at Reynolds numbers high enough to inspire confidence in the characterization of the flow field, the probe effect is much larger than any effect due to diffusion in the free stream [3]. At Reynolds numbers low enough to permit extensive separation by diffusion the nature of the flow and its interaction with the probe becomes highly uncertain. This dilemma is an inevitable consequence of the similarity between the diffusion of momentum (viscosity) and species. It seems likely that immaterial probes such as light and electron beams offer the most hope for obtaining quantitative data on species diffusion effects in high gradient flows because they permit *in situ* determination of composition far away from *any* surface.

REFERENCES

1. A. Kogan, *Int. J. Heat Mass Transfer* **9**, 1–10 (1966).
2. F. L. Daum, J. S. Shang and G. A. Elliott, *AIAA Jl* **3**, 1546 (1965).
3. F. S. Sherman, *Physics Fluids* **8**, 773 (1965).

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AUTHOR'S REPLY

While I fully agree with Professor Fenn's suggestion that immaterial probes, such as electron beams or light, should be in principle more suitable for obtaining unequivocal quantitative data on diffusion of species in high gradient flows, I must disagree with some of his comments concerning interpretation of the experimental results presented in the paper.

The convergent (subsonic) part of the nozzle was bounded by four plane surfaces at small inclinations to the throat section. With such geometry one would expect, by continuous flow theory, zero boundary-layer thickness at the throat [1].

It should be clear that the measured background pressure represents a stagnation pressure. For a ratio of stagnation pressures p_{02}/p_{01} of the order 0·1, a monoatomic gas should reach Mach numbers in excess of 5·5 before supersonic flow breakdown. Thus the available pressure ratio was adequate for attainment of supersonic flow at $M = 3$ and beyond.

An experimental check on my assertion that, up to the relatively low Mach numbers of this investigation, the boundary-layer displacement thickness is quite small can be inferred from Fig. 5. A build-up of a thick boundary layer should lead to a corresponding lag in Mach number development in the central part of the flow, yet the values of M in Fig. 5 are at most about 5 per cent below their nominal value.

There is no doubt that the composition "seen" by the pressure gauge is not the same as that entering the probe, nor as that in front of it. Moreover, there is no reason to expect that the probe effect should be constant all along the survey line. That is why the process of extrapolation at both ends of the experimental curve of Fig. 7 has been adopted in an effort to evaluate correctly the probe effect. From many data similar to those shown in Fig. 7, it was apparent that appreciable variation of probe effect could have occurred only over a relatively narrow region. The procedure adopted for correcting the data for probe effect should therefore be satisfactory.

REFERENCE

1. L. Rosenhead (editor), *Laminar Boundary Layers*. Clarendon Press, Oxford (1963).

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