

XBT/XCTD Standard Test Procedures

for Reliability and Performance Tests of Expendable Probes at Sea

- Revised Draft -

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1. Introduction

Expendable bathythermographs (XBTs) launched from ships of opportunity have played a major role in data collection for many large scale oceanographic research programmes such as the World Ocean Circulation Experiment (WOCE) and Tropical Ocean Global Atmosphere (TOGA). XBTs will continue to play an important role in upper ocean thermal research programmes as well as in operational oceanographic programmes such as the ongoing Global Ocean Observing System (GOOS). It is expected that new expendable devices as the recently developed TSK/Sippican XCTD (expendable CTD) designed to sample the T/S field of the upper ocean from vessels underway routinely and precisely will soon become operational for Ships-of-Opportunity Programmes.

Insuring the quality of the XBTs and XCTDs currently in use and of any new expendable probe that may enter the market is a very important part of assuring a high quality data base. Provided that the system is working correctly, there are three main error sources which could affect the data quality. These are

- digitizer errors which are responsible for inaccuracies in the conversion of the electronic signal into temperature and/or conductivity units.
 - Sensor errors due to various reasons, e.g. wrong thermistor response, air bubbles in the conductivity cell (bubble adhesion) or calibration failures.
 - Depth fall rate errors, e.g. due to an inaccurate depth time equation or production changes.
- It must be the goal of a well designed quality test strategy to keep all three main error sources under control.

The best way to assure a quality XBT or XCTD is to implement a standard set of procedures for testing the probes. This document proposes a three step process for insuring XBT/XCTD quality:

1. Start with a set of specifications that must be adhered to, by either laboratory testing or documentation from the manufacturer, before proceeding onto the field evaluations.
2. Next is a standard reliability testing procedure under normal ship of opportunity conditions, i.e. on a vessel underway.
3. Finally and most important is a side-by-side comparison with a cable lowered high precision CTD as a field reference.

Whereas XCTD performance requirements have been defined to meet the demands of large-scale measurements of the upper ocean density field in particular for WOCE the XBT performances are based on the U.S. Navy specifications for the T-4 and T-7 probes. Specifications include precise declarations on depth, temperature and conductivity sensing range, resolution and accuracy up to detailed information on signal wire configuration etc. Each probe type must meet its specifications prior to any field evaluation by either laboratory testing or documentation from manufacturer testing.

Reliability testing is required to assure that XBT/XCTDs can be successfully launched under normal ship of opportunity operations without data error or mechanical failure of the probe and should also be carried out regularly to check the variability caused by production changes or production intolerances (batch-by-batch variability). The test consists of dropping a sample of probes at sea, under regular ship of opportunity conditions, until the sample is exhausted.

Comparing an XBT/XCTD with a well calibrated and co-located CTD reference needs more effort than reliability tests but is the best way to evaluate both the signal and depth

accuracy under field conditions and at relatively low costs. On top of this it also provides good information on the system's overall functionality and quality and thus is the only method to check the manufacturer's claimed system performance independently, i.e. from a customer's point of view. The CTD measures depth, temperature and conductivity using sensors whose accuracy is at least an order of magnitude better than that of the XBT and even often an order of magnitude better than that of the XCTD. By launching expendables simultaneously with a CTD, one can measure accurately the overall performance of the XBT/XCTD system in the field.

2. XBT Probe Specifications (Sippican)

About general equipment description and operation see manufacturer's operation manuals (Sippican, Inc.; The Tsurumi-Seiki Co.). Under presently designed systems, all current to the XBT probe is supplied by the recorder bridge circuit, with the thermistor acting as a variable passive element of the circuit. The current supplied to the probe by the bridge circuit will be 190 μ A maximum within the operating temperature range and no less than 100 μ A to avoid any "bowing problem" (Bailey, 1990; Szabados, 1990). The manufacturer's (Sippican's) specification for all XBT types is given as:

Temperature range:	-2 °C to +35 °C
Temperature resolution:	0.01 °C
Temperature accuracy:	+/- 0.15 °C over full range
Temperature drift per year:	
Sampling rate:	10 Hz
Depth range:	Probe type dependent
Depth resolution:	65 cm except T-11 (fine structure probe)
Descent rate:	Probe type dependent
Depth formula:	$a \cdot t - b \cdot t^2$ (coefficients probe type dependent)
Depth accuracy:	+/- 2 % or 5 m whichever is greater
Sea state:	SS 5 maximum
Rated vessel speed:	Probe type dependent
Thermal response:	- In 1 m depth 63 % of a step change in temperature - In 3 m depth 95 % of a step change in temperature
Launch height:	1 m minimum, 15 m maximum
Shelf life:	5 years
Stowage temperature range:	- 60 °C to + 70 °C
Operating temp. range:	0 °C to + 50 °C
Probe weight tolerance:	

For further details of military specification e.g. on non-operating conditions like vibration, shock or humidity see corresponding U.S. Navy documents (e.g. US Navy MIL-STD-810D, 1986).

3. XCTD Probe Specification (TSK)

The XCTD is a relatively new device. In the 1990s separately developed as two competing systems by Sippican and TSK at present only a single XCTD is now available on the market which is based on a modified TSK probe and a modified Sippican MK-12 recorder (new XCTD system). The overall performance of this new instrument has not yet been fully characterized. About general equipment description and operation see manufacturer's operation manuals (Sippican, Inc.; The Tsurumi-Seiki Co.). The specification for the new XCTD is given by the manufacturer (TSK) as:

Temperature range:	-2 °C to +35 °C
Temperature resolution:	0.01 °C
Temperature accuracy:	+/- 0.02 °C over full range
Temp. sensor drift:	
Conductivity range:	20 mS/cm to 74 mS/cm
Conductivity resolution:	0.017 mS/cm
Conductivity accuracy:	+/- 0.03 mS/cm
Cond. sensor drift:	
Sampling rate:	25 Hz
Depth range:	1000 m
Depth resolution:	17 cm
Descent rate:	3.4 m/sec
Depth formula:	$a \cdot t - b \cdot t^2$ (a = 3.42543, b = - 4.7026 E-4)
Depth accuracy:	+/- 2 % or 5 m whichever is greater
Calibration accuracy:	
Sea state:	
Rated vessel speed:	12 knots
Thermal response:	
Launch height:	
Shelf life:	
Stowage temperature range:	
Operating temp. range:	
Probe weight tolerance:	
Life of built-in battery:	20 minutes after ready to measure

4. The Reliability Test (successive probe launching)

The purpose of this simple test is mainly to evaluate the at-sea functionality and reliability of the XBT probe. It is also useful for supervision of batch-to-batch variability. Considering the practical guidelines for field work given by Cook and Sy (2000) the procedures are as follows:

- a) Determine an XBT sample size for the test. For statistical reasons 30 or more probes are recommended. Make sure all probes are handled with greatest care.
- b) Weight the probes as accurate as possible and note weight and serial number. The weight differences may give a first indication to production intolerances.
- c) The laboratory calibration of the probes (Roemmich and Cornuelle, 1987) can be very useful to detect smaller temperature errors, however, it has to be noted that it cannot be excluded that wet calibration procedures may effect the probe's fall rate due to corrosion induced change of the probe's nose drag in sea water. An alternative method is suggested by Budéus and Krause (1993) who describe a simple procedure to calibrate XBT probes at

one temperature point immediately before launching and thus avoiding a possible corrosion effect.

- d) Select a ship that will not exceed the speed allowed by the probe type under consideration but will operate near or at the maximum allowed speed for optimum testing.
- e) Select a launch site that is not more than 15 m above the surface of the water and has a clear path from the launcher to the water surface. Any contact of the probe and/or wire with the ship's hull will constitute a disqualified launch. To assure this won't happen the XBT launch site should always be on the leeward side of the ship preferably at the stern.
- f) Select an ocean area which is characterized by a well established thermocline (large gradient from sea surface to terminal depth).
- g) Assure that the sea state conditions are not greater than 5 of the international scale during the trial.
- h) Keep a log of launches which includes drop number, date, time, probe's serial number, weight, latitude, longitude, water depth, ship's speed, wind and sea condition, date of manufacturing and any other useful comments about the launch (see Table 1).
- i) Launch XBTs in succession until sample is exhausted. Put a lot of care into the launching procedure.
- j) When launching is complete compare profiles and sort outliers. Underway XBT measurements carried out in succession should produce nearly congruent profiles. Determine the failure rate of the probes. The failure rate may not exceed 6 % of the sample size. A failure is defined as (see e.g. Bailey et al., 1994; Cook and Sy, 2000):
 - wire break above rated maximum depth,
 - wire stretching,
 - any other mechanical malfunction, e.g. probe nose/body separation, wrong electrical connection,
 - thermistor failure,
 - any spike or noise appearing in the trace.Any failure associated with the probe or its component making contact with the vessel shall be eliminated from the sample prior to, and without regard to, examination of the trace.
- a) Summarize your results in a well documented report which, if timely distributed, can serve as the basis for further discussions with both the manufacturer and the community.

In principle XCTD probes' reliability and functionality can be tested in the same way as with XBT probes, however, due to the high costs of XCTDs it seems not to be reasonable to take it into consideration.

5. The Performance Test (XBT or XCTD versus CTD Comparison)

XBT versus CTD comparisons have been varied over the years, ranging from comparing sections with XBTs interspaced CTD stations, over dropping an XBT near a CTD station while the ship is still moving through to dropping an XBT at the CTD station simultaneously with the descent of a CTD. Dropping XBTs or XCTDs within the first 10 to 15 minutes of the CTD descent, so as to coincide with the CTD within the thermocline, is the recommended in-situ testing strategy. This side-by-side measurement provides the most accurate comparison because it reduces the possibility of depth differences due to temperature/salinity field variations in time or space (e.g. by internal waves). The procedures and recommendations are as follows:

- a) Calibrate both the CTD and the XBT/XCTD recording equipment before and after the field trial. No wet probe calibration is recommended because corrosion of the probe's nose may change the drag in the sea water and thus may increase the probe-by-probe depth fall rate variability. Due to high costs of XCTD probes, however, a quick functionality check in a seawater bath (the bucket test) prior to launch is recommended. If failures appear the probe can serve as proof which, of course, is not the case if the same failure appears after launch. Note the short life time of the built-in battery of the probe after the power of the probe is turned on (ready to measure). An XCTD test canister test may also be helpful, however, for shipboard unit verification only.
- b) It is always a good idea to announce the test in the cruise plan and to develop good arguments to get the captain's agreement at an early planning stage. You have to keep in mind that no ship's captain is happy to get a wire in the screw, even not a thin XBT signal wire.
- c) Determine an XBT or XCTD sample size for the test. For statistical reasons 30 or more probes are recommended. Make sure all probes are handled with greatest care. Because of high costs of XCTD probes a sample number of less than 30 probes has to be accepted as being sufficient for the test purpose. One can argue that due to its much better performance in all aspects and manufacturer's quality supervision (calibration) statistical arguments are not as much important as for XBT probes.
- d) Weight the probes as accurate as possible and note the weight and serial number.
- e) Determine a good launch site. The launch site should be as far away from the CTD launch location as possible on the leeward side of the ship to avoid wire tangles with the CTD and/or contacts with the ship's hull. Also make arrangements with the captain and the chief scientist to avoid getting signal wire in the ship's screw. Some appropriate soft manoeuvring during probe's launch will help to keep the screw clear and also to prevent premature wire breaks.
- f) Determine at which CTD station the comparison will be done. Select only those CTD stations which provide a significant hydrographic structure at all depths and whose depth is at least as deep as the maximum probe depth. In case the vessel is equipped with a good echo sounder an alternative could be to select a shallow water CTD station (water depth just less than the rated probe depth). This strategy provides an additional independent depth comparison by means of echo sounding and bottom hit signal in the trace (Gould, 1990).
- g) Create a log to record launches which should include drop number, CTD cast number, date, time of launch, CTD depth when probe is dropped, probe's serial number, weight, latitude, longitude, water depth, wind and sea condition, date of manufacture and any other useful comments about the launch as e.g. echo sounding at signal termination (see Table 1).
- h) Once on a selected station wait until the CTD has entered the water, adapted to its new environment and has been started to descent at a speed of 1 m/s so as to launch the XBT (speed about 6 m/s) or XCTD (speed about 3.4 m/s).
- i) During the decent of the CTD through the thermocline carefully load and launch as many probes as feasible. Make sure all data are processed and saved on disk. Drop probes during the downcast of the CTD only.
- j) Stop launching probes when the CTD is close to the lower depth limit of the probe.
- k) When field evaluation is complete compare profiles under different aspects which depend on whether an XBT or XCTD performance test has been carried out (Sy, 1993; 1996; 1998):
 - Determine depth errors and derive a new depth fall rate equation according the temperature-error-free method of Hanawa et al. (1995).

- Examine the profiles for sensor errors as e.g. wrong sensor responses (Fig....), bubble adhesion (Fig....), temporal sensor mismatch (time-lag), noise or calibration failures.
 - Check the profiles for systematic errors like digitizer errors, wrong shipboard system calibration or inaccurate software procedures.
 - Estimate the probe's signal accuracy by comparisons of traces in homogeneous layers (Fig....) or by comparisons of identical structures of the thermocline (Fig....).
- l) Summarize your results in a well documented report which, if timely distributed, can serve as the basis for further discussions with both the manufacturer and the community.

6. Conclusions

A high quality data base is very important for current and future oceanographic research. Various scientific and operational uses, ranging from regional and ocean wide forecasts through to monitoring of climate change trends depend highly on consistent ocean data of good quality. Assuring that the XBTs and XCTDs used to populate the data archives are providing quality data is an important process which needs a strengthening effort with increased focus on regular at-sea tests. Implementing the proposed procedures as cost-effective standards for testing expendable devices will assure uniform and comprehensive testing of currently used probes and any new designs that may enter the market in the future and thus will contribute to a better and more reliable data quality.

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