IMPLEMENTATION OF OVERSET GRID IN OPENFOAM AND ITS VALIDATION TO PMM MODEL TEST OF A CONTAINER SHIP

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Keywords: *Overset grid, Ship hydrodynamics, PMM Model test, Ship manevering*

Introduction

Overset grid approach is practical and elegant method in the use of computational fluid dynamics (CFD) to simulate certain complex problems that considering the flow around multiple moving bodies, deforming bodies, or bodies with complex geometries. In ship hydrodynamics, overset grid has been widely used in the simulations including self-propulsion [1, 2, 3], see-keeping [4], turning and zig-zag test [2, 3, 5] and PMM model test [6, 7, 8, 9], slamming [10] and ship maneuvering in waves [11]. In these literatures, the ships have large amplitude of motions, the geometries of propeller rudder and appendages are complex and the propeller and rudder have relative rotating motions to the ships. The results demonstrate the capability and the advatage of the overset grid methodology to deal with problems with large amplitude motions and violent flows.

In [1, 4, 5] Carrica use CFDShip-Iowa a FDM CFD solver with Suggar++ [12] and DiRTlib [13] to calculate domain connectivity information (DCI) that connect the solutions among multiple overset component grids. DiRTlib is a solver neutral library that simplifies the addition of an overset capability to a flow solver by encapsuating the required operations. In [14], Boger firstly brought overset grid mehodology in OpenFOAM. The foamedOver library stands separately from OpenFOAM and it inserts easily into solvers e.g. potentialFoam, icoFoam, interDyMFoam of OpenFOAM. foamedOver also benefits from the software packages Suggar++ and DiRTlib. Indeed, DiRTlib makes it easier for Suggar++ to be applied to different CFD solvers. As illustrated in [2], Shen implementes the overset technique into an OpenFOAM-based in-house solver naoe-FOAM-SJTU. Suggar++ is used to obtain the DCI and a lagged mode is used to allow OpenFOAM and Suggar++ to run in parallel so that shortens the waiting time of the CFD solver and Suggar++. Simillarly, Chris and Darrin in [15] developed the library Caelus also based on Suggar++. Andreas in [16] developed an Open source overset grid library Bellerophon, which extends OpenFOAM with capabilities for overset grid. This library is publicly released and can be dynamically linked to any standard OpenFOAM solver without changing the solver it self, but the low efficiency of DCI calculation limits its application to dynamic problems. In [17], Chandar described an overset grid implementation for moving grids in OpenFOAM. A dynamic library OPErA linked independently to OpenFOAM that provides DCI is developed. Flood-fill algorighm is utilized for hole cuttibg and inverse map strategy is utilized for donor search. Compared with Bellerophon, OPErA is more efficient and has been used to carry out simulations on ship hydrodynamics in [18, 19], where the overset computation results are compared with results given by StarCCM+, ANSYS Fluent and experimental measurements for validation and verification purpose. But similar with Suggar++, OPErA is not publicly released or open-source so far. The latest release version OpenFOAM-v1712 and foamextend-4.0 also include overset package but so far are not widely used and validated especially for ship maneuvering cases.

As we can see, overset grid methodology performs well for simulations with large amplitude motions and complex geometries. So far it has been widely and successfully used in ship hydrodynamics, especially for simulations of ship motion in waves, ship maneuvering, ships with full appendages. And many researchers have made their effort to extend OpenFOAM with capabilities for overset grid. Some are using commercial software like Suggar++ and DiRTlib, others are using in-house library as Bellerophon or OPErA. And the latest release version of OpenFOAM-v1712 and foamextend-4.0 also include their own overset grid package. All these codes have their own merits and limitations and most of them are not publicly released or validated. So in order to simulate ship maneuvering tests such as PMM model test, turning test, zigzag test el al, we developed a dynamically linked third party package to perform efficient Overset Grid Assembly (OGA). As with Suggar++, Bellerophon and OPErA our package will make no changes to existing standard libraries in OpenFOAM and a few changes to top-level applications. We used the existing linear solver and lduMatrix. Besides, only a few changes were made to the existing workflow.

As illustrated in [20], we extended the open-source overset grid assembly package tioga, proposed in [21], to arbitrary polyhedral grid as generated by snappyHexMesh. And connected it to top level solvers in OpenFOAM like interDyMFoam and pimpleDyMFoam as a dynamic linked library. We have applied this package to simulate sphere water entry case, pure yaw and pure sway motion of DTMB-5415 hull , that verify the DCI calculation, flow field interpolation and multi-bodies motion control part of the program. But quantitative comparisions are still required to valid the accuracy of the solver. Considering that, in this paper, we take a container ship, which is designed by us, as an example. We have carried out resistance and PMM model test of this hull in our towing tank and the experimental measurements of hydrodynamic forces experienced by the hull together with the resulting ship motions are compared with the numerical results obtained in this paper.

Test overviews

The main dimensions of the container ship considered in current study are listed in Table 1 . The ship model used in current study does not have appendages or bilge keels but with rudder and propeller in some test cases and all the model test conditions are listed in Table 2 and 3 .

Table 1: Main dimensions of the container ship

Items	Full scale	Model scale
Waterline length (L_{wl})	389.4m	4.327m
Length between perpendicular (L_{pp})	383.0m	4.256m
Beam (B)	54m	0.6m
Fore draft (T_F)	16m	0.178m
Aft draft (T_A)	16m	0.178m
Block coefficient (C_B)	0.709	0.709

Table 2: Static PMM model test conditions

Test name	Model speed(m/s)	Drift angle(°)	Heel angle(°)	(w/o) rudder and propeller
Resistance test	$1.084, 1.204, 1.356$	0	0	o
Static drift test	1.204	$\pm 2, \pm 4, 6, 8, 10, 12$	released	w/o
Constant heel angle	1.204	0	$0, \pm 5, 8, -10$	o

Table 3: Dynamic PMM model test conditions of the bare hull

Test name	Model speed(m/s)	Drift angle(°)	Heel angle(°)	Frequency	Amplitude(m)
Pure sway	1.204	0	released	$0.0833, 0.1, 0.125$	0.4
Pure yaw	1.204	0	released	$0.0833, 0.1, 0.125$	0.4

Simulation design

In this study, we take grid independence study based on the resistance test case with advancing speed $V = 1.204$. Three sets of grids named as ”Coarse”, ”Medium” and ”Fine” are considered. All these three sets of grids guarantee $30 < y^+ < 80$ as required by the $k - \omega$ turbulence model when wall functions are used. Considering the fact that the flow separations will increase and result in strong side forces and moments with the growing of the drift angle β in static drift tests, a hybrid URANS/LES approach called kOmegaSSTIDDES is utilized and the grids in the wake region of the hull where flow separations may happen are refined. Table 4 presents the specific grid definition and the grid convergence verification. As is illustrated, the ”Medium” grid is fine enough to capture the flow feature and yield an accurate results for the forces experienced by the ship during the resistance test with advancing speed $V = 1.204$, so the ”Medium” grid is used to simulate other test cases. To summarize, this paper implement simulations of static and dynamic PMM model tests for a container ship to validate the OpenFOAM solver combined with our in-house overset grid assembly package. The numerical results together with the experimental measurements will be published in the full text.

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Table 4: Grid description and convergence verification

Items	Coarse	Medium	Fine	Exp
Number of cells	$2.8m$	$7.8m$	$12m$	
Resistance(N)	8.23	8.53	8.56	8.75
Errors(%)	5.9	2.5	2.2	

Table 5: Numerical results of static PMM tests

Drift angle(°)	Item	CFD(N)	Errors(%)	EFD(N)
0	F_x	8.53	2.5	8.75
0	F_y	0.03	-113	-0.23
12	F_x	10.18	0.3	10.15
12	F_y	25.68	1.8	26.15

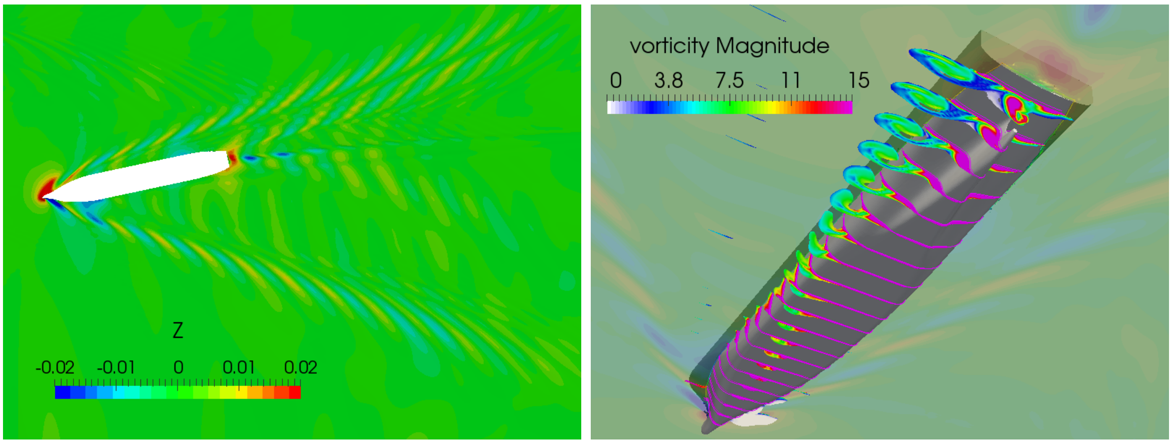

Figure 1: Numerical results of wave pattern and vortex of the container ship with drift angle $\beta = 12°$

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