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Reply by the Authors to F. Motallebi

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MOTALLEBI argued that the velocity-profile family of Huang et al.[1] failed to predict the boundary layer at low Reynolds numbers. His argument was based on the observation of experimental data of Winter and Gaudet[6] and Stalmach.[7] In particular, in Figs. 3a ($M_\delta = 2.2$, $Re_\theta = 14{,}640$) and 5a ($M_\delta = 3.7$, $Re_\theta = 2115$), the data close to the wall show higher velocity values than those predicted by the profile family of Huang et al. Motallebi attributed the failure to predict the velocity profile near the wall as "Reynolds number influence" and argued that extra information is needed to explain the low Reynolds number behavior. In his comments, he cited his own reference (Ref. 9) as the source of the explanation for the extra information. But Ref. 9 was simply a letter to the authors to enquire how to get a converged solution with the conditions specified in Huang et al.[1] and the only relevant remark was "More explanations were needed." Now, the velocity profile in a zero-pressure-gradient boundary layer is uniquely defined by any chosen thickness (plus the Reynolds number based thereon) and by the Mach number and heat-transfer parameter. Our velocity-profile family does, of course, need various pieces of empirical information (e.g., the Van Driest transformation and the useful fact that the wake parameter is nearly independent of Mach number). Motallebi apparently failed to observe that although the Reynolds number in Fig. 6a ($M_\delta = 3.7$, $Re_\theta = 10{,}484$) is smaller than that of Fig. 3a, the data in Fig. 6a show a good match to the predicted profile. Note that although the freestream Mach number in Fig. 6a is larger than that in Fig. 3a, the increase of the freestream Mach number tends to

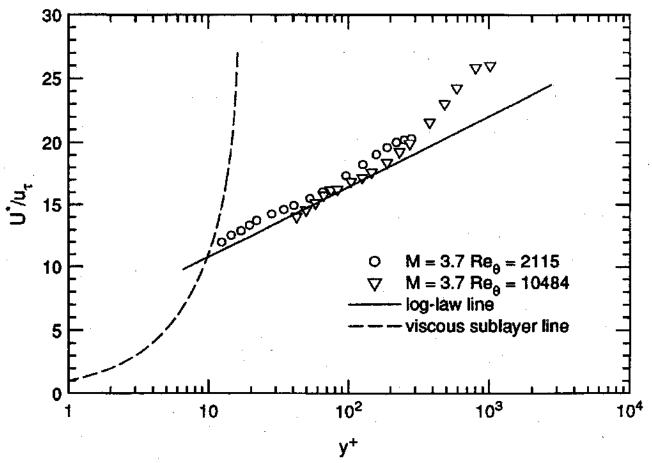

Fig. 1 Transformed velocity profiles (experimental data of Stalmach).

reduce the effective Reynolds number (see Huang et al.[1] for further discussion).

Near the wall (say, $y^+ < 5$), all experimental data have to satisfy

$$\frac{dU^+}{dy^+} = \frac{\mu_w}{\mu} \tag{1}$$

By applying the Van Driest transformation to Eq. (1) and performing the integration from the wall following the assumption that $\mu_w/\mu = (T_w/T)^{0.7}$, one may get a sublayer transformed velocity profile as a function of molecular Prandtl number Pr and two dimensionless parameters

$$M_\tau \left\{ \equiv \frac{u_\tau}{a_w} = \frac{u_\tau}{\sqrt{(\gamma - 1)c_p T_w}} \right\}$$

and

$$B_q \left(\equiv \frac{q_w}{\rho_w c_p u_\tau T_w} \right)$$

(the details of the viscous-sublayer analysis are discussed in Huang and Coleman[2]). Away from the wall ($y^+ > 30$), experimental evidence indicates that the data are good collapse to the incompressible law of the wall line, when the velocity is transformed to the Van Driest variable.

It is difficult to believe that the experimental data quoted by Motallebi, which show log-law regions for y^+ as low as 7 (see Fig. 3a, the lower limit usually quoted is 30–50), are entirely correct. Here, for purpose of illustration, the data of Stalmach are plotted (cases 58020301 and 58020306) in Fig. 1. In the figure, both log-law and viscous-sublayer lines are also shown. In our opinion, the main cause of the discrepancy between data and our predicted profiles is experimental error or scatter—these are rather old data!—rather than an insufficient number of parameters or missing physical information in our analysis, as suggested by Motallebi.

Motallebi seems to overlook many other low Reynolds number compressible flow data included in Ref. 7, which show well-behaved sublayer and buffer-zone characteristics. Perhaps the most interesting comparison of the low Reynolds number compressible near-wall flow can be seen from the paper by Huang and Coleman,[2] in which the data were obtained from a direct numerical simulation of compressible channel flow. Unlike the data shown by Motallebi, the direct numerical simulation data of Huang and Coleman[2] clearly showed three distinct regions—the sub, buffer, and log layers.

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