行政院國家科學委員會補助專題研究計畫成果報告

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※ 次奇點理論推導及其全非線性三維浮體運動計算模型之建立 ※

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Fully Nonlinear Wave Computations for Arbitrary Floating Bodies Using The DELTA Method

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ABSTRACT

Fully nonlinear water wave problems are solved using Eulerian-Lagrangian time stepping methods in conjunction with a desingularized approach to solve the mixed boundary value problem that arises at each time step. In the desingularized approach, the singularities generating the flow field are outside the fluid domain. This allows the singularity distribution to be replaced by isolated Rankine sources with the corresponding reduction in computational complexity and computer time.

Examples of the use of the method in three-dimensions are given for the exciting forces acting on a modified Wigley hull and Series 60 hull are presented.

KEYWORDS

fully nonlinear 、 Eulerian-Lagrangian 、 time stepping、isolated Rankine sources

INTRODUCTION

When body motion becomes large, nonlinear waves are generated and higher-order hydrodynamic forces appear. These phenomena can not be explained by linear theory since nonlinear effects are essentially excluded. Therefore, time-domain calculations are necessary for fully nonlinear problems since frequency-domain computations are only good for linear problems or a few very specific body-exact problems

Longuet-Higgins & Cokelet [8] first introduced the mixed Eulerian-Lagrangian time-stepping scheme for solving two-dimensional fully nonlinear water wave problems. Faltinsen [6] used a similar scheme to study the nonlinear transient problem of a body oscillating on a free surface.

Vinje & Breving [12] continued the approach of Longuet-Higgins & Cokelet [8] to include finite depth and floating bodies but retained the assumption of spatial periodicity. Baker, Dommermuth & Yue [5] used the mixed Eulerian-Lagrangian method and postulated a far-field boundary matching algorithm by matching the nonlinear computational solution to a general linear solution of transient outgoing waves.

The desingularization method was first developed by von Karman [13] in which an axial source distribution was used to determine the flow about an axisymmetric body. A non-singular formulation of the boundary integral equation method was proposed by Kupradze [7]. The exterior Dirichlet problem was solved by using an auxiliary surface located outside the computational domain. Webster [14] investigated the numerical properties of the desingularization technique for the external potential flow around an arbitrary, three-dimensional smooth body. He concluded that the use of this desingularization technique greatly improved the accuracy of the solution.

Cao, Schultz & Beck [2, 3, 4] solved nonlinear problems for waves generated by a free surface pressure disturbance or a submerged body by combining the time-stepping scheme and the desingularized boundary integral equation method. Cao, Lee & Beck [1] extended the method to study nonlinear water wave problems with floating bodies, Scorpio et al [9] used a multipole accelerated desingularized method to compute nonlinear water waves. Lee & Cheng [10, 11] used the desingularized method to solve fully nonlinear wave calculations for arbitrary float bodies.

FULLY NONLINEAR PROBLEM FORMULATION

As shown in Fig.1, cartesian coordinates that refer to an absolute inertial frame are used. The z-axis points upward and the x - y plane is coincident with the still water level. The fluid domain, D, is bounded by the free surface, S_f, the body surface, S_b, the bottom surface, S_h, and the enclosing surface at infinity, S_∞.

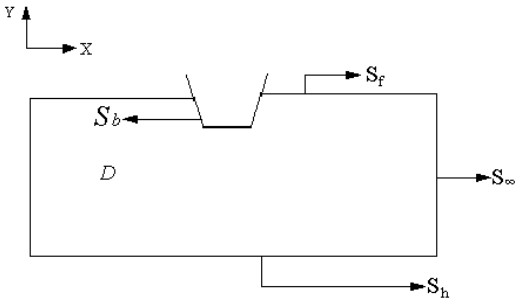

Fig. 1: Problem definition and coordinate system

The desingularized boundary integral equations for the unknown strength of the singularities $\pm(\vec{X}_s)$ are :

$$\iint_{\Omega} \pm(\vec{X}) \frac{1}{\left|\vec{X}_f - \vec{X}_s\right|} d\Omega = ¤_0\left(\vec{X}_f\right) \qquad \left(\vec{X}_f \in \Gamma_d\right) \tag{1}$$

and

$$\iint_{\Omega} \pm(\vec{X}) \left(\frac{1}{\left|\vec{X}_f - \vec{X}_s\right|}\right) d\Omega = ¡\left(\vec{X}_f\right) \qquad \left(\vec{X}_f \in \Gamma_n\right) \tag{2}$$

where

$\vec{X}_s$ is the point on the integration surface ; $\vec{X}_f$ is the field point on the real boundaries ;

$¤_0$ is the given potential value at X_f ; $¡$ is the given normal velocity at X_f ;

Γ_d is the surface on which $¤_0$ is given ;

Γ_h is the surface on which $¡$ is given

DISCRETIZATION AND SINGULARITY DISTRIBUTION

To solve the integral equation for $\pm(\vec{X}_s)$, the collocation method is used. Field points are chosen along the real boundary and sources are distributed outside the computational domain. A set of field points and the corresponding source points are chosen along the contours, S_f, S_b, and S_h, as shown in Fig. 2.

In the DELTA method, the sources are distributed on the integration surface so that the source points never coincide with the field points and the integrals are nonsingular. In addition, a simple isolated sources rather than a distribution is used. The equivalent accuracy in the solution is then obtained.

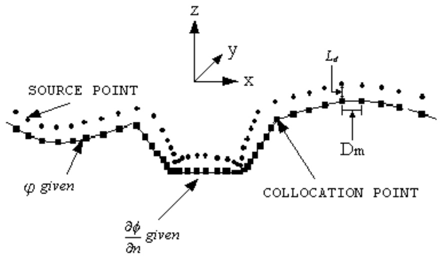

Fig. 2: Model for numerical simulation

The singularities are distributed above the field points on the free surface in the normal direction of the boundaries. Inside the body, the isolated singularities are placed along the normal direction from the field points in the body surface. Numerical difficulties may occur in the vicinity of a sharp edge. One of the difficulties is that the singularity distribution may cross over the bisector of two body surfaces or even the other side of the body surface since the desingularization distance is proportional to the local grid size.

These types of difficulties can be avoided by careful discretization and desingularization. The desingularization distance near a sharp corner is modified so that the singularities are distributed on the bisector of the two body surfaces to avoid the cross over of the singularities beyond the centerline or the body surfaces.

the nondimensional desingularization distance is set to be

$$L_d = l_d(Dm)^{a} \tag{3}$$

Where l_d reflects how far the integral equation is desingularized, D_m is the non-dimensional local mesh size (usually the square root of the local mesh area in 3-D problems and the local mesh size in 2-D problems). a is a parameter associated with the convergence of the solution as the mesh is refined. Cao, Schultz & Beck [2] conducted numerical tests in which an integral of a constant source distribution over a square flat surface is evaluated at a point above the center of the square with a distance given by Eqn. 3 They found that a = 0.5 and l_d = 1.0 are about the optimum values for the performance of the desingularization method.

a linear system of $m \times m$ algebraic equations is set to be

$$A_{m\times m} \cdot \vec{X}_m = \vec{B}_m \tag{4}$$

where

m is the total number of field points ;

$A_{m\times m}$ is the influence function matrix with $m \times m$ elements ;

$\vec{X}_m$ is the unknown source strength vector, $\pm\left(\vec{X}_m\right)$,to be solved ;

$\vec{B}_m$ is the known vector which contains the values of ¤ at the field points on the free surface and the values of ∂¤/∂n at the field points on the body

Once Eqn. 4 is solved, ∇¤ can be evaluated on S_f, and the combined free surface boundary conditions on the free surface can be integrated in time.

NONDIMENSIONALIZATION

The fundamental variables, ρ, g and L are used to nondimensionalize all the other variables, ρ is the density of the fluid, g is the gravitational acceleration and L is the initial draught of the body. Thus,

$\bar{L} = 1.0$ is the nondimensional draught ; $\bar{D} = \frac{D}{L}$ is the nondimensional position ;

$\vec{X} = \frac{\vec{X}}{L}$ is the nondimensional vector ;

$\bar{B} = \frac{B}{L}$ is the nondimensional radius ;

$\bar{D}_m$ is the nondimensional panelize ; $\vec{V}_b = \frac{\vec{V}_b}{\sqrt{gH}}$ is the nondimensional body velocity

The nondimensionalized system, the bar system, will be used but bars on all the variables will be dropped from now on. The numerical results shown in this thesis are all based on nondimensionalized variables unless otherwise mentioned. Also, ρ_{air} is the air pressure and is taken as zero. Consequently, the nondimensional governing equation and boundary conditions are

$$\Delta\phi = 0 \qquad (on\ S_f) \qquad (5)$$

$$\frac{D\vec{X}_f}{Dt} = \nabla\phi \qquad (on\ S_f) \qquad (6)$$

$$\frac{D\phi}{Dt} = \frac{1}{2}\left|\nabla\phi\right|^2 - zf \qquad (on\ S_f) \qquad (7)$$

$$\frac{\partial\phi}{\partial n_b} = \vec{V}_b \bullet \vec{n}_b \qquad (on\ Sb) \qquad (8)$$

$$\frac{\partial\phi}{\partial n_h} = \vec{V}_h \bullet \vec{n}_h \qquad (on\ Sh) \qquad (9)$$

$$\nabla\phi \rightarrow 0 \qquad (on\ S_\infty) \qquad (10)$$

NUMERICAL COMPUTATION RESULTS

Figs. 3~4 show the mesh of the free surface profiles due to the motion of the wigley ship model. The froude no.(Fn) is 0.316. The time(t) histories shown in the figs. 3~4 are 0, 20 respectively.

Figs. 5~6 show the mesh of the free surface profiles due to the motion of the Series 60 ship model.The froude no.(Fn) is 0.316. The time (t) histories shown in the figs. 5~6 are 0, 35 respectively.

CONCLUSIONS

The conclusions of this work are summarized as followings:

1. The desingularization method is robust in simulating the motions of floating bodies with complicated shapes.
2. The desingularization method shows no difficulty in treating the body-free surface intersection point.
3. For the desingularization method, no special treatment for the coefficient of the influence matrix is necessary. The stability of the desingularization method is better than that of the conventional boundary integral equation method.
4. The desingularization method is promising for further application to floating structures with arbitrary shape undergoing arbitrary motion.

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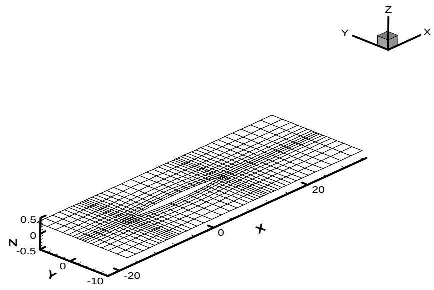


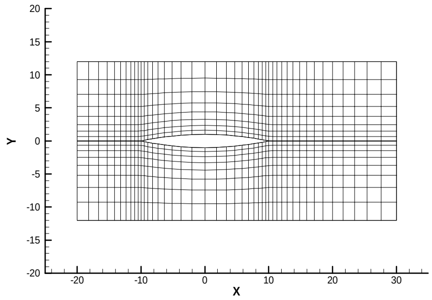
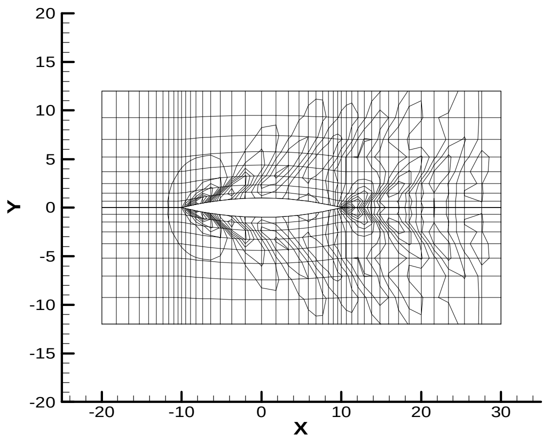


Fig. 3: the mesh of the free surface, Fn=0.316, t=0, (Wigley ship model)



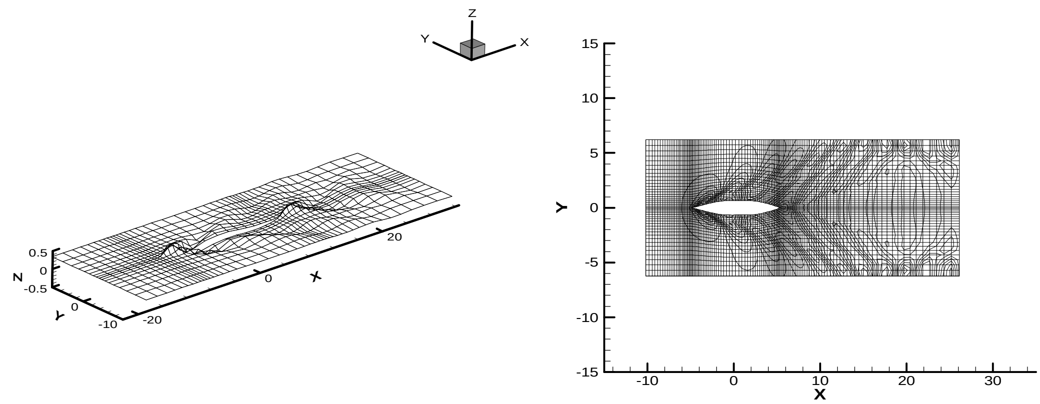


Fig. 4: the mesh of the free surface, Fn=0.316, t=20 sec, (Wigley ship model)

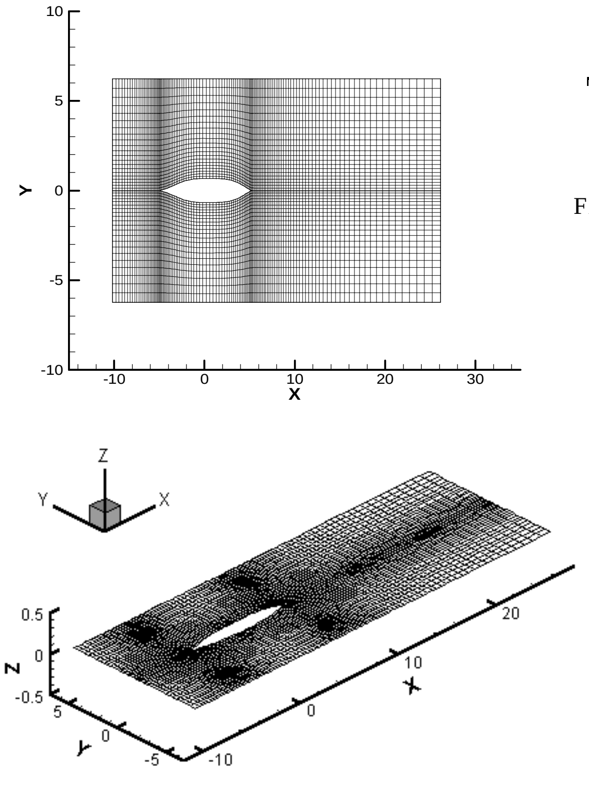


Fig. 5: the mesh of the free surface, Fn=0.316, t=0, (Series 60 ship model)

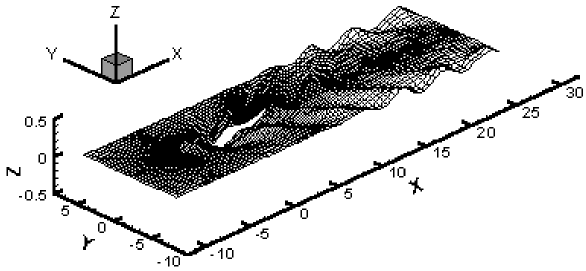


Fig. 6: the wave of free surface in acceleration, Fn=0.316, t=35 sec, (Series 60 ship model)