They have been helpful in pointing out some areas of misunderstanding concerning this work and provoked a stimulating exchange which we hope has been of interest to other investigators in this area.

References

[1]Fancher, R. B., "Low Area Ratio Thrust Augmenting Ejectors," *Journal of Aircraft*, Vol. 9, No. 3, March 1972, pp. 243–248.

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[3]Fancher, R. B., "Low Area Ratio Thrust Augmenting Ejectors," AIAA Paper 71-576 Palo Alto, Calif., 1971

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Comments on the Comment by Philip A. Graham and Reply by Paul M. Bevilaqua

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GRAHAM'S very complete analysis of Fancher's paper pointed out an error in the presentation of ejector potential (ideal) augmentation ratio (Fig. 2), questioned the primary nozzle area (size) used in the experiment and observed that something was missing from the Eq. (11) used to define augmentation ratio with inlet and nozzle losses. He also noted that Fancher's equations were developed for a unique case of equal flow densities ($\rho_0 = \rho_1$) rather than the case of a hot primary (nozzle) flow.

Bevilaqua's reply verified a plotting error in Fig. 2, explained the nozzle area question (a wrong dimension in Fig. 6) and pointed out that Graham used a different reference thrust than did Fancher in the definition of ejector augmentation ratio.

These additional comments are offered to clarify Fanchers Eq. (11), point out why Graham's Eq. ($\overline{11}$) is different and to include some remarks on the effects of hot nozzle flow.

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The augmentation ratio, ϕ, for a static ejector system using incompressible fluids of the same density, an unchoked primary nozzle, a constant area mixing section and a full flowing diffuser discharging an ambient pressure is (using Fancher's nomenclature)

$$\phi = \eta_N(1 + xu)^2(A_2/A_3)/(x + 1)[1 - (1 + \xi_1)\eta_N{}^2u^2]^{1/2} \tag{A}$$

One may assume that Fancher did not include the $(1 + \xi_1)\eta_N{}^2$ term in his Eq. (11) because the product was almost unity (= 0.939 for $\xi_1 = 0.04$, $\eta_N = 0.95$) for the hypermixing ejector being tested.

Substituting Graham's nomenclature in Eq. (A) gives

$$\phi = (\bar{\eta}_N)^{1/2}(1 + xu)^2(A_2/A_3)/(x + 1)[1 - (\bar{\eta}_N/\eta_I)u^2]^{1/2} \tag{B}$$

where

$$\bar{\eta}_N = \eta_N{}^2, \quad \eta_I = 1/(1 + \xi_1)$$

Graham's Eq. ($\overline{11}$) is identical with Eq. (B) except for the first term, $(\bar{\eta}_N)^{1/2}$. The reason this term does not appear in Graham's equation is because he used a different definition of V_0' in the thrust reference for augmentation ratio. Francher used the conventional definition of isentropic velocity for V_0'. Graham used V_0' as the velocity from an actual nozzle having the same thrust efficiency as the nozzle employed in the ejector system.

Note that nothing is technically wrong with the definition used by Graham since it is still a matter of choice as to what reference is employed for augmentation ratio, ϕ. And it is a very simple matter to convert from Graham's ϕ to Fancher's ϕ using nozzle velocity coefficient $[C_V = \eta_N = (\bar{\eta}_N)^{1/2}]$ as the conversion factor. In the past, several references have been used for ϕ in ejector systems that employed choked convergent nozzles or underexpanded convergent-divergent nozzles. The conventional isentropic velocity reference (as used by Fancher) has well served as an unofficial "standard" for over 20 years and (as noted by Bevilaqua) should be employed for evaluating or comparing different type ejector systems on an absolute basis.

As for the effects of hot nozzle flow on ejector thrust augmentation, it should be noted that the simple incompressible flow equations presented in Fancher's paper were never intended for such application. Hot nozzle flow can be accounted for by using the compressible flow relationships and the task is best handled today with computer programs. Hand calculations may be performed for one-dimensional steady compressible flow using the analysis presented in Ref. 1. In general, augmentation ratio of an ideal ejector is degraded by the use of a hot nozzle flow. In real ejectors the degradation may be greater or less depending on how the loss factors change with hot flow.

References

Turner, R. L. et al.,"Charts for the Analysis of One-Dimensional Steady Compressible Flow," TN 1419, Jan. 1948, NACA.