RESISTANCE AND LIFTING FORCE OF A SUBMERGED BODY WITH A WING PRODUCING A DOWNWARD LIFTING FORCE

Kazu-hiro Mori
Faculty of Engineering, HiroshimaUniversity
Kagamiyama 1-4-1, Higashi-Hiroshima, 724 Japan

Introduction

The resistance of a submerged body with a wing is reviewed stimulated by the paper by E.O.Tuck and M.P.Tulin[1] where a possibility is discussed for a body with a downward lifting force to generate no waves. All the results presented here are referred from [2][3][4][5] which are on the studies of a high speed semi-submersible vehicle with wing. The vehicle is expected to realize a high speed by submergence by a downward lifting force generated by a wing. The situation is exactly the same as that discussed in [1] where the downward lifting force cancels the buoyancy force. The resistnace was less both in the calm water and among waves when the downward force was produced by wing.

Experiments and Computations

The experiments were carried out by making use of a model with a wing whose general view is shown in Fig.1[2]. The wing is "inverse" to be upside down compared with the conventional hydrofoil to generate the downward lifting force. The hull form is mathematically expressed and the wing has NACA 4412 section. No optimization as to the hull form and the position of the wing are made. The length of the model used(L) is $1m$. For the brevity, here, the model with the wing is designated by "model-w" while that without, "model-o". Wave analysis was done to determine the wavemaking resistance component in the calm water. All the measurements among waves were carried out among regular waves whose length-height ratio λ/ζ_a was 60[3]. Computations are carried out by a boundary element method where the fully nonlinear problem is solved iteratively by the time-marching method satisfying the Kutta condition also[4].

Results and Discussions

Fig.2 shows that the total resistance(C_t) of model-w is appreciably less than that model-o. Because the wavemaking resistance(C_w) is almost one half, we can conclude that the reduction by the wing have come from the wavemaking resistance component. The comparison of the measured wave profiles at two Froude numbers, shown in Fig.3, supports the above conclusion where the wave profiles of model-w are much less in amplitude. Fig.4 shows the computed results of the wavemaking resistance[4]. Although it is not so much as the measured, the resistance of model-w is less than that of model-o. Fig.2 shows another interesting fact that the total resistance is minimum at the angle of attack $\alpha = 4^o$ while the wavemaking resistance is at 8^o. This is because the viscous component and the induced drag increased as the angle of attack increased.

Fig.5 shows the measured downward lifting force where the angle of attack is a parameter. Although the difference of the wave resistance between $\alpha = 0^o$ and 4^o is larger than that between $\alpha = 4^o$ and 8^o, the lifting force is opposite. The reduction of the wavemaking resistance can be suppose not always proportional to the lifting force. Fig.6 shows the computed results of the wavemaking resistance and the lifting force[5]. Contrary to the ordinary hydrofoil, the lifting force increases as the submergence depth becomes shallower which is favorable for our vehicle.

Fig.7 shows that the averaged added resistance(F_x-F_{x0}) among the heading waves is positive as common for the case of model-o but negative for the case of model-w except some cases of the shallower depths in the shorter waves. This means that the wing can produce a propulsive force among the heading waves. Fig.8 shows the results under the following sea condition where both the averaged resistance and the amplitude of the wave-induced resistance(f_x) are reduced by the wing regardless of the relative speed of the model to the phase velocity(C); V: model speed.

Concluding Remarks

Needless to say, the main purpose of the wing is to produce a downward lifting force for the body, but it is very favorable for our vehicle that the wing reduces the resistance additionally to the gain by the submergence. It is still more favorable that the wing generates a propulsive force among the waves both the heading and the following waves.
Interesting findings about the "inverse" wing encourages us to study theoretically to find an optimal hull and wing forms and their configurations.

References

[1] E.O.Tuck and M.P.Tulin; Submerged Bodies That Do Not Generate Waves, Proc. of 7th International Workshop on Water Waves and Floating Bodies, 1992.

[2] K.Mori, et.al.: A Study on Semi-Submersible High Speed Ship with Wings, Naval Architecture and Ocean Engineering, Vol.27, 1989

[3] K.Mori, et.al.:A Study of the 3-Freedom Motions and Characteristics among Waves of a Semi-Submersible High Speed Ship with Wings, Trans. of The West-Japan Society of Naval Architects, No.80, 1990 (in Japanese).

[4] Xu Qi and K.Mori: A Boundary Element Method for the Numerical Simulation of 3-D Nonlinear Water Waves Created by a Submerged Lifting Body, Jour. of Soc. of Naval Arch. of Japan, vol.167, 1990.

[5] K.Mori, et.al.:Numerical Simulation of Flows and Motions of Semi-Submersible High Speed Shop with Wing, Trans. of The West-Japan Society of Naval Architects, No.82, 1991 (in Japanese).

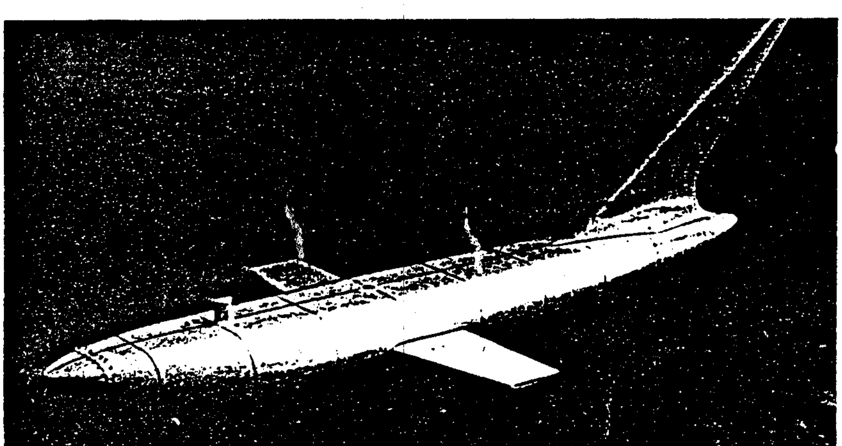

Fig.1 General view of the model with wing producing downward lifting force

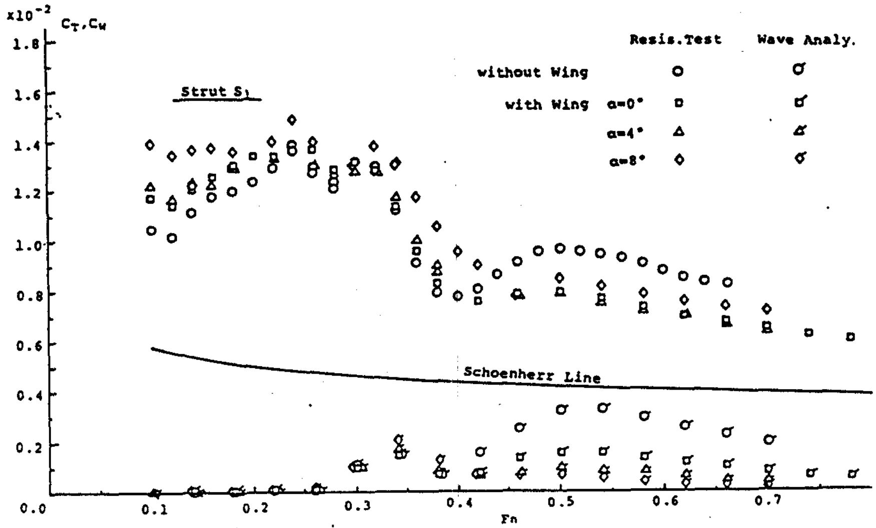

Fig.2 Comparison of the resistances between with and without wing.

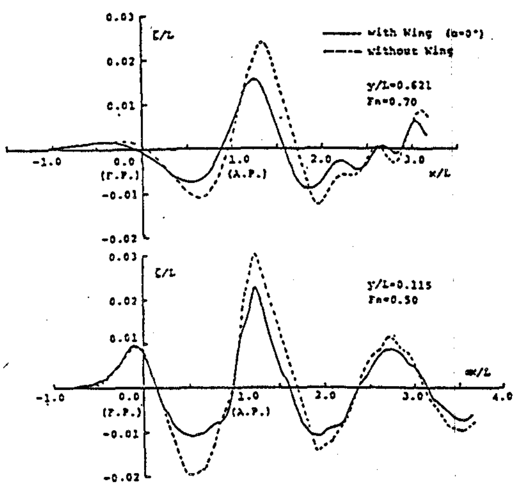

Fig.3 Comaprison of wave profiles between with and without wing.

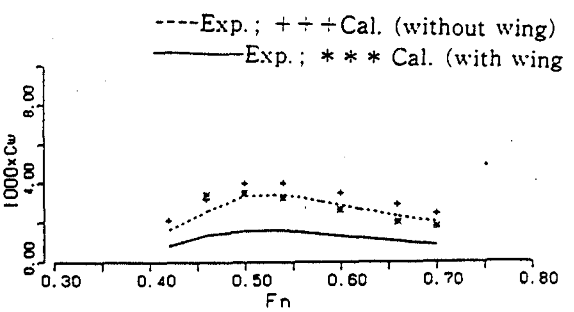

Fig.4 Computed and measured wavemaking resistance

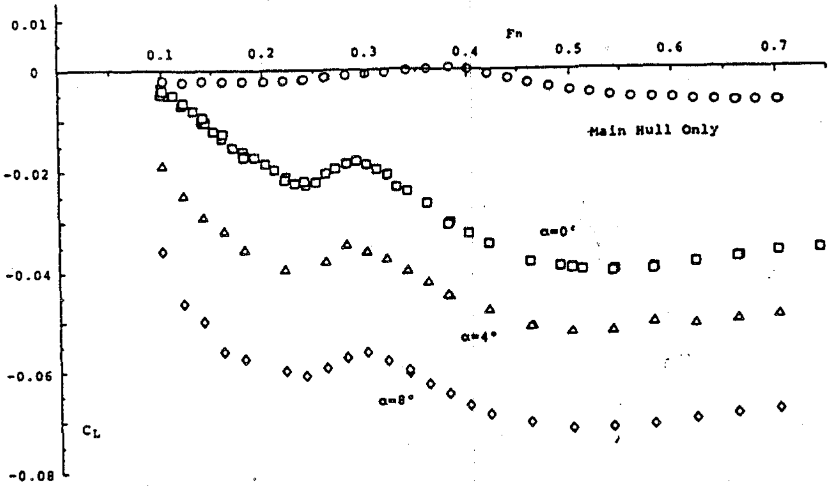

Fig.5 Measured lifting force at various angles of attack

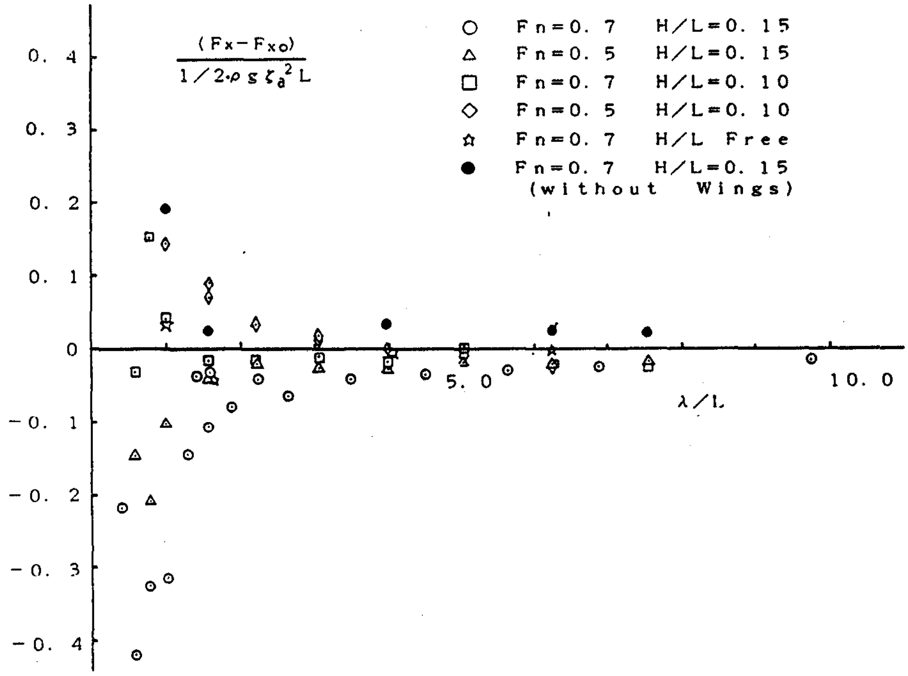

Fig.6 The averaged increment of resistance among heading waves

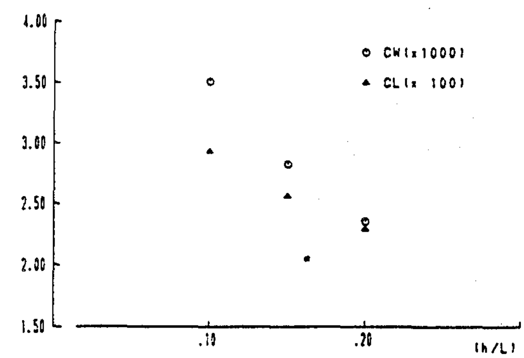

Fig.7 Dependence of the computed wave-making resistance and lifting force on the submergence depth

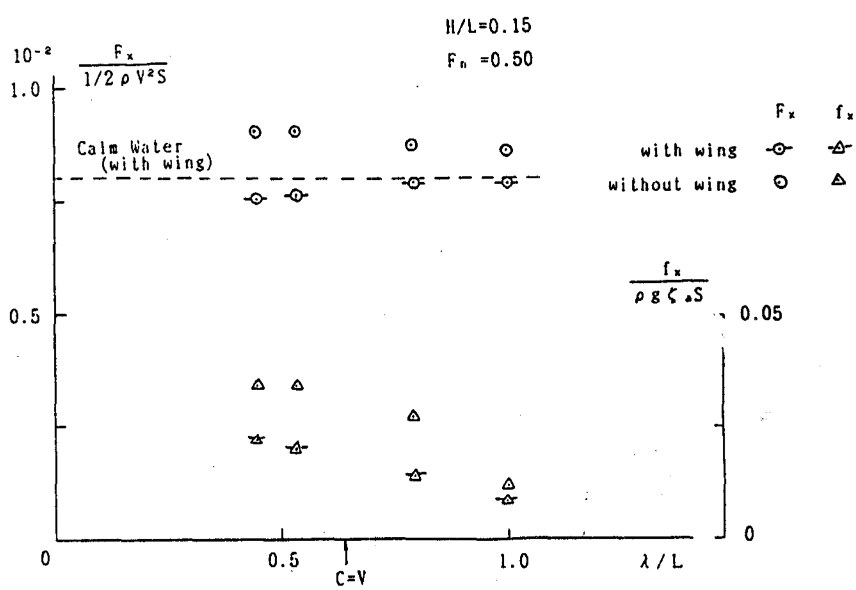

Fig.8 The average and the amplitude of the resistnace among the following waves