The Specialist Committee on Waterjets

Final Report and
Recommendations to the 22^{nd} ITTC

1. GENERAL

The Specialist Committee on Waterjets has existed for two conference periods. This committee has been tasked to improve the understanding of waterjet hydromechanics and powering prediction methods. The primary responsibility has been to formulate guidelines for waterjet performance prediction methods based on both the momentum flux and direct thrust measurement methods.

1.1 Membership

The Specialist Committee on Waterjets appointed by the 21st ITTC consisted of the following members:

- Dr. Gun-Il Choi
Hyundai Maritime Research Institute
Ulsan, Korea

- Mr. John George Hoyt III (Chairman)
Naval Surface Warfare Center, Carderock Division (NSWCCD)
West Bethesda, USA

- Dr. Bertrand Lamberti
Bassin d'Essais des Carènes
Paris, France

- Mr. Per Lindell
SSPA Maritime Consulting AB
Götenborg, Sweden

- Dr. Tom Van Terwisga
Maritime Research Institute Netherlands (MARIN)
Wageningen, The Netherlands

- Dr. Mehrdad Zangeneh (Secretary)
University College London
London, United Kingdom

1.2 Meetings

Three formal meetings were held, with the final committee meeting including a one-day open discussion with representatives of some of the leading waterjet manufacturers. The following committee meetings and open discussion were held:

- 4-5 December 1997 hosted by the Bassin d'Essais des Carènes, Val de Reuil, France.

- 16-18 June 1998 hosted by the University College London, London, United Kingdom.

- 20-21 October 1998 hosted by The Maritime Research Institute Netherlands, Wageningen, Netherlands.

- 21 October 1998 A meeting with Waterjet Manufacturers was held at The Maritime Research Institute Netherlands, Wageningen, Netherlands.

1.3 Recommendations Of the 21st ITTC

The 21st ITTC Waterjet Committee concluded that, in order to make reliable performance predictions for waterjet propelled craft, model self-propulsion experiments are required. Furthermore, since the expected interactions between the hull and waterjet system components can be significant, the committee concluded that cooperation between the waterjet manufacturers, ship designers, and the towing tanks must be improved.

The five recommendations of the 21st ITTC Waterjet Committee were to:

- Investigate and promote more accurate model self-propulsion tests versus reliance upon resistance tests only.

- Promote cooperation between the towing tanks and the waterjet manufacturers.

- Continue evaluation of model self-propulsion tests evaluated by the momentum flux method.

- Continue evaluation of model self-propulsion tests evaluated by the direct thrust measurements as an alternative to the momentum flux method.

- Collect and publish full-scale waterjet trial data.

1.4 Report To the 22nd ITTC

With the first meeting of the Waterjet Committee, it was clear that in order to accomplish the goals of our predecessors, a series of standardization experiments, traditional to the ITTC, were required. Interaction with representatives of several waterjet manufacturers was also essential in order to obtain their valuable insights and contributions to this effort.

To reach the objectives of the 21st ITTC Committee, it is essential to have open contacts with jet manufacturers, as they are responsible for the internal performance of the jet system, which is an essential part in the overall powering performance of the vessel. Ideally, when predicting the powering performance of a waterjet driven vessel, data from the jet manufacturer and from a towing tank should match each other so that the overall performance prediction can be obtained in a straightforward manner.

Consequently, three early recommendations were proposed to the Advisory Council:

- An open meeting with representatives of several of the major waterjet manufacturers be held to discuss common goals and possible cooperation.

- A representative from one of the waterjet manufacturers should be invited to participate in the next Waterjet Committee.

- The 22nd Waterjet Committee should begin planning for the performance and administration of a series of waterjet self-propulsion standardization experiments to be presented in the Committee Report.

The Waterjet Committee decided that the standardization exercise would need to be broader and more comprehensive than what could be obtained through just a towing basin self-propulsion experiment. To assess the validity of the self-propulsion experiment, the performance of the waterjet pump and its interactions with the inlet and associated ducting must also be measured. Two additional experiments, the "waterjet pump ", and the "waterjet system " water tunnel tests were proposed in conjunction with the traditional self-propulsion test to do this.

It was also felt that the use of computational fluid dynamics (CFD) to improve the estimation of parameters used in the performance of the momentum flux method must also be considered. The momentum flux method currently relies upon several fundamental assumptions, such as the estimation of the inlet capture area and the scaling of the boundary layer thickness from model to full-scale.

The standardization experiment also provides an opportunity to obtain correlation with numerical predictions. The practicality of using early CFD assessments to estimate the inlet capture area and the boundary layer "scale" adjustment must be investigated. Secondary issues, such as the determination of the 3-dimensional nature of the velocity field in the region of the capture area, or identification of potential "problem areas" that may effect the experiment, can also be assessed through a CFD analysis.

The Advisory Committee agreed with all three recommendations. A joint meeting with representatives of several waterjet manufacturers was hosted by MARIN. Representatives from KaMeWa, Hamilton Jets, Vosper-Thorneycroft, Bird-Johnson, LIPS Jets, North American Waterjets, Band-Lavis, Marine Propulsors Company, and the United States Navy participated in an open discussion.

The following committee members participated in the Manufacturers Meeting:

ITTC Committee

J. Hoyt III	NSWC (Chair)
Gun-il Choi	Hyundai
B. Lamberti	Bassin d’essais des carenes
P. Lindel	SSPA
T. Van Terwisga	MARIN
M. Zangeneh	UCL (Secretary)

The following visitors participated in the Manufacturers Meeting:

Manufacturer Representatives

R. Aartojärvi	KaMeWa (Sweden)
A. Becnel	NSWCCD (USA)
S. Hampson	Vosper Thornycroft (UK)
L. Hill	North American Marine Jets (USA)
N. Olofsson	KaMeWa (Sweden)
R. Parker	Vosper Thornycroft (UK)
P. Rae	Hamilton Jets (New Zealand)
E. Roessler	Bird Johnson (USA)
J. Stricker	Marine Propulsor Co. (USA)
R. Verbeek	LIPS Jets (NL)

The objective of the Waterjet Manufacturers meeting was to explore the willingness and the extent to which the jet manufacturers are prepared to participate in a worldwide standardization test circuit. A draft test plan for the "standardization experiments" was presented with a three-tier approach to obtain the ultimate goal of a recommendation for a commercially viable procedure.

It was explained that tests will eventually lead to a consistent procedure for both self-propulsion and pump loop experiments. This is considered an important step in improving the integrity of results irrespective of where the tests are performed. In order to define the reliability of full-scale predictions (which is the final aim), it is also necessary to know the reliability of the extrapolation procedure.

The participants showed an interest in the efforts of the ITTC, and voiced an interest of participating, in some way, in both the closed-loop evaluation of the waterjet pump and the open loop evaluation of the waterjet system. The conclusions from this joint meeting with the manufacturers were:

- Manufacturers currently rely largely on their empirical database to account for the interaction between the hull and the jet. This procedure, which relies largely upon resistance tests, has been an economic necessity for the majority of the manufacturers. Until recently, most manufacturers have provided propulsion systems for primarily small craft, where a budget to support extensive model tests or full scale trials did not exist. These economic factors, combined with the lack of confidence in the towing tank's present procedures, have limited the development of data.

- Self-propulsion tests were considered to be required only for special hull forms and unusual speed regimes (mostly high speeds).

- However, improving the reliability of self-propulsion tests is of some importance to the jet manufacturers, and the proposed standardization test program is an important step in this direction.

The preferred powering prediction method results from a balance between the present uncertainty in experimental prediction techniques and the reliability governed by market demands. The Waterjet Committee expects that the developing market will only drive the prediction reliability to higher standards.

2. LITERATURE UPDATE

The global objective of the Waterjet Committee is to improve the understanding of waterjet hydromechanics and to improve powering prediction methods for waterjet driven craft. The Waterjet Committee of the 21st ITTC recommended that this committee collects experience with the "momentum flux method" and further evaluates the “direct thrust measurements” on waterjets. Full-scale data are to be collected for verification of prediction techniques.

This review presents an update of the literature released since the 21st ITTC, which was held in the summer of 1996. The literature review is constrained to an update on experimental techniques, preliminary prediction methods, and CFD developments. The literature on experimental techniques is discussed in more detail, as it is directly related to the main objective of the Waterjet Committee.

Major sources contributing to the literature on waterjet propulsion are the FAST’97 Conference in Sydney and a special symposium on waterjet propulsion, organized by the RINA in Amsterdam in October 1998.

2.1 Experimental Techniques

There are two distinct methods for the experimental determination of the powering characteristics of a jet-hull system. The most frequently used method is referred to as the “momentum flux method”; an alternative method is referred to as the “direct thrust measurement method”. The 21st ITTC [1996] Waterjet Committee describes both methods.

Theoretical Models in Experimental Analysis

Most publications deal with the momentum flux method. Probably the most controversial discussion about this method deals with the relation between momentum flux and hull resistance. The method described by the 1996 ITTC Waterjet Committee provides a relation between the momentum flux and an effective hull resistance. However, a relation between this effective and bare hull resistance is not provided. This is especially an omission in the preliminary design stage where no test results are available, but where a proper estimate of the bare hull resistance is usually known.

A relation between waterjet thrust and bare hull resistance is provided through the so-called thrust deduction fraction t, as introduced by the ITTC [1987]. Disagreement in the literature is however observed on the issue of whether a thrust deduction fraction has any meaning in waterjet propulsion. This is because of the difficulty in separating the jet thrust from the hull resistance.

Van Terwisga [1993] refines the definitions presented by the ITTC [1987] and separates hull and jet characteristics. Van Terwisga and Alexander [1995] derive a simple relation for net thrust (instead of gross thrust as defined by the 18th ITTC [1987]). This definition allows for a physical interpretation of the difference between jet thrust and bare hull resistance. This difference can be expressed in a thrust deduction, which lends itself to an empirical prediction due to its straightforward physical interpretation, Van Terwisga [1996].

Dyne and Widmark [1998] expand on the difficulty of separating the jet thrust from the hull resistance, and defend the thesis that the concept of conventional thrust is better discarded in favor of a definition of momentum flux. A consequence of the choice of momentum flux instead of net thrust is that no overall propulsive efficiency of the jet-hull combination can be found, nor can the jet-hull interaction be expressed explicitly. However, Van Terwisga [1996] showed that there is no fundamental obstacle to such a development. The Committee holds the opinion that the proposed standardization tests will promote discussion on this issue and a final proposal is aimed for at the end of the next term.

An original contribution to the discussion on experimental waterjet powering methods for high speed planing craft is presented by Yamano et al. [1998]. These authors solve the three equilibrium equations (horizontal, vertical and pitching moment), yielding the hull's attitude and thrust. The effect of the jet system on the hull forces and moments is obtained from a set of model tests and is expressed in simple relations showing only the effect of the intake velocity ratio (IVR).

Efficiency Relation

Allison [1993] provides a good review of the state of the art of contributions to the overall efficiency. The overall efficiency (or non-dimensional power) is defined here in the same way it is done for propeller propulsion:

$$\eta_{OA} = \frac{P_E}{P_D} \qquad (1)$$

where P_E is the effective power, based on bare hull resistance (with closed intakes and including entrained water) and P_D is the power delivered to the impeller. The efficiency equation compiled by Allison [1993] contains a pressure term that has been modified by Van Terwisga and Alexander [1993]. These authors separate the overall efficiency found in the freestream as well as the jet-hull interaction efficiency. The contribution of intake drag and the net effect of the pressure term in the ingested momentum flux are also discussed.

Dyne and Widmark [1998] present the overall efficiency relation based on the terminology presented by the 1996 ITTC Waterjet Committee. The effective power P_E in eq. (1) is defined here by the effective resistance under self-propulsion conditions associated with the definition of momentum flux.

Ingested Boundary Layer Flow

The amount of ingested boundary layer flow has to be assessed from an assumption of the capture area ahead of the intake and the measured or calculated boundary layer velocity distribution.

Roberts et al. [1997] as well as Roberts and Walker [1998] present experimental data on the capture area that is measured well in front of the intake ramp tangency point (in excess of 20% of the intake length). They show a slight widening of the capture area for increasing IVR.

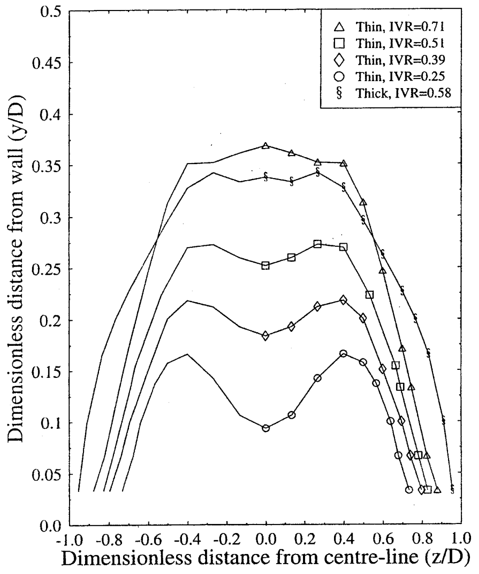

Figure 1. Capture area for various IVR's. (Roberts and Walker [1998])

They also show that for the higher IVR values, the capture area resembles an ellipse, but that for the lowest values (IVR<0.4), a noticeable dip in the capture area occurs at the centerline (Fig. 1).

The elliptical capture area measured by Roberts and Walker [1998] is a factor 1.5 to 1.9 wider than the geometric intake width. Alexander et al. [1994] also noticed an elliptic capture area with a width of approx. 1.5 times the geometric width and largely independent of craft speed over the speed range investigated.

The effect of capture area geometry and width on ingested momentum flux and thrust was assessed by Van Terwisga [1996]. He compared the effect of a rectangular capture area with a capture area width of 1.3 times the geometric width (ITTC [1996]) with that of an elliptic capture area with a width of 1.5 times the geometric width. He concluded that a maximum deviation in derived net thrust occurred of approximately 1.5%, whereas the maximum effect on the total interaction efficiency was within 0.5% for a representative nozzle velocity ratio (NVR) of 1.7. This effect is expected to slightly increase for lower NVR values. This conclusion contradicts the conclusion by Roberts and Walker [1998], who conclude that application of the rectangular capture area suggested by ITTC [1987] may lead to an under-prediction of gross thrust by some 10% for a typical high speed ferry design.

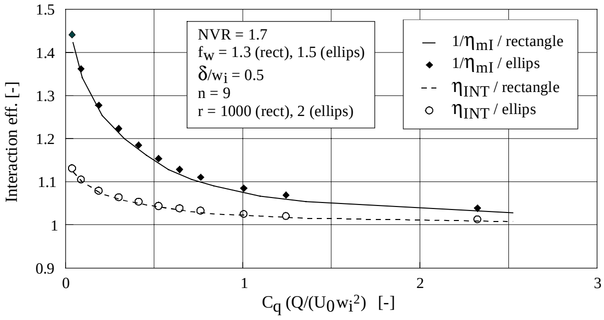

Figure 2. Effect of capture area geometry on interaction. (Van Terwisga [1996])

2.2 Full Scale Results

An interesting contribution to the issue of extrapolation of model results and the actual difference between bare hull resistance and thrust (thrust deduction) is presented by Svensson et al. [1998]. The authors present full-scale data on measured velocity distributions in the boundary layer just ahead of the waterjet intakes. They use a correlation factor to relate the full-scale derived thrust T_s with the predicted bare hull resistance from model tests R_{bhs}. The correlation factor t_{corr} has the form of a thrust deduction:

$$t_{corr} = \frac{(T_s - R_{bhs})}{T_s} \qquad (2)$$

It is demonstrated in the paper that an underestimate of the boundary layer thickness by 45% results in an artificial discrepancy between thrust and resistance of some 5% for the presented case.

2.3 Preliminary Design and Prediction Methods

Two publications deal with a powering prediction in the early design stage, where the bare hull resistance is used as input. Van Terwisga [1997] presents a parametric method, incorporating an estimate of interaction effects. Cavitation limits are treated through the use of empirical limits on the suction specific speed. Koushan [1998] also presents a method for selection and powering prediction of a waterjet system. He includes three generic pump diagrams to estimate the pump performance in off-design conditions.

2.4 CFD Developments in Design and Analysis

A number of publications deal with the application and validation of RANS codes for intake analysis and design such as Hu and Zangeneh [1998], Roberts et al. [1997], Roberts and Walker [1998], Seil et al. [1997], Turnock *etal* [1997], Turnock et al. [1998], Verbeek et al. [1998] and Watson [1998]. These publications demonstrate the applicability of RANS codes for the prediction of velocity fields at the end of the intake, the risk of separation in the intake, intake energy loss, and risk of cavitation. The RANS codes can also be successfully used to determine the capture area of the ingested streamtube (Roberts et al. [1998]). This capture area affects the ingested boundary layer flow and consequently the ingested momentum and energy flux.

Although the limited applicability of potential flow codes in intake analysis has been demonstrated by e.g. Kashiwadani [1985] [1986] and Van Terwisga [1996], Kashiwadani [1997] demonstrates that they can be a useful tool in intake design.

CFD codes are now also being used in pump design and analysis. Allison et al. [1998] provides a brief review of the history of the design of pumps for waterjet propulsion. The authors discuss methods from the simple one-dimensional momentum theory to the more sophisticated coupling of impeller lifting surface theory with axisymmetric RANS codes. Taylor et al. [1998] expand on the technique that couples a lifting surface program for blade row calculations with an axisymmetric RANS solver for computation of the pump through flow. Turnock and Hughes [1998] use a combination of a RANS code for the prediction of the pump inlet flow and a propeller surface panel code to compute the flow about the impeller.

2.5 Results of Recent Model Experiments

The results of three model experiments involving waterjet propulsion in various type craft have been published. Stepanov and Fedorov [1994], Suh [1994], and McMahon, et al. [1999] investigated the effects of waterjet-hull interactions on the thrust requirements compared to the bare hull resistance measurements. Results found interaction effects can be significant and can either increase or decrease thrust requirements for different types of craft applications. Displacement craft, with their larger frictional drag component, indicate more potential for negative thrust deductions.

3. RECOMENDED POWER PREDICTION METHODS FOR WATERJET PROPULSION SYSTEMS

3.1 Momentum Flux Method

The procedures and nomenclature presented by the 21st ITTC Waterjet Specialist Committee for the measurement of momentum flux as a power prediction method for waterjet propelled craft is the preferred method of the current Committee. It is the recommendation of the Committee that this method, as presented in the ITTC Quality Manual section 4.9-03-03-05.2, be adopted with the following additions.

As pointed out in the 21st ITTC Waterjet Specialist Committee Report, there is still some debate over the details of executing the momentum flux method. For example, there are still no recommendations for estimation of tow-rope force, capture area, measurement of mass flow rate, or even the preferred location of Station 1. The lack of definition for these parameters, as well as other details, are discussed in the 21st ITTC report. This level of uncertainty will only be resolved through examination of model data and correlation to full scale trials, or the use of more advanced procedures utilizing CFD. The proposed procedure should be considered an interim solution, which provides a "point of departure" for all future experiments. This tentative nature of the procedure should be reflected in the ITTC Quality Manual.

3.2 Direct Thrust Measurement Method

Although the direct thrust method is not the preferred procedure of the current Committee, it is still important to continue evaluation of this method as an alternative to the momentum flux method. The direct measurement of the forces and moments imparted upon the hull by the waterjet system may provide insights into the interactions. For this reason, the direct measurement of the waterjet forces is recommended as an integral part of the proposed "Standardization Experiments".

4. WATERJET SELF-PROPULSION STANDARDIZATION TEST

The recommendations of the 21st ITTC Committee were to promote cooperation between the towing tanks and waterjet manufacturers, continue evaluation of model self-propulsion tests evaluated by the momentum flux and direct thrust measurement methods, and collect and publish full scale waterjet trial data. Cooperation between the towing basins and the manufacturers is essential. The vast majority of the experimental and trial data is the proprietary property of the manufacturers. They hold the key for access to this data. However, given the manufacturers competitive positions, it is understandable why this information is closely controlled.

There is a false assumption that the manufacturers possess a vast resource of comparative data. Because of the Committee's discussions with the manufacturers, it is clear that there has been a dependence, on their part, upon estimation of powering performance based on extrapolation of resistance experiments only.

This reliance upon resistance tests has been an economic necessity for the manufacturers. Until recently, most manufacturers have provided propulsion systems for primarily small craft, where a budget to support extensive model tests or full-scale trials did not exist. These economic factors, combined with the lack of confidence in the present experimental procedures, have limited the development of data.

The current recommendations of the ITTC on the performance of waterjet self-propulsion experiments are still subject to debate. In order to validate self-propulsion experimental methods both model and trial data are required. Consequently, the Specialist Committee on Waterjets proposes to the Conference that a series of "standardization" experiments on a suitable hull and waterjet system be performed. These tests should be performed in close cooperation with the waterjet manufacturers. These tests should be comprehensive enough to evaluate the current best standard practice in propulsion tests as compared to reliance on resistance experiments with "experience" based interaction factors. Finally, use of CFD to aid in the determination of assumed parameters such as inlet capture area and model to full-scale boundary layer scaling is anticipated.

4.1 Goals

The main goals of the waterjet self-propulsion standardization experiments are to:

- Provide a recommendation for a procedure for the estimation of the propulsive power required for waterjet propelled craft that is sufficiently reliable and commercially viable.

- Perform a comprehensive measurement uncertainty analysis from a broad base of experimental data. Acknowledge bias error sources and assess their magnitude through cross validation of test techniques (such as measurement of flow rate or inlet velocity profile) and through the use of CFD results.

The recommendation for the power prediction method should be based on a validation of model self-propulsion tests by the momentum flux method. These results are to be compared to results from the direct thrust measurement method.

4.2 Organization

There is an opportunity to participate in a joint three-year effort through a regional program sponsored by the United States Office of Naval Research. The Gulf Coast Regional Maritime Technology Center (GCRMTC) is administrated by the University of New Orleans. This center is tasked with the development of technologies to stimulate the maritime industry in the Gulf Coast region of the United States. The GCRMTC is currently funding an effort by Band-Lavis and Associates and the Naval Surface Warfare Center, Carderock Division to investigate the interactions of the hull, inlet, and jet of a waterjet system.

It is the goal of this study to adapt and develop numerical tools to predict the forces and moments acting on an integrated hull/propulsor system. In order to accomplish this, a baseline hullform and integrated waterjet configuration will be developed to exercise these computational methods. There are plans to use the results of this effort to design an advanced hullform and propulsion system that will take advantage of hull-inlet and hull-jet interactions.

The ITTC's role will be to validate the self-propulsion, water tunnel, and pump loop experimental techniques so that the performance of the system can be evaluated and correlated to the numerical predictions. Part of this correlation will be the determination of a comprehensive measure of experimental uncertainty obtained from the results of different laboratories. To achieve this goal, a model of the baseline hullform as well as the waterjet and inlet design can be made available to the ITTC for the standardization experiment. It is hoped that two hull models, complete with inlets, will be available for this project. In addition, one set of scale waterjets will also be available for the experiments.

It is recommended that two types of participants be recruited. The first type of participant will be those who will be asked to execute the model experiments. Member ITTC facilities as well as non-members such as waterjet manufacturers will be invited to participate. The inclusion of the waterjet manufacturers is essential to the project. The manufacturers possess the extrapolation experience as well as operate many of the world-class pump loops and water tunnels. However, other organizations that may not have the facilities to take part in these model experiments should be encouraged to participate in the analysis of the data as well as the generation and correlation with numerical predictions.

4.3 Administration

The proposed standardization experiment has three administrative components:

- Permit two rounds of experimentation to allow facility calibration.

- Confidentiality of data obtained by the use of a double blind method through a neutral party.

- Use of a three-tier test plan to execute the experiment in distinct degrees of detail.

Two-Round Approach to Facility Calibration

A significant goal of this standardization exercise is to obtain a cross validation of test techniques used by several towing basins. It is also a goal to increase awareness of improved or alternative testing techniques. Therefore, each participating facility should be able to use this exercise to "calibrate" their methodology after reviewing their results relative to the group.

To provide to each facility the opportunity to "calibrate" using the group results, an optional second round of testing should be offered. The option to "re-test" will permit participants to check procedural changes considered after a comparison to the group results.

Data Confidentiality

In order to promote the free exchange of data, it is proposed that the originator of all test data shall be kept confidential. All data will be identified simply by a batch number with no reference to the provider. This will be done by a double blind method through a university serving as a neutral party.

All first round data, in an agreed digital format, will be provided to the neutral party. The data will then be compiled, merged, and distributed to all of the participants for analysis. Any participant who requests a "re-test" will have the option to re-submit their data for merger and distribution.

Three Tier Test Plan

A three-tier approach to obtain the ultimate goal of a recommendation for a commercially viable procedure is proposed.

The first tier (Tier I) in the test plan is a comprehensive series of experiments designed to validate the complete process of predicting self-propulsion with a waterjet. This level of effort will not be practical for all of the participants in the standardization exercise, nor will it be a commercially viable procedure. It may not be possible for any single participant to execute all of the test measurements required for Tier I. However, the Tier I specification given in Appendix A is the current preliminary test plan proposed for NSWCCD support of the GCRMTC project. These results are expected to provide a very comprehensive set of data for comparative purposes.

The second tier (Tier II) represents the fundamental experiments required to obtain an estimate of powering for a waterjet propelled craft. Tier II will be tailored to each participants capabilities. Not every facility participating in this exercise can or will be asked to perform the entire Tier I items. However, a distribution of testing tasks amongst the participants will be attempted that will provide overall coverage and adequate duplication of much of the Tier I experiments.

The third tier (Tier III) will comprise the recommended commercial procedures for execution of both the self-propulsion and pump loop experiments. These procedures will result from the evaluation of NSWCCD's Tier I study combined with the ITTC's Tier II results and the numerical predictions. The recommendation for a commercially viable test procedure is the desired outcome of this effort.

4. 4 Hull Form Selection

The selection and design of the hullform and waterjet propulsion system will be the responsibility of the GCRMTC. Selection of the baseline hull and waterjet propulsion system will have taken place by the time of the 22nd ITTC Conference. Input is required from the ITTC to assure that the baseline hull and waterjet system will be adequate for the standardization experiments. The following guidelines have been provided to the GCRMTC project team.

- A conventional mono-hullform with inlet and waterjet pump consistent with current practice is preferred by the ITTC for the baseline.

- The hullform should be selected to be within what can now be modeled numerically.

- Only flush or moderately dropped inlets should be considered.

- A displacement or semi-displacement hullform has more immediate interest.

- A single or twin propulsion system is preferred from a simplification of testing viewpoint.

- This hullform should permit the study of below, near, and above waterline discharge of the jet.

- A speed regime below a Froude Number of 0.80 should be considered.

4.5 Role of Computational Fluid Dynamics

Numerical performance prediction methods, as currently used for waterjet systems, are very simple and cannot adequately account for interacting hull and propulsor flows. Experimental methods are also considered largely unproven. However, with the availability of advanced computational techniques, accurate means may be developed to both predict forces and powering characteristics of waterjet installations to be used in the validation of the experimental methods.

To date, little consideration of jet/hull flow interaction phenomena has been given because impingement occurs in most cases far from the hull. Some recent experimental work has shown that jets impinging on free-surface or near-surface hull flows can favorably influence both lift and thrust forces. Means of understanding and modeling these effects are now available through the application of CFD techniques.

A somewhat better understanding exists regarding inlet-hull interactions. Boundary layer ingestion is normally accounted for in the inlet design process. The effects of inlet flows on overall resistance are, however, not predictable except for configurations that have been tested. It is likely that future optimized geometries will feature hull afterbody lines that are quite different from the adapted propeller-driven hullforms of today.

The current experimental methods depend upon several simplifying assumptions. The use of CFD as an aid in determining certain of these critical parameters may improve the fidelity of these experimental methods. CFD could improve the estimation of the following parameters:

- Determination of the optimum longitudinal location for measurement of the inlet capture area (Station 1).

- Estimation of the shape of the inlet capture area at Station 1.

- Scaling of the ingested boundary layer at Station 1 from model to full scale.

- Determination of the thrust augment to use in estimation of the tow rope force.

- Estimation of the contraction coefficient to be applied to the calculated nozzle velocity, if the average jet velocity is not measurable at the Vena contracta.

- Estimation of the location of the waterjet Vena contracta.

- Correlation of the thrust measured by the direct thrust method to that computed from the momentum flux method.

4.6 Waterjet Pump Loop Evaluation

There is an ongoing discussion about the merits of estimating powering performance by determining the relative contributions of the hull, inlet, ducting, pump, and nozzle versus measuring the total system. It has been argued that reasonable estimates of required power can be made from the bare hull resistance by using the pump characteristics with assumed interaction coefficients and losses for the other components. It has also been argued that the use of model self-propulsion experiments does give a "total system" estimate. However, this is so only if a scaled representation of the complete system is tested at a sufficiently high Reynolds Number, such that the components of this model system are not subject to scaling effects.

There is concern that for a practical scale model, the pump may be subject to scaling effects great enough to influence the end results. It is common practice, when either performing the momentum flux or direct thrust measurement methods, to use a well-characterized "surrogate" pump in place of a scale representation. The full-scale performance is then estimated by substituting the characteristics of the design pump for the model. In order to validate the methods recommended for performing a waterjet self-propulsion experiment, the process of characterizing both the actual and model pump must be considered. With this in mind, the standardization exercise should include a waterjet pump loop experiment.

Section 1 of Appendix A provides an outline of the preliminary specifics for the pump loop experiment. The final details of the ITTC test specifications will depend upon the hull form selected.

The objective of this pump loop experiment is to analyze the waterjet pump characteristics. For the design of the internal components of a waterjet pump, a more extensive list of measurements and parameters, as indicated in Tier I, is required. However, for the purpose of "substitution" in the self-propulsion experiment, this required list can be greatly reduced to the following:

n	Shaft speed of pump
Q	Shaft torque of pump
Q_P	Volume flow rate through pump
p_i	Local static pressure at pump face
H_{35}	Headrise of pump
P_{pe}	Effective pump power
η_p	Pump efficiency

It is proposed that in Tier II only the "uniform flow" condition be performed to obtain what is required to support the self-propulsion experiment. During the performance of the self-propulsion component of this exercise, each facility will be free to use either a scaled representation of the design pump, or a "surrogate" pump of their choice.

Both a large model, intended solely for the pump loop test, and a small model, scaled to the model hull, will be available for pump loop testing. By having two scale models, it is hoped that a greater number of facilities can participate in these experiments. It will also provide an opportunity to investigate scaling problems.

Cavitation will also need to be addressed at some time to obtain an understanding of how cavitation affects waterjet performance. It is recommended that, during these experiments, some quantification of cavitation be attempted as an option. It is proposed that cavitation be quantified by identifying the speeds and cavitation number where there is a reduction in the headrise of 3% from the baseline at the pump working point under consideration.

4.7 Waterjet System Water Tunnel Test

The full-scale performance prediction is estimated by substitution of component characteristics into the results of the propulsion tests. If the pump characteristics as measured in a uniform flow are used, it is implicitly assumed that pump performance is not greatly affected by non-uniformities in the in-flow caused by the inlet and that there are no other potential scaling problems.

There is a concern that if a surrogate pump is used, and powering is estimated by substitution, then the effect of non-uniformities in the in-flow may not be adequately accounted for. In addition, flow phenomena in the inlet such as separation and cavitation may also not be adequately represented in a self-propulsion experiment. To quantify whether these phenomena exist in the inlet and pump system used for the standardization exercise, a limited number of waterjet system experiments should be performed.

Section 2 of Appendix A provides an outline of the preliminary specifics for the waterjet system experiment.

Many facilities perform these waterjet system experiments to use in conjunction with the results of the bare hull experiments to estimate powering performance. The objective of this waterjet system experiment is to first identify any potential problem areas in the inlet where unacceptable flow may exist. The effect of non-uniform flow on pump performance will also be investigated.

These experiments can be performed in either an open or closed loop. For the closed inlet/waterjet loop the list of measurements and parameters are:

n	Shaft speed of pump
Q	Shaft torque of pump
Q_P	Volume flow rate through pump
p_i	Local static pressure at pump face
H_{35}	Headrise of pump
P_{pe}	Effective pump power
η_p	Pump efficiency
V_{BP}	Tunnel bypass velocity
IVR	Inlet velocity ratio

For an open loop experiment, the effect of the nozzle can be determined and the gross thrust measured by impinging the jet upon a reaction target. The list of measurements and parameters can then be supplemented with:

p_n	Local static pressure at nozzle
H_{36}	Headrise of waterjet
T_G	Gross thrust of waterjet
η_{WJ}	Waterjet efficiency

It is proposed that in Tier II, again, only the "uniform flow" condition be performed. Both a large and small model inlet, scaled to match the two scale pumps, will be available for testing.

Cavitation can also be addressed during these experiments as an option. In addition to cavitation observations to the pump (see Section 4.6), cavitation observations can be made on the intake lip and ramp.

4.8 Waterjet Self-Propulsion Test

The main component of this standardization exercise is the self-propulsion experiment. As stated previously, it is the goal to validate both the momentum flux and direct thrust measurement methods.

Section 2 of Appendix A provides an outline of the preliminary specifics for the waterjet system experiment for both Tier I and Tier II. The recommendations of the 21st ITTC Waterjet Committee should be used by the participating facilities as a starting point for planning of their respective experiments. The goal of this exercise is to validate the waterjet model self-propulsion methods as well as obtain cross validation of test techniques used by several towing basins. To achieve this, the methods to be used are at the discretion of the experimental facilities.

It is proposed that in Tier II that all Tier I test components other than flow visualization be performed. These components include measurement of the bare hull resistance with inlet covers in place, bollard thrust, and performance underway. Each facility will be free to use either a scale representation of the design pump, or a "surrogate" pump of their choice.

5. CONCLUSIONS AND RECCOMENDATIONS

The 21st ITTC Waterjets Committee concluded that "reliable performance predictions for waterjet propelled craft require that model self-propulsion tests are carried out. Performance predictions, based on resistance tests only, may lead to serious errors." In addition it was concluded that "For successful performance predictions the co-operation between towing tanks and waterjet manufacturers must be enhanced, largely with regard to decisions on the geometry of inlet, ducting, pump and nozzle, as well as in relation to pump performance, both at model and full scale."

After meeting with representatives of several waterjet manufacturers, in order to foster this co-operation, a consensus was found from this community. The representatives of the manufacturers voiced the opinion that self-propulsion tests were necessary only for special cases involving hull shapes or high speeds for which little or no experience is available. At first, this appears to be in direct conflict with the thoughts of the 21st ITTC Waterjet Committee. However, this opinion correctly reflects the general lack of confidence found with the two most favored test techniques, as well as the lack of validated model to ship correlations.

There is also a common assumption that to obtain the required accuracy and reliability, the cost of the self-propulsion experiment becomes prohibitive. It is essential to guard against creating recommendations aimed solely at research objectives and ignoring the less stringent but more affordable "common commercial practice."

This is not so much a problem with measurement uncertainty as it is with perception of proven reliability. The ways and means to perform these experiments exist. The level of measurement uncertainty can and has been ascertained for prior experiments. However, there are insufficient ship to model correlation studies available in the open literature to draw any sort of conclusions on the validity of the experimental process. The first objective of the Waterjets Committee was to evaluate the procedures for model waterjet self-propulsion tests through actual experiments. As always, funding was limited and there were few opportunities to participate or benefit from ongoing waterjet self-propulsion tests, let alone full scale trials. The next step in the development of the "waterjet self-propulsion test" should be the performance of a series of model standardization experiments.

5.2 Recommendations to the Conference

Adopt the procedure for the measurement of momentum flux as a power prediction method for waterjet systems (ITTC Procedure 4.9-03-03-5.2).

Adopt the nomenclature presented by the 21st Waterjets Committee for the measurement of momentum flux as a power prediction method for waterjet systems.

5.3 Recommendations For Future Work

It is recommended that the next step in the development of the "waterjet self-propulsion test" should be the performance of a series of standardization experiments as presented in the report of the 22nd Waterjets Committee. This study would be performed on a voluntary basis, by participating ITTC experimental facilities and other interested parties such as waterjet manufacturers. The major goals of these studies are to obtain cross validation of test techniques, correlation with numerical predictions, comparison of results between laboratories, and to perform a comprehensive measurement uncertainty analysis.

Three different types of experiments are proposed in order to investigate and validate the methods currently used to estimate the powering characteristics of a waterjet-propelled ship. These three experiments, the waterjet pump loop, the waterjet system water tunnel, and towing basin self-propulsion tests using both the momentum flux and direct measurement methods, will be performed by the participants, as appropriate.

It is recommended that the next Waterjets Committee also draft the procedures and nomenclature for the performance of both the waterjet loop test and waterjet system test. The successful estimation of powering performance of the waterjet is dependent upon these quasi open-water characteristics of the pump and inlet.

6. REFERENCES

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APPENDIX A

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT TEST PLAN OUTLINE TO TIER II

ITEM	TASK	TIER I	TIER II
1.0.0.0	**Waterjet Pump Loop Test**		
1.1.0.0	Administration & Documentation		
1.1.1.0	Required NSWC/ISO Documentation	X	
1.1.2.0	Required GCRMTC Documentation	X	
1.1.3.0	Required ITTC Documentation	X	X
1.1.4.0	Additional Documentation As required	X	X
1.2.0.0	Model & Auxiliary Components		
1.2.1.0	Pump Components (Test Pump To Be Provided By GCRMTC)		
1.2.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	
	30?Isometric Assembled & Exploded View	X	provided
	Blade Radial Cross-Sections @ Tip, mid-span & Root	X	provided
	Inspection Drawing	X	provided
1.2.1.2	Engineering Data		
	Blade Surface Data For NC Machining	X	
	Performance Map Of Flow Rate, Head Rise, Thrust, Torque, & Shaft Power As A Function Of Shaft Speed	X	provided
	Blade Upper & Lower Offsets @ Tip, mid-span & Root	X	
	Blade Stress Analysis (Speed Versus Stress Indicating mid-span & 100% Allowable)	X	
	Tip Deflection Versus Speed For Both Forward & Reverse Operation	X	
	Rotational Dynamics To The 5th Mode	X	
	Cavitation Limits	X	provided
	Expected Velocity Profile @ Pump Face	X	
1.2.1.3	List Of Materials Cross Linked To Drawings Consisting Of		
	Number Required Including Spares	X	
	If Commercial Item (Manufacturer, Description, Part Number, etc.)	X	
	Construction Material (MILSTD, Alloy, Manufacturers Identification, etc.)	X	
	Special Instructions	X	
1.2.1.4	Tolerances		
	Dimensions	X	
	Surface Finish	X	
	Interference & Fit	X	
	Tip Clearance	X	
	Overall After Assembly	X	
	Balance	X	
	Special Instructions	X	
1.2.1.5	Detailed Inspection Report Including		
	Detailed Inspection Report Including	X	X
	Overall Component Dimensions As Per Inspection Drawing For Detailed Inspection	X	X
	Overall Assembly Dimensions As Per Inspection Drawing For Detailed Inspection	X	X
	Blade Upper & Lower Surface @ Increments Of 10% Radius	X	
	Blade Upper & Lower Offsets @ Tip, mid-span & Root	X	1 blade
	Tip Clearance @ 10?Increments	X	
	Minimum & Maximum Tip Clearance For Each Blade	X	X
	Dynamic Balance	X	
	Surface Finish	X	
	Weight Of Each Component	X	X
1.2.1.6	Photos & Video		
	Multi-View & Close-Up Photos Of All Components & Assembly	X	optional
	Multi-View & Close-Up Video Of All Components & Assembly	X	optional
1.3.0.0	Facility & Support Equipment		
1.3.1.0	Pump Loop Facility		

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT
TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
1.3.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	X
	30?Isometric Assembled	X	
1.3.1.2	Engineering Data		
	Performance Map Of Flow Rate, Head Rise, Average Velocity @ Test Section, & Shaft Power As A Function Of Shaft Speed	X	optional
	Test Section Static Pressure Range As A Function Of Shaft Speed	X	optional
	Velocity Profile @ Test Section For 5 Speeds	5 spds	1 spd
	Air Content & Void Fraction	X	
	Mechanical Vibration @ Test Section As A Function Of Shaft Speed	X	
	Acoustic Noise @ Test Section As A Function Of Shaft Speed	X	
1.3.1.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
1.3.2.0	Wake Screen		
1.3.2.1	Engineering Drawings Consisting Of		
	3 View Assembly	X	optional
1.3.2.2	Engineering Data		
	Static Pressure Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
	Total Pressure Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
	Velocity Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
1.3.2.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
1.4.0.0	Instrumentation & Data Collection		
1.4.1.0	Required Measurements (time history & statistics: mean, std.dev., max., min.)		stats only
1.4.1.1	Tunnel Pump Speed	X	X
1.4.1.2	Tunnel Flow Rate		
	Integration Of Velocity Profiles	X	optional
	Measurement Of Flow Rate Independent To Integration Of Velocity Profiles	X	X
1.4.1.3	Waterjet Pump Speed	X	X
1.4.1.4	Waterjet Angular Position Of "Blade 1"	X	
1.4.1.5	Waterjet Torque	X	X
1.4.1.6	Waterjet Blade Axial Root Strain (Number As Required)	X	
1.4.1.7	Test Section Static Pressure @ Wall 2 Diameters Forward Of Pump Face		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
1.4.1.8	Pump Face Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
1.4.1.9	Intermediate Stations Static Pressure @ Wall (Number As Required)		
	Average	X	
	12 Circumferential Locations (30?increments)	X	
1.4.1.10	Exit Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
1.4.1.11	Radial Static Pressure Profile 2 Diameters Forward Of Pump Face		
	12 Angular & 5 Radial Locations	X	optional

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT
TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
1.4.1.12	Radial Static Pressure Near Pump Face		
	12 Angular & 5 Radial Locations	X	
1.4.1.13	Static Pressure @ Intermediate Stations		
	As Required	X	
1.4.1.14	Radial Exit Static Pressure Profile		
	12 Angular & 5 Radial Locations	X	optional
1.4.1.15	Total Pressure Profile 2 Diameters Forward Of Pump Face		
	12 Angular & 5 Radial Locations	X	X
1.4.1.16	Total Pressure Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
1.4.1.17	Total Pressure @ Intermediate Stations		
	As Required	X	
1.4.1.18	Exit Total Pressure Profile		
	12 Angular & 5 Radial Locations	X	X
1.4.1.19	3 Axis Velocity Profile @ Least 2 Diameters Forward Of Pump Face		
	12 Angular & 5 Radial Locations	X	
1.4.1.20	3 Axis Velocity Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
1.4.1.21	Velocity Incident Angle @ Intermediate Stations		
	As Required	X	
1.4.1.22	3 Axis Velocity Profile @ Exit		
	12 Angular & 5 Radial Locations	X	
1.4.1.23	Water Temperature	X	X
1.4.2.0	Data Collection Rate		
1.4.2.1	Time Averaged Channels Over @ Least 10 Seconds Of Steady Conditions	X	optional
	7 X The Maximum Waterjet Speed	X	optional
	Filter @ 1/4 Collection Rate	X	optional
1.4.2.2	Transient Channels (Torque & Blade Root Strain) Over @ Least 10 Seconds	X	
	7 X The Maximum Waterjet Speed X The Number Of Blades (Use Row Set With Greatest Number Of Blades)	X	
	Filter @ 1/4 Collection Rate	X	
1.4.3.0	Photos & Video		
1.4.3.1	Multi-View Photos Of Test Setup	X	optional
1.4.3.2	Photos Of Operation	X	optional
1.4.3.3	Multi-View Video Of Test Setup	X	optional
1.4.3.4	Video Of Operation	X	optional
1.4.3.5	High Speed Or Stop Action Photos Or Video To Identify Cavitation	X	optional
1.5.0.0	Test Execution		
1.5.1.0	Tunnel Characterization Tests		
1.5.1.1	Tunnel Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	optional
1.5.1.2	Tunnel Pressures		
	Reduced Pressures @ All Speeds	TBD	optional
1.5.2.0	Uniform Flow Pump Evaluation		
1.5.2.1	Tunnel Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
1.5.2.2	Tunnel Pressures		
	Ambient	TBD	TBD
	Cavitation Scaled	TBD	optional
1.5.2.3	Waterjet Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
1.5.3.0	Wake Adapted Pump Evaluation		
1.5.3.1	Tunnel Speeds		
	Same As Uniform Flow Test	TBD	

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
1.5.3.2	Tunnel Pressures		
	Ambient	TBD	
	Cavitation Scaled	TBD	
1.5.3.3	Waterjet Speeds		
	Same As Uniform Flow Test	TBD	
1.5.4.0	Cavitation Inception Survey		
1.5.4.1	Tunnel Speeds		
	Same As Uniform Flow Test	TBD	optional
1.5.4.2	Tunnel Pressures		
	Incremental Decrease To Point Of 3% Torque Unloading	TBD	optional
1.5.4.3	Waterjet Speeds		
	Same As Uniform Flow Test	TBD	optional
1.6.0.0	Reporting		
1.6.1.0	Information Available For Open Literature		
1.6.1.1	Introduction	X	X
1.6.1.2	Inspection Report	X	X
1.6.1.3	Experimental Setup	X	optional
1.6.1.4	Experimental Methods	X	optional
1.6.1.5	Experimental Data	X	
1.6.1.6	Experimental Data Analysis		
1.6.1.7	Discussion Of Data	X	
1.6.1.8	Observations	X	X
1.6.1.9	Conclusions	X	optional
1.6.1.10	Recommendations	X	optional
1.6.2.0	Anonymous Experimental Results		
1.6.2.1	Experimental Data	TBD	TBD
1.6.2.2	Experimental Data Analysis & Calculations	TBD	TBD
2.0.0.0	**Waterjet System Water Tunnel Test**		
2.1.0.0	Administration & Documentation as per 1.1.0.0		
2.2.0.0	Model & Auxiliary Components		
2.2.1.0	Pump & Inlet Components (Test Pump & Inlet To Be Provided BY GCRMTC)		
2.2.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	
	30?Isometric Assembled & Exploded View	X	provided
	Solid Modeling Of Inlet Volume	X	provided
	Blade Radial Cross-Sections @ Tip, mid-span & Root	X	provided
	Inspection Drawing	X	provided
2.2.1.2	Engineering Data		
	Blade Surface Data For NC Machining	X	
	Performance Map Of Flow Rate, Head Rise, Thrust, Torque, & Shaft Power As A Function Of Shaft Speed	X	provided
	Blade Upper & Lower Offsets @ Tip, mid-span & Root	X	
	Blade Stress Analysis (Speed Versus Stress Indicating mid-span & 100% Allowable)	X	
	Tip Deflection Versus Speed For Both Forward & Reverse Operation	X	
	Rotational Dynamics To The 5th Mode	X	
	Void Fraction	X	
	Cavitation Limits	X	provided
	Expected Velocity Profile @ Pump Face	X	
	Inlet Area & Velocity Schedule For 5 Speeds	X	
	Lip Stagnation Point As Function Of Speed	X	

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT
TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
2.2.1.3	List Of Materials Cross Linked To Drawings Consisting Of		
	Number Required Including Spares	X	
	If Commercial Item (Manufacturer, Description, Part Number, etc.)	X	
	Construction Material (MILSTD, Alloy, Manufacturers Identification, etc.)	X	
	Special Instructions	X	
2.2.1.4	Tolerances		
	Dimensions	X	
	Surface Finish	X	
	Interference & Fit	X	
	Tip Clearance	X	
	Overall After Assembly	X	
	Balance	X	
	Special Instructions	X	
2.2.1.5	Detailed Inspection Report Including		
	Overall Component Dimensions As Per Inspection Drawing For Detailed Inspection	X	X
	Overall Assembly Dimensions As Per Inspection Drawing For Detailed Inspection	X	
	Blade Upper & Lower Surface @ Increments Of 10% Radius	X	
	Blade Upper & Lower Offsets @ Tip, mid-span & Root	X	1 blade
	Tip Clearance @ 10?Increments	X	
	Minimum & Maximum Tip Clearance For Each Blade	X	X
	Centerline Profile Of Inlet	X	X
	Transverse Profile @ 5 Stations Between Point Of Tangency & Pump Face	X	
	Dynamic Balance	X	
	Surface Finish	X	
	Weight Of Each Component	X	X
2.2.1.6	Photos & Video		
	Multi-View & Close-Up Photos Of All Components & Assembly	X	optional
	Multi-View & Close-Up Video Of All Components & Assembly	X	optional
2.3.0.0	Facility & Support Equipment		
2.3.1.0	Water Tunnel Facility		
2.3.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	X
	30?Isometric Assembled	X	
2.3.1.2	Engineering Data		
	Performance Map Of Flow Rate, Head Rise, Average Velocity @ Test Section, & Shaft Power As A Function Of Shaft Speed	X	optional
	Test Section Static Pressure Range As A Function Of Shaft Speed	X	optional
	Velocity Profile @ Test Section For 5 Speeds	5 spds	1 spd
	Air Content	X	
	Mechanical Vibration @ Test Section As A Function Of Shaft Speed	X	
	Acoustic Noise @ Test Section As A Function Of Shaft Speed	X	
2.3.1.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
2.3.2.0	Boundary Layer Wake Screen		
2.3.2.1	Engineering Drawings Consisting Of		
	3 View Assembly	X	optional

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT
TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
2.3.2.2	Engineering Data		
	Static Pressure Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
	Total Pressure Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
	Velocity Profile @ Test Section (Pump Face) For 5 Speeds	5 spds	optional
2.3.2.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
2.4.0.0	Instrumentation & Data Collection		
2.4.1.0	Required Measurements (time history & statistics: mean, std.dev., max., min.)		stats only
2.4.1.1	Tunnel Pump Speed	X	X
2.4.1.2	Tunnel Flow Rate		
	Integration Of Velocity Profiles	X	optional
	Measurement Of Flow Rate Independent To Integration Of Velocity Profiles	X	X
2.4.1.3	Waterjet Pump Speed	X	X
2.4.1.4	Waterjet Angular Position Of "Blade 1"	X	
2.4.1.5	Waterjet Torque	X	X
2.4.1.6	Waterjet Reaction Thrust		
	Measured Against Reaction Target	X	optional
2.4.1.7	Waterjet Blade Axial Root Strain (Number As Required)	X	
2.4.1.8	Inlet Static Pressure @ Top & Bottom Of Centerline @ 1/4 Pump Diameter Increments From One Diameter Forward Of Point Of Tangency To Pump Face	X	1/2 diam
2.4.1.9	Inlet Static Pressure @ Top & Bottom Of Quaterlines @ 1/2 Pump Diameter Increments From One Diameter Forward Of Point Of Tangency To Pump Face	X	
2.4.1.10	Inlet Static Pressure @ Port & Stbd Vertical Centerlines @ 1/2 Pump Diameter Increments From Entrance To Pump Face	X	
2.4.1.11	9 Inlet Lip Static Pressures @ Centerline @ 1/10 Pump Diameter Increments One @ Leading Edge, 4 On Either Side	X	optional
2.4.1.12	Pump Face Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
2.4.1.13	Intermediate Stations Static Pressure @ Wall (Number As Required)		
	Average	X	
	12 Circumferential Locations (30?increments)	X	
2.4.1.14	Nozzle Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
2.4.1.15	Static Pressure Profile 1 Diameter Forward Of Point Of Tangency		
	Over Capture Area As Required	X	optional
2.4.1.16	Radial Static Pressure Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
2.4.1.17	Static Pressure @ Intermediate Stations		
	As Required	X	
2.4.1.18	Nozzle Radial Static Pressure Profile		
	12 Angular & 5 Radial Locations	X	optional
2.4.1.19	Radial Static Pressure Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
2.4.1.20	Total Pressure Profile 1 Diameter Forward Of Point Of Tangency		
	Over Capture Area As Required	X	X
2.4.1.21	Total Pressure Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	

WATERJET SELF-PROPULSION STANDARDIZATION EXPERIMENT TEST PLAN OUTLINE

ITEM	TASK	TIER I	TIER II
2.4.1.22	Total Pressure @ Intermediate Stations		
	As Required	X	
2.4.1.23	Nozzle Total Pressure Profile		
	12 Angular & 5 Radial Locations	X	X
2.4.1.24	Total Pressure Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
2.4.1.25	3 Axis Velocity Profile 1 Diameter Forward Of Point Of Tangency		
	Over Capture Area As Required	X	
2.4.1.26	3 Axis Velocity Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
2.4.1.27	Velocity Incident Angle @ Intermediate Stations		
	As Required	X	
2.4.1.28	3 Axis Velocity Profile @ Nozzle		
	12 Angular & 5 Radial Locations	X	
2.4.1.29	3 Axis Velocity Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
2.4.1.30	Water Temperature	X	X
2.4.2.0	Data Collection Rate		
2.4.2.1	Time Averaged Channels Over @ Least 10 Seconds Of Steady Conditions	X	optional
	7 X The Maximum Waterjet Speed	X	optional
	Filter @ 1/4 Collection Rate	X	optional
2.4.2.2	Transient Channels (Torque & Blade Root Strain) Over @ Least 10 Seconds	X	
	7 X The Maximum Waterjet Speed X The Number Of Blades (Use Row Set With Greatest Number Of Blades)	X	
	Filter @ 1/4 Collection Rate	X	
2.4.3.0	Photos & Video		
2.4.3.1	Multi-View Photos Of Test Setup	X	optional
2.4.3.2	Photos Of Operation	X	optional
2.4.3.3	Multi-View Video Of Test Setup	X	optional
2.4.3.4	Video Of Operation	X	optional
2.4.3.5	High Speed Or Stop Action Photos Or Video To Identify Cavitation	X	optional
2.5.0.0	Test Execution		
2.5.1.0	Tunnel Characterization Tests With Inlet Closed		
2.5.1.1	Tunnel Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	optional
2.5.1.2	Tunnel Pressures		
	Reduced Pressures @ All Speeds	TBD	optional
2.5.2.0	Uniform Flow Pump Evaluation		
2.5.2.1	Tunnel Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
2.5.2.2	Tunnel Pressures		
	Ambient	TBD	TBD
	Cavitation Scaled	TBD	optional
2.5.2.3	Waterjet Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
2.5.3.0	Boundary Layer Adapted Pump Evaluation		
2.5.3.1	Tunnel Speeds		
	Same As Uniform Flow Test	TBD	
2.5.3.2	Tunnel Pressures		
	Ambient	TBD	
	Cavitation Scaled	TBD	
2.5.3.3	Waterjet Speeds		
	Same As Uniform Flow Test	TBD	

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ITEM	TASK	TIER I	TIER II
2.5.4.0	Cavitation Inception Survey		
2.5.4.1	Tunnel Speeds		
	Same As Uniform Flow Test	TBD	optional
2.5.4.2	Tunnel Pressures		
	Incremental Decrease To Point Of Cavitation Inception	TBD	optional
	Incremental Decrease To Point Of 3% Torque Unloading	TBD	optional
2.5.4.3	Waterjet Speeds		
	Same As Uniform Flow Test	TBD	optional
2.6.0.0	Reporting		
2.6.1.0	Information Available For Open Literature		
2.6.1.1	Introduction	X	X
2.6.1.2	Inspection Report	X	X
2.6.1.3	Experimental Setup	X	optional
2.6.1.4	Experimental Methods	X	optional
2.6.1.5	Experimental Data	X	
2.6.1.6	Experimental Data Analysis		
2.6.1.7	Discussion Of Data	X	
2.6.1.8	Observations	X	X
2.6.1.9	Conclusions	X	optional
2.6.1.10	Recommendations	X	optional
2.6.2.0	Anonymous Experimental Results		
2.6.2.1	Experimental Data	TBD	TBD
2.6.2.2	Experimental Data Analysis & Calculations	TBD	TBD
3.0.0.0	**Waterjet Self-Propulsion Test**		
3.1.0.0	Administration & Documentation as per 1.1.0.0		
3.2.0.0	Model & Auxiliary Components		
3.2.1.0	Surrogate Pump, Inlet, & Hull Components (Only Test Hull & Inlet To Be Provided By GCRMTC)		
3.2.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	
	30?Isometric Assembled & Exploded View	X	provided
	Solid Modeling Of Inlet Volume	X	provided
	Lines Drawing Of Hull	X	provided
	Blade Radial Cross-Sections @ Tip, mid-span & Root	X	provided
	Inspection Drawing	X	provided
3.2.1.2	Engineering Data		
	Hull Surface Data For NC Machining	X	
	Performance Map Of Flow Rate, Head Rise, Thrust, Torque, & Shaft Power As A Function Of Shaft Speed For Surrogate Pump	X	X
	Hull Particulars & Hydrostatics	X	provided
	Expected Velocity Profile @ Pump Face	X	
	Inlet Area & Velocity Schedule For 5 Speeds	X	
	Lip Stagnation Point As Function Of Speed	X	
3.2.1.3	List Of Materials Cross Linked To Drawings Consisting Of		
	Number Required Including Spares	X	
	If Commercial Item (Manufacturer, Description, Part Number, etc.)	X	
	Construction Material (MILSTD, Alloy, Manufacturers Identification, etc.)	X	
	Special Instructions	X	
3.2.1.4	Tolerances		
	Dimensions	X	
	Surface Finish	X	
	Interference & Fit	X	
	Special Instructions	X	

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ITEM	TASK	TIER I	TIER II
3.2.1.5	Detailed Inspection Report Including		
	Overall Component Dimensions As Per Inspection Drawing For Detailed Inspection	X	X
	Overall Assembly Dimensions As Per Inspection Drawing For Detailed Inspection	X	
	Centerline Profile Of Inlet	X	X
	Transverse Profile @ 5 Stations Between Point Of Tangency & Pump Face	X	
	Centerline Profile Of Hull	X	
	Transverse Profile @ 10 Stations	X	mid ship
	Surface Finish	X	
	Weight Of Each Component	X	X
3.2.1.6	Photos & Video		
	Multi-View & Close-Up Photos Of All Components & Assembly	X	optional
	Multi-View & Close-Up Video Of All Components & Assembly	X	optional
3.3.0.0	Facility & Support Equipment		
3.3.1.0	Towing Facility		
3.3.1.1	Engineering Drawings Consisting Of		
	3 View of Each Component & Assembly	X	optional
	30?Isometric Assembled	X	
3.3.1.2	Engineering Data		
	Tank Cross-section & Dimensions	X	X
3.3.1.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
3.3.2.0	Towing Apparatus		
3.3.2.1	Engineering Drawings Consisting Of		
	3 View Assembly	X	optional
3.3.2.2	Engineering Data		
	Inplace Cross-Axis Static & Dynamic Calibration Of Force Dynamometer	X	
3.3.2.3	Photos & Video		
	Multi-View & Close-Up Photos Of Assembly	X	optional
	Photos Of Operation	X	optional
	Multi-View & Close-Up Video Of Assembly	X	optional
	Video Of Operation	X	optional
3.4.0.0	Instrumentation & Data Collection		
3.4.1.0	Required Measurements (time history & statistics: mean, std.dev., max., min.)		stats only
3.4.1.1	Carriage Speed	X	X
3.4.1.2	Pump Flow Rate		
	Integration Of Velocity Profiles	X	optional
	Measurement Of Flow Rate Independent To Integration Of Velocity Profiles	X	X
3.4.1.3	Waterjet Pump Speed	X	X
3.4.1.4	Waterjet Angular Position Of All "Blade 1's"	X	
3.4.1.5	Waterjet Torque	X	X
3.4.1.6	Hull Drag	X	X
3.4.1.7	Hull Trim	X	X
3.4.1.8	Hull Heave	X	X
3.4.1.9	Inlet Static Pressure @ Top & Bottom Of Centerline @ 1/4 Pump Diameter Increments From One Diameter Forward Of Point Of Tangency To Pump Face	X	1/2 diam
3.4.1.10	Inlet Static Pressure @ Top & Bottom Of Quaterlines @ 1/2 Pump Diameter Increments From One Diameter Forward Of Point Of Tangency To Pump Face	X	
3.4.1.11	Inlet Static Pressure @ Port & Stbd Vertical Centerlines @ 1/2 Pump Diameter Increments From Entrance To Pump Face	X	

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ITEM	TASK	TIER I	TIER II
3.4.1.12	9 Inlet Lip Static Pressures @ Centerline @ 1/10 Pump Diameter Increments One @ Leading Edge, 4 On Either Side	X	optional
3.4.1.13	Pump Face Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
3.4.1.14	Intermediate Stations Static Pressure @ Wall (Number As Required)		
	Average	X	
	12 Circumferential Locations (30?increments)	X	
3.4.1.15	Nozzle Static Pressure @ Wall		
	Average	X	X
	12 Circumferential Locations (30?increments)	X	
3.4.1.16	Static Pressure Profile 1 Diameter Forward Of Point Of Tangency (Station 1)		
	Over Capture Area As Required	X	optional
3.4.1.17	Radial Static Pressure Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
3.4.1.18	Static Pressure @ Intermediate Stations		
	As Required	X	
3.4.1.19	Nozzle Radial Static Pressure Profile		
	12 Angular & 5 Radial Locations	X	optional
3.4.1.20	Radial Static Pressure Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
3.4.1.21	Total Pressure Profile 1 Diameter Forward Of Point Of Tangency (Station 1)		
	Over Capture Area As Required	X	X
3.4.1.22	Total Pressure Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
3.4.1.23	Total Pressure @ Intermediate Stations		
	As Required	X	
3.4.1.24	Nozzle Total Pressure Profile		
	12 Angular & 5 Radial Locations	X	X
3.4.1.25	Total Pressure Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
3.4.1.26	3 Axis Velocity Profile 1 Diameter Forward Of Point Of Tangency (Station 1)		
	Over Capture Area As Required	X	
3.4.1.27	3 Axis Velocity Profile Near Pump Face		
	12 Angular & 5 Radial Locations	X	
3.4.1.28	Velocity Incident Angle @ Intermediate Stations		
	As Required	X	
3.4.1.29	3 Axis Velocity Profile @ Nozzle		
	12 Angular & 5 Radial Locations	X	
3.4.1.30	3 Axis Velocity Profile @ The Assumed Vena Contracta		
	12 Angular & 5 Radial Locations	X	
3.4.1.31	Water Temperature	X	X
3.4.2.0	Data Collection Rate		
3.4.2.1	Time Averaged Channels Over @ Least 10 Seconds Of Steady Conditions	X	optional
	7 X The Maximum Waterjet Speed	X	optional
	Filter @ 1/4 Collection Rate	X	optional
3.4.3.0	Photos & Video		
3.4.3.1	Multi-View Photos Of Test Setup	X	optional
3.4.3.2	Photos Of Operation	X	optional
3.4.3.3	Multi-View Video Of Test Setup	X	optional
3.4.3.4	Video Of Operation	X	optional
3.4.3.5	Underwater Photography Or Video Of Flow Streamlines Near Inlets	X	optional

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ITEM	TASK	TIER I	TIER II
3.5.0.0	Test Execution		
3.5.1.0	Bare Hull Experiment With Inlet Closed		
3.5.1.1	Carriage Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
3.5.1.2	Other Measurements		
	Flow Streamlines In Inlet Area	X	
3.5.2.0	Bollard Experiments		
3.5.2.1	Waterjet Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
3.5.1.2	Other Measurements		
	Flow Streamlines In Inlet Area	X	
3.5.3.0	Self-Propulsion Experiment		
3.5.3.1	Carriage Speeds		
	Speeds To Bracket Range Of Test Conditions	TBD	TBD
3.5.3.2	Waterjet Speeds		
	Speeds To Bracket Self-Propulsion Point	TBD	TBD
3.5.3.3	Other Measurements		
	Flow Streamlines In Inlet Area	X	
3.6.0.0	Reporting		
3.6.1.0	Information Available For Open Literature		
3.6.1.1	Introduction	X	X
3.6.1.2	Inspection Report	X	X
3.6.1.3	Experimental Setup	X	optional
3.6.1.4	Experimental Methods	X	optional
3.6.1.5	Experimental Data	X	
3.6.1.6	Experimental Data Analysis		
3.6.1.7	Discussion Of Data	X	
3.6.1.8	Observations	X	X
3.6.1.9	Conclusions	X	optional
3.6.1.10	Recommendations	X	optional
3.6.2.0	Anonymous Experimental Results		
3.6.2.1	Experimental Data	TBD	TBD
3.6.2.2	Experimental Data Analysis & Calculations	TBD	TBD