Journal of Ship Research, Vol. 20, No. 4, Dec. 1976, pp. 233–234

Comments on Hess: "On the Problem of Shaping an Axisymmetric Body to Obtain Low Drag at Large Reynolds Numbers"

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THE TITLE PAPER[4] deals with a classical problem and it invites several comments to fully explore its technical impact.

1. The author states that operational speeds of underseas vehicles (no specification is made of Reynolds number) are high enough to be detrimental to the maintenance of laminar boundary layer on an axisymmetric body; this is contradicted by the *Dolphin* test data reported by Carmichael [1][5] showing that laminar flow was maintained over 50 percent of the body length up to 60 knots in seawater (length Reynolds number ~35 millions). The author wishes to assume the boundary layer to be entirely turbulent; this is not unreasonable for many underseas applications. This assumption was used by Goldschmied [2] for large underseas vehicles. It is our belief that the general drag optimization method should comprise the full range of boundary-layer options and that specific assumptions should be made only for particular missions.

2. Reference is made by the author to a Purdue University report by Parsons and Goodson [3]. Since this report is not readily available to the reader, it would be proper to reference also our published journal paper [4].

It is stated that we concentrated on reducing drag by obtaining the greatest possible extent of laminar flow on the body, on the basis of a given transition criterion. The unstated implication is that we did not investigate the optimization of all-turbulent bodies; this is not true, since in reference [3] (pp. 90–92) we reported on three optimization runs made with laminar/turbulent transition tripped at 5 percent length and for a constant volume Reynold's number corresponding to the upper end of the Gertler [5] test range. The best all-turbulent body was termed I-36 and its profile and velocity distribution are shown in Fig. 30 of reference [3]. The computed drag coefficient was $C_D = 0.020$, in good agreement with that of the best Gertler [5] body. The significant result of the three all-turbulent optimization runs is the fact that the volume drag coefficient varies but little for wide variations of the geometric profile parameters; therefore, for the all-turbulent application domain, we concluded that means other than body shaping alone are needed to reduce drag and therefore propulsion power. In his conclusion the author acknowledges that his work strongly verifies this fact, and we are in agreement.

3. From the optimization viewpoint, the reported investigations of prolate spheroids (with and without conical boattails) and of constant-pressure bodies (similar to the Reichardt [6] design) are limited parametric studies in the sense that only one parameter, that is, fineness-ratio, was systematically varied in an attempt to reduce drag. The author concludes that the lowest drag coefficient (on volumetric basis) occurs for fineness ratios between three and four. Thirty-seven years ago, Young [7] performed a similar parametric investigation of the drag of axisymmetric equal-volume bodies against fineness ratio (Table 3 and Fig. 11 of Reference [7]) and found a minimum drag for fineness ratios ranging between 4.5 and 5.5. Using a more general body class with five geometric parameters, we reported that a large number of bodies in this class, with fineness ratios ranging between five and seven, had drag coefficients within one percent of the best I-36 body [3] and of the best Gertler [5] body.

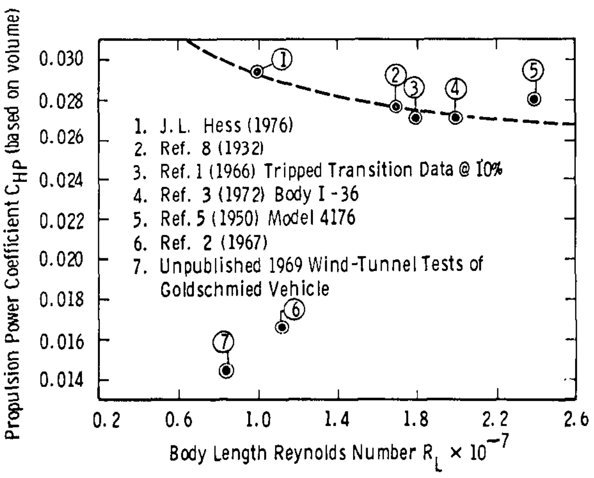

Fig. 1 Propulsion power assessment for all-turbulent vehicles

4. As stated in the foregoing, we are in agreement with the author that body shape alone cannot yield substantial drag reduction for the all-turbulent case. The author mentions (without specific references) that such drag reduction may be achieved by one of a number of advanced techniques, such as surface suction, polymer additives, or compliant surfaces, and omits the Goldschmied [2] approach, which is based on all-turbulent boundary layers and is backed by experimental wind-tunnel evidence.

In the design of large underseas self-propelled vehicles, the main consideration is the total power required for propulsion of the given volume with suitable empennage (tail fins) at the specified speed. The drag is of primary importance only for the limited application of towed bodies. A general assessment of the situation can easily be made, as shown in Fig. 1, by plotting the power coefficient C_{HP} (based on volume) against the Reynolds number (based on body length). The guidelines are as follows:

(*a*) Transition is always triggered or assumed near the nose,

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[4] Hess, John L., "On the Problem of Shaping an Axisymmetric Body to Obtain Low Drag at Large Reynolds Numbers," JOURNAL OF SHIP RESEARCH, Vol. 20, No. 1, March 1976, pp. 51–60.

[5] Numbers in brackets designate References at end of note.

Manuscript received at SNAME headquarters July 7, 1976.

at 5 per cent or 10 percent length; that is, the boundary layer is entirely turbulent in accordance with the preference of the author.

(*b*) An additional drag $C_D = 0.003$ is imposed on all bodies Nos. 1 through 7 to account for the empennage (tail fins) resistance.

(*c*) Stern wake-propeller efficiency of 85 percent is assumed for bodies Nos. 1 through 5.

(*d*) For the Goldschmied vehicle, a pump efficiency of 90 percent is assumed (Nos. 6 and 7).

It is seen that the present Hess results, as well as Nos. 2, 3, 4, and 5, follow a definite trend line and demonstrate that no significant power reduction is possible for conventional all-turbulent bodies with stern propellers.

If the Goldschmied data points Nos. 6 and 7 are considered, however, it is seen that propulsion power is reduced in half, even with the boundary layer tripped at 10 percent length and with the same empennage drag. No distributed surface suction, polymer additives, or compliant surfaces are required.

5. Considerably better results may be obtained for the Goldschmied vehicle from a system optimization study which would produce the best possible match between the hull profile, the single suction-slot, the pump, and the stern propulsive jet. Mathematical models for the several components are available and can be combined into a system. For instance, five parameters may be allocated to the hull profile, two parameters to the suction slot, two parameters to the pump, and one parameter to the propulsive jet; the ten parameters may then be simultaneously optimized by the methods of reference [4], subject to a set of suitable constraints.

References

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