Ability to predict the added resistance of ships in waves has matured

Over the last five years the RAW working groups in CRS have investigated the nature of the added resistance of ships at sea and the merits of alternative ways to predict its magnitude.

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The investigation made use of MARIN's potential flow Rankine source code FATIMA, and CFD contributions from DNV GL, Lloyd's Register, ABS, Bureau Veritas, Chantiers de 'l Atlantique, Navantia and MARIN. CETENA examined the impact of course-keeping. These numerical results were compared with scale model tests at MARIN and DGA.

In the first years, the work focused on the added resistance of a container ship, a full block tanker and a fast, naval hull in waves from four directions. We learned that the added resistance is not always described adequately in terms of a quadratic transfer function, and the work in later years has focused on deviations from this concept.

Prediction techniques The dispersion of the reflected and radiated waves at forward speed is a key element in the relative wave elevation in the diverging flow at the bow and the associated contribution to the added resistance. To account for this, the potential flow calculations were performed with a Rankine source code.

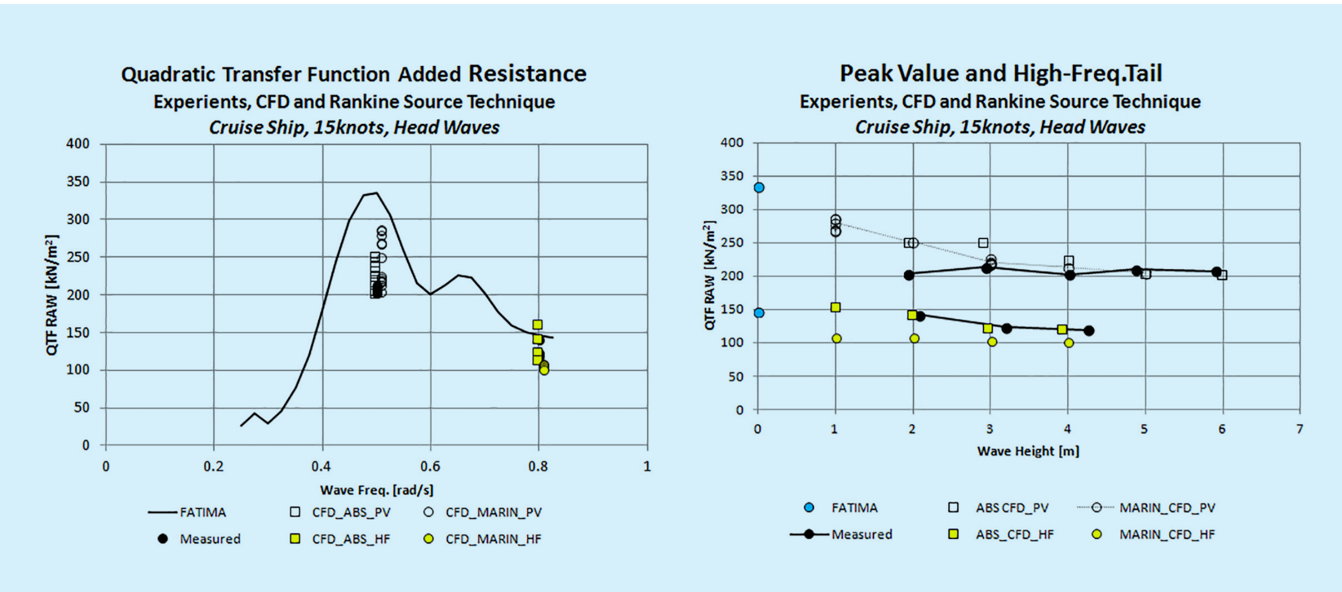

Figure 1: Quadratic transfer function of the added resistance of a cruise ship, Fn=0.150, in head waves, comparison of results from a Rankine source code (MARIN), CFD (ABS, MARIN) and experiments (DGA)

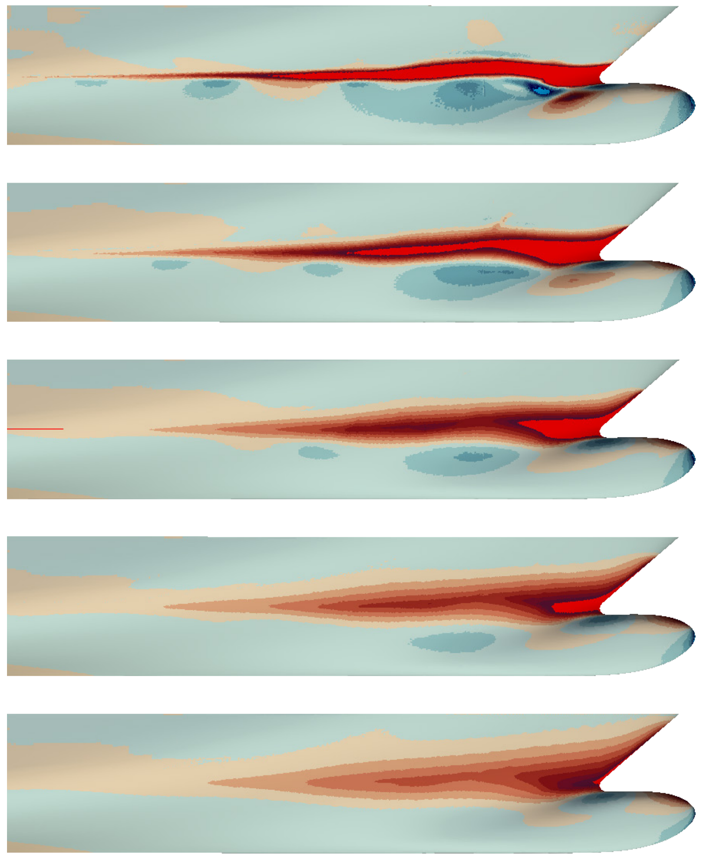

Figure 2: Local added resistance as a function of wave height at the peak of the QTF, Cruise ship, Fn=0.150, Head Waves

The analysis of the (negative) contribution of the second order pressure drop to the added resistance made clear that the results of the FATIMA code required a correction for local spurious effects.

Various working group members performed CFD calculations using RANS codes, namely Star-CCM+, OpenFOAM and ReFRESCO. The accuracy of these calculations increased in the course of the project as the parameters influencing the quality were discovered. Among the key parameters, the quality of the propagation of the incoming, radiated and diffracted waves was highlighted, as well as the convergence of the coupled system per time-step. Other key points were the location at which the reference wave is determined, and the magnitude of the reference resistance in calm water. CRS has certainly advanced the ability to generate optimised CFD meshes for seakeeping applications and the RAW working groups have contributed significantly to this development.

One important finding for accurate predictions based on model tests is that it is essential to control and fix the speed of the model for the assessment of the difference between the resistance in waves and the resistance in calm water. This was why MARIN used a semi-captive set-up in the first sets of experiments. Tests at DGA were performed with a towed model. All results made clear that the accuracy of the derived added resistance is not self-evident. Amongst other precautions, careful monitoring of the reference resistance in calm water proved essential to obtain accurate results.

Counterintuitive finding The most important finding from the investigation is that the three prediction methods yield a consistent impression of the added resistance of a ship in waves. Another, quite remarkable and counterintuitive, finding is that for ships with a substantial bow flare, the peak value of the quadratic transfer function (QTF) of the added resistance showed a marked decrease with the wave height.

Figure 1 illustrates these findings with the QTF of the added resistance of a cruise ship at a moderate speed in head waves. The fact that the added resistance QTF shows a decrease in higher waves may appear counterintuitive. In the first instance this phenomenon was attributed to the fact that the reflected and radiated waves show a transition to a non-linear flow regime, demonstrated by the observed spray. In a later stage we realised that the CFD shows that the mean pressure drop – just below the free surface – is also highly dependent on the wave height. Figure 2 shows the change in the mean pressure experienced by the hull as a function of wave height. Several of the phenomena in low waves where the steady flow plays a role, disappear in higher waves.

Non-quadratic behaviour As the potential flow methods, CFD and experiments show a consistent picture, we conclude that the prediction of added resistance has become mature. We also conclude that the added resistance of ships with considerable flare at higher speed shows a non-quadratic behaviour in higher waves. The dependency of the added resistance on wave height is less than quadratic.

Considering the rather delicate (hull form, speed and wave height dependent) changes in the pressure field and the level of expert judgement that is still inevitable in setting-up and interpreting the potential flow, CFD and model test results, the prediction of added resistance still comes with some level of uncertainty. However, we feel that the predictions are certainly sufficiently accurate to find the delicate balance between building and operational costs in ship design.