OVERSET GRID BASED SIMULATION OF MOVING BODY IN VISCOUS FLOWS WITH FREE SURFACE

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Summary Our recent developed solver naoe-FOAM1.0 based on a structured overset grid approach coupled with Reynolds-Averaged Navier-Stokes (RANS) method is presented to provide accurate resolution of moving surface ships in viscous fluids. The simulating results indicate the feasibility of the presented solver naoe-FOAM1.0 to compute the complex viscous free surface flows.

INTRODUCTION

The study of moving body in viscous flows with free surface covers a wide range of engineering and environmental flows, such as flow about ships or marine structures. The flow problem to be simulated is rich in complexity and poses many modelling challenges because of the existence of moving interface and moving boundary. In this paper, our recent developed code solver naoe-FOAM1.0 based on a structured overset grid approach coupled with Reynolds-Averaged Navier-Stokes method is presented to provide accurate resolution of moving surface ships in viscous fluids. The RANS equations with shear stress transport (SST) $k-\omega$ model are employed to treat the viscous turbulent flows. The fully nonlinear boundary condition at the free surface is satisfied at each time step and the evolution of the free surface is achieved by using the level set method. A structured overset grid approach is employed to allow flexibility in grid generation, local mesh refinement, as well as the simulation of moving objects while maintaining good grid quality. The overset interpolation coefficients are computed with the dynamic overset interpolation schemes. The presented code solver naoe-FOAM1.0 is demonstrated by viscous flows around an advancing trimaran ship. The simulating results indicate the solver naoe-FOAM1.0 can be able to handle very well the challenge in the simulations of the flows around free surface ships in viscous flows or in waves, including the interactions between the large deformation of the free surface and the moving boundary of the ship hulls.

GOVERNING EQUATIONS

The non-dimensionalized RANS equations as usual for incompressible fluid flows are as follows,

$$\frac{\partial \mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}=-\nabla p+\nabla\cdot\left(\frac{1}{\mathrm{Re}_T}\nabla\mathbf{u}\right),\quad \nabla\cdot\mathbf{u}=0 \tag{1}$$

where **u** is velocity, the p is the non-dimensional piezometric pressure defined by

$$p=\frac{p_a}{\rho U_0^2}+\frac{z}{Fr^2} \tag{2}$$

here p_a is the absolute pressure, U_0 is the freestream velocity, Re_T is the effective Reynolds number and Fr is the Froude number, defined as

$$\mathrm{Re}_T=\frac{U_0 L}{\nu+\nu_t},\qquad Fr=\frac{U_0}{\sqrt{gL}} \tag{3}$$

here L is the characteristic length, g is gravity acceleration, ν_t is the turbulent viscosity which is obtained by solving the blended SST $k-\omega$ model of the turbulence[2].

Suppose ϕ is a distance to the interface, positive in water and negative in air, then the location of the interface is given by the zero level set of the function ϕ, which should satisfy[4],

$$\frac{\partial \phi}{\partial t}+\mathbf{u}\cdot\nabla\phi=0 \tag{4}$$

The air-water interface normal **n** and curvature κ can be computed from the level set function ϕ as follows

$$\mathbf{n}=-\frac{\nabla\phi}{|\nabla\phi|},\quad \kappa=\nabla\cdot\mathbf{n} \tag{5}$$

NUMERICAL METHODS

In order to solve the governing equations of Eq.(1) and Eq.(4), combining a finite difference discretization and level set method is employed to compute the free surface ship flow. The steady state solution is computed using an unsteady approach. An Euler backward difference in the time domain is applied for temporal discretization. A scheme following the PISO (pressure-implicit split-operator) [1,7] algorithm is adopted to separate the velocity and pressure coupling. The second order upwind biased (QUICK) scheme is used to discretize the convective terms, and the second order

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central scheme is applied to the viscous term. Besides the momentum equations and the continuity equation, the transport equation for the level set function should be also solved. From Eq.(5), the interface normal **n** and curvature κ are determined by the level set function ϕ, and the normal must be accurately evaluated at the interface because it is used in Eq.(1) and it must also be reasonable everywhere in air since it is used to extend the velocities into the air to transport the level set function ϕ. However, due to the natural consequence of the convection process in Eq.(4), the level set function ϕ may become very steep or flat in some regions, particularly in the vicinity of the interface as time goes. Therefore, for keeping ϕ as a distance function, reinitialization of ϕ is needed. We can construct a function, $\tilde{\phi}$, with the properties that its zero level is the same as ϕ and that $\tilde{\phi}$ is the signed normal distance to the interface. Here ϕ is the level set function obtained after the level set convection step in Eq.(4), $\tilde{\phi}$ is the new level set function after reinitialization[2-6]. The main procedure of overset grid method is the domain connectivity, which consists of three steps: projection, hole cutting and fringe-point interpolation[8]. Projection process shifts the surface points to remove the effect of surface-discretization errors, which often occur in the more complex conditions, such as surface interpolation. However, in this paper, since the hull shape is simple and no surface interpolation is required, the procedure is ignored. Hole cutting is to remove the unnecessary grid points from one gird which are inside another grid. Interpolation step is to search stencil points which provide interpolation information for fringe points (the remaining boundary points after hole cutting). Interpolation coefficients are calculated in this step. And thus, the fringe points can receive information from the other mesh though the interpolation of stencil points.

NUMERICAL EXPERIMENTS

Numerical simulations of viscous flows around an advancing trimaran ship composed of three Wigley hulls are carried out to validate the presented numerical approach. The length of main body is equal to one meter, and for the side bodies, the length is 0.36 meters (see Fig.1). Fig.2 shows the transverse section of the overset grid. The blue grids represent the side bodies and the red one is main body. Each hull grid is embedded into the black background grid and remains some layers of overlapping points to build the connectivity between each grid. Fig.3 shows the wave patterns. It can be seen that the bow of side bodies reside in the bow waves produced by the main body, and two kinds of bow waves overlap and create a large wave height. So do the stern waves. And therefore, the wave resistance of this case is largest.

Fig. 1 Geometry of Trimaran Ship

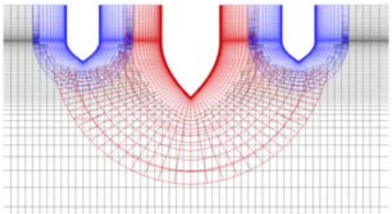

Fig. 2 Transverse Section of Overset Grid

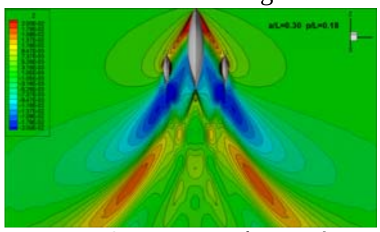

Fig. 3 Waves Patterns of trimaran ship

CONCLUSIONS

Our recent developed solver naoe-FOAM1.0 based on overset grid method coupled with level set method has been applied to the simulations of free surface viscous flows. The RANS equations with shear stress transport (SST) $k-\omega$ model are employed to treat the viscous turbulent flows. The fully nonlinear boundary condition at the free surface is satisfied at each time step and the evolution of the free surface is achieved by using the level set method. A numerical experiment of wave-making viscous flows over an advancing trimaran ship composed of three Wigley hulls is carried out to test the capability and efficiency of the presented solver naoe-FOAM1.0. Due to the limitation of this paper length, more computed results of free surface flows around practical ship hulls cannot be shown.

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