Comments on "Tracer-Spark Technique for Velocity Mapping of Hypersonic Flow Fields"

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IN a recent note, Kyser[1] suggests a method to determine the density distribution in hypersonic wakes involving measurement of the local flow velocities. The velocities are to be measured by a variation of Bomelburg's technique (Ref. 1 of Kyser's paper) and are based on photographs of a rapid sequence of precisely timed electric sparks between two parallel rod electrodes. Since each spark tends to follow the ionized path of the preceding discharge, the velocity distribution can be found from the displacement and distortion of the spark columns shown on photographic records. It is the purpose of these comments to point out a potential source of errors of such measurements.

It was observed[2] that a spark column follows the gas flow exactly only if the flow velocity is constant, and that it moves faster than the gas if the flow is accelerating. The column velocity may exceed the gas velocity by as much as 60% if the acceleration is produced by a shock wave. This behavior of the spark-heated column may be explained by the difference of the density of the column and that of the surrounding gas. One may consider the flow accelerations as being caused by an equivalent gravitational field; the net force acting on the column is then the difference between its weight in this field and the buoyancy force that is equal to the corresponding weight of surrounding gas displaced by the column. As a result of its motion relative to the gas, the column is practically instantaneously transformed into a vortex, and, although this transformation consumes a large fraction of the energy of the relative motion, sufficient energy is left to cause an appreciable residual velocity difference.

A theory for the dynamics of a small gaseous region having a different density than the surrounding gas shows, in agreement with experimental observations of bubbles of known density ratio, that the ratio of a change of the gas velocity to the corresponding change of the bubble velocity is constant regardless of the magnitude of the acceleration.[2] This result applies only if the density ratio is constant and does not account for changes of the effective density ratio by cooling and diffusion. Because of these effects, the excess velocity of a spark column over the gas velocity behind a shock wave is reduced from its initial value of about 60 to 40% if the average velocity is determined for an interval of about 50 μsec.

Since these errors apply only to the accelerated part of the gas flow, the over-all error in a particular flow may be considerably smaller than the values indicated in the foregoing and may even be negligible in some cases. In Fig. 1, let the heavy solid line represent the motion of the gas in the position-time plane, and place the origin of the coordinates at the point corresponding to a spark discharge. If the next spark had been discharged after a time interval Δt and the gas had continued to flow at its initial velocity V_0, it would have traveled the distance $V_0\,\Delta t$, and the spark column would have traveled exactly the same distance. In the accelerating flow shown in the figure, the gas travels the distance Δx, whereas the spark column, traveling along the broken line, travels Δx_S. According to the preceding discussion, the ratio of the accelerated parts of the motion is equal to a value α, which depends somewhat on the time interval between the sparks and possibly also on the experimental conditions, so that

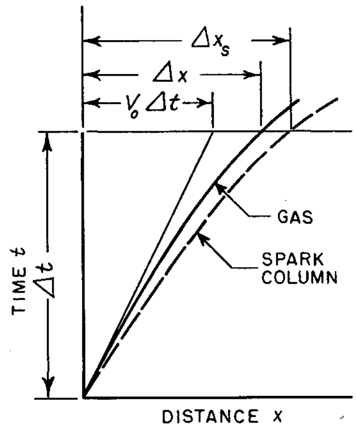

Fig. 1 Position-time plot of an accelerating gas flow and the corresponding motion of a spark column.

$$(\Delta x_S - V_0\Delta t)/(\Delta x - V_0\Delta t) = \alpha \quad (1)$$

According to the foregoing, the value of α is approximately 1.4 for a typical interval $\Delta t = 50$ μsec and for the experimental conditions of Ref. 2 (air at near-atmospheric pressure, a spark gap of about 1 cm, and a spark produced by a 1-μf capacitor charged to 400 v and discharged through an automobile spark coil). The average gas velocity is given by $V = \Delta x/\Delta t$ and the velocity measured by observation of the spark column by $V_S = \Delta x_S/\Delta t$. Equation (1) therefore yields the velocity error as

$$V_S - V = (\alpha - 1)(V - V_0) \quad (2)$$

This result shows that the velocity error is approximately equal to 40% of the velocity change between consecutive sparks. In the empty test section of a hypersonic tunnel, the velocity may change less than 1% in the distance that the gas moves during 50 μsec, and the error of the velocity measurement then would be less than $\frac{1}{2}$%. However, the corresponding velocity change in the wake of a model may well exceed 10%, resulting in a velocity error of more than 4%. Since the gas density is essentially proportional to $1/V^2$, the density error would then exceed 8%.

These remarks do not mean that the technique of "tagging" a flow with a spark discharge is unsuitable for velocity measurements, but that the behavior of the spark columns should be considered in each case in order to ascertain that errors caused by flow accelerations do not exceed tolerable limits.

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References

[1] Kyser, J. B., "Tracer-spark technique for velocity mapping of hypersonic flow fields," AIAA J. **2**, 393–394 (1964).

[2] Rudinger, G. and Somers, L. M., "Behavior of small regions of different gases carried in accelerated gas flows," J. Fluid Mech. **7**, 161–176 (1960).

Reply by Author to G. Rudinger

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IN the preceding comment, Rudinger analyzes the effects on density measurements of a velocity error of 40% of the velocity change between consecutive sparks. The factor α, which is used in the analysis, is a measure of this error and is given in Ref. 1 as 1.4 for a particular experiment. In Ref. 1,

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