Technical Comments

Comment on "An Experimental Model for the Sharp Flat Plate in Rarefied Hypersonic Flow"

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A RECENT paper[1] by McCroskey, Bogdonoff, and McDougall reports some careful measurements of fluid properties past the sharp leading edge of a fixed plate in a hypersonic stream of nitrogen. These results show that downstream of the so-called merged layer the strong interaction theory of hypersonic viscous flow (HSIT) correctly predicts the shock shape and the wall pressure. However, the authors of Ref. 1 choose a position for the outer edge of the boundary layer (see their Fig. 5) in a way that is seemingly arbitrary but which is in clear disagreement with the prediction of the complete HSIT (e.g., Refs. 2 and 3). According to this theory, the ratio of the outer edge of the boundary layer to that of the shock wave is, for $\gamma = 1.4$, less than 0.593 by a quantity $0(\bar{\chi}^{-1})$ when $\bar{\chi}$ is large.†

This Comment points out that the density variation with distance from the wall observed in Ref. 1 is in qualitative agreement with HSIT. Figure 1 shows the extent of the agreement, and it is believed that, considering it in conjunction with the excellent agreement already mentioned, there is some justification for adopting the flow model implied by HSIT (e.g., Ref. 2, p. 164) rather than that in Fig. 1 of Ref. 1. The principal difference between the two is most pronounced at the junction between the strong interaction region and the merged layer, the latter being defined on p. 1580 of Ref. 1 as a region "beginning at the first point along the plate where any part of the phenomenon can be described by the equations of continuum fluid mechanics. The downstream limit occurs when a distinct inviscid layer of flow develops between the shock wave and the viscous layer adjacent to the plate." There is no satisfactory theory of the merged layer. (It is even doubtful whether it is a valid conception.) It seems, however, that in the layer virtually all the terms of the Navier-Stokes equations are of equal significance, but that towards the downstream end the viscous terms become negligible in the upper part of the layer, while in the lower part, the equations reduce to the boundary-layer form. The lack of a satisfactory theory means that on theoretical grounds the junction with the strong interaction region can only be estimated to occur when $\bar{V} \ll 1$, where $\bar{V} = M(C/Re_x)^{1/2}$. The experimental results in Ref. 1 indicate that HSIT is valid if $\bar{V} \leq 0.15$. At $\bar{V} = 0.15$ the flow model adopted in Ref. 1 has the edge of the boundary layer coincident with the shock, whereas HSIT asserts that the two are still quite distinct.

As further evidence in support of HSIT, we may compare the values of p_w/p_s predicted by the theory with the experimental results in Fig. 13 of Ref. 1. Here p_w is the wall pressure and p_s the pressure just behind the shock, at a particular value of $\bar{\chi}$. So far as one can estimate from Fig. 13 by using a ruler, $p_w/p_s = 0.57$ at $\bar{V} = 0.15$, $\bar{\chi} = 85$; according to HSIT, $p_w/p_s \doteqdot 0.60$ when $\bar{\chi} \gg 1$.

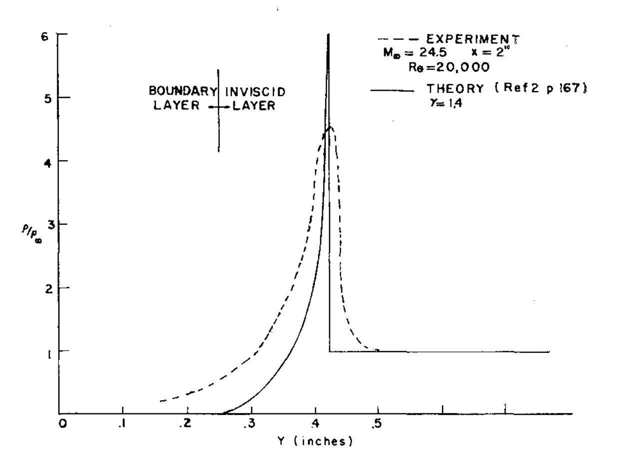

Fig. 1 The extent of the agreement of the experiments of Ref. 1 with the strong interaction theory of hypersonic viscous flow.

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† The notation of Ref. 1 is used in the present Comment.

References

[1] McCroskey, W. J., Bogdonoff, S. M., and McDougall, J. G., "An Experimental Model for the Sharp Flat Plate in Rarefied Hypersonic Flow," *AIAA Journal*, Vol. 4, No. 9, Sept. 1966, pp. 1580–1587.

[2] Stewartson, K., "On the Motion of a Flat Plate at High Speed in a Viscous Compressible Fluid II," *Journal of the Aeronautical Sciences*, Vol. 22, 1955, p. 303.

[3] Stewartson, K., *The Theory of Laminar Boundary Layer in Compressible Fluids*, Oxford, 1964, p. 161.

Reply by Authors to K. Stewartson

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THE term "merged" used in the subject paper refers to a range of x in which viscous effects are significant throughout the shock layer. In this range, hopefully, a continuum model may be adequate. Downstream of the merged layer an inviscid region appears in some way, with viscosity important between this region and the body. Outside the inviscid region lies what may be interpreted as a classical shock wave. The experimental results of the subject paper would indicate that the inviscid region is thin when it first appears and is distinguishable, and that its thickness grows downstream. Thus we do not agree with Professor Stewartson's

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