Ref. 2 for entry at circular velocity ($\bar{z}_e = 0$). The equivalence of the two solutions indicates that elimination of the term referred to by Nayfeh is based, in the limiting case $f_e' \to 0$, on restricting the effect that the small but nonzero entry density has on the solution.

Approximate solutions to physical problems must be judged on their accuracy and their utility. Figures 1 and 2 and the additional results of Ref. 2 provide a basis for assessing the value of the solution obtained in Ref. 2.

References

[1] Nayfeh, A. H., "Comments on 'An analytic solution for entry into planetary atmospheres' " AIAA J. **4**, 758 (1966).

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[3] Eggers, A. J., Jr., "The possibility of a safe landing," *Space Technology* (John Wiley & Sons, Inc., New York, 1959), Chap. 13, pp. 13–18 and 13–19.

Comments on "Simplified Solutions for Ablation in a Finite Slab"

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In a recent note, Chen[1] presents a solution of a differential equation, which is assumed to present a model of a charring ablator. The model used assumes that the original material is decomposed at a known ablation temperature T_m (all nomenclature used here are the same as those used by Chen) and a known surface temperature T_0. The latter assumption does not recognize the fact that the solution of the problem of charring ablation is governed by heat balance rather than by an imposed surface temperature. The net heat transferred to the material must equal the heat stored plus the heat absorbed by decomposition. Specification of the surface temperature presupposes the knowledge of the heat balance, which can be obtained only after the complete problem is solved. The surface boundary condition for negligible radiation therefore should be written as: heated conducted into the material = aerodynamic heat input − heat blocked by injection of gases into the boundary layer. Neither the net heat transfer into the material nor the surface temperature is known a priori.

This, however, is a minor point in comparison with the assumption implied in Chen's basic equation [Eq. (1)]. The equation neglects the convective effects, i.e., the heat transferred from the char to the gaseous products of decomposition. A simple order of magnitude analysis yields the ratio

$$\frac{\text{Heat absorbed by the gases}}{\text{Heat absorbed by the decomposition}} \approx \frac{(T_0 - T_m)}{L} C_{pg} \frac{(\rho_u - \rho_c)}{\rho_u}$$

where C_{pg} = specific heat of the gases. In any practical application of any common charring ablator for which a reaction temperature is assumed, this ratio is about one or greater. There are indications that some materials have a very low heat of depolymerization, so that the ratio actually can be much greater than one. Thus, Chen's solution neglects an effect that is as important as the one that is retained in his boundary condition.

It seems, therefore, that Chen's simplifying assumptions lead to a steady-state solution for a constant temperature sink (reaction zone) with known surface heat transfer and surface temperature, rather than for a charring ablator.

Reference

[1] Chen, N. H., "Simplified solutions for ablation in a finite slab," AIAA J. **3**, 1148 (1965).

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Reply by Author to A. Wortman

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Ablation is a complicated phenomenon. It deals with conduction, diffusion, chemical reaction (or combustion), kinetics, etc. The products of the combustion are char and multicomponent gaseous mixtures. In addition, the heat input from the environment to initiate the ablation in a rocket motor also is concerned with multicomponent exhaust gaseous mixtures. Because of this complex nature, it is certainly impossible to obtain a closed form solution to account for all these effects. Hence, in order to have an approximate analytical expression, "simplified assumptions" must be made.

With these simplified assumptions in mind, the following "heat" terms, as indicated by A. Wortman, already have been considered in my recent note.[1] The heat blocked by injection of gases into the boundary layer was eliminated because of assumption 7 in my note.[1] The heat absorbed by the gases from the decomposition was neglected on account of assumption 3.[1] The heat absorbed by the gases from the environment was taken into consideration in the char-gas layer.

In regard to the surface temperature T_0, it is true that it varies with time. However, for a particular instant, there exists such a temperature. This temperature is not known, as indicated by A. Wortman, but is determined from the heat balance equations in my note.[1]

Moreover, T_m was defined as the ablation temperature in my note, but not as the reaction temperature. These two temperatures may not be equal. The latter one, as suggested by A. Wortman, does not fit into my proposed model.

Reference

[1] Chen, N. H., "Simplified solutions for ablation in a finite slab," AIAA J. **3**, 1148–1149 (1965).

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Comments on "Calibration of Preston Tubes in Supersonic Flow"

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Sigalla[1] has noted an interesting application of the reference-temperature method for compressible boundary layers to a calibration formula for Preston tubes. The writers

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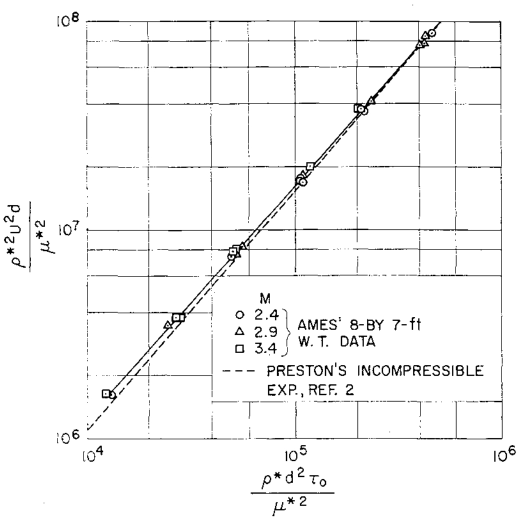

Fig. 1 Supersonic calibration of Preston tubes based on Sigalla's functional equation (1).

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, $\Delta p = 0.7M^2 p$ (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

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

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

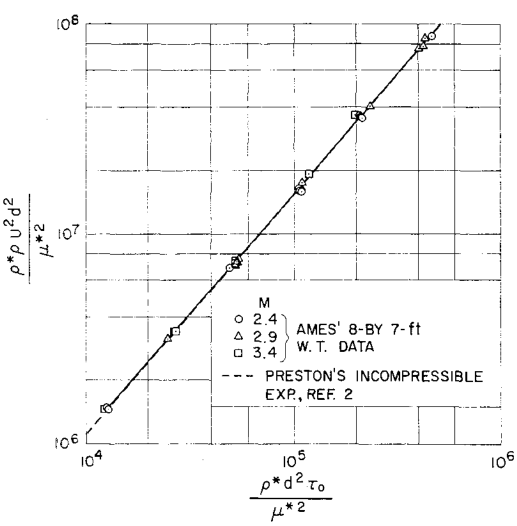

Fig. 2 Supersonic calibration of Preston tubes based on Hopkins-Keener's functional equation (2).

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

T_w/T_∞	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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