Evaluation of Preston Tube Calibration Equations in Supersonic Flow

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Theme

STUDIES by many investigators have for some time established that the surface pitot tube can be used to measure local turbulent skin friction. Circular surface pitot tubes are generally called "Preston Tubes," after the author of Ref. 1. Basically, the Preston Tube technique, as seen in Fig. 1, consists of bringing a tube of appropriate size into contact with the test surface at the location where local skin friction is desired, measuring the pitot pressure sensed by this tube, and combining this pressure with local freestream conditions and tube diameter to calculate local skin friction from an existing calibration equation. The main advantages of the Preston Tube over other skin-friction measuring techniques is its sturdiness, simplicity of use, and the fact that calibration of individual tubes is not required.

In previous calibration experiments in supersonic flow,[2,3] it was found that data from all Reynolds numbers, Mach numbers, and tube diameters tested collapsed into a single narrow band when the appropriate calibration parameters were used. The calibrations were thus reported to be independent of Mach and Reynolds numbers and tube diameter. The range of tube sizes theoretically usable, however, is very large; much larger than that used by the previous investigators in performing their calibrations. This study was thus initiated to provide calibration data at larger Reynolds-number-based-on-tube-diameter (R_D) and higher supersonic Mach numbers (M_e) than previously existed. These new data and existing supersonic data are used in this study to evaluate both existing Preston Tube calibration equations and new equations developed in this study in light of the new data. The larger values of R_D and M_e of the new data facilitated the evaluation of the various calibration equations since they tend to diverge for these conditions. For all the calibration data presented herein, local skin friction was directly measured by floating element skin-friction balances. Of the six calibration equations evaluated in this study, three will be selected for discussion in this synoptic.

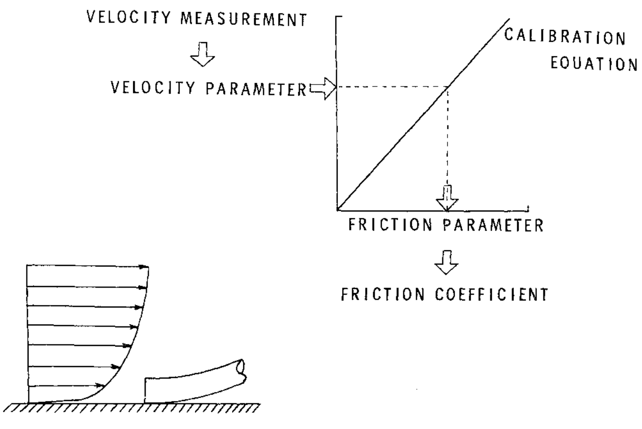

Fig. 1 Description of Preston Tube technique.

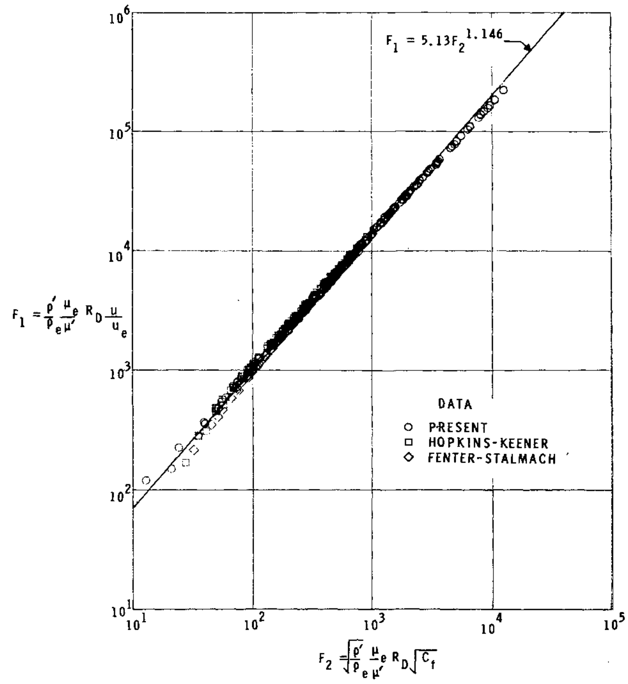

Fig. 2 Sigalla calibration equation.

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Figure 2 shows the Sigalla calibration equation compared with the data. The calibration parameters used by Sigalla collapse the data into a single band, but the equation misses the trend of the data at the higher values of the calibration parameters. The distance between the data and curve at the higher values of the parameters represents about a 20% error in skin friction. Note that the present results contain data at values of the calibration parameters which are an order of magnitude larger than those of the previous data.

Figure 3 shows how the Hopkins-Keener equation compares with the data. The high Mach number ($M_e = 4.63$), large tube diameter data of the present study do not collapse into the data band of the previous sets of data for the calibration parameters used by Hopkins and Keener. Instead, they collapse into a separate band which diverges from the previous data. The distance between this upper band of data and the curve represents as much as a 50% error in skin friction.

Figures 2 and 3 were presented as examples of the deficiencies noted in examining existing calibration equations in light of the

Synoptic received May 31, 1973. Full paper available from National Technical Information Service, Springfield, Va., 22151, as NASA TN D-7190 at the standard price (available upon request).

Index category: Boundary Layers and Convective Heat Transfer—Turbulent.

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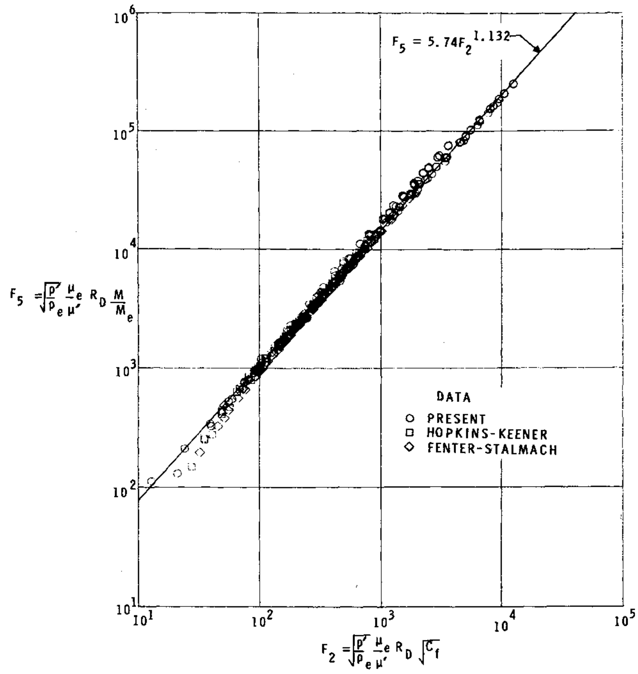

Fig. 3 Hopkins-Keener calibration equation.

new data. These deficiencies indicated that an improved calibration equation was needed; hence several attempts were made at obtaining improved results. The best equation examined was a second-order least squares fit to the data, and is shown in Fig. 4. The data collapse here is good and the equation follows

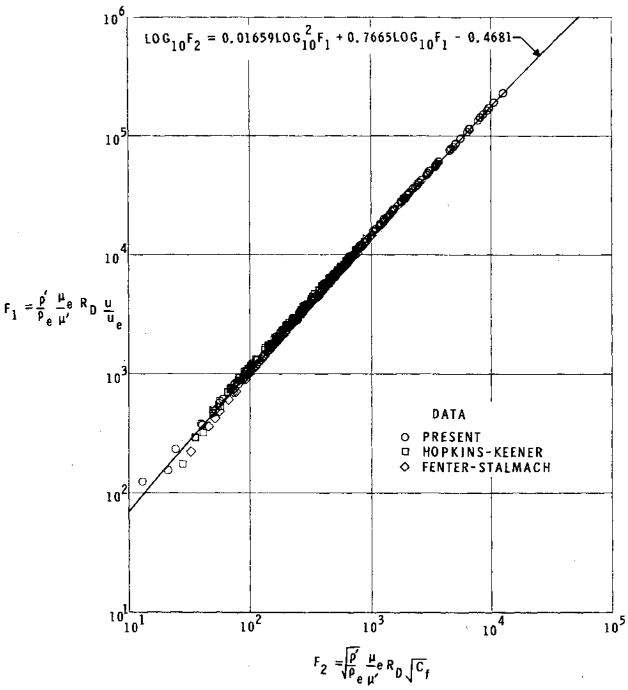

Fig. 4 Second-order least-squares calibration equation.

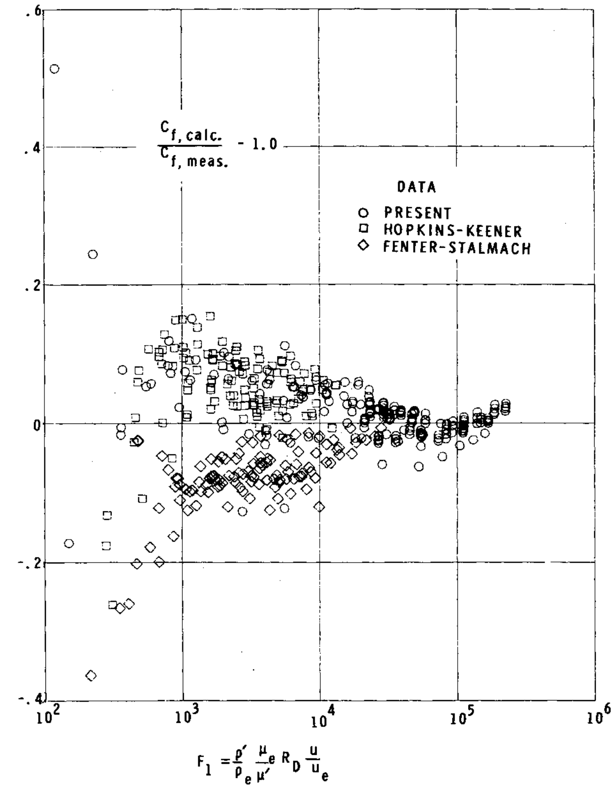

Fig. 5 C_f error in second-order least-squares equation.

the trend of the data throughout the range of the calibration parameters.

It is difficult from this log-log plot to ascertain the skin friction error represented by this band of data; hence Fig. 5 is presented to show the percent skin friction error between the data and curve for each of the data points shown in Fig. 4. It can be seen by the large data scatter in the very low range of the calibration parameter F_1 (below $F_1 \approx 10^3$), that the Preston Tube technique is very inaccurate in this range. The upper limit of this low range is used to define the smallest tube size which can be used to obtain accurate data. Above this low range the data scatter is limited to about $+15\%$ to -12% with increasing accuracy with increasing values of the calibration parameter. It should be noted from this result that valid data were obtained even with the largest tubes tested; tubes which were as much as 70% of the boundary-layer thickness and about twice as large as the theoretical maximum usable size.

Because of the over-all improved correlation, this second-order least-squares curve is evaluated as being the best Preston Tube calibration equation for existing supersonic data.

References

[1] Preston, J. H., "The Determination of Turbulent Skin Friction by Means of Pitot Tubes," *Journal of the Royal Aeronautical Society*, Vol. 58, Feb. 1954, pp. 109–121.

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[3] Hopkins, E. J. and Keener, E. R., "Study of Surface Pitots for Measuring Turbulent Skin Friction at Supersonic Mach Numbers—Adiabatic Wall," TN D-3478, 1966, NASA.