

**Research Article**

**Motion and Wave Loads Prediction of Hybrid Monohull Considering Viscous Effect**

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**Abstract:** Hybrid monohull is a kind of special monohull with a built-up appendage on the bottom of the bow. The appendage can produce a large damping force (moment) which conclude obviously viscous damping to greatly upgrade the ship's longitudinal motion performance. In this study, the RANS method is used on calculating the hydrodynamic coefficients of different ships with and without the built-up appendage. By comparing with the calculating results using potential theory the viscous effect of the appendage is obvious. The longitudinal motion and wave loads of the two ships are predicted. The calculating results of the two ships are compared with each other to analyze the importance of viscous effect for the hybrid monohull. The calculating results are also compared with the model test results to validate the precision of the predicting method.

**Keywords:** Hybrid monohull, hydrodynamics, motion and wave loads, viscous

**INTRODUCTION**

Hybrid monohull is a kind of high performance ship with good sea keeping performance and its resistance performance in calm water is almost the same as round bilge ship. The feature of hybrid monohull lies on the longitudinal stability built-up appendage which is fixed on the bottom of the bow. The appendage is built up with a semi-submerged bow and two fins and the sketch of the built-up appendage is shown in Fig. 1. The longitudinal motion will be stabilized by the viscous and lifting damping force (moment) producing by the appendage. It has been indicated by theory and experiment researches that hybrid monohull has very good sea keeping performance (Cai *et al.*, 2003; Liu *et al.*, 2002). The research results indicate that methods based on potential theory can not reflect the reducing effect of the appendage (Zhang and Li, 2007; Li and Zhang, 2008). The reason lies on the ignoring of viscous effect of potential theory, however, the viscous damping play a very important part in the reducing impact of the built-up appendage (Sun *et al.*, 2009; Gao and Shuzheng, 2011). So we have to modify the viscous terms during the motion and wave loads prediction.

In this study, RANS method is used for calculating the hydrodynamics of the bow with built-up appendage. The hydrodynamics will be put into the motion equations for solving. The results indicate that the motion and wave loads are both different from the normal ship and the method used in this study can reflect the viscous effect and improve the prediction precision.

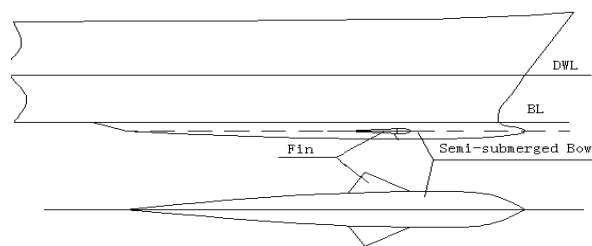


Fig. 1: Form of the hybrid monohull

Table 1: Principal dimensions of the ship

Ships	$L_{wl}$ (m)	B (m)	T (m)	$\nabla$ (t)
R0	125	15.2	4.5	3450
V0	125	13.8	4.2	3350

Table 2: Principal dimensions of semi-submerged bow

$L_{max}$ /m	$B_{max}$ /m	$H_{max}$ /m	$\nabla$ (t)
25	4	1.5	61

The ships calculated in this study is a round bilge ship (R0) and a deep-V hybrid monohull (V0) which has a longitudinal stability built-up appendage fixing on the bottom of the bow. The parameters of the ships and the built-up appendage are shown in Table 1 and 2. The hydrodynamics calculation will be introduced as follows.

**MODELING AND OPTIMIZATION**

**Model introduction:** In this study the hydrodynamics of the sections with built-up appendage are calculated using potential method and RANS method. It is to say that the bow is divided to 10 sections and the space is 0.5 or 0.25 stations according to the necessary. The

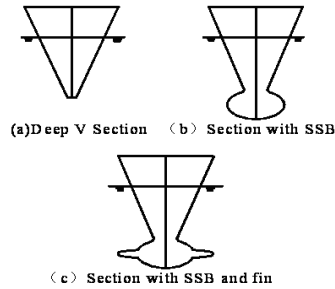


Fig. 2: Sections of ships

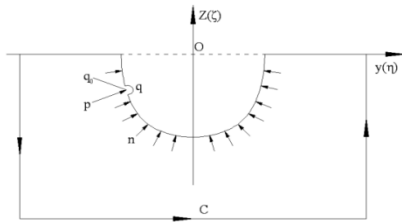


Fig. 3: Sketch of coordinate for 2D section's surge

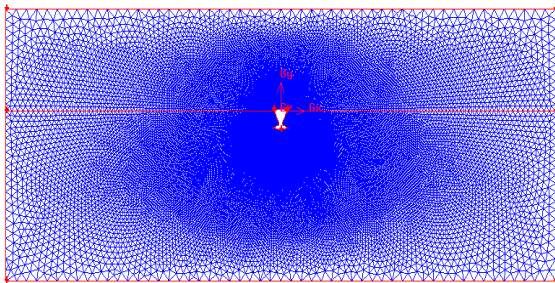


Fig. 4: The sketch of calculation field and grids

sections with the built-up longitudinal-stabilizing appendages are shown in Fig. 2.

The potential method used in this study is source/dipole mixed-distribution approach. Figure 3 shows the coordinate for the 2D section's surge.

The 2D frequency domain Green function is introduced to solve the problem of 2D section surging:

$$\left. \begin{aligned} \frac{\partial^2 G}{\partial y^2} + \frac{\partial^2 G}{\partial z^2} &= \delta(p, q) \\ p(y, z) &\text{ is field point,} \\ q(\eta, \zeta) &\text{ is source point} \\ \frac{\partial G}{\partial z} - kG &= 0 \quad (z = 0) \\ \lim_{z \rightarrow -\infty} \nabla G &= 0 \\ \lim_{y \rightarrow \pm\infty} \frac{\partial G}{\partial y} - ikG &= 0 \end{aligned} \right\} \quad (1)$$

The 2-D frequency domain Green function could be written as:

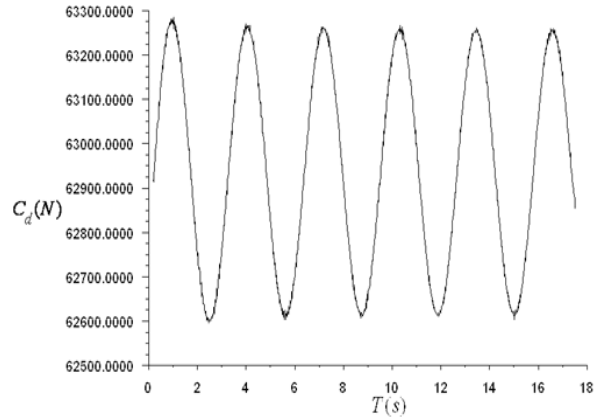


Fig. 5: The unsteady surging force of a section

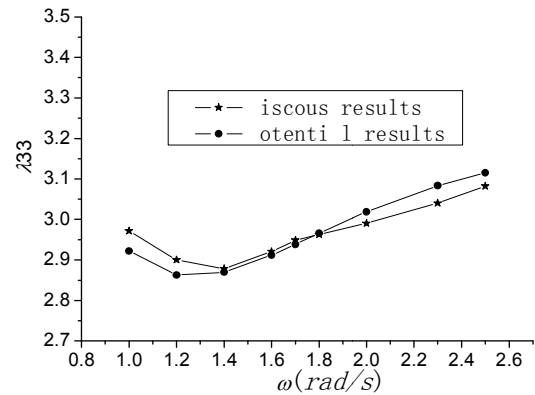


Fig. 6:  $\lambda_{33}$  of section with SSB

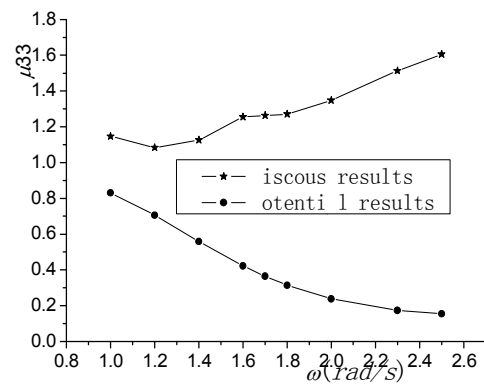


Fig. 7:  $\mu_{33}$  of section with SSB

$$\begin{aligned} G(p, q) &= G(y, z; \eta, \zeta) \\ &= \ln \frac{r_{pq}}{r_{p\bar{q}}} + 2p.v. \int_0^\infty \frac{1}{k-m} e^{m(z+\zeta)} \cos m(y-\eta) dm \\ &\quad - 2\pi i e^{k(z+\zeta)} \cos k(y-\eta) \\ &\stackrel{\Delta}{=} G_1 + G_2 + G_3 + G_4 i \\ r_{pq} &= [(y-\eta)^2 + (z-\zeta)^2]^{1/2} \\ r_{p\bar{q}} &= [(y-\eta)^2 + (z+\zeta)^2]^{1/2} \end{aligned} \quad (2)$$

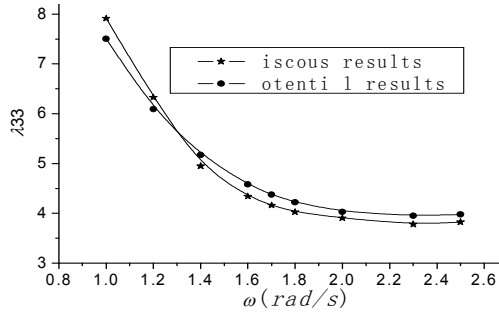


Fig. 8:  $\lambda_{33}$  of deep-V section

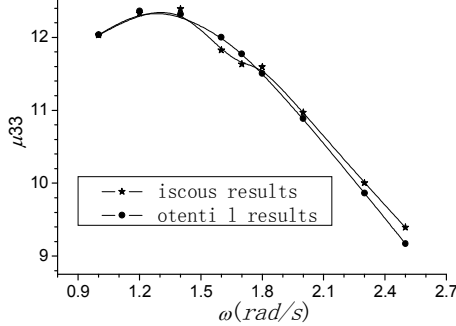


Fig. 9:  $\mu_{33}$  of deep-V section

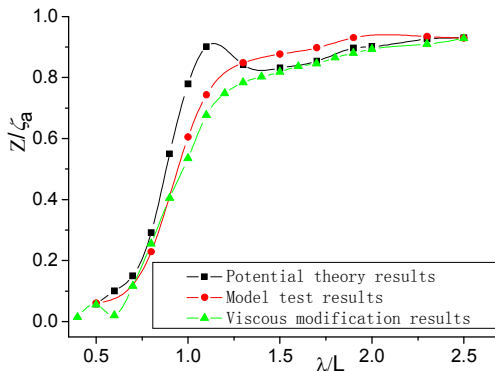


Fig. 10: Amplitude of heave response (V0)

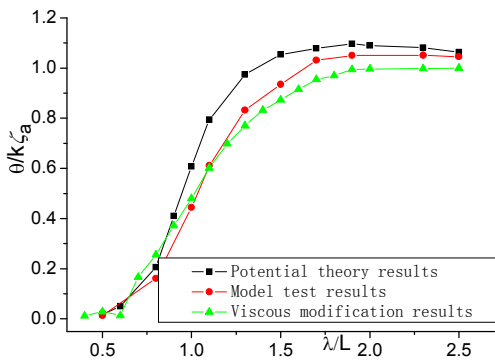


Fig. 11: Amplitude of pitch response (V0)

The velocity potential of any point  $p$  in the flow field could be expressed as below:

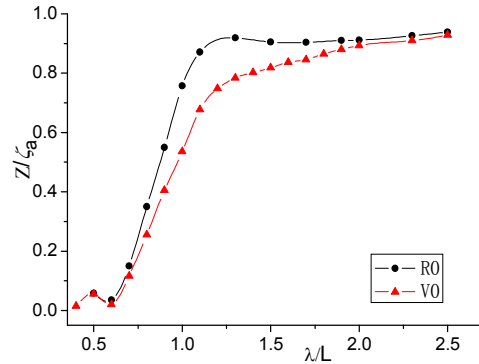


Fig. 12: Amplitude of heave response (R0) where,

$$\phi(p) = \frac{1}{2\pi} \int_c [\phi(q) \frac{\partial G(p, q)}{\partial N_q} - G \frac{\partial \phi(q)}{\partial N_q}] dl \quad (3)$$

The line  $c$  presents the boundary of flow field with the normal direction pointing outside the flow field and the direction is shown as Fig. 1.

The additional mass of section  $m_{kj}$  and damping coefficient  $\mu_{kj}$  can be got from the equation below:

$$\rho \int_{c_0} \phi_j(y, z) \frac{\partial \phi_k}{\partial N} dl = m_{kj} + \frac{i}{\omega_e} \mu_{kj} \quad (4)$$

**Establishing and optimizing model:** The RANS method is used for calculating the unsteady surging force of the sections and the amplitude of surging is 0.02 m. The calculating field and the grids are shown in Fig. 4. The LVM method is used for the segregation, the field is  $10B \times 10T$  and the smallest grids lie on the ship body is 0.1 m. The triangle unstructural grids are carried and the field is divided into two parts which are air and water, so the VOF method is used for dealing with the free surface. The PISO equation, RNG- $\kappa - \epsilon$  model and dynamic mesh are also used. Like Fig. 5 shows the calculation results of the unsteady surging force of section 3 at 2 rad/s.

Where  $B$  is the breadth of water line,  $A$  is the surging amplitude,  $F_a$  is the surging force amplitude and  $\theta_0$  is the original phase.  $\rho$ ,  $g$ ,  $B$ ,  $A$  and  $\omega$  are all knowable, so the add mass  $\lambda_{33}$  and the damping coefficient  $\mu_{33}$  can be get by separating  $F_a$  and  $\theta_0$  from the unsteady surging force  $F$ . Figure 6 to 9 show the results of  $\lambda_{33}$  and  $\mu_{33}$  of sections 1 and 2.

The calculation results show that, for section 1 (no fin) the add mass calculated by potential theory is not very different from viscous method, but the damping coefficients are as more different as the increasing of surging frequency. So the viscous effect of SSB is reflected. However, for section 2 the add mass and damping coefficients calculated by potential theory are both very different from the results of viscous method, so the viscous effect of SSB and fins are reflected. The reason lies on the viscous damping is proportional to

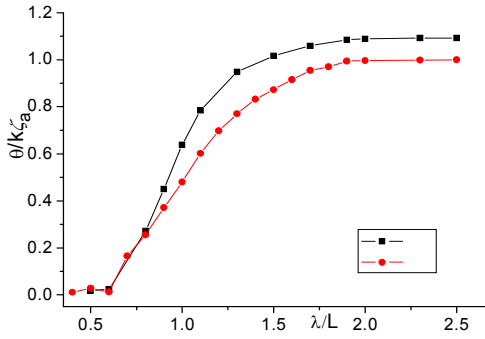


Fig. 13: Amplitude of pitch response (R0)

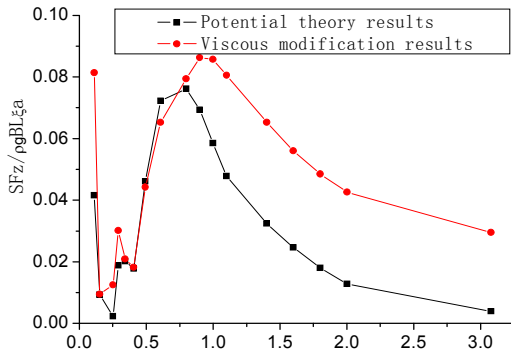


Fig. 14: Vertical shearing force of section 10

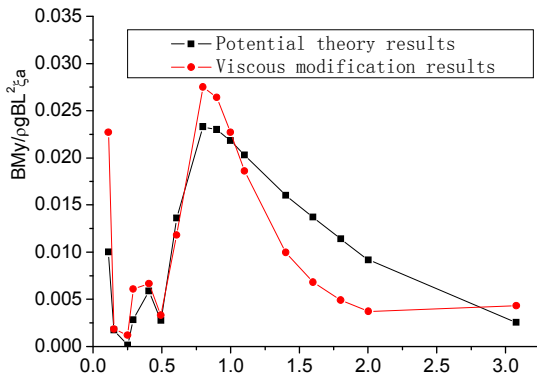


Fig. 15: Vertical moment of section 10

the square even more powers, so the viscous effect have to be considered in motion prediction of hybrid monohull.

**APPLICATION EXAMPLE**

Put the viscous and lifting modification coefficients into the motion equations we can get:

$$\begin{bmatrix} [C + C^f] + [D] - \omega^2 [A + A^*] \\ +i\omega [B + B^* + B^f] \end{bmatrix} \{\eta\} = \{F - F^f\} \quad (5)$$

where,

\* = Viscous modification terms  
f = Lifting modification terms

According to the d’Alembert principal the loads equations can be deduced. Using the above method the head sea longitudinal motions and wave loads of a deep-V monohull and a hybrid monohull as Fr = 0.43 are predicted and the prediction model is STF method.

The motion prediction results of the hybrid monohull when Fr = 0.37 are shown in Fig. 10 to 11 which show the comparison of potential theory method, viscous modification method and model test in tank. The motion prediction results of the original ship and the hybrid monohull are shown in Fig. 12 to 13. The wave loads prediction results are shown in Fig. 14 to 15 which show the comparison of potential theory method and viscous modification method.

**CONCLUSION**

From the research of the above we can get some conclusions:

- Viscous effect is important for the motion and wave loads prediction of hybrid monohull.
- The built-up appendage can reduce the longitudinal motion effectively.

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