

Also define

$$J \equiv \bar{V}_m / \bar{V} \dots \dots \dots [18]$$

Then the momentum equation may be written for a constant-area duct as

$$A(P_2 - P_3) = \frac{w_3}{g_0} \bar{V}_{m_3} - \frac{w_2}{g_0} \bar{V}_{m_2} \dots \dots \dots [19]$$

Then a modified Equation [2] is obtained by combining Equations [14] through [19]

$$\bar{T}_3 = \frac{P_3 R_2}{P_2 R_3} \frac{\bar{T}_2}{(1+f)^2} \left[\frac{R_2 \bar{T}_2 g_0}{\bar{V}_2^2 J_3} \left(1 - \frac{P_3}{P_2} \right) + \frac{J_2}{J_3} \right] \dots \dots [20]$$

which may be used to determine an average temperature at point 3.

Combining Equation [18] with [15] and [17]

$$J = \frac{A \int_A \rho V^2 dA}{\left[\int_A V dA \right] \left[\int_A \rho V dA \right]} \dots \dots \dots [21]$$

The values of J at two points are the same if the ratios of T/T_{CL} and V/V_{CL} are each the same functions of r at the two points. The value of J is unity if V and T are uniform across the duct, e.g., one-dimensional flow.

Discussion

S. W. GREENWOOD.⁴ The authors quote Blackshear who obtained static temperature results with the sodium D line-reversal method higher than the stagnation values obtained with a thermodynamic instrument using two consecutive flow elements. A study of the literature on the line-reversal method indicates that temperature values closely approaching, and in some cases even exceeding, the theoretical values for complete combustion are frequently obtained. The discrepancy between the two sets of results noted by Blackshear may, perhaps, therefore be partly attributed to defects in the line-reversal method.

With regard to the thermodynamic method tentatively proposed by the authors, and centering on Equation [2], the limitations inherent in the assumptions on which the equation is based appear to be quite severe. The value for T_3 determined in practice would be too high, the error depending on the extent to which the basic assumptions were invalid.

It would be interesting to know whether any correlation has been effected between the proposed theory and practical cases of heat addition.

The refinement of Equation [2], given as Equation [20] in the Appendix, requires a knowledge of the velocity distribution at Section 3. It would seem that this requires a knowledge of the density variation across the section, which in turn requires a knowledge of the temperature variation. If this is known, the analysis is not required! Comment on this point would be appreciated.

With respect to Fig. 9, one feels that when $P_1 - P_w$ is zero, then ΔT per cent should also be zero. Could the authors account for the departure from this condition?

It would be interesting to know where the static-pressure taps in the duct wall were placed relative to the probe. Was any investigation made of the effect of varying the position of the taps?

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In connection with the proposal of the authors to place free-stream static-pressure taps in the outer wall of the probe, it might be desirable to position such taps in a plane perpendicular to the probe stem, to avoid the influence of the stem and of proximity to the duct walls on the static-pressure readings obtained.

AUTHORS' CLOSURE

We wish to thank Mr. Greenwood for his thoughtful and interesting comments on this work.

We agree that it is highly probable that the apparent discrepancy in Blackshear's results may be attributed to irregularities in the sodium D-line method. The conclusions drawn from Mr. Greenwood's literature survey in regard to the sodium D-line method are consistent in character with those of our reference 5, indicating the need for care and caution on the part of the experimenter if this presently widely used technique is to be employed in the measurement of high gas temperatures. Our experience with this method has involved the use of a fairly inexpensive spectrometer in experiments in which our objectives were to attempt to inject liquid sodium at a "point" in a gas stream and to determine the lowest temperature at which reversal could be observed. Attendant to the accomplishment of these objectives we encountered difficulty with obtaining and maintaining the proper slit adjustment on the spectrometer, clogging of the sodium injection system, and an unsatisfactorily sensitive calibration of the comparator lamp, all of which were inherent with our relatively simple setup. In addition we found, in general, not a precise reversal point but rather a band over which it was difficult to assign the exact reversal temperature. Frequently it appeared that one of the D-lines reversed while the other did not, again lending uncertainty and inaccuracies. Our conclusion was that to be more satisfactory the instrumentation would have to be more complicated and expensive and unwieldy. These latter characteristics seem to be found in many successful D-line installations and as such limit their use principally to the laboratory. One of our objectives in this present study was to develop a "temperature meter" of reasonable simplicity and expense at no sacrifice in mechanical reliability nor precision.

We are aware that Equation [2] would not be adequate for many constant area combustion processes owing to the departure from one-dimensional conditions because of the effects of flame holders and asymmetrical fuel injection and combustion. For this reason we re-emphasize the approximate nature which Equation [2] could assume, depending on the conditions of each particular combustion process. To our knowledge no experiments have been conducted on the method of Equation [2]. However, we doubt the value of such experiments, except to the particular individual and apparatus concerned, since the subject method is based on an experimental equation of state and three well-established principles: namely, Newton's Second Law; The Conservation of Mass; and the Second Law of Thermodynamics, each of which has not been contradicted in countless experiments. Thus any experiments using the method of Equation [2] would not check the method but would simply demonstrate the degree of departure of the conditions of the experiment from the assumptions underlying the method. Obviously, the results would have only local significance.

We do not share the enthusiasm of Mr. Greenwood's comment on our Equation [20]. We think a broader viewpoint is possible. It is true that to determine the velocity variation at station 3, Fig. 2, knowledge would be required of the temperature variation. This fact brings out the weakness of all such "bulk" methods and shows the necessity for an instrument which is a "temperature meter," as given by our Equation [4] and discus-

sion. However, once such velocity and temperature profiles have been established, say, as a function of some nondimensional quantity as a Reynolds number, then the J factors can be evaluated. We can visualize the convenience afforded to the experimenter who then uses these J factors in Equation [20] and is able to compute accurately the average downstream static temperature by making one simple measurement in the high-temperature region, namely, the static pressure. It is also conceivable that one might choose to "extrapolate" lower-temperature velocity and temperature profiles in order to improve the approximation of the determination of T_3 .

We believe that inherent installation and instrument errors caused the manometer to indicate a zero difference in $P_1 - P_w$ when P_1 was actually less than P_w . This would result in the flow into the probe being similar to case 3, Fig. 8.

The static-pressure taps in the wall were located in the plane of the probe's entrance, as shown in Fig. 5. No investigation was conducted on the effect of changing the location of these pressure taps.

We agree that pressure taps located on the probe itself would

probably be best placed in a plane perpendicular to the stem, although recent work at the NACA⁵ has shown this not to be particularly critical if reasonable care is observed.

In addition to the comments on Mr. Greenwood's points we wish to make two more. During the initial stages of our experiments we found that excessive cooling of the gas sample was as serious as insufficient cooling. That is, with a high rate of coolant flow, water vapor would condense on the heat-exchanger surfaces resulting in incorrect measurement of mass flow. This was remedied by reducing the cooling flow, thus maintaining the heat-transfer surfaces hotter and dry.

In regard to our comment following Equation [13] it has been pointed out that once the static temperature has been determined, then an accurate value can be calculated for k . This being the case, the stagnation temperature as calculated by our Equation [13] is independent of uncertainties in gas composition.

⁵ "Effects of Pressure-Rake Design Parameters on Static-Pressure Measurement for Rakes used in Subsonic Free-Jets", by L. N. Krause, NACA TN 2520 unclassified October 1, 1951.