Separation over a Flat Plate-Wedge Configuration at Oceanic Reynolds Numbers

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Theme

IN the design of hydrodynamic vehicles, knowledge of the factors influencing flow separation is essential. The occurrence of boundary-layer separation over the compression corner formed by the wing and control surface of a high-speed vehicle has been well documented. To this author's knowledge, there has been no effort whatsoever to investigate the similar phenomenon that occurs at extremely low velocities. In the design of deep submersible vehicles for scientific exploration, control surfaces and other vehicle components are subject to low-speed flow separation. The intent of this paper is to present experimental results for a flat plate-wedge configuration at very low Reynolds numbers, typical of deep submersibles, and draw some comparisons with separation phenomena occurring at much higher Mach and Reynolds numbers.

Contents

In the analogous low-speed situation, the presence of figuration, the mean flow experiences an increase in pressure in the vicinity of the compression corner. Rising streamwise pressure results in flow separation ahead of the corner.

In the analogous low-speed situation, the presence of the wedge gives rise to two different pressure tendencies. In the region away from the surface, yet within the zone of influence of the wedge, the fluid accelerates in the stream direction consistent with a favorable pressure gradient. Near the surface, the pressure field is dominated by the decelerative effect of the wedge obstructing the normal flow path. Here the fluid experiences an adverse pressure gradient, which if sufficiently strong results in a corner separation bubble.

Two experiments were designed to investigate this latter low-speed flow separation. One experiment utilized a hydrodynamic tow tank facility and covered a range of freestream Reynolds numbers (Re_{∞}) from 0.5 to 1.0 × 10^4/ft. Data was limited to flow visualization using tracer particles suspended in the water and subsequent optical measurements on streak line photographs.

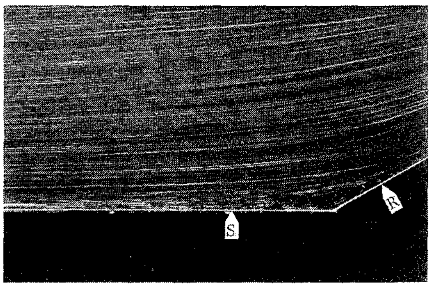


Fig. 1 Wedge flow separation, tow tank facility, visualization by aluminum tracer particles.

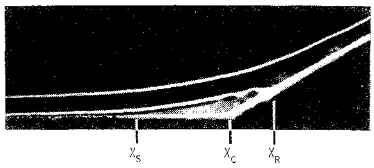
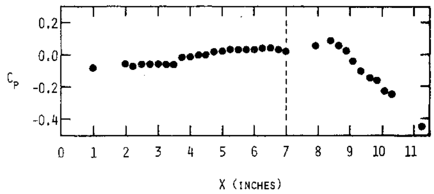


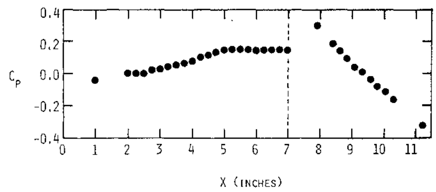
Fig. 2 Wedge flow separation, wind-tunnel test, smoke flow visualization.

A second experiment with a low-turbulence wind tunnel covered the range of Re_{∞} from 0.8 to 1.8 × 10^5/ft. In addition to conventional smoke photographs, the models were equipped with streamwise and spanwise static pressure taps. For typical sea water properties at approximately 2000 m,[1] this range of Reynolds numbers would correspond to vehicle velocities of 0.1 to 3.0 fps.

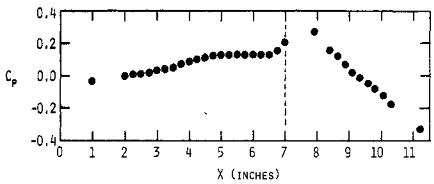
In both experiments, 20° and 30° wedge angles were tested. On the tow tank model, the wedge was positioned 11 in. downstream of the plate leading edge. Model span was 3 in. On the wind-tunnel model, the wedge was located 7 in. from the leading edge and the span measured 9



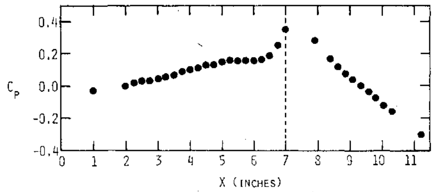
a) Re_{∞} = 8.81 × 10^4/ft



b) Re_{∞} = 1.24 × 10^5/ft



c) Re_{∞} = 1.49 × 10^5/ft



d) Re_{∞} = 1.74 × 10^5/ft

Fig. 3 Surface pressure coefficient vs distance from plate leading edge, 20° wedge.

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

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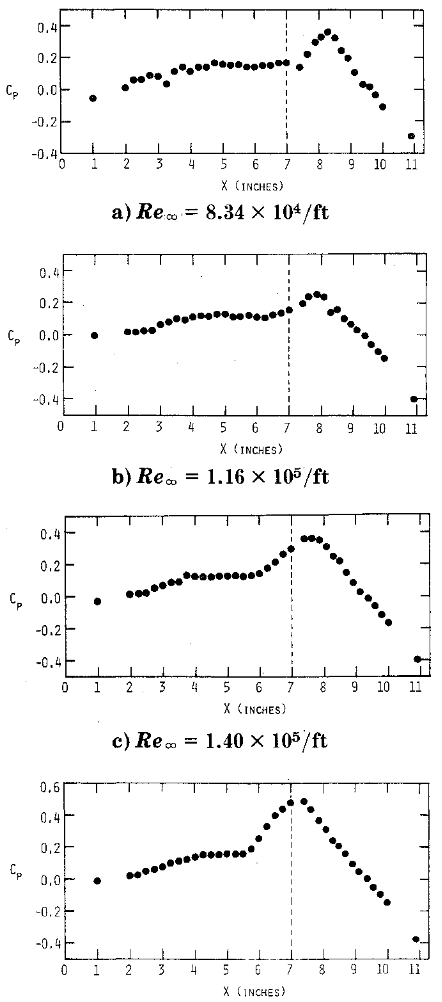

a) $Re_\infty = 8.34 \times 10^4$/ft

b) $Re_\infty = 1.16 \times 10^5$/ft

c) $Re_\infty = 1.40 \times 10^5$/ft

d) $Re_\infty = 1.80 \times 10^5$/ft

Fig. 4 Surface pressure coefficient vs distance from plate leading edge, 30° wedge.

in. All models were side-plated. Further details of the experimental facilities and test models can be found in Ref. 2.

A typical streak line photograph from the tow tank experiments is shown in Fig. 1. Limits of the recirculation eddy are indicated by an S and an R signifying the points of separation and reattachment. A sample smoke flow photograph from the wind-tunnel tests is contained in Fig. 2.

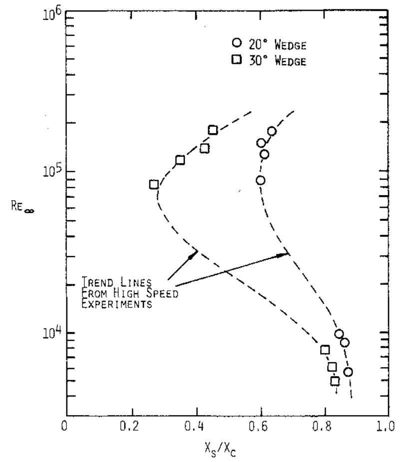

Fig. 5 Influence of Reynolds number on location of flow separation.

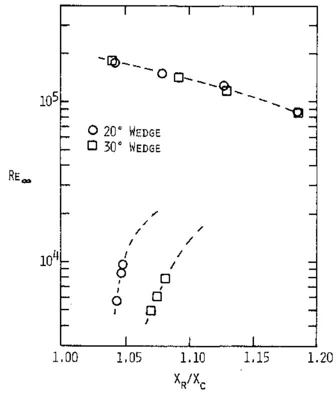

Fig. 6 Influence of Reynolds number on location of reattachment point.

Static pressure along the centerline of the wind-tunnel models was measured for each set of test conditions. Figure 3 contains plots of pressure coefficient (C_P)† vs distance from the model leading edge for the 20° wedge. Figure 4 contains similar data for the 30° wedge. All of the pressure profiles exhibit similar characteristics; an adverse pressure gradient preceeding separation, followed by constant pressure within the separation bubble, then rising pressure to the point of reattachment, finally decreasing pressure after reattachment. The pressure rise to reattachment may be wholly or partially the result of transition occurring within the separated shear layer. Decreasing pressure past reattachment is consistent with the acceleration of the main stream fluid past the wedge.

The influence of Reynolds number on the location of separation is dependent on the character of the flow, a fact well established for high Mach number flows.[3] For the present study, Fig. 5 depicts the relationship between Re_∞ and the location of separation (X_S). An increase in Re_∞ produces an upstream movement of X_S provided the separated shear layer remains laminar. When the shear layer is transitional (or turbulent), transport of momentum across the shear layer is greatly increased resulting in a deflation of the separation bubble. Consequently, for transitional separation an increase in Re_∞ produces greater momentum transfer and a delay in separation. The dashed curve in Fig. 5 connecting the higher and lower Reynolds number data is purely a trend line based upon Re_∞ dependence reported for supersonic studies. Figure 6 depicts the dependence of the reattachment point on free-stream Reynolds number. There is insufficient data to determine the precise shape of the curve connecting the higher and lower Reynolds number points. Wedge angle appears to have negligible affect on reattachment location at transitional Reynolds numbers.

References

[1]Riley, J. P. and Skirrow, G., eds., "The Physical Properties of Sea Water," *Chemical Oceanography,* Vol. 1, Academic Press, New York, 1965, pp. 73–120.

[2]Campbell, D. R. and Mueller, T. J., "A Numerical and Experimental Investigation of Incompressible Laminar Ramp-Induced Separated Flow," Rept. UNDAS TN-1068-M1, 1968, Dept. of Aerospace Engineering, Univ. of Notre Dame, Notre Dame, Ind.

[3]Johnson, C. B., "Pressure and Flow-Field Study at Mach Number 8 of Flow Separation on a Flat Plate with Deflected Trailing-Edge Flap," TN D-4308, 1968, NASA.

†C_P defined as $(P - P_\infty)/q_\infty$.