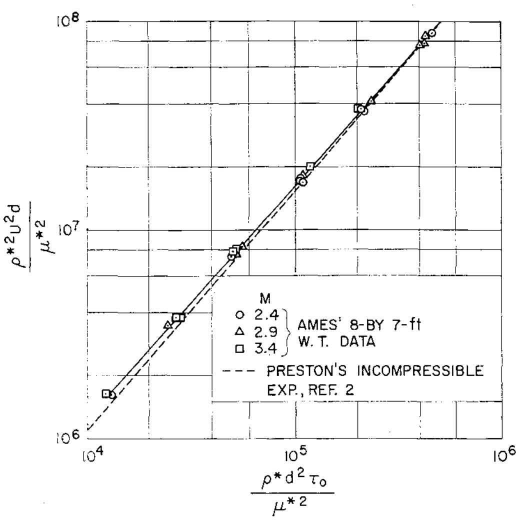

Fig. 1 Supersonic calibration of Preston tubes based on Sigalla's functional equation (1).

independently had applied a reference-temperature method in a slightly different manner than Sigalla to obtain a calibration curve for Preston tubes up to a Mach number of 3.4. This calibration curve is nearly the same as the original Preston incompressible curve. The latter investigation was conducted in June of 1964 on the side wall of the Ames 8- by 7-ft wind tunnel where the boundary layer is 5 to 7 in. thick, and the flow conditions are nearly adiabatic. The calibration factors of Sigalla and the writers are the same when based on reference-temperature flow conditions, except for the manner of substituting for the incompressible Δp term in the case of compressible flow. For the incompressible case, this Δp term corresponds to the difference between the Preston-tube pressure and the local static pressure (the dynamic pressure indicated by the Preston tube). For the compressible case, Sigalla chose to replace Δp with the expression $\Delta p = 0.5\rho^* U^2$ (where ρ^* is the reference density and U is the velocity indicated by the Preston tube), whereas the writers chose to replace Δp with the dynamic pressure indicated by the Preston tube, $\Delta p = 0.7M^2p$ (where M is the Mach number indicated by the Preston tube and p is the surface static pressure). For comparison with Sigalla's substitution, the latter equation is rewritten as $\Delta p = 0.5\rho U^2$ (where ρ and U are the density and velocity, respectively, indicated by the Preston tube). The two functional equations for calibrating Preston tubes, that of Sigalla and that of the writers, are listed below in terms of Sigalla's nomenclature

$$(\rho^* d^2 \tau_0)/\mu^{*2} = f_s[(\rho^{*2} U^2 d^2)/(\mu^{*2})] \quad \text{(Sigalla)} \quad (1)$$

$$(\rho^* d^2 \tau_0)/\mu^{*2} = f_h[(\rho^* \rho U^2 d^2)/(\mu^{*2})] \quad \text{(Hopkins-Keener)} \quad (2)$$

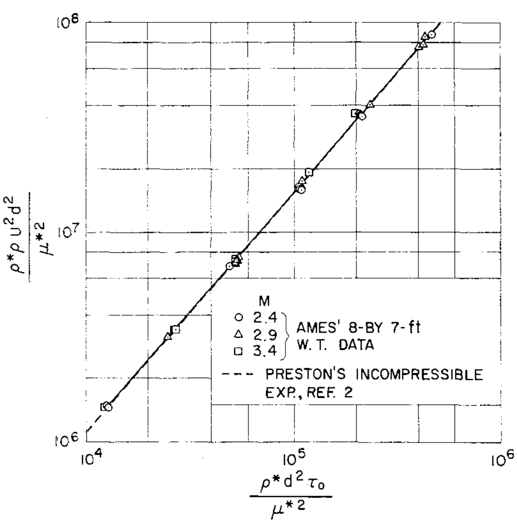

Fig. 2 Supersonic calibration of Preston tubes based on Hopkins-Keener's functional equation (2).

In Figs. 1 and 2 the writers' data are presented on the basis of functional equations (1) and (2). Included on these figures is the incompressible curve of Preston.[2] For each figure, the reference temperature used for obtaining the reference flow quantities (denoted by asterisks) was taken as that given by Sommer and Short.[3] It can be seen that the writers' functional equation reduces their supersonic data to the incompressible Preston curve and that Sigalla's functional equation reduces these same data to a curve, which has slightly less slope than Preston's. A similar result also was obtained at both higher and lower Reynolds numbers in the writers' investigation. Further comparisons will be required at higher Mach numbers both with and without heat transfer to determine which functional equation for calibrating Preston tubes gives the best collapsibility of the data to an incompressible calibration curve.

References

[1] Sigalla, A., "Calibration of Preston tubes in supersonic flow," AIAA J. **8**, 1531 (1965).

[2] Preston, J. H., "The determination of turbulent skin friction by means of pitot tubes," J. Roy. Aeronaut. Soc. **58**, 109–121 (1954).

[3] Sommer, S. C. and Short, B. J., "Free-flight measurements of skin friction of turbulent boundary layers with high rates of heat transfer at high supersonic speeds," J. Aeronaut. Sci. **23** (1956).

Comment on "Review of Theoretical Investigations on Effect of Heat Transfer on Laminar Separation"

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TABLE 1 of Ref. 1 presents the adverse pressure gradient parameter, $-m$, of the compressible boundary-layer similarity solutions as a function of wall temperature, required for zero skin friction. In an added note to the table, it is stated that the discrepancy in m for $T_w/T_\infty = 0.25$ may be due to a difference in the Prandtl number used in the cited

Table 1 Similarity solutions

$\frac{T_w}{T_\infty}$	Values of m for $\tau_w = 0$
2.0	−0.0608
1.5	−0.0727
1.0	−0.0904
0.9	−0.0948
0.6	−0.1097
0.5	−0.1168
0.25	−0.1315
0.2	−0.1338
0	−0.1403

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references. This is indeed the case. For a Prandtl number of unity, the table of Ref. 1, with additional temperature ratio values, would be as cited[2] in Table 1. Therefore, as stated in Ref. 1, as the wall is cooled, a consistently larger adverse pressure gradient is required for separation.

References

[1] Morduchow, M., "Review of theoretical investigations on effect of heat transfer on laminar separation," AIAA J. **3**, 1377–1385 (1965).

[2] Ball, K. O. W., "Similarity solutions for the compressible separated laminar boundary layer with heat and mass transfer," (to be published).

Comments on "Phugoid Oscillations at Hypersonic Speeds"

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Laitone and Chou[1] have presented a good exposition of high-speed longitudinal dynamics, but a few points merit comment (mostly in their notation). In Fig. 1,[1] evidently the artist was given too much liberty. Using the given equations results in the trends of phugoid period shown in this Comment's Fig. 1. It is evident that the simple classical expression, which ignores the density gradient,

$$T = (2)^{1/2}\pi U/g \quad (1)$$

is adequate at approach and landing speeds, and that it remains a fair approximation at all subsonic speeds. The correction for earth curvature becomes significant at about the point shown[1] (half the orbital speed) but is smaller than Laitone and Chou indicated at higher speeds. Even so, at all suborbital speeds an excellent approximation is

$$T = \frac{(2)^{1/2}\pi U}{g[1 - (U^2/2g)(1 - F^2)(\rho'/\rho)]^{1/2}} \quad (2)$$

when, as in Ref. 1, derivatives are invariant with Mach number. The drag effect is negligible, except possibly at landing speeds for $L/D < 3$. In any case Laitone and Chou properly apply the drag correction to the period, not to the undamped natural frequency ω_n.

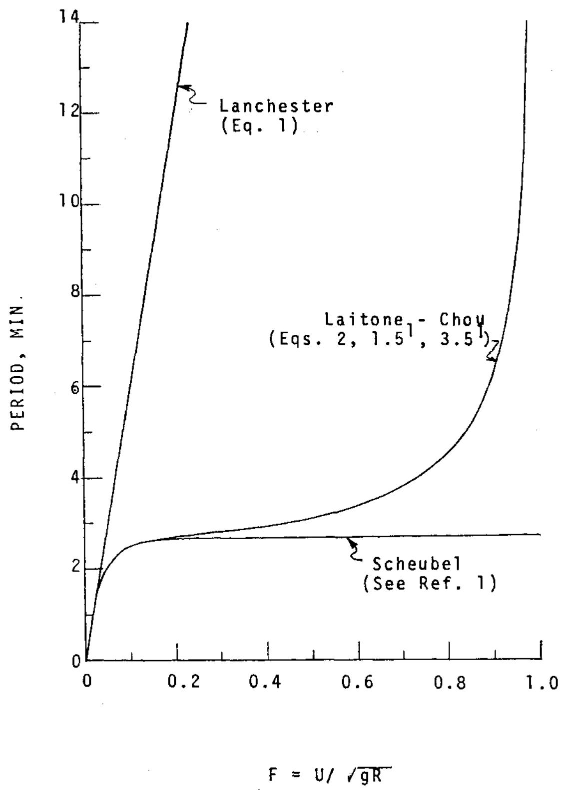

Fig. 1 Phugoid period.

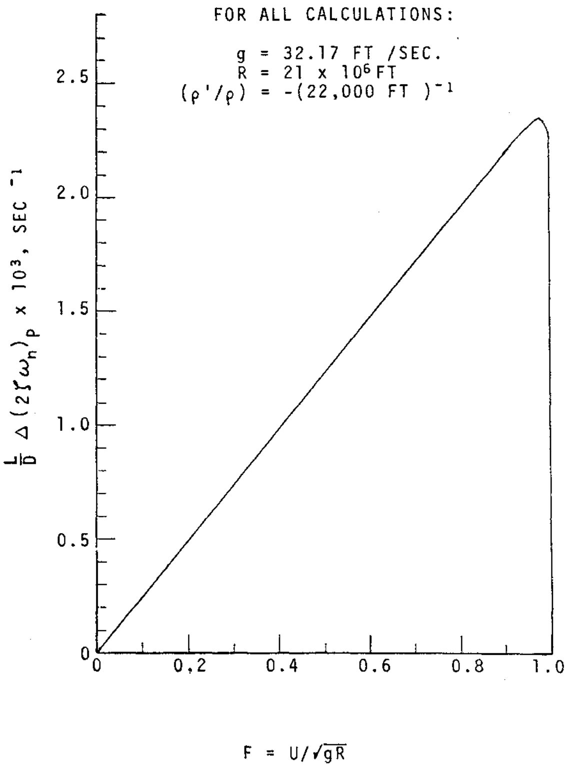

Fig. 2 Phugoid damping factor correction.

An obvious modification of the damping expression, Eq. (3.8) or (3.9),[1] gives the phugoid-mode damping coefficient

$$2\zeta\omega_n = \left(\frac{\rho US}{m}\right) C_D + 2\left(\frac{C_D}{C_L}\right) \times \left[\frac{-[(\rho'/\rho) + (1/R)]U + 2(g/U)}{-(\rho'/\rho)R + (2/F^2) + [F^2/(1 - F^2)]}\right] \quad (3)$$

making the correction a function of L/D, ρ'/ρ, U, and R. The damping-coefficient correction can then be plotted in the same way as the period (Fig. 2). Of course, in a reentry deceleration or for any nonlevel mean flight path, ζ and ω_n may change markedly during only one cycle of the extremely slow phugoid motion.

Contrary to Laitone and Chou,[1] aerodynamic drag does damp the phugoid oscillation when "the thrust exactly cancels the drag force." A constant engine thrust is equivalent to the gravity "thrust" in gliding flight. The force along the flight path is given by

$$X = T - \tfrac{1}{2}\rho U^2 SC_D - W \sin\gamma \quad (4)$$
$$X_{\text{trim}} = X_0 = 0$$

So, we have the derivative about the trim point

$$\partial X/\partial u = (\partial T/\partial u) - \tfrac{1}{2}\rho_0 U_0^2 S\partial C_D/\partial u - \rho_0 U_0 SC_D = \partial T/\partial u - \tfrac{1}{2}\rho_0 U_0^2 S\partial C_D/\partial u - (2/U_0)(T_0 - W \sin\gamma_0) \quad (5)$$

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