

A PRACTICAL METHOD FOR HYDRODYNAMIC COEFFICIENT CALCULATION WITH OPENFOAM

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Keywords: KVLCC2, added mass, damping, CFD method, OpenFOAM,

In the procedure of predicting ship motions in waves, the hydrodynamic coefficient should be obtained in advance for solving ship's motion equation. The added mass and damping is usually computed with potential method [1], however the potential theory is based on the hypothesis of potential flow, and its result can not include the viscous effect and failed to obtain the nonlinear component. In this work, we proposed a method to obtain hydrodynamic coefficient and non-linear hydrodynamic coefficient by analysing the force-time curve of ship hull, and the force-time curve is obtained by simulating forced oscillations of ships in OpenFOAM[2]. Meanwhile, an efficient mesh manipulation model specific for simulating ship oscillation is put forward in this work. The hydrodynamic coefficient computed by the present method is compared with the result obtained by potential method, which shows the accuracy of the present method.

1. Hydrodynamic coefficient computation method

For a ship hull forced oscillation with specified degree of freedom (DOF), the total hydrodynamic force can be discomposed as follow [3],

$$F_{i,j} = F_{i,j}^C + C_{i,j}\xi_i + A_{i,j1}\ddot{\xi}_i + A_{i,j2}(\ddot{\xi}_i)^2 + B_{i,j1}\dot{\xi}_i + B_{i,j2}(\dot{\xi}_i)^2 \quad (i, j = 1, 2, \dots, 6) \quad (1)$$

where the $F_{i,j}^C$ is the constant force which including the ship gravity and wave making resistance, $A_{i,j1}$ and $B_{i,j1}$ are the added mass and damping respectively, $A_{i,j2}$ and $B_{i,j2}$ are the nonlinear added mass and damping, $C_{i,j}$ is the hydrostatic recovery force and can be expressed as follow

$$C_{i,j} = \begin{pmatrix} 0 & 0 & & & & 0 \\ 0 & 0 & & & & 0 \\ & \rho g A_w & & 0 & & \rho g A_w x_f \\ \vdots & 0 & \rho g (A_w d_1^2 + z_B \nabla) & & 0 & \vdots \\ & \rho g A_w x_f & & 0 & & \rho g (A_w d_2^2 + z_B \nabla) \\ 0 & 0 & & & & 0 \end{pmatrix} \quad (2)$$

where the A_w is the water plane area, d_1 is the inertial radius around the X axis and d_2 is the inertial radius around the Y axis. z_B is the Vertical coordinate of buoyant centre, x_f is the x coordinate of floatation centre, ∇ is the volume of displacement.

In case of oscillation motion, the displacement ξ_i can be expressed in harmonic form. The displacement, velocity and acceleration can be expressed as follow

$$\begin{cases} \xi_i = \xi_{i0} \sin(\omega t) \\ \dot{\xi}_i = \xi_{i0} \omega \cos(\omega t) \\ \ddot{\xi}_i = -\xi_{i0} \omega^2 \sin(\omega t) \end{cases} \quad (i = 1, 2, \dots, 6) \quad (3)$$

Substituting Eq. 3 into Eq. 1 gives

$$F_{i,j} = \left(F_{i,j}^C + A_{i,j2} \frac{\xi_{i0}^2 \omega^4}{2} + B_{i,j2} \frac{\xi_{i0}^2 \omega^2}{2} \right) + (C_{i,j} \xi_{i0} - A_{i,j1} \omega^2 \xi_{i0}) \sin(\omega t) + (B_{i,j1} \omega \xi_{i0}) \cos(\omega t) + \left(-A_{i,j2} \frac{\xi_{i0}^2 \omega^4}{2} + B_{i,j2} \frac{\xi_{i0}^2 \omega^2}{2} \right) \cos(2\omega t) \quad (4)$$

By monitor the force of ship oscillation movement, the force-time curve can be obtained, and which curve can be fitted in Fourier series form.

$$F_{i,j} = F_{i,j0} + F_{i,j a1} \sin(\omega t) + F_{i,j b1} \cos(\omega t) + F_{i,j a2} \sin(2\omega t) + F_{i,j b2} \cos(2\omega t) \dots \dots \quad (5)$$

Comparing the Eq.4 and Eq.5, it's easy to obtain the added mass, damping, nonlinear added mass and nonlinear damping, the expression are showed as Eq.6.

$$\begin{cases} A_{i,j1} = \frac{-F_{i,ja1} + C_{i,j}\xi_{i0}}{\omega^2\xi_{i0}} \\ B_{i,j1} = \frac{F_{i,jb1}}{\omega\xi_{i0}} \\ A_{i,j2} = \frac{F_{i,j0} - F_{i,jb2} - F_{i,j}^C}{\omega^4\xi_{i0}^2} \\ B_{i,j2} = \frac{F_{i,j0} + F_{i,jb2} - F_{i,j}^C}{\omega^2\xi_{i0}^2} \end{cases} \quad (i, j = 1, 2, \dots, 6) \quad (6)$$

It is worth to mention that the movement amplitude ξ_{i0} is displacement in the motion modality of $i=1,2,3$, while in the motion modality of $i=4,5,6$, the ξ_{i0} is the rotational amplitude with the dimension of radian. The Eqn.6 is suitable for the hydrodynamic calculation of all motion modality.

2. Mesh manipulation model in OpenFOAM

To simulate the simple harmonic motion of ship hull, a suitable mesh manipulation model is necessary for an efficient computation. Considering that each motion is just with one Degree of Freedom, and moving amplitude is rather small compared to the mesh size in the far field, we give out a dynamic mesh model named `smallOscillationFvMesh`. The `smallOscillationFvMesh` is originated from the mesh manipulation model of `movingConeTopoFvMesh`, and the process of the present method are showed in the figure below.

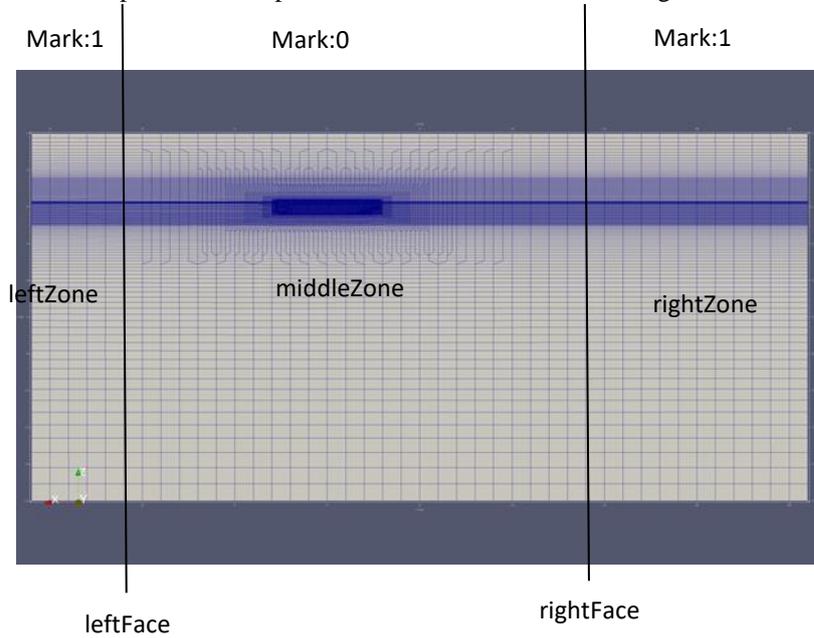


Figure 1: Mesh setting for surge motion

Figure 1 gives the mesh manipulation for ship surge simulation. As the mesh for ship motion simulation is trend to be coarse and regular in the far field, so it is easy to find two sets of faces that the transverse grid scale between which is far larger than the motion amplitude. Then, the zone that between the two face is marked 0 which means the point in this part shall moving according to the given expression, the other part we marked 1 to keep the point in which zone steady. The motion amplitude of ship surge is set 0.05m which is far smaller than the transverse scale of the grid adjacent to the leftface and rightface which is 1.0m, so the topology needn't to be changed, and all the manipulation that preparing for changing topology is discarded to minimize the time cost on mesh moving. For the motion of heave and sway, the method is still working by adjusting the direction and position of the two faces shown in the figure

It should point out that the original `movingConeTopoFvMesh` is not suitable for ship motion simulation, because there exists large grid aspect ratio grid near the free surface, and the topology changing manipulate may cause bad mesh quality.

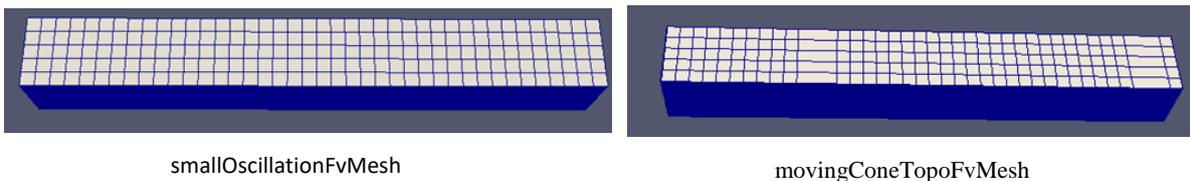


Figure 2: Mesh after a period

The Fig.2 gives the mesh scene after a period with the present method and the original movingConeTopoFvMesh to handle the mesh with large aspect ratio with same setting, and which proves the present smallOscillationFvMesh model can keep high quality of meshes, besides it is convenient to use and efficient when comparing with overset mesh or other dynamic mesh model.

3. Some results and conclusion

3.1 model and mesh

The forced oscillation of KVLCC2 ship hull is simulated in this work. The performance of KVLCC2 ship hull has been widely studied by many researchers^[4] as a standard ship hull, and there exist plenty of experiment data of this ship hull. The length of the hull is 5.5172m, the other main dimensions can be fined in reference 5. The main motion parameters are shown in Table 1.

Table 1: Motion parameters

Parameter	value
Advancing velocity	0.1047m/s
Motion amplitude (surge, heave, sway)	0.05m
Motion amplitude (roll, yaw, pitch)	0.01 radian
Motion frequency (dimensionless)	1.0; 2.0;2.75;3.75;5;10

The mesh used for simulation is generated by snappyHexMesh^[6] tool, and the grid quantity is about 770,000 for half domain. The near wall mesh is shown in Fig. 3. The turbulence model chooses KomegaSST^[7].

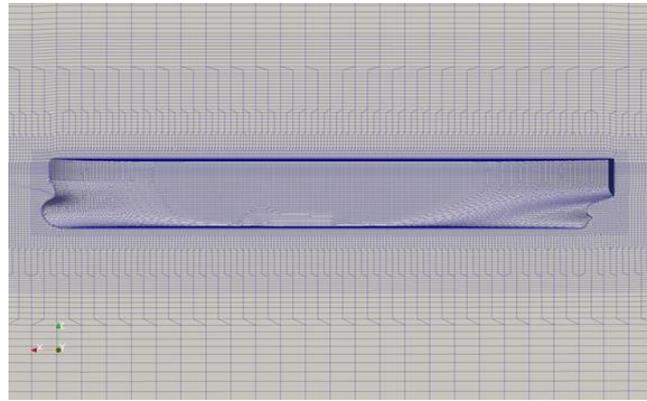


Figure 3: Mesh near ship hull

3.2 Data processing

For each advancing velocity, motion frequency and motion modality, a set of time-force and time-moment curves can be obtained by interDyMfoam solver in OpenFOAM.

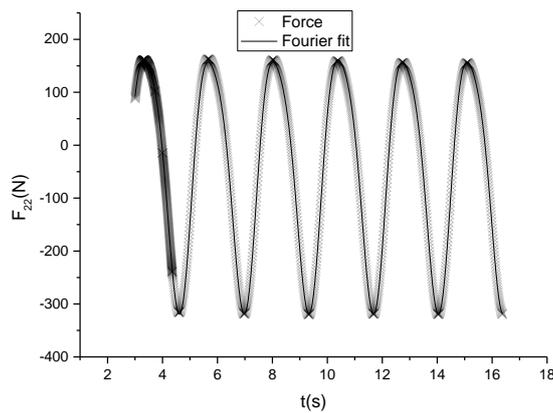


Figure 4: F₂₂-t curve and Fourier fit

The figure 4 gives the F₂₂-t curve at advancing velocity is 0.142 and omega is 2.6676, and which curve is fixed with a 6-expansion Fourier expression. The fit curve can be expressed as follow.

$$\begin{aligned}
 F_{2,2} = & -48.41 + 75.32\sin(\omega t) - 223.4F_{i,jb1}\cos(\omega t) + 7.723\sin(2\omega t) - 35.96F_{i,jb2}\cos(2\omega t) \\
 & -1.05\sin(\omega t/3) - 1.396F_{i,jb1}\cos(\omega t/3) + 0.2179\sin(2\omega t/3) + 1.501F_{i,jb2}\cos(2\omega t/3) \\
 & +0.3912\sin(4\omega t/3) + 0.8571F_{i,jb1}\cos(4\omega t/3) - 0.9586\sin(5\omega t/3) - 1.243F_{i,jb2}\cos(5\omega t/3) \quad (7)
 \end{aligned}$$

Comparing the Eq. 7 and Eq. 5, it is easy to obtain the needed $F_{i,j0}$, $F_{i,ja1}$, $F_{i,jb1}$ and $F_{i,jb2}$. Form the expression of Eq. 7, it is obvious that the parameter what we needed is much larger than the others, which means the present force

decomposition model contains almost all force component and the remaining high-order hydrodynamic coefficient can be ignored.

3.3 Part of hydrodynamic results

The obtained hydrodynamic coefficient results are shown in the figure below.

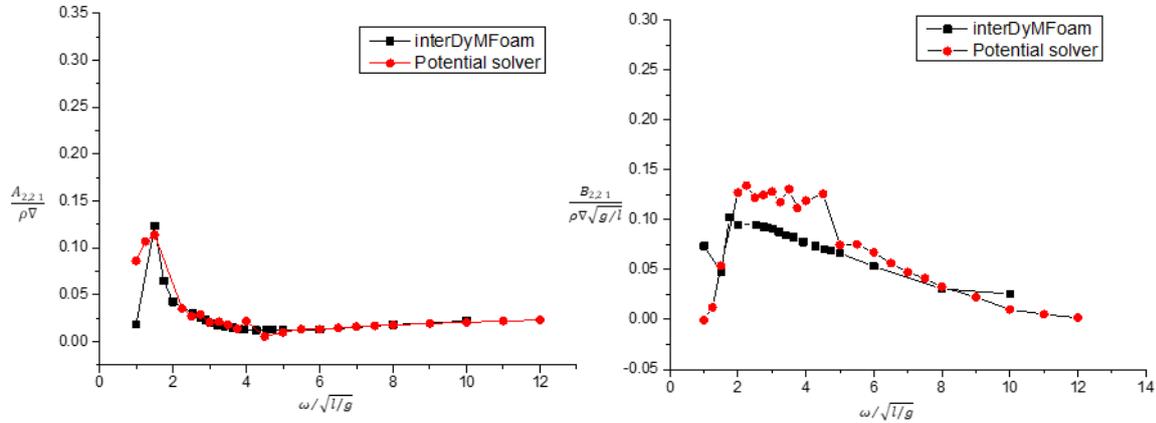


Figure 5: Added mass and damping result

Fig. 5 give out the added mass and damping result calculated with the present method and a translating–pulsating source potential solver^[1]. The added mass coefficient results coincide with the potential result very well, while there exists some gap between in the comparing of the damping coefficient, and this phenomenon is caused by the inviscid hypothesis in the potential method. The results show that the present method can make full use of the result to obtain each component hydrodynamic force, and suitable for hydrodynamic coefficient calculation with the considering of viscous and nonlinear effects.

Acknowledgements

The author acknowledges the discussions with Dr Zhou Wenjun and the translating–pulsating source potential solver offered by Hong Liang.

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