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The Flow Around a Surface Combatant at 10° Static Drift: Assessment of Turbulence Models

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Abstract. This paper presents a computational study of the flow around the DTMB 5415 at 10° static drift. Two RANS (Reynolds Averaged Navier-Stokes) turbulence models, as the isotropic $k-\omega$ SST and the non linear anisotropic EARSM (Explicit Algebraic Reynolds Stress Model) and one hybrid RANS-LES model, the DES (Detached Eddy Simulation) based on the $k-\omega$, are used with the flow solver ISIS-CFD. All numerical results are compared to experimental data. The numerical results show that the DES model is the one turbulence model that able to predict correctly the behavior of the flow in the core of the SDTV (Sonar Dome Tip Vortex), and particularly the high level of the turbulence kinetic energy.

Keywords: Turbulence models · DTMB 5415 · Static drift.

1 Introduction

For ship design, environmental aspects and signature characteristics, it is important to understand the three-dimensional flow around a ship and in the wake of the hull under straight ahead or static drift conditions. For this geometry and these conditions, the flow is dominated by the onset of longitudinal vortices progressing in the close vicinity of the hull. With a Reynolds Averaged Navier-Stokes (RANS) approaches, using an Explicit Algebraic Reynolds Stress Model (EARSM) or Reynolds Stress Transport Model (RSTM), the averaged iso-wakes or longitudinal vorticity were in agreement with the measurements [6, 1]. However, for two hulls, the Japanese Bulk Carrier (JBC) and the David Taylor Model Basin (DTMB) 5415, the level of the turbulent kinetic energy (TKE) predicted with a RANS turbulence model is underestimated compared to the experimental data. For the JBC, a Large Eddy Simulation predict a high level of TKE [8].

The geometry used in this study is the DTMB 5415, see Figure 1, which has a length between the perpendiculars $L_{PP} = 3.048$ m. The draught of the ship is $T = 0.248$ m and the hull is fixed. The model is a bare hull except the bilge keels. The Reynolds number, based on the length L_{PP} and the towing velocity $U = 1.531$ m/s, is $Re = 4.65 \times 10^6$ and the Froude number is $Fr = 0.28$.

In this study, the ship has a drift angle $\beta = 10^\circ$ and all flow measurements have been performed by IIHR [10] which provides tomographic PIV information at several stations. Due to the static drift, the flow is asymmetric about the hull



Fig. 1. Geometry of DTMB 5415.

centerline as the hull is oriented obliquely to the incoming flow. The main vortices are the sonar dome tip vortex (SDTV), the bilge keel tip vortex (BKTV) and the aft-body keel vortex (ABKV). In the following of the paper, the comparisons will examine SDTV.

2 ISIS-CFD at glance

ISIS-CFD, developed by the Ecole Centrale de Nantes and CNRS and available as a part of the FINE/Marine computing suite, is an incompressible Unsteady Reynolds-Averaged Navier-Stokes (URANS) method. The solver is based on the finite volume method to build the spatial discretization of the transport equations. The unstructured discretization is face-based, which means that cells with an arbitrary number of arbitrarily shaped faces are accepted. A second order backward difference scheme is used to discretize time. The solver can simulate both steady and unsteady flows. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass equation constraint, or continuity equation, transformed into a pressure equation. In the case of turbulent flows, transport equations for the variables in the turbulence model are added to the discretization.

The solver features sophisticated turbulence models: apart from the classical two-equation $k-\varepsilon$ and $k-\omega$ models, the anisotropic two-equation Explicit Algebraic Reynolds Stress Model (EARSIM), as well as Reynolds Stress Transport Models, are available [2, 3]. All these are RANS models. One hybrid RANS-LES method used is the Detached Eddy Simulation (DES), based on the $k-\omega$ model [7]. Recently, some modifications of this formulation proposed by Grisevich et al. [4] includes recalibrated empirical constants in the shielding function and a simplification of the original Spalart-Allmaras-based formulation. This new model is called Improved Delayed Detached Eddy Simulation (IDDES). These hybrid RANS-LES models have been validated on automotive flows characterized by large separations [5].

Free surface flow is simulated with a multi-phase flow approach: the water surface is captured with a conservation equation for the volume fraction of water, discretized with specific compressive interface-capturing scheme [9].

3 Results

The mesh is generated by HexpressTM, an automatic unstructured mesh generator. A first refinement box including the hull with a cell size of 10 mm in each

direction is used. Two other boxes, one including the sonar dome until $X/L_{PP} = 1.0$ and the other including the windward bilge keel until $X/L_{PP} = 1.0$, are used. For these two boxes, the cell size is $\Delta x = 1.5$ mm and $\Delta y = \Delta z = 0.7$ mm. Finally, a last box covering the sonar dome until $X/L_{PP} = 0.6$ is used with the cell size $\Delta x = 0.75$ mm and $\Delta y = \Delta z = 0.35$ mm. The final mesh contains 162.6 million cells.

Figure 2 presents a comparison of the axial velocity in a plane located at $X/L_{PP} = 0.4$. In this slice, only the SDTV vortex is visible. The comparison of the vortex size with the different turbulence models is similar and in agreement with the experimental data.

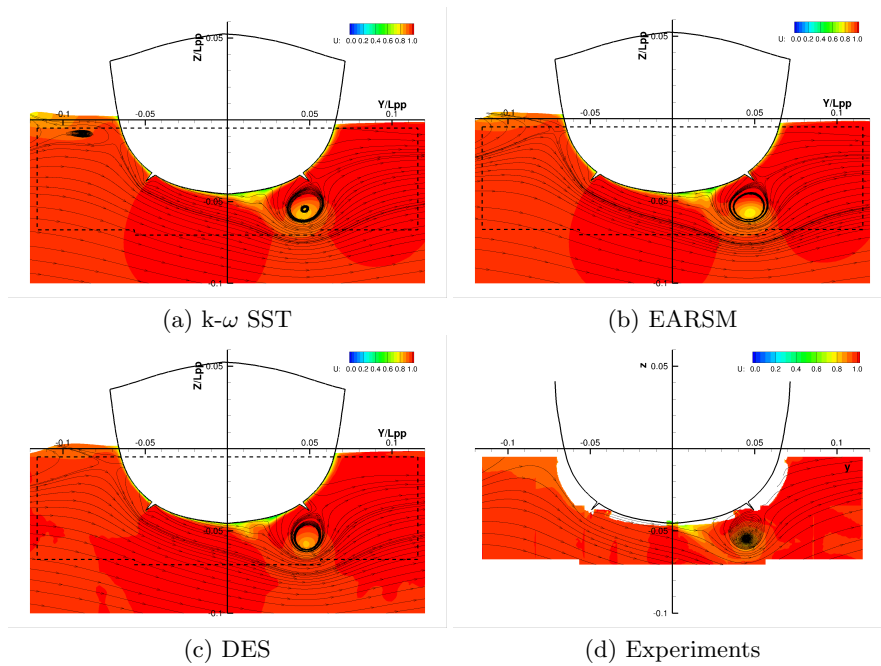


Fig. 2. Comparison of the axial velocity at $X/L_{PP} = 0.4$.

For the same slice, it is possible to plot the turbulence kinetic energy, see Figure 3. In the experiments, a maximum of TKE is observed in the core of the vortex while with the RANS turbulence models, a minimum of TKE is predicted. Only the hybrid RANS-LES model predicts this high level of TKE in the core of the vortex.

With the help of several slices, it is possible to plot the longitudinal evolution in the core of SDTV and BKTV, see Figure 4 which presents the position of the vortex core, the axial velocity and TKE. The positions of SDTV and BKTV are very well predicted by all numerical simulations. For the axial velocity, the velocity predicted with the EARSM turbulence model is not in agreement with

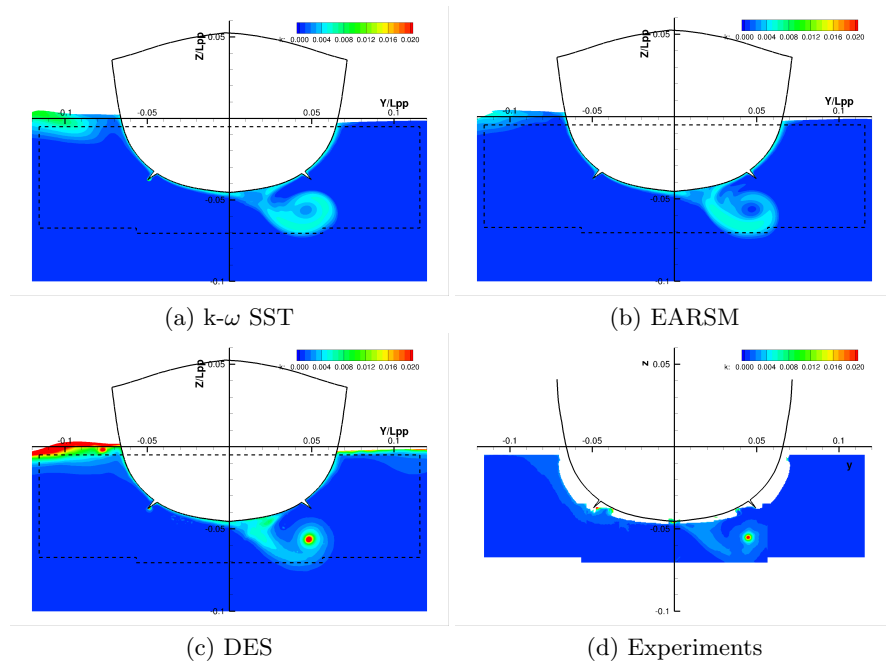


Fig. 3. Comparison of the turbulent kinetic energy at $X/L_{PP} = 0.4$.

the experimental data. Indeed, in the numerical simulation, a decrease of the velocity is predicted until $X/L_{PP} = 0.8$ while in the experiments, the velocity increases until $X/L_{PP} = 0.6$ and then decreases slightly. With the $k-\omega$ SST turbulence model, the velocity is constant until $X/L_{PP} = 0.6$ and then increases. The DES model is the only one that is able to predict the correct behavior of the velocity in the core of SDTV. For the turbulent kinetic energy, the RANS models predict a decrease when we move along the hull. However, in the experiments, the level of TKE is constant in the core and the hybrid RANS-LES model is able to predict this behavior.

This high level of turbulent kinetic energy is due to a population of ring vortices, see Figure 5 which shows the core of the SDTV vortex obtained with the hybrid RANS-LES model, that comes from the periodic shedding at the trailing edge of the sonar dome. These vortices are driven in a global rotation motion around the axis of the SDTV and then create a high level of resolved fluctuations in its core. So, the high level of k in the core is not due to vortex meandering.

4 Conclusions

In this paper, an investigation of RANS and hybrid RANS-LES models for the flow simulation around a DTMB 5415 at 10° static drift has been conducted. This

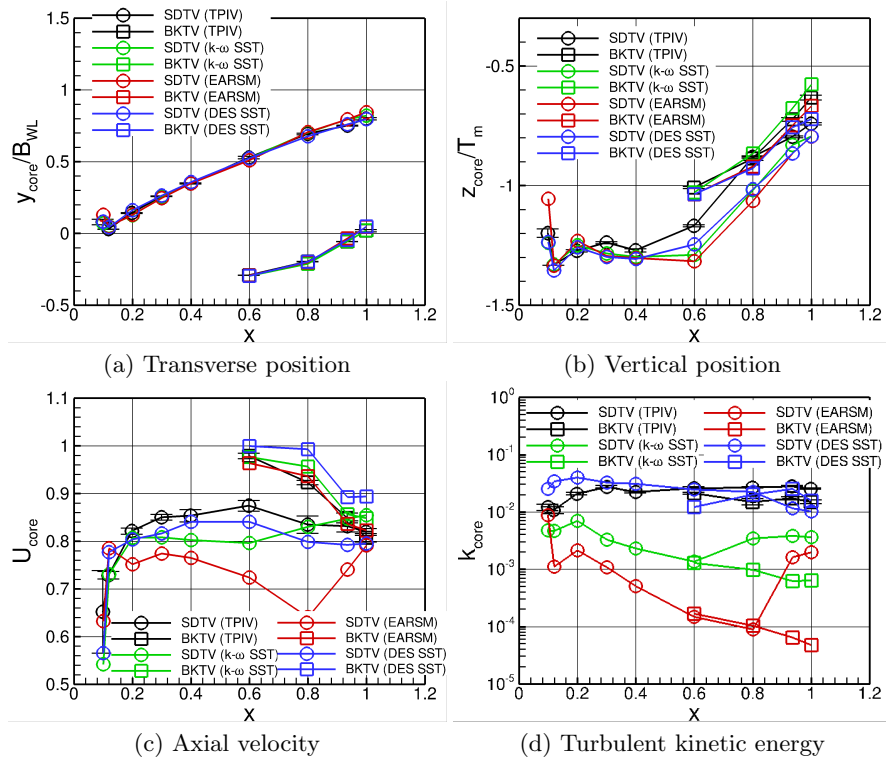


Fig. 4. Longitudinal evolution in the core of SDTV.

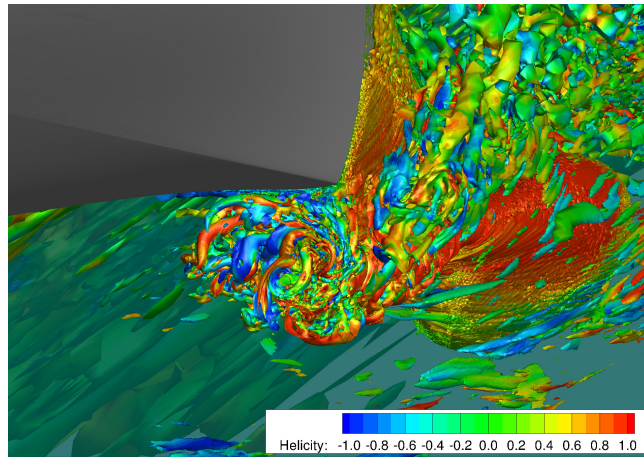


Fig. 5. View of an iso-surface of non-dimensional Q ($Q^* = 50$) around the SDTV vortex.

numerical study has been carried out with the flow solver ISIS-CFD. It has been shown that the use of the hybrid RANS-LES model offers an advantage over RANS models, particularly in terms of the turbulence kinetic energy in the core of the vortex. This high level of turbulent kinetic energy prediction is due to a vortex shedding on the trailing edge of the sonar dome.

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