2 The compressible contraction coefficient for any orifice in any installation operating at any pressure ratio below critical (i.e., supercritical) can be approximated by equation (42).

3 The generalized force coefficient required for both subsonic and supercritical regimes can be approximated by equation (30).

4 These approximations have been shown to be well supported by the available experimental data. Such approximate compressible contraction coefficients are expected to be within 2 percent of the actual coefficients.

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DISCUSSION

H. S. Hillbrath[2]

I would like to call the author's attention to the work of Frost[3] which shows that the author's assumption of uniform velocity at the vena contracta defines the upper bound for the possible values of discharge coefficient. If instead the assumption of maximum isentropic thrust is used a lower bound is obtained for which flow limiting occurs at sufficiently low values of the pressure ratio. Frost presents conical nozzle data for which the maximum thrust assumption provides a better fit than the author's analysis. This trend is also apparent in the author's Fig. 14 (*a*). The deviation of the two solutions increases at low pressure ratios where the author's data is limited. Great caution must be used in applying a partially empirical analysis beyond the range of the test data.

While study of compressible flow through orifices provides a fascinating problem combining the most difficult aspects of separated flows with the most difficult aspects of compressible flows, I feel that for flow measurement applications the circular arc critical flow venturi as described by Smith and Matz[4] provides overwhelming advantages due to its close approach to ideal, isentropic, one dimensional flow. This device is rapidly gaining acceptance as a standard form in a wide range of sizes.

Author's Closure

Mr. Hillbrath's comments are appreciated, especially his indication that the assumption of maximum isentropic thrust provides a lower bound for the discharge coefficient. However, it is still believed on the basis of the many experimental papers listed in the References, and based on our own experimental evidence, that the approximation presented here is well within the 2 percent figure given in the Summary.

Concerning his comment as to the most advantageous method for measuring compressible flow rates, I would like to point out that this was never the subject of this paper. We were interested here in approximating contraction coefficients (which lead incidentally to discharge coefficients and expansion factors) for openings of any geometry operating at any pressure ratio. This information is of use in many fluids problems (as flow with losses) where flow measurement is not even a consideration.

The author again would like to thank Mr. Hillbrath for his interest in our work.

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