Technical Comments

Comments on "Boundary-Layer Turbulence Measurements with Mass Addition and Combustion"

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IN Ref. 1 an investigation was made of the turbulent velocity fluctuation field in an isothermal boundary layer with homogeneous injection. The authors measured the shear stress distribution across the boundary layer and displayed the results in Fig. 5 of their paper as normalized shear stress as a function of velocity ratio ϕ.

In Ref. 2 Meroney developed an analytical expression for the velocity profile across the turbulent transpired boundary layer together with an approximate technique to determine the normalized shear stress distribution. He proposed for a velocity profile near the wall

$$u^+ = y^+ + \tfrac{1}{2}(v_w^+)y^{+2} + (1/3!)(v_w^{+2})y^{+3} + U_4^+y^{+4} \quad (1)$$

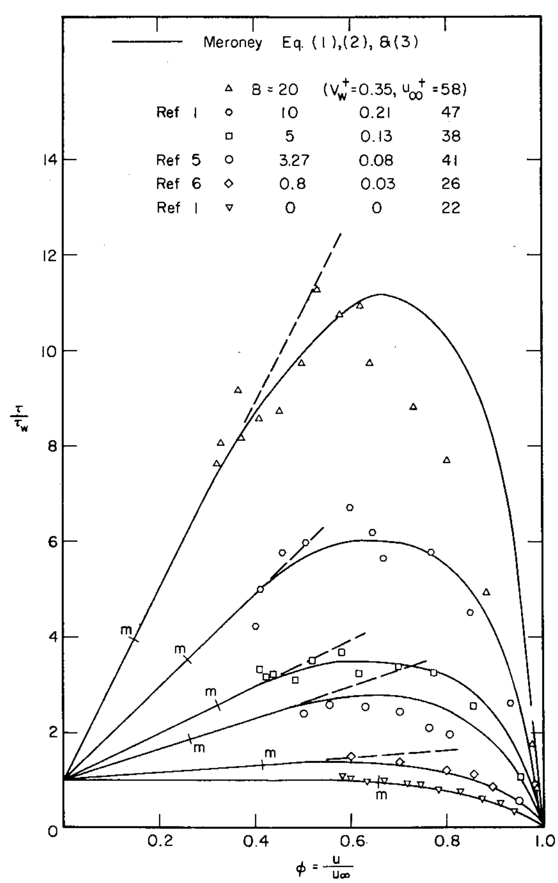

Fig. 1 Shear stress distribution across the isothermal turbulent boundary.

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and farther from the wall

$$u_\infty^+ - u^+ = \frac{v_w^+}{4k^2}\ln^2\frac{y^+}{\delta^+} - \frac{1}{k}(1 + v_w^+u_\infty^+)^{1/2}\ln\frac{y^+}{\delta^+} + \frac{\pi}{k}(1 + v_w^+u_\infty^+)^{1/2}\left[2 - \omega\left(\frac{y^+}{\delta^+}\right)\right] \quad (2)$$

where the nondimensional nomenclature have their conventional definitions, and the matching conditions have been computed to be

$$y_m^+ = 15.67 - 860(v_w^+)^{1/2}/u_\infty^{+2} - 11.4v_w^{+0.45}$$

$$U_y^+ = -5.4 \times 10^{-4} - 1.3(v_w^+)^{1.7}/u_\infty^{+2} - 1.6 \times 10^{-2}v_w^{+1.7}$$

The shear profile may be determined from the velocity profiles from

$$\frac{\tau}{\tau_w} \simeq (1 + v_w^+u^+) - (1 - v_w^+u_\infty^+) \times \frac{2\int_0^{y/\delta}(u^+)^2d\xi - u^+\int_0^{y/\delta}u^+d\xi}{2\int_0^1(u^+)^2d\xi - u_\infty^+\int_0^1 u^+d\xi} \quad (3)$$

Near the boundary Eq. (3) reduces to

$$\tau/\tau_w \simeq 1 + v_w^+y^+ + (v_w^{+2}/2!)y^{+3} + v_w^+U_4^+y^{+4} \quad (4)$$

Figure 1 compares the calculated distributions of shear stress from Eqs. (1–3) with the data displayed in Fig. 5 of Ref. 1. The comparison is good except at very high blowing rates. Figure 2 compares measured values of the normalized maximum shear stress with computed values. Equation (3) seems to provide better agreement with this variation than a previously suggested correlation by Tennekes in Ref. 3.

The rather large divergence of theory and data at high blowing rates in Fig. 1 may represent separation of the main flow from the transpired wall. If the flow parameters are compared with the somewhat limited criteria for attachment suggested by Hacker[4], this premise is strengthened. Hacker suggested an empirical blow-off criteria of $[(\rho v)_w/(\rho u)_\infty]Re^{1/5} = 0.08$ for air into air transpiration at low Mach numbers.

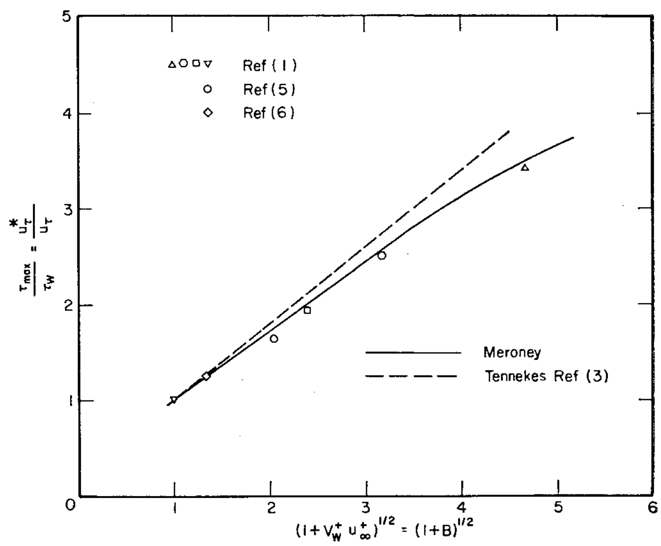

Fig. 2 Variation of pseudofriction velocity with mass transfer number.

When the mass transfer number B equals 20 for the data in Ref. 1, this expression equals approximately 0.11. In addition, the kink observed in the velocity profiles displayed as Fig. 2 of Ref. 1 for $B = 20$ suggests the presence of separation.

References

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Comments on "Ion-Neutral Propulsion in Atmospheric Media"

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In a recent paper, Christenson and Moller[1] have derived some performance parameters for an electrostatic "fan" in which the negative ions are produced by multiple point corona discharges. Their experimental findings qualitatively agreed with theory and showed a peak flow power efficiency

$$\eta = \tfrac{1}{2}\rho u^3/jV_0$$

to be 0.9%. Approximately 90% of the input electrical power jV_0 was found to be transferred into heat. Such low efficiency levels obviously do not make an attractive propulsion device. This negative finding is in agreement with that reached by the writer in an earlier analytical investigation[2] of electrostatic propulsion. In Ref. 2, the equations governing the one-dimensional electrostatic propulsion channel were solved numerically, permitting a reduction in simplifying assumptions.

The writing of the present Comments has been prompted primarily by Christenson and Moller's discussion of possible increased efficiency through reductions in ion mobility. Their indicated effort here is to effect this reduction by the utilization of pulsed high voltages, estimating that a reduction of the ion mobility in air by two orders of magnitude would result in a power efficiency of approximately 30%. However, it appears doubtful that such reductions of mobility will be accomplished by a pulsating applied field alone. Even if this indeed could be accomplished, serious inherent shortcomings of the device would still be retained, as can be demonstrated by the following considerations. Using the nomenclature of Ref. 1, the momentum added to the flow, i.e., the thrust produced per unit cross-sectional area is $\rho u^2 = (\epsilon/2)E_L^2$.

Now the collector field E_L cannot exceed the breakdown field E_b at the prevailing atmospheric conditions. In fact, engineering experience has shown that E_L would have to be appreciably below E_b if serious operating difficulties are to be avoided. Setting $E_L = E_b$ therefore represents an optimistic upper limit. Using $E_b = 3 \times 10^6$ v/m the maximum thrust produced is computed to be 0.832 psf.†. This upper limit on thrust is independent of the ion mobilities. It is apparent that very large areas of corona arrays would be required to produce thrust levels of any practical interest. Since the storage of large quantities of electrical energy is impractical aboard vehicles flying in the atmosphere, additional weight penalties would be incurred due to the power conversion and high-voltage conditioning equipment. Large corona array areas would also be detrimental to the over-all drag. It is in the light of these practical considerations that the possibility of a 30% power efficiency (neglecting internal drag losses) becomes more remote.

The writer is aware of the fact that the breakdown electric field can be exceeded in high frequency corona discharges. However, the work of Early and Martin[3] on pulsating field coronas (5–12 kc/sec) has shown that most of the added electrical energy in this operating mode goes into heating, ionization, and other energy states but not into directed momentum increase, which would augment thrust. Also not to be ignored is the fact that field pulsations will be detrimental to thrust by lowering the average value of E_L, all other conditions being held constant.

References

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† This is the sea-level thrust; with altitude, thrust would diminish because of the decrease in E_b.

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Reply by Author to A. Maciulaitis

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We agree with Maciulaitis that the low efficiency level does not indicate immediate construction of a useful aerodynamic propulsion unit of the type investigated. This, however, was not the intent of our study.[1] The purpose of the investigation was to obtain explicit theoretical performance relationships that could be validated by experimental results. One advantage in obtaining such closed-form expressions is that the gross physical behavior of the mechanism in question and the dependence of performance on certain physical parameters can more readily be determined. For example, we feel that the dependence of velocity, thrust, and power efficiency on the parameter ϕ is immediately made clear by the explicit relations in spite of the necessary assumptions.

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