Technical Comments

Comment on "Shaping of Axisymmetric Bodies for Minimum Drag in Incompressible Flow"

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REFERENCE 1 is something of a milestone in hydrodynamics; the first publication in the open literature of a complete method for calculating the resistance of a body of revolution, so that the drag minimization problem is taken away from the empiricism of the test tank and put on the computer. It is not a new concept in aerodynamics, of course,† but in hydrodynamics it was not attempted until 1969, principally because: a) it was generally felt that a laminar boundary layer could not be maintained at large Reynolds numbers (*Re*), (despite Carmichael's [3] clear proof to the contrary); and b) no one seemed willing to fund the rather considerable effort of constructing a computer program, and then comparing its output with experiment. In 1969, it became possible for us to break through this log jam, to model the problem, and to build and test a full-scale semioptimized low drag body. In their preoccupation with sophisticated methods of optimizing the mathematical model, the authors of Ref. 1 have understandably forgotten to give a little credit to this earlier work. Yet the story is interesting, and is offered as a footnote to a truly excellent paper.

In 1967, in connection with a study of high-speed (200 knot) airships, the writer concluded, from the literature available at that time, that extensive laminar flow was possible at large Reynolds numbers. A typical two-dimensional result for a linear velocity gradient

$$u = u_o(1 + \theta x) = u_o + \Delta u \quad (1)$$

is reproduced in Fig. 1, based on Thwaites[4] criterion for instability and Granville's[5] spontaneous transition criterion. Other classes of velocity distribution (exponential, for example) give even higher critical Reynolds number predictions. Additionally, if it is in water, and if heat is to be rejected from the body, its rejection through a skin cooler will presumably further stabilize the Schlichting-Tolmien waves, in accordance with Schlichting's[6] postulate.

In late 1968, M. Mead‡ asked the writer if the resistance of a torpedo could be reduced to 25% of the then current state-of-the-art. The writer replied that a substantial reduction could probably be obtained by designing for extensive laminar flow, and after transition, by so shaping the body that the boundary layer rapidly approached Stratford's[7] "zero skin friction" velocity profile. It was agreed to construct a computer program which would model the axisymmetric laminar, transition and turbulent boundary layers, with potential flow outside the displacement thickness, and to then manually seek an optimum shape. We envisioned "pop-up" testing at sea of a full-size prototype following Carmichael.[3]

For reasons of convenience, we performed the work as a subcontractor to Westinghouse's Oceanic Division, rather than as prime. S.L.Quick monitored the program for Westinghouse, and asked the writer to find an independent

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†See, for example, the summaries given by Thwaites.[2]

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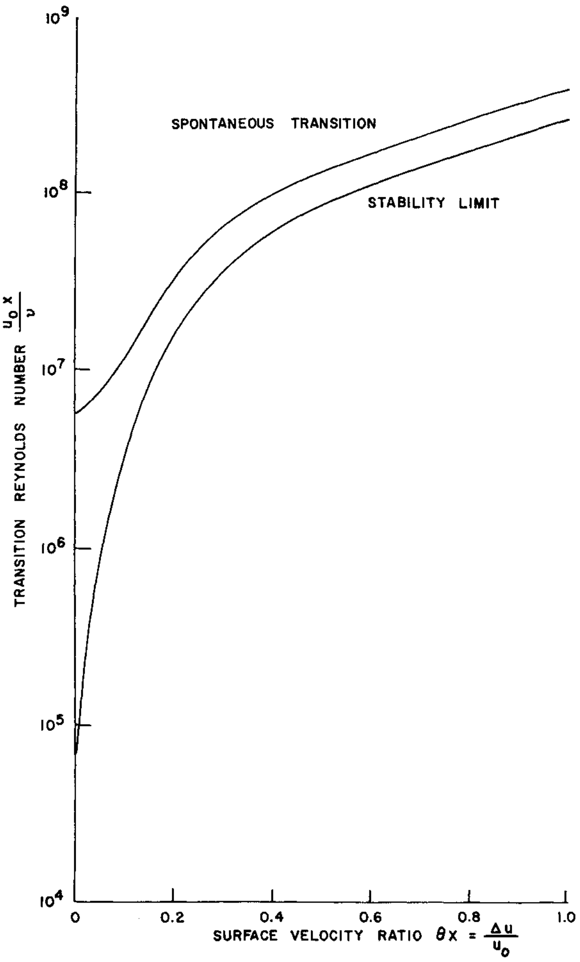

Fig. 1 Transition Reynolds number in a linear velocity gradient.

consultant, not in the Payne team, to assist him. Because of Ref. 8, we suggested F. Goldschmied. He accepted the assignment, and in due course, he brought in A. T. McDonald to assist him. Both were technical referees at this time, and did not contribute to the Payne effort, which Goldschmied, at least, being an advocate of boundary-layer suction, initially felt to be unsound.

The bulk of the analytical work was carried out by E. G. U. Band§ and the programing by A. Jolly of Wyle Laboratories, Huntsville Division. By comparison with Ref. 1, our methods of seeking an optimum shape were crude, and relied heavily on personal intuition in making a configuration change before the next "run." But even so, the shape of our full-size prototype was almost identical to the best volume-optimized shapes of 1974. Eventually, Westinghouse took over the program and used the NSRDC tank to test our prototype instead of the "pop-up" tests. After some initial teething troubles, the tank data generally confirmed the predictions of the mathematical model.

For the record, we completed the computer program, obtained a reasonably optimized profile, and designed and built the prototype in an elapsed time of about six months. It was clearly impossible to build much sophistication into the optimization procedures in such a tightly compressed program. The authors of Ref. 1 have not only repaired this omission most elegantly, but have continued to improve the drag model as new theory and data have become available.

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References

[1]Parsons, J.S., Goodson, R.E., and Goldschmied, F.R., "Shaping of Axisymmetric Bodies for Minimum Drag in Incompressible Flow," *Journal of Hydronautics,* Vol. 8, July 1974, pp. 100-107.

[2]Thwaites, B., editor, *Incompressible Aerodynamics,* Oxford at the Clarendon Press, Oxford, England, 1960.

[3]Carmichael, B.H., "Underwater Vehicle Drag Reduction Through Choice of Shape," AIAA Paper 66-657, June 1966.

[4]Rosenhead, L., ed., *Laminar Boundary Layers,* Oxford at the Clarendon Press, Oxford, England, 1963, p. 303.

[5]Granville, P.S., "The Calculations of Viscous Drag of Bodies of Revolution," Rept. 849,1953, The David Taylor Model Basin, Naval Ship and Research Development Center, Washington, D.C.

[6]Schlichting, H., *Boundary Layer Theory,* 6th Ed., New York: McGraw-Hill, 1968.

[7]Stratford, B.S., "An Experimental Flow with Zero Skin Friction Throughout its Region of Pressure Rise," *Journal of Fluid Mechanics,* Vol. 5, Pt. 1, Jan. 1959.

[8]Goldschmied, F.R., "Integrated Hull Design, Boundary-Layer Control, and Propulsion of Submerged Bodies," *Journal of Hydronautics,* Vol. 1, July 1967, pp. 2-11.

Reply by Authors to P. R. Payne

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and

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FIRST, P.R.Payne's compliments on our paper are appreciated. The paper's achievements are based on combining the optimization algorithm and a state-of-the-art hydrodynamics model which exists in the open literature. Recognizing that more work is needed in the drag modeling area, the optimization algorithm has been developed independent of the hydrodynamics code so that model in optimization improvements can be easily incorporated into the method. For example, the transition criterion is critical in any drag model. In this regard, the third author has recently presented a new transition prediction algorithm to be used in this optimization procedure.[1]

Second, Payne gently chided us for forgetting to credit his earlier work. We are not aware of any previous efforts by Payne and his associates in the area of automatic design of optimum bodies for minimum drag. Payne, moreover, does not quote any publication documenting such work which we might have used.

Finally, the third author believes it is misleading to be classified as "an advocate of boundary-layer suction"; rather, he is an advocate of the optimum integration of hull design, boundary-layer control, and jet propulsion (Payne's Ref. 8). Such integrated design is another problem that may be handled by the optimization strategy of the present paper.

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References

[1]Goldschmied, F.R., "Transition Prediction Algorithm for Axisymmetric Submerged Bodies," U.S. Navy Ordnance Hydroballistic Advisory Committee Meeting, Newport, R.I., Oct. 1974.

Addition to the Reply by Author to a Comment by P. R. Payne

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THE reply by Sallet which was published in this journal (Vol. 8, No. 3, July 1974, p. 123) was in response to a different comment by Payne, and was not in response to the comment which is printed immediately preceeding the reply. In the original version of Payne's comment, from which the reply was drafted and which was approximately 1/5 the length of the printed version, Payne gave a short conclusion to which the author's reply was addressed. In essence this conclusion is now reflected in the two paragraphs on p. 121 below Eq. (7). It is misleading to the reader if the discusser changes his discussion after he has read the reply by the author. At the very least, the discusser should notify the author that the comment was changed.

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