Technical Comments

Comment on: "A Unified Analysis of Gaseous Jet Penetration"

E. E. ZUKOSKI*
California Institute of Technology, Pasadena, Calif.
AND
F. W. SPAID†
University of California, Los Angeles, Calif.

A RECENT discussion of the Zukoski-Spaid model [1-4] for the flowfield created by injection of gas into a supersonic primary flow by Billig, et al.[5] is a gross misinterpretation of that model. The aim of the Spaid and Zukoski model was to develop a characteristic length which could be used to predict the influence of a various parameters on the scale of the disturbance produced by secondary injection, the absolute value of which is of no consequence. This aim is clearly stated. For example, in Refs. 1–4 (which were quoted in Ref. 5 as Refs. 1–4), the following paragraphs appear: "It is proposed that the radius h can be used as a measure of the scale of the disturbance produced by injection. Note that, although the expression given in Eq. (3) contains no adjustable constants, the exact correspondance between values calculated from Eq. (3) and any measured feature of the flow, such as the penetration height, is purely fortuitous. However, it is to be expected that changes in scale of flow features will be proportional to changes in h."

In addition, when discussing the concentration profiles, Refs. 3 and 4 contain the following, with similar statements in Refs. 1 and 2: "... It is obvious that the observed and calculated penetration height corresponds much more closely to the line of maximum concentration than to the outer edge of the injectant stream. ... Farther downstream, mixing is slower. From this result, it is obvious that the no-mixing approximation made in the model can only be useful close to the injector. However, h is a measure of the scale of the injectant flow, and hence it is reasonable to expect that it would be the characteristic dimension for the mixing process too." Despite these statements, Billig et al. chose to interpret the characteristic scale as a physical length (e.g., Figs. 14 and 15 of Ref. 5), which is certainly unwarranted, and as expected gives invalid results.

The model of Spaid and Zukoski is based on the assumption that the injectant expands isentropically to the ambient static pressure at the downstream face of the control volume. This fixes the momentum flux from the control volume, and combination of this result with a Newtonian drag assumption allows the characteristic height to be found.

A region of strong recirculation exists immediately downstream of the injectant jet, and therefore an unknown fraction of the control volume exit area A_c is occupied by this stagnant flow and is not available for injectant flow. Billig et al. have ignored the existence of this region. Hence, contrary to the statement made in Ref. 5, a continuity argument connecting mass flow and control volume cross sectional area A_c could not be and was not used. Specific attention was drawn to this fact. For example, in Refs. 1 and 2, the statement is made, "Note that the injectant is allowed to expand to the static pressure of the undisturbed flow, but is not assumed to completely fill the semicircular cross section of the downstream face of the quarter sphere which forms the nose of the equivalent solid body." Similar statements were made in Refs. 3 and 4, and a figure in Ref. 4 was used to illustrate this point. The model leads to a limiting value of freestream Mach number, depending upon the particular injectant conditions, above which the computed area available for flow is insufficient for the passage of the injectant. This limitation is normally not encountered in practical applications. It is primarily a result of the crude assumption of isentropic expansion and turning of the jet. It is well known that the trends predicted by such a model are quite insensitive to the of the assumed turning process, as long as the no-mixing assumption is retained (see Fig. 3, Ref. 5). As a result, this difficulty can easily be overcome without changing the basic concept or the resulting scaling relationships.

Finally, the relatively simple model developed by Spaid and Zukoski accurately scales a wide range of experimental results concerning sonic injection normal to a wall. The model taken in its proper sense is in good agreement with the data presented in Refs. 1–4, with data presented by a number of other authors such as Chrans and Collins,[6] and even with the data presented by Billig et al. in their Figs. 14, 15, and 17.

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* Professor of Jet Propulsion. Associate Fellow AIAA.
† Assistant Professor of Engineering. Member AIAA.

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Reply by Authors to E. E. Zukoski and F. W. Spaid

F. S. BILLIG,* R. C. ORTH,† AND M. LASKY ‡
Johns Hopkins University Applied Physics Laboratory, Silver Spring, Md.

IN the discussion in Ref. 1 of the mathematical model used by Zukoski and Spaid,[2] the point was not that they employed a continuity agreement (which they did not) but rather that a model which does not violate continuity is to be preferred. The new unified model presented in Ref. 1 not only takes into account the presence of a Mach disk in the stucture of an underexpanded

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* Supervisor Hypersonic Ramjets Project. Associate Fellow AIAA.
† Engineer Hypersonic Ramjets Project. Member AIAA.
‡ Associate Mathematician, Hypersonic Ramjets Project.