Aero/Hydrodynamic Forces and Moments on Self-Propelled Slender Bodies in Incompressible Flow

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Theme

THE forces and moments exerted on slender, self-propelled bodies are of practical importance in the design and operation of submersible bodies. To design control systems and to analyze the stability of such vehicles, it is first necessary to measure the aero/hydrodynamic forces and moments acting on the bodies. The effect of running propellers on these forces and moments is important, since propellers are the most predominant method of propulsion. The possible influence of various propeller arrangements is also of interest.

This investigation consisted of an experimental study of the forces and moments on two models that roughly correspond to modern high-speed submarines at various pitch angles. The two models both had a fineness ratio (length/max. diam) of 12:1, but they differed in that one was propelled by a single propeller, whereas the other had side by side, counterrotating propellers. The forces and moments were measured by an internally mounted strain gage balance in both the self-propelled and nonpropelled configurations, and the results are presented in terms of standard aerodynamic-type force and moment coefficients.

All of the tests were conducted in the Virginia Polytechnic Institute and State University 6 ft×6 ft subsonic stability tunnel at a dynamic pressure of 5.0 in. of water (approx 157 ft/sec) yielding a Reynolds number based on diameter of 4.4×10^5. Both models used the same parabolic plexiglas forebody and cylindrical aluminum centerbody, and both tail bodies were plexiglas ogives. The first body had a single shaft which extended out the stern, and the second body had twin shafts which flared out at a 7° angle through the stern.

Both models had 2.75-hp dc motors. The single-shaft model was direct drive, whereas the dual shaft model used a belt driven 1:1.5 stepup from the motor. This was necessary to achieve the higher rpm's needed for this model in the self-propelled mode.

The single shaft model employed a 6-in.-diam, three-bladed model airplane propeller and the dual shaft model used two 4.375-in.-diam, three-bladed propellers which were cut down versions (*RH* and *LH*) of the single propellers. All of the propellers were heated at the root and twisted to a higher pitch to operate more efficiently at the high air speeds used. The effective pitch of the larger propellers as modified was 2.46. The smaller propellers were twisted to the same angle. The single-propeller model was run at 12060 rpm at zero pitch angle to give a self-propelled condition, and the double-propeller model was self-propelled at 19250 rpm in the same condition. The forces and moments were measured by a six-component strain gage balance internally mounted with the effective pitch center located 26.3 in. from the nose.‡

Contents

All of the forces and moments were put into coefficient form and plotted vs the angle of pitch. For each model, the self-propelled and nonpropelled cases were plotted together for comparison. There were no significant side forces or yawing moments measured with proper alignment of the models.

Consider first the results for the single-propeller model. In Fig. 1 the drag coefficient is shown vs pitch angle for both the unpropelled (no propeller) and self-propelled cases. A true self-propelled condition was achieved by simply zeroing the axial force during the test for $-4° < \alpha < 4°$. This procedure produced small errors $[C_D \approx (C_D)\text{unpropelled}/10]$ for larger pitch angles. The drag of the unpropelled body increased rather sharply for positive pitch angles. The data show unexpected "jumps" at two points. The tests were repeated, and the same behavior was noted. Care also was taken to insure that there was no rubbing of the strut or the supply lines against the model. The balance returned to a true zero after each individual run (each data point corresponds to a separate run since the model had to be manually adjusted to each pitch angle) and this would seem to rule out any spurious forces or contact. The "sail" appendage could produce such "jumps". Some users may, however, prefer to fair a curve through the data points and regard the jumps as scatter.

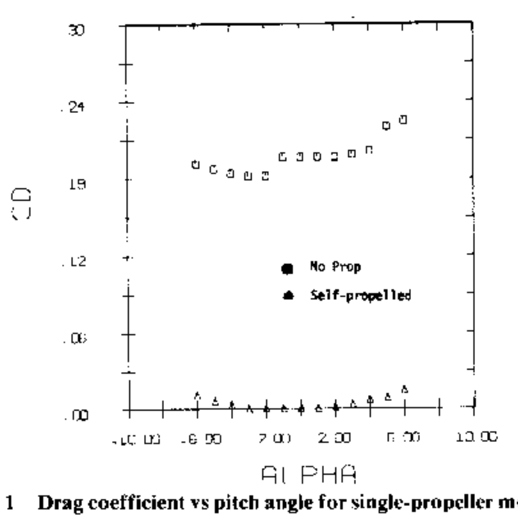

Fig. 1 Drag coefficient vs pitch angle for single-propeller model.

The lift coefficient data are given in Fig. 2 where it can be seen that the addition of running propellers increases the lift curve slope. The change is more pronounced at positive pitch angles. The increase in lift curve slope is due to at least two effects. The first is the component of thrust normal to the wind vector which gives an increase in C_L proportional to the sine of the pitch angle. The second effect is a normal body

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Index categories: Marine Hydrodynamics, Vessel and Control Surface; Marine Propulsion.

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‡This was incorrectly reported in the back-up document as being at the model center of gravity.

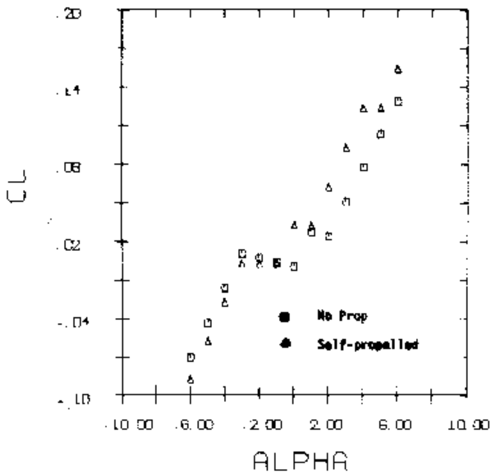

Fig. 2 Lift coefficient vs pitch angle for single-propeller model.

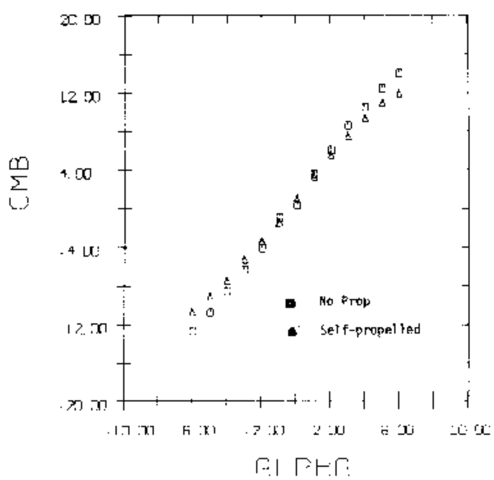

Fig. 3 Pitching moment vs pitch angle for single-propeller model.

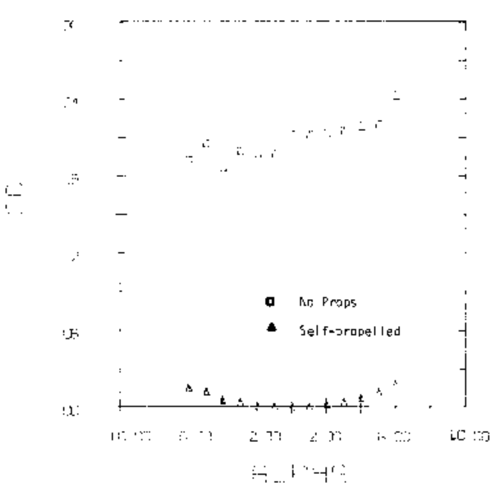

Fig. 4 Drag coefficient vs pitch angle for dual-propeller model.

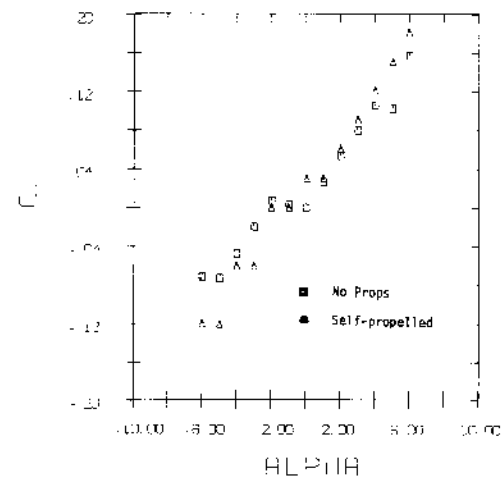

Fig. 5 Lift coefficient vs pitch angle for dual-propeller model.

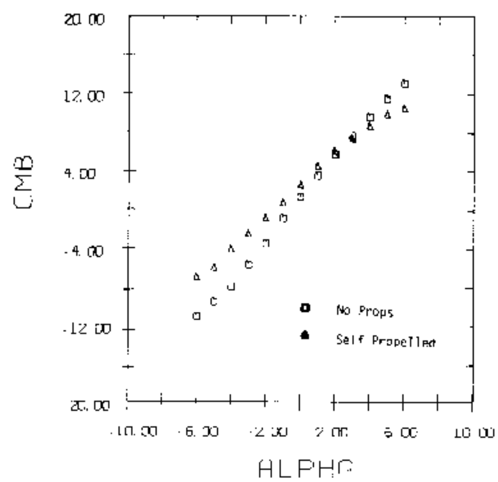

Fig. 6 Pitching moment vs pitch angle for dual-propeller model.

force on the propeller when the body is pitched, produced by turning the fluid passing through it.

Pitching moment results are presented in Fig. 3. A small decrease in the slope of the curve is produced by the propeller. Since the thrust is always along the body axis, only the effects of fluid turning by the propeller when the body is pitched are felt here.

Figures 4-6 contain the results obtained for the dual-propeller model. The drag coefficient results in Fig. 4 are qualitatively similar to those for the single-propeller case. The no-propeller drag is somewhat higher, presumably because of the presence of the exposed shafts.

The effect of propulsion on the variation of the lift coefficient with pitch angle (Fig. 5) is perhaps less but similar in character to that on the single-propeller model. On the other hand, the spread for the propelled and unpropelled arrangement for pitching moment in this case is larger than that for the single-propeller model.

Acknowledgment

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