Waterjets Group

Committee Chair: Prof. C. Kruppa
Session Chair: Prof. You-Sheng Wu

I DISCUSSIONS

Discussion of Report of Waterjets Group

by Stuart Cohen
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University of Michigan, Ann Arbor, USA

I would like to make four comments regarding our experience with flow rate measurements covered in Section 3.3.

My first comment concerns suggestions discussed on page 193. Instead of a single waterjet with one "T"-tube as described by KaMeWa, we used a twin waterjet model. Each waterjet outlet was separately piped transversely to the outboard sides so drag measurements could be made independently of the jet momentum. A ballast weight was removed to compensate for the static and dynamic weight of the water in the pipes. In high speed tests in waves, the pipes came out of the water and did not disturb the flow. In calm water, we raised the stern manually until hydrodynamic forces kept the pipes out of the water.

My second comment concerns Pitot measurements of the flow rate. From a suggestion from David Taylor Model Basin, a wedge style Pitot tube was chosen. It has the advantage that it does not lose prime when out of the waterjet flow. We attached it to a stepping motor and measured across the entire jet at irregular intervals. Assuming the flow was axi-symmetric, we merged all the data. This gave a good indication where the edge of the jet was both near the outer edge and near the inner cone. All measurements were made at the vena contracta. Multiple rapid measurements near the edge gave good definition of the jet diameter.We compared the integrated velocities to a direct force measurement of the jet impinging on a load cell force box. The agreement was excellent.

Comment three concerns measurements of air ingested at the waterjet inlet. We found a PhD thesis from California Institute of Technology which described an impedance void fraction meter. Our laboratory manufactured such a device and installed it in one of the two outlet pipes mentioned previously. The void fracture meter measures the electrical properties of a fluid with up to 10 % air by volume. We calibrated it by introducing known volumes of air. Electrodes were installed in slots milled into the side of the starboard pipe. The portside pipe contained a mass flow rate meter. We carefully balanced the flow rates between the two jets such that the model did not move in surge nor yaw when the jets were operating and the model was at zero speed. The mass flow rate meter measured the liquid water flow rate and the void fraction meter measured the proportion of air in the mixture. Between the two, the total flow rate of the mixed flow was accurately found. This device is described in MHL Report 030208 as listed on p. 546 in the 21st ITTC High Speed Marine Vehicles Committee Report.

My fourth comment concerns tests in which controlled amounts of air were injected into the inlet of a 10 inch model waterjet. We found that small amounts of air made about 15 % reduction in thrust. Additional air had only a small additional loss in thrust. In the case where reducing the variation of thrust is more important than achieving the maximum thrust, it may be useful to inject a small amount of air to prevent large variations of engine torque.

For very large injections of air, we used an electric solenoid to provide bursts of air from a reservoir. When the air entered the jet, the engine RPM rose rapidly. As the waterjet began to pump liquid again, the water shot out of the nozzle non-symmetrically, starting at the bottom. This sent the jet slightly to the side so it struck the face of the load cell box and sprayed the area until the jet stabilized. The results are available in MHL Report on burst air tests.

From the burst air tests we found that although the loss of thrust was abrupt, the increase back to full thrust had almost no overshoot. We also found that the loss of prime for extremely large quantities of air was not relative to the volume of air but rather to the proportion of the duct that was simultaneously liquid free. This means that extremely fast flows required much more air to lose prime than slow flows, whether injected quickly or slowly.

Thank you for the opportunity to make these remarks.

Discussion of Report of Waterjets Group

by Olle R tgersson
KTH, Stockholm, Sweden

First I would like to congratulate the group to a very fine report with a thorough discussion of the theoretical treatment of this difficult problem.

Being responsible for the writeup to the recommendations of the High Speed Committee for the 18th ITTC I know the difficulties and appreciate the improvements supplied in the present report.

However, testing waterjets and supplying a reliable power prediction is not only a theoretical task. I believe some practical problems have to be addressed further.

The group has already dealt in some detail with the problem of measuring the flow which is of major importance when testing waterjets. Another problem which is not addressed is the interface between a towing tank, performing a self-propulsion test with a "simulated" pump but with a scaled inlet and outlet, and the manufacturer testing the full waterjet in a cavitation tunnel.

Recently a project was conducted at KTH where one of my students closely followed tests in a cavitation tunnel, self-propulsion tests and full-scale tests for a small waterjet propelled craft. The idea was to gain some figures on scale effects and coefficients for further project studies.

Unfortunately this study raised more questions than it solved problems. Based on this study I believe there are important problems in the interaction between the towing tank and the cavitation test which have to be solved before we can get reliable predictions. I would like to hear the opinion of the Waterjets Group on how this new method should be used when the tests are shared between a towing tank and a cavitation tunnel. I believe this could be an important task for a coming Waterjets Group.

Thanks once again for a fine report.

Johansson, A., 1996, "Influence of Running Trim on the Waterjet Performance for a Small Planing Craft". Msc Report, Royal Institute of Technology (KTH), Department of Naval Architecture, Stockholm.

Discussion of Report of Waterjets Group

by Michael Schmiechen
VWJ, Berlin, Germany

The Waterjets Group has done a very good job in discussing possible power prediction methods for waterjet propulsion systems. I feel that the group has set a standard for future Specialist Committees.

I want to make only two remarks. The first one concerns the use of the term momentum flux, the second one concerns the scaling of the internal efficiencies.

In my view the Waterjets Group has used the term momentum flux consistently for the invariant flux transformed to the undisturbed pressure and this is of course not the standard terminology. Consequently I propose to consider at least a special notation as I have suggested earlier in 1968.

As has been pointed out the introduction of the invariant momentum fluxes and consequently the effective thrust, i.e. the thrust of the equivalent propulsor outside the displacement wake, avoids the problem of thrust deduction.

I would like to take this opportunity to express my satisfaction seeing the conceptual framework I have proposed nearly thirty years ago, and have promoted since as rational theory of hull-propulsor interaction, finally being applied.

In presenting the method it would have been advantageous in my view to clearly separate the conceptual problems from those of interpretation in terms of measurements.

Concerning the scaling of the internal efficiency I would like to mention, that INSEAN has been suggesting and using the well established codes available for water turbines and pumps.

Once again I would like to thank the Waterjets Group for an excellent report.

Discussion of Report of Waterjets Group

by Tom van Terwisga
MARIN, Wageningen, The Netherlands

First I would like to congratulate the committee with their comprehensive comparison of the two possibilities for self-propulsion tests with waterjets; the "momentum flux method" and the "direct thrust measurement" method.

Further, I would like to make the following comments on their report:

Importance Of Model Self-propulsion Tests

In their first recommendation, the committee emphasizes the importance of model selfpropulsion tests. Their conclusion is supported by data collected at MARIN during a five year research project on waterjet-hull interaction. As the major objective of self-propulsion tests is to quantify the interference between jet system and hull on each others powering characteristics, its necessity is clearly illustrated by the total interaction effect over a speed range. The total interaction effect can be isolated from the overall powering characteristics and is expressed in an interaction efficiency η_{INT} (Van Terwisga, 1993):

$$\eta_{INT} = \frac{\eta_{OA}}{\eta_0} \qquad (1)$$

where η_{OA} is overall efficiency; P_E/P_D and η_0 is free stream efficiency of the jet system, comparable to the open water efficiency of the propeller.

Figure 1 (Van Terwisga, 1996) shows the envelope area comprising all values of interaction efficiency collected from a selection of propulsion tests that have been conducted at MARIN. The set of hull forms involved covers a wide variety, ranging from a low L/B monohull (L/B = 3) to a high L/B Catamaran (L/B demihull = 15). Due to the non-systematic nature of the data, it is not meant to provide design guidance.

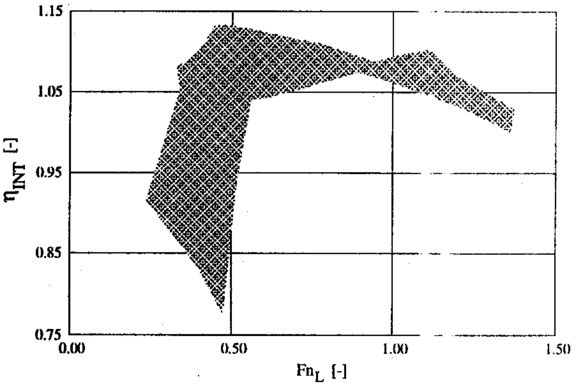

Figure 1. Collected total interaction efficiencies η_{INT} as a function of Froude number.

Cooperation With Jet Manufacturers

MARIN wholeheartedly supports the view from the committee that a close cooperation between jet manufacturers and towing tanks is important. To have a successful and efficient cooperation, however, the responsibilities of both parties need to be clear. It is therefore extremely important that the performance characteristics of both the hull and the jet system are well separated. A clear separation of systems and corresponding definition of interaction is proposed by Van Terwisga (1993).

The *performance of the jet system* is the responsibility of the jet manufacturer, the *hull performance* and most likely the *jet-hull interaction* is the responsibility of the main contractor, usually the yard. MARIN sees it as her responsibility to provide accurate powering predictions of the *hull performance and jet-hull interaction effects*. A prediction of the overall performance can be given if the jet manufacturer provides the so-called jet system efficiency η_{JS}:

$$\eta_{JS} = \eta_P \eta_{duct} \tag{2}$$

where η_P is pump efficiency (including installation effects); $\eta_P = P_{PE}/P_D$ and η_{duct} is ducting efficiency, allowing for internal viscous energy losses; $\eta_{duct} = P_{JSE}/P_{PE}$.

This separation of responsibilities, has proven to work out well in our cooperation with e.g. Lips Jets and Hamilton Jet, resulting in overall powering predictions from the propulsion tests.

Momentum Flux Method

Based on more than 10 years of experience with waterjet self-propulsion tests, MARIN has developed a preference for the momentum flux method. During this period, both methods have been used, although the direct measurement method has been discarded in the early years. More experience with the direct thrust measurement method has been obtained later in a cooperative project with Hamilton Jet (see e.g. Alexander et al., 1994). An argumentation for our preference for the momentum flux method has been communicated to the committee. Summarized, these reasons are:

a. Ease of modelling.
b. Absence of internal scale effects or smaller model limitation.
c. Complexity of measuring set-up for direct thrust measurements.

The committee has skilfully bypassed the issue of net thrust delivered by the waterjet system, by referring to a change in momentum flux ΔM instead of a thrust. Especially in the early design stage however, the designer has usually information on the bare hull resistance of his design. It is subsequently important to him in the selection process of the propulsion system, to know the resistance increment of the hull due to the jet action and to match the total resistance with the net thrust from the jet system. It can be demonstrated (Van Terwisga, 1996) that the net thrust can be determined fairly simple from either propulsion tests (provided the nozzle is free from the stern flow) or measurements on an isolated jet system. The net thrust is then obtained from:

$$T_{net} = \rho Q U_0 (NVR - c_m) \tag{3}$$

where NVR is nozzle velocity ratio and c_m is velocity coefficient to account for the viscous momentum deficit by the boundary layer.

Nomenclature

The Committee uses the concept of energy velocity V_E, referring to an average velocity that is used to simplify the expression for the energy flux. They introduce however, a pressure term in the expression for energy velocity V_{E7} to account for a difference in jet pressure at the nozzle and the ambient pressure. It would be more consistent to leave the pressure term out of the definition of an average energy velocity and account for this pressure difference explicitly.

Sensitivity Aspects

The sensitivity aspects as discussed by the committee provide an indication of the effect of possible measurement errors. A similar sensitivity analysis was made at MARIN (Van Terwisga, 1996). In this study, the effect of errors in the dependent parameters on the net thrust was expressed in a relative sensitivity θ', defined by (see also Lin et al., 1990):

$$\theta_i'(R) = \frac{\partial R}{\partial x_i} \frac{\bar{x}_i}{\bar{R}} \tag{4}$$

where R is result of a test or calculation (in this case net thrust T_{net}) and x_i is dependent parameter.

The sensitivities of errors in flow rate Q or bollard pull thrust T_{jet}, nozzle area A_n and specific mass ρ could thus be visualized for a range of NVR (Nozzle Velocity Ratios), as seen in Figure 2. This figure also shows the advantage of deriving the net thrust from a bollard pull calibration instead of deriving it from a flow rate calibration.

From a further uncertainty analysis, a total uncertainty with a 95 % confidence level in net thrust of approx. 2.5 % is obtained at an NVR value of 2.0 and a $Q/Q_{bl} = 1.5$. The total uncertainty for the jet system power P_{JSE} is obtained in a similar way and is some 30 % higher than for the net thrust for this condition (Van Terwisga, 1996).

References

Alexander, K.V., Coop, H. and Terwisga, T. van, 1994, "Waterjet-Hull Interaction: Recent Experimental Results", SNAME Annual Meeting, New Orleans.

Lin, W.C. et al., 1990, "Report of the Panel on Validation Procedures", 19th ITTC, Madrid.

Terwisga, T.J.C. van, 1993, "A Theoretical Model for the Powering Characteristics of Waterjet-Hull Systems", FAST'93 Conference, Yokohama.

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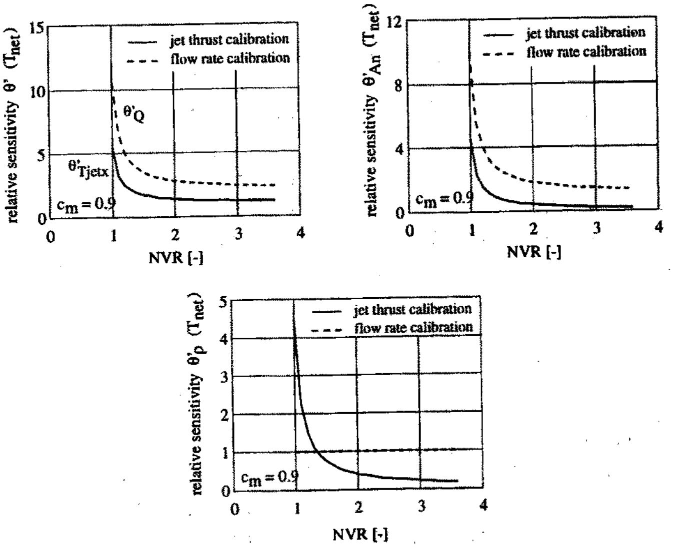

Figure 2 Relative sensitivities for bollard pull thrust and flow rate, for nozzle area A_n and for mass density ρ

II REPLIES BY WATERJETS GROUP

The members of the Waterjets Group greatly appreciate the comments by Dr. van Terwisga and wish to respond to a few aspects of this thorough discussion of the report. A major decision made by the group was to replace the gross and the net thrust, with their many different definitions, by the change of momentum flux ΔM. The principle of this quantity ΔM was first discussed by Fresenius (1921) and again applied in the sixties by Wald, in connection with the analysis of the propulsion of bodies of revolution. The increase of momentum flux is compared for two flow cases, i.e. for the self-propelled model and the towed model. By combining the results from these two cases and assuming that the losses of the outer flow are the same in the two cases, one obtains for the model self-propulsion point

$$T = R_T = M_{7\,self\text{-}prop.} - M_{7\,towed}$$

$$\cong \left(M_7 - M_1\right)_{self\text{-}prop.} = \Delta M$$

Thus, ΔM is a measure of the resistance in the self-propulsion flow case.

The main reason for the disagreement between the group's opinion and that of Dr. van Terwisga is that different definitions are used. Dr. van Terwisga uses the bare hull resistance R_{T0} which in many cases differs from ΔM. The main causes of discrepancy are different draft and trim as well as quite different flow behaviour around the stern when part of the jet is ejected below the water surface. This difference is well illustrated in Dr. van Terwisga's first figure where the Froude number variation of his interaction efficiency is documented. With the group's definition this interaction efficiency should always be $\eta_{INT} = 1.0$.

Dr. van Terwisga is also discussing the energy velocity which he is referring to as an average velocity. This is not correct. The energy velocity is rather a local value which can be computed from the total velocity and the static pressure. Thus the energy velocity is not a vector quantity but a measure of the flow energy. This means that outside the boundary layer and the wake it is equal to the undisturbed velocity V. Inside the boundary layer the energy velocity is lower than V due to the influence of viscosity. In the jet it is higher than V due to the increase of energy delivered by the pump.

The group confirms the results presented by Dr. van Terwisga regarding sensitivity investigations on change of momentum flux and pump power, for deviations in nozzle area and flow rate. However, the implications of calibration against bollard pull rather than flow rate remain somewhat unclear.

Professor Rutgersson discusses the question of how model self-propulsion tests and cavitation tests are best combinded for the prediction method proposed by the group. As this combination directly refers to the problem of how to split up work and responsibilities between towing tank and manufacturer some of the aspects touched upon in the Waterjets Group Report should be enhanced further.

As was stated in the report all replies to the questionnaire of the group endorsed the necessity for a close cooperation between towing tank and manufacturer. The towing tank has to handle data of so-called „reference tests“ in the same manner as open water tests in conventional ship propulsion. It will perform these tests with the same pump that will be used in the model self-propulsion tests, and in many cases this pump will be a dummy pump, not geometrically similar to the full scale pump. On the other hand, the manufacturer deals with „reference tests“ made with a model of the actual pump, with the aim of interpreting scale effects and the influence of cavitation.

It will most certainly be bad politics to use different ways of measuring or calculating the propulsive force when complementary tests are performed in different facilities (i.e. by the towing tank and by the manufacturer). The same holds for the comparison of „reference tests“ and self-propulsion tests when interaction effects are determined. Standardisation of the measuring and analysing techniques is therefore a stringent demand if full scale data are to be properly interpreted and scaling effects better understood.

In the report it is recommended to perform the self-propulsion tests with correctly modelled inlet and nozzle and to concentrate on measuring the change of momentum flux ΔM. For the full scale prediction, pump efficiency, internal losses and cavitation performance must be known. This requires tests in a cavitation tunnel with the actual impeller. Ideally these tests should be carried out with a simulated full scale boundary layer and for a change of momentum flux which has been derived from the model self-propulsion tests, allowing for the scale effects between towing tank and cavitation tunnel models.

In this context attention should be drawn to the sensitivity analysis quoted in the report where it was shown that large variations in the inlet flow conditions only resulted in less than 1 % variations in change of momentum flux and pump power. On the other hand, it was pointed out that non-uniform flow in the free jet could have a significant influence on these quantities. Thus, correct modelling of the jet flow, both in model self-propulsion tests and in cavitation tests is regarded a stringent requirement, whereas the permissible margin is higher for the inlet flow.

For free running models without tow rope force ventilation phenomena in a seaway should be studied at the correct flow rate. This condition can be fulfilled for the model self-propulsion point if the nozzle diameter is reduced. The same method can be applied for measuring added power in waves.

Referring to the details of the investigation at KTH described in Professor Rutgersson's discussion the group fully agrees that a lot of problems related to model testing of waterjet propelled craft and full scale predictions remain to be solved. Based on the available information about the KTH tests it is believed that part of the problems encountered are related to the special design of the pump which had a rather long stator. This resulted in most of the flow acceleration taking place inside the stator. Consequently Stations 5 and 6 were fairly close together and the static pressure drop $p_5 - p_6$ may not have been suitable for measuring the flow rate with sufficient accuracy.

Professor Schmiechen points out that the group has used the term momentum flux in a unorthodox way. Even if this was true the group believes to have given a definition of ΔM which is clear enough not to be mistaken. Maybe the next Specialist Committee on Waterjets should attempt to find a more appropriate name.

As to the scaling of internal efficiencies the group has suggested in the report that the model self-propulsion test is complemented by special tests with a larger scaled waterjet unit in a cavitation tunnel, with correct inlet and nozzle as well as a full scale boundary layer at Station 1. These tests must be performed at high Reynolds numbers to permit a calculation of the scale effects. It is certainly a good idea to study the established codes for testing water turbines and pumps beforehand, although the problem of inflow irregularities may be different in this kind of hydraulic machinery.

In his oral contribution Mr. Cohen describes some interesting towing tank tests with a waterjet propelled model. Unfortunately the MHL-Report referred to was not made known to the Waterjets Group for adequate study before the conference.

In conclusion, the Waterjets Group wishes to thank all contributors for their discussions as well as valuable suggestions for corrections and future tasks.

III ERRATA

The Waterjets Group wishes to amend and correct its report in two points.

Firstly, the group wishes to endorse that, without a clear statement, the static pressure coefficient C_p was defined in such a way as if no free water surface existed. This means that the value of C_p at the surface of the jet discharged above the water surface is zero. Due to the definition of C_p adapted by the Waterjets Group the elevation loss has to be added separately as shown in APPENDIX A, **Items 8 (Elevation Power)** and **10 (Effective Pump Power)** of the report.

Secondly, the complete paragraph Item No. 8 of **Chapter 3.3. (Momentum Flux Method)** should be deleted from the report.