

they are efficiently entrained by the thruster exhaust the background neutrals, on the average, are stationary. The measurement will, therefore, underestimate the average velocity of the beam neutrals. Furthermore, at a given neutral flow rate, the density of the beam neutrals decreases with increasing axial velocity. The higher the true velocity, the more this measurement would underestimate it.

The magnitude of this effect is clearly appreciable in the experiments of Malliaris and Libby (configuration *a*). In the typical MPD conditions considered by the authors [after Eq. (14)], the beam density is taken as $2(10)^{14} \text{ cm}^{-3}$ (ions plus neutrals). This corresponds to the lowest mass flow rate considered (10 mg/sec), so presumably the lowest tank pressure (10 μ) would be appropriate. The temperature of the background gas would be about the same as that of the tank wall or room temperature. Thus, for $10 \mu \approx 10^{-5} \text{ atm}$, the background neutral density would be:

$$N \approx 10^{-5} N_0 \approx 2.6(10)^{14} \text{ cm}^{-3} \quad (1)$$

where N_0 is the density at standard conditions. By the author's own arguments, the background gas would diffuse freely into the beam region. Since the estimated background density exceeds the estimated density of neutrals in the beam, a doppler shift measurement would significantly underestimate the velocity in this case.

The above effect may account for some of the qualitative difference between the results of Malliaris and Libby and those reported earlier by Sovie and Connolly.^{2,3} Sovie and Connolly reported much higher neutral velocities than those observed by Malliaris and Libby. The Sovie and Connolly experiments, however, were performed at two orders of magnitude lower background pressure where the effect described above would be negligible.

References

- ¹ Malliaris, A. C. and Libby, D. R., "Spectroscopic Study of Ion-Neutral Coupling in Plasma Acceleration," *AIAA Journal*, Vol. 9, No. 1, Jan. 1971, pp. 160-167.
- ² Sovie, R. J. and Connolly, D. J., "A Study of the Axial Velocities in an Ammonia MPD Thruster," *AIAA Journal*, Vol. 7, No. 4, April 1969, pp. 723-725.
- ³ Sovie, R. J. and Connolly, D. J., "Effect of Background Pressure on Magnetoplasmadynamic Thruster Operation," *Journal of Spacecraft and Rockets*, Vol. 7, No. 3, March 1970, pp. 255-258.

Reply by Author to D. J. Connolly and R. J. Sovie

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CONNOLLY and Sovie¹ argue that the background particle density in our experiments² is comparable to the particle density in the beam. This might be so but, in an ammonia MPD flow, the beam fluid is much richer in atomic species (such as H and N), than the background fluid. The environmental background fluid (mainly NH_3 , H_2 and N_2) diffusing into the beam, well downstream of the accelerator, has a much smaller chance of being dissociated because of the much milder conditions prevailing at these downstream stations. Thus, the presence of atomic species of background origin is fractionally negligible in the beam.

More important are the following experimental facts: in our experiments² we have used two configurations, *a* and *b*. The first is unfavorable to a strong ion-neutral coupling, while

the opposite is true for the second. These configurations have been tried under experimental conditions which overlap over a certain range (see Table 1 of Ref. 2). In this range, whatever background effects are present in the expanded beam of configuration *a* should also be present in *b*. However, under otherwise identical conditions, the neutrals in *a* were found to be much slower than those in *b*. It follows that the background effect mentioned by Connolly and Sovie is not sufficiently strong to affect our measurements.

References

- ¹ Connolly, D. J. and Sovie, R. J., "Comment on Spectroscopic Study of Ion-Neutral Coupling in Plasma Acceleration," *AIAA Journal*, Vol. 9, No. 9, Sept. 1971.
- ² Malliaris, A. C. and Libby, D. R., "Spectroscopic Study of Ion Neutral Coupling in Plasma Acceleration," *AIAA Journal*, Vol. 9, No. 1, Jan. 1971, pp. 160-167.

Comments on "Flow with $M_\infty = 1$ Past Thin Airfoils"

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IN a recent paper¹ a comparison of theoretical² and experimental³ sonic pressure distributions is presented for airfoils having ordinates Z and chordwise location $(x/c)_{Z \max}$ of the maximum thickness given by

$$(Z/c) = A[(x/c) - (x/c)^n], \quad (x/c)_{Z \max} = (1/n)^{1/(n-1)} \dots \quad (1)$$

and

$$(Z/c) = A[(1 - x/c) - (1 - x/c)^n], \quad (x/c)_{Z \max} = 1 - (1/n)^{1/(n-1)} \dots \quad (2)$$

in which $A[\tau n^{n/(n-1)}]/[2(n-1)]$, c is the chord length and τ is the thickness-chord ratio. For maximum thickness locations rearward of $(x/c)_{Z \max} = 0.50$, the discrepancy between the theoretical and experimental distributions ceases to be small.

The validity of the experimental data quoted has been questioned by Thompson,⁴ since they derive from wind-tunnel "bump" tests using a ventilated working section that may not have been adjusted precisely for interference free conditions. Also the chord length (3 cm) was relatively large in relation to the working section height (7 cm) and span (5 cm). These suspicions have been substantiated by measurements on symmetrical airfoils made in the 81 cm high, 53 cm span, Transonic Wind Tunnel at A.R.L., Melbourne.⁵ The tunnel wall open area ratio and the airfoil chord-tunnel height ratio were varied in order to assess the extent of the interference. Airfoil chord length varied from 6.27 cm-20.32 cm, while thickness-chord ratio was held at 0.12 throughout. The maximum thickness location was $(x/c)_{Z \max} = 0.3$ (strictly 0.3011) corresponding to $n = 6$ in Eq. (2) above. Data for maximum thickness location $(x/c)_{Z \max} = 0.7$ corresponding to $n = 6$ in Eq. (1) above were obtained by reversing the airfoils.

Results estimated to be reasonably free of interference are presented in Fig. 1 as chordwise distributions of the transonic

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