NOAA Technical Report NOS CO-OPS 38

Triaxys Directional Wave Buoy for Nearshore Wave Measurements - Test and Evaluation Plan

Silver Spring, Maryland
January 2003

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

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U.S. Department of Commerce

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Triaxys Directional Wave Buoy for Nearshore Wave Measurements - Test and Evaluation Plan

H.H. Shih

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NOTICE

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ABSTRACT

A Triaxys directional wave buoy was acquired by CO-OPS with funds from the NOS Partnership, “Tools and Technical Guidance to Improve Restoration of Coastal Habitat”. It is to be deployed at Barren Island and other sites in the Chesapeake Bay in support of marsh restoration. In the future, it may be used to support other CO-OPS programs, such as PORTS® and other coastal programs. The buoy contains three solid state accelerometers, three angular rate sensors, and a fluxgate compass, and derives directional wave information from dynamic motion measurements and six degrees of freedom buoy motion equations. The technique is relatively new and requires validation by NOS for operational use by NOS. This document outlines a test and evaluation plan which provides a framework for developing detailed test procedures that can be carried out in- house or via contractual arrangement.

1. INTRODUCTION

1.1 Needs for Wave Information

Surface waves provide principle energy inputs to many near shore processes such as long shore currents, changes in beach profiles, longshore transportation of sand. There has been growing interest in coastal wave information from maritime commerce, environmental managers, and engineering and scientific communities. Previous user surveys have found that the surface wave observations and forecasts are usually one of the top three variables requested or used by marine users. The other two variables are surface winds and currents. The Oceans.US Phased Implementation Plan for the US IOOS [1] also identifies waves as number 3 priority under physical observations, following temperature and salinity.

Identified areas of application include wave nowcast/forecast model verification, marsh restoration and shore erosion, hazardous material spill response, coastal storm induced flooding, engineering design and construction, dredging, ship routing and scheduling, cargo loading and unloading, and recreational boating. Wave observation networks in ports and harbors have been established in several countries including Japan, Netherlands, and Spain.

In the U.S., user groups include Federal agencies (NOAA, USCG, USACE, Navy, EPA, and USGS), State and local governments (Port Authorities, Civil Defense, Public Work, Recreation, and Natural Resources), private industry and general public [2].

There is an identified gap in NOS in operational observing system capabilities for waves in ports, harbors, and bays.

1.2 Existing Wave Measurement Systems

Several wave measurement systems/networks are presently installed in the U.S. The NOAA/National Data Buoy Center (NDBC) maintains and operates a network of large wave buoys in order to gather wave information in deeper ocean basins as well as in the Great Lakes. Some of NDBC’s coastal C-MAN stations also are equipped with water level sensors which produce non-directional wave information [3]. The U.S. Army Corps of Engineers (USACE) together with the Scripps Institution of Oceanography (SIO) maintain and operate pressure transducer arrays and Waverider buoys for directional and non-directional wave measurements in shallower coastal waters [4].

There are also other special research programs, such as the Navy's North Gulf Littoral Initiative and Louisiana State University's Wave-Current-Surge Information System [5]. Wave monitoring near shore such as in and around ports, harbors and bays, however, is not common.

1.3 Available Instruments

Available instruments can be categorized into two groups: in situ and remote sensing. A brief description and comments about commonly used sensors or technologies are given below.

A. In Situ Instruments

In situ techniques are ideal for collecting large quantities of wave data at a specific point. However, deployment and maintenance for long term services are expensive. Commonly used instruments, their advantages and disadvantages are listed below.

a) *Surface piercing type*

a1. Resistance gauges - The gauge consists of two vertical parallel conducting wires. The two wires are insulated from one another at the lower ends. Water will short the wires and creates a circuit. The resistance of this circuit is related to the depth of submergence of the wires and hence the water surface elevation.

Advantages: high frequency response; easy to install; widely used in laboratory.
Disadvantages: non-directional wave data; changes in the water salinity will affect the calibration of the gauge; fouling of wires also present a problem; requires continual maintenance.

a2. Capacitance gauges - the gauge consists of a single Teflon coated wire. The conducting wire and the water form the two plates of a capacitor, separated by the insulating coating. The dielectric constant of the capacitor varies with the length of submergence.

Advantages: high frequency response; insensitive to salinity changes; easy to install; widely used in laboratory.
Disadvantage: non-directional wave data; marine fouling and damage of insulating coating of the wire often affect the gauge performance; requires continual maintenance.

a3. Transmission line gauges (such as the Baylor wave staff) - The gauge consists of two inductive wire ropes held vertically in parallel under tension. These wires form an electric transmission line terminated by the water surface. The impedance of the transmission line varies with the water surface elevation and can be easily measured. The gauges have an accuracy and resolution of 1 and 0.1 percent full scale, respectively.

Advantages: rugged, easily to install and maintain; used widely by offshore oil industry.
Disadvantages: non-directional wave data;

b) *Bottom mounted instruments*

b1. Pressure transducer array - compute surface elevation and direction from water pressure and phase measurements.

Advantages: less susceptible to damage from dynamic water surface;
Disadvantages: measures depth attenuated pressure; uses linear wave theory to derive correct pressure; needs water density and barometric pressure data in water surface height conversion; need data telemetry to shore; has relatively poor high frequency response due to water depth pressure attenuation.

b2. Acoustic Doppler Current profiler (ADCP) - derive surface wave information from wave orbital velocity and pressure measurements.

Advantages: measure both current profiles and directional wave information; more compact and rugged than bottom pressure array.
Disadvantages: High frequency wave measurements may be limited due to water depth pressure attenuation. The instrument uses linear wave theory for pressure correction.

b3. PUV sensor – This includes the SonTek Acoustic Doppler Profiler and Velocity Meter (ADP and ADV) and InterOcean's S4 electromagnetic current meter. Statistics of sea surface elevation are derived from pressure measurements at a point and wave direction is computed from phase differences between surface elevation and orbital velocities (U and V).

Advantages: measure both current profiles and directional wave information; more compact and rugged than bottom pressure array.
Disadvantages: Uses linear wave theory for pressure correction and has low directional resolution.

c) Surface buoys

c1. Slope-following buoys - Heave-pitch-roll buoy such as NDBC disc and torous buoys.

Advantages: rugged and used often in deep water.
Disadvantages: hull and mooring system are expensive; accurate measurement requires that the buoy be designed to follow water surface and the accelerometer remains vertical

c2. Particle following buoys – These include Datawell's Waverider and AXYS' **Triaxys buoy**. Typically spherical shape; uses a compliant mooring system; The Waverider sensing package consists of a gyroscopically stabilized platform, accelerometers (heave), surface slope (pitch and roll) and compass. The Triaxys sensing package consists of accelerometers, rate gyros, and compass.

Advantages: less expensive; portable; widely used.
Disadvantages: susceptible to theft, vandalism and damage from shipping; could be overturned by steep breaking waves (often occur in shallow waters less than 8 m); accurate measurement requires that the buoy be designed to follow water particles; accuracy degrades in very highest waves or short crest seas, and measuring nonlinear wave properties.

B. Remote Sensing Techniques

Remote sensing techniques, ground-based, aircraft borne, or satellite borne, are capable of measuring the surface wave field (locally or global). However, only limited instruments are operational or quasi operational. Several others are in the developmental phase and require adequate validation. Existing technologies are briefly listed below.

a) *Ground-based, ship-based, or aircraft-borne:*

a1. Microwave radar - Mostly are used in scientific experiments (such as NOAA, U.S. Naval Research Lab). Several European products are in the market (such as Miros, SAAB, MAREX microwave radar, and GSK marine radar).

Advantage: above sea surface, provide wave pattern information, useful in research and site specific studies.
Disadvantage: performance has not been adequately validated.

a2. Laser and sonic - Several ranging instruments have been used for non-directional wave measurement (such as IR laser wave height sensor by Schwartz electro-Optics used by NDBC, THORN/EMI wave height sensor used in Europe, Western Marine Electronics' sonic sensor).

Advantage: non-contact with water surface
Disadvantage: non-directional and performance has not been adequately validated.

b) *Satellite-borne:*

b1. Radar altimeter (1986-1990 GEOSAT, 1992-present TOPEX, 1991 - present ERS1, 1995-present ERS2) - not applicable to coastal area where wave field has significantly spatial variability (due to large footprint, approximately 10 km in diameter), ocean coverage and repeat paths are relatively course; no wave period or direction can be obtained; requires validated signal transfer functions; typical accuracy is about $\pm$ 0.5 m or 10% in significant wave height, whichever is greater.

b2. Synthetic Aperture Radar (SAR, installed on SEASAT, ERS1, ERS2, RADRSAT) - A coherent radar that looks at right angles to the flight path. Swath path is about 100 km wide and offset from the satellite track by about 250 km. ERS1 and 2 are capable of providing 10 km x 5 km wave-mode images every 200 km along the satellite track.

Advantage: potentially global directional wave spectra, providing wave pattern information.
Disadvantage: Mechanisms in deriving wave information from SAR images are complex and are still under study. Application to near coast area (ports, harbors and bays) is limited.

1.4 NOS Application Environment

The requirement to provide wave information for safe and efficient navigation in major ports as well as for marsh restoration and other environmental management programs in estuaries and marine sanctuaries could lead to a new service area, either by NOS alone, or through cooperative efforts with other partners.

Since winds in enclosed or semi-enclosed waters are limited in fetch, locally wind generated waves are typically of short periods. However, ocean waves and swells coming from open oceans may produce large surface oscillations, especially when the periods are close to the resonant oscillation periods of the enclosed waters. Very long period swell, seiches, and tsunami waves can significantly impact ship operations.

Other environmental characteristics in ports, harbors and bays include the presence of a large tidal range, strong currents, storm surges, varying water densities of the surface layer, varying water depth, bottom topography and sediment types, and floating ice. Another feature often observed at entrances to rivers, harbors, and bays is steeper waves due to wave-current interactions. These areas should be of higher priority for wave (and current) measurements.

Long term wave monitoring at strategic locations in and around bays and ports will provide valuable data sets for wave nowcast/forecast model development and validation. Its importance is similar to the PORTS water level data that are integral part of the hydrodynamic nowcast and forecast model operation and evaluation.

The relatively small water body, the intense utilization of the water and its densely populated shoreline may require much tighter requirements for wave measurements compared to that for Open Ocean and coastal waters. Suggested accuracy requirements are $\pm$ 10 cm in wave heights, $\pm$ 3 degrees in wave direction, and $\pm$ 1 second in wave period.

1.5 Test and Evaluation Objectives

The data and experiences gained from test and evaluation will be used for detailed assessment of the suitability of the Triaxys buoy for NOS operations.

Specific objectives for test and evaluation are:

A. to obtain and validate data on technical performance of the Triaxys system and critical components and major subsystems.

B. to obtain operational data (such as measurement limitations, reliability, maintainability) for determining that Triaxys system is suitable for NOS application.

C. to obtain data for developing data quality assurance procedures and to verify data quality.

D. to evaluate system performance in terms of critical technical, operational and logistical requirements (such as calibration, handling, setup, inspection, site selection, deployment, etc.).

E. to identify system malfunction/failure/breakdowns/problems such as mooring failure, component aging, solar/battery charging, radio interference, system work-hardening effects, and impacts of physical modifications (change in battery weight and mooring line configurations etc.) for developing corrective measures and system improvements.

F. to verify the adequacy of technical manuals and other documents for operational use.

G. to evaluate overall performance based on NOS coastal wave measurement requirements, and to develop an operational plan.

2. THE TRIAXYS DIRECTIONAL WAVE BUOY

2.1 Principle of Operation

The Triaxys Wave Buoy, like the widely used Datawell Directional Waverider Buoy, is a water particle-following buoy that measures the water particle motion in three orthogonal directions. However, the wave measuring techniques for the two instruments are different. The Triaxys buoy uses three accelerometers to measure total accelerations along the mutually orthogonal X, Y, Z axes of the buoy; three angular rate sensors to measure rotation rates about the roll, pitch and yaw axes, and a gimbaled compass to measure sensor heading. An algorithm for a 6-degrees-of-freedom non-linear equation of motion of sensor and a Maximum Entropy Method are used to derive wave height and directional frequency spectra. In comparison, the Waverider buoy uses heave-pitch-roll sensors, two horizontal hull-fixed accelerometers, and compass to determine directional wave information.

The Triaxys buoy also differs from the traditional NDBC disc buoy, a surface slope following buoy, which uses a similar sensor package as Waverider.

The Triaxys buoy wave measuring technique is claimed to be more flexible and accurate. However, its accuracy and reliability have not been fully evaluated.

2.2 Major Components and Manufacturer's Specifications

The major system components consist of the sensor and telemetry module (TAS), the Triaxys Digital Receiver (TDR) and antenna, a power supply subsystem consisting of solar panel assembly and batteries (TAB), navigation light, antenna, and an infrared serial port, upper dome cover and clamping ring, lower hull (including purge port, lifting bridle, and magnetic key), rubber fender, and mooring hardware. A User's manual, WaveView software, and spares kit are also included in the delivered package.

Sensors and data processing software include compass, accelerometers (along X, Y, and Z axes), angular rate gyros (about X, Y, and Z axes), and PC104 wave processor. Other measurements include water temperature, system voltages and currents, solar currents, and battery currents. Data telemetry subsystems include VHF radio system and antenna, GPS and ARGOS. An internal PCMCIA RAM stores data up to 128 MB. The WaveView software allows the user to monitor data collection in real-time.

Figs. 1 and 2 show the major components of the Triaxys buoy and manufacturer suggested standard mooring configuration, respectively. Manufacturer's specifications and acceptable ranges for sensors at static, level, and upright position and static tilt positions are summarized in Tables 1 and 2, respectively.

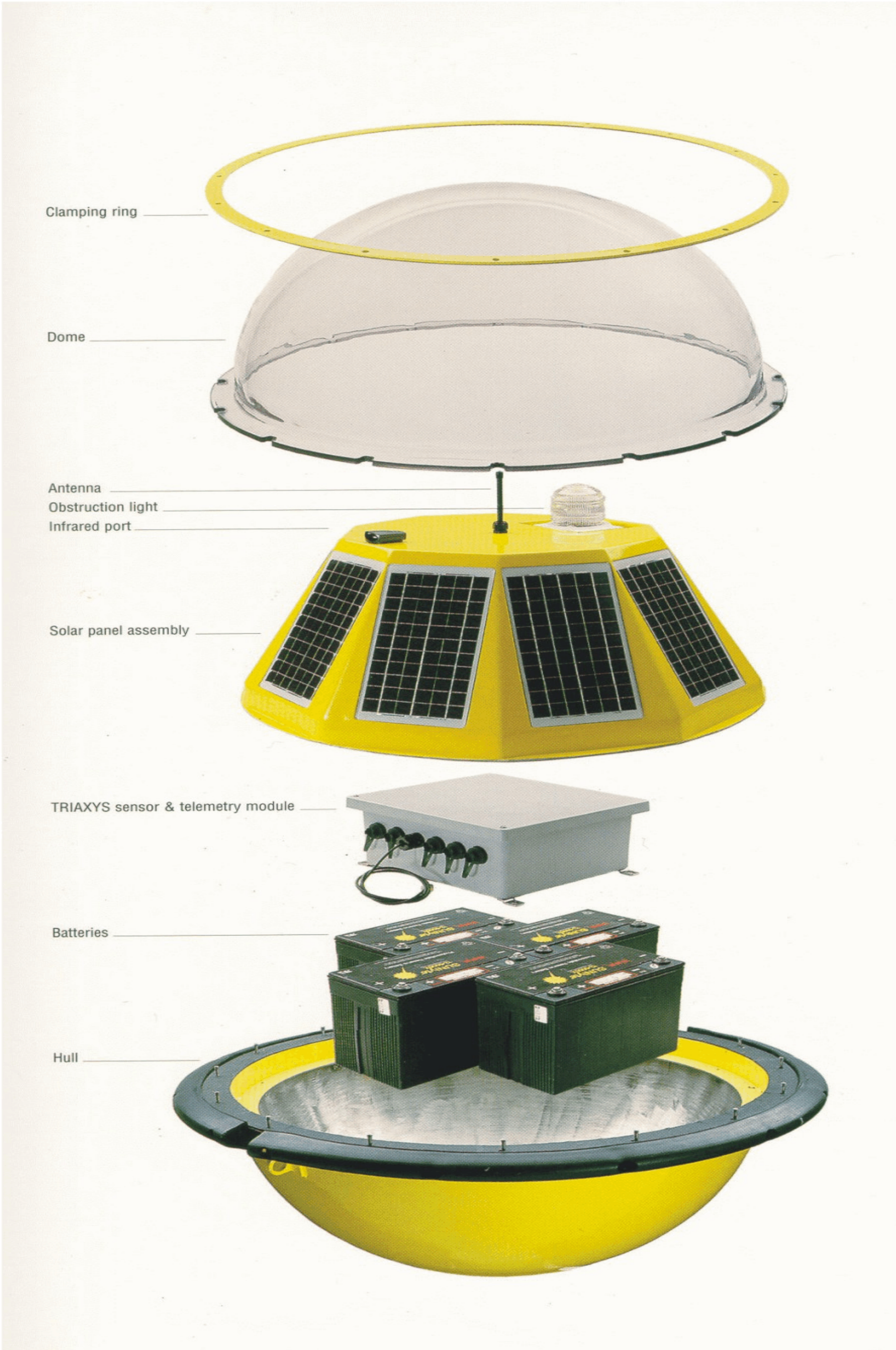

Figure 1. Major components of Triaxys directional wave buoy [5]

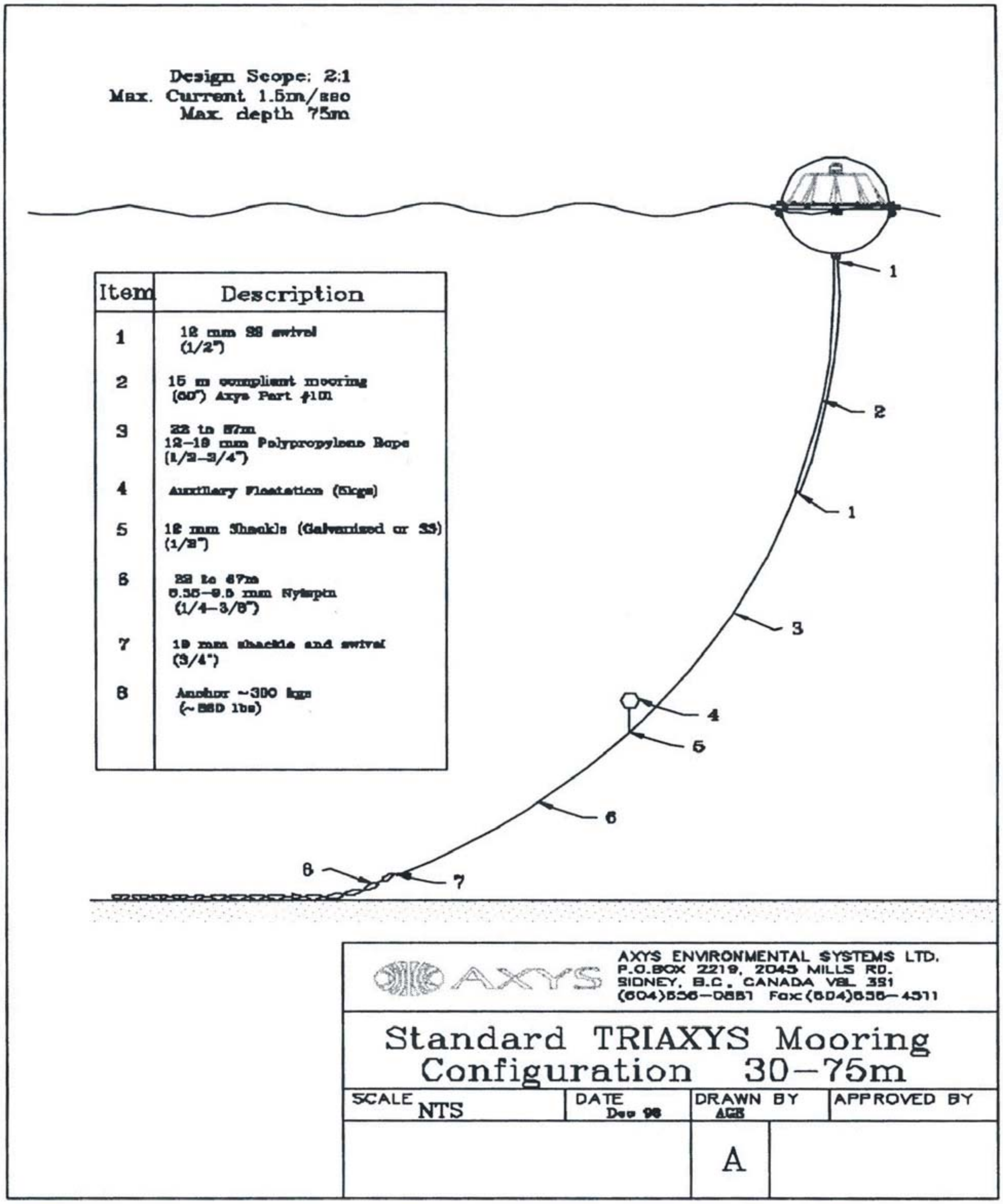

Figure 2. Triaxys standard mooring configuration in deep water [5]

Table 1. Triaxys Directional Wave Monitoring System Specifications [5]

ITEM	SPECIFICATION		
Physical Description			
Diameter	nominal, around bumper - 1.10 m (43.5 inches) O.D.		
	Stainless steel hull - 0.91 m (36 inches)		
Weight	197 kg (including 4 batteries); 90 kg (excluding batteries)		
Purge port	3/4" - 16 UNF with Swagelock hex plug		
Obstruction light	Amber LED source; programmable flash sequence, three miles visibility		
Materials			
Hull	Stainless steel		
Dome	Polycarbonate Cyrolon ZX (tested to ASMT D3763 and ISO 6603-2 impact specifications)		
Solar panel assembly	Fiberglass over foam		
Clamping ring	Stainless steel		
Sensors/Processor			
Water temperature	Thermilinear composite network		
Accelerometers	Flexure suspension servo (range: ± 2g)		
Rate	Piezoelectric vibrating gyroscope (max. angular velocity: ± 80 deg. /s)		
Compass	Microprocessor controlled fluxgate (accuracy: ± 0.5 deg.)		
A/D and sampling frequency	8 channel 14 bit at 4 Hz		
Microprocessor	PC104 and 80C552		
GPS	12 channels		
Resolution/Accuracy			
	Range	Resolution	Accuracy
Heave	± 20 m	0.01 m	better than 2%
Period	1.56 to 33.33 seconds		
Direction	0 to 360 degrees		± 1 degree
Water temperature	-5 to +50 deg. C		± 0.1 degree C

ITEM	SPECIFICATION
Power System	
Operational system voltage	11.0 to 14.1 VDC
Batteries	4 @ GNB SunLyte 5000X 12 volt, 100 amp hr
Solar panels	10 @ 6 watt Siemens SM6
Smart charger	Sunsaver-6
On/off switch	**Turn buoy on when Magnetic Key is removed**
Telemetry	
30 to 50 MHz	Synthesized VHF transmitter (standard)
Effective radiated output	0.5 watts
Data Format	Binary transmission
Transmission rate	2400 Baud
Maximum range (VHF line-of- sight)	16 km (10 miles) over water (less over land)
Optional transmission	ARGOS
Optional watch-circle beacon	ARGOS or INMARSAT D+
Input/output	power and data through Belgian connector; frequency bands up to 123
Operating temperature	-30 to +60 degree C
Storage/transit temperature	-40 to +70 degree C
Data transmission	standard: multiple transmissions of each data set; directional wave characteristics and spectra; wave statistics; SST; battery voltage; solar current; error checking. optional: VHF (30-39 MHz, or 39-50 MHz, synthesized frequency selection), or ARGOS; real-time; programmable configuration communication: 19,200 baud, 8 bits, 1 stop, no parity
Power	supply: +12 to 14 VDC consumption: 0.134 amp-hr per 20-min sample transmission: 3 watts @ 12 VDC; VHF range to 10 nautical miles battery: 4 gel cells solar panel: 10 @ 6 watts
Position	GPS/ARGO (optional)

Table 2. Acceptable ranges for sensors at rest position (still, level, and upright)

Sensor	Range	Check Procedure
Compass Heading	0 to 359	check against hand held compass
Accelerometer X	near 0 $\pm$ 0.06 g's	x axis is north
Accelerometer Y	near 0 $\pm$ 0.06 g's	y axis is east
Accelerometer Z	near -1 $\pm$ 0.06 g's	z axis is positive downward
Water Temperature	-5°C to 50°C (0 to 25°C with dummy plug)	check with measured value of air temperature
System Voltage	11 to 14.1 volts	measure before installing the dome
System Current[1]	20 to 50 milliamps	PC104, motion sensors & transmitter not powered
	550 to 750 milliamps	PC-104 only powered
	120 to 200 milliamps	motion sensors only powered
	100 to 200 milliamps	transmitter only, powered on but not transmitting
Rate Gyro X	near 0 $\pm$ 6 °/sec	
Rate Gyro Y	near 0 $\pm$ 6 °/sec	
Rate Gyro Z	near 0 $\pm$ 6 °/sec	
Solar Current	1.1 to 1.5 amps	bright sunshine
	0.5 to 0.8 amps	shade
	0.0 to 0.2 amps	overcast
Battery Current[2]	-1.0 to +1.8 amps	battery current = solar current - system current, check that the battery current is correct as per the above formula

Notes:
1. System current = Solar current - Battery current. If there is no solar current then the Battery current (negative) will approximately equal the System current (positive).
2. These values for currents assume daylight conditions and do not include any current draw that might be associated with the operation of the light.

Table 3. Acceptable ranges for accelerometers at static tilt position

Sensor	**Range in g** ($\pm$ 0.03g)	**Procedure**
Accelerometer X	-sin θ (for θ = 20°, VALUE -	North down
Accelerometer Y	0	North down
Accelerometer Z	-cos θ (for θ = 20°, VALUE -	North down
Accelerometer X	+sin θ (for θ = 20°, VALUE	North up
Accelerometer Y	0	North up
Accelerometer Z	-cos θ (for θ = 20°, VALUE -	North up
Accelerometer X	0	West up
Accelerometer Y	-sin θ (for θ = 20°, VALUE -	West up
Accelerometer Z	-cos θ (for θ = 20°, VALUE -	West up
Accelerometer X	0	West down
Accelerometer Y	+sin θ (for θ = 20°, VALUE	West down
Accelerometer Z	-cos θ (for θ = 20°, VALUE -	West down

3. Test and Evaluation

3.1 Scope

Since the Triaxys system is being considered for deployment as an operational system, the focus of the tests will be:

A. to verify system performance and functionality of subsystems.

B. to demonstrate the suitability of the system to NOS applications.

C. to establish that the data quality satisfies NOS requirements.

3.2 Approaches

3.2.1 General Guidelines

The followings are general guidelines for tests and evaluations:

A. System to be tested and evaluated includes all hardware, software, internal and external interfaces and documents.

B. System will be inspected/checked after delivery from manufacturer, tested/checked prior to deployment, and calibrated/tested after 1-2 years of service.

C. Test requirements, plans, and procedures will be evaluated to ensure compatibility between tests.

D. Determine whether the delivered system meets NOS requirements.

E. Existing well accepted instruments and methods will be used as references for evaluating the performance of the instrument and its components.

F. Components testing will be kept to a minimum whenever valid test data exist. Duplication of testing will be kept to minimum (except those for deployment and acceptance).

G. Data to be evaluated consists of those obtained by manufacturers, other users, from laboratory, field tests, and service records.

H. It is assumed that the manufacturer has conducted all necessary design tests after burn-in, prior to delivery. These include functional tests in service configurations, environmental tests under extreme conditions, reliability tests, maintainability tests, subsystem integration tests. These tests will not be repeated unless test records are not available or new design modifications are made. Sample manufacturer's factory test records (for the NOS Buoy S/N TAB00311) are shown in Appendix A.

I. Documents will be reviewed by operating personnel and users for accuracy and clarity.

J. Software will be reviewed and tested for accuracy and functionality.

3.2.2 Type of Test

Several types of test will be conducted in order to meet the test and evaluation objectives. These are described below. A description of some of the associated test facilities are given in Section 3.5

A. Acceptance Test

An acceptance test will be performed after receiving of product. It will be done mostly in the laboratory to verify that the delivered system meets contractual requirements. Recommended tests include:

a) Sensor range value test under static level and tilt positions (Tables 2 and 3). Fig. 3 shows the buoy convention for heading, and roll axes used in the range value tests.

b) Visual inspections (S/N of major components, cleanness and scratches, and cracks around the dome flange area; lifting bridle, magnetic key, and other attachments).

c) Verification and documentation of contractor provided items (S/N and other pertinent data of hardware, software, user's manual, spares kit, IR device/harness, antenna cable and 3 db antenna, etc.)

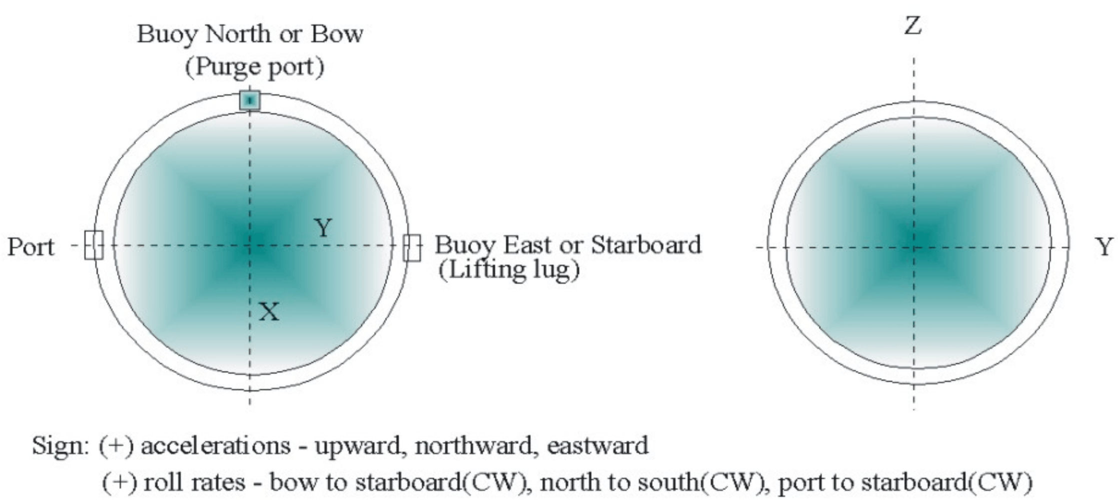

Figure 3. Buoy conventions for heading and roll axes

B. Subsystem/Module/Component Test

This is to verify that subsystems, modules, components, and interfaces function properly. These will be conducted when anticipated operational conditions are close to the limits of the specified range (such as operating temperature), a new design modification or change has been made, the sensors' function needs to be validated, or special issues identified in the field tests are to be investigated. Recommended tests include:

a) Validation of sensor range values under static level and tilt positions.

b) Validation of angular rate gyros via pendulum test (Fig. 4).

Sample form is shown in Section 7.4 of Triaxys sensor validation sheets in Appendix B.

c) Calibration of wave height and period measurements using rotating arm facility (or Rotating/or Swing Calibrator, Fig. 5).

It is recommended that tests (a) and (b) be conducted whenever there is concern about the functions of the system. Test (c) should be performed by the manufacturer prior to return from repair.

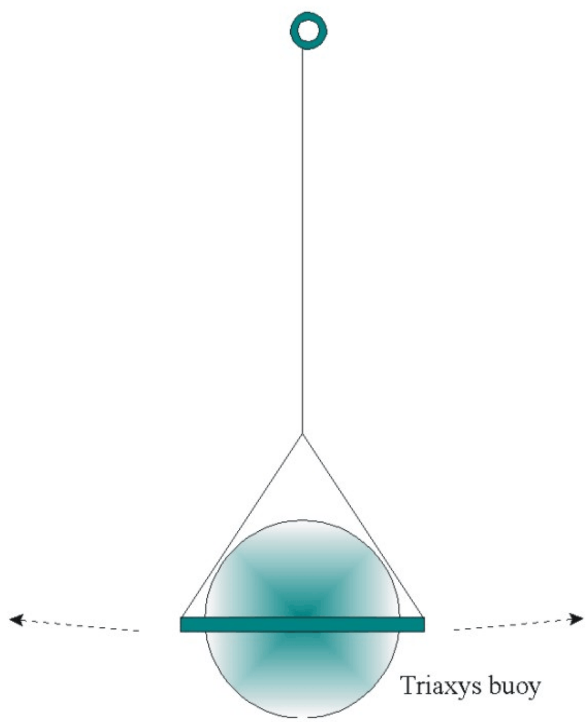

Figure 4. Pendulum test setup

d) Wave processor (PC104) test – This is to check the processor for accuracy. It is desirable to check the processor outputs using simulated sensor inputs (compass, accelerometers and angular rates). The Triaxys Wave Processing Diagnostics Menu allows user to check the processor using simulated sinusoidal wave amplitudes and periods.

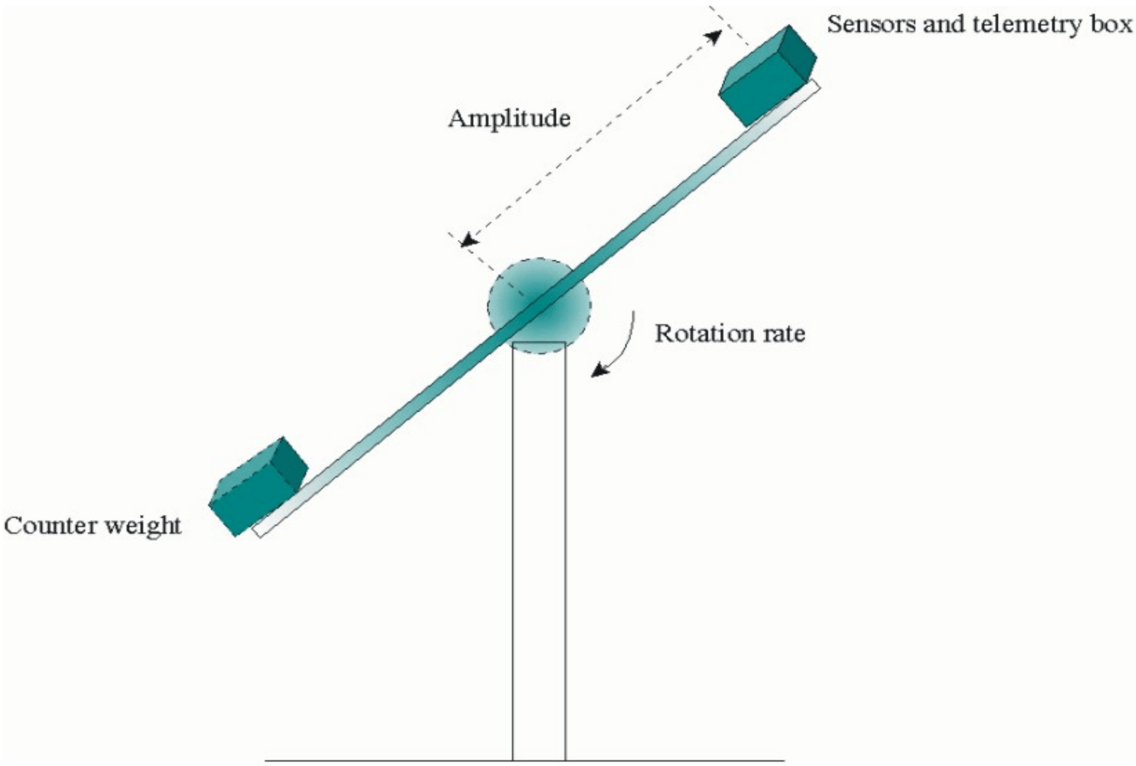

Figure 5. Rotating arm test (swing calibrator) setup

e) Radio base station subsystem test/check. The subsystem includes the Triaxys Digital Receiver (TDR), antenna, and associated software. If the received signal is affected by RF interference the antenna should be relocated and/or reconfigured. Typical acceptable background noise level is around 2 dB and signal strength is around 3 dB. The VHF radio operating frequency is set at the factory (42.6 MHz for NOS buoy S/N TAB00311). This value is indicated on the receiver panel. For a minor frequency change, a channel change is sufficient. When a major frequency shift occurs, a complete realignment of the radio should be done at the factory.

The manufacturer should be contacted for problems related to other subsystems such as ARGOS and GPS.

C. System Performance Test
Inter comparison tests using accepted reference instruments provide the ultimate performance validation. System performance tests will be conducted in event driven pilot projects due to limitations in budget and staff resources. As shown in Table 3, the planned system performance tests are:

a) Field tests at Duck, NC - A cooperative effort with NDBC and Army Corps of Engineers' Field Research Facility (FRF) will enable us to inter compare with FRF's reference wave instruments in high energy coastal area. Ancillary data include wind, current (low) and temperature.

b) Field deployments in the Chesapeake Bay - This is to support marsh restoration, wave modeling, hazardous material spill analysis, and to evaluate advanced underwater data telemetry technology through the NOS Partnership program. Ancillary data include water level and current measurements. NOS' tide station and other bay monitoring network (such as EPA and University of Maryland at Hines Point) in the vicinity provide other environmental data such as wind, air and water temperature.

c) Other special wave measurement projects - There are a few other PORTS® sites and coastal navigation waterways where wave information is of importance to mariners. These include, Los Angles/Long Beach harbor complex, Puget Sound, Chesapeake Bay entrance, Cape Cod Canal, etc. and are potential test sites when resources are available.

The varied environmental conditions at these sites offer excellent opportunity to fully evaluate the Triaxys' performance.

D. Data Quality Assurance Test
The time series data and results of statistical analyses obtained from tests will be studied to assess the data quality.

To facilitate data processing and analysis and maintain high quality of data the following tasks should be performed.

a) Develop automated methods and procedures for real-time data quality check, analysis (wave energy spectra, zero crossing, and statistics) and data storage.

b) Analyze failure and faults to identify causes and to develop correction procedures.

c) Perform Inter comparisons with reference instruments and/or wave model hindcasts.

d) Develop methods and formats for data products and dissemination.

E. Operational Test
This is to verify that the delivered system performs its required functions in a wide range of NOS operational environments and situations when operated and maintained by NOS personnel. To ensure that system is well prepared for the test, a manufacturer recommended field checkout procedure (Appendix C) should be followed prior to each deployment. Detailed setup and check out procedures are also described in Section 8 of the user's manual [5].

3.3 System Issues to Be Verified

The unique PORTS® requirements dictate that certain system performance and design issues be evaluated. These include:

A. Measurement accuracy

a) Current effect - measurements in strong currents where buoy is in a pulled down altitude,

b) Frequency response to long waves - a common concern for this type of buoy.

B. Reliability of mechanical components

a) Rubber fender attachment, hull leakage, fouling and corrosion, and elastic mooring cord.

b) Mooring dynamic performance and design variations for different site and environment (such as requirement of sub-surface floatation in deeper water).

C. Reliability of sensing and electrical components

a) Flash light and sensor assembly.

b) Antenna and other data transmission system components.

D. Power supply

a) Performance of solar power system in wave environment.

b) Efficiency of battery charging

E. Mooring design and analysis

Since the mooring dynamics will affect the Triaxys buoy response characteristics, a capability of conducting mooring analysis and modify design to adapt to different deployment site is needed.

F. GPS positioning system

a) Multi-path problem due to low antenna elevation and wave environment.

3.4 Responsibility

CO-OPS personnel will be responsible for preparing and approval test plans, conducting and /or monitoring tests, reviewing test results, and conducting or supporting operational tests.

3.5 Test Facilities

Facilities that are applicable to the various tests described in above sections include:

A. Environmental chamber test - to test system or component in simulate temperature and humidity conditions. Available facilities include the NWS' Sterling laboratory in Sterling, VA.

B. Static tests - to validate Triaxys sensor function under static conditions (see Appendix B). These tests can be easily done with buoy placed on the shipping cradle or similar structure.

C. Pendulum test - to validate sensor function under quasi-dynamic conditions (see Appendix B). Fig. 4 illustrates a simple setup for this test.

D. Rotating arm (or swing calibrator) test - to validate wave measurement accuracy under simulated sinusoidal wave conditions. Fig. 5 illustrates a conceptual setup configuration. Various wave amplitudes (maximum value is limited by the available facility), periods (short to long in order to check the sensitivity and stability of accelerometers and integrators), and directions (via orientation of the sensor/telemetry box, limited) can be simulated. Such equipment are available at NDBC, AXYS (amplitude: 2m, periods: 5-25s), and Scripps Institute of Oceanography (to be constructed, amplitude: 6m).

E. Wave basin test - Laboratory wave basins with appropriate water depth (say, 6m and above) could be used for testes under controlled wave conditions. These include the U.S. naval David Taylor Model Basin (DTMB, 110m long x 73 m wide x 6.1 m deep) at Cardercok, MD, deep water wave basin at Texas A&M University at College Station, and wave tank (76m long x 10 m wide x 5.4m deep, with 9 m pit) at CBI Industries, Inc.

3.6 Schedule

The planed and anticipated events for field testing are shown in Table 4.

Table 4 Planed and anticipated field testing events

Deployment/Test Site	Reference Instruments	Environment	Partnership
Duck, NC 12/01-3/02	Waverider, pressure transducer array, Baylor staff	Depth 8m, mean tide range: 1m Alongshore currents: <30 cm/s	NDVC, USACE
Chesapeake Bay Barren Is. (10/9/02-1/9/03) Eastern Neck (1/22-4/22/03) Taylor Is. (4/1-8/31) Bay entrance (?)	ADCP and NDBC buoy near the Bay entrance	Depth: 6 – 10m Mean tide range: 1m Mean tidal currents: <50 cm/s	NDBC, U. MD
Puget Sound, WA (?)	ADCP	Depth: Deep Mean tide range: to 3m, Mean tidal currents: 1.5 m/s	TBD
LA/LB Harbor (?)	ADCP	Depth: 15m Mean tide range: 1.2 mean tidal currents: < 50 cm/s	TBD
Cape Cod Canal, MA	ADCP	Depth:	TBD

4. DOCUMENTATION, REVIEW, AND PLANNING

To achieve the full value of test and evaluation program, the following activities should be performed.

4.1 Test Report

At the conclusion of the tests appropriate documents such as a test report and evaluation sheets should be completed. Contents should include test results, notes and comments which will be helpful in identifying problem areas and formulate future solutions.

4.2 Review and Planning

Test results will be reviewed by a panel consisting of users (NOS/CO-OPS) and invited advisors (such as NDBC, Triaxys, USACE/FRF, U. of Penn, U.S. Navy, and other users). Corrective and preventative actions will be developed by the CO-OPS review panel and recommended to the manufacturer and field personnel for implementation.

ACKNOWLEDGMENTS

Several of my colleagues contributed to this work: Kristen Tronvig arranged funds for the purchase of NOS' first Triaxys buoy; Mark Bushnell acquired the system, Maureen Kenny, Kristen Tronvig, Kate Bosley, Mark Bushnell, and Tom Mero reviewed the manuscript; and Brenda Via and Gina Stoney provided publication support. The writer is also grateful to Dr. C. C. Teng of NDBC and William Birkemeier of the Field Research Facility of the Coastal Engineering Research Center (CERC), U.S. Army Corps of Engineers for useful discussions.

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4. USACE/SOI network (web site: cdip.ucsd.edu)
5. Louisiana State University, Coastal Studies Institute: Wave-Current –Surge Information System (WAVCIS) (web site: wavcis.csi.isu.edu)
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APPENDICES

A. Triaxys Factory Check Sheets
B. Triaxys Sensor Validation Sheets
C. Triaxys Field Checkout/deployment Sheets

A. Triaxys factory check sheets

AXYS	**Axys Technologies Inc.**	**0240010C.doc** **Check Sheets** **TRIAXYS™ Wave Buoy System Assembly Record**	**8/22/2001** **Page 1 of 3** Template #: QT10-01-02.doc

When printed, make sure you are using the most current revision of this document

1.0	**Purpose:**	To record assembly and testing of complete Buoy System
2.0	**Part:**	TRIAXYS™ Wave Buoy System
3.0	**Scope:**	Assembly Record of TRIAXYS™ Wave Buoy
4.0	**References**	
	02300XXQ	TRIAXYS™ Wave Buoy Final Quality Inspection
	02400XXE	Work Instructions for the Vacuum Test
5.0	**Definitions:**	None
6.0	**Responsibilities:**	Production Department
7.0	**Process:**	This check is performed during the TRIAXYS™ Buoy Final Assembly Process

TAT

Serial Number: TAT 007 Revision Number: 0 Antenna Type: Rubber Duck

			Pass
Solar Panel Assembly assembled and mounted as per specs			☑
TRIAXYS Power Interface S/N: 27		Revision Number: 4	
Solar Panels Connected			☑
System Charging			☑
Navigation Light	Default Flash Sequence: 9E = GpFl5 in 20 sec	Connected	☑
GPS Manufacturer/Model Garmin	GPS Serial Number 63415639	Installed	☑
JetEye IR Port		Working	☑

TDR

Serial Number: TDR 00330

TDR Power Supply	Manufacturer/Model		Serial Number 003	
Rx Radio	Manufacturer/Model VR-3H045-SW	S/N 10126		Frequency 46.2 MHz
Modem	Manufacturer/Model TS2000	S/N 02234		
Cell Phone	Manufacturer/Model N/A	S/N		Phone #
Rx Antenna	Manufacturer/Model Cushcraft	Gain		Frequency 46.2 MHz

TAS

Serial Number: TAS 00370 **Type of TAS:** Triaxys

Telemetry Particulars

Tx Radio	Manufacturer/Model VT 3H045-SWA300	S/N 10116	Frequency 46.2 MHz
Modem	Manufacturer/Model TS 2000	S/N 02201	
Cell Phone	Manufacturer/Model	S/N N/A	Phone #
Argos	Manufacturer/Model Seimac wildcat	S/N M622	Program ID 25449
Tx Antenna	Manufacturer/Model Rubberduck	Gain	Frequency 46.2 MHz

Sensor	Range	Value	Procedure	Pass
Compass Heading	0 to 359		Check against hand held compass	☑
Accelerometer X	Near 0 ± 0.06g's			☑
Accelerometer Y	Near 0 ± 0.06g's			☑
Accelerometer Z	Near -1 ± 0.06g's			☑
Water Temp	-5 C to 50 C			☑
System Voltage	11 to 14.1 volts			☑
System Current	20 - 50 milliamps		PC104, Motion sensors & Tx not powered	☑
	550 - 750 milliamps		PC-104 only powered	☑
	120 - 200 milliamps		Motion Sensors only powered	☑
	100 - 200 milliamps		Tx Circuit Board only powered	☑
Rate Gyro X	Near 0 ± 6 °/sec			☑
Rate Gyro Y	Near 0 ± 6 °/sec			☑
Rate Gyro Z	Near 0 ± 6 °/sec			☑
Solar Current	0 to 1.8 amps		Overcast ~0.1, Shade ~0.6, Bright Sunshine ~1.2	☑

Battery Current	-1.0 amps to +1.8 amps	Battery Current= Solar Current - System Current Check that the Battery Current is correct as per the above formula. If there is no Solar Current then the Battery Current will approx. equal the System Current	☑

TAB

Serial Number: TAB 00311 — **Serial Number Plate Installed** ☑

Batteries — **Pass**

Battery	S/N		Last Date Charged		Estimated Charge	Pass
Battery #1 S/N:	00198 0024	Last Date Charged	11 Oct 00	Estimated Charge:	90 %	☑
Battery #2 S/N:	00198 0022	Last Date Charged	10 oct 00	Estimated Charge:	90 %	☑
Battery #3 S/N:	00 1970080	Last Date Charged	5 oct 00	Estimated Charge:	90 %	☑
Battery #4 S/N:	00 1970076	Last Date Charged	10 oct 00	Estimated Charge:	90 %	☑

Nov 6 /01 fully charged 12.9V

Mechanical Systems and other tests — **Pass**

		Pass
Swing Test (see records)		☑
Radio Power	Forward: 2.5 Watts (2.5 w) Reflected: 0.1 Watts (0.2 21/09/01)	☑
Visual Inspection (clean and no visible scratches)		☑
Polycarbonate Dome Torqued to Specs		☑
Four Quadrant Compass Check Completed		☑
Vacuum Test		☑
Purge Port Plug replaced following Vacuum Test and torqued to 20 Nm		☑
Lifting Bridle Installed and shackles seized		☑
Ratchet Strap Installed		☑
Shipping Palette Complete		☑
Magnetic Key Installed, Buoy turned OFF		☑
Embroidered Cloth Cover Installed		☑

	Pass
1. 02051XX Is the TRIAXYS – Data Receiving Package (WaveView, antenna cable and 3 dB antenna) included?	☑
2. 02437XX Is the TRIAXYS – Jeteye IR Device/Harness (modified for 19200 baud) included?	☑
3. 02202XX Is the TRIAXYS – Spares Kit included?	☑
4. 02261XX Is the TRIAXYS Directional Wave Buoy Users Manual included? Rev# 7 Q-Pulse Rev# 7 ?	☑
5. 02261XX Is the Addendum (yellow) inserted at beginning of the Manual? Rev# 4 Q-Pulse Rev# 4 ?	☑
6. 02398XX Is the section "Model Identification by Serial Numbers" of Page i of the TRIAXYS Directional Wave Buoy Users Manual completed?	☑
7. 02401XX Is a copy of the Swing Test included in the Manual?	☑

Setup Parameters:

AC INT: 60 MIN; AC DUR: 24 MIN; AC START OFFSET: 0
Station ID: TAS 00370; Transmission Repeat Times: 1
GPS-ARGOS Watch Circle Option: N/A DISABLED
Data Logging: Raw: YES; Processed: YES; WaveView Ver: 2.2.5
Argos enabled (but not during acquisition duration), if applicable: DISABLED

Data:

Printout of Status & Wave Statistics History from WaveView, shows 60 hours of continuous data. ☑

Have WaveView files from burn in been copied to the TAB or TAS Q:/Burn in tests/TRIAXYS/ folder? ☑

Printout of system output when in Run mode ☑

If installed, check the existence of all the files from the 60 hour burn in test are on Flash RAM ☑

If installed, check the existence of all the files from the 60 hour burn in test are on the hard drive ☑

VHF (Received ☑ Hexadecimal or ☐ Binary data from WaveView™) ☑

ARGOS (Production Manager has access to this data) ☑

Other (define) ☐

Notes:

8.0 Records

8.1 Records are maintained as per QP16-01 Retention of Quality Records

	Production Technician	Production Manager
Initials	[signature]	[signature]
Date	Nov 6 / 2001	Nov 7/2001

B. Triaxys sensor validation sheets

AXYS	Axys Technologies Inc.	0260701E.DOC Work Instructions TRIAXYS™ Sensor Validation **When printed, make sure you are using the most current revision of this document**	11/20/2002 Page 1 of 4 Template # QT05-03-04

1.0 **Purpose:** To confirm that the TRIAXYS™ Buoy is within specification.

2.0 **Part:** TRIAXYS™ Buoy

3.0 **Scope:** Because the buoy is comprised of solid-state sensors, there is no need for re-calibration as long as the values from the sensors are within the ranges indicated by the following tests.

4.0 **References :** TRIAXYS™ Directional Wave Buoy User's Manual

5.0 **Definitions:** None

6.0 **Responsibilities:** It is the responsibility of the user of the TRIAXYS™ Buoy to ensure that the buoy is validated prior to a deployment.

7.0 **Process:** For all the following tests the TRIAXYS™ buoy must be turned on (magnetic key removed) and the data coming from the IR port captured.

All of the following tests are performed with the buoy displaying the following menu:

2. Real Time System Sensors Display at 1 Hz, under menu **6. Systems Diagnostics** of the TRIAXYS **Main Menu.**

TAB Serial Number: TAB ______

7.1 Test #1: Compass

With the buoy in a level horizontal position, turn the buoy through the four quadrants (4 at 90 degrees) and check that the direction shown on the compass changes accordingly.

Pass ☐

7.2 Test #2: Whole System

With the buoy at rest in a static, upright and level position, check that the values from the sensors are within the given ranges:

Sensor	Range	Value	Procedure	Pass
Compass Heading	0 to 359		Check against hand held compass & Buoy N	☐
Accelerometer X	Near 0 ± 0.03g			☐
Accelerometer Y	Near 0 ± 0.03g			☐
Accelerometer Z	Near -1 ± 0.03g			☐
Water Temp	-5º C to 50º C		With the buoy out of the water, this will correspond closely to the ambient air temperature	☐
System Voltage	11 to 14.1 volts			☐
System Current*	20 - 50 milliamps		PC104, Motion sensors & Radio **not powered**	☐

	550 - 750 milliamps		PC-104 only powered (Hit P to toggle)	☐
	120 - 200 milliamps		Motion Sensors only powered (Hit M to toggle)	☐
	100 - 200 milliamps		Transmitter (Radio) only powered (Hit R to Toggle)	☐
Rate Gyro X	Near 0 ± 2 º/sec			☐
Rate Gyro Y	Near 0 ± 2 º/sec			☐
Rate Gyro Z	Near 0 ± 2 º/sec			☐
Solar Current	0 to 1.8 amps		Overcast ~0.1, Shade ~0.6, Bright Sun ~1.2	☐
Battery Current	-1.0 amps to +1.8 amps		Battery Current=Solar Current -System Current Check that the Battery Current is correct as per the above formula. If there is no Solar Current then the Battery Current will approximately equal the System Current	☐

***Use menu 3. System Voltage and Current Display, under menu 6. Systems Diagnostics of the TRIAXYS Main Menu.**

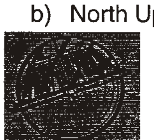
7.3 Test#3: Accelerometers

a) North Down:

Tilt the North edge (Purge Port) of the buoy downwards through an angle θ. If the buoy is on its shipping cradle, it can be tilted to ~20°, at which point the mooring tab will contact the inside edge of the cradle!

Sensor	**Range in g** (± 0.03g)	**Displayed Value in g**	**PASS**
Accel X	-sinθ (for θ = 20°, value = -0.34)		☐
Accel Y	0		☐
Accel Z	-cosθ (for θ = 20°, value = -0.94)		☐

b) North Up



Tilt the North edge (Purge Port) of the buoy upwards through an angle θ. If the buoy is on its shipping cradle, it can be tilted to ~20°, at which point the mooring tab will contact the inside edge of the cradle!

Sensor	**Range in g** (± 0.03g)	**Displayed Value in g**	**PASS**
Accel X	+sinθ (for θ = 20°, value = +0.34)		☐
Accel Y	0		☐
Accel Z	-cosθ (for θ = 20°, value = -0.94)		☐

b) Pull the buoy towards Buoy North (Purge Port) by approximately half a diameter. Release the buoy and let it swing naturally in a pendulum mode until it comes to a rest. When swinging towards Buoy North the sign is positive, and when swinging toward Buoy South it is negative.

Sensor	Range in °/s (± 2 °/s)	Displayed Value in °/s	PASS
Rate Gyro X	0		☐
Rate Gyro Y	~+5°/s to +20°/s swinging towards Buoy North ~-5°/s to -20°/s swinging towards Buoy South		☐
Rate Gyro Z	0		☐

c) Pull the buoy towards Buoy East (in line with the lifting lugs) by approximately half a diameter. Release the buoy and let it swing naturally in a pendulum mode until it comes to a rest. When swinging towards Buoy West the sign is positive, and when swinging toward Buoy East is negative.

Sensor	Range in °/s (± 2 °/s)	Displayed Value in °/s	PASS
Rate Gyro X	~+5°/s to +20°/s swinging towards Buoy West ~-5°/s to -20°/s swinging towards Buoy East		☐
Rate Gyro Y	0		☐
Rate Gyro Z	0		☐

Note: CW Clockwise; CCW Counterclockwise.

Date of Tests ___________ Test Location ___________________________

Approval Name ________________ Approval Signature______________________

8.0 Records

8.1 It is recommended that a signed and dated copy of this document is forwarded to Axys Environmental Systems (email: systems@axys.com or fax: 250-655-5856) for inclusion in the Quality Records for the buoy

8.2 This document, signed and dated, can be stored as a Quality Record for the user of the buoy.

C. Triaxys field checkout/deployment sheets

TRIAXYS™ Directional Wave Buoy Manual, 0226108Z.doc, November 2001

APPENDIX C: SAMPLE TRIAXYS™ Buoy Field Checkout / Deployment Record

General				
TRIAXYS Serial Number:		TDR S/N:		
Form Completed by:		WaveView Version:		
Date:				
Deployment Location				
Functional Checkout:				
KVH Compass				
Readings (0):	Readings (90):	Readings (180):	Readings (270):	Passed:
Rotate buoy through a full circle checking the output of buoy North against a hand compass.				
Accelerometers				
X Axis :	(near 0 ± 0.06 g's)			Passed:
Y Axis :	(near 0 ± 0.06 g's)			Passed:
Z Axis (Down):	(near -1 ± 0.06 g's)			Passed:
Rate Gyros				
X Axis :	(near 0 ± 6°/sec)			Passed:
Y Axis :	(near 0 ± 6°/sec)			Passed:
Z Axis (Down):	(near 0 ± 6°/sec)			Passed:
Other Devices				
Buoy Hull Water Temperature Test:		Ambient Temp.		Passed:
Navigation Light Flash Sequence:		Settings:	Lamp Test:	Passed:
GPS: **Y/N**	S/N:	Local Position: Lat-	Long-	Passed:
IR Port				Passed:
Software Setup and Tests				
Station ID:				Passed:
ACINT (mins):	ACDUR (mins):	ACSTART Offset (mins):		Checked:
System Voltage (11.0-14.0):		System Current (0.03-1.15):		Passed:
Battery Current (0.03-1.15):		Solar Current (0.0-1.5):		Passed:
System Time and Date Set:			Time Zone:	Set :
Watch Circle Enabled: **Y / N**		Watch Circle Diameter:	m	Set:
Boottimes Reset to Zero				Zeroed:
Real Time Sensor				Checked:
Internal Data Logger Installed: **Y / N**		Type/Size: MB		Checked:
Old Data Files Removed: **Y / N**		First Logged File Time/Date:		
Captured Setup File:			File:	Y/N
Captured Sample Record / Results:			File":	Y/N
Telemetry				
Radio Type:	Frequency:	Tx Repeat:	Data Tests: **Y / N**	Passed:
ARGOS Tx: **Y / N**	Continuous: **Y / N**	ID: Rep Rate:	sec	Passed:
INMARSAT D+:**Y / N**	ID:	Poll Msg #____ Rep Rate:	min	Passed:
Items To Be Checked if Dome Removed				
Battery Brackets Secure		Processor Module Secure		
Power/Solar Leads Connectors Secure		Navigation Lamp Connected		
All Sensors Connected		Antenna Connected		
Battery #1 SN:	Voltage:			
Battery #2 SN:	Voltage:			
Battery #3 SN:	Voltage:			
Battery #4 SN:	Voltage:			
Mooring Components				
Compliant Mooring Section				Passed:
Synthetic Mooring Segment 1				Passed:
Synthetic Mooring Segment 2				Passed:
Connectors/Shackles				Passed:
Anchor: kgs				Passed:

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