Calibration of Preston Tubes in Supersonic Flow

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Nomenclature

τ_0 = wall shearing stress
d = outside diameter of Preston tube
ρ^* = density of fluid evaluated at reference temperature
ν^* = kinematic viscosity of fluid evaluated at reference temperature
U = velocity ahead of the Preston tube as obtained from the Rayleigh Pitot formula
i_1 = enthalpy in the freestream
r = recovery factor
γ = ratio of the specific heats
M = freestream Mach number

Introduction

HYPOTHESIS of a reference temperature, or enthalpy, has proved of great value in the development of rapid and accurate methods for calculation of turbulent skin friction in supersonic boundary layers.[1] The purpose of this note is to show that this same hypothesis can be used to obtain a calibration formula for Preston tubes that may be applied to both compressible and incompressible flow.

Discussion

It will be recalled that the Preston tube is a small total head tube aligned in the flow direction inside a boundary layer. Preston[2] has shown that it is possible to obtain local values of the shear stress from the reading of the total head tube. Since then, when used in that fashion, the instrument has often been referred to as a Preston tube. The method is based on the universal law of the wall for turbulent boundary layers, and its validity now has been well demonstrated.[3,4]

A calibration of Preston tubes in supersonic flow was first obtained by Fenter and Stalmach.[5] Figure 1 shows how the data from Ref. 5 can be used to obtain a calibration formula by means of the reference temperature hypothesis. It also shows a relationship between two nondimensional groups of parameters $\tau_0 d^2/4\rho^*\nu^{*2}$ and Ud/ν^*.

The reference temperature is calculated (for an adiabatic wall) by means of the formula given in Ref. 6 for the reference enthalpy i^*, $i^* = i_1[1 + 0.35r\ (\gamma - 1)M^2]$. The points shown in Fig. 1 have been obtained directly from Fig. 15-A of Ref. 5. The data shown were obtained with a number of different Preston-tube diameters in a Mach number range from 1.74 to 3.68. The line drawn through the points in Fig. 1 may be represented by

$$(\rho^* d^2\tau_0)/\mu^{*2} = 0.0529[(\rho^* d^2\Delta p)/\mu^{*2}]^{0.873} \qquad (1)$$

where Δp is related to U by $\Delta p = \frac{1}{2}\rho^* U^2$, and $\mu^* = \nu^*\rho^*$. In incompressible flow Δp would be the difference between the total pressure reading of the Preston tube and the local static pressure. The calibration from Fig. 1 is presented in Eq. (1) so that it may be compared directly to the calibrations of Preston tubes in incompressible flows given in Eqs. (2–4):

$$(\rho d^2\tau_0)/\mu^2 = 0.0478[(\rho d^2\Delta p)/\mu^2]^{0.875} \qquad (2)$$

$$(\rho d^2\tau_0)/\mu^2 = 0.0543[(\rho d^2\Delta p)/\mu^2]^{0.875} \qquad (3)$$

$$(\rho d^2\tau_0)/\mu^2 = 0.0511[(\rho d^2\Delta p)/\mu^2]^{0.877} \qquad (4)$$

These equations were obtained by Preston,[1] Relf et al.,[7] and Smith and Walker,[8] respectively. It can be seen that the calibration formula obtained from the supersonic data by means of the reference temperature hypothesis is in very good agreement with calibration formulas obtained in incompressible flow. The result indicates that the reference temperature concept is not only useful for the calculation of supersonic skin friction, but can also be profitably applied to the analysis of other aspects of compressible boundary-layer flow.

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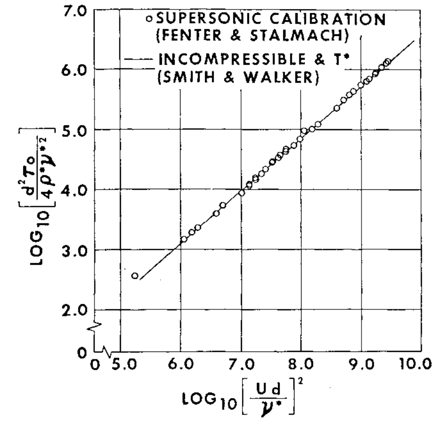

Fig. 1 Supersonic calibration of Preston tubes.

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Blunt-Body Integral Method for Air in Thermodynamic Equilibrium

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THE direct (Dorodnitsyn-Belotserkovskii) integral method has been adapted for application to an adiabatic flow process involving an arbitrary smooth axisymmetric or two-dimensional blunt-body in supersonic flow. The gas under consideration is argon-free air in thermodynamic equilibrium.

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