Development of hybrid RANS-LES methods for flow simulation in ship stern area using OpenFoam

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Abstract

The paper presents first results of implementation of various hybrid LES and RANS methods in OpenFoam. LES is becoming attractive for shipbuilding applications because of its capability to resolve strong concentrated unsteady vortex structures. It could be very useful when the ship wake behind the ships with a large block coefficient (for instance, tankers) is determined. This practical task is very important for prediction of the overall propulsion, cavitation and vibration of propulsors. At the beginning of the presentation, the feasibility of the full LES is estimated. The estimation method is validated for the case of a turbulent boundary layer on the flat plate. This analysis shows that the full LES demands a huge resolution and computer power even at small Re numbers $(\sim 10^6)$ for ship models. Therefore the only possible solution is the development of hybrid methods. We have implemented hybrid methods based on combinations of Smagorinsky, Dynamic Smagorinsky (DSM) and Dynamic Mixed LES SGS models with $k-\varepsilon$ v2f and $k-L$ RANS models. The switching between RANS and LES models proceeds depending on the ratio between the integral length and cell size. If the integral length is larger than the cell size, the LES is used. Otherwise, the flow is calculated using RANS. The test benchmark used in the paper is the tanker KVLCC2 which resistance and wake in the propeller disk were thoroughly measured by the Korean colleagues. Additionally to RANS and LES we performed flow simulations using SAS and DES. The main results of the study are as follows

- SAS, $k-\varepsilon$ v2f and the hybrid method based on the DSM and $k-\varepsilon$ v2f give very good results for the resistance (see table 1),
- the resistance obtained using full LES with a moderate resolution is too small because of the under resolution of the ship boundary layer,
- SAS , $k-\varepsilon$ v2f and the hybrid method based on the DSM and $k-\varepsilon$ v2f reproduce the field of the mean longitudinal velocity very well (see Fig.1), whereas DES fails,
- All URANS models, SAS and DES are not able to reproduce unsteady character of the wake flow in the propeller disk,
- Hybrid method predicts the unsteadiness of the propeller disk wake flow. The frequency analysis allows one to distinguish two typical dominating frequencies.

These results indicate that the unsteadiness of the wake has to be taken into account when estimating the vibration and cavitation of propellers. This effect can be captured only by hybrid LES-RANS methods. This numerical finding will be proven by comparison with PIV measurements which have to be performed by SVA Potsdam this year.

The results of the presented study demonstrate that the OpenFoam package is a very attractive tool for maritime applications. New generations of ship CFD methods with a more detailed modeling of unsteady effects and turbulence can be developed on the basis of OpenFoam package.

Table 1. Results of the resistance prediction in comparison with measurements.

Open FOAM-1.6 Model of tanker KVLCC2 Mesh: 600.000 cells

	Resistance coef.	Pressure resistance	Viscous resistance
KRISO Exp.	0.00411	15%	85% (ITTC 57)
RANS k-e-v2-f	0.00400	16%	84%
k-omega-SST-SAS	0.00380	18%	82%
LES Dynamic Mixed Model	0.00170	81%	19%
Hybrid RANS-LES	0.00407	17%	83%

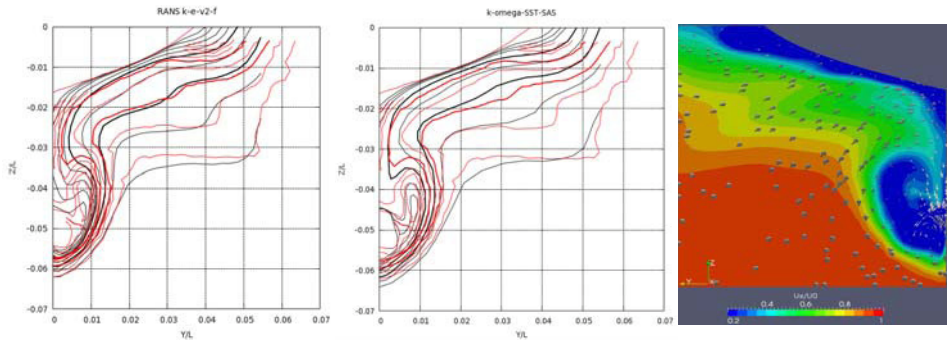

Fig.1 Wake field in the propeller disk. Red curves- KRISO measurements, black- OpenFoam simulations, colour picture- instantaneous field obtained by the hybrid method.

Key words: hybrid methods, OpenFoam, ship wake, propeller.