Application of Chimera grid concept to simulation of the free-surface boundary condition

Shukui LIU[1, a], **Apostolos PAPANIKOLAOU**[1, b]

[1]Address of authors: Ship Design Laboratory, National Technical University of Athens, Athens, Greece

[a]liushukui@deslab.ntua.gr, [b]papa@deslab.ntua.gr

1. INTRODUCTION

Due to the highly oscillatory behavior of the time domain transient Green function, it proves intricate to apply directly the Time Domain Green Function method (TDGF) to seakeeping problems of floating bodies. Though some improved numerical scheme for the fundamental problem has been developed in recent time [2], no significant development of this approach could be noted. On the other hand, hybrid-type methods were more widely studied and successfully applied to many free surface problems [3,7,9,11]. Commonly used hybrid methods are a combination of a time-domain transient Green function method [10] for the outer domain and a Rankine source method for the inner domain of the fluid. Herein, the quite robust Rankine source method is applied in the inner domain to find the dominant velocity potential equation, while the transient Green function method is used in the outer domain to obtain matching relationships for the velocity potential and its normal derivative between the inner and outer domain solution. In this approach, the free surface needs to be numerically simulated, whereas the captured free surface area needs to be very large for specific problems and the panel size needs to be adjusted to the specific demands of numerical stability. Thus, there is an inherent need for efficient numerical schemes for the treatment of the free surface condition. In this paper, we introduce the Chimera grid concept to efficiently simulate the free surface and to demonstrate its application by use of a hybrid method to the wave resistance problem of a ship-like hull form.

2. Free-surface condition

The linearized free-surface condition can be expressed in earth coordinate system as:

$$\frac{\partial^2 \Phi}{\partial t^2} + g\frac{\partial \Phi}{\partial z} = 0 \qquad (1)$$

This expression can be rewritten as:

$$\frac{\partial^2 \Phi}{\partial t^2} = -g\frac{\partial \Phi}{\partial z}$$

Integrating the above equation with respect to time *t* twice and taking into account the initial conditions, we will get the following expression:

$$\Phi = -g\int_0^t (t-\tau)\frac{\partial \Phi(p,\tau)}{\partial n}d\tau \qquad (2)$$

This formulation, first developed by Wang [5], is very simple and also proved to be a robust free-surface simulator [8]. It should be noted that during the development of the above expression, the integration is done with respect to time from moment *0* to moment *t* and the initial condition is set as $\Phi\big|_{t=0} = \frac{\partial \Phi}{\partial t}\Big|_{t=0} = 0$. This is valid only for the area that is free from disturbance/occupation by the moving hull. For the area that is in the wake of the hull or the area which is occupied by the hull at the very beginning but gradually becomes free, the free surface condition is expressed as following:

$$\Phi(p,t) = \Phi(p,t_0) + \frac{\partial \Phi(p,\tau)}{\partial \tau}\bigg|_{\tau=t_0}(t-t_0) - g\int_{t_0}^t (t-\tau)\frac{\partial \Phi(p,\tau)}{\partial n}d\tau \qquad (3)$$

Herein, $\Phi\left(p,t_0\right)$ and $\left.\frac{\partial\Phi\left(p,\tau\right)}{\partial\tau}\right|_{\tau=t_0}$ can be approximated by the corresponding values on the adjacent hull panel or by the value on its adjacent panel in the downstream, as will be elaborated in section 3.

3. Special consideration on the changing free-surface: Chimera grids concept

As the ship is travelling in water, the intersection between the hull and the free surface will be moving accordingly. This will result to a time-varying free-surface geometry. In order to solve the corresponding equations by the hybrid method[9], we need to update the influential matrices at every time step; thus, to partly update the elements related to the panels which are disturbed by the moving hull and partly to update those elements related to the panels on the moving hull itself. For those panels on the free-surface, special attention is needed as the change is complicated.
The free-surface area is panelized by splitting it into *four* zones, as shown in FIGURE 1. Zone I to Zone III will not be disturbed by the moving hull so that the panelization will remain the same. For Zone IV, the Chimera grids concept is introduced for accurate and efficient simulation.
The Chimera grids method is being widely used in aerodynamic engineering problems [6]. Generally, it involves a panelization system, which discretizes the domain boundary by separately generated but overlapping grids that exchange information between each other through certain interpolation scheme. This method has been previously used successfully in solving problems with dynamically moving bodies. In this paper, a very simplified chimera grid system is constructed to simulate the near-ship free-surface condition.

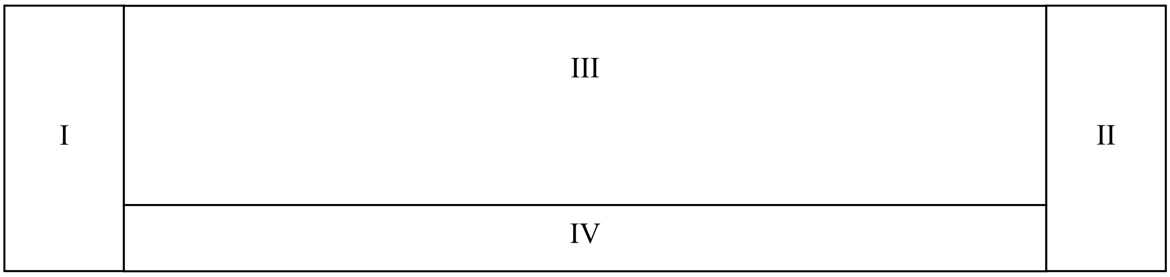

Figure 1. Overview of the different zones of free-surface panelization

The chimera grids system involves three major steps: 1) overlapping grids generation. 2) an algorithm for cutting holes, and 3) to interpolate data in overlapping grid area. A brief introduction and example can be found in J. Guerrero's paper [4]. Following this concept, two sets of panelization are created for the free-surface area Zone IV in the present program: the *Parent Panel System* and the *Sub Panel System*. The *parent panels* are in the same level of the panels in other zones so that they will participate in the influential matrices (not directly, as treatment is needed at every time instant). The *sub panels* have two functions. First, they are used to give a good representation of the area occupied by the hull. Second they are used as a *bridge* to find out proper information for their *parent* panels. At the beginning of the procedure, a control loop is conducted to check for all the sub panels whether they are inside or outside of the ship's waterline intersection, thus to *cut the hole*. Since the sub panels are in defined locations and the advancing speed is constant, it is possible to adjust the time interval so that the ship will pass one sub panel in x-direction during each time interval. Thus the occupied panels, or "*the hole*" geometry, can be captured/predicted. As the active sub panels are determined, the status of the parent panels can be classified as: 0, means occupied /passive; or 1, means free/active. Those marked as 0, they will not participate in the influential matrices; those marked as 1, they will take their original geometry information to participate in the computation. After this matrices update, the influential matrices can be computed.
Regarding the free-surface condition of the parent panels: if a panel is marked as 0, it is passive so that we simply skip this panel; if it is marked as 1 and located behind of the hull, then we compute the free surface condition of *every sub panel* by using their historical information and store the average value; if it is marked as 1 and located ahead of the hull, then we compute the free surface condition directly.
For the free-surface condition of subsidiary panels, if one is marked as 0, it is passive so that we simply skip this panel; if it is marked as 1 and located behind of the hull, then we compute the free surface condition by using their initial conditions when they became active and historical information since then; if it is marked as

1 and located ahead of the hull, then we compute the free surface condition by using their own historical information in recent steps and their parent panel's historical information in previous steps.

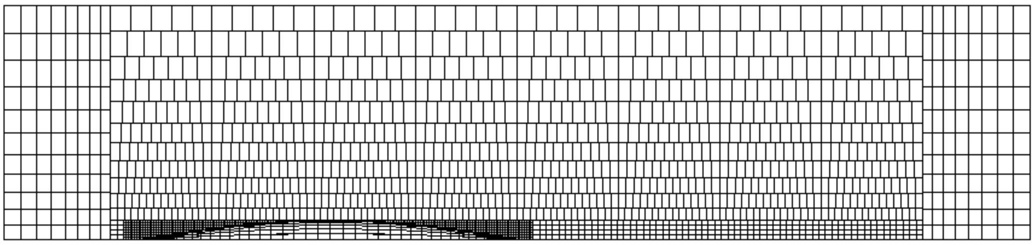

Figure 2. Example of runtime panelization

4. RESULTS AND DISCUSSION

As a demonstration of the above procedure, our hybrid method [9] is applied to the steady free-surface problem, namely the ship advancing at constant forward speed in calm water; herein, the calculated wave making resistance of a standard Wigley hull is presented and discussed. The studied Wigley hull is defined by $y/B=\left[1-\left(2x/L\right)^2\right]\left[1-\left(z/H\right)^2\right]$, where $2B/L=0.1$ and $H/L=0.0625$. The Froude number is denoted by $Fn=U/\sqrt{gL}$. In the shown example, the panelization used in the computation includes in total about 3000 panels (Figure 2).

Figure 3 shows the potential Φ and boundary condition $\partial\Phi/\partial n$ on the downstream wetted panels at the end of a simulation. The results appear to be stable and reasonable, despite some gap between results on the Parent Panel and Sub Panel, which can be readily improved by introducing some more advanced scheme *to interpolate data in the overlapping grid area*.

Figure 4 shows the results for the wave making resistance of the studied Wigley hull, without sinkage/trim correction. The comparison has been made with available experimental data [1] and corresponding SHIPFLOW results [12]. A good agreement is observed, both with respect to the magnitude and the hump/hollow trend.

ACKNOWLEDGEMENTS

The presented work is part of the PhD work of the first author; the financial support of NTUA-SDL and the continuous guidance by the second author are highly appreciated. Prof. W. Duan (Harbin Engineering University) and Dr. D. Spanos (NTUA-SDL) have contributed to this work through many discussions, which proved very important for the development of the present method, thus their support is also appreciated.

REFERENCES

[1] C.Y. Chen and F. Noblesse, "Comparison between theoretical predictions of wave resistance and experimental data for the Wigley hull," Journal of Ship Research, Vol.27, 1983.

[2] W.Y. Duan and Y.S. Dai, "Integration of the Time-Domain Green Function", 22th International Workshop on Water Waves and Floating Bodies, 2007.

[3] H. Yasukawa, "Application of a 3-D Time Domain Panel Method to Ship Seakeeping Problems," 24th Symposium on Naval Hydrodynamics, 2003.

[4] J. Guerrero, "Overset composite grids for the simulation of complex moving geometries," DICAT, University of Genoa, Italy, 2006

[5] J. F. Wang, "Numerical Simulation of the Linear Free-Surface Condition," Master Thesis, Harbin Engineering University, 2003.

[6] N. P. Weatherill, B. K. Soni and J. F. Thompson, "Handbook of Grid Generation," CRC Press, 1999.

[7] S. Kataoka and H. Iwashita, "Seakeeping estimations of ships by a time-domain hybrid method," Inter. RIAM Symposium, 2005.

[8] S. Liu and A. Papanikolaou, “A time-domain hybrid method for calculating hydrodynamic forces on ships in waves,” 13th Inter. Congress of the Inter. Maritime Association of the Mediterranean, 2009.
[9] S. Liu and A. Papanikolaou, Time-domain hybrid method for simulating large amplitude motions of ships advancing in waves. ITTC Workshop on Seakeeping, 2010
[10] S. Liu and A. Papanikolaou, W. Duan, “A Time Domain Numerical Simulation Method for Nonlinear Ship Motions, Journal of Harbin Engineering University,” Vol.27, 2006.
[11] S. Zhang, W.M. Lin and K. Weems, “A hybrid boundary-element method for non-wall-sided bodies with or without forward speed,” 13th International Workshop on Water Waves and Floating Bodies, 1998.
[12] SHIPFLOW, “SHIPFLOW 3.0 examples manual,” http://www.flowtech.se/, 2005.

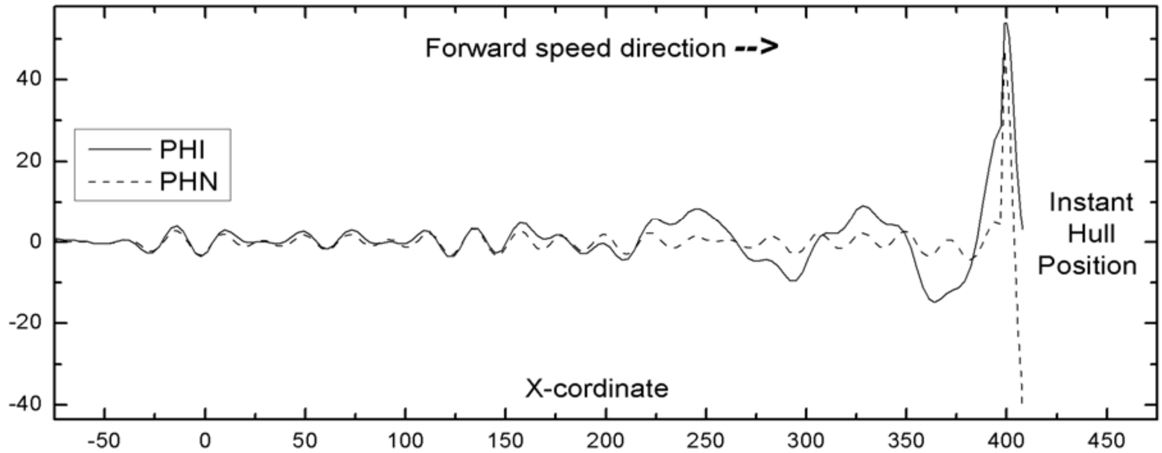

Figure 3. Downstream potential results along longitudinal direction, Fn=0.275

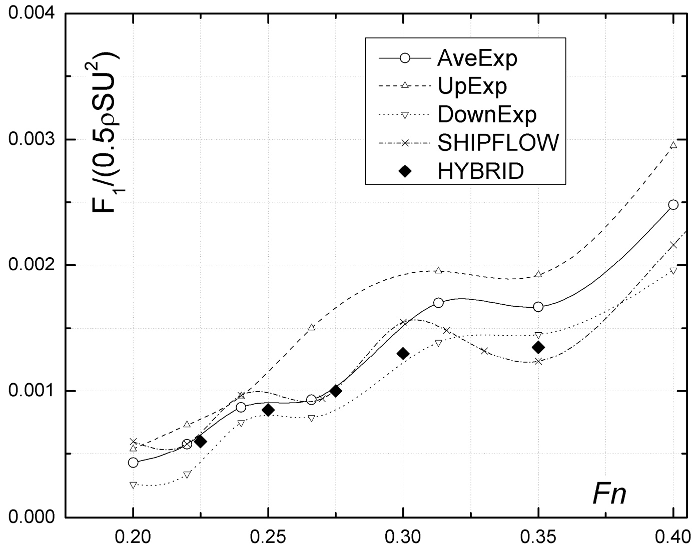

Figure 4. Wave making resistance of a Wigley hull, without sinkage/trim correction