Advanced tools for waterjet performance prediction

Waterjet propulsion has superior performance advantages over propeller propulsion for high-speed vessels at speeds of over 30 knots due to its high efficiency and good manoeuvrability features. Unlike a propeller that transmits its blade force to the hull through the shaft, the principle of thrust generation and transmission for a waterjet unit is somewhat different. Thrust is not only transmitted via the shaft: part of the thrust is also generated on the ducting channel and transmitted directly to the hull body. This difference urges a completely different measuring technique in model tests and a different speed-power prediction method. SSPA has been in close cooperation with clients to assist their design and performance prediction of various waterjet systems, and has been involved in the development of measurement techniques and contributions to ITTC guidelines in the past. Today the effort goes further …

Flow rate measurement methods

Performance prediction based on model tests remains a challenge, as many variables may have an influence on accuracy. Flow rate is a variable that is crucial for performance prediction but tricky to measure. It is particularly difficult to measure the flow rate during the self-propulsion tests and it is important to achieve the best possible accuracy, as an error of 1% in volume flow will give 4% error in jet thrust.

In the past, a method of measuring pressure difference in combination with a bollard pull test for calibration has been used at SSPA. The problem with this method is that it is difficult to ensure the pressure sensors to be completely free of air bubbles. A typically position level for a waterjet system is with the pump shaft at the still waterline. This means that the pressure sensors at the upper part of the pump will be in the air and this is where the problem starts.

Today, two new pieces of equipment are in use: a T-junction and a hub dynamometer. With the transducer mounted inside the hub, the hub dynamometer will measure the torque of rotor blades with higher accuracy than the conventional way of torque measurement.

The T-junction is used to measure the reaction force caused by the discharged momentum flux from the nozzle. The jet flow at the nozzle shoots into the mouth of the T-junction, the jet flow is then re-directed 90° to the side by the T-junction, the force acting on the T-junction is recorded by a force transducer, and the flow rate is calculated by momentum conservation law.

The method can be used both at rest for calibration purposes and at speed. It works well in the speed range where the transom is dry and the T-junction has no contact with the stern wave. Below that speed range, the T-junction will interfere with the stern wave and distort the measurement, as discussed below.

T-junction during model test at high speed.

From failure to success

The method for measuring the flow with the T-junction is based on the fact that waterjet is best for higher speeds, such as 30 knots and up. In this speed range, the stern will be dry and the T-junction will not interfere with the wash wake.

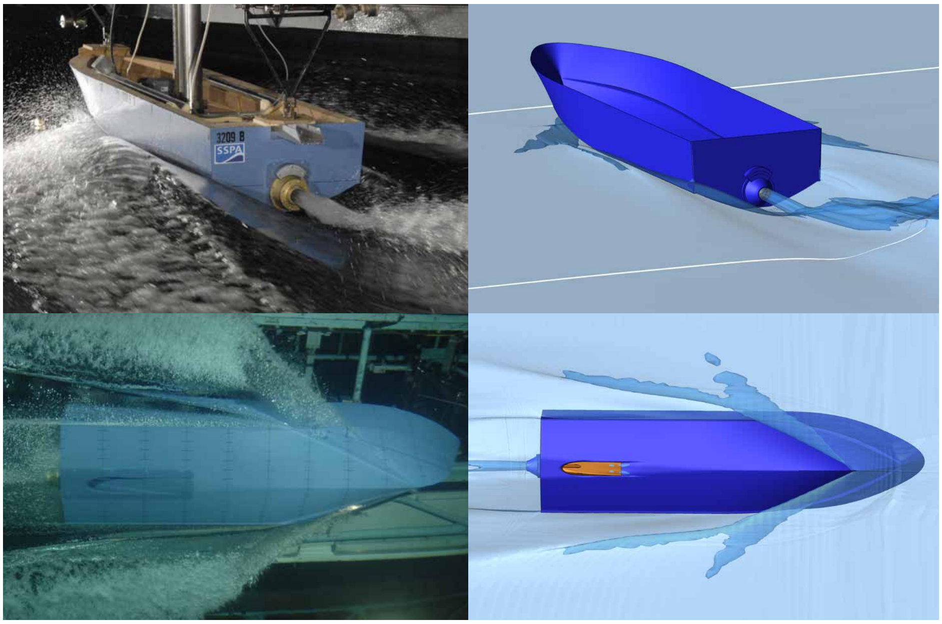
However, in some tests we were also interested in measuring at slow speeds like F_{nL} 0.3 -0.4 and at the slowest speed, parts of the T-junction were dragging in the water. We considered this a failure. Our solution was then to tow the ship model with the T-junction mounted but not running the pump.

The idea was to measure the extra drag from the T-junction when the stern was still wet and use the measured drag from the T-junction to correct the measured jet force. The result was surprising: the total drag was reduced! We measured and checked everything again and got the same result. Compared with the bare hull drag without the T-junction, the drag was reduced up to about 7%, as if the T-junction was pushing the vessel forward! How is this possible?

After checking the equipment over and over again and many hours of thinking, we concluded that the wash was running forward above the transom wave and actually pushed on the T-junction. We have thus invented the "Push-plate"!

CFD calculations confirmed this effect. There is a circulating stream aft of the stern at speeds of around F_{nL} 0.3 to 0.4 that can be taken advantage of if the "push plate" has the correct depth and width.

This can certainly be optimised for different kinds of vessels. Ironically enough, the arrangement does not work well together with waterjet pro-



The wave pattern and the jet flow predicted in simulation as compared with the observations during model test.

pulsion due to the jet, but should work well on propeller-driven boats below hump speed.

To conclude: what we first thought was a failure turned into something that can be regarded as a success!

Insight into the flow physics of waterjet-driven craft

Using state-of-the-art CFD tools, CFD analysis of the flow around the waterjet-driven vessel is possible at different levels of complexities.

The most comprehensive one will simulate a complete waterjet-driven vessel, including the pump detail and free surface effects in self-propulsion mode, whereas a simpler variant is to model the pump effect with a body-force disc or a fan model.

CFD analysis not only predicts the total thrust and torque of waterjet units, but also provides flow details in the computed domain. For example, by inspecting the pressure distribution and the streamlines passing the waterjet unit, the designer can get an idea of where the stagnation point occurs on the intake lip, whether and where there is a risk of cavitation inception, and whether the vertical force on the ducting channel be a lift or a downward force that eventually modifies the trim and sinkage at speed. Questions such as whether there are any rotational losses in the jet-flow at the nozzle outlet or whether the thrust deduction is positive or negative can also be addressed.

This kind of information can be very useful in assisting the designer to identify existing design issues or to optimise the design at an early stage. Such details cannot be obtained by a routine towing tank test. In such simulations, the experience and knowledge of the CFD analyst, the quality of meshes, selection of boundary conditions, discretisation schemes, turbulence models and the capability of compute power all play a role.

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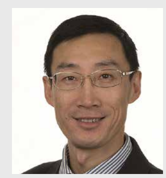

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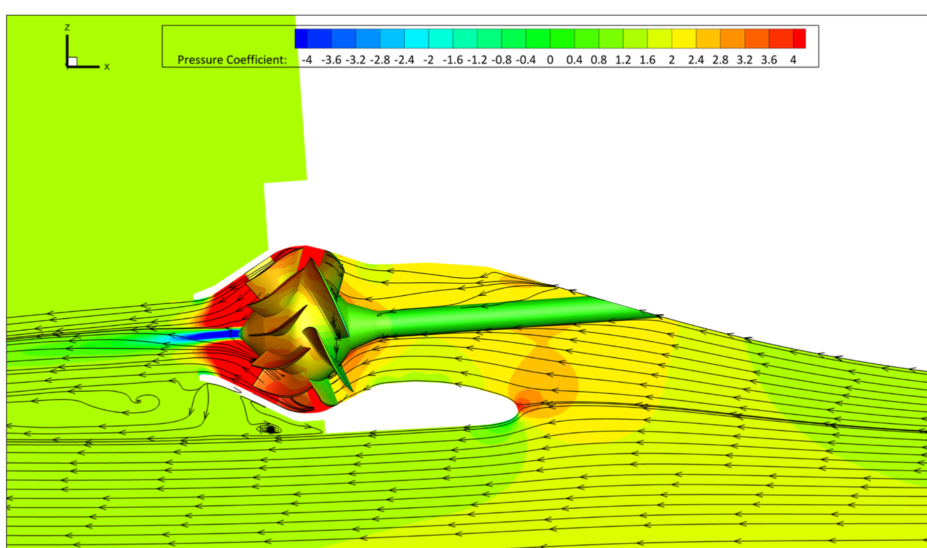

Pressure distribution and streamlines at the central plane cutting through the waterjet unit.