Aspects of the Calculation of High-Reynolds-Number Flows with RANS solvers

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Abstract

In this presentation, the focus is on the Reynolds-Averaged Navier-Stokes (RANS) equations, which are still the most common model for the solution of engineering flow problems at high Reynolds numbers (above 10^6). It is well known that the RANS equations do not form a closed system due to the presence of the Reynolds stresses (produced by the statistical handling of the Navier-Stokes equations). In all the examples included in this presentation, we will model these terms by one or two-equation eddy-viscosity models.

PARNASSOS [1] is a RANS solver for incompressible flows that has been developed in ongoing cooperation between the Maritime Research Institute of the Netherlands (MARIN) and IST. It uses an unusual solution strategy: the continuity and momentum equations are solved in a fully-coupled way with the continuity equation written in its original form (divergence of velocity equals 0). Although it requires structured grids, it has a multi-block capability and can compute free-surface flows [2] by a surface fitting method. One of the outstanding qualities of PARNASSOS is that it allows to compute high-Reynolds number flows (up to 10^9) without the use of wall functions and without performance deterioration.

As an example of the potential of such code, figure 1 presents the friction, C_F, and pressure, C_P, resistance coefficients of the KVLCC2 tanker at model (5×10^6) and full (2.03×10^9) scale Reynolds numbers. Results are presented for sets of six grids with five eddy-viscosity turbulence models: three versions of the $k - \omega$ two equation model [3, 4] (TNT,BSL,SST); the one-equation model of Menter [5] (Mν_t) and the recently proposed $k - \sqrt{k}L$ two-equation model [6].

Although such CFD application might be considered fairly standard for these days, there is a strong emphasis on the importance of Code Verification and Solution Verification [7]. Addressing the problem of numerical uncertainty is mandatory to avoid misleading conclusions. Predicting scale effects with the coarsest grids data could well lead to the

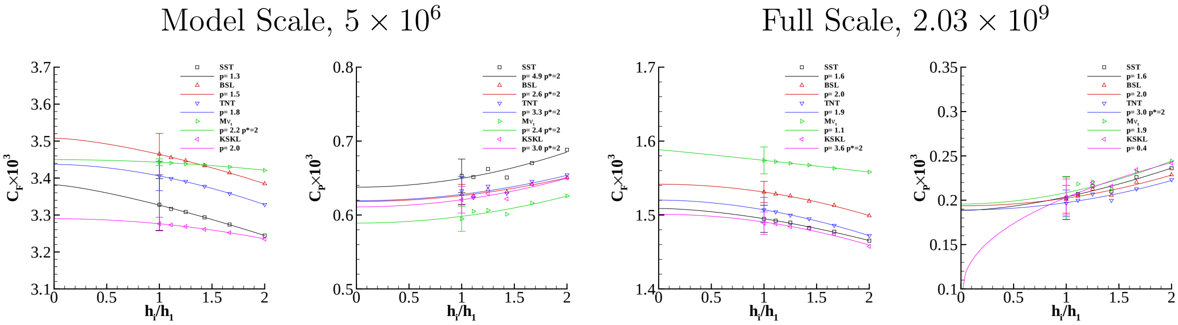

Figure 1: Convergence of the friction, C_F, and pressure, C_P, resistance coefficients with the grid refinement ratio, h_i/h_1. KVLCC2 tanker.

opposite tendency as found by using the finest grids results, if there is no estimate of the numerical uncertainty.

Code Verification requires error evaluation, i.e. the knowledge of the exact solution. In the RANS context, this leads to the Method of Manufactured Solutions [8]. Such Manufactured Solutions should include the turbulence quantities transport equations [9], because it has been found that the observed order of accuracy may be affected by the turbulence model [10].

Verification of Calculations requires error estimation for an unknown exact solution. Although the numerical error of a RANS solution includes contributions from the round-off, iterative and discretization errors, the latter is usually dominant. Most of the techniques available for the estimation of the discretization error rely on the existence of an 'asymptotic range', which is basically the dominance of the lowest order term of a power series expansion of the error as a function of the typical cell size. Attaining the 'asymptotic range' in RANS solutions of complex turbulent flows requires much denser grids than what is common practice nowadays. Therefore, developing a reliable error estimator for RANS solutions of practical complex turbulent flows remains an open challenge.

Keywords: RANS solvers, Verification, Numerical Errors.

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