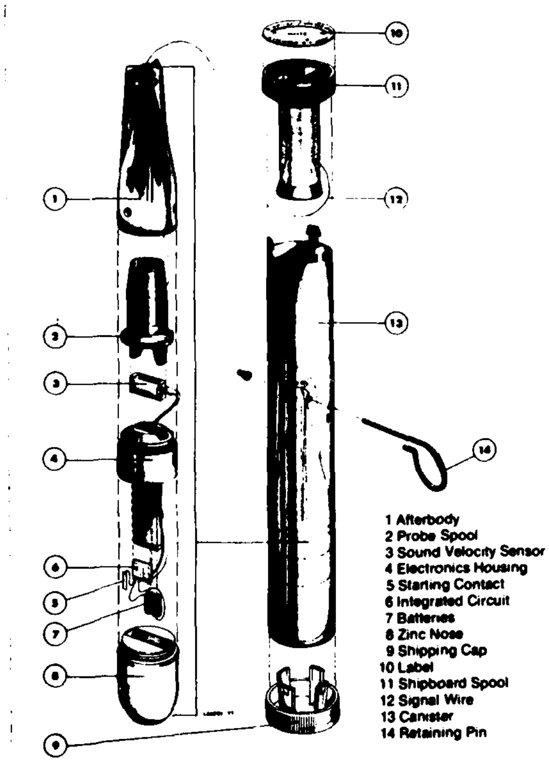
Since depth is determined by rate of fall, the total weight is held within a very tight tolerance. The XSV descent characteristic is described by the following expressions where d is depth in meters and t is time in seconds:

$d = 5.3672t - .001476t^2$ for 850m probe, or
$d = 5.5895t - .001476t^2$ for 2000m probe

Depth accuracy is ±2% or 5 meters, whichever is greater.



Clear models: XBT (top), XSV (bottom)



XSV Exploded View

XSV Specifications

Depth XSV-1	850 meters 15 knots
XSV-2	2000 meters 8 knots
System Sound Velocity Accuracy	± .25 meters/sec.
Depth Accuracy	±2% or 5 meters (whichever is greater)
Dimensions	7cm × 39.5cm
Weight	1.2 kg.
Packaging	12 per case
Shipping Weight Per Case	17.5 kg.

FIGURE 12. EXPENDABLE SOUND VELOCIMETER PROBE. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

EXPENDABLE BUOYS

There are expendable instruments which are expensive but are expendable because it is not practical to retrieve them. Some are designed to produce a long time series of data, essentially to the end of the life of the instrument, and the salvage value is low. This category includes drifting buoys and unmanned stations. In general, buoys or stations must be installed in their desired initial location. Due to the hazards and limitations of remote and severe environments, much thought has been put into aircraft or ship delivery systems which do not require personnel on the ice.

In ice-covered oceans a large variety of expendable instruments are positioned or implanted by landing an aircraft or establishing a camp on the ice. Some systems have been sophisticated and expensive, and data systems have been quite versatile. Such instruments have been used to measure atmospheric parameters as well as ice and oceanographic parameters. Chains of sensors have been lowered in the water beneath the ice, and data have been retrieved by telemetry. There is a large battery pack for a long time series of data. Data sets have mixed spatial and temporal measurements due to drifting of the instrument with ice or water movement.

Although aircraft and shore-based receivers have been used to collect data, and revisits to the ice have been made, the most effective means to collect the data is by satellite links. Satellites which carry the Argos random access memory (RAM) system have near-polar orbits. Although their data transmission capacity is limited, their frequent revisiting permits a data rate per day that is usually acceptable. The Polar Research Laboratory, Inc. (PRL), of Santa Barbara has built most of these expendable buoys. Some are relatively simple; for example, an air-dropped instrument can be deployed by parachute to measure atmospheric pressure and temperature for long periods of time on the ice. The pressure is used in the calculation of geostrophic wind, and the temperature is necessary for the pressure sensor calibration. The sensing of atmospheric or surface temperature itself involves many questions concerning locality, shielding, and calibration; no expendable instrument is known to do this reliably.

There are specialized expendable buoys built for specific applications. One such instrument must be dropped in open water or very thin ice, since the sensors must fall away in the water while the data system, including its telemetry, must remain above the surface. A cable connecting the above-surface data transmission system with the below-surface data sensors must survive crushing and shearing motions of the ice. The telemetering antenna must orient itself vertically and survive mistreatment (such as given by polar bears). An application using hydrophones has been attempted with some success. Considerable skill and judgment is needed in the deployment of this instrument in leads and polynyas. If deployed during Fall freeze-up, it will lock itself into the ice and probably survive. Deployed during the Spring break-up, it is less likely to survive. PRL has substantial experience in delivery systems and data systems for expendable instruments on and near the ice, and adaptation to unusual sensors or data requirements can be built on this experience.

A more sophisticated expendable weather station is under development. It extends legs and rights itself after impact. There is a Savonius-rotor wind anemometer. The rotor is caged when not in use, and various efforts are made to minimize icing problems, such as enclosing the sensor when not making a measurement. A Teflon coating is applied to the rotor to prevent ice crystals from adhering, and tests in the eastern Arctic have been encouraging.

Drifting buoys have been developed, both for ice-covered oceans and for ice-free oceans. They are usually installed in the ice or dropped into polynyas or leads. During the melt season they must float like a buoy, and during freeze-up they must remain upright. The data transmission system must remain above the ice. Buoys deployed in the ice are usually long vertical cylinders, like spar buoys, while those deployed in the open ocean have followed the Richardson design of a cone shape for static stability. The open ocean variety has been used in ice marginal regions, but is sometimes lost in the ice. Some have been known to free themselves and continue drifting in the open water. Similar buoys are moored to icebergs to determine iceberg drift.

Freely drifting buoys usually have a drogue intended to lock them to a certain depth level of water motion. Various sensors can be put on these buoys and battery packs can be loaded to last more than a year. Data transmission is usually through the satellite Argos system. Many buoys have been deployed, both in the Arctic and Antarctic waters. Networks of buoys have been deployed in efforts to distinguish spatial and temporal scales in the recorded data. Larger data systems on drifting buoys lend themselves to computer control of instrumentation. The data management aboard these expendable instruments include adaptive systems and controlled sampling.

Some of the more complex sensor systems employed on drifting buoys include thermistor strings. A thermistor string buoy was deployed at FRAM III in the Arctic Ocean in the spring of 1981; it had 200 meters of cable with a thermistor spacing of 20 meters. The temperature range was $-2^{o}C$ to $+3^{o}C$ and the resolution was $0.02^{o}C$. Data samples were recorded at 40 sec intervals over a two-hour "window" four times daily and telemetered through the satellite Argos system. During its active life the buoy drifted 1,000 nautical miles south along the coast of Greenland. A pressure sensor at the bottom of the string was used to determine the shape of the cable and thereby the approximate depth of each thermistor.

Conductivity sensors have been tried, but calibration drift and marine fouling are significant factors to consider. In one experiment, Aanderaa conductivity cells drifted the equivalent of one part per thousand in salinity in one year. These cells were retrieved and recalibrated, but the drift as a function of time was not predictable. Sea Bird conductivity and temperature cells have been used in two Argos buoys designed for making measurements in the upper Arctic Ocean. One buoy has been tested at FRAM III and at Pond Inlet, N.W.T. Comparisons with hydrocast data at Pond Inlet indicate the buoy can achieve accuracies of $\pm 0.02^{o}$/oo in salinity over a two-month period. Biological fouling has not been a problem in these tests. A recording package and a string of twelve temperature plus conductivity sensors suitable for deployment beneath a buoy can be obtained from Applied Micro-Systems, Inc., for about $14,000. There is some indication that the drift in these sensors may be as low as 0.03°/oo parts per thousand salinity per year. There is some opinion that most of the drift occurs in the first three months of deployment.

Fouling is usually controlled by application of a poisonous coating such as tributyl tin. Growth of fouling material is inhibited until the coating is leached off the surfaces. Fouling agents can affect the conductivity measurement, but since tributyl tin does not ionize in solution, it may not have this problem. An application of tributyltitinate as an anti-foulant was found to keep a glass conductivity cell clean with no effect on the measured conductivity.

There are many expendable instruments which must be omitted or only mentioned in passing because people are continually devising new ones. For example, the motion of an ice field has been tracked by radar. Simple passive targets were air-dropped on the surface and a ship's radar was used to monitor their positions. Other targets, both passive and active, have been dropped on icebergs to keep track of their position. In some cases, position is determined by aircraft overflights with aircraft location noted by navigation techniques or by shore-based radio. A Motorola navigation system has been available for monitoring positions of both passive and active targets.

An Expendable Current Profiler (XCP)

A system to measure horizontal current velocity from a moving ship, much as the XBT measures temperature on a rapid survey basis, is being put into manufacturing practice at Sippican. The system has been developed by Dr. Tom Sanford and Bob Drever of the University of Washington and Woods Hole Oceanographic Institution, with assistance from Sippican Ocean Systems.

The measurement technique relies on geomagnetic induction principles which were the basis of the earlier GEK (Geomagnetic Electro-Kinetograph). Tests to date have shown that the expendable has the potential to produce high resolution measurement of the variation in horizontal velocities from the sea surface to 800 meters of depth.

This variation in velocities — or shear — is an extremely valuable measurement in the study of energy transport in the ocean. From a near synoptic measurement of shear, increased knowledge of such parameters as the vertical range of ocean currents, internal waves, spatial and temporal variability and the structure of eddies and fronts will lead to a better understanding of energy propagation, transport and mixing processes.

Preceding Efforts

The parent instrument of the present device is the Electromagnetic Velocity Profiler (EMVP), also developed by Sanford and Drever.[1] The EMVP is a device 3.5m by .5m which is allowed to freely descend and return to the surface measuring electric currents, conductivity, temperature and depth. Its descent and rise are acoustically tracked, and it is recovered using aids such as radio, flashing light and acoustics. The development of this device and the expendable current profiler has been funded by the Office of Naval Research (ONR) and the Naval Ocean Research and Development Activity (NORDA).

The Measurement

The principle of operation of both devices (EMVP and XCP) relies on the generation of weak electric fields by the motion of seawater through the earth's magnetic field. As electrical conductors, sections or layers of seawater moving through the ocean interact with the earth's magnetic field thereby generating a current in the seawater. The magnitude of the electric current is related to the velocity of the conductor, its conductivity, and the strength of the magnetic field. We can picture an ocean section, from the surface to the bottom, as having variations in velocities in the horizontal and vertical planes. We can also picture the layers of water as having different induced electric fields, and thus, if we can measure the electric current in each velocity layer, we can distinguish differences, or shear, in the vertical profile. This electric current can be determined from the voltage measured between horizontally spaced electrodes falling through the water column. In the case of the expendable current profiler, where the electrodes are separated by 5 cm, a measured voltage of 50 nanovolts equates to 1 cm per second of relative water motion (shear). In order to establish the directional components, a compass coil is used in the spin stabilized probe.

The System

The probe (Figure 1) contains the electrodes, compass coils, electronics, batteries and XBT-type wire spooling components. It is launched from a ship using standard XBT launchers and, to date, the XCP data has been recorded on an acquisition system comprised of laboratory test equipment assembled for use at sea. More serviceable prototype deck equipment is presently being built. It consists of an interface unit designed to function with the Hewlett Packard 9845 desktop computer.

Data Samples

The data shown in Figure 2 were taken by the expendable current profiler in the vicinity of Caryn Seamount. Of particular interest are stations 109 and 113 which were separated in space by one mile and in time by one hour 20 minutes. Note the repeatability of the data as shown by the close comparison of both the East component and the North component of these two measurements.

To date, Sippican has produced several hundred probes for evaluation by the

[1]See Deep Research, 1978, Vol. 25, pp. 183 to 210

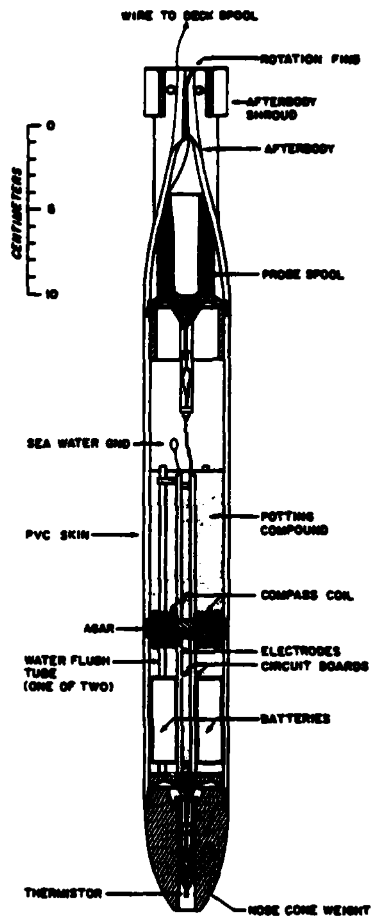


FIGURE 13. EXPENDABLE CURRENT PROFILING PROBE. (FIGURE COURTESY OF J. HANNON OF SIPPICAN)

EXPENDABLE CURRENT PROFILING PROBE

The expendable current probe (XCP, Figure 13) is deserving of more detailed description because of its potential for use in marginal ice zones where a strong velocity signature sometimes accompanies the strong temperature and salinity signatures; all three are necessary in determining the structure of mesoscale and smaller scale circulations. This probe measures relative current profiles. The mechanism employed is that of measuring electric fields generated by the motion of sea water in the earth's magnetic field. The probe is locked into this motion. A pair of embedded electrodes simulate the measurement of voltage at the skin of the probe. The probe rotates as it falls producing a modulation at a frequency of about seven Hz. This converts the basic dc measurement in the environment into a seven Hz signal in the electronics, easily modulated for transmission to the recorder. In addition, a compass measuring coil is wrapped around the electrode sensor. As the probe rotates, the coil produces a sinusoidal signal at about seven Hz, that is used as a reference frequency for phase sensitive demodulation. The demodulation result is a compass heading for the vector of the electric field with respect to the compass (North): the Cartesian components are east and north. The analog signals are converted to fm signals for transmission over the wire link to the vessel. The demodulation and velocity computations are performed on the ship.

Great care is necessary when utilizing the expendable velocity probe. Because it measures weak electric fields, the probe is sensitive to fields generated or distorted by the launching platform, and is not normally deployed within about two ship lengths of a ship. The present method uses an expendable float to which the probe is attached by a safety fuse. The lighted fuse burns about 60 to 70 sec before releasing the probe which is sufficient time for a ship to move beyond the influence range. The probe uses a Sippican wire system, and the ship pays out wire from the launcher as it moves away from the float; when released from the float, the wire is free to sink and the probe pays out wire as it falls. The probe is also affected by geomagnetic storms, so it is desirable to avoid major solar disturbances and to deploy the probe when the ionosphere or earth's magnetic field is not severely disturbed.

The expendable velocity probe can be made extremely sensitive. Intercomparison drops in the ocean indicate that it has a velocity resolution of about ± 1 centimeter per sec over a vertical spatial resolution of about 10 meters. Present limitations to resolution are in instrument noise and the stability of the probe. Because the electrodes themselves have instabilities of the order of millivolts they are buried in Agar, a highly refined substance made from seaweed; use of Agar reduces the noise level at the interface between the probe and the water to the order of 50 nanovolts. Without the Agar filled ports, the noise is about 20 microvolts. The resolution of 1 centimeter per sec is equivalent to a voltage measurement of about 50 nanovolts. The probe has been dropped in the Autec range and compared against acoustically tracked profilers. Tests in these areas, having both strong and weak shear, have given excellent results (Figure 14).

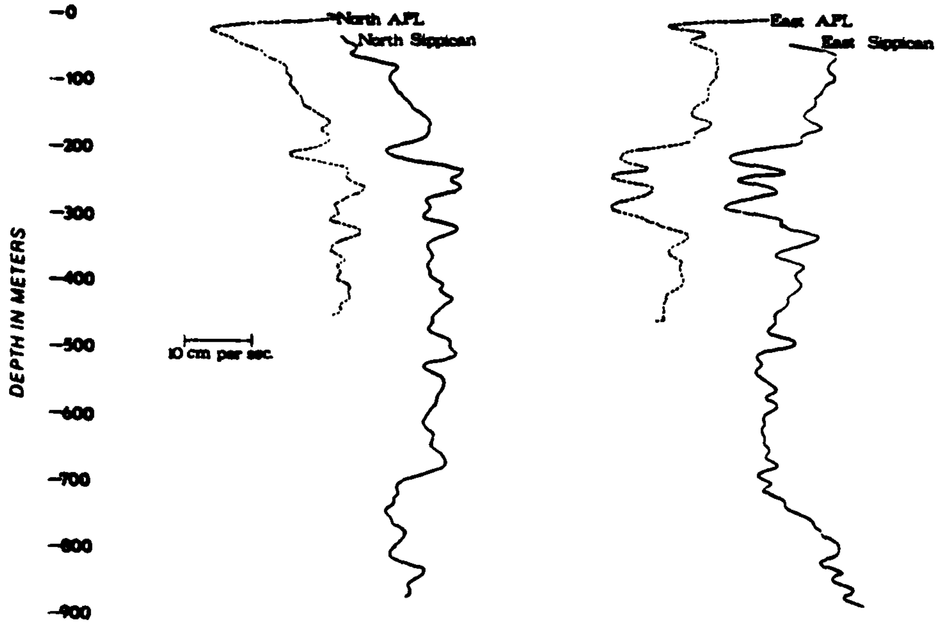


Figure 14. Comparison of North and East Velocity Components for the APL Sound Source and the Sippican XCP. (Data courtesy of J. Hannon of Sippican)

Since this instrument utilizes the earth's magnetic field, the latitude of deployment should be considered. The vertical field is used for the electric field being sensed and the horizontal field is used for the compass signal. Thus, there can be a limiting magnetic latitude for a given probe design. More turns can be wound on the coils producing higher sensitivity at higher latitudes. As with any Fluxgate compass, there are calibration changes from equatorial to Arctic latitudes. Because the compass sensor responds to a time derivative of the magnetic field, rotation is necessary to produce a phase relationship used in phase sensitive demodulation of the electric field signal as a function of east or north.

Because the earth's vertical magnetic field is used to sense ocean currents and its horizontal magnetic field lines are being cut to generate the sinusoidal signal, tilting or wobbling of the probe as it descends causes one component to leak into the other. These psuedo-vertical velocities are calculated and removed in determination of horizontal velocities. Such errors tend to be larger in the north component than the the east. Because of the apparent effect of psuedo-vertical velocities, effort is being devoted to the problem of attenuation of the signal in the wire as it is being payed out. A reduced attenuation will permit addition of other sensor signals, which can be used to determine probe orientation, in the $\pm 1/3$ Hz band width of frequency modulated transmission up the wire.

Sippican has delivered 1,000 expendable velocity probes at a cost of approximately $600 per probe. Possibilities for launch from aircraft are being considered. The radio telemetry for air delivery might be used for launch from ships to achieve adequate ship hull distance and to avoid wire breakage in a highly disturbed sea. Manned ice camps may be comparable to ships because electric generating stations and other sundry equipment will not only produce electric fields but also distort magnetic fields. For ice camps, a cable could be layed so that the launch position would be removed from these disturbances.

Because the probe utilizes the electric currents that exist in the water due to the motion of the water itself as a reference, the probe must be locked to the motion of the water in which it is immersed. Thus, this sensor cannot be tethered. It is possible that an embedded probe can be a means for measuring the velocity of the ice. In this case a bias must be considered, similar to the bias in shallow water, that comes from electric currents in the sea floor.

There is much reprocessing of data to produce a $\pm$1cm/sec resolution. For example, once the relative velocity is determined, the possible tilt of the probe as it falls can be calculated. This tilt can then be reentered into the components of data and new values of velocity can be determined. A stronger electric field signal is obtained at higher latitudes because of the increased vertical component of the magnetic field. This produces a more sensitive ocean current reading, but there is a corresponding loss in sensitivity for determining direction. Again, reprocessing is possible. The present design has a strong signal-to-noise ratio at midlatitudes and should be tested at high magnetic latitudes to determine changes in signal-to-noise for a more optimum high latitude design.

A scientific point can be made for measuring velocity profiles. Mesoscale structures usually have a velocity signature. For example, eddies were first detected in the ice-covered ocean by current meters rather than by CTD profiles. Variations in water currents may be more evident than variations in salinity or temperature. A current meter lowered from the ice will measure the motion of water relative to the current meter, or ice platform. Thus the absolute motion of the ice must be known. (This need is circumvented by the expendable velocity instrument.) A single velocity profile from this probe contains a lot of information. Some of the inferences about both the time-averaged currents and the high and low frequency currents can be drawn from this profile. A separation between internal waves and low frequency currents can be inferred. Geostrophic currents, which tend to have shears that extend over the whole thermocline, can be separated from the energetic higher modes of variability. This kind of information is important when one is trying to determine vertical heat and mass transfer.

AIR-DEPLOYABLE OCEAN MOORING

Possibly the most expensive and complex expendable instrument under development is the Air-Deployable Ocean Mooring (ADOM). There are two versions: one for the open ocean and one for the ice-covered ocean. Major components have been developed and tested at sea. ADOM will contain a complete data system, from a long string of sensors extending to great depths to sophisticated data compression and sampling techniques. Both real time and delayed data transmissions are planned through a satellite system to laboratories in the United States. It is designed to be carried by patrol aircraft (P-3 type) but can be launched from almost any aircraft having cargo doors or cargo bays. It has been launched from the Lockheed Hercules C-130.

The concept is to deploy an ADOM from a high flying aircraft at any predetermined location in the ice-covered ocean without visibility or any prior assessment of ice condition. Descent is by parachute, and penetration can begin without prepositioning. After penetration, a 1,000 meter string of oceanographic instruments is deployed. In this version ADOM is moored to the ice. In the open ocean version it is moored by anchor from the bottom and maintains a float at the surface. The anchor senses the bottom during its fall and pays out only enough mooring line for a taut-line mooring in any depth of ocean. This anchor and taut-line system has been demonstrated at sea.

One of the intriguing aspects of the ice-covered-ocean version is the ice penetration system (Figure 15). This drilling system has the ability to seek vertical from any landing attitude, even among the rubble of a large pressure ridge. The energy source is a battery pack, and the drill is a water scrubbing and recirculating system. Only sufficient ice is melted to fill the boundary layer of the 6-in diameter bullet-shaped drill. The hole it makes is permitted to fill with water, and the melted water is recirculated past the heating element for the continuation of drilling. It is a most energy-efficient system that could be reliably manufactured to operate totally unmanned and unpositioned by man. It drills at the rate of up to 1 ft per minute and has been used to penetrate 50 ft of ice. It is estimated that 95% of the ice cover on the Arctic Ocean is less than 50 ft in thickness. A microprocessor controls the drilling for optimum heat transfer. Water melted in the drilling process is maintained only a few degrees above freezing, and the computer control of the drill permits efficiencies averaging 73% on the basis of the latent heat of fusion, so it is really a scrubbing process with an optimum heat transfer. In one test, a 15 meter hole required 27 kWh of energy. The technology for high-energy-density battery packs is transferable from torpedo technology.

The data system for the ADOM has high level structured language and is capable of a large amount of onboard intelligence. Data compression of 200 sensors and data transmission through LES satellites is being studied. The ADOM is designed to last at least one year. As in other highly sophisticated expendable instruments, this one is not retrieved because the retrieval cost exceeds the salvage value in most applications.

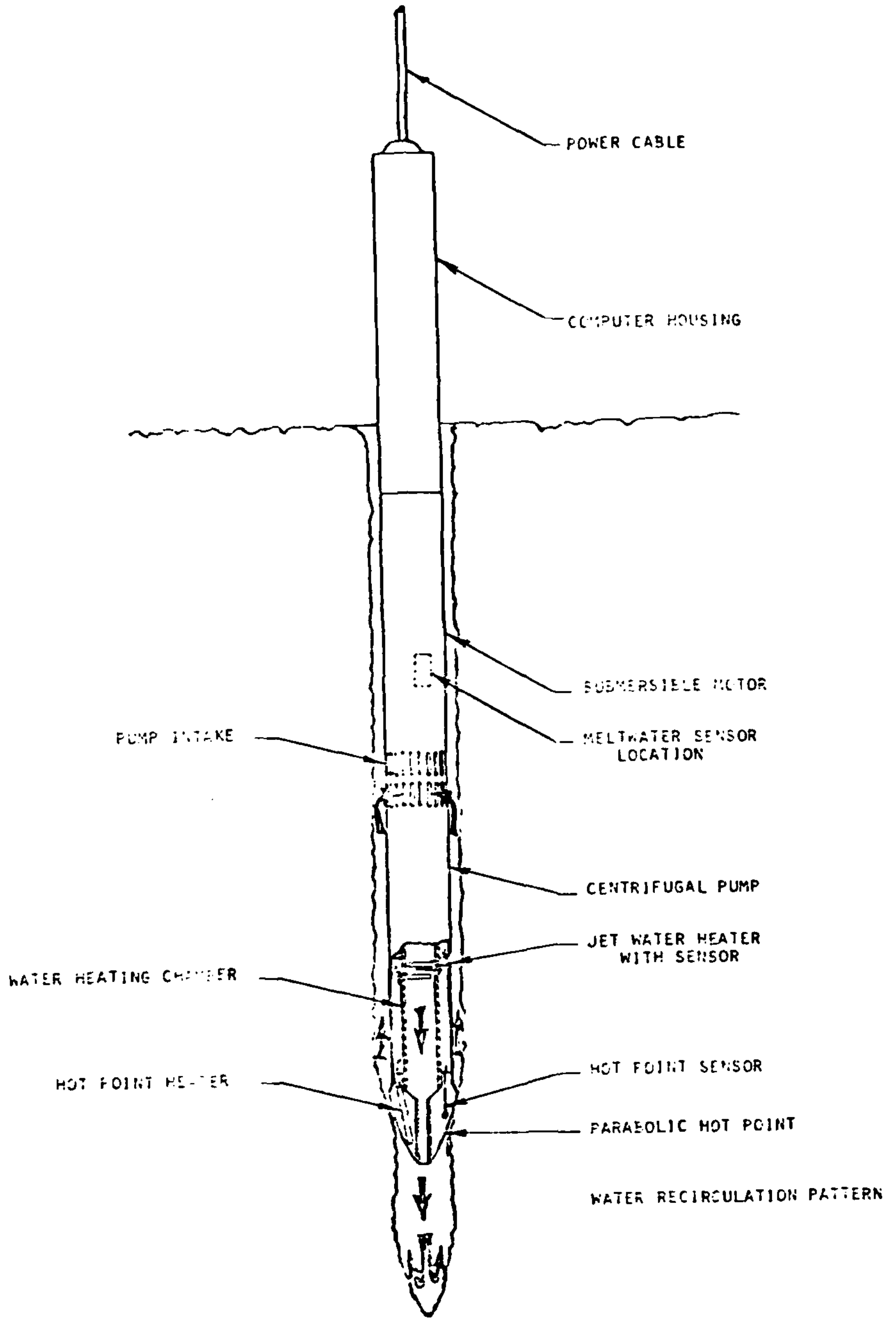


FIGURE 15. AN EXAMPLE OF AN ADVANCED DESIGN ICE DRILL (FIGURE COURTESY OF R. CORELL OF UNIVERSITY OF NEW HAMPSHIRE)

SCIENTIFIC AND TECHNICAL ISSUES

Because engineering and technological requirements are derived from scientific needs, there must be a scientific background for the application of expendable technology in Arctic regions. Essentially, expendable ocean technology is part of the broader ocean technology to obtain important data sets from which improved scientific knowledge and scientific descriptions of the ocean are distilled. Assembling engineers and scientists to address expendable technology provides the engineer with a broader appreciation of the scientific questions being addressed and simultaneously provides the scientist with a deeper appreciation of the potential technologies for new and unusual data sets. Furthermore, as expendable instruments have in the past been developed almost entirely for use in warmer oceans, their practical application to oceanographic data in polar regions must be considered both in light of field experience in these severe environments and of limitations and applications of existing technology in other ocean regions. A review of scientific issues is appropriate to the orientation of this technology towards future applications in polar regions.

Much thought has been put into the descriptive modeling of an ice-covered ocean. Likewise there are research programs to describe the circulation and structural features of completely ice-free oceans. However, our understanding of the broad transitional regime from the completely ice-covered ocean to the completely ice-free ocean, centered on the marginal ice zone, is still primitive. Although the significant forcing functions in the atmosphere and ocean in the marginal ice zone may be sufficiently understood, it is not intuitively obvious that the resulting mesoscale structure in the ocean will be explanable. Data obtained from ice breakers following sawtooth-pattern cruise tracks in the marginal ice zone as well as data obtained in camps on the ice near the marginal zone indicate the presence of strong fronts and eddies having spatial and temporal scales shorter than those normally found in ice-free oceans. Sharp vertical discontinuities and unusual processes, such as double diffusion, make the marginal ice zone a very complex region to describe. Sufficient data to describe its synoptic structure and formation and dissipation processes almost defy the efforts of well-planned field experiments. Expendable instruments can be a component of the broader strategy to obtain data sets from which advances in scientific understanding can be made. Expendable instruments are complementary to other data systems, which include not only conventional oceanographic stations but also applications of remote sensing technology. To illustrate the complexity, the ice marginal zone in the Greenland Sea may be sufficiently different from that of the Bering Sea to warrant distinguishing applications of expendable instrumentation.

Field experiments are planned for the next several years, beginning in the spring of 1983. Some of the questions being addressed are: What determines the location of the edge of the ice pack, and what processes modify that location? What are the relative importances of forcing functions which influence the marginal ice zone? There is a large seasonal migration; what are the spatial and temporal scales of this migration? There are many feedback processes in the coupled atmosphere, ice, and ocean environment of the marginal ice zone; one needs to know the interrelationship of parameters to be measured. A major scientific question addressed by those who are planning large field experiments is: What is the effect of the marginal ice zone on the global climate? The modeling of climate involves complex and interrelated factors in several feedback mechanisms. The ice marginal zone is thought to be significant in these processes but that fact is not established. Any modeling of the air-ice-sea interaction processes in the ice marginal zone must begin with parameterization. The range and importance of significant parameters must be estimated in order to plan the necessary technology for field experiments. Sensitivity and accuracy of instrumentation must be specified in terms of these scientific requirements.

In a simple model of an ice-covered ocean, the water column beneath the ice may be approximately isothermal but can have a strong salinity component which determines the density structure. However, in a completely ice-free ocean, the water column usually has a strong temperature structure which reflects the density profile and its salinity structure can be easily approximated. In the marginal ice zone, there are strong temperature and salinity signatures along with a correspondingly strong velocity structure. Thus, the ranges and sensitivities of individual expendable sensors must be reviewed in considering technology transfer from the warmer ice-free oceans to the marginal ice zone.

An estimate of the Rossby radius of deformation, which implies the horizontal scales that must be sampled in the ice marginal zone, is about 5 km. Thus, mesoscale processes can be anticipated down to this spatial scale. Eddies have been detected in the marginal ice zone having diameters of approximately 30 km (within the magnitude of 2 pitimes the Rossby radius). Smaller scale processes, both vertically and horizontally, including internal waves, inter-leaving water masses, upwelling, double diffusion, and convergences and divergences leading to strong shears. In such strong frontal features there can be strong internal waves with relatively high wave numbers, and shears which change across the front. A sampling scale must not miss the scales of these important features.

An important scientific objective may be to determine the relationships between the ice edge and the polar front. These interactions may be explored best with instruments which will determine density structure, rather than temperature structure alone. However, important fronts can be detected on a basis of temperature, and temperature is most important to the thermodynamic balance. One difficulty is that the polar front is thought to be mostly beneath the ice or on the ice side of the marginal zone. This may require the deployment of expendable instruments within pack ice regions through leads and polynyas on through holes made in the ice.

Since salinity must be determined, it is highly desirable to develop a practical cost-effective expendable conductivity and temperature instrument. It was suggested that a highly sensitive but simple and cheap conductivity and temperature probe could be used as an indicator of turbulence level in the ocean.

A reconnaissance survey of an area using a network of expendable conductivity probes might be useful in planning the deployment of more classical oceanographic instrumentation. Expendable instruments could be used to accomplish scouting or reconnaissance in order to determine the optimum location of a ship or an ice camp. The corollary of this potential application of expendable instruments is that they may be used to fill in, on smaller space and time scales, data between major hydrographic stations, where such stations cannot be closely spaced for cost and logistics reasons. For example, a major air-sea interaction program across the tropical Pacific between Hawaii and Tahiti utilized Navy patrol aircraft flights with AXBTs to produce synoptic cross sections. These sections were supplemented by hydrographic stations occupied by ships continually steaming along meridional sections.

Another advantage of expendable instruments is that of quick response. When studying sporadic events such as the onset of conditions to produce upwelling along the ice edge, it may be important to do a rapid aerial survey with expendable instrumentation for a synoptic impression of the developing structure. In a broader sense, the scouting application of expendable instruments can be addressed to oceanographic processes which are intermittent in time and space. There are some very expensive and definitely not-expendable oceanographic instruments for obtaining data on microstructure. Logistics to utilize these instruments are substantial, and since the process is known to be intermittent, it is wasteful to have a ship and crew standing by or scouting to find the best place for obtaining new fundamental data. The total package of resources could be employed more creatively if suitable expendable instruments could be utilized to determine areas of greatest activity reachable with more sophisticated, accurate equipment. Thus expendable instruments are complementary to more costly technology.

DETERMINATION OF DENSITY STRUCTURE

Since there is presently no accurate and reliable expendable density probe, methods for calculating density must be considered in selection from available instruments or in encouragement of new development. It is best to have an expendable instrument which measures both conductivity and temperature with appropriate sensitivities and time constants for performing a straightforward and accurate calculation of density. However, because such an instrument is not available in quantity, other approaches have been attempted.

For example, the expendable sound velocimeter was fitted with a thermistor to obtain temperature and sound velocity which was used to calculate density (Figure 16). Tests were conducted at sea comparing such expendable instruments with CTD stations. Although a sound velocity profile may be relatively smooth, any small noise or inaccuracy in the temperature signal is magnified in the calculation of density. Electrical leaks in the wire cause a positive temperature excursion. Noise in the temperature signal due to electronic noise in the recording unit can be recognized and removed before calculating density. Some processing methods permit the smoothing out of spikes due to wire leaks and, when combined with a direct measurement of conductivity, reasonably accurate values of salinity can be obtained. But backward calculation from sound velocity and temperature alone to salinity may produce errors in salinity, which are difficult to detect. Assuming sensors performing perfectly and no data transmission or recording problems, the backward calculation of salinity from sound velocity and temperature can result in an error band of $\pm 0.2\ ^{o}/oo$ in salinity (two standard deviations). When using sound velocity and temperature to calculate salinity, any temperature error converts to three times as large a salinity error as in the direct method of computing from conductivity and temperature.

There is a depth or pressure error in the conversion from temperature and sound velocity to salinity. This depth-induced error in salinity can be as much as 20 to 40 times as large as in the direct calculation. Results of sea tests indicate that, for presently available instruments, it is necessary to have some standard as reference in revealing the errors leading to large errors in salinity. Sea tests using a sound velocimeter and thermistor probe provided by Sippican contained errors in sound velocity. Small errors occurred at the surface with a gradient offset in the mixed layer with the resultant bias all the way down the profile. Some of this sound velocity error was offset by temperature error. Such errors were very difficult to perceive without a standard for comparison.

Results of an ONR sponsored intercomparison between Sippican XSVT probes and Grundy XSTD probes in 1978 off British Columbia showed that while both probes compared similarly in accuracy, ($0.18^{o}/oo$ vs. $0.13^{o}/oo$ respectively), small errors in SV conductivity or temperature could offset the entire profile.

The determination of depth is an important concern in the calculation of salinity from any instrument. Few expendable instruments use a pressure sensor and when they do the pressure sensor must be calibrated for temperature. All commercially available expendable instruments depend on knowing the time rate of fall of the probe to determine depth. A depth equation must account for the calibrated fall velocity of similar probes through different density strata of the water column. It must also account for the loss in mass due to paying out of the wire system. There can also be dynamic terms in the equation. The result of the depth equation is a determination of depth vs. time from the first indication that the probe is actually falling in the water. Probes have been dropped in different water masses in order to check and improve on empirical coefficients and power factors in the depth equation.

Controlled tests at sea indicate that the depth error is of the order of ±5 meters (See Figure 11). Larger errors might be encountered. For example, in the Sargasso Sea, where water is very warm, a probe will fall faster; while in the Arctic, where water is very cold, a probe would fall slower than the usual depth equation predicts. Other errors in expendable instruments which relate to depth or pressure, can involve electronics in the probe, such as capacitors or other parts which are pressure sensitive, but potting of these components reduces or eliminates pressure-related problems. These biases in the recorded values are difficult to determine and remove, and may also be a function of temperature.

Since the marginal ice zone is located over deeper waters in the eastern Arctic than in the Bering Sea, it is necessary to consider depth requirements for expendable instruments. A 1,000 meters depth capability may be a more realistic requirement for the eastern Arctic while presently available expendable instruments limited to 400 meters may be adequate for the western Arctic.

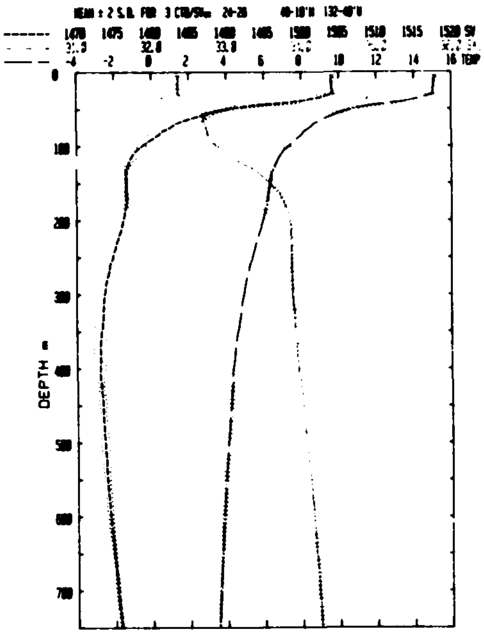
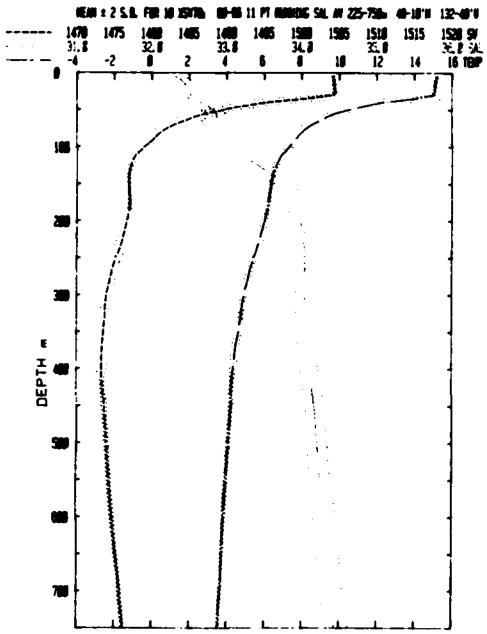


FIGURE 16A



NOSC FIGURE 16B

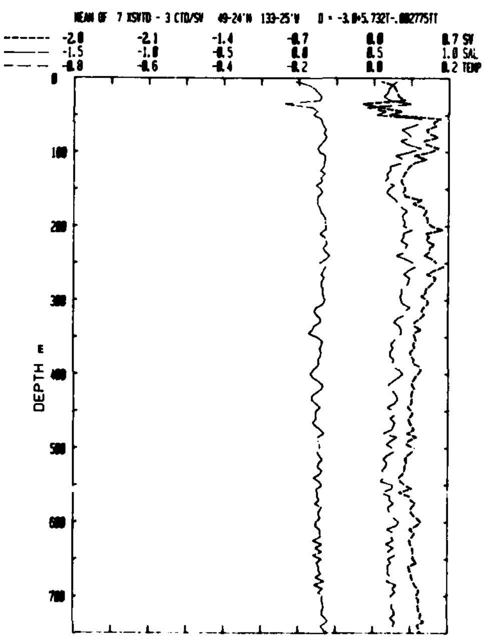
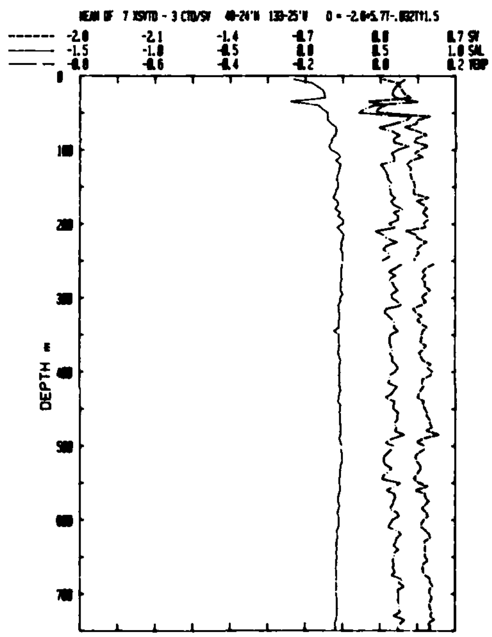


FIGURE 16C



NOSC FIGURE 16D

AT-SEA TESTS OF SPECIAL EXPENDABLE SOUND VELOCIMETER COMPARED WITH CTD CASTS (DATA COURTESY OF J. LOVETT OF NOSC; EXPLANATION GIVEN IN REPORT OF A NORDA WORKSHOP)

PLATFORMS

Platforms available for delivery of expendable instruments in the marginal ice zone include ships, aircraft (fixed-wing and helicopters), and ice camps. Of course, an aircraft platform is immediately attractive because of speed and versatility and because it places people in less hazardous situations than in operating on the ice surface. However, one of the limitations of an aircraft is that of navigation. The spatial and temporal scales of ocean features being studied may require extremely skillful navigation and timing for the deployment of sensors, a capability presently unavailable on most aircraft. There is hope that the NAVSTAR system will resolve these problems when it is operational sometime after 1986. Since deployment of instruments from aircraft usually depends on visibility, poor visibility often encountered in marginal ice zone regions places a severe limitation on placement accuracy. Further, low visibility is hazardous for aircraft operations.

Helicopters and fixed-wing aircraft are used differently. A helicopter usually becomes an extension of a manned ice camp, icebreaker, or other ship. Deployment of instruments can be made by dropping from the air or by landing on the surface and deploying through the ice. Hovering can be accomplished over visually determined locations. Usually, the location of the helicopter with respect to its base camp is known, and navigation becomes a problem of relative position with respect to a central location. Since fixed-wing aircraft do not hover, deployment techniques and determination of location of deployed instruments involve different problems.

The radio link between aircraft and deployed instrument may be limited to only a few channels. For example, there is a maximum of three radio channels available in the AXBT although Sippican has built a number of AXBTs with 5 channels for Johns Hopkins University Applied Physics Laboratory. When a number of instruments have been deployed, the aircraft must wait until a buoy of a given channel has stopped transmitting before deploying more AXBTs. This can lead to a problem in navigation. A line of three stations may be flown on a suitable course and heading at a suitable speed. In a severe environment with poor visibility, skill in dead reckoning is usually necessary to continue successive groups of three along a track and to reposition for a parallel or orthogonal track.

Spatial and temporal scales of processes being studied may require greater positional accuracy than is normally available by navigational and bush pilot techniques. For example, it is sometimes easier to visually deploy an instrument through a lead or polynya or in open water but very difficult to accurately determine its deployed position with respect to others already deployed.

Equipment and techniques have been developed which permit an aircraft to obtain data on the ice without establishing an ice camp. When a landing can be effected on the ice, the necessary oceanographic data can be obtained before the aircraft must leave the ice. Equipment is available to cut holes rapidly in the ice, permiting the lowering of instrumentation and discharge of expendable instruments into the water beneath. One technique involves successive helicopter landings along lines radially from a manned station. Holes are bored and oceanographic data are obtained at each landing site. Expendable instruments are used to avoid the time required to set up a windlass and to retrieve lowered instruments. Fixed-wing aircraft, such as the Twin Otter, are used in much the same manner but require a more substantial landing surface. Radio fixes on the aircraft provide one way of navigating and determining location of data stations with respect to the home base.

Successful deployments are more difficult in leads and polynyas than in open water. Unless visibility is good, it is difficult to detect a thin layer of tiny crystals of frazzle ice on the water. The frazzle ice can cause icing of the thermistor, resulting in the appearance of nearly isothermal water. This is sometimes difficult to identify where there is little thermal structure in the water. Launching adjacent to ice in leads can lead to wire damage. It may be necessary to develop a more rugged wire system for Arctic use. Air-launched expendable instruments which require a buoy at the surface with a radio data link can have a much more rugged wire system.

Some air-dropped expendable instruments require that the data system survive for an extended length of time. In a mix of water and ice where there is ice motion, it is necessary that the electrical connection to underwater sensors be rugged enough to survive at the interface. Several innovations to improve the survivability of the data system have been tried. Some units ride up on growing pressure ridges; others freeze into the ice and remain intact. An alternative is to land on thick ice and make a hole for instruments. Usually, some design which controls pedestaling and melting will lead to survival in thick ice. Buoys have been designed which float during melt and remain upright during refreezing. The ADOM system is designed to operate under almost any ice condition.

One of the conditions which must be considered in aircraft-deployed instruments is the temperature of the environment. The AXBTs may be carried in a cluster in the bomb bay where temperature is determined by the altitude of the aircraft. When launched, the instrument descends on a parachute, which further permits it to be near the temperature of the air. Thus, the instrument may arrive at the surface at a temperature of 20 to 30° C below zero. It may ice up immediately on contact with water near zero C. Residence time and the water surface may reduce this problem. In other circumstances, probes kept inside a warm aircraft may be warm and moist on exposure to the cold air. An accumulation of frozen moisture on the probe and its sensor can survive the descent and immersion in salt water near zero C.

Several aircraft have been used for Arctic instrument deployments. The AXBT has been launched from the Navy four-engine P-3 patrol aircraft (see Figure 6) and C-130 cargo aircraft (Figure 17). A three engine DC-3 special aircraft (Tri-Turbo Three, Figure 18) using a Navy launch and recording system has been demonstrated. AXBTs and XBTs have been launched from helicopters. The C-130 aircraft has been used for dropping many packages in the water or on the ice. It is the aircraft being used in development tests for the ADOM system.

Another platform often suggested and sometimes used is a submarine. Submerged submarines have launched expendable instruments during polar transits. These include the expendable sound velocity probe and XBT. An expendable launcher, connected to the submarine recording system by an umbilical, containing the probe is ejected from the submarine. On deployment, the launcher rises to a predetermined depth near the surface before the expendable probe drops away. The

Sippican wire system is used for transmitting data to the launcher. When the probe reaches its maximum depth the umbilical is cut and the expendable launcher is scuttled. This system is normally launched from an underway submarine at a speed of less than 10 knots. The buoyant launcher rises at about 10 fps and a kite-like feature causes the launcher to clear the submarine's propulsion system. The launcher can be set to discharge the probe at the surface in open water or at a predetermined depth under the ice. The profile obtained from the expendable sound velocity probe reaches about 2,500 ft depth. A 3 to 5 sec period is necessary for the launcher to settle at the surface or predetermined depth before releasing the probe. This system has been used successfully in several submarine cruises under the ice.

Figure 17. C-130 Unloading equipment at Ice Camp 375 miles North of Point Barrow. (Photo courtesy of Polar Research Laboratories, Inc.)

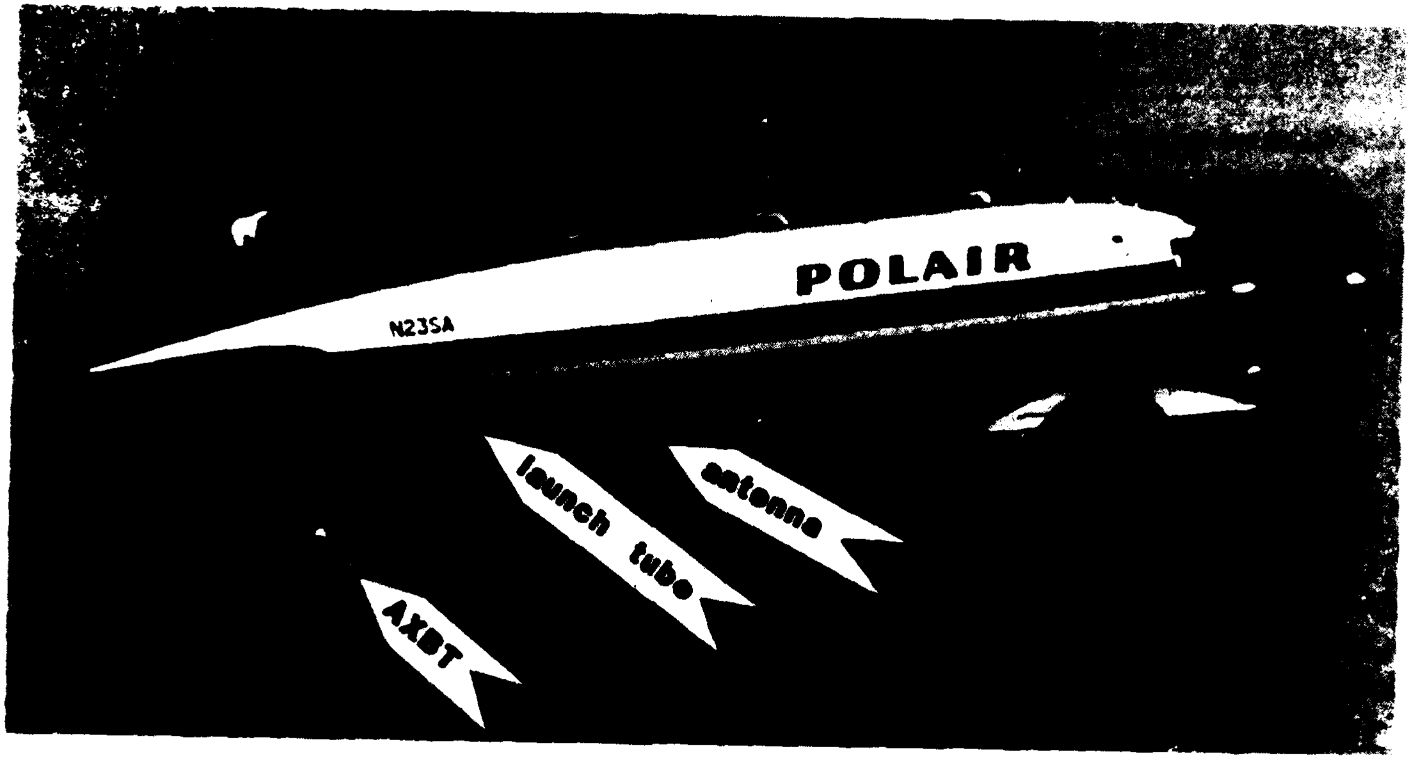


Figure 18. Tri-Turbo Three, modified DC-3 Aircraft (Photo courtesy of Polar Research Laboratories, Inc.)

INSTRUMENT REQUIREMENTS

The requirements and specifications for expendable instruments in the Arctic environment are varied and can be different from those addressed in the development of expendable instruments for warmer environments. Calibrations at low temperatures and large salinity variations are necessary considerations to achieve desired accuracies. Rapid response in sensor and electronic circuitry is desirable where there are large or rapid changes in water density; changes which can frequently happen in the marginal ice zone. There are deployment constraints such as small diameter when working through a temporary hole in the ice. Perhaps one of the most important requirements is cost effectiveness. This usually translates into the lowest possible cost achieved in mass production of instruments.

The XBT is, of course, a prime example of cost effectiveness. Although mass production for Navy requirements can lead to high reliability, there are potential problems in the care and use of these instruments. For example, rough handling can lead to despooling of the wire in the Sippican wire system. This condition may not be detected until the instrument is used and a tangle occurs. Poor storage practices can lead to corrosion. Although probes are usually packed in individual plastic bags in the packing cases, those in storage for a long time may be out of date, and some have been observed to contain water in the plastic bag. Although the Arctic atmosphere has very low humidity, moisture as ice seeps into anything that is stored outdoors for long periods of time. The combination of outside storage and over-age expendable instruments is not recommended.

Future larger instruments may possess batteries. Those which have a long lasting data system, such as drifting buoys or ADOM, must consider the reliability of batteries. The lithium thionyl chloride battery appears to be one that can give high reliability in Arctic regions. There is Navy research and development on the non-rechargeable version of this type of battery. Development of large batteries for possible use in torpedoes includes considerations of storage and use in various environments; considerations which are also addressed in the ADOM program. Batteries immersed in the ocean beneath the ice are in an almost uniformly low temperature environment - a condition conducive of great stability. However, battery packages on the ice can experience the low temperatures of winter and the near freezing temperatures of summer or solar heating can make them warmer.

Experience in the use of AXBTs in temperate climates has led to confidence in achieving improved accuracy over that required by Navy specifications. The output signal is specified to be within some frequency range, but if the calibration curve is used indiscriminately, then the AXBT becomes a $\pm 0.05^{\circ}C$ instrument. Recently-produced manufacturing lots of AXBTs exceed these operational requirements. If one calibrates sample instruments from given manufacturing production lots, an accuracy of about $\pm 0.15^{\circ}C$ can be achieved. The curve of temperature versus frequency is nonlinear so that special calibrations for temperature ranges of use in the Arctic are desirable. For best accuracy it is necessary to coordinate with the manufacturer and to know that a given production lot contains one production run of thermistors without changes in coatings or other things related to thermal lag. Reliability of the AXBT has been impressive.

Some are launched from altitudes above 15,000 ft, and both storage in the launch tube plus slow descent on a parachute may produce a very cold instrument before it hits the water. The instrument's plunge into the water and stabilizing time before release of the probe helps in adjusting to the environment to avoid freeze-up.

Of course, specifications, such as for accuracy of an instrument, should depend on the scientific phenomenon being investigated. There can be large or small signals to the ocean structure. For example, in the passage between Greenland and Spitzbergen, there is polar water on one side and Atlantic water on the other. Differences in temperature are but a few hundreds of a deg C, but that is enough to change the whole regime. There can be melting conditions on the Spitzbergen side and freezing conditions on the Greenland side in this small temperature range. Thus, one of the basic questions being addressed in a crossing is, "Is the water above the freezing point?", which can lead to a severe requirement for accuracy.

Precision, accuracy, and standard deviation should be distinguished in requirements. Also, in reconnaissance applications of expendable instruments, an emphasis is placed on resolution. To avoid misunderstandings about the precision of an instrument, it is better to state precision and standard deviation separately so that the user may understand the probability of achieving a desired accuracy when running an oceanographic line of many similar instruments. In comparing data from a grou of similar expendable instruments, it is necessary to know their accuracy because, although there may be high precision in the instruments, the use may not have the desired accuracy. Definitions are: precision is the ability to get the same measurement with the same instrument, accuracy is the absolute relationship of the instrument against some external standard, and resolution is the smallest difference one can record in the data.

A concensus on the requirements for an expendable conductivity temperature depth instrument was reached, as follows: for temperature, the resolution should be $0.01^{\circ}C$, and the precision should be $\pm 0.02^{\circ}C$, while the accuracy should be $\pm 0.05^{\circ}C$; the corresponding resolution in salinity should be $0.02^{\circ}/oo$. If there were a pressure sensor on the instrument, it should produce a resolution of 2 meters in vertical position. To be consistent with salinity requirements, the pressure sensor should have a precision of ± 5 meters and an accuracy of ± 1 meters. The depth capability should be at least 500 meters, and it is desirable to have some go to 800 meters.

The temperature range for an instrument in the marginal ice zone is from $-2^{\circ}C$ to $+3\frac{1}{2}^{\circ}C$. However, there are some places on the Spitzbergen side that reach nearly $5^{\circ}C$. This puts temperature above the 8-bit range for digital recording. The range for salinity is even more difficult. A maximum of about $35^{\circ}/oo$ has been recorded. On the other hand, pure water has been recorded in some places, so that the minimum is zero. There are many compromises. At low salinities it is possible to degrade accuracy.

It is possible to develop depth equations specifically for Arctic use. For example, the XBT which is considered to have a depth error of $\pm 2\%$ of the range should be better in cold, nearly isothermal, water.

The price of an expendable temperature conductivity depth instrument should be some fraction of the cost of obtaining similar data by non-expendable instruments. A crude estimate of the cost of a CTD cast is about $500, so that it would be desirable to have an expandable instrument which produces comparable data and is available for a price less than $100. This would permit some tradeoff in costs of logistics and probabilities for imperfect data.

The expendable current instrument has a resolution of 1.0 mm/sec with a full scale range of 5 knots. Actually, the resolution depends on range and may not be quite this small. It also depends on configuration. The accuracy is closer to ±1.0 cm/sec in velocity and about ±10 meters in vertical depth. The compass is considered to be close to an accuracy of $\pm 2^{\circ}$, but this varies with magnetic latitude. Tilt of the probe feeds into the current value, and processing can remove most of the interactions.

Since expendable instruments may be used in a survey or reconnaissance role, the comparison of data from many similar instruments is important, and accuracy must be specified for the correlation of data from all similar instruments. Calibration may produce the desired accuracy in a given manufacturing lot of similar instruments, and with care and with special calibration for the environment, will provide the confidence needed in planning field experiments using such instruments.

WORKSHOP FINDINGS

One of the major findings of the workshop was that the salinity structure is often a dominant feature to be determined. This immediately leads to the need for an expendable instrument which can be used to calculate salinity, and the workshop found that no such expendable instrument exists now which meets all of the requirements. Of course, there are long-life drifting buoys which have instruments to determine salinity. These include the Seabird instruments which use the Beckman-type 2-electrode cells made by Pedersen. What would be desired in some applications such as survey and reconnaissance is a much simpler expendable instrument.

The strategy for use of exendable instruments in the marginal ice zone may be quite different from their use in more moderate oceans. Due to the hazards involved in other means of obtaining data, an expendable instrument becomes a means for obtaining data not otherwise considered or for extending the effort beyond what would normally be made. Again, because of the severe environment, the placing of non-expendable instruments for necessary data sets must be very prudently done. Survey and reconnaissance of general areas can be made with expendable instruments in order to more precisely position a ship or camp or a platform which is going to use or install non-expendable instruments such as deep hydrograph stations.

Perhaps one of the discoveries in the workshop was the versatility and potential application of the expendable current instrument in the marginal ice zone. With complex data processing and proper scientific interpretation this vertical profile of current can be used to infer a substantial amount of information about the processes going on in the ocean.

An emphasis on aircraft as delivery platforms for expendable instruments is perhaps much greater in remote and severe environments than in ocean areas where expendables were originally applied, such as moderate or tropical climates. In like manner, a greater interest in satellite data links may be apparent in Arctic applications. Polar orbiting satellites visit Arctic regions more frequently, that is, a given satellite is seen from a given point on the surface more times in any 24-hour period in the Arctic than it is at the Equater. The availability and high utilization of the Argos system from some satellites has also served to encourage this applicatiion for data transmission.

A broad recommendation from the meeting was that expendable instruments be considered in a survey and reconnaissance mode in the decisions concerning locations of field experiments. This is both in surveying desirable areas and in final positioning of other instruments in most effective locations. The application of expendable instruments to the extension of data efforts in remote and hazardous regions can take on other forms which not only play a survey role but also provide better temporal and spatial resolution to the basic data stations by filling in between non-expendable instrument stations with a series of expendable instruments.

While expendable instruments are usually expended in a very short period of time, measured in minutes, some are expensive long-term instruments that are never recovered. If one considers these as expendable, it is necessary to address ion of fouling on any conductivity cell immersed for long periods of development of an Arctic expendable conductivity temperature depth for short-period application has the greatest need.

endable instruments can produce more accurate data when calibrated, and irable to calibrate instruments for the conditions normally found in :ers. These conditions of low temperature and small temperature range, s large changes in salinity, are different from the conditions normally moderate or tropical waters. Therefore, special calibrations are :d.

:ause of the remote and severe environment in Arctic regions and because :omplexity of ocean structures, it is desirable to consider more .ted expendable instruments, including smart instruments containing data ; and recording. Programming for specific applications may be desirable. through satellite systems offer possibilities for the recovery of more data sets in Arctic regions. There is a corresponding need for new data which produce partially analyzed digital records.

possibility for a cost effective expendable conductivity temperature e which is normally expended in a few minutes should be again addressed year.

Appendix A

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