Wave Making Resistance of a Submerged Hydrofoil with Downward’ Force

Kazu-hiro Mori
Hiroshima University

Shigeki Nagaya
Ship Research Institute

Submerged hydrofoil with downward force

The wavemaking resistance of a submerged lifting body can be reduced by generation of downward force[1] [2] . This phenomenon is interesting from the viewpoint not only from practical applications but from hydrodynamics. However, little has been studied so far. Fig. 1 shows the comparison of the computed waves with and without downward force. The latter is computed without satisfying the Kutta condition. The waves with downward force is remarkably less.

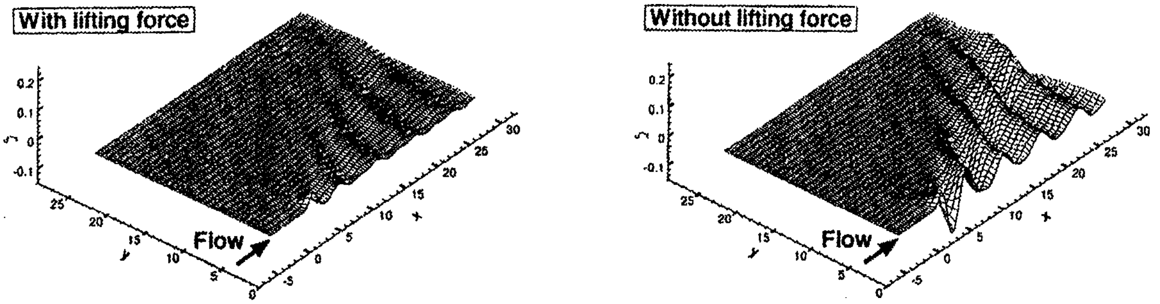

Fig. 1 Comparison of wave patterns between with and without lifting force $(\alpha=-2^{\circ})$

Results of numerical computations and measurements

For the numerical computation, the flow around a hydrofoil is assumed potential flow and a direct boundary element method is used where the fully nonlinear free-surface boundary conditions are imposed. The Kutta condition at the trailing edge is satisfied by introducing a wake sheet behind the hydrofoil on which the velocity potential has a jump.

Three dimensional rectangular hydrofoils with NACA sections are studied. The total drag coefficient C_T and the lifting force coefficient C_L are obtained by the integration of pressure over the foil while the wave pattern resistance coefficient C_{wp} is determined from the computed wave profiles by the wave pattern analysis. C_B is the buoyancy force coefficient, All the

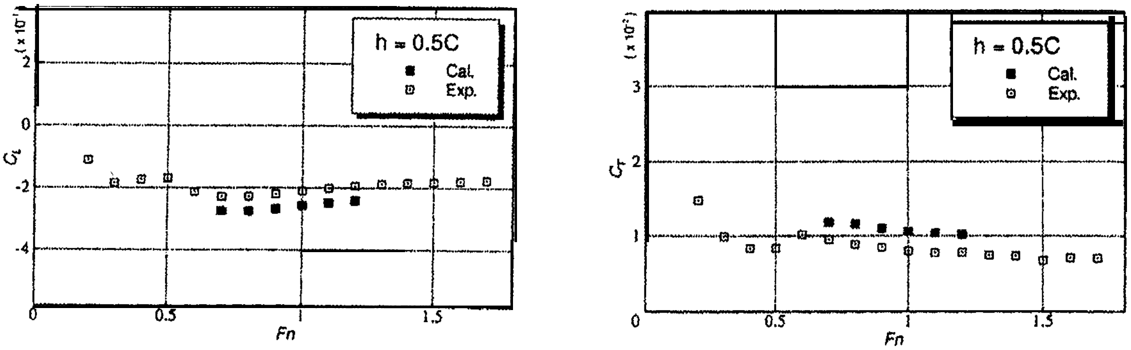

Fig.2 Comparisonof drag and lifting force between calculated and experimenal results (NACA4412, Fn=1. 0)

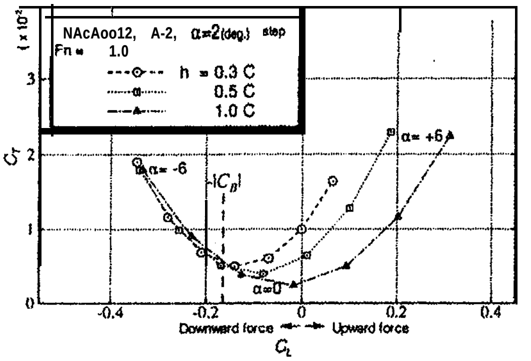

Fig.3 Total resistnace at various submergence depth

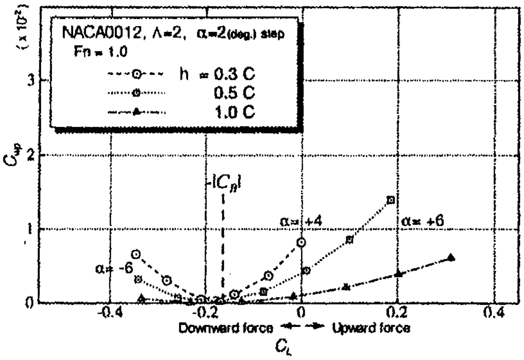

Fig. 4 Wave resistance at various submergence depth

coefficients are normalized by $1/2 \rho U^2 S$, where ρ is the fluid density, U, the speed and S, the plane area of the hydrofoil given by a product of the chord length C and span width. Thus C_B depends on the speed although the force itself does not changed.

An experiment is carried out to measure the forces acting on the foil. The drag of the flat plate with the same area and the supporting strut has been subtracted from the measured value; C_T gives the sum of the induced drag and wavemaking resistance.

Fig. 2 shows the comparison of the computed values with the measured. The computed results agree rather well with those of measured although the lifting force is slightly less than the measured while the drag is larger.

Figs. 3 and 4 show C_T and C_{wp} at three different submergence where h, α and A are the submergence depth, the angle of attack and the aspect ratio of foil respectively. It is clearly demonstrated that the wave pattern resistance is minimum and almost zero where the downward force is equal to the buoyancy force. This finding is proved for the different Froude numbers and for the foils with different displacement volume as seen in Figs. 5 and 6.

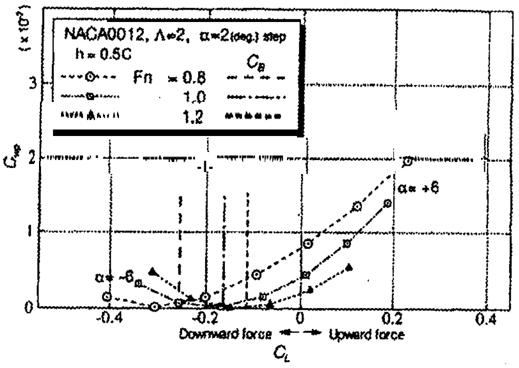

Fig.5 Total resistnace at various Froude number

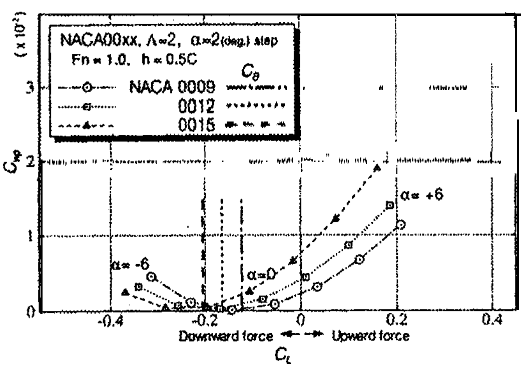

Fig. 6 Wave resistance at various displacement volume

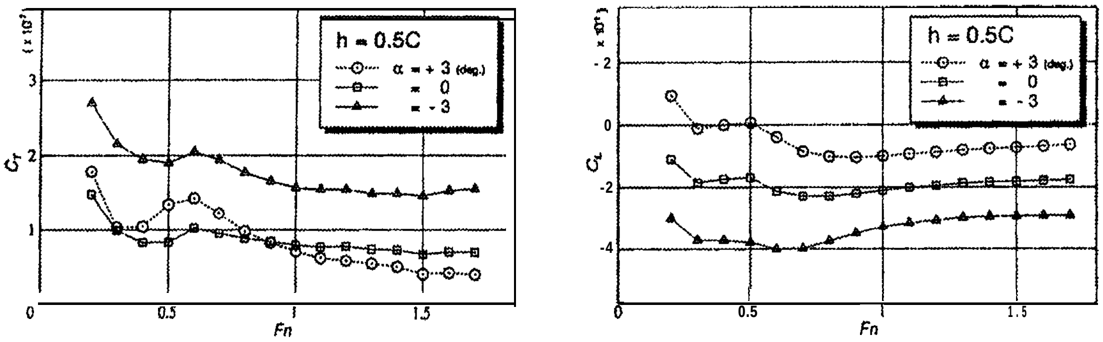

Fig.7 Measured total drag and lifting force(NACA4412)

Fig.7 shows the results of measurements. Because the total drag includes the induced drag, it is not clearly demonstrated, but the total drag is less when the lifting force is equal to the buoyancy force.

Shape in terms of wave-free singularity

Expecting to find a shape of a lifting body with zero-wavemaking resistance, studies have been carried out so far by an optimization method where the shape is iteratively changed to find out that with the minimum wavemaking resistance[3]. Here the shapes generated by a distribution of the wave-free singularity whose velocity potential is given by the combination of doublet and vortex as

$$\Phi(x,z) \;=\; Ux + Ua^2\{D(x,z+h) - D(x,z-h) - \kappa[V(x,z+h) - V(x,z-h)]\} \qquad (1)$$

where

$$D(x,z\pm h) = \frac{x}{x^2+(z\pm h)^2} \qquad V(x,z\pm h) = \tan^{-1}\frac{z\pm h}{x}$$

and (x, z) are the coordinate system where x and z are the streamwise and virtical directions respectively and κ, the wave number given by g/U^2. (1)

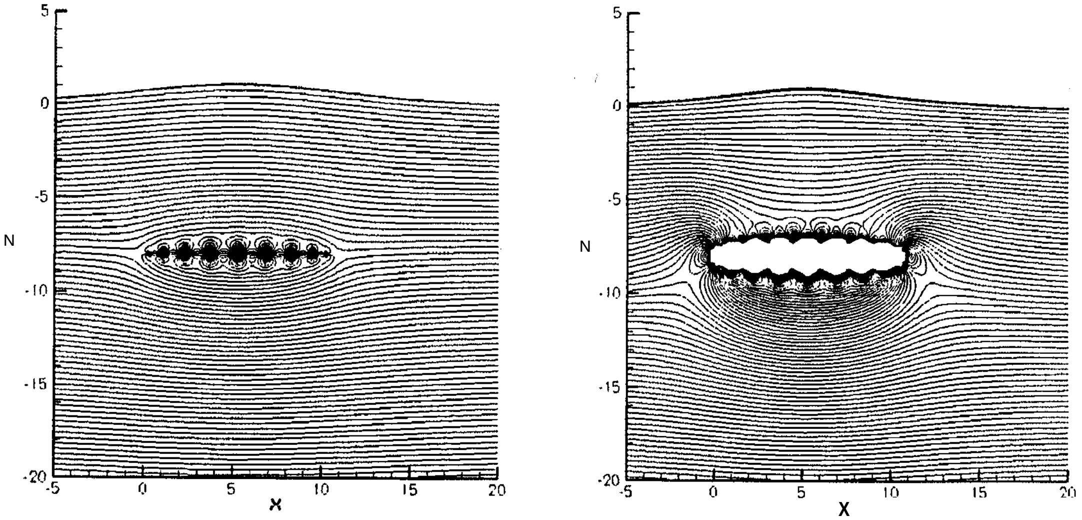

Fig. 8 Streamlines (left) and pressure contours (right) of a line distribution of singularity

satisfies the linearlised free surface condition.

The streamlines around a line distribution of the discrete sigularities given by (1) and its pressure contours are shown in Fig.8 where the free-surface profile is drawn by a thick line. As expected, the pressure field is producing the downward force, but the shape is symmetry and no signifficant difference can be seen from that only by the dipole distribution. In other words, we cannot expect such a free-surface elevation by the generated shape unless a circulation is realized by any means which is equal to the total intensity of the second term of (1). A distribution along a cambered line with a sharp trailing edge satisfying the Kutta condition may provide the wave-free shape.

Concluding remarks

It is definitely made clear that zero wave making resistance can be realized when the downward force is equal to the buoyancy force. The shape of such lifting bodies can be generated in terms of wave-free singularities, although the relation between the circulation and the shape should be studied more.

References

[1]Mori K., et al :A Study on Semi -Submersible High Speed Ship with Wings, Jour. of Soc. Naval, Arc. Japan, Vol. 164, (1988).

[2] Tuck E. 0. and Tulin M. P. :Submerged Bodies That Do Not Generate Waves, Proc. of 7th International Workshop on Water Waves and Floating Bodies, val de Reuil, France, (1992).

[3] Nagaya S. , Xu Q. , Mori K. :On Resistance of a Submerged Lifting Body which Generates Downward Lifting Force, Jour. of Soc. Naval. Arc. Japan, Vol. 182, (1997).