The 32nd International Workshop on Water Waves and Floating Bodies, Dalian, China, 23-26 April, 2017.

Time domain hybrid TEBEM for 3D hydrodynamics of ship with large flare at forward speed

J.K. Chen, W.Y. Duan*, B.B. Zhao and Q.W. Ma

[1] College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China
*Email: duanwenyang@hrbeu.edu.cn

HIGHLIGHTS:

- This paper presents the solution of forward speed hydrodynamic problems of ship by a hybrid Taylor Expansion Boundary Element Method (TEBEM). The flow domain is divided into two parts where the inner domain is solved by first-order TEBEM with simple Green function and the outer domain is solved by zero order TEBEM with transient free surface Green function. The two solutions are matched through continues of potential and normal velocity on wall-sided artificial surface.
- The solution by hybrid TEBEM is stable for ship with large flare where the solution by general panel method with transient free surface Green function is divergent. The results show that TEBEM can provide high accuracy solutions for corresponding boundary integral equation with high rate of convergence.

1 INTRODUCTION

Accurate prediction of wave-induced motions and hydrodynamic loads is very important in ship design. Traditionally, the problem is linearized and formulated in frequency-domain. An alternative to the frequency-domain approach is to formulate the problem in time-domain. During recent years, the analysis of wave loads and marine structure motions by time-domain free surface Green's function methods has attracted many investigations (see, for example, Adachi & Ohmatsu 1979, Yeung 1982, Newman 1985, Beck & Liapis 1987, King et al 1988, Korsmeyer et al 1988, Beck & Magee 1990, Lin & Yue 1990, Ferrant 1990, Zhang & Dai 1993, Bingham et al 1994, Duan 1997, Korsmeyer & Bingham 1998). As discussed by Beck 1994, the time-domain Green's function method appears to have advantages over the frequency-domain Green's function method, especially for forward speed problems.

It is notable that numerical results for a surface-piercing body reported in the above mentioned studies are focused on simple hull forms, such as Wigley Hull, of which the characteristic is either wall-sided or small flare at the waterline. For many practical ships (like container ships), the angle between hull surface and the free surface (it will be named flared angle hereafter) is nearly 10 degrees. In calculating the linear or body-nonlinear hydrodynamic problem of these flared ships, the difficulty that time-stepping calculations give divergent results will be encountered. The smaller the flared angle, the worse the calculated results are. To get stable results, a matched integral equation with inner domain distributed by simple Green function and outer domain distributed by transient free surface Green function was proposed by Duan & Dai 1997, Lin and Zhang 1999. This strategy is very useful for zero forward speed problems, but not so robust for forward speed cases. The urge to realize the origin advantage of free surface Green function method motivate the present research. A hybrid TEBEM with Integral Form Free surface condition is proposed for flared floating body, stable numerical results for ships with large flare is presented.

2 TIME DOMAIN HYBRID TEBEM

Consider a ship moving at constant mean forward speed with arbitrary heading in regular sinusoidal waves. It is assumed that resulting oscillatory motions are linear and harmonic. Let (x,y,z) be a right-handed orthogonal coordinate system fixed with respect to mean position of the ship, with z vertically upward through the center of gravity of ship, x in the direction of forward motion and origin in the plane of the undisturbed free surface.

Let's introduce a wall-sided arbitrary control surface S_C which divides the fluid field outside the ship into an inner domain (D_{in}) and an outer domain (D_{out}) as shown in Figure 1. The inner domain is enclosed by the wetted body surface S_H, the free surface S_F, and the control surface S_C. The free surface S_F intersects the body surface and is truncated by the control surface S_C at the water line C_{WL}. The outer domain is the rest of the fluid filed enclosed by S_C, an imaginary far field surface S_{FAR} and the remaining free surface intersected by S_C and S_{FAR}.

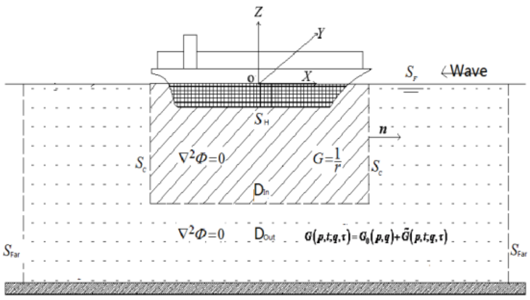


Fig. 1 The reference frame and surfaces of inner and outer fluid domain

Total velocity potential can be separated in two parts, one is the time-independent steady contribution due to the forward motion of the ship and the other the time-dependent part associated with the incident wave system and the unsteady body motion. The unsteady potential $\Phi(p,t)$ which satisfied the Neumann-Kelvin linearized free surface condition in the outer domain is solved through the boundary integral equation (1) on the control surface S_C involving the transient free surface Green function. To derive equation (1), attention should be paid on the normal direction of the boundary surface which point into the outer domain D_{out}.

$$\begin{aligned}-2\pi\Phi(p,t)+\iint_{S_C}\left[\Phi(q,t)\frac{\partial}{\partial n_q}\left(\frac{1}{r}-\frac{1}{r'}\right)-\left(\frac{1}{r}-\frac{1}{r'}\right)\frac{\partial\Phi}{\partial n_q}\right]\mathrm{d}s_q=\int_0^t\mathrm{d}\tau\iint_{S_C}\left(\tilde{G}\frac{\partial\Phi}{\partial n_q}-\Phi\frac{\partial\tilde{G}}{\partial n_q}\right)\mathrm{d}s_q-\\ \frac{1}{g}\int_0^t\mathrm{d}\tau\int_{C\omega l}\left[u^2\left(\tilde{G}\frac{\partial\Phi}{\partial\xi}-\Phi\frac{\partial\tilde{G}}{\partial\xi}\right)-u\left(\tilde{G}\frac{\partial\Phi}{\partial\tau}-\Phi\frac{\partial\tilde{G}}{\partial\tau}\right)\right]d\eta\qquad(p\in S_C)\end{aligned}\tag{1}$$

The unsteady potential $\Phi(p,t)$ in the inner domain is solved through the boundary integral equation (2) involving the simple Green function on the inner domain surface which include body surface S_H , control surface S_C, the free surface between the body surface and control surface S_F

$$2\pi\Phi(p,t)+\iint_S\left[\Phi(q,t)\frac{\partial}{\partial n_q}\left(\frac{1}{r}\right)-\left(\frac{1}{r}\right)\frac{\partial\Phi}{\partial n_q}\right]\mathrm{d}s_q=0(p\in S,\ S=S_H+S_F+S_C)\tag{2}$$

The Double-Body free surface condition in the inner domain is expressed by the integral form ,equation(3),which is more stable in the time stepping solution than the differential form as shown in Zhang and Duan (2011).

$$\Phi(p,t)=2(U-\nabla\varphi)\int_0^t\frac{\partial\Phi}{\partial x}d\tau-(U-\nabla\varphi)^2\int_0^t(t-\tau)\frac{\partial^2\Phi}{\partial x^2}d\tau-g\int_0^t(t-\tau)\frac{\partial\Phi}{\partial z}d\tau+\int_0^t F(\Phi,\varphi)(t-\tau)d\tau\tag{3}$$

Where: φ is the steady potential based on double-body assumption, $F(\Phi,\varphi)$ is the inhomogeneous term of free surface condition.

It is noticed from equation (3) that the velocity potential on the free surface satisfied the mixed condition which involves the function value and its in-plane derivatives at each time instant. Different with the other high-order boundary element method, we use the TEBEM, which has the advantage to solve the velocity potential and tangential velocity simultaneously as shown by Duan et al (2015).

Zero-order TEBEM with plane panels are used to discretize the boundary integral equation (1) and trapezoid rule for time integral of equation (1) and (3). First-order TEBEM is used to discretize the boundary integral equation (2). Same as other hybrid method, the velocity potential and normal velocity are enforced to satisfy the continue condition on the control surface.

3 NUMERICAL RESULTS AND DISCUSSION

The container ship KCS is used to validate the present method, which stern is flared. Figure 2 shows sketch of dispersion panels on the ship KCS. Figure 3 shows the wave elevation calculated by hybrid TEBEM. We can find that there is no the reflected wave into the inner domain, so the disturb wave can transmit outward by the transient free surface Green function on the match surface. Convergence confirmation of heave and pitch motion due to time-step, body surface mesh, free surface mesh and match surface mesh are shown in Fig.4 as $\lambda / L = 0.85, \beta = 360^{\circ}, Fn = 0.261$. It can be found that time history is stable in 15 periods. Hence the hybrid TEBEM method could simulate the ship motion for large flared ship effectively, compared to transient free surface Green function method. It also can be found the convergence of heave and pitch motion results are satisfactory. The RAOs of heave and pitch motion are shown in fig. 5. We also give out the experiment solution of heave and pitch motion from the 2015 CFD report in Tokyo. A good agreement can be obtained for pitch motion, while the amplitude of heave motion is bigger than experiment solution slightly. EEDI （Energy Efficiency Design Index ）is currently the hot topics of the shipbuilding industry and the coefficient f_w for speed loss has a serious effect on the verification of EEDI. While added resistance for a ship in waves is one of the main factors of coefficient f_w, hence, it is significant to investigate the calculation of added resistance. The added resistance of KCS calculated by hybrid TEBEM is shown in the fig. 6. We can found time history of added resistance is stable, and the convergence results could be obtained, when mesh number on body surface is 809. Compared to experiment solutions, the relative error of added resistance of hybrid TEBEM is about 13%.The detailed numerical results and discussions will be shown at the workshop.

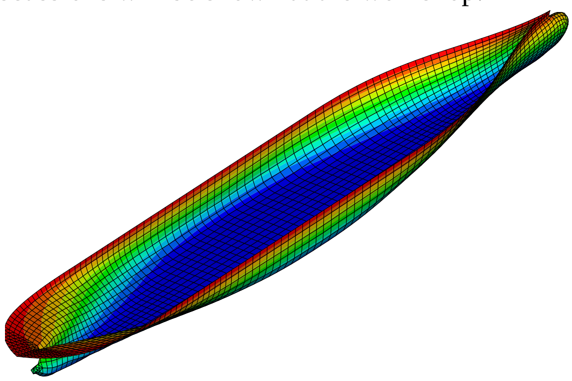


Fig. 2 Mesh of KCS ship for the hybrid TEBEM

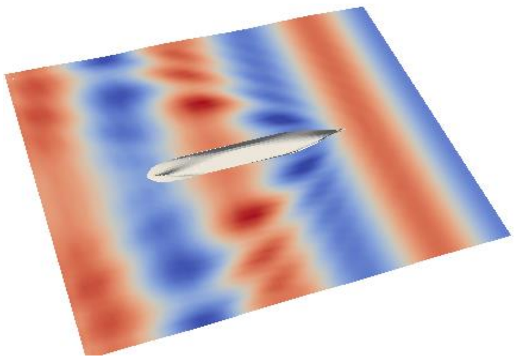
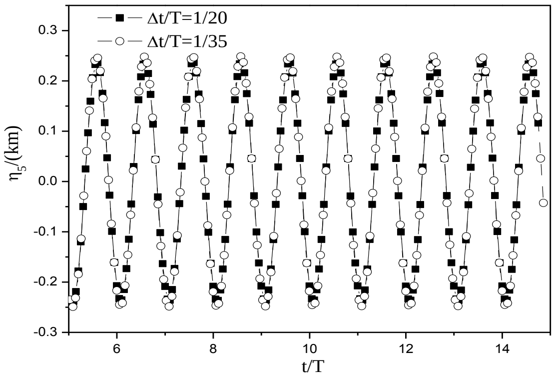
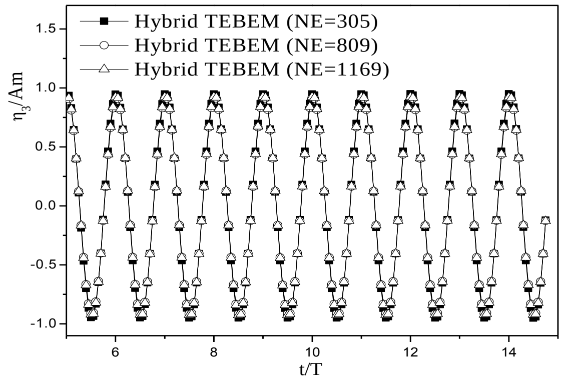


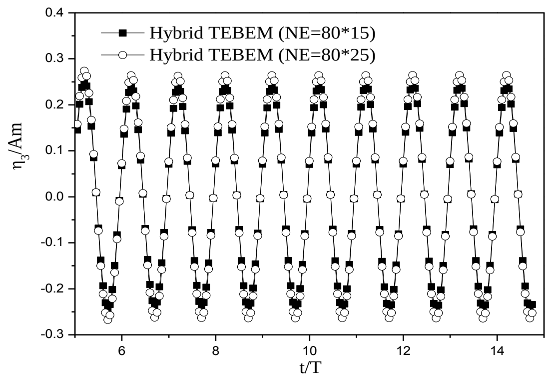
Fig. 3 Wave elevation of KCS by hybrid TEBEM



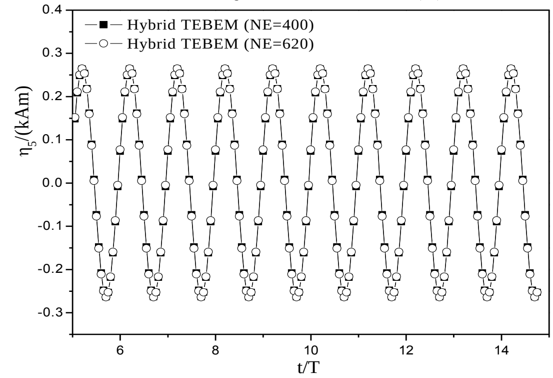
Time-step (a)



Body-surface mesh (b)

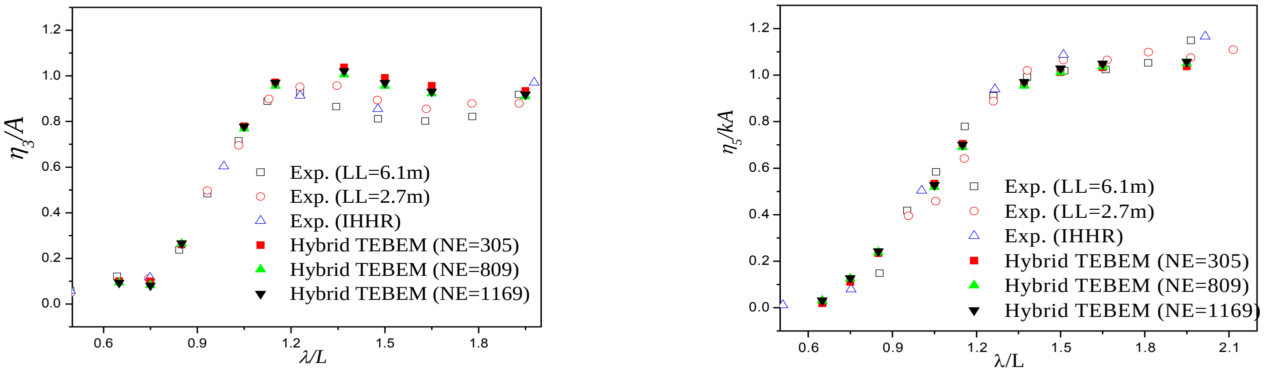


Free surface mesh (c)



Match surface mesh (d)

Fig. 4 Convergence confirmation of heave and pitch motion of KCS ship due to time-step (a), body surface mesh (b), free surface mesh (c) and match surface mesh (d) $\lambda / L = 0.85, \beta = 360^{\circ}, Fn = 0.261$.



Heave motion (a) **Pitch motion (b)**

Fig. 5 Heave and pitch RAOs of KCS ship for different dispersion element model on the body surface as $\lambda / L = 0.85, \beta = 360^{\circ}, Fn = 0.261$**.**

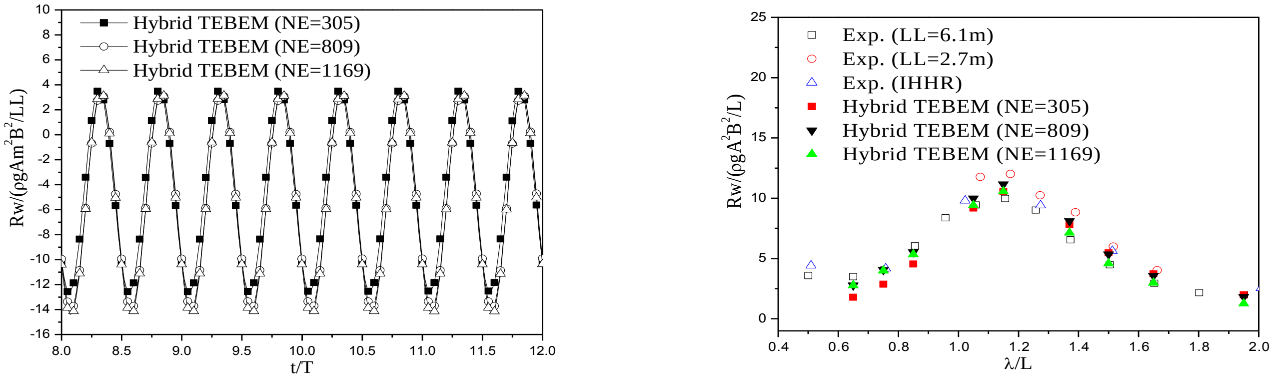


Fig. 6 Time history ($\lambda / L = 0.85$ **) and RAOs of Added Resistance of KCS ship as** $\beta = 360^{\circ}, Fn = 0.261$**.**

4 CONCLUSIONS

This abstract introduces a new method, named hybrid TEBEM method, to solve the hydrodynamic problem of forward speed ships with large flare, which overcomes the shortcoming of the transient free surface Green function method, which results are divergent of the ships with large flare. A good agreement of ship motion and added resistance can be obtained, compared to experiment solutions.

ACKNOWLEDGMENTS

This work is sponsored by The National Natural Science Foundation of China (11272097).

REFERENCES

Beck R.F., Liapis S., 1987. Transient motions of floating bodies at zero forward speed. Journal of Ship Research. 31: 164-176P.

Beck R.F., Magee A.R., 1990. Time domain analysis for predicting ship motions. Proceedings of International Symposium on Dynamics of Marine Vehicles and Structures in Wave. 91-106P.

Duan W.Y., Dai Y.S., 1999. Time-domain calculation of hydrodynamic forces on ships with large flare. International Shipbuilding Progress. 46: 223-232P.

Duan W.Y., Chen J.K., Zhao B.B., 2015. Second-order Taylor expansion boundary element method for the second-order wave radiation problem. Applied Ocean Research. 52: 12–26.

King B.K., Beck R.F., Magee A.R., 1988. Seakeeping calculation with forward speed using time domain analysis. Proceeding of 17th Symposium on Naval Hydrodynamic.

Zhang S.G., Lin W.M., Weens K., 1998. A hybrid boundary-element method for non-wall-sided bodies with or without forward speed. Proceedings of 13th International Workshop on Water Waves and Floating Bodies. Alphen an den Rijn, Netherlands. 179-182P.

Zhang C.W. Duan W.Y., 2012. Numerical study on a hybrid water wave radiation condition by a 3D boundary element method. Wave Motion . 49 :525–543P.