A Framework for the Laboratory Testing of Eulerian Current Measuring Devices

Edited By

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Abstract and Foreword

THE DEVELOPMENT of testing techniques and procedures required to understand the performance of devices used to measure water currents has proven to be one of the most difficult and challenging tasks that the oceanographic community faces. It has long been recognized that some type of controllable relative water motion was a necessary element in the process of determining the accuracy of a current meter. A widely accepted solution is the towing tank where a current meter fastened to a moving carriage is moved through "still" water. A simple measurement of carriage speed over the ground compared to the current meter's flow measurement gives an indication of the accuracy of the device. Although this approach satisfied many, a sense that this technique was not sufficient spawned a few short-lived attempts at simulating time-varying flow conditions and developing deterministic models (transfer functions) for the response of inertial transducers. In addition, mathematical modeling of the motion of buoy moorings was attempted by a variety of investigators. In the late 1960's and early 1970's, the response of a current meter to the complex time-varying ocean environment became a major issue within the oceanographic community. It was clear that this information could not be obtained by simple steady-flow tow tank testing and that either dynamic controllable techniques must be developed or our ability to characterize the measurement environment must be improved.

The driving force behind this evolution has come from the scientific segment of the community. Commercial current meter manufacturers, although aware of the evolution, have had little incentive from their market to provide specific information about accuracy of current meters in dynamic environments. Steady flow tow testing was usually adequate, but not necessary for all applications. This was, in a sense, fortunate for the manufacturers since the relatively small current measurement instrument market precluded capital investment in large testing facilities. Hence, for a manufacturer to keep his product within a competitive price range, he simply could not afford to carry out a comprehensive performance testing program.

Times are changing, however. The community as a whole is becoming more aware of the need for some certification of instrument performance. We are slowly advancing our capability to both simulate the environment in the laboratory and characterize it *in situ*. This advancing engineering capability and its impact on the manufacturing community must be evaluated. The notion of standards relative to current measurement technology is being discussed and must be carefully considered. It is important that these issues and problems be addressed and solved collectively on a community-wide basis. To this end, the Current Measurement Technology Committee (CMTC) has been established within the IEEE Council on Oceanic Engineering to provide a continuous forum in the marine community for addressing the issues and problems related to technology for measuring water currents. The following report has been prepared under the auspices of the CMTC. It is intended to convey to the reader a sense of the philosophy currently being applied to current meter testing as well as a menu or framework of laboratory tests that experience has shown to be useful in understanding the performance of Eulerian current measuring devices.

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Contents

I

Standards for Current Measurement Technology

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Measurements of ocean currents by different investigators using different equipment, though taken at the same relative time, place, and depth in the ocean, will often yield different results. The differences may exceed the "error limits" assigned by the investigators. Moreover, the differences may exceed the "error" of the particular current meter(s) as determined from steady flow laboratory calibrations. Elaborate laboratory calibrations in dynamically varying flow conditions may yield results which are quite sensitive to the particular laboratory conditions employed, and often may be as difficult to interpret as the oceanic measurements.

The above situation simply reflects the relatively immature state of current measurement technology. There are now no standard instruments for field use, nor standard laboratory tests that can unambiguously calibrate a field instrument. The term unambiguously is the key problem, for the difficulty is more fundamental than the selection of acceptable tests or instruments from those presently available. In the present state of the art, any candidate standard would yield results that would vary with actual field conditions, yet those conditions and their effects on the measurement cannot yet be quantified. Thus the usual criteria for the definition of a standard cannot be met.

The development of standards would certainly benefit the entire current measurement community, but there are two specific applications, which at this time provide the best motivation. First, in the engineering area, ocean current measurements are used for the design of offshore structures and the planning of offshore operations. The engineering calculations are based on empirical coefficients relating measured currents to stresses. If the conditions at a new site are determined with a current measurement device that differs from that used to develop the coefficients, then design errors may result. Such errors, a consequence of the lack of traceable standards, can be dangerous, expensive, or both. The result of this is that the utility of data measured for engineering purposes is questionable.

A second application that highlights the need for standards is in the legal and regulatory process. The permissibility of such diverse activities as pipeline emplacement, terminal construction, or industrial waste disposal may hinge upon the magnitude of the ocean currents that will impact the activity. Admittedly, the selection threshold of current beyond which the proposed activity may, or may not, be permitted is highly arbitrary. Such arbitrary decisions are found throughout the regulatory process. However, the lack of any accepted standards of current measurement further complicates the process and provides a fertile field for conflicting expert testimony. This not only slows the regulatory process but tends to discredit the oceanographic community.

The needs for, and benefits of, technology standards are easily understood. The process of developing the standards is, however, not trivial. Creating standards in any field is an extremely difficult and time-consuming process and the continuing evolution of current measurement technology further complicates the task. The CMTC feels that although the development of hardware standards is important, it may be premature and the initial emphasis should be directed toward the establishment of interim standards or guidelines for the testing of current measuring devices.

As a first step, this document provides a framework of laboratory tests that are recommended for determining the performance of a particular type of system. The relevance of a particular test would depend on the specific design of the instrument and its intended application. Thus an instrument designed for use under specified conditions need not bear the stigma of failure under other conditions; the omission of certain test conditions would indicate the limitations of the instrument, and thus reduce the undesirable use of instruments in inappropriate environments.

Such guidelines would not solve the fundamental problem; the performance of an instrument deployed in the field might still be different from the performance defined by the laboratory tests, even when deployed under conditions the guidelines were intended to represent. However, the guidelines would certainly be better than no testing at all, or *ad hoc* calibrations by the manufacturer for his own convenience. They would provide a means for comparing different instruments under controlled identical conditions.

By serving as benchmarks, the tests would provide an important focus for further studies. Users and manufacturers would readily expound upon why the tests were inapplicable in their particular case: other mooring motions, confused sea states, nonlinearities at higher frequencies, etc. When documented, these problems, plus the research efforts aimed directly at current measurement technology, would provide the foundation for the next generation of tests. As this gradually evolved, users working under the interim tests would learn of the limitations of both the tests and the instruments themselves, and could apply the necessary cautions and qualifications to their own work. A vital consideration in developing these guidelines is that they must be generated from within and sanctioned by the current measurement community.

The real progress, of course, will come through further research into current measurement technology; but, it appears that the adoption of the test framework can be useful because of the guidance such tests can provide to the further development of the technology.

II

Framework Objective

GEORGE Z. FORRISTALL AND ROBERT A. STACY

As man's uses of the ocean expand, the importance of physical oceanography increases. Rapidly developing instrumentation technology has created the potential for greatly improving our knowledge of ocean currents. The rapid expansion of the field has brought in many new individuals as project managers, scientists, and engineers who do not have a wide background in current measurement technology. All of these potential users of current meters should not be required to become specialists in current measurement technology.

Confronted by the need to measure ocean currents, the users are immediately faced with the problem of choice of the appropriate measuring system including sensor, recording system, and mooring. It soon becomes apparent that the information needed for such a choice either does not exist, is not in a useful form, is incomplete, or is filed "somewhere (?)."

The purpose of this framework of test procedures is to provide users with a catalog of tests which have proven useful for understanding the behavior and performance of current meters. This document is not meant to exclude additional tests which may be developed, nor to require that all of the tests be done on each instrument. It will, however, define which tests are useful and why, so that the user may make an intelligent choice of which tests are required for his particular application. Performing tests based on the standardized format suggested here should make comparison between test results from different facilities and different instruments much easier than it has been in the past.

The entire complement of tests required to completely define the performance of an instrument will not be required in all applications. A large batch of identically manufactured meters might require only a simple calibration check before use, provided that the system performance on a generic basis is adequately understood. Rather than describe which types of tests are required for different applications, this framework, as a first step, will focus on the laboratory tests that should be considered when doing generic testing of an Eulerian type of current measuring device. Appropriate application of the tests, Lagrangian device tests, and field tests will be considered in similar future reports.

III

Framework of Laboratory Tests

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I. INTRODUCTION

The following description is intended only for guidance in developing comprehensive test procedures. To be of value, the tests should be conducted with care and are best performed by trained personnel. Careless performance of the tests will lead to, at best, ambiguous and, frequently, misleading results. The bibliography lists sources for obtaining more information, descriptions of methods and procedures, and test results obtained by various investigators.

The facilities and equipment necessary to perform these tests can be expensive and difficult to access. It is recommended that a tow type facility be used as opposed to a flow facility. Although both facilities have inherent problems associated with their use, it is considered that the tow type facility offers the greater accuracy with proper use. The number of adequate and accessible towing facilities in the United States is extremely limited. The largest and perhaps best facility is located at the David Taylor-Naval Ship Research and Development Center (DT-NSRDC) in Carderock, MD.

Dynamic tests require specialized facilities and instrumentation. The Vertical Planar Motion Mechanism (VPMM) was developed by NOAA several years ago for the specific purpose of evaluating the performance of current measuring devices. This mechanism is capable of simulating time-varying flow and is attached to the tow carriage at DT-NSRDC.

It is suggested that the executive committee of CMTC be contacted before initiating any large-scale evaluation program. Extensive test information is available on many of the popular current meters that may preclude the need for additional work. It may be desirable to contract evaluation work to an experienced laboratory to avoid many of the pitfalls. In either case, the CMTC can provide valuable guidance and advice toward the accomplishment of your objective.

II. STEADY FLOW TESTS

These tests are designed to determine the steady flow characteristics of the instrument under controlled simulated conditions. The tests are conducted over the design range of the instrument with the expectation that the systematic errors of the measurement process are one order of magnitude smaller than those of the instrument tested. Such testing accuracy is rarely achieved in practice.

If the instrument has a preferential measurement orientation, it is so aligned in the test apparatus and facility. Test data are collected at specific speed intervals over the range. Data collection methods and intervals are selected to yield data that when analyzed statistically provides the desired confidence limits. All tests are repeated at least twice.

It is important that all tests be performed on the current meter as it will be deployed in the field, i.e., the normal mounting configuration and surrounding cages must be arranged so the test results will represent total performance characteristics. Appropriate care must be taken to insure that during testing the free stream velocity the transducer "sees" is not disturbed by the test mounting.

A. Horizontal Plane Azimuthal Response

If no preferential orientation exists or if field conditions may result in instances of nonpreferential orientation, then tests should be performed to determine the horizontal directivity response characteristics. These tests are performed at preselected angular increments in the horizontal plane such that, if possible, a full 360° is traversed, thus defining the transducer's response at each angle. Tests are repeated at several flow speeds to determine the characteristics and the resultant data are plotted in polar coordinates to visualize the characteristics of directional response.

B. Flow From a Single Direction

Once the directional response is determined, a selection is made of the proper azimuthal angle or angles at which to obtain steady flow test data. Usually, three test runs at specific velocities are performed over the range specified by the manufacturer or the user. If the angles chosen for the steady flow test are the ones at which the above directional tests indicate that the output is a maximum and minimum, all of the instrument's parameters for steady flow speed accuracy can be determined.

C. Vertical Plane Response

If the instrument may experience unknown vertical attitudes due to mooring tilt angles or flow vectors that may have vertical plane components, tests should be conducted to determine the vertical directivity response. Steady flow tests are conducted at preselected vertical angular increments, usually in the range of ±90° about the normal attitude, depending on symmetry. The angular interval, flow speeds, and data sampling techniques are chosen to assure statistical significance of the results.

D. Direction

On varied instruments it becomes necessary to determine the time response and alignment threshold of the vane in consideration of total direction errors. Time response of the vane is usually referred to a "distance constant." This is determined by restricting the vane to 180° from the true flow and timing the response from release to true alignment with the current. When this is repeated at several speeds, a "distance constant" is determined by computing the distance traveled to reverse the vane 180°. This is an indication of the ability of the vane to respond to near-surface wave dynamics or reversing flows. Vane threshold is determined by restricting the vane to 90° from the true flow and determining the resultant direction indication upon release. This is performed in decreasing speeds until the vane misalignment remains at 5-10° from the true direction. This will indicate the direction threshold as a function of speed.

Direction uncertainties of solid-state instruments can be computed from the speed uncertainty of the orthogonal output channels. This error can be considerable at low speeds and should be added to the compass errors.

III. ZERO FLOW-THRESHOLD-STALL TESTS

These tests are conducted to determine the low-speed measurement characteristics of the instrument. Tests are performed from a condition of no flow up to the point at which an output is initially indicated and then the speed is reduced to determine the point at which the output ceases (stall). In the case of "solid-state" type transducers, zero-flow "noise" and offset indications should be noted and distinguished from the threshold. These tests should be repeated sufficiently so that statistical analysis will yield the desired confidence in measurement uncertainties. Solid-state output drift characteristics should be previously established to avoid erroneous statements of threshold.

IV. DYNAMIC TESTS

Dynamic tests should be conducted on any instrument that may be subjected to unsteady flows created by the environment or by motion imparted to the system. These tests should be performed regardless of whether the unsteady flow is the desired measurement or is to be filtered out as unwanted noise. The range of frequencies, amplitudes, and directions of these unsteady motions is dependent on many factors, including buoy location and configuration, mooring type and instrument depth.

In general, large or macro scale dynamics are those generated by surface wave action. These frequencies of motion are less than 1 Hz with amplitudes typically greater than 25 cm. The motions could be circular or elliptical and horizontal or vertical relative to the instrument measurement plane. Tests should be conducted at various signal-to-noise ratios (the steady flow component is the signal and the dynamic velocities are the noise) over the range expected in the field. The response should be determined under each type of motion and at various attack angles relative to the steady flow direction. Statistical analysis of the test data will provide the expected uncertainties in determining velocity within defined confidence limits under dynamic conditions.

Small or micro scale dynamics are those generated by structural vibrations due to vortex shedding or by turbulence created by near bottom shear flows and surface wind driven shear. The uncertainties caused by these effects may be considerably smaller than the macro scale uncertainties and are generally a function of the transducer design. The frequencies of interest are from 1 to 20 Hz with amplitudes less than 25 cm. Tests should be conducted to determine if turbulence effects can be detected on the particular type of transducer. If effects are discovered, specific tests should be designed to determine their cause and significance.

V. ENVIRONMENTAL TESTS

The use of instrument systems to measure environmental parameters usually results in the need to deal with effects of the environment on the instrument, since exposure of the device to the elements often leads to degradation of the data collected. In the case of current measurement systems, there are a number of environmental factors which may singly or jointly affect current measurements. These include, but are not limited to, temperature, vibration, shock, pressure, biological fouling, flotsam, and corrosion.

The impact of these environmental factors can be reduced by several actions considered essential to any measurement program: proper selection of instrumentation, regular maintenance, proper installation, and appropriate testing. The instrument should be selected to satisfy the measuring requirements to the extent technology will permit. Proper maintenance is essential, not only to proper instrument functioning, but also to minimizing environmental effects such as corrosion and fouling. Proper installation at the measurement location can also minimize environmental effects. Complete testing is necessary to quantify the effects of the environment on the instrument so that minimum loss or degradation occurs in the measured data.

Environmental test methods have been developed by the military services to cover the entire range of conditions that electrical and electromechanical equipment may be subjected. In 1979, the Test and Evaluation Laboratory of NOAA completed a contract with Dayton T. Brown, Inc. to develop *Environmental and Reliability Test Methods for Marine Scientific Instrumentation.* The document represents a compilation of the most applicable military and other environmental test methods for marine instrumentation. It is recommended by the committee that this document be used as guidance in determining which environmental tests are necessary. It may be obtained from the National Technical Information Service (NTIS), Springfield, VA 22161, Document Number PB-81-232001.

In general, most environmental tests deal with stability and failure in electrical components or mechanical integrity of the system. However, some environmental conditions may affect the transducer directly, i.e., biological fouling and flotsam. Tests for the effects of biological fouling can be performed, but flotsam fouling presents a more difficult problem. Specific tests for flotsam fouling are difficult, but if the problem is anticipated or encountered, the selection of instrumentation that may be less susceptible, or the development of deflection devices is suggested. However, deflection devices should be accounted for in the calibration process.

VI. COMPASS TESTS

Proper compass performance is essential in most moored current meters. Directional accuracy affects shear and Reynolds stress calculations, enters directly into vector averaged speed computations, and is required on moving measurement platforms to obtain the magnetic reference. An accuracy of ±1-5° is typical and presently seems adequate for many moored current meter applications. Unfortunately, malfunctions of the compass are not always apparent in the recorded data, so care in proper design, testing, and servicing is needed. The purpose of compass tests can be summarized as follows:

1) determine product performance bounds (accuracy, tilt, temperature effects, etc.);
2) screen new instruments for satisfactory performance;
3) identify new malfunctions in old instruments;
4) flag possible future failures (slightly sticky bearings and marginal readout levels);
5) follow replacement intervals and history of individual units;
6) assure data quality during the next deployment.

Two major types of compasses are in general oceanographic use: mechanical and flux-gate. Both types determine magnetic north by means of two sensors, one each for the local magnetic and gravitational fields. (The required signal is the horizontal component of the magnetic field.) Table I lists various technical considerations used for oceanographic compass evaluation. In the table, column A gives the general specifications, column B the performance characteristics, column C the forcing functions, and column D the testing tools.

TABLE I
TECHNICAL CONSIDERATIONS FOR OCEANOGRAPHIC COMPASS EVALUATION

A GENERAL SPECIFICATIONS	B PERFORMANCE
SIZE	LINEARITY
WEIGHT	OFFSET
POWER	REPEATABILITY
HOUSING	STABILITY
INTERFACE	RESPONSE TIME.
MAXIMUM TILT	BALANCE (LATITUDE ERROR)
MOUNTING	SURGE
TEMPERATURE RANGE	
SHOCK	
ACCELERATION ERRORS	
C. FORCING	**D TOOLS**
LATITUDE (MINIMUM FIELD) TILT (PITCH AND ROLL) TEMPERATURE	HANDHELD MAGNET (1-2 mm DIAMETER AND 5 cm LONG); USED TO FIND SMALL MAGNETIC PARTS AND DISPLAY COMPASS HYSTERESIS
VIBRATION COMPLETE INSTRUMENT NON-MAGNETIC PARTS DYNAMICS	ROTATING TABLE WITH TILT; BASIC OPERATIONAL TEST FIXTURE;WITH ANGULAR ERROR PLOT CAPABILITY USED TO SEMI-AUTOMATICALLY CHECK PERFORMANCE UNDER REPRESENTATIVE CONDTIONS
	SMALL D.C. MAGNETIC PROBE; USED PRIMARILY IN SET-UP AND DESIGN OF COMPASS TESTS
	HELMHOLTZ COIL;ALLOWS TESTS OF PERFORMANCE MARGINS AND QUANTITATIVE MEASUREMENTS OF IMPORTANCE OF FIELD STRENGTH; USED TO CALCULATE LATITUDE EFFECTS AND DETECT MISALIGNMENT OF THE VERTICAL

A. Basic Tests

The basic tests of the mechanical compass are for accuracy of initial alignment to magnetic north and subsequent bearing wear. By simply deflecting the compass to one side and then to the other (e.g., with a screwdriver) and noting the steady-state offsets (hysteresis), one can make a first-order check of the bearings. A better and highly recommended test uses steady rotation (clockwise and counterclockwise) with and without tilt and an angular error readout device. Because the true magnetic reading is readily determined in the laboratory, errors can be displayed as the difference between indicated and true magnetic heading.

The basic test for the flux-gate compass is an x-y plot of the two-axis output as the compass is rotated to all azimuths. If working properly, the result is a circle centered on electrical zero with no hysteresis or other distortion.

Dynamic response of a compass is also important since in both types the vertical is usually determined by a pendulous gimbal mounting with its own resonant response.

B. Mechanical Balance

Balance is an often overlooked requirement in mechanical compasses. The vertical component of the earth's field pulls the north end of the compass down. To bring the compass back in balance, a small weight is added on the south arm. The added weight moves the center of gravity off the center of support. Acceleration (surge, etc.) can then cause the compass to swing erratically. Next, since the compass magnets must be level, the amount of added mass varies with the magnetic latitude. Systematic errors can thus be introduced by adjusting a compass at one latitude and using it at another. The two-bearing type mechanical compass has additional inherent error terms with tilt. For example, in the local magnetic latitude near Boston, a 1° error in the vertical alignment of the compass causes a ±3° peak-to-peak error in the compass reading.

C. Instrument Effects

Addition of batteries, new options, the pressure case, off-center magnetic parts, magnetic washers, etc., can cause serious compass errors even when the compass *per se* is working properly. Over the years, numerous examples of such oversights have been experienced in both new *and* old instruments.

D. Testing Facilities

A special magnetic facility is convenient, but not necessary. Adequate fixtures and electronics for proper testing need not be expensive or difficult to maintain. Some very good tests can even be made with simple equipment (see Table I, column D–Tools). A field far from local magnetic influences can be used as a simple and inexpensive calibration facility. By aligning the compass or the entire instrument to magnetic north as determined by an independent compass of known accuracy, the instrument may be rotated stepwise and the angular errors determined (remember to empty your pockets and put tools away).

Mechanical compasses have bearing and readout problems. Flux-gate compasses have stability problems. Tests are not difficult, but are often overlooked in the system quality control. Current meter velocity measurements on moving moorings require good compass performance. Assure yourself that the compass is not the weak link in your current meter application.

VII. TEST DATA PROCESSING AND ANALYSIS

The comparability of test results acquired using identical procedures is also dependent on the processing and analysis methods applied to the test data. In the determination of accuracy, a variety of descriptors have been used, i.e., repeatability, precision, two standard deviations, etc. In the interest of commonality of methods and terminology, it is proposed that "measurement uncertainty" be adopted as a more appropriate term than accuracy.

The determination of the measurement uncertainty of a particular current meter is obtained by performing systematic tests and analyzing the results. The Estimated Calibration Uncertainties (ECU) define instrument performance under controlled laboratory conditions and are determined from the results of a calibration process. The processing and analysis of calibration data to arrive at the measurement uncertainties is discussed in detail in Chapter 7 of "NOS Strategic Petroleum Reserve Support Project: Final Report, Volume Two–Measurements and Data Quality Assurance," available from the National Technical Information Service (NTIS), Springfield, VA 22161, Document Number TB-81-236681. This report, along with references cited in the Bibliography, should provide background on processing and analysis methods for interpretation of test data.

The main point is that in whatever manner data are acquired, processed, and analyzed, through explanations should be provided on the methods and assumptions made. This will allow others to follow your procedures in determining comparability of results.

IV

Relationship of Laboratory and Field Testing

J. DUNGAN SMITH

The testing program for any oceanographic sensor must be designed to determine a basic set of specific characteristics. To specify appropriate tests requires a detailed understanding of 1) the salient features of the environment in which the sensor will be used, 2) a comprehensive knowledge of the operating characteristics of the sensor, and 3) a good understanding of basic fluid mechanics.

At one extreme in a testing program lies the field test. If a site is judiciously chosen, perhaps the conditions at this location will be representative of those under which all measurements with the instrument are to be made. Unfortunately, there is no guarantee of this and it often is not the case. Moreover, environmental conditions rarely are known satisfactorily, let alone completely, further complicating the issue. Furthermore, this approach provides information only as accurate as the characterization of the environment at the test site.

In contrast, simple laboratory tests aim to model and simulate particular facets of the natural environment. It is assumed that an instrument's response to each major component of the environment is independent of its response to all others. As an example, a response to a quasi-steady current is simulated using a tow carriage running at a steady speed and pulling the instrument through still water. Specific aspects of the instrument's response are investigated and understood from an observational point of view. A potential for error exists because nonlinear interactions between the sensor and the complicated environment to which they are actually subjected are possible. Neither of the two asymptotic approaches (field testing alone or simple laboratory testing) are acceptable.

In order to conduct a useful evaluation program, the field environment must be understood as must the interaction of the instrument with the environment. We do not have perfect sensors to use for references in a field testing program; we use the same types of instruments that are being tested to measure the flow. In this situation, field tests are of limited value because there is no way to characterize the environment into which the sensor has been placed. In principle, the calibration might be based on theoretical considerations but in practice, oceanographic theory is not good enough for this purpose.

The only satisfactory way to proceed with testing of current measuring instruments is the iterative approach. With this method, one determines the characteristics of the environment in which the sensor will be used, then breaks the environment into major components, each of which can be reproduced separately in the laboratory. Finally, these components are combined in simple ways to determine whether or not their interaction affects the instrument in a nonlinear manner. For example, if one is concerned with deploying current meters from a rigid frame in the beach zone, he first chooses a sensor that seems to be capable of measuring both steady and time-dependent flows. Tow tank tests are needed to determine the steady flow response of the current sensor as well as its directional response. Next, dynamic tests must be carried out in which oscillatory flow is superimposed on steady flow to determine whether the turbulence will produce errors in sensor response. The goal is not to model the environment into which the sensor was inserted because conditions may well be substantially different during the next deployment, but rather it is to understand the sensor response to simple flows of the same general nature, thus to develop at least a qualitative predictive capability. Planning of this test sequence must be based on the understanding of instrument response gained from steady flow tests.

With the iterative approach and a comprehensive testing program, the sensor characteristics can be determined to some defined level of accuracy. Once this has been done, the salient features of the environment may be measured with the sensor. Of course, this does not mean that instruments developed for near-shore use can be expected to operate on offshore platforms during hurricanes. It may be that specific test results indicate that such use is likely to be successful, but unless tests are carried out with very high steady currents and very high oscillatory velocity components, this contention is not confirmed and the resulting measurements must be held suspect.

It is the general feeling that enough is known about the natural environment to permit the development of a suite of laboratory tests that covers all potential uses. Certainly enough is known to define a suite of simple tests capable of determining instrument response in 1) quasi-steady flows, 2) oscillatory flows, and 3) flows with normal turbulence spectra beyond some specified low-frequency limit. Nevertheless, there will always be some conditions and some sensors for which the laboratory testing program is insufficient. Remote sensors and profiling sensors in many instances cannot be evaluated in a laboratory. Only in these cases, however, would a field testing program be more desirable than a laboratory investigation.

Flow sensors by themselves do not comprise a current measurement system and it is essential that the effects of all components of an oceanographic instrument system be clearly understood. If a current meter is mounted in the neighborhood of a flow-disturbing pressure case or on a frame that is not fixed rigidly in space, then the limitations on the measurement's accuracy may well be associated with the nature of the flow disturbance and the frame motion rather than with the sensor's characteristics. Furthermore, interactions between the flow, mounting frame, and sensor characteristics can be particularly important. Sensor response to flow disturbances and frame motion can be predicted to some degree from results of the basic testing program, but the types of disturbances to be encountered during deployment and the nature of the frame motion must be known to do this. In the case of flow disturbance, fluid mechanics theory can be of great value and programs to treat mooring and frame motion are becoming more accurate than was the case a few years ago. Nevertheless, some type of testing program must be carried out in conjunction with such calculations.

It is relatively difficult to calibrate flow sensors with pressure cases and mounting brackets on them and extremely difficult to test entire current measurement systems in the laboratory. In an earlier part of this section, we demonstrated the necessity for laboratory testing over field testing of flow sensors. In contrast, it is frequently necessary to field test the entire current measurement system because of the need to assure operation as designed and predicted. However, this must be done in a judicious manner, selecting field sites that display relatively simple or at least characterizable flows. These flows must be determined with reasonable precision using current meter systems of known characteristics.

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