Prediction of unsteady loading on energy saving device in ship using hybrid RANS-LES turbulence model

Sina Samarbakhsh

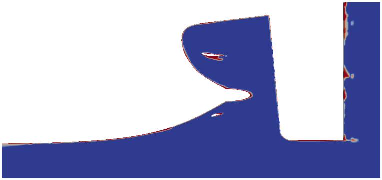
Nikolai Kornev

Faculty of Mechanical Engineering and Marine Technology
Chair of Modeling and Simulation

Contents

Motivation

- RANS can calculates resistance and mean velocity precisely
  - While is not able to capture the unsteady effects especially in the wake
- The application of vortex resolving method like LES is necessary
  - Pure LES is still impossible for high Reynolds number due to high computational cost
- Hybrid URANS/LES methods is a feasible alternative to solve practical problems



hybrid turbulence model: Red: RANS, Blue: LES

LeMoS hybrid (LH) URANS/LES method

The momentum equation written in terms of URANS and LES can be presented in a general form:

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} + \frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right) - \tau_{ij}^{h}\right] + \overline{f}i \qquad (1)$$

- Hybrid viscosity is represented as a sum of kinematic turbulence viscosity and subgrid scale viscosity:

$$\nu_h = f\nu_t + (1-f)\nu_{sgs} \qquad (2)$$

- In LeMoS hybrid model computationla domain dynamically decomposed into RANS and LES

$$h = h(\mathrm{x}, t) = \frac{L(\mathrm{x}, t)}{\Delta(\mathrm{x})} \qquad (3)$$

- the blending function $f = f(\mathrm{x}, t)$

$$f(x) = \begin{cases} 0, & h > 1.05 \\ 1, & h < 0.95 \\ \gamma(h), & 0.95 \leq h \leq 1.05 \end{cases}$$

LH: LeMoS hybrid URANS-LES model
SLH: Shielded LeMoS hybrid URANS-LES model. The shielding function is introduced to overcome the artificial grid induced separation.

Ship flow test case

The performance of LeMoS hybrid model for presiction of wake and integral force acting on the ship have been analyzed and compared with DES based hybrid models

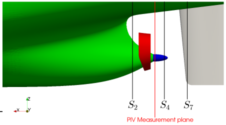
Ship model test case						
	length between perpendiculars L_{pp}	Draft	Beam	Block coefficient C_b	Fr	Re
Ship at model scale	$6[m]$	$0.35[m]$	$1[m]$	0.79	0.169	7.4×10^6

The CFD calculation for both URANS and hybrid models were carried out using OpenFOAM which is a free open source software for CFD. A 3D meshes consist of predominately hexahedral cells has been created with cfMesh. cfMesh is a library for automatic mesh generation that is built on top of OpenFOAM.

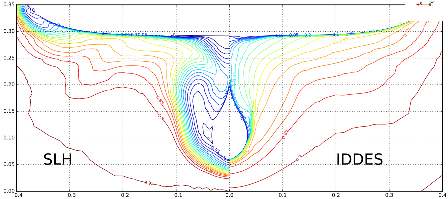
Numerical domain properties				
	domain size $L \times W \times H$	total grid cells	y^+ Bow, midHull, Stern	spatial resolution in a wake
Ship at model scale	$20L_{pp} \times 12L_{pp} \times 2L_{pp}$	$19Mio$	$14, 14, 12$	$0.0005L_{pp}$

Results and discussion

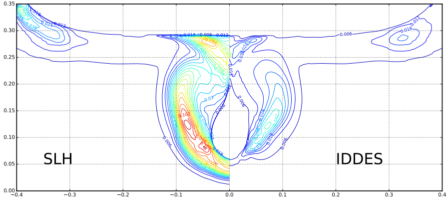
Influence of turbulence model at $S_2 = \frac{x}{L_{pp}} = 0.9628$, with ESD



- Transition from RANS to LES branch in DDES and IDDES has not been achieved correctly. The value of TKE in SLH model is much larger than DDES and IDDES.

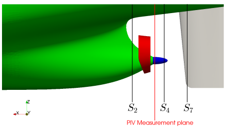


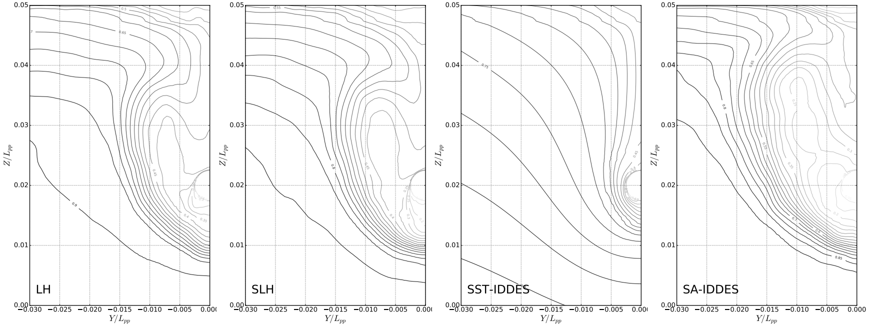
isoline of x-component of average velocity



isoline of total kinetic energy

Results and discussion



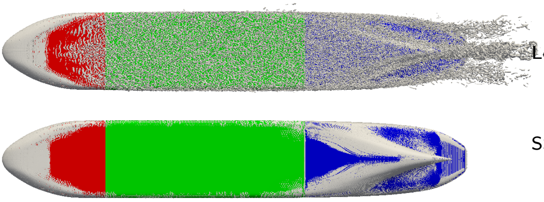


isoline of x-component of mean velocity, PIV measurement plane

- Transition from RANS to LES branch in DDES and IDDES has not been achieved correctly.

Results and discussion

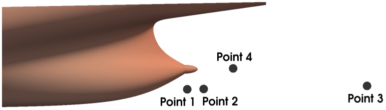
- Vortical structure visualized by Q criterion

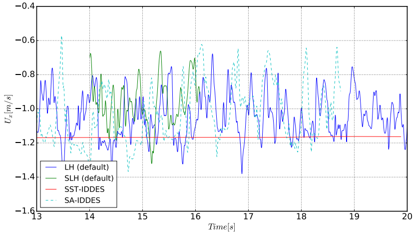


LeMoS hybrid model

SST IDDES

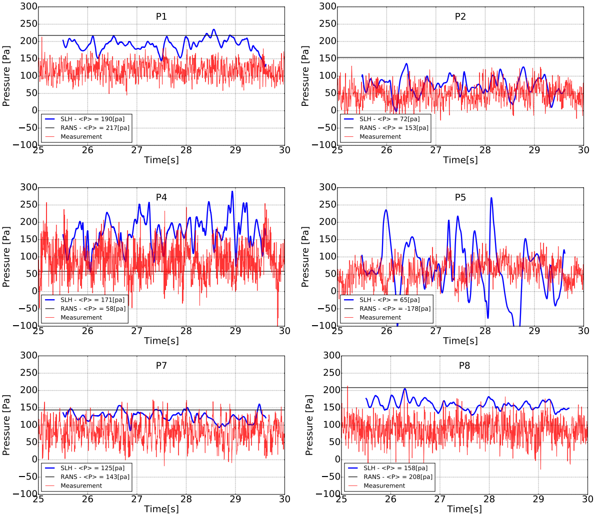
- Time history of velocity signal at different prob locations show RANS-like velocity signal for DDES and IDDES.

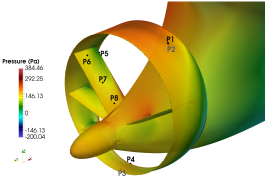




point 3

Results and discussion unsteady pressure fluctuation on duct Turb model: SLH, Mesh: 19Mio-cfMesh

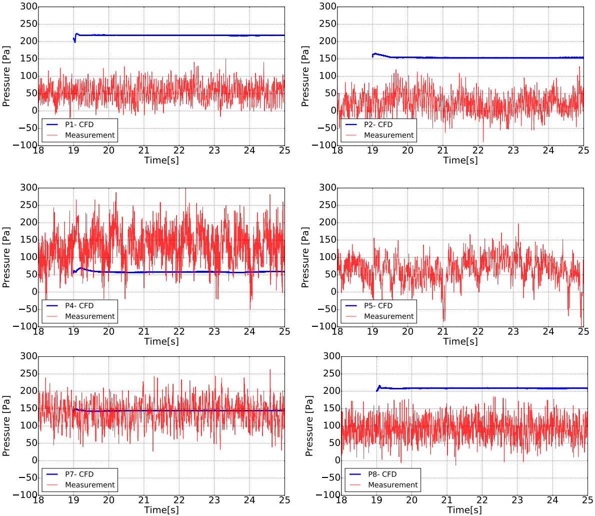


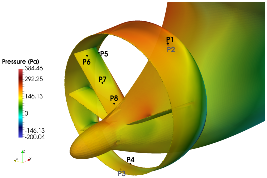


- Reproducing unsteadiness in the pressure over the duct
- Over prediction in all pressure tap locations

Results and discussion unsteady pressure

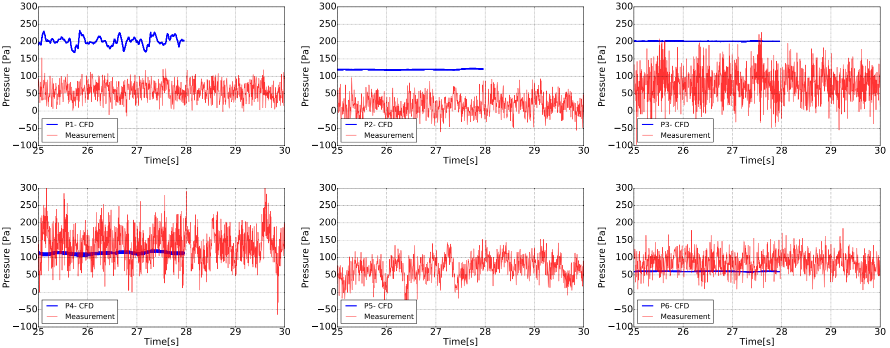
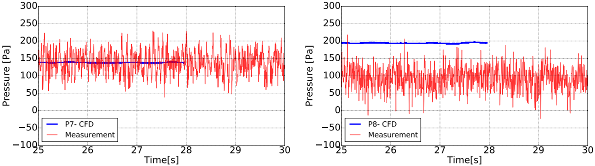
fluctuation on duct Turb. model: URANS



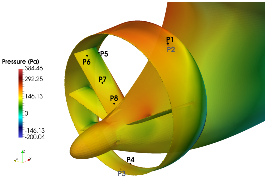


- URANS doesnt show the unsteadiness behavior of pressure

Results and discussion unsteady pressure fluctuation on duct Turb. model: DDES

- DDES shows smooth presure signal resulting from URANS to LES transition issue (gray area problem)



Results and discussion

Ship resistance at $Fn = 0.169$ with different turbulence model

SteadyState: Ship hull (without rudder and ESD), 19Mio grid with cfMesh			
	EFD	k-ω SST	Spalart Allmaras
$C_T \times 10^{-3}$	3.92	3.917	4.03
$C_f \times 10^{-3}$	3.16	3.31	3.47
$C_p \times 10^{-3}$	0.72	0.607	0.56

Unsteady: Ship hull (without rudder and ESD), 19Mio grid with cfMesh			
	EFD	LeMoS hybrid RANS-LES	SST-IDDES
$C_T \times 10^{-3}$	3.92	3.36	3.992
$C_f \times 10^{-3}$	3.16	2.67	3.42
$C_p \times 10^{-3}$	0.72	0.69	0.56

- The prediction of forces are underestimated by SLH compared to SST-IDDES.

Summary and conclusions

- SST-IDDES can predict forces in a good agreement with the measurement while delay in RANS-LES transition results in the smoothing of the unsteady effects in the wake.

- The hull in this study is well streamlined and strong separation are absent, the application of a turbulent generator is needed.

- LeMoS hybrid model is capable of resolving unsteady effect caused by vortices in the wake while the prediction of the forces are underestimated compared to SST-IDDES.

- Decomposition of the computational domain into the RANS and LES region. The LES branch is only activated in the stern area. In this approach an inflow-generator should be used at the RANS-LES interface to produced the resolved turbulent content in order to remedy the gray area problem.

Acknowledgments: The support of the Federal Ministry for Economic Affairs and Energy (Bundesminis-terium für Wirtschaft und Energie) of Germany within the framework of the project HyDesign 03SX493D.