Quality Control Group

Final Report and Recommendations to the 21st ITTC

1 GENERAL

1.1 Memberships and Meetings

The Quality Control Group (QGC) appointed by the 20th ITTC consisted of the following members: Dr. E. Baba (Chairman), Mitsubishi Nagasaki R&D Center, Japan; Dr. B. Della Loggia, CETNA, Italy; Dr. F. Peterson, DTMB, Naval Surface Warfare Center, USA; Dr. W. van Berlekom, SSPA Maritime Consulting AB, Sweden; Mr. I. Walsh, BMT Quality Assessors Limited, UK.

Dr. Peterson was elected Secretary at the first meeting. Mr. Walsh resigned from the Group; he did not attend any of the Group meetings. Dr. Baba moved from Mitsubishi Nagasaki R&D Center to Hiroshima University in September, 1995.

Since the 20th ITTC, the Group has held three meetings: Nagasaki, March 1994; Rome, October 1994; London, February 1996

1.2 Recommendations of the 20th ITTC

The following recommendations of the Quality Control Group were accepted by the 20th ITTC.

Recommendations to the Conference.

- Members should practice quality control in their day-to-day operations. They should undertake uncertainty analyses and validation studies for theoretical and experimental methods and full-scale trials, and they should use procedures which conform to the quality standard ISO 9000.
- The Guidelines of the 19th ITTC Validation Panel should continue to be used and their implementation should be advanced through training programs.

Recommendations for the Future Work of the Committees.

- Continue to work as an advisory group, under the supervision of the Executive Committee, to support, stimulate and encourage the technical committees in their quality work.
- Keep abreast of the quality control issues of relevance to the ITTC community and advises the technical committees in their work.
- Liaise with the International Standards Organization and guide the technical committees so that the ITTC standard procedures and code of practice conform to ISO 9000.
- Continue to compile registers of bench-mark data and completed uncertainty analyses cases.

2 ACTIVITIES OF 21ST ITTC QCG

2.1 Approach Adopted by the Group

At the 20th ITTC the ISO 9000 standards were introduced for the first time. From the member organizations important responses were made.

van den Boom (MARIN) suggested that the ITTC Quality Control Group should develop a Quality Assurance (QA) system describing the typical processes in the service of ITTC members. Further, he suggested that an essential part of QA is the audit. The performance audits at member institutions which have adopted the QA system could be a fruitful task for ITTC itself.

Kenrick (ISSC Ontario, Canada) and Mehmel (SVA Potsdam) stated that the ISO 9000 series are management system standards and an ITTC procedure by itself cannot get a certification; the member organizations need to tailor their applications of ITTC procedures to their own structure. Davies (BMT) requested to the QCG to set out the "normal interpretation of the requirements of ISO 9000, in order to show where technical codes of practice enter into the system. It is these codes of practice that ITTC's Technical Committees can create or contribute to." Davies pointed out that technical committees are not asked to specifically conform to ISO 9000, but rather to assist in the production of reference material that ITTC members can use when putting together their own ISO 9000 Quality System.

20th ITTC QCG made a closure responding to these important opinions as follows: A possibility is to encourage technical committees to select subjects of importance in their respective technical areas, such as a typical experiment or a performance prediction procedure, and to work with interested ITTC member organizations to develop appropriate sets of essential technical material and procedures as standards for quality management and ISO 9000 certification.

The present QCG followed this closure and in the light of the recommendations of the 20th ITTC, especially the recommendation to all the technical committees with respect to ISO 9000, the Group considered that its primary task was to support each technical committee in responding to this recommendation. Since the validation work has been set as a base work of each technical committee, more emphasis was put on how to stimulate each technical committee in this new area of ISO 9000 standards. However, the QCG is not disregarding the work in progress for the assessment of benchmark data, test cases, and related uncertainty analysis, and thus mention of the technical committee efforts in this area is also given.

Based on initial communication with the 21st ITTC technical committees, it was clear that the technical committees were uncertain what they should do to assist in the ISO 9000 certification process. It was also unclear to the committees the role of the QCG and what support they could expect from the QCG. Thus, the initial efforts of the QCG were to work with the committees to develop a common understanding of what can be done by the ITTC to support member organizations in the ISO 9000 certification.

ISO 9000 provides the standards for quality management of the member organizations for their quality assurance. Neither the QCG nor the technical committees can provide this quality assurance, but support in terms of recommended standard procedures can be provided. This is in keeping with the draft RULES OF ORGANIZATION OF THE 22ND ITTC which state in paragraph 2.4: *Establishing procedures to help the member organizations to maintain their institutional credibility with regard to quality assurance of products and services, such as, performance prediction and evaluation of designs by either experimental or computational means.*

The member organizations can decide to use these procedures or they can document and develop, as necessary, their own procedures. It should be noted that the QCG serves at the pleasure of the ITTC Executive Committee and has no role in the assessment or certification of an organization's quality program.

To promote a common understanding, a draft summary was made of topics in the ISO 9000 standards that are potential candidates for the technical committees' consideration and draft guidance was provided.

All the committees received the draft guidance from the QCG and were asked for their opinions. It appears that with only a few exceptions, the ITTC is ahead of the member organizations in preparing for ISO 9000 certification. Thus, only a few technical committee members have participated in discussion on the subject in their own organizations.

A short questionnaire on quality assurance and ISO 9000 was then sent by the QCG to all Advisory Council members for summary in the QCG report to the 21st ITTC.

2.2 Summary of the ISO 9000 Standards (3rd Ed., 1993) That Are Candidates for the Technical Committee Consideration

Definitions. (ISO/DIS 8402) Quality Assurance: All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality.

Quality System: The organizational structure, responsibilities, procedures, processes and resources needed to implement quality management.

Quality Manual: A document stating the quality policy and describing the quality system of an organization. (The manual serves as the permanent reference in the implementation and maintenance of the quality system. It could have several tiers of documents, each becoming progressively more detailed; this can include specific procedural manuals.)

Standard References from which topics have been selected as pertinent to the ITTC committees include:

ISO 9000: Quality Management and Quality Assurance Standards—Guidelines for Selection and Use

ISO 9000-3: Quality Management and Quality Assurance Standards—Part 3: Guidelines for the Application of ISO 9001 to the Development, Supply and Maintenance of Software

ISO 9002: Quality Systems—Model for Quality Assurance in Production and Installation

ISO 9003: Quality Systems—Model for Quality Assurance in Final Inspection and Test

ISO 9004: Quality Management and Quality System Elements—Guidelines

ISO 9004-2: Quality Management and Quality System Elements—Part 2: Guidelines for Services

ISO 10012-1: Quality Assurance Require-Ments for Measuring Equipment—Part 1: Management of Measuring Equipment

The standard ISO 9001 is most likely the one that ITTC organizations will need to satisfy because it contains the section on design and development. ISO 9000 provides the "road map" for the entire series. ISO 9000-3, ISO 9004, and ISO 9004-2 provide detailed guidance and are the documents of most concern to the ITTC QCG and technical committees.

ISO 9000-3 is concerned primarily with developing software to be provided to a customer. Although some ITTC organizations sell software, the QCG recommends that this topic not be addressed by the current committees due to its limited application.

ISO 9004 (1987) states that the typical form of the document describing the quality system is the "quality manual." The technical committees can make a major contribution by recommending procedures for the performance of tests and reviewing experimental data to determine whether it qualifies as "benchmark" data. In the section 4.9.2 of ISO 9001, Special Processes, the committees can also be of considerable assistance by providing recommended procedures and collecting and publicizing benchmark data. These are the processes where the results cannot be fully verified prior to delivery to the customer; for example, the scaling of model test data to predict full-scale performance. This may involve the use of an existing data base, the use of software with some empirically derived data, or the use of software for broad application.

ISO 9004-2 (1991) was specifically written to give guidelines for services. This is the primary work of ITTC organizations. It applies to design, engineering, consulting, testing, research, development, and many other service areas. The quality manual and the service delivery procedures are again major areas that must be addressed. Service delivery includes a description of the characteristics that directly affect service performance and a standard of acceptability for the service. In the context of the ITTC the service may be a test in a facility or a numerical prediction of performance. The use of statistical techniques is specifically called for in ISO 9000 services. Quoting from ISO 9001 (1987), "Where appropriate, the supplier shall establish procedures for identifying adequate statistical techniques required for verifying the acceptability of process capability and product characteristics." In fact, the standard ISO 10012-1 (1992) is concerned specifically with accuracy of measurements. In the context of the ITTC, this applies to the accuracy of simple devices, such as a Pitot tube, and to the complex laser systems, such as the Laser Doppler Velocimeter. Each technical committee can outline procedures for the tests and methodology to determine the measurement accuracy.

2.3 Interpretation of the Relationship Between ITTC and ISO 9000

In support of the ITTC member organizations' interest in quality assurance, the following interpretations of the relationship between ITTC and ISO 9000 are provided.

With the process of globalization now occurring, the need for international quality standards has caused a rapid worldwide acceptance of ISO 9000 for quality management. ISO 9000 covers four generic product categories: hardware, software, processed material, and services. In the ITTC some organizations are involved with the development, supply, and maintenance of software, but most use the software in the support of services. "Services" is the product category that most appropriately covers the work of ITTC organizations. The ISO 9000 family of standards consists of the series 9000 through 9004 and their subdivisions, the series 10001 through 10020, and 8402. Of these, only 9001, 9002, and 9003 are for certification and contractual purposes. The other standards are for guidance in software development, auditing, quality management, metrology, definitions, and others. ISO 9001 is the most comprehensive of the three because it included design, development, and services; therefore, ISO 9001 is the standard of most general interest to the ITTC.

In order to be certified to the ISO 9000 standard, an organization's quality policy and quality system must be documented. Although not required by the standards, a "Quality Manual" is the most common method to organize the documentation. If proprietary material is included, it is called a "Quality Management Manual." The manual for external use with auditors and customers is called a "Quality Assurance Manual".

The ISO 9000 Compendium, 3rd edition, include the draft ISO/DIS 10013 standard "Guidelines for Developing Quality Manuals." This standard is a useful guide to follow for quality manual preparation. It specifically points out an area where the ITTC committees can be involved: "Wherever appropriate and to avoid unnecessary document volume, reference to existing recognized standards or documents available to the quality manual user should be incorporated."

The QCG recognizes that each of the ITTC members has its own historical data base, unique facility characteristics, distinct software, and specialized procedures all developed over many years. Each organization has a history of successfully satisfying its customers. However, ISO certification means that the processes are all documented in a manner understandable to the customers and that the system for quality assurance is documented. This quality assurance becomes a contractual issue when ISO certification is referenced in the contracts. The challenge for the QCG and the technical committees is to provide support in a context that allows each organization to provide the details unique to its own organization.

It has been found convenient to document the quality system by a series of tiers, each successive tier providing an increasing level of detail. For example,

Tier 1 — overall policy defined
Tier 2 — general description of organization, responsibilities, and procedures
Tier 3 — specific procedures described (how job is done and who does it)
Tier 4 — work instructions, standard forms, etc.

The quality system documented in the manual consists of, or refers to, the procedures followed to maintain quality. Each organization must write the manual to reflect its unique needs, but each manual must address every element within the ISO 9000 standard for which certification is wanted. For example, ISO 9001 has 20 elements. These procedures form the basic documentation of the activities within an organization that impact on quality. A procedure covers both the interrelationship of personnel and the description of how the activity is to be performed, documented and controlled. Each documented procedure should cover a distinct activity or a distinct grouping of interrelated activities. The ITTC can provide an important contribution to these procedures, particularly in how the activity is performed and documented by recommending "codes of practice." More detailed information is provided in work instructions which may be organization and facility specific. Quoting from the ISO/DIS 10013 guideline on quality manuals, "A quality manual should consist of, or refer to, the documented quality system procedures intended for the overall planning and administration of activities which impact on quality within an organization." It is the phrase "...overall planning and administration of activities..." that provides the direction where the ITTC can assist.

A quality manual communicates and explains an organization's quality system; it also demonstrates, to those outside the organization, compliance with the appropriate ISO 9000 standard in contractual situation. The quality manual can make direct reference to ITTC recommendations, for example, codes of practice, as an authoritative source. Therefore, ITTC recom-mendations intended for inclusion in quality system procedures and work instructions must be carefully reviewed and considered by the membership at large.

There are many areas where the ITTC can assist by providing recommendations that would contribute to the product quality of member organizations and assist customers in receiving a contractual level of quality. Each committee of the ITTC can come up with specific examples of activity procedures appropriate to their areas of responsibility. General examples appropriate to most committees include: software validation, software calibration, design verification process, design acceptance criteria, design validation, geometry definitions, instrumentation calibration, and statistical techniques.

A basic service which the ITTC organizations provide is design verification. ISO guidance here is that the verification of a design should involve personnel other than those responsible for the design work under review. Thus, standardized definitions and procedures should be detailed to prevent misunderstanding when several organizations are involved. In addition to the issue of measurement accuracy, the ISO guidance states that validation of the software used in the design computations, modeling, and analyses must be considered.

Among its many applications, software is used to create a design, to analyze a design, to control experimental equipment, to process experimental data, and to predict performance. Software "validation" is the process that ensures that the software achieves a specific outcome for a given application (Bradley, May 1988). If the same software is to be used for a different type of application, then another validation is required. If the software is to be used outside the validation range and has parameters adjusted to give agreement with experiment, then it is "calibrated." The ITTC can provide recommendations on how to determine the accuracy of the experimental data and the procedures to validate and calibrate the software.

In the development of a design there is the need to verify that the design is achieving the original requirements. This verification is commonly accomplished by doing alternative calculations, comparing with a proven similar design, and carrying out tests and demonstrations. This activity, "design verification," can be documented in a procedure or a series of procedures with work instructions that give specific details. Typical examples of ITTC contributions could include a Cavitation Committee recommendation on how to do a model scale cavitation pattern test or how to standardize the process of determining cavitation inception on a propeller. The ITTC recommendations must be generic in order to be referenced in an organization's quality manual. Each organization must include those aspects that are unique to the organizational data base, facilities, instrumentation, and personnel.

The relationship between software and experiments can be considered multi-dimensional. Using terminology from the CFD community there are three stages of software development: research, pilot, and production (Marvin & Holst, August 1990). Experiments can also be subdivided into three types: building block, benchmark, and design.

Building block experiments provide the physical understanding and the numerical modeling guidance for the research phase of the software. Benchmark experiments define the parameter space over which the pilot codes will be validated or calibrated. Design experiments, on the other hand, provide the performance data on a hardware design. Building block experiments and benchmark experiments are related to the software assessment whereas the design experiment is to develop performance data on a hardware design. All of these experiments require accuracy assessments. The 20th ITTC Quality Control Group sent to each technical committee the recommended ASME statistical methods to assess experimental accuracy, based on a 1986 publication. It should be noted that most of the experiments performed by ITTC organizations consist of a single experiment instead of multiple experiments specifically planned to increase experimental accuracy. Thus, to use the available experimental data base numerous sets of experimental data need to be used for software validation and calibration.

To satisfy the ISO 9000 standards, the accuracy of the software used to do designs and make performance predictions and the accuracy of the experiments used to verify performance must be known. The procedures for determining the accuracy must be given, or referenced, in the quality manual.

All of the above discussion is in keeping with the draft RULES OF ORGANIZATION OF THE 22ND ITTC which state in paragraph 2.4: *Establishing procedures to help the member organizations to maintain their institutional credibility with regard to quality assurance of products and services, such as, performance prediction and evaluation of designs by either experimental or computational means.*

2.4 Guidance Provided by the QCG

The QCG recommended topics for the 21st ITTC technical committees' action based on the summary in section 2.3. The guidance was:

1. Provide comments to QCG chairman on the QCG draft summary of ISO 9000 topics for technical committee action.

2. Continue to encourage the performance and documentation of benchmark quality experiments.

3. Collect and review existing documented standard procedures, revise as appropriate to support item 1 above, and send to the QCG for compilation and publication.

2.5 Questionnaire to Advisory Council Members

Background. The QCG has been using as its guide the draft rules for the 22nd ITTC, in which paragraph 2.4 states, *"Establishing procedures to help the member organizations to maintain their institutional credibility with regard to quality assurance of products and services, such as, performance prediction and evaluation of designs by either experimental or computational means."*

The following letter was sent to all Advisory Council Members.

More and more shipyards and their suppliers are becoming ISO 9000 certified. Now, at the direction of the ITTC, every ITTC technical committee is working to assist in the quality assurance process and the ISO 9000 certification process.. The QCG believes it is important to report also on the progress that the member organizations are making toward ISO 9000 certification. Therefore, the QCG will summarize the Advisory Council (AC) members' replies to the following questionnaire in the QCG's report to the 21st ITTC.

Questionnaire.

1. Have any of your customers been ISO 9000 certified and have they approached you about certification?
2. Are you interested in following the ISO 9000 procedure for certification?
3. Are you preparing for ISO 9000 certification now?
4. Do you have a quality manual in use today?
5. What can the QCG do to help you to address paragraph 2.4 of 22nd ITTC Draft Rules?

Replies From AC Members. Twenty-six of the thirty-five AC member organizations replied to the questionnaire from the QCG, including almost all of the large organizations. A summary of the replies follows:

To **Question 1 (a)**: Have any of your customers been ISO 9000 certified? YES: 20, NO: 6

To **Question 1 (b)**: Have they approached you about certification? YES: 6, NO: 20

To **Question 2**: Are you interested in following the ISO 9000 procedure for certification? YES: 22, NO: 4

To **Question 3**: Are you preparing for ISO 9000 certification now? YES: 13, NO: 13

To **Question 4**: Do you have a quality manual in use today? YES: 17, NO: 9

It is noted that a large number of ITTC customers have been certified to a ISO 9000 standard. At present, however, the certification for the tankery work has not been required.

To **Question 5**: What can the QCG do to help you to address paragraph 2.4 of 22nd ITTC Draft Rules?

To this question valuable comments were given and are summarized as follows:

1. Establish ITTC standards related to tank experiments and software development: for this task encourage the technical committees to provide recommended procedures in their particular disciplines for use of the member organizations. Encourage the technical committees to establish the method of uncertainty evaluation and the method of certification on individual tools. (The QCG had already provided recommendations for technical committee work prior to the mailing of the questionnaire to the AC members.)

2. Encourage all members organizations to pursue quality procedures in conformance with ISO 9000 standards:

   (Step 1) QCG recommends to all members of the 21st ITTC to implement a QC system complying with ISO 9000 standards. (This has been addressed already at the 20th ITTC.)

   (Step 2) In the QCG report for the 21st ITTC an example of Quality Manual should be included.

   (Step 3) QCG organize an international workshop concerning Quality Systems in ship hydrodynamics laboratories.

In addition the QCG was requested by IMD/NRC, Canada to comment on the importance of accreditation as a testing laboratory in compliance with "ISO/IEC Guide 25," General Requirements for the Competence of Calibration and Testing Laboratories. The IMD/NRC says that perhaps we can develop a similar guide for our organizations, addressing technical credibility and competence issues which are not incorporated in ISO 9000 standards.

The QCG appreciates the replier's valuable comments on the importance of accreditation as a testing laboratory. According to the reference provided by the replier (Russell, A J 1993): "Unlike the ISO 9000 series of standards, ISO/IEC Guide 25 was not primarily intended as a contractual model for suppliers and their customers. Its purposes are to establish general requirements for demonstrating laboratories' compliance to carry out specific calibrations or tests, and to provide a basis for use by accreditation and certification bodies in assessing competence of laboratories.

Introduction of ISO/IEC Guide 25: 1990 states: "Laboratories meeting the requirements of this Guide comply, for calibration and testing activities, with the relevant requirements of the ISO 9000 series of standards, including those of the model described in ISO 9002, when they are acting as suppliers producing calibration and test results."

At present, no ITTC AC member organization has been required by their customers to have ISO 9000 certification. The QCG, therefore, considers that the effort of ITTC member organizations should be towards the implementation of quality system based on ISO 9000 standards. According to the needs from customers for specific calibrations for tests, a guide such as ISO/IEC Guide 25 should be implemented.

The QCG believes that development of validation procedures and benchmark data contribute to the confidence in the quality of products and services from ITTC member organizations. These activities are a good preparation for getting accreditation as a testing laboratory, if necessary.

In addition to the replies to the questionnaire, MARIN contributed to the QCG with an example of their quality assurance system (Appendix A).

3 REPORT OF TECHNICAL COMMITTEES' WORK ON QUALITY CONTROL ACTIVITIES

3.1 Brief Historical Review of Standardization Efforts by the ITTC

The first important collaboration of the ITTC was the determination of a correlation line for powering predictions. In 1957, the so-called The ITTC 1957 model-ship correlation line was set up after long discussions in the Skin Friction and Turbulence Stimulation Committee. Then, at the 9th ITTC in Paris (1960) the Propulsion Committee recommended that propulsion and resistance experiments should be carried out and analyzed generally in accordance with the methods described in "A Procedure for Resistance and Propulsion Experiments with Ship Models" by D. I. Moor and A. Silverleaf, Zagreb, September 1959, and NPL Report SH R10/59. This procedure provides fundamentals of model testing and its spirit is still alive today.

In 1963 at the 10th ITTC in Paris, the Cavitation Committee made an effort to provide testing procedures for propeller cavitation in uniform flow. Two important contributions were included in the committee report. One was by H. Lindgren, "A Note on Test Procedure, Correlation and Presentation," and the other by A. Silverleaf, "A Proposed Code for the Description of Propeller Cavitation." However, at the 11th ITTC in Tokyo (1966) the Cavitation Committee reported that: "The Conference recognizes that it is not yet possible to recommend standard procedures for water tunnel experiments with propeller models, but considers that efforts should continue to be made towards specifying such procedures." In the following years the Cavitation Committee put more emphasis on the physics of cavitation, while maintaining a continuous interest in the standardization of testing procedures. In 1975 at the 14th ITTC in Ottawa a result of the efforts was reported in Appendix 8 of the committee report: Standards for Cavitation Tests by A. Gorshkoff (pp. 154-158).

Meanwhile, at the 10th ITTC in Paris the ITTC 1963 Trial Code was prepared by the Propulsion Committee. Effort was made by the 11th ITTC Performance Committee to revise and submit it to the 12th ITTC for final approval as "ITTC Guide for Measured-Mile Trials" (pp. 194-197). Further, the Performance Committee made a great effort to produce the so-called "1978 ITTC Performance Prediction Method for Single Screw Ships." In this recommended method, a computer program was included for conformity of its use among organizations. Then the extension of this method was made to twin screw ships at the 17th ITTC in Goteborg in 1984. Along with this, the computer program was revised (pp. 326-333), and further modifications were made in 1987 at the 18th ITTC in Kobe (pp. 266-273).

Since the introduction at the 9th ITTC of the standard procedure for resistance and propulsion experiments with ship models in calm water, the need had been felt for a standard procedure to be specified for experiments in waves. At the 12th ITTC (1969) the Seakeeping Committee presented "Proposed Standards for Seakeeping Experiments in Head and Following Seas." In 1978 at the 15th ITTC in The Hague, the Seakeeping Committee presented "Revision of the Standards for Seakeeping Experiments" (pp. 56, 60-62). The revised standards differed from the 1969 standards in their extension to oblique seas and in amplification of the section concerning testing in irregular waves. In the report of 18th ITTC (1987) a recommendation is added for experiments related to rarely occurring events (pp. 468).

At the 12th ITTC the Committee also proposed "Standard Wave Spectra for Tank Experiments," as an interim spectral formulation standard adopted at the 11th ITTC in 1966. Some amendments were made in the following ITTCs: 1978 (pp. 113), 1984 (pp. 533-534).

The Maneuverability Committee also made efforts to produce standards. A proposed procedure presented in 1963 at 10th ITTC was revised in 1975 as "ITTC 1975 Maneuvering Trial Code" (pp. 348-365). It was recommended as a tentative standard code for ship trials conducted in cooperation with ITTC member organizations, and for comparative studies with free-running models or computer simulation predictions based on captive model test results. A partial revision was added at 20th ITTC in San Francisco (1993) with regards to uncertainty analysis and use of the GPS for position determination.

Since the 16th ITTC, the Ocean Engineering Committee started activities and made intensive review work on its specialized experimental methods, such as modeling techniques including elastic components, experimental operational techniques, and analysis techniques. The 17th ITTC Ocean Engineering Committee noted that a very wide range of different analysis techniques were in use by ITTC members. Then the 18th ITTC Committee planned a comparative data analysis study for regular and irregular waves. In order to eliminate uncertainties about the type of data being analyzed and to remove digital sampling differences, it was decided to synthesize regular and irregular signals by digital techniques. The digital data were sent to those ITTC members who had agreed to participate in the study. Harmonic and spectral analyses of certain time traces defined by the Committee showed that some of the results were quite disappointing in terms of spread in resulting amplitude and phase angles. Reflecting this result, the 19th ITTC Ocean Engineering Committee recommended to the ITTC a regular wave testing procedure (pp. 488-490). This was reviewed and revised by the 21st ITTC Ocean Engineering Committee.

3.2 Technical Committees of the 21st ITTC

The QCG received positive responses from technical committees. However, some committees were carefully reviewing their testing and computational procedures and will report the results of their work in their report. Initially, the QCG asked each technical committee to pass its recommended procedures to the QCG for publication. However, the QCG reconsidered this request and now is of the opinion that all newly recommended procedures should be approved by the conference before publication as ITTC recommended procedures. In the present report of QCG only the state of the progress of activities by the technical committees are summarized. The technical committees will present their recommended procedures to the ITTC. The Quality Control Group's recommendations to each of the committees of the 21st ITTC were to develop standard methods and procedures for use in ISO 9000 certification. It was further recommended by the QCG that existing documented standard procedures be reviewed and revised as appropriate. Committee progress in addressing these recommendations is now summarized.

Powering Performance Committee. The Powering performance Committee undertook two efforts. The first was to develop a standardized uncertainty analysis for representative testing methods for powering predictions and the second was to update the ITTC Guide for Measured Mile Trials. The uncertainty analysis method follows that of the American National Standards Institute (ANSI) and the American Society of Mechanical Engineers (ASME) "Standard on Measurement Uncertainty," using the approach described by Coleman and Steele in their book "Experimentation and Uncertainty Analysis for Engineers." Presented are methods for uncertainty analysis in the model experiments associated with powering predictions: resistance tests, propeller open water tests, and self-propulsion tests, along with examples of bias and precision errors and overall uncertainties. The updated Guide for Measured Mile Trials was developed after conducting a detailed evaluation of a questionnaire sent to all member organizations regarding the conduct of Full Scale Powering Trials. It is proposed that the guide can be used by member organizations as a procedure to follow when pursuing ISO 9000 certification for the conduct of powering trials.

Cavitation Committee. The Cavitation Committee has focused their efforts on better understanding the contributors to uncertainty and on identifying the physics associated with cavitation scaling. Therefore the committee emphasis has been on the experimental methods employed in cavitation experiments. Error estimates for the measurements must relate to liquid and flow properties, geometry accuracy, and inception detection method. The committee considers the overall measure of the errors to be the difference between the model- and full-scale cavitation performance predictions. Since the instrumentation calibration techniques lead to high accuracy relative to the model-/full-scale performance predictions, the committee has focused on quantifying the liquid quality and the wake field.

Of the many different types of experiments and tests related to cavitation, the committee selected the Model Scale Cavitation Pattern Test for their first effort to recommend a standard procedure. The intent is that this procedure would be referenced in the Quality Systems documentation of an organization seeking ISO 9000 certification. The committee's recommended procedure was based on reviewing the current procedures used at numerous cavitation test facilities around the world.

Ocean Engineering Committee. The committee reviewed and revised a 19th ITTC Regular Wave Testing Procedure. A recommendation has been added on the verification of the prediction procedure. The use of a different computer program is also recommended. This recommended procedure will be included in the committee's report to the ITTC.

Maneuvering Committee. The committee discussed intensively the use of the term "standard." As a result, the term "standard" was avoided to eliminate unnecessary pressures from customers who would ask formally to follow the standard when ITTC recommended. The committee selected one basic experiment for ship maneuverability study, PMM tests, as an example of "recommended" (instead of standard) procedures. A generic description of the testing procedure for the PMM was recommended. In this recommended procedure, descriptions are provided for model manufacture, preparation, test and data analysis. The length of the scaled model is not specified because it is dependent on tank size. Inspections are requested for the dimensions, hull configuration, weight, etc. Calibration of load cell signals is requested. The oblique towing test, pure swaying test, pure yawing test, and yawing with drift test are all recommended with specified drift angles, circular frequency of oscillation, and amplitude of yaw rate. Rudder angles for tests of rudder forces are included. In the analysis, derivatives with respect to sway velocity and yaw angular velocity, and inertia derivatives are obtained to determine hydrodynamic coefficients for hull forces. By employing the MMG-model, hydrodynamic coefficients for rudder forces are also obtained. Finally, the simulation of ship maneuvering is recommended with the use of the hydrodynamic coefficients obtained through the above described process.

Resistance and Flow Committee. The committee has given extensive consideration to the topic of Quality Control. Recommendations are included in the committee report for standards to be used in the development of User's Guides and Code Validation. Existing benchmark data has been evaluated using both the CFD developer's point of view and the ship designers' (end users).point of view, and a discussion is presented in the report. The committee has concluded that until reference hull forms are defined and accepted by the conference, it is not recommended to perform CFD calculations to define the quality and quantity of validation data needed from future benchmark experiments.

Propulsor Committee. The Propulsor Committee has concentrated its efforts on the issues of recommended procedures and benchmark data. The committee has thus made an inventory of computations and model tests for which recommended procedures should be developed. Based on this inventory the first exercise was to propose a recommended procedure for the propeller open water test, which will be included in the Propulsor Committee Report. The committee has also calculated benchmark data for the validation of panel codes for propeller analysis.

Seakeeping Committee. The Seakeeping Committee has mainly concentrated its effort to uncertainty analysis and validation procedures. The committee has made a review of recent studies on uncertainty analysis. A benchmark study on uncertainty analysis was carried out for the S-175 container ship in regular waves. The proposed data base of the 20th Seakeeping Committee was extended to recent data on S-175 container ship and also to high speed monohull series. The committee also considered the validation of seakeeping calculations and continued the work reported by the 20th Seakeeping Committee. The committee started work on recommended procedures to be adopted to conform with ISO 9000.

4 ISO CERTIFICATION PROCESS

In November 1995 the Full Scale Trials Branch within the Hydromechanics Directorate of the David Taylor Model Basin, along with three other components of the Naval Surface Warfare Center, became the first U.S. Navy activity and second U.S. government agency to receive ISO certification of its quality management system. The registration certificate states that the Full Scale Trials Branch complies with ISO 9001 standards when conducting Performance and Special Trials for validation of hydrodynamic ship designs.

Also in November 1995 the Korea Research Institute of Ships and Ocean Engineering (KRISO) became the first ship research institution in Korea to receive certification. The KRISO certification to ISO 9002 covers ship and offshore structure model tests in the towing tank and the cavitation tunnel, including resistance, propeller open water, propulsion, wake survey, ship motion, maneuvering, and propeller cavitation tests.

4.1 Process Example

In order to achieve certification the Full Scale Trials Branch developed a quality management system that is in compliance with the 20 elements of ISO 9001. A management hierarchy for the quality system was established, a single ISO point of contact (ISO program manager) was designated, and a group established to develop quality policy and procedures (ISO steering committee). Training covered the ISO concepts and basics, writing procedure and work instructions, conducting internal audits, and conducting corrective and preventive actions. Various assessments such as internal audits and gap analyses of the Branch were undertaken over the one-and-one-half-year period leading to certification. The periodic assessments of the differences between the Branch quality system status and the ISO standard provided a means for measuring the Branch's progress toward compliance to the standards. A registration audit conducted by ABS QE, an affiliate of the American Bureau of Shipping, validated Branch compliance to the standards and was the final step in the registration approval process.

A Quality Policy Statement was established. Procedures were developed and approved for each of the 20 elements of ISO 9001. Nineteen detailed work instructions were established for the Branch core processes, including calibration of specific instrumentation, preparation of trial agendas, conduct of trials, analysis of data, and reporting of trial results. This information and the Quality Policy Statement were assembled into a controlled document that became the cornerstone of the Quality Management System. The Quality Management System at the David Taylor Model Basin was put in place in order to provide:

1. Compliance with an internationally recognized set of standards,
2. Documentation of standardized procedures,
3. Traceability to known standards of measurement,
4. Defined responsibility throughout the system,
5. Cost efficiency due to reduction in rework and duplication of work,
6. Preservation of corporate knowledge.

The current ISO certification efforts in the Hydromechanics Directorate of the David Taylor Model Basin are directed toward model predictions and correlations and propeller design. Ultimately, their plan is to certify a quality management system which encompasses the processes of model testing, ship powering predictions, full scale testing, validation of predictions, full scale/model scale correlation, and propeller design.

4.2 Procedures Recommendations

The recommended procedures by the ITTC technical committees are to be used as base documents in preparing the work procedures (as in Tier 3 in section 2.3) and work instructions (as in Tier 4 in section 2.3) for the Quality Manual conforming to ISO 9000.

It is advisable that the technical committees, when preparing recommended procedures, consider as far as possible the form of documentation required by ISO 9000.

For reference in the future work of the committees, examples of a certified procedure and a certified work instruction at DTMB are given in appendices B and C, respectively.

5 ISO CERTIFICATION—THE CURRENT TREND

5.1 General Status Regarding Certification

Among the clients of the ITTC members, which include shipyards, consultants, and ship owners, a large interest in quality control and certification is evident. The questionnaire answers from AC members give a rather significant view of the present situation, which is also applicable to the clients. Most clients are following the quality control requirements according to the ISO 9000 standards. As regards ISO 9000 certification there are some differences.

On a worldwide basis it can be estimated that about 120,000 companies were ISO 9000 certified at the end of 1995. The geographical distribution is such that UK is dominant with more than 40% of the certified companies; Europe, not including UK, about 30%; North

America, about 10%; and the remaining 20% mainly in Australia and the Far East.

Statistics on certification is rather incoherent; but to obtain some measure on how many companies within shipbuilding and related industries are certified, the statistics from the Nordic countries has been used. At the end of 1995 the total number of certified companies was about 4000, and the shipbuilding-related industries, including ship owners, was less than 1% of this number. It may be noted that the total number of certified shipyards was less than 10 in this area.

The current trend is that many companies are in the process of ISO 9000 certification and mainly those companies which are supplying products and/or are subcontractors to ISO 9000 certified firms.

Information as regards certification is generally found specifically for each country. In UK, the DTI QA Register is published which includes lists of certified companies divided according to type of business. In the USA, a list of certified firms is published as "Registered Company Directory." In the Nordic countries, information on certified companies can be found in "Scandinavian Buyers Guide." All these publications are updated on a regular basis. Information on certified companies can also, to some extent, be obtained from the ISO 9000 certifying firms like Lloyds Register, Det Norske Veritas, American Bureau of Shipping, etc.

5.2 Certification of ITTC Members

It is generally recognized among ITTC members that a quality control system, such as ISO 9000, is required and that in many cases it must be demonstrated to the clients. As regards certification to ISO 9000 standards there is some ambivalence among members. Many AC members have stated that preparations related to the certification process are ongoing, but they hesitate to actually go through the certification process. The main objection being the costs to obtain—but also to maintain—a ISO 9000 certification.

The decision to obtain a certification must be made by each ITTC member based on the clients' demands. These demands can vary quite substantially depending on such factors as clients' line of business, type of work, geographical area, etc. The strategy that many members have adopted is to use the ISO 9000 standards as a guideline for their quality control. This implies also that a Quality Manual has been issued, which in many cases satisfies the clients' requirements as regards quality control. The next step is then to have a certified quality control system which is based on the Quality Manual.

6 CONCLUSIONS

The QCG has provided guidance to the technical committees on how they can support the ITTC in quality assurance and the certification process for ISO 9000.

The progress of the 20th ITTC technical committees has been significant. The committees appear to have committed to serious consideration of the issues of quality assurance, and the committees have initiated efforts to support member ITTC organizations by preparing relevant procedures for reference in a quality manual. Previously proposed procedures have been reviewed, new procedures proposed, and an overall heightened level of interest has been generated in supporting the ISO9000 certification process.

The QCG recommends the member organizations:

- identify whether quality control is important for business
- introduce a quality manual to the users in their operations, and
- certify their quality control system.

Each member has to decide how far to pursue their quality control system.

7 RECOMMENDATIONS TO THE CONFERENCE

1. Member should maintain their institutional credibility with regard to quality assurance of products and services by use of ISO 9000 as a guide for quality management.

2. Members should support technical and/or specialist committees' work in producing recommended testing and evaluation

methods, recommended computational procedures, benchmark data and test cases for uncertainty analyses.

8 REFERENCES

ISO 9000 International Standards for Quality Management, 3rd Edition, 1993.

Bradley, R. G., May 1988, "CFD Validation Philosophy," Paper No. 1, AGARD - CP 437, Vol. 1, Validation of Computational Fluid Dynamics, Lisbon, Portugal.

Marvin, J.G., and Holst, T. L., August 20-22 1990, "CFD Validation for Aerodynamic Flows—Challenges for the '90's," AIAA Paper 90–2995, AIAA 8th Applied Aerodynamics Conference, Portland, Oregon, USA.

APPENDIX A. EXAMPLE: CURRENT MARIN QUALITY ASSURANCE SYSTEM DOCUMENT

"MARIN: Quality in R&D for the International Maritime Industry"

General

The Maritime Research Institute Netherlands, founded in 1929, is an independent non-profit organization performing research, development and testing for the international maritime industry.

The main activities comprise model testing, software development, sea trials and consulting services. For this purpose MARIN operates five large test basins and two cavitation tunnels in Wageningen and a depressurized towing tank in Ede, The Netherlands. For the model tests advanced testing equipment and measurement techniques are available. MARIN also operates advanced equipment for measurements on board ships and platforms. Both for processing of measured data and for software development a modern computer network is used.

Organization and Staff

MARIN's organization provides a maximum guarantee for customers that the work will be carried to their specifications. The main activities for the market are the responsibility of the Ship Research Department, the Offshore Research Department, and the Software Engineering Department. These departments are responsible for client contacts and performance of the work. For technical development, support, and maintenance, the Automation and Instrumentation Department is engaged (see Department Information Leaflets). Services of this department are rendered to third parties through the Technology Transfer Group. The heads of departments are members of the Management Team and report directly to the Managing Director.

The permanent staff of MARIN consists of approximately 200 employees, half of whom have a technical education. Training and education of MARIN employees is considered a continuous responsibility of the management.

Quality Assurance

MARIN has a strong commitment to Quality in all the aspects of its operations. Established in the Netherlands, the institute complies to all Dutch Laws, including the strict rules and regulations concerning health, safety, and environment.

General procedures concerning the operation of the organization are described in the "Quality Manual MARIN." Rules and regulations on the following subjects are embedded in the manual.

1. Articles of Association
2. Board of Directors & Advisory Board
3. Organization & Responsibilities of Key Personnel
4. Management
5. Employee Council
6. Condition of Sale and Purchase
7. Tariff & Project Cost Administration
8. Labor Conditions and Human Resource Management
9. Security
10. PR & Marketing
11. Document management
12. Miscellaneous

Control of the quality of the MARIN organization is the responsibility of the Managing Director.

For their specific activities each of the MARIN departments operate according to specific quality plans. In each of the departments a Quality Assurance Manager is appointed who is responsible for the control of the quality management and who directly reports to the head of the department. The relevant QA-documents are listed in the table below.

Audits

MARIN QA-Documents can be disclosed to clients on request. Audits by or on behalf of clients shall be accommodated by the concerned department and its QA-manager.

Department	QA-Documents	QA-Manager
Ship Research	QA-Procedures for Ship Model Tests	G G J Mennen
Offshore Research	QA-Manual for Offshore Projects	J E W Winchers
Software Engineering	QA Manual for Software Engineering (according to ISO 9001)	M Th van Hees
Automation & Instrumentation	QA Manual for Instrumentation Development	M C Gottmer

APPENDIX B. SAMPLE DTMB ISO 9000 PROCEDURE

Title:	Procedure Number: 00-5230-113-01	Revision Number: Rev 3	Effective Date: April 12, 1996
Control of Inspection, Measuring and Test Equipment	Prepared by: **D. Downin**	Approved by: R. J. Stenson	Page : 1 of 2

Section 11.0 - Control of Inspection, Measuring and Test Equipment

Calibration of Torsionmeter/Thrustmeter Equipment

In addition to Division procedures for Inspection, Measuring and Test Equipment, the Full Scale Trials Branch calibrates torsionmeters and thrustmeters capable of determining propeller shaft torque and thrust. The calibration of the torsionmeters is traceable to ISO 9001 Certificate of Registration 12 100 4192 and the National Institute of Standards and Technology (NIST). The calibration of the thrust load cells are traceable to NIST.

Calibrations will meet or exceed manufacturer's specifications. Bias limits will be calculated at the conclusion of each calibration and will be held to established standards. If the difference between the pre-trial calibration and the post-trial calibration values are greater than the bias error at full-scale voltage, the trial data must be adjusted. The Pass/Fail Instrumentation Check and Calibration Work Instruction 00-5230-114-03 provides further guidelines as well as bias limit values for various data channels.

11.1 Purpose

To provide a procedure for torsionmeter and thrustmeter calibrations which are not covered under Division procedures.

11.2 Responsibilities

The Branch Equipment Manager (BEM) is responsible for ensuring the effective implementation of this process.

11.3 Torsionmeter Calibration Procedure

11.3.1 All Full-Scale Trials Branch Torsionmeter systems will be calibrated in accordance with the Torsionmeter Calibration Work Instruction 00-5230-114-01 prior to use.

11.3.2 Calibration will be done according to the specifications requested by Program Managers using either Calibration Request Form 11A or 11B.

11.3.3 Once a calibration is complete and approved by the requester, a copy of the calibration is put into the Torsionmeter Calibrations book by the person calibrating the torsionmeter. A copy of the calibration is filed in the Ship's Project file by the person requesting the calibration.

11.3.4 Upon return of torsionmeter equipment, a post-calibration is performed on all systems in accordance with the Torsionmeter Calibration Work Instruction 00-5230-114-01.

Title:	Procedure Number: 00-5230-113-01	Revision Number: Rev 3	Effective Date: April 12, 1996
Control of Inspection, Measuring and Test Equipment	Prepared by: **D. Downin**	Approved by: R. J. Stenson	Page : 2 of 2

11.3.5 Once a post-calibration is complete and approved by the requester, a copy of the post-calibration is put into the Torsionmeter Calibrations book by the person post-calibrating the torsionmeter. A copy of the post-calibration is filed in the Ship's Project file by the person requesting the calibration.

11.4 Thrustmeter Calibration Procedure

11.4.1 All Full-Scale Trials Branch thrustmeter load cells will be calibrated in accordance with Thrustmeter Calibration Work Instruction 00-5230-114-02 prior to use.

11.4.2 Once a calibration is complete, a copy of the calibration is filed in the Ship's Project file and in the Thrustmeter Calibration Book by the person calibrating the thrustmeter. A notation of this calibration will be made in the Branch Equipment File by the person requesting the calibration.

11.4.3 Upon return of the thrustmeter load cells, a post-calibration is performed on the thrustmeter system in accordance with the Thrustmeter Calibration Work Instruction 00-5230-114-02.

11.4.4 Once a post-calibration is complete, a copy of the post-calibration is filed in the Ship's Project file and in the Thrustmeter Calibration Book by the person calibrating the thrustmeter.

11.5 References

1. Form 11A - Torsionmeter Calibration Request Form **(see Tier 3 Quality records for current revision level)**
2. Form 11B - Confidential Torsionmeter Calibration Form **(see Tier 3 Quality records for current revision level)**
3. Form 11C - Torsionmeter Data Sheet **(see Tier 3 Quality records for current revision level)**
4. Form 11D - Confidential Torsionmeter Data Sheet **(see Tier 3 Quality records for current revision level)**
5. Torsionmeter Calibration Book
6. Thrustmeter Calibration Book
7. Torsionmeter Calibration Work Instruction 00-5230-114-01
8. Thrustmeter Calibration Work Instruction 00-5230-114-02
9. Pass/Fail Instrumentation Check and Calibration Work Instruction 00-5230-114-03

Calibration Request

Ship #: ____________ Ship Name: ____________

Type of Trial: Builders ___ Acceptance ___ Special ___

Requestor's Name: ____________ Requestor's Signature: ____________

Date Required By: ____________ Date of Request: ____________

DESIGN REQUIREMENTS	VALUE		SOURCE	
Design Torque	(lbft)			
Full-Scale Torque	(lbft)			
Transient Torque	(lbft)			
RPM				
Horsepower				
Modulus of Rigidity	(enter individual values below)			
PRIMARY SYSTEMS	**PORT (3) or Single**	**STBD (1)**	**PORT (4)**	**STBD (2)**
Ring #				
Ring Bore				
Shaft O.D.				
Shaft I.D.				
Modulus of Rigidity				
10 or 16 MHz				
Shaft Rotation (aft -> fwd)				
PANEL METER DISPLAY	**PORT (3) or Single**	**STBD (1)**	**PORT (4)**	**STBD (2)**
Torque (4 digits)				
RPM (3 digits)				
Horsepower (3 digits)				

SPARE SYSTEM

# of Spares Required: ____________ 10 or 16 MHz: ________

ET Box ____ Sensor & Demod ____ Filter ____ RPM/Period ____ HP Calc ____

Panel Meter ____ 160 kHz Supply ____

Please check all parts required.

NOTE:

- Standard procedure is to calibrate to 5.000V Q Filtered at design torque and to to 150% design torque.
- Make any additional notes or special requirements on the reverse of this sheet.

SEPTEMBER 1995

Form 11A (Rev1)

CONFIDENTIAL

(when filled in)

Calibration Request

Ship #: ____________ Ship Name: ____________

Type of Trial: Builders ___ Acceptance ___ Special ___

Requestor's Name: ____________ Requestor's Signature: ____________

Date Required By: ____________ Date of Request: ____________

DESIGN REQUIREMENTS	VALUE		SOURCE	
Design Torque	(lbft)			
Full-Scale Torque	(lbft)			
Transient Torque	(lbft)			
RPM				
Horsepower				
Modulus of Rigidity	(enter individual values below)			
PRIMARY SYSTEMS	**PORT (3) or Single**	**STBD (1)**	**PORT (4)**	**STBD (2)**
Ring #				
Ring Bore				
Shaft O.D.				
Shaft I.D.				
Modulus of Rigidity				
10 or 16 MHz				
Shaft Rotation (aft -> fwd)				
PANEL METER DISPLAY	**PORT (3) or Single**	**STBD (1)**	**PORT (4)**	**STBD (2)**
Torque (4 digits)				
RPM (3 digits)				
Horsepower (3 digits)				

SPARE SYSTEM

# of Spares Required: ____________ 10 or 16 MHz: ________

ET Box ____ Sensor & Demod ____ Filter ____ RPM/Period ____ HP Calc ____

Panel Meter ____ 160 kHz Supply ____

Please check all parts required.

NOTE:

- Standard procedure is to calibrate to 5.000V Q Filtered at design torque and to to 150% design torque.
- Make any additional notes or special requirements on the reverse of this sheet.

CONFIDENTIAL

(when filled in)

Form 11B (Rev1)

SEPTEMBER 1995

APPENDIX C. SAMPLE DTMB ISO 9000 WORK INSTRUCTION

Title: Control of Inspection, Measuring and Test Equipment **Thrustmeter Calibration**	**Work Instruction** Number: 00-5230-114-02	Revision Number: Rev 1	Effective Date: April 12, 1996
	Prepared by: J. Webb	Approved by: R. J. Stenson	Page : 1 of 4

Thrustmeter Calibration Work Instruction

Purpose

The purpose of this work instruction is to provide a guideline for calibrating a thrustmeter system for use on Full Scale trials. Each thrustmeter system consists of a number of load cells which are calibrated independently.

Scope

This work instruction applies to the preparation, calibration, and installation of thrustmeters for use in Full Scale trials. It establishes test requirements, procedures and limits.

Responsibility

The Trial Engineer is responsible for the implementation of the procedures outlined in this work instruction.

Procedure

Introduction.

1. Compression Load cells are purchased and maintained in inventory and are installed in the ahead and astern thrust bearings of each shaft when conducting ship trials. Load cells are calibrated prior to installation in accordance with the procedures outlined in this work instruction.

2. Depending on the bearing design the load cells mount in holes in either the shoes or in the leveling plates.

3. Load cells are placed behind every shoe on the ahead and astern side of the thrust bearing. A typical two shaft installation would require 8 ahead and 8 astern shoes per bearing, i.e., 32 load cells must be supplied, calibrated and installed.

Prior to calibration

1. Assemble load cells.

   a. Check branch inventory for suitable sizes and quantities of load cells for the job. This should be done sufficiently in advance so that the load cells can be purchased if they are not available in stock. Typical delivery times for load cell orders are 6 to 12 months.

Title: Control of Inspection, Measuring and Test Equipment	**Work Instruction** Number: 00-5230-114-02	Revision Number: Rev 1	Effective Date: April 12, 1996
Thrustmeter Calibration	Prepared by: J. Webb	Approved by: R. J. Stenson	Page : 2 of 4

b. Most load cells are wired in a Wheatstone bridge circuit with a separate resistor board assembly. The correct resistor board (trimmed to match a given load cell) must be matched to the appropriate load cell by serial number.

c. The trial engineer should **develop** and assemble a system which provides:

- excitation **for each load cell** (typically 5 to 15 VDC),
- Bridge completion (i.e., wiring between resistor board and load cell),
- oil-tight connectors to get **cables** into the thrust housing,
- a provision to shunt cal the bridge,
- amplifiers (with a typical gain of 200).

2. Assemble equipment for the Calibration.

a. An appropriately sized compression load machine is used for the calibration. The machine's range must meet or exceed the full scale rating of the load cells being calibrated. The machine should be in good **operating order**, i.e., when the machine is set to a particular steady load, the applied load will not drift. **The machine should also have a current calibration which is traceable to NIST.** A copy of the calibration papers must be obtained and filed in **the ship's project file, the Trial Engineer's Log/Notebook, and the Thrustmeter Calibration Book.**

b. **A high impedance voltmeter (at least 1 meg ohm input) that is accurate to 1 micro-volt is used to record data at the bridge level.** Typical full scale outputs of our load cells are 10 to 30 mv full scale. An Analog to Digital converter may be used if it does not load the system **and meets the accuracy requirements of 1 µvolt.** A voltmeter is connected to the bridge and used for visual observations.

c. **A computer maybe used in conjunction with Analog-Digital converters or digitizing voltmeters to record calibration data**

d. In the laboratory, the load cell system is assembled with excitation **sources**, bridge completion and system cabling duplicating the upcoming trial configuration. Though not preferable, the load cell can be calibrated without an amplifier. The excitation and resistor board must be connected. If more than one load cell shares one excitation source, then all load cells on that source need to be connected to avoid system problems.

e. Load cells must be calibrated in a leveling plate or shoe, as applicable. Machinists metal blocks are used to support the leveling plate in the load machine.

Title: Control of Inspection, Measuring and Test Equipment	Work Instruction Number: 00-5230-114-02	Revision Number: Rev 1	Effective Date: April 12, 1996
Thrustmeter Calibration	Prepared by: J. Webb	Approved by: R. J. Stenson	Page : 3 of 4

Calibration

1. Software

a. Though data can be collected **manually**, a computer **and Analog-Digital converters or digitizing voltmeters** will be used to the maximum extent possible. Use of the computer will facilitate **collecting**, plotting, curve fitting and uncertainty analysis of the data.

2. Data collection

a. Load cells must be connected and allowed to warm up at least one hour before taking data. Load cells should be cycled in **the compression load machine** by **raising** the load to full scale and back to zero 3 times prior to data collection. **This exercises** the cell and **decreases** the occurrences of hysteresis.

b. Data is taken over the full range of the load cell or over the range of interest. **Data is taken at zero (unloaded) and at intervals of approximately 20% of the expected full load range of the load cell. Upon reaching the maximum load, data is collected at the same points as the load is incremently decreased down to and including zero.** Upon completion of a full cycle from zero to peak load and back, a second cycle should be done. The second cycle, repeating every other point of the first cycle, is done to check absolute drift. (see **Thrustmeter Calibration Form 11E**).

c. Prior to the first data cycle and after the second data cycle the cal switch will be thrown and the cal step data recorded. Cal steps are to be taken only at zero applied load. A zero reading should be recorded **prior to** each **calibration** reading.

d. Data to be recorded include applied load (lbs), load cell serial number, load cell excitation voltage (v), load cell output voltage (mv), amplified load cell output (v), and resistor board serial number. (See **Thrustmeter Calibration Form 11E**)

e. A running plot of voltage versus load should be created as the data is collected. **Check the data plot for linearity, repeatability of second points and repeatability of the zero points.** If problems are noted, the calibration should be stopped until the problems are corrected. Loose connections, bad solder joints, improper wiring, bad amplifiers, etc. are possible causes of problems.

f. Load cell resistances are checked. Breaks in load cell cables, if not inside the load cell, are repaired. The load cell, if bad, is often used as a blank to fill the hole in the leveling plate unless additional load cells (rare) are available. Thus every attempt to find and repair problems must be accomplished.

Title: Control of Inspection, Measuring and Test Equipment	**Work Instruction** Number: 00-5230-114-02	Revision Number: Rev 1	Effective Date: April 12, 1996
Thrustmeter Calibration	Prepared by: J. Webb	Approved by: R. J. Stenson	Page : 4 of 4

After calibration

1. **Data tables are to be filed as calibrations in the ship's project file, the Trial Engineer's Log/Notebook, and the Thrustmeter Calibration Book.**

2. Curve fits (least squares etc.) to the data will be used to arrive at an overall best gain to be used for each load cell with the trials instrumentation

3. A Calibrated Load Cell Summary table is made listing Gains, Zeros, and Cal steps for each load cell calibrated. **Copies will be filed in the ship's project file and in the Trial Engineer's Notebook.**

4. **Bias limits will be calculated for each load cell calibrated.**

5. Personnel conducting the trial should assign each load cell a location within the thrust bearing based on the quality of the calibration. If all calibrations are **satisfactory**, the order does not matter. If several cells show non-linearity or other anomalies, they should be placed on the astern side of the thrust bearing if the astern cells are the same type/size as the ahead units.

6. Upon completion of trials, the thrustmeter load cells and leveling plates are removed from the ship's thrust bearing. The bearing is restored to its original condition by reinstalling standard unmodified leveling plates/shoes. This generally occurs at the first yard availability period after trials.

7. Upon return of the load cells to NSWC a post-**calibration** of the load cells is accomplished. The post-**calibration** is **to** be examined by the Trial Engineer. If significant changes are noted, the trials data and or reports are modified accordingly.

References

1. Trial Engineer Log/Notebook

2. **Thrustmeter Calibration Book**

Thrustmeter Calibration Form

Ship or Project: ____________________ Date of Calibration: ______________

Calibrated by: ____________________ Initials of Calibrator: ______________

Checked by: ____________________ Initials of Checker: ______________

Load cell Serial No: ________________ Amp S/N: ____________________

Amp Gain: ____________________ DVM S/N: ____________________

Leveling plate Serial No.: ____________ Resistor board Serial No.: ___________

Load %F.S.	Load (lbs)	Bridge out (mV)	Amp out (v)	Excitation (v)
0	______	__________	__________	__________
	Cal step	__________	__________	__________
20	______	__________	__________	__________
40	______	__________	__________	__________
60	______	__________	__________	__________
80	______	__________	__________	__________
100	______	__________	__________	__________
80	______	__________	__________	__________
60	______	__________	__________	__________
40	______	__________	__________	__________
20	______	__________	__________	__________
0	______	__________	__________	__________
40	______	__________	__________	__________
80	______	__________	__________	__________
100	______	__________	__________	__________
80	______	__________	__________	__________
40	______	__________	__________	__________
0	______	__________	__________	__________
	Cal step	__________	__________	__________