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NUMERICAL UNCERTAINTY ESTIMATION IN MARITIME CFD APPLICATIONS

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The availability of computer power and computational fluid dynamics (CFD) software, both commercial and open-source, has led to routine use of CFD simulations in maritime industry during the design phase of ships and offshore structures. The incompressible Reynolds-averaged Navier-Stokes (RaNS) equations are mostly used, discretized by co-located finite-volume methods for (un)structured, body-fitted grids. Simulations with this model provide detailed flow fields that can help in diagnosing problems, improving designs and studying scale effects. However, before making any design decisions, the reliability of such simulations needs to be established. Here, we consider the numerical uncertainty estimation procedure used at the Maritime Research Institute Netherlands (MARIN). Once the numerical uncertainty is quantified, the CFD engineer can assess the reliability of the results.

The verification and validation procedure is based on research carried out over the past decade together with the Instituto Superior Técnico (IST). An overview is found in [1]. At the core of the procedure is an estimator of the discretization error based on the expansion

$$\phi_i = \phi_0 + \alpha h_i^p$$

where ϕ is a quantity of interest such as drag, ϕ_0 is the estimate of the exact value ϕ_{exact}, α is a constant, h_i is the typical cell size of grid i and p is the observed order of grid convergence. The values ϕ_0, α and p can be determined when at least three grids are used for the simulation. The error estimator is then used to provide an uncertainty U_ϕ such that

$$\phi_i - U_\phi \leq \phi_{\text{exact}} \leq \phi_i + U_\phi$$

The procedure is refined to deal with other sources of uncertainty and with the scatter and noise that occur in 'real-life' applications. A detailed description is found in [2] together with an evaluation of the uncertainty estimates for manufactured solutions. The main question here is whether reasonable levels of uncertainty can also be obtained in practical applications.

To answer this question, the uncertainty estimation method is applied to various cases from maritime industry, simulated with MARIN's CFD software ReFRESCO. In [3], current coefficients are computed for a LNG carrier and a semi-submersible at model and full scale. In [4, 5], manoeuvring coefficients are computed for a generic submarine hull and a crude carrier. Thrust and torque coefficients of various propellers are computed in [6]. In many of theses cases, numerical uncertainties below 5% are obtained for global quantities such as force coefficients, which is low enough for practical purposes. When available, the experimental values are often within this range, thereby validating the RaNS model for these cases. What these cases have in common are highly-refined, block-structured grids, good iterative convergence, and modest inflow angles. When these conditions are not fulfilled, the numerical uncertainty can be higher. These applications clearly show under which circumstances reliable CFD results can be obtained. Future research should aim at extending uncertainty estimation to unstructured, locally refined grids that are increasingly popular.

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