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A Field Performance Test of the Sippican Deep Aircraft-Deployed Expendable Bathythermograph

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A field test of the performance of the initial design, deep (760 m/2500 ft.) Sippican aircraft-deployed expendable bathythermograph (AXBT) has been conducted. Thirty-seven AXBT's were deployed beside a research vessel, which was conducting conductivity, temperature, and depth (CTD) casts to 1000 m. A total of five CTD casts were made. A comparison between the AXBT and CTD data showed that the AXBT's provided temperature profiles with accuracies that depended upon the particular formulae chosen for frequency-to-temperature conversion and fall rate. The three sets of formulae used here were the standard Navy formulae, the formulae published by the Sippican Corporation, and a combination of a frequency-to-temperature formula published by the Naval Oceanographic Office (NAVOCEANO) and a fall rate determined from data collected during this study. Two of the three methods produced data that appeared to be within the Navy's AXBT accuracy specifications, taking the CTD data as standard. A temperature offset of about 0.4°C was found in the data set using the Sippican formulae, and this puts the temperature accuracy just outside the Navy's specified limits for higher temperatures. The best comparison between AXBT and CTD data was found with the NAVOCEANO formula and our fall rate, which provide a temperature accuracy better than 0.25°C. Our fall rate was quite close to the standard Navy fall rate (less than 2 m difference at 760 m depth), so the use of the latter is suggested. The recommended formulae for the initial design Sippican 760 m AXBT's are as follows: $T = -66.8857 + (7.0273 \times 10^{-2})F - (2.1807 \times 10^{-5})F^2 + (3.6311 \times 10^{-9})F^3$, $D = 1.52t$, where T = temperature in degrees Celsius, F = frequency in hertz, D = depth in meters, and t = elapsed time in seconds. The statistics of the AXBT data set suggest that the precision of the Sippican thermistor is better than 0.06°C.

1. Introduction

The aircraft-deployed expendable bathythermograph (AXBT) is used primarily by the U.S. Navy to conduct surveys of the thermal structure of the upper ocean. AXBT's have also been used within the past few years to rapidly collect temperature data for oceanographic research. The speed of an aircraft survey can provide an essentially synoptic view of the temperature field within a large oceanic volume, a result usually unobtainable with conventional ship surveys. Until recently, the U.S. Navy model AN/SSQ-36 AXBT's in use had a specified operational depth of 305 m (1000 ft). As a result of a program which began in 1976, the Sippican Corporation of Marion, Massachusetts, has developed an AXBT with a depth capability of 760 m (2500 ft). Sippican claims that in addition to its extended depth range, their "deep" AXBT promises to provide better depth accuracy and improved temperature response and accuracy than the earlier style AXBT, thereby producing high quality scientific data.

We recently had the opportunity to use a number of the initial design, deep Sippican AXBT's, and to collect data sufficient to evaluate certain aspects of the performance of the units. The purpose of this paper is to document and describe the results from that field test. Our evaluation centers on a comparison between concurrently measured AXBT and CTD temperature profiles. Taking the CTD as an acceptable standard, the capability of the AXBT's to accurately measure temperature to a depth of 760 m was examined. Since a deployed AXBT transmits temperature as an audio-frequency–modulated RF signal, the reconstruction of a temperature profile requires the use of formulae for frequency-to-temperature conversion and fall rate. In this study we considered three sets of formulae. They are the standard Navy formulae, the formulae published by the Sippican Corporation, and a combination of a frequency-to-temperature formula published by the Naval Oceanographic Office (NAVOCEANO) and a fall rate formula determined from data collected during our study.

In section 2 of this paper we describe the Sippican deep AXBT and give the Navy formulae which the AXBT's performance is designed to meet. Section 3 presents results from previous testing and calibration studies of the Sippican AXBT. Our performance and intercomparison testing is described in section 4. Our results are described in section 5 and discussed in section 6.

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2. Description of the Deep AXBT

Two models of the AXBT have been produced by Sippican. The initial design was used in the manufacture of 2,500 units, which were produced as lot numbers 1–5 under Office of Naval Research contract number N00163-80-C-0134. These units are sometimes referred to as "preproduction" AXBT's, and all incorporate 760 m probes.

A modified design was adopted for the production of 42,000 units, which began in 1981 under Navy contract number N00163-81-C-0287. The 6,000 AXBT's in lot numbers 1–10 of this contract incorporated deep probes, while the remaining 36,000 AXBT's used 305 m probes. This paper presents data on the performance of the initial design AXBT's. Results from a similar test of the later design units will be the subject of a future report. Differences between the two designs are suf-

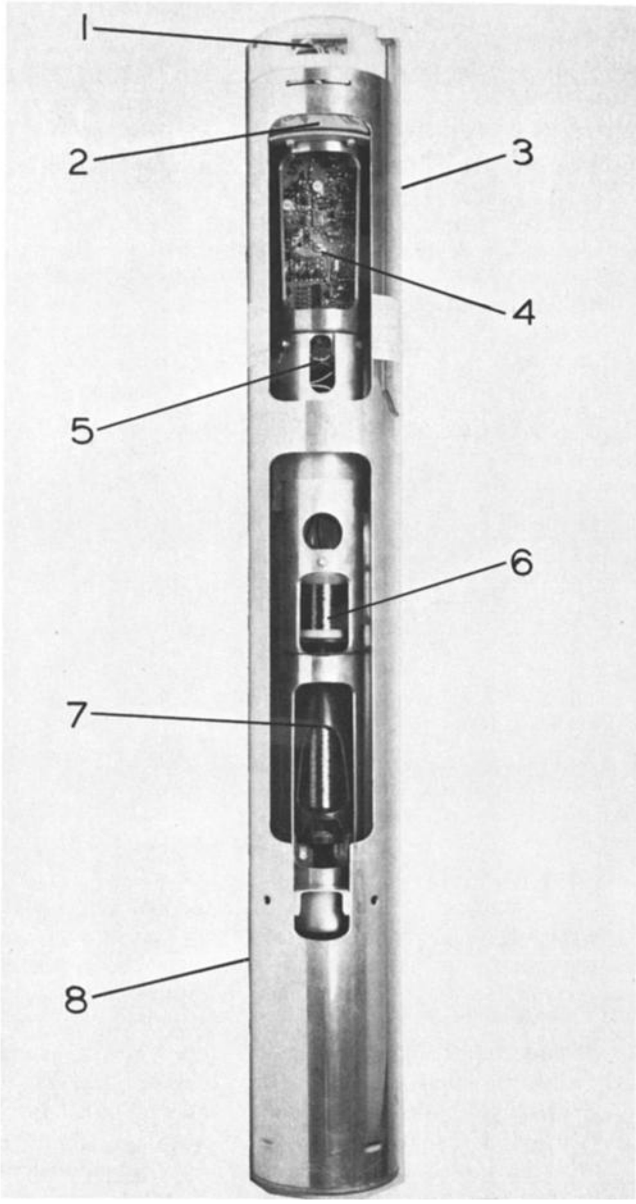

Fig. 1. The Sippican initial design deep AXBT package. This cutaway shows the following components: 1, parachute; 2, antenna; 3, wind flap; 4, transmitter; 5, seawater battery; 6, spool; 7, probe; 8, outer cylindrical housing. (Photo courtesy of the Sippican Corporation.)

ficient to make the results which we present here applicable only to the initial design AXBT's.

The initial design deep Sippican AXBT is packaged in a cylindrical housing approximately 12 cm in diameter and 91 cm in length, the same dimensions as the earlier Navy AN/SSQ-36 AXBT. Figure 1 shows the design of these units. Contained within the deep AXBT package is a small parachute with a wind flap deployment device, a floatation bag with a wire monopole antenna, a 1-W VHF transmitter, signal-conditioning electronics, a seawater battery, the XBT probe containing the thermistor and a spool with about half of the XBT wire, and another spool with the remainder of the XBT wire.

An AXBT package is generally deployed top-end first from a chute in the lower rear of the aircraft's fuselage. As the AXBT leaves the aircraft, the spring-loaded wind flap separates from the package body and pulls out the cross-type parachute. The parachute stabilizes the package in an upright position and controls the speed of the package during descent to the ocean's surface. After water impact the seawater battery activates and turns on timing circuitry, which triggers a mechanism to inflate the floatation bag. As this bag inflates it forces a plate out of the outer cylindrical housing allowing the parachute and the outer housing to be discarded. A smaller cylinder containing the battery, electronics, floatation bag, and XBT probe with wire and spools remains at the ocean's surface. The VHF transmitter is turned on and sends an unmodulated RF signal to the aircraft on one of three possible VHF carrier frequencies (170.5, 172.0, and 173.5 MHz). Approximately 40 s after battery activation, the XBT probe is released from the small cylinder and begins temperature profiling. Temperature is converted to an audio-range frequency in the probe; that frequency is transmitted up the hard wire link to the surface electronics; then the RF carrier is modulated with the audio frequency. Probe descent time is later converted to depth and audio frequency to temperature to produce a temperature-depth profile by using appropriate formulae. About 1 min after completion of the descent of the probe, a current is sent through a resistive heater wire attached to the inside of the floatation bag causing it to puncture, thereby allowing the package to sink.

The Sippican AXBT is designed to meet the Navy specifications for temperature-to-frequency conversion and fall rate. According to these specifications, temperature is converted to frequency with the equation

$$F = 1440 + 36T \qquad (1a)$$

which may be inverted to give

$$T = -40.00 + (2.778 \times 10^{-2})F \qquad (1b)$$

where F = frequency in hertz and T is temperature in degrees Celsius. This relationship must be followed to within ± 20 Hz (about $\pm 0.56°$C) in the temperature range $-2°$ to 35°C. The XBT probe fall rate specification is

$$D = 1.52t \qquad (2)$$

where D = depth in meters and t = elapsed time after probe release in seconds. The depth accuracy specification is $\pm 5\%$.

3. Previous Sippican AXBT Testing and Calibration

At least two earlier studies have provided information on the performance of the initial design Sippican AXBT. The Sippican Corporation has reported on tests conducted by several Navy facilities [*Hudson*, 1980, 1981]. As a result of this testing, formulae for both fall rate and temperature-to-frequency conversion have emerged. The Sippican formula for temperature as a function of audio frequency is

$$\begin{aligned} T = & -126.662 + 0.219954F - (1.705096 \times 10^{-4})F^2 \\ & + (7.70534 \times 10^{-8})F^3 - (1.7958 \times 10^{-11})F^4 \\ & + (1.73823 \times 10^{-15})F^5 \end{aligned} \qquad (3)$$

The Sippican formulae for fall rate is

$$D = 1.5926t - (1.8 \times 10^{-4})t^2 \qquad (4)$$

Temperature and depth accuracies using (3) and (4) are reported to be $\pm 0.18°$C and $\pm 2\%$, respectively. Table 1 compares the performance characteristics reported by Sippican by using (3) and (4) to the standard Navy AN/SSQ-36 specifications.

Static temperature calibrations were performed on 48 Sippi-

TABLE 1. Operational Specifications for the Sippican AXBT and the Standard Navy AN/SSQ-36 AXBT

	Sippican AXBT	Standard AN/SSQ-36
Probe operating depth	760 m	305 m
Probe drop rate	1.52 m s^{-1}	1.52 m s^{-1}
Depth accuracy	$\pm 2\%$	$\pm 5\%$
Thermal time constant	100×10^{-3} s	1000×10^{-3} s
Temperature accuracy	$\pm 0.18°C$	$\pm 0.55°C$

The Sippican specifications are from Hudson [1981].

can AXBT probes at NAVOCEANO and reported by *Gent* [1982]. He found a difference ranging from $-0.165°C$ to $+0.319°C$ between the actual temperature and the AXBT measured temperature using the standard Navy equation (1). To determine a better frequency-to-temperature formula, a third-order least squares curve fit was performed on data from a 12 point calibration. The resulting formula is

$$T = -66.8857 + (7.0273 \times 10^{-2})F - (2.1807 \times 10^{-5})F^2 + (3.6311 \times 10^{-9})F^3 \quad (5)$$

No fall rate information was gathered in *Gent*'s [1982] study. He did, however, provide information on thermal response times of the Sippican probes. Additionally, he reported on similar calibration studies of older model AXBT's.

Equations (1), (3), and (5), although numerically different polynominals, all produce similar temperatures in the frequency range $1368 < F < 2700$ Hz (approximately $-2°$ to 35°C). The three equations are plotted in Figure 2 as temperature versus frequency. The Navy formula (equation (1)) is shown as a broken line, the Hudson formula (equation (3)) as a solid line, and the Gent formula (equation (5)) as a dashed line. The Navy and Gent formulae are quite close, the two lines being almost indistinguishable in this figure. The Hudson formula produces consistently higher temperatures than the other two, except near the low temperature end of the range ($T < 1°C$) where all three formulae give similar results.

The fall rate formulae given by the Navy (equation (2)) and Hudson (equation (4)) have been plotted for comparison as depth versus time in Figure 3. A third fall rate formula which we determined using data from our field performance test has been plotted in this figure also. Our fall rate formula is given

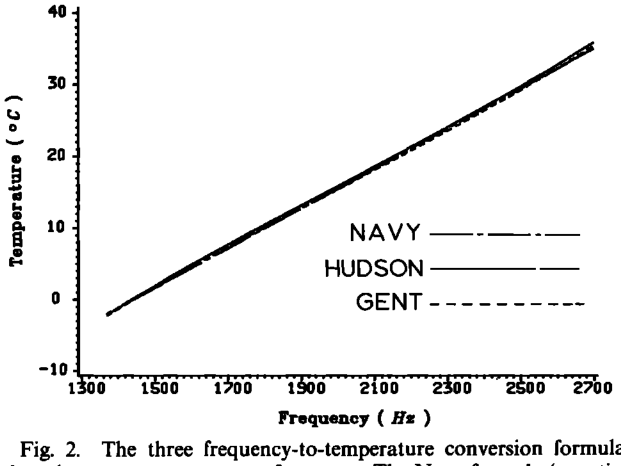

Fig. 2. The three frequency-to-temperature conversion formulae plotted as temperature versus frequency. The Navy formula (equation (1*b*) is shown as a broken line, the Hudson formula (equation (3)) is shown as a solid line, and the Gent formula (equation (5)) is shown as a dashed line.

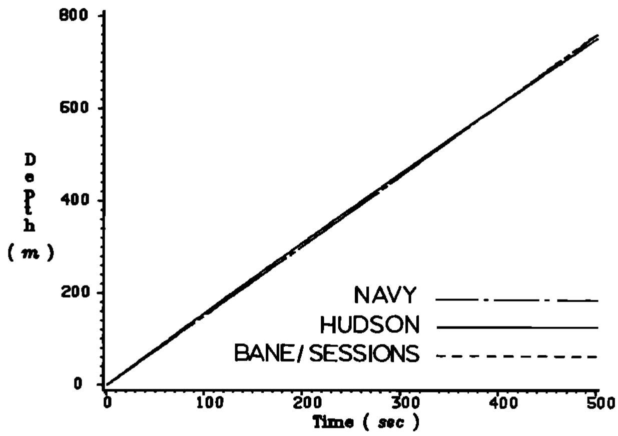

Fig. 3. The three fall rate formulae plotted as depth versus time. The Navy formula (equation (2)) is shown as a broken line, the Hudson formula (equation (4)) is shown as a solid line, and our formula (equation (6)) is shown as a dashed line.

below as (6). The method used to determine this formula will be discussed in section 4. It is evident from Figure 3 that the Navy fall rate formula (broken line) and our fall rate formula (dashed line) give essentially the same result. The two curves overlie one another throughout most of the range. The Hudson formula (solid curve) produces slightly greater depths in the 100–600 m range and slightly shallower depths in the 600–760 m range than do the other two formulae.

4. PERFORMANCE AND INTERCOMPARISON TESTS

One flight was made aboard a Lockheed P-3D aircraft operated by the NOAA Research Facilities Center in Miami, Florida, to deploy AXBT's in close proximity to a research vessel taking conductivity, temperature, and depth (CTD) casts. These data were used to provide an intercomparison between deep Sippican AXBT temperatures and those of the CTD. The NOAA Vessel *Researcher* was occupying a CTD station near 25°N 71°W in the North Atlantic Ocean, and from it five casts to 1000 m depth were made with a Neil Brown Mark III CTD system during the time the AXBT's were dropped. Pertinent specifications for this CTD are as follows: depth accuracy, 6.5 m; thermal time constant, 30 ms; and temperature accuracy, 0.005°C. Each CTD cast took approximately 30 min to complete.

The CTD data sets consist of temperature and salinity values at 1 m depth intervals. One of the CTD temperature profiles is shown in Figure 4*a*. All five CTD temperature profiles are documented in the report by *Bane* [1983]. Figure 4 also shows the mean of the five profiles ± 2 standard deviations and the mean and range of the five profiles. These figures give an idea of the oceanic variability that occurred at the CTD station during the 4 hour duration of the study. CTD standard deviations are typically 0.02°–0.05°C, and the ranges are typically $\pm 0.1°C$ about the mean. These values indicate that the real temperature variability at most depths was less than the accuracy of the AXBT's (see Table 1).

Thirty-seven Sippican AXBT's were deployed during this flight. (Additionally, nine Hermes and four Magnavox AXBT's were deployed, thereby providing further information on the performance of these earlier models. See *Bane* [1983] for further details). The AXBT's were deployed from the aircraft three at a time, each one having a carrier frequency different from the other two. Drops were made as close to the ship as possible. AXBT's usually fell within a few tens of meters of the

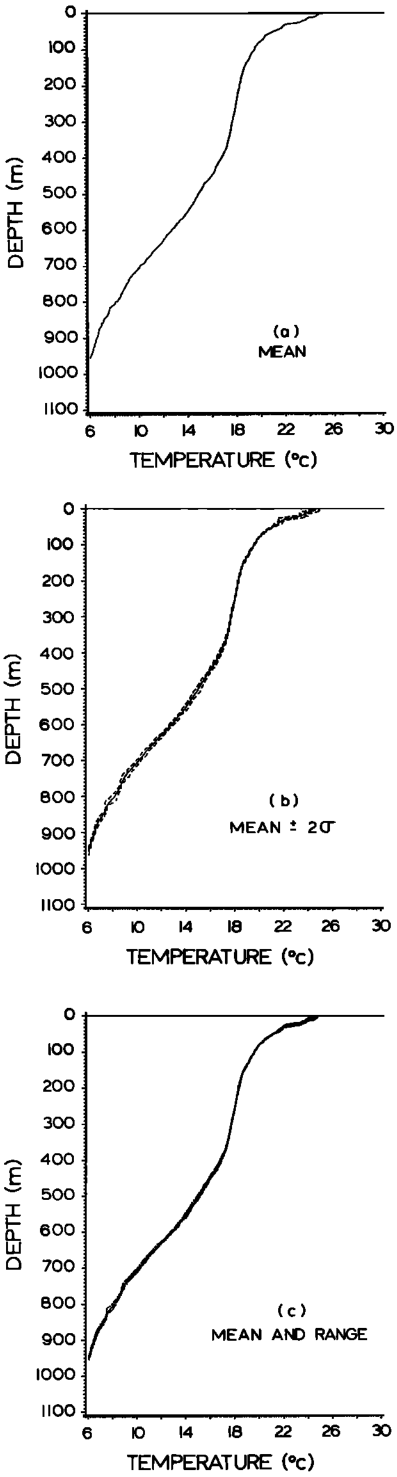

Fig. 4. Data from the Neil Brown CTD. Displayed here are (*a*) the temperature profile from the first cast, (*b*) the mean of all five profiles ±2 standard deviations from the mean, and (*c*) the mean and range of all five profiles. These data provide an indication of the real temperature structure and variability during the study.

Researcher. Eleven malfunctioning (or "dud") Sippican AXBT's were experienced out of the 37 that were deployed. This failure rate of 30% is higher than the desirable level of about 5%. The types of failures encountered included "hung" probes which began audio frequency transmission but were not released from the surface package (three units), units which did not transmit at all (five units), and probes that gave a very noisy or partial temperature trace, thereby rendering the data useless (three units). (During a Gulf Stream mapping exercise a few months later, we deployed 145 deep Sippican AXBT's with a more respectable failure rate of 4%.)

Each AXBT profile was recorded as audio frequency at 1 s intervals following release of the AXBT probe from the surface package. It was later possible to convert these data to temperature versus depth by applying appropriate formulae. Three

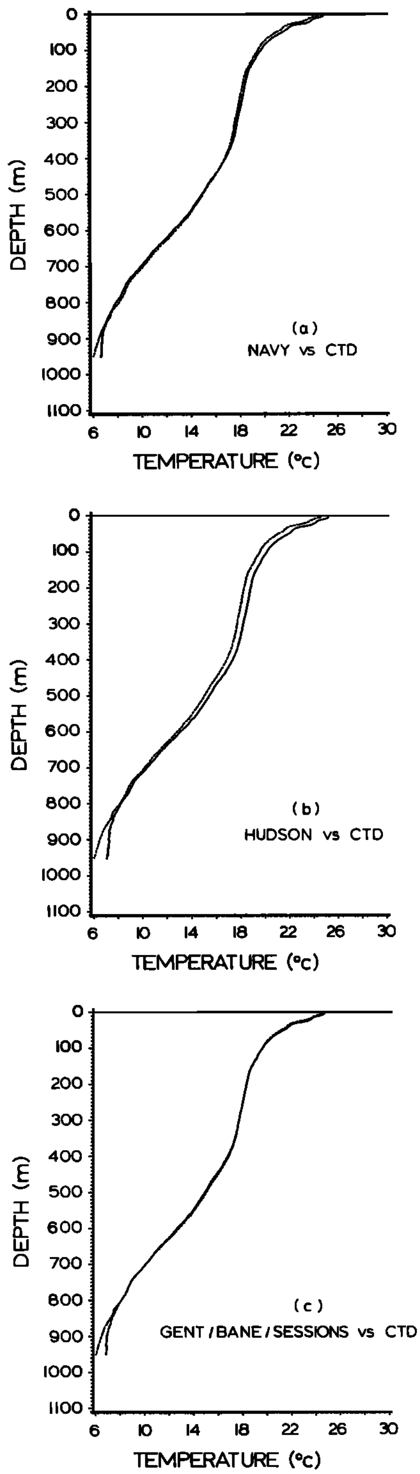

Fig. 5. AXBT-CTD comparison profiles. Each panel shows a mean AXBT profile as a solid curve and the mean CTD profile as a dashed curve. In the three displays are (*a*) the Navy-formula profile, (*b*) the Hudson-formula profile, and (*c*) the Gent-formula profile.

temperature values were computed for each frequency value by using the three formulae described above. In the following discussion we will refer to the various temperature values as "Navy-formula" temperature if the frequencies were converted to temperatures by using (1*b*), "Hudson-formula" temperature if (3) was used, and "Gent-formula" temperature if (5) was used.

In an effort to determine the optimum fall rate for the particular AXBT's used for this study and under these conditions, we compared the depths of several distinctive features in the AXBT temperature profiles to the depths of the same features in the CTD profiles. Seventeen such features could be identified and usually consisted of an abrupt change in the temperature gradient, thereby giving the profile a cornerlike appearance. Using a standard least squares technique, the mean AXBT "corner" depths (in terms of elapsed time) were fit to the mean CTD "corner" depths to provide the following fall rate formula:

$$D = 1.516t + (1.553 \times 10^{-5})t^2 \quad (6)$$

Three sets of temperature profiles were then plotted. Navy formula temperatures were plotted against depth determined from the standard Navy fall rate formula (equation (2)). The Sippican formula, (4), was used to calculate depths for the Hudson formula temperatures. The third set of profiles were plotted using the Gent temperature formula, (5), and our fall rate formula, (6).

5. RESULTS

Basic Statistics

The mean, standard deviation, and high- and low-range values were computed for each set of AXBT temperature profiles. The mean profiles are shown in Figures 5*a*–5*c*. The mean CTD profile is plotted in each case for comparison. These figures are useful for estimating which set of formulae provide the best results, but before considering these profiles further it is worthwhile to look at the basic statistics of the AXBT data sets.

The standard deviation and high and low range values were plotted as functions of depth for each set of AXBT profiles. Few differences were found in these statistics from set to set.

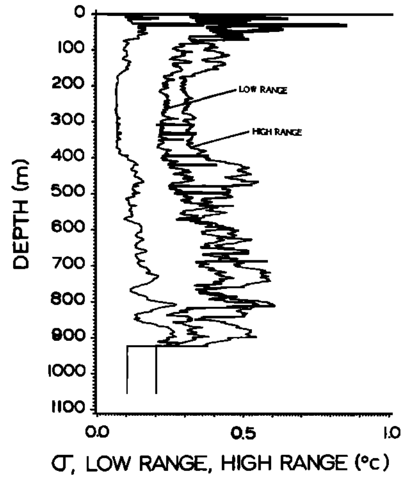

Fig. 6. Statistics from the Navy-formula AXBT data set. Displayed as functions of depth are the standard deviation, the high range minus the mean (labeled "high range"), and the mean minus the low range (labeled "low range"). For clarity, the low range and high range profiles have been offset by 0.1°C and 0.2°C, respectively.

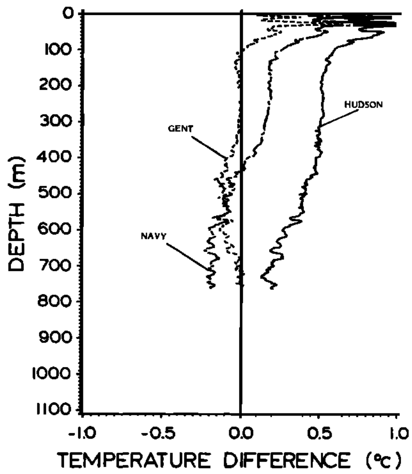

Fig. 7. AXBT minus CTD temperatures as functions of depth. Each curve shows the difference between one of the mean AXBT profiles (Navy, Hudson, Gent) and the mean CTD profile.

This is not surprising since there is, of course, only one primative AXBT data set. The subsequent conversion of the frequency-time data to temperature-depth data produces similar statistics among the three derived data sets, due to the similarities in the formulae used for the conversion.

The statistics of the Navy-formula temperature data set are displayed in Figure 6. Shown here are the standard deviation, the highest temperature minus the mean ("high range" for convenience), and the mean minus the lowest temperature ("low range" for convenience). Each curve is plotted as a function of depth. For clarity, the low range and high range profiles have been offset by 0.1°C and 0.2°C, respectively. The standard deviation was typically 0.06°C–0.15°C, with isolated higher values near strong temperature gradients. The lowest standard deviation occurred in a layer between 180 and 390 m. This is within the 18° water, which is a layer characterized by a relatively low vertical temperature gradient. Hence, the standard deviation within this layer is least affected by fall rate differences between probes, and it indicates that the precision of the AXBT thermistor (as measured by standard deviation) is at least as good as 0.06°C.

The low and high range profiles also exhibit relatively low values within the layer of 18° water. The low and high values differ from the mean by about 0.10°C–0.15°C within this layer. Higher values for the low and high ranges occur above and below this layer in regions of higher vertical temperature gradient, as was the case with standard deviation. We attribute these higher values to probe-to-probe variation in fall rate.

AXBT-CTD Comparison

Consider now the comparisons between the AXBT mean profiles and the CTD mean profile. It is apparent from the temperature profiles themselves (Figures 5*a*–5*c*), and confirmed by the difference profiles (Figure 7) that the best fit of the AXBT data to the CTD data is provided by the Gent-formula, (5), and our fall rate formula, (6). The Navy formulae profile is the next best fit, with the Hudson formulae profile differing the most from the CTD profile.

The difference profiles in Figure 7 show the Gent formula mean temperatures to be slightly higher than the CTD mean temperatures above about 110 m. Below that depth the Gent temperatures are lower than the CTD temperatures. The differences are typically less than 0.10°C, except between the surface and about 70 m depth where two strong thermal gradients existed. The two profiles plotted in Figure 5*c* suggest that the differences in the upper 70 m are due to depth error caused by the fall rate formula, since the two strong thermal gradients in the Gent profile are each shown to be slightly deeper than the corresponding gradient in the CTD profile. Taking the depth error as the cause of the relatively great temperature differences in the near-surface layer, we see that the temperature error is less than 0.10°C. Since the standard deviation is typically < 0.15°C, this gives a temperature accuracy of better than 0.25°C for the Gent formula data set. The depth error for this data set was found to be less than 3 m in the layer above 100 m, and to be almost zero below 100 m. This depth accuracy is within the $\pm 5\%$ Navy specification.

The characteristics of the Navy formula data set are similar to those of the Gent formula data set, except that the AXBT-CTD temperature differences are typically larger for the Navy data (Figure 7). Again, relatively great differences exist within the upper 70 m near the strong thermal gradients. Below 70 m the differences range from about -0.20°C to about $+0.20$°C. These differences are due primarily to error introduced by the Navy temperature formula, (1*a*). Taking into account the standard deviation, the temperature accuracy is 0.35°C for the Navy formula data set.

The Hudson formula data set was found to have a temperature offset of about 0.4°C. Figures 5*b* and 7 show that an adjustment of the AXBT temperature data downward by this amount would reduce the temperature differences considerably. Figure 2 is consistent with the notion that the Hudson frequency-to-temperature formula, (3), produces slightly high temperatures, since the Hudson formula curve is above both the Gent formula and Navy formula curves for temperatures greater than about 1°C. If this 0.4°C offset were removed from the Hudson formula data, the temperature differences would then range from about -0.20°C to about $+0.10$°C, except in the upper 70 m where there are relatively large differences near the strong thermal gradients. The temperature differences at greater depths are due partially to depth error caused by fall rate formula inaccuracy. It is clear from Figure 5*b* that the Hudson formula profile is shallower than the CTD profile by about 20 m near 760 m. Figure 3 is consistent with this characteristic, showing the Hudson fall rate curve to be below both the Navy and Bane/Sessions curves for depths greater than about 600 m. The use of the Hudson fall rate formula, (4), does not, however, introduce a depth error greater than the Navy specification. This is not the case with the Hudson frequency-to-temperature conversion formula, (5). Use of this formula with the initial design units may give a temperature error slightly greater than the ± 0.56°C Navy specification for higher temperatures.

6. DISCUSSION

A field test of the performance of the initial design deep (760 m/2500 ft) Sippican AXBT has been conducted. Thirty-seven AXBT's were deployed beside a research vessel which was conducting CTD casts to 1000 m. A total of five CTD casts were made. A rather high AXBT failure rate of 30% was experienced in this study. (A subsequent mapping exercise which used 145 deep AXBT's gave a more respectable failure rate of 4%.)

A comparison between the AXBT and CTD data showed that the AXBT's provided temperature profiles with accuracies that depended upon the particular formulae chosen for frequency-to-temperature conversion and fall rate. The three sets of formulae used here were the standard Navy formulae, (1) and (2); the formulae published by the Sippican Corporation [*Hudson*, 1981, 1982], (3) and (4); a combination of a frequency-to-temperature formula published by *Gent* [1982], (5); and a fall rate determined from data collected during our study, (6). Two of the three methods produced data which were within the Navy's AXBT accuracy specifications, taking the CTD data as standard. The best comparison between AXBT and CTD data was found with the Gent formula temperatures and our fall rate. Temperature accuracy for this data set was found to be better than 0.25°C. These data also indicate the thermistor precision to be better than 0.06°C. The Navy formula temperature accuracy was 0.35°C. A 0.4°C temperature offset was found in the Hudson formula data set which could put the temperature accuracy just outside the Navy's specification of ± 0.56°C.

The fall rate which we calculated was close to the Navy fall rate. Neither of these formulae appeared to contain a slight depth error which appeared in the Hudson formula data. All fall rates were found to be within the $\pm 5\%$ Navy specification. It should be noted that the fall rate determined here, (6), may not be the best for other operational environments. The fact that it is quite close to the Navy formula (maximum difference less than 2 m at 760 m) suggests that the use of the Navy formula, (2), should be dependable. Our results also support the use of *Gent*'s [1982] frequency-to-temperature formula, (5).

A particular characteristic of these AXBT's worth noting is the temperature error at depths greater than the maximum operational depth of 760 m. It is apparent in Figure 5 that the AXBT temperatures are consistently higher than the CTD temperatures at depths below about 800 m or so. We have not investigated the source of this error, but at least three possibilities may be suggested. They are decrease in fall rate, due perhaps to the wire not winding off of the spools correctly at great depths; temperature and/or pressure effects on the electronics within the XBT probe; and pressure effects on the thermistor. Since this error occurs outside the designed depth range of the probe, it does not represent a legitimate performance problem; however, we feel it is important to note this error here, since AXBT users oftentimes will utilize data from depths greater than the designed depth range. We do not recommend using data from these initial design probes below 800 m.

Any changes in thermistor, or in the design of the XBT probe itself may introduce changes in the accuracy of the results obtained with a particular set of AXBT's. In the past there have been differences in performance noted between AXBT's produced by different manufacturers, and even between AXBT's produced in different lots from the same manufacturer [*Sessions et al.*, 1976; *Sessions and Barnett*, 1980]. This may be anticipated for the Sippican deep AXBT, as Sippican has implemented design changes and updates in this instrument, beginning with contract number N00163-81-C-0287. New calibration information will allow the AXBT's to produce high quality scientific data. Static temperature calibration of the AXBT thermistor, such as that done by *Gent* [1982], is capable of producing temperature accuracy much better than the Navy specification. As has been shown here, an accuracy better than 0.25°C is possible.

The determination of the best fall rate for a given type of AXBT probe is usually a more laborious task than the thermistor calibration, requiring either simultaneous CTD data for comparison, such as we have done here, or a modification of the AXBT probes themselves to allow a direct measurement of pressure [*Sessions and Barnett*, 1980]. The importance of determining an accurate fall rate cannot be over emphasized. Our determination here of a fall rate for this particular probe design which is not significantly different from the standard Navy fall rate was fortunate, in that any users applying the Navy formula will have introduced no important errors into their data in doing so.

Our general feeling is that Sippican has produced an AXBT which will give a respectable performance in scientific studies. The increased depth capability of the deep AXBT is of great scientific value. Further improvements will hopefully include even greater depth capability, and a faster fall rate, so that the data transmission and recording time for an individual AXBT profile is reduced. A faster fall rate will allow closer spaced AXBT stations in oceanographic temperature surveys and will reduce the likelihood of the aircraft flying out of signal range of the deployed AXBT before the profile has been completed. It is also desirable to see additional oceanographic sensors packaged for aircraft deployment, such as the expendable conductivity, temperature and depth probe [*Lancaster*, 1983] and the expendable current profiler [*Lansill*, 1983]. We strongly encourage and support the increased use of aircraft research in oceanography.

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