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Calculation of Wavemaking Resistance of High Speed Catamaran Using a Panel Method

Seung-Joon Lee[1] **and Young-Ryeol Joo**[2]

Abstract

In this work, a panel method is described, which can solve the flow field around a surface-piercing body that experiences lift and wave resistance. As the body boundary condition, a Dirichlet type is employed, and as the free surface boundary condition the Poisson type is implemented, while in its discretization Dawson's 4-point upwind difference scheme is utilized, and as the Kutta condition a Morino-Kuo type is chosen. As to the type of singularity, source panels are distributed on the free surface, and source and dipole panels on the body surface, and dipole panels on the wake surface. For a sample run, a catamaran of the parabolic Wigley hull is chosen, for which experimental data are available, and the predictions by the numerical means and by the experiment are compared for a wide range of parameters.

1 Introduction

Recently, as the demand for the high speed small ship has increased, catamarans of displacement type have received considerable attention. In this study we consider catamarans of the displacement type for the range of high speed, for which the Froude number ($Fn = U/\sqrt{gL}$) is greater than, say, 0.5, where U is the speed of a ship, g the gravitational acceleration, and L the LWL of the demihull(here only the symmetric demihulls will be considered), respectively. The study on catamarans of the planing type is left as a future application of the numerical tool developed through this study.

It is well known that catamarans have better transverse stability characteristics than the conventional displacement type ship of monohull. Hence, in the process of designing a catamaran, usually much attention is given to the resistance characteristics around the service speed, and, once the geometry of the demihull is determined, major parameters of consideration are the ratio of the separation distance s between the centerplanes of demihull and L, and the interference factor τ of the wavemaking resistance, which is the ratio of the wavemaking resistance of monohull and that of the demihull of catamaran's.

Insel & Molland(1991)(hereafter abbreviated by IM) carried out a series of resistance experiments for catamarans of 4 different hulls including the Wigley parabolic

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[1] Member, Chungnam National University, Taejon, KOREA

[2] Member, Samsung Heavy Industry, Taejon, KOREA

one. They also used a modified thin ship theory to have a theoretical guide, and concluded that the theoretical method can be used as a preliminary design tool.

This study was motivated to provide a panel method which can be used as a design tool for catamarans. In the preliminary stage of this study, a panel method was developed(see Shin et al.(1994a)), which can solve the nonlifting flow around the ship-like body, and it was found that the method did not work for high speeds. Thus the present panel method, which can solve the lifting flow around the surface-piercing body, was developed.

In the sequel, first the developed panel method is briefly described, and the numerical results and the discussion follow, and then finally the conclusions and the future works for improvement are mentioned.

2 Panel method

Panel methods have been in wide use ever since the work of Hess & Smith(1962) in the solution process for the nonlifting and lifting flow about arbitrary 3-dimensional bodies. The panel method described here was developed following the guideline given in Katz & Plotkin(1991)(hereafter abbreviated by KP), and the treatment of the free surface boundary condition was done after the fashion of Lee(1992).

Let's take the right-handed co-ordinate system shown in Fig. 1, and assume that the flow field around the body of interest is an irrotational flow of an inviscid and incompressible fluid, then the following Laplace equation should be satisfied in the fluid everywhere, possibly except in the vortical region behind the body for lifting flows.

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = 0 \tag{1}$$

Here, $\Phi(x, y, z)$ is the total velocity potential. Impermeability condition on the body surface S_B can be written as follows.

$$\frac{\partial \Phi}{\partial n} = 0, \quad \text{on } S_B. \tag{2}$$

Equation (2) may be called the Neumann type boundary condition(bc), and it is not the only form of the body bc as explained in KP. One of the Dirichlet type is

$$\Phi_i = \Phi_\infty, \quad \text{on } S_B^-, \tag{3}$$

where Φ_i is the total velocity potential inside the body, and Φ_∞ is the velocity potential of the incoming uniform flow. In applying (3), source and dipole panels are distributed on S_B, and dipole panels on the wake surface S_W. Wake surface is a vortex surface formed downstream side of the 3-dimensional lifting body, and the dipole strength on the surface must be the same along a streamline or on a dipole strip. The strength of a dipole strip is given by the Kutta condition applied at the trailing edgeline(TE), and we chose the following Morino-Kuo type(Morino & Kuo(1974)).

$$\mu_u - \mu_l = \mu_w, \quad \text{at TE}, \tag{4}$$

where μ_u and μ_l is the dipole strength of the upper and lower panel connected to TE, respectively, and μ_w is that of the strip on S_W.

In addition to the bc's stated above, for the fluid domain with a free surface in contact with the atmosphere, it is necessary to satisfy the bc on the free surface. We decided to use the Poisson type free surface bc, which has been tested for similar problems successfully(e.g. Lee(1992)), and can be written as

$$\frac{\partial u}{\partial x} + Kw = 0, \quad \text{on } S_F(z = 0), \tag{5}$$

where (u, v, w) is the velocity vector, and $K = g/U^2$ the wave number, respectively. Since the boundary value problem formed by (1, 3, 4, 5) does not give a unique solution, we have to require an additional condition, which is called the radiation condition, namely that there should be no wave disturbance far upstream. Now, as a solution to such boundary value problem, using the elementary singularities of (1), we may assume as follows,

$$\Phi = Ux + \frac{1}{4\pi}\int_{S_B+S_W} \mu \frac{\partial}{\partial n}(\frac{1}{r})dS - \frac{1}{4\pi}\int_{S_B+S_F} \sigma(\frac{1}{r})dS \tag{6}$$

where r is the distance between the point of interest and the area element on the integral surface. Here, following KP, σ on S_B should be given by

$$\sigma = -n_x, \quad \text{on } S_B, \tag{7}$$

where n_x is the x-component of the outward normal unit vector on S_B. Then (3) can be rewritten using the singularity distributions as

$$\frac{1}{4\pi}\int_{S_B+S_W} \mu \frac{\partial}{\partial n}(\frac{1}{r})dS - \frac{1}{4\pi}\int_{S_F} \sigma(\frac{1}{r})dS = -\frac{1}{4\pi}\int_{S_B} n_x(\frac{1}{r})dS, \quad \text{on } S_B^-. \tag{8}$$

Equation (8) is a Fredholm integral equation of the second kind, where the unknowns are μ on S_B and σ on S_F, since μ on S_W is determined by (4) in terms of μ on S_B. Now the remaining equation (5) can be satisfied in a discretized form as follows,

$$D_x u + Kw = 0, \quad \text{on } S_F, \tag{9}$$

where $D_x u$ is the finite difference representation of $\frac{\partial u}{\partial x}$. For D_x the 4-point upwind difference used by Dawson(1977) was adopted, then its usage guarantees the satisfaction of the radiation condition as pointed out by Van & Lee(1993), and its application can be found in Shin et al.(1994a).

Distributing N_B panels on S_B, and N_F panels on S_F, respectively, and assuming that panels are quadrilaterals and that the strength on a panel is constant, from (8) and (9), which form the core of the present panel method, we can derive a closed system of linear algebraic equations of dimension $N_B + N_F$. Calculation of influence coefficients is straightforward(see KP), and left is the computation of various physical quantities once the strength of singularities on each panel is obtained. Some authors call the method described above as a potential based panel method, and seek the velocity on S_B by differentiating the strength of dipole in the direction desired, and by doing so save the computation time significantly. However, it should be pointed out that (3) is only a variation of (2). And it is strongly recommended to compute influence coefficients not only for velocity potential but also for velocity components, so that the check whether the normal component of the velocity on S_B vanishes can be done directly, and that the tangential velocity on a panel can be obtained using these coefficients without differentiating the strength.

In order to solve (9) more conveniently, we employ the image of the body(wake) with respect to S_F such that the induced velocity on S_F by the body(wake) and its image is directed toward x-axis. Then, since source panels on S_F do not induce velocity in z-direction except the self panel, w in (9) can be replaced by $-\sigma_j/2$, where σ_j is the strength of the source on the self panel. Also the symmetric property of the flow field is fully exploited so that only the region $y > 0$ is taken as the computational window.

3 Numerical results and discussions

Even if the desired code has been developed, there are many points which should be made clear before the code is applied to real general problems. First, we need to know how big the computational window should be for various cases in order to obtain meaningful results, and second, the dependence of the numerical results on the panel size and its shape, and third, the convergence behavior of the solution as we increase the number of panels. Frankly speaking, we have not yet acquired the complete understanding of the developed code, and the following results should be taken as the interim ones.

When the demihull has a longitudinal symmetric plane and the plane meets the transverse plane at stern on a curve, there is no difficulty in applying the Kutta condition. However, for instance for hulls of transom stern, the real form of the hull may need to be slightly changed so that the 'trailing edgeline' can be defined. At the moment we can only conjecture that the Kutta condition need to be satisfied as the speed of the ship increases, because the difference in velocity and in the corresponding pressure between the inner and the outer side of the demihull gets larger for catamarans.

For a sample run, we chose a catamaran of the Wigley parabolic hull which can be represented by

$$y = \frac{s}{2} \pm \frac{B}{2}\{1 - (\frac{2x}{L})^2\}\{1 - (\frac{z}{D})^2\}, \tag{10}$$

where (B, D) is (breadth, draft) of the demihull, and here $(L, B, D) = (16, 1.6, 1)$. In the following numerical results will be compared with the experimental data of IM.

Let's define the wavemaking resistance coefficient as follows,

$$C_W = \frac{R_W}{\frac{1}{2}\rho U^2 A_W}, \tag{11}$$

where R_W is the wavemaking resistance, ρ the density of the fluid, and A_W the wetted surface area of the ship, respectively. In Fig. 2 we show the comparison of our numerically obtained values of C_W for a monohull ship of the Wigley parabolic form with the experimental data. It can be observed that the general trend of C_W with Fn is in good agreement, but the absolute magnitude of the values of C_W predicted numerically are significantly less than those measured experimentally for the range of Fn being larger than 0.4. The similar trend was also reported by Shin et al.(1994b), who used SHIPFLOW for their computation.

We show the data of the panel arrangement for computing the flow field around catamaran in Table 1, where λ is the characteristic wavelength, and xup and xdn are the x co-ordinates of the upstream and the downstream boundary of the computational window, respectively. In the Table all lengths are nondimensionalized by L. For all cases reported here, the width of the computational window was taken as 1.5 times L, and the total number of panels did not exceed 1000.

In Fig. 3 the comparison of C_W for the catamaran of Wigely hull is given for 4 different values of separation distance. In Fig. 3a, there are reverse triangles representing the data taken from IM, and they are in good agreement with the numerical results. But this is fortuitous, since they correspond to the case of wave breaking due to the narrowest tunnel, the region between the demihulls. Except the case $s/L = 0.2$, the general behavior of C_W with Fn is well predicted by the numerical code. We note that the position of the peak of C_W and its magnitude as the separation ratio decreases are all well predicted by the computational results. However, the magnitude of C_W for Fn larger than 0.5 is underpredicted, just as in the case of monohull.

As the separation distance varies, the interference of the wave system generated by each demihull changes also, and IM concluded that over a critical speed for a given separation distance there is not much change of the interference effect. In Fig. 4 the comparison of τ for the catamaran of Wigley hull is shown for various values of separation distance. Although the tendency of C_W with Fn is generally similar both for the monohull ship and for the catamaran, due to the low prediction of C_W for high Fn for monohull by numerical results, the interference factor does not tend to unity as Fn increases, which is in contrast to the conclusion of IM. It seems required to look into more deeply the reason why the values of C_W for high Fn are so underpredicted.

4 Conclusions

As shown above the developed panel method can be used as a preliminary design tool for predicting the performance of the chosen hull form of catamaran. However, as noted above, there are a few points that require improvements and/or further detailed study. In order to give robustness to the developed code, as pointed out at the beginning of the previous section we need have good grasp on the various aspects of the developed code. Furthermore, to enhance the applicability of the code, it seems necessary to investigate into the detailed flow pattern around the ship, especially in the tunnel region and in the region near the stern.

If the study above suggests the need for the higher order accuracy in the free surface boundary condition, we may first try the improved Poisson type, proposed by

Lee(1994) and applied to 2-dimensional problems by Lee(1995). If the characteristics of the wavemaking phenomena for catamarans especially in the tunnel region is highly nonlinear, we may employ the desingularization method in implementing the fully nonlinear free surface bc.

And if the detailed study on the flow pattern near the stern suggests the improvement by applying the more accurate Kutta condition, we may use the pressure condition proposed by Lee(1987), which requires again a nonlinear treatment.

References

[1] Dawson, C.W., "A Practical Computer Method for Solving Ship-Wave Problems", Proc. 2nd Int. Conf. Num. Ship Hydro., 1977.

[2] Hess, J.L. & Smith, A.M.O., "Calculation of Non-Lifting Potential Flow about Arbitrary Three-Dimensional Bodies", Rpt. E.S. 40622, Douglas Aircraft Co., 1962.

[3] Insel, M. & Molland, A.F., "An Investigation into the Resistance Components of High Speed Displacement Catamarans", Trans. RINA, 1991.

[4] Katz, J. & Plotkin, A., *Low-Speed Aerodynamics; from Wing Theory to Panel Methods*, McGraw-Hill, Inc., 1991.

[5] Lee, J.T., "A Potential Based Panel Method for the Analysis of Marine Propellers in Steady Flow", Ph. D. Dissertation, Dept. Ocean Engineering, MIT., 1987.

[6] Lee, S.J., "Computation of Wave Resistance in the Water of Finite Depth Using a Panel Method", Trans, SNAK, Vol. 29, No. 4, 1992.

[7] Lee, S.J., " A Practical Method for Computing Wave Resistance", Trans, SNAK, Vol. 31, No. 1, 1994.

[8] Lee, S.J., " A Nonlinear Calculation of 2-Dimensional Hydrofoil with Shallow Submergence", J. Hydrospace Tech. Vol. 1, No. 2, 1995.

[9] Morino, L. & Kuo, C.C., " Subsonic Potential Aerodynamics for Complex Configurations: a General Theory", AIAA J., 12(2), 1974.

[10] Shin, M.S., Lee, S.J., Wee, C.W., " A Nonlinear Calculation of Wave Resistance for Catamarans", Proc. Autumn Meeting of SNAK, 1994.

[11] Shin, Y.K., Kim, S.K., Choi, S.H., Kim, S.K., " Hull Form Design and Consideration on Fast Catamaran", Proc. Autumn Meeting of SNAK, 1994.

[12] Van, S.H. & Lee, S.J., "Comparison of Free-Surface Boundary Conditions for Computing Wave Resistance", Trans, SNAK, Vol. 30, No. 2, 1993.

	Type 1	Type 2	Type 3	Type 4
Fn	[0.3 ,0.4)	[0.4 ,0.5)	[0.5 , 0.7)	[0.7 ,1.0)
λ	0.56 ~ 1.0	1.0 ~ 1.6	1.6 ~ 3.0	3.0 ~ 6.28
(xup,xdn)	(-1.0,1.0)	(-1.5,1.5)	(-2.0,2.0)	(-2.0,3.5)

Table 1. Data of the panel arrangement for Catamaran

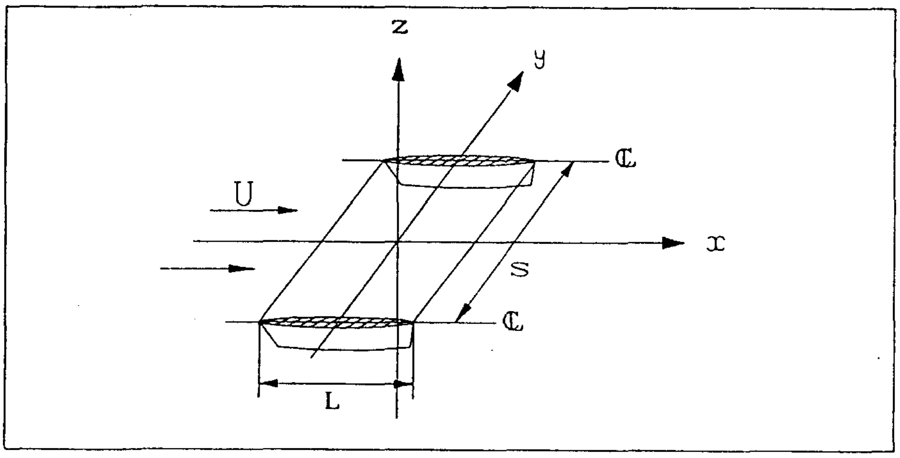

Fig. 1 Co-ordinate system

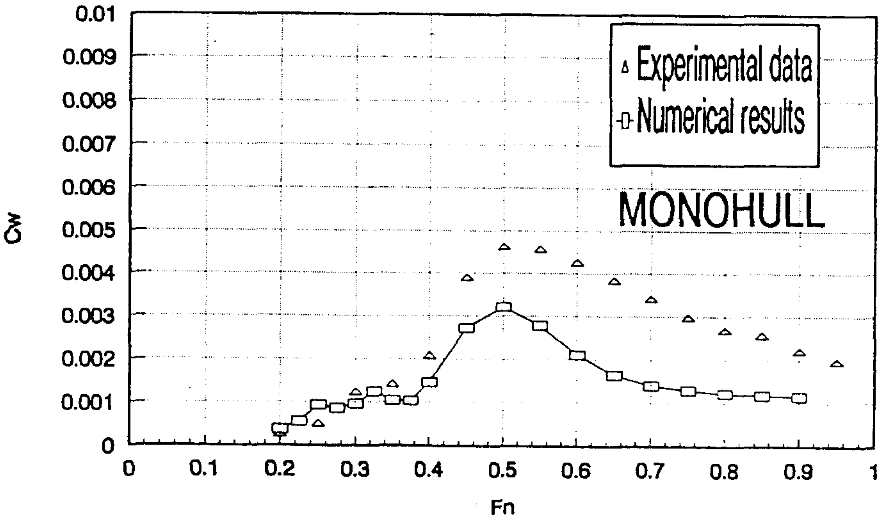

Fig. 2 Comparision of C_W by panel method with experiments of Insel & Molland(1991) for the Wigley hull.

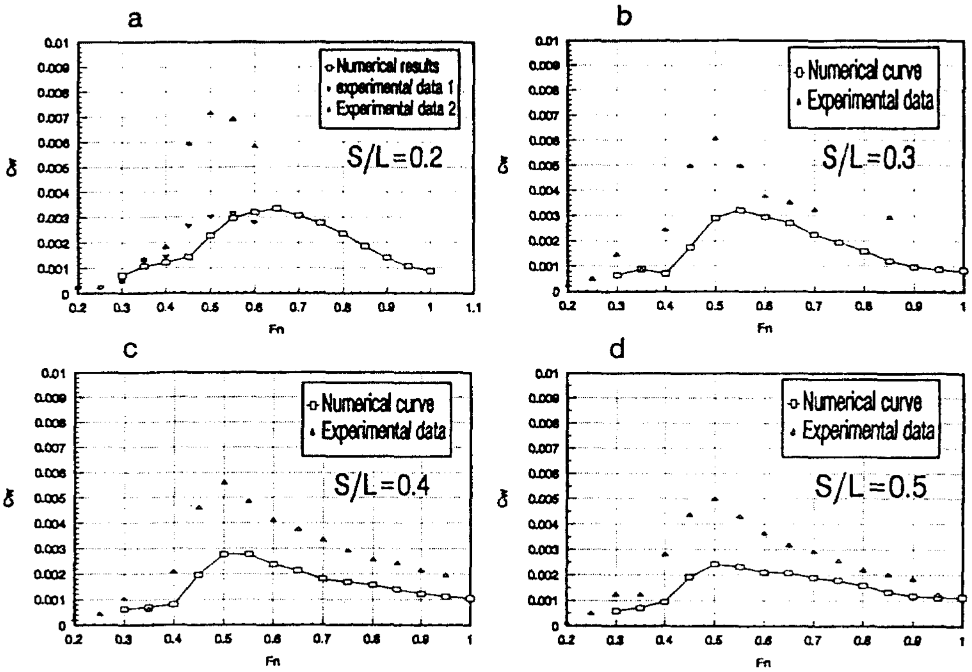

Fig. 3 Comparision of C_W by panel method with experiments of Insel & Molland(1991) for the catamaran of Wigley hull.

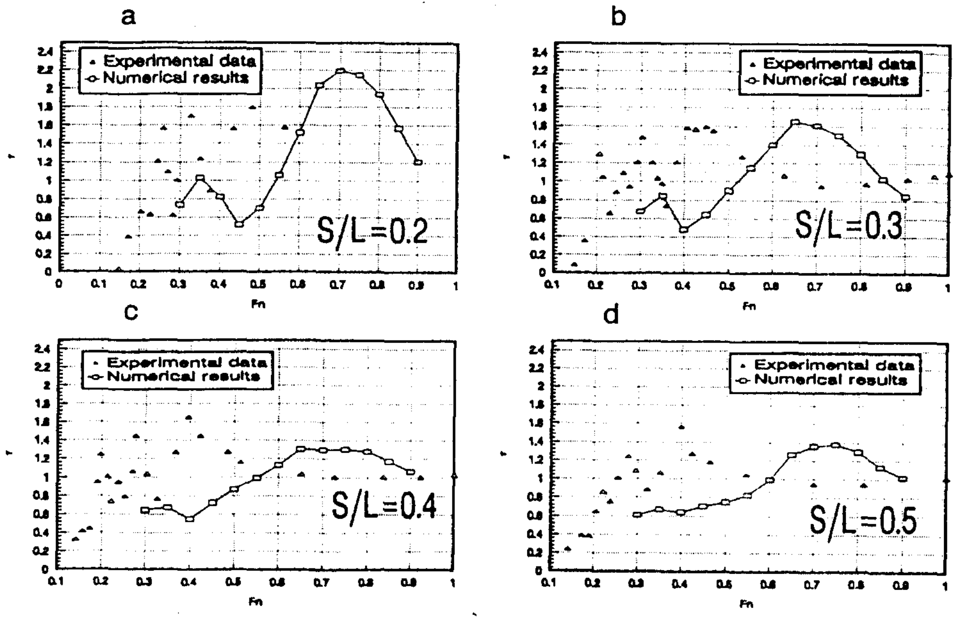

Fig. 4 Comparision of τ, interference factor, by panel method with experiment Insel & Molland(1991) for the catamaran of Wigley hull.