

RAREFIED GAS DYNAMICS

PROGRESS IN DEVELOPING HIGH ENERGY NOZZLE BEAMS

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Abstract

Some exploratory studies utilizing the electron beam to investigate the phenomena of the skimmer influence on nozzle beam formation are presented. These suggest that the dominant region producing observed beam scattering is inside the skimmer. Photographs of the density field around a pre-skimmer and skimmer are also included.

Results and Discussion

Evidence has been accumulating<sup>(1,2)</sup> that, for the nozzle-skimmer separations corresponding to maximum beam intensity, the highly collimated core flow is accompanied by a widely dispersed low velocity molecular flow, which can often be the dominant gas load on the collimation chamber pump, as well as a potential nuisance in certain classes of experiments. We report here some indications of the role that the skimmer may play in this phenomena, obtained using the electron beam flow visualization technique in two variations. In the first variation, a camera viewed the free jet flow field from the side, and the camera shutter was held open while moving the electron beam steadily downstream to map out a plane containing the flow axis and perpendicular to the camera axis. In the other variation the electron beam was more precisely collimated (0.2 mm diameter instead of 1 mm.) and a photomultiplier was used with imaging optics which selected one small element of the beam length. This assembly traversed with the electron gun, so that the density variation along the axis of the free jet could be mea-

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sured. The photomultiplier plus optics could also be traversed vertically to measure off-axis densities.

Some earlier photographs obtained using the first technique concerned the interaction of an argon free jet and a 2.54 mm diameter skimmer of  $35^\circ$  external half-angle<sup>(3)</sup>. At high Mach numbers and skimmer Knudsen numbers ranging up to unity, no detached external shock or apparent increased density field was found in front of the skimmer, although there was some indication that the density increase behind the external shock wave extended to a small localized region wrapped around the skimmer lip. The photographic evidence was inconclusive at the low densities, but in Fig. 1, some nitrogen density measurements are reported which corroborate our earlier suggestion that the main region of beam degradation must be inside the skimmer. The curves were obtained at a fixed nozzle-skimmer separation of  $23.8 d_0$ , at various source pressures. They indicate that, on the centerline, the density starts to increase about one local mean free path ahead of the skimmer, but that up to a skimmer Knudsen number of 1.18 (based on the simple hard sphere mean free path) the external density field is not nearly large enough to account for the large amount of wide-angle scattering which is found to be present from radial traverses of the molecular flux downstream of the skimmer. Also, the shape of the curves suggests significant further density increases inside the skimmer.

Some radial traverses in front of the skimmer were also obtained. Figure 2 is a density trace at an axial position 0.15 skimmer diameters ahead of the skimmer, normalized to the isentropic free jet density at this position, for the stagnation pressure of 120 Torr. The curve confirms the fact that the perturbation effect is strongly associated with the skimmer lip region, rather than emanating from inside the skimmer. There is noticeable asymmetry in the disturbance, which was even more pronounced in other runs which we do not include here because of uncertainties in the electron beam position. This asymmetry suggests that to a measurable extent the lip radius contributes to the density increase, since manufacturing irregularities are impossible to eliminate entirely at the lip. Under the microscope the skimmer lip radius to hole radius ratio was estimated to be .03 averaged around the rim; some segments were poorer.

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At this point an attempt was made to see if the flow passing through the skimmer could be influenced by the use of a pre-skimmer (or stripper), as suggested by Skinner and Moyzis<sup>(1)</sup>. Their suggestion was that the main source of molecules which trigger the scattering region inside the skimmer was the diffuse shocked region external to the skimmer rather than direct reflection from the lip radius, and that the supply of molecules to this region could be reduced by using a pre-skimmer to shadow this region from the main flow. Preliminary photographs showed some interesting effects so we include them here although not all aspects are understood.

Figures 3(a) to (d) comprise a series of nitrogen flow fields using a pre-skimmer of  $43^\circ$  external half angle, 0.20" diameter, positioned so that the calculated Mach line from its tip would intercept the main skimmer just outside the lip. The free jet source is out of view to the right. It can be seen that at  $P_0 = 400$  Torr (stripper Knudsen number = 0.39, Mach number = 9.75) a relatively strong shock is produced, converging ahead of the main skimmer. The flow remains highly collimated even though it has been processed by this shock wave, as indicated by the very dark high vacuum region around it. It is tempting to speculate that in fact the conical shock converges the flow to some extent so that a higher number flux is able to pass through the skimmer, producing the enhanced beam which Skinner and Moyzis observed. The shock system became more diffuse at lower pressures but the density observable on the center line behind the pre-skimmer indicates that the flow has undergone compression, when compared to photographs (not included here) of the undisturbed free jet.

The pre-skimmer might be considered as a conventional skimmer operating in the region of the minimum in beam intensity (i.e. at a nozzle-skimmer separation yielding skimmer Knudsen numbers in the range .01 to 0.1). These pictures then extend the earlier Schlieren pictures obtained by Bier and Hagena<sup>(4)</sup> to much lower density. They seem to suggest that a strong compressive disturbance emanating from the lip is responsible for the beam degradation under this skimmer operating condition. This pattern is similar to that inferred by Rogers and Williams for two-dimensional geometry under similar flow conditions<sup>(5)</sup>. Studies are continuing of the flow field behind skimmers operating at

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Knudsen numbers of order unity and larger, using the photomultiplier technique.

Figures 4(a) to (c) is a similar series of photographs using argon. It can be seen in Fig. 4(a) that the shock converges upstream of the position for nitrogen, and at the higher pressures it is evident that the gas is processed by another shock wave downstream of the convergence point, which would deflect the flow away from the axis again.

To summarize, the photomultiplier data indicates that the dominant region of scattering is within the skimmer. Also, visual evidence of the operation of a conical skimmer or pre-skimmer has been presented. It suggests that significant disturbances penetrate quickly to the core of the flow up to skimmer Knudsen numbers of 0.1 at least. There is some indication that the skimmer lip radius may have an effect of the strength of the disturbance. Work is continuing to examine the flow field inside the skimmer in order to minimize beam degradation and perhaps utilize skimmer effects to enhance separation in seeded beams.

References

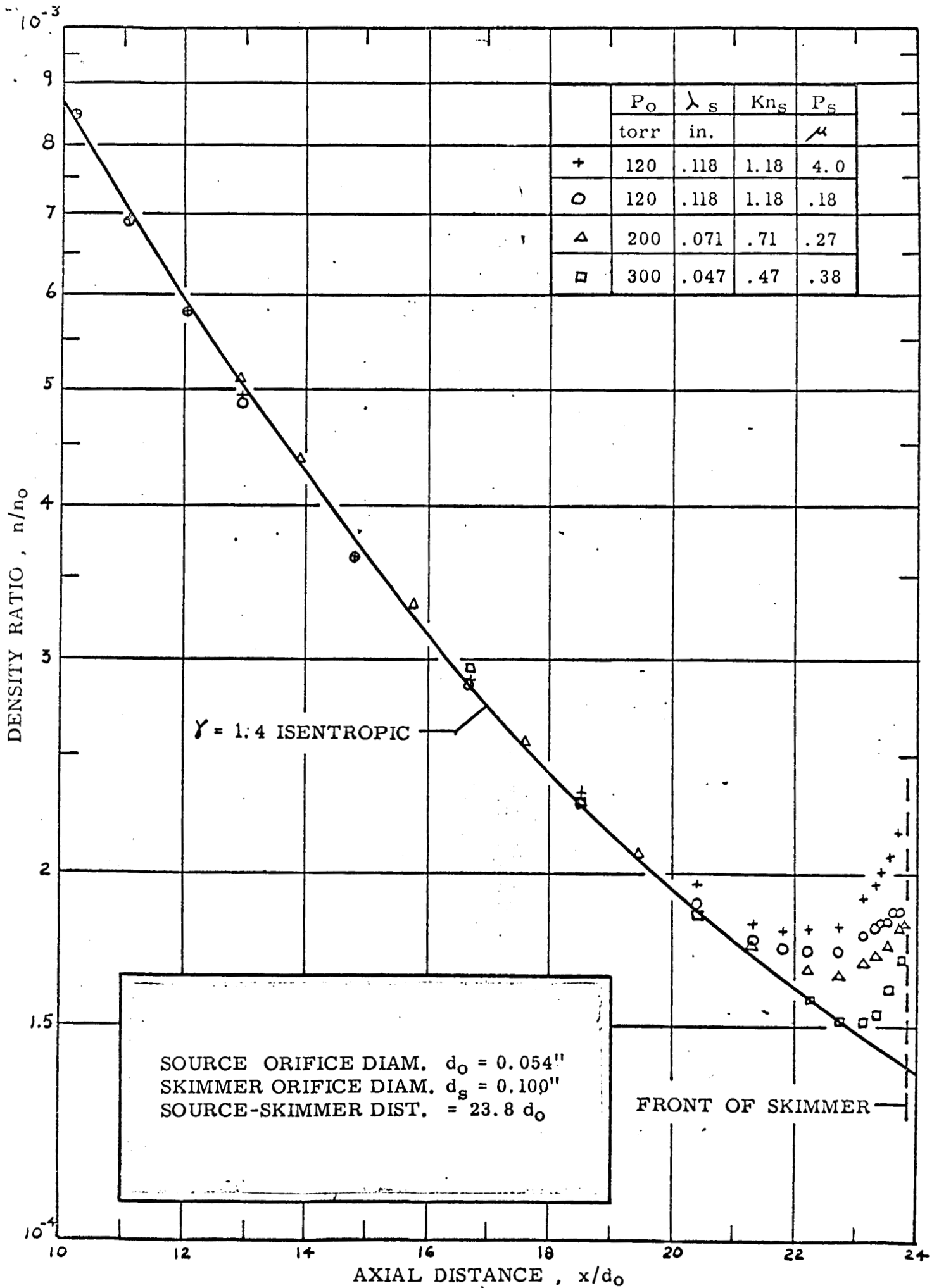
1. G. T. Skinner and J. Moyzis, Phys. of Fluids, 8, 452 (1965).
2. J. B. French and D. R. O'Keefe, "Omeatron Studies of a Skimmer Beam System" in Rarefied Gas Dynamics, Vol. 2, J. H. de Leeuw (Ed.), Academic Press, N.Y., 1966.
3. G. E. McMichael and J. B. French, "Electron-Beam Studies of Skimmer Interaction in a Free Jet", accepted for publication, Physics of Fluids, July or August, 1966.
4. K. Bier, and O. Hagen, "Influence of Shock Waves on the Generation of High Intensity Molecular Beams by Nozzles", in Rarefied Gas Dynamics, Vol. 1, J. A. Laurmann (Ed.), Academic Press, N.Y., 1963.
5. T. Rogers and J.C. Williams, III, "Experimental Investigation of Low Density Axial Flow Through Short Tapered Ducts" in Rarefied Gas Dynamics, Vol. 2, J.H. de Leeuw (Ed.), Academic Press, N.Y., 1966.

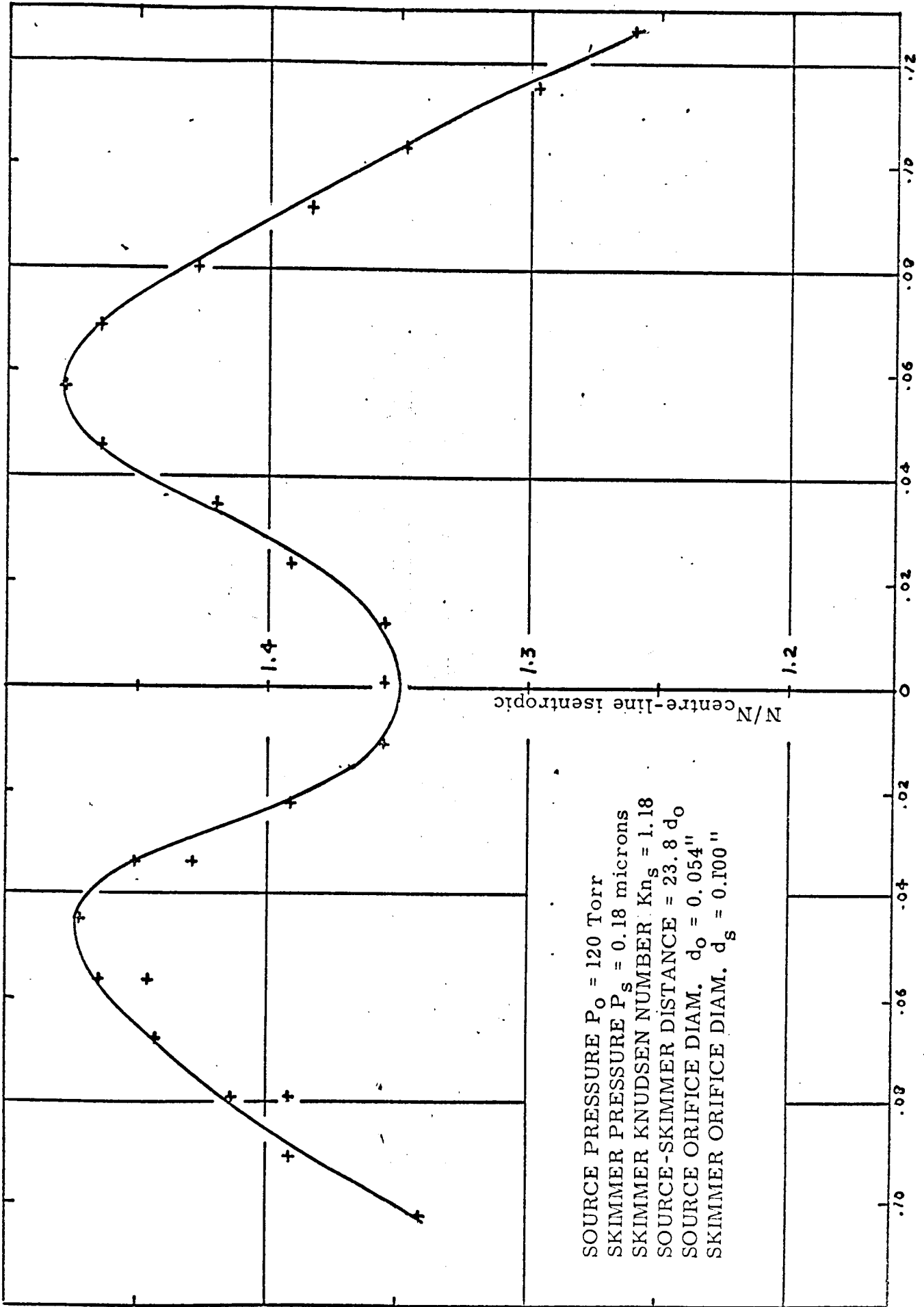
FIG. 1 CENTERLINE DENSITY DISTRIBUTION IN FRONT OF A CONICAL SKIMMER IN NITROGEN FREE JETS

FIG. 2 RADIAL DENSITY TRAVERSE 0.015" IN FRONT OF A CONICAL SKIMMER IN A NITROGEN FREE JET

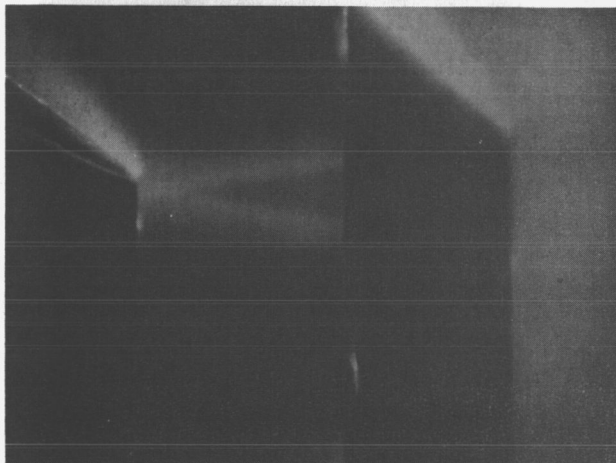
FIG. 3 SKIMMER AND PRE-SKIMMER IN A NITROGEN FREE JET.  
GEOMETRY: Source dia.  $d_0 = .060$ , "pre-skimmer dia = 0.200", position =  $12.5 d_0$ , skimmer dia. = 0.100", position =  $21.7 d_0$  NOMINAL CONDITIONS: pre-skimmer Mach No. 9.75 Source pressure and pre-skimmer Knudsen No. Fig. 3(a) 500 Torr, .031; Fig. 3(b) 400 Torr, .039; Fig. 3(c) 300 Torr . 052; Fig. 3(d) 200 Torr. 078.

FIG. 4 SKIMMER AND PRE-SKIMMER IN AN ARGON FREE JET.  
GEOMETRY: as in Fig. 3. NOMINAL CONDITIONS: Source pressure and pre-skimmer Knudsen No. Fig. 4(a) 300 Torr, .032; 4(b) 200 Torr, .048; 4(c) 100 Torr, .097.





SOURCE PRESSURE  $P_0 = 120$  Torr  
 SKIMMER PRESSURE  $P_s = 0.18$  microns  
 SKIMMER KNUDSEN NUMBER  $Kn_s = 1.18$   
 SOURCE-SKIMMER DISTANCE =  $23.8 d_0$   
 SOURCE ORIFICE DIAM.  $d_0 = 0.054$ "  
 SKIMMER ORIFICE DIAM.  $d_s = 0.100$ "



3(a) 500 Torr, .031;

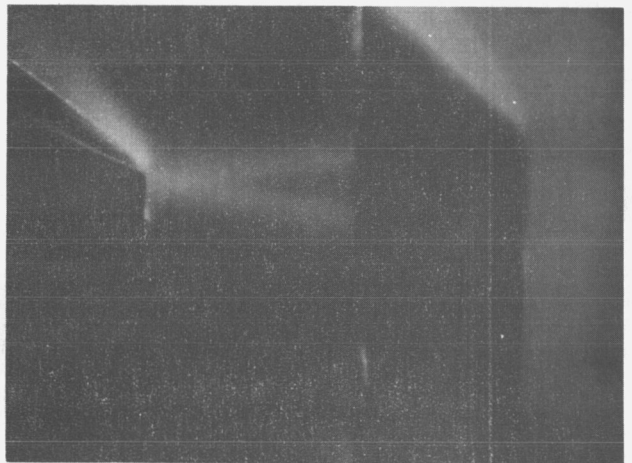


Fig. 3(b) 400 Torr, .039;

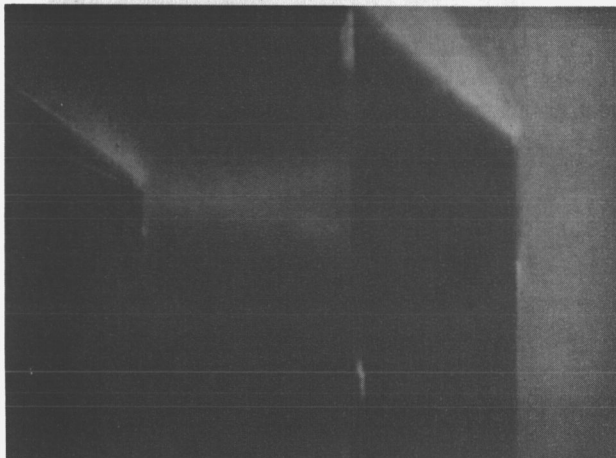


Fig. 3(c) 300 Torr . 052;



Fig. 3(d) 200 Torr. 078.

FIG. 3 SKIMMER AND PRE-SKIMMER IN A NITROGEN FREE JET.  
GEOMETRY: Source dia.  $d_0 = .060$ , "pre-skimmer dia =  
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No. 9.75 Source pressure and pre-skimmer Knudsen No. Fig.



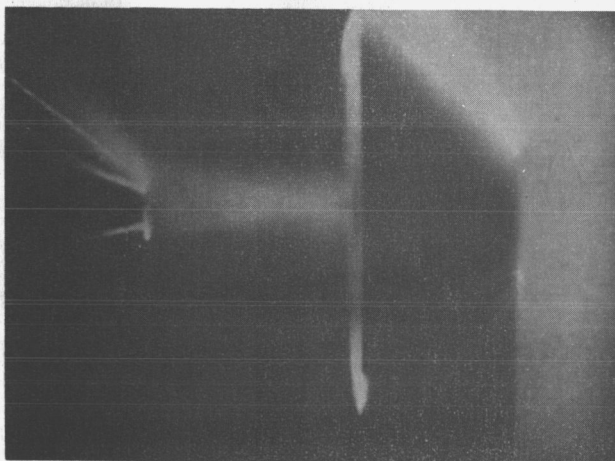
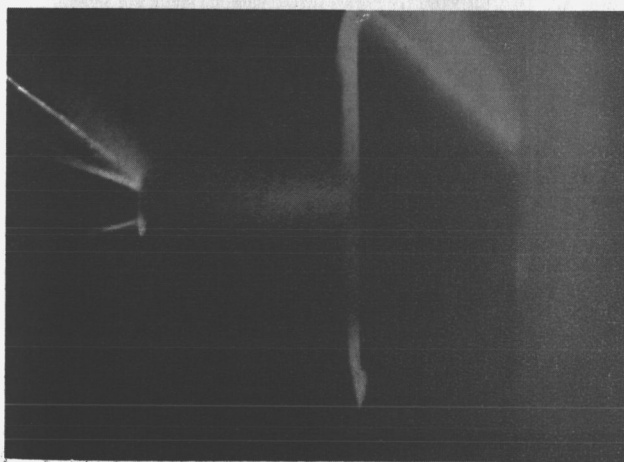
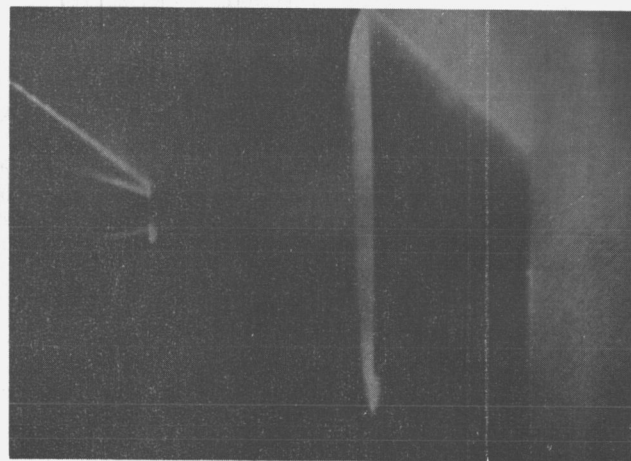


Fig. 4(a) 300 Torr, .032;



4(b) 200 Torr, .048;



4(c) 100 Torr, .097.

FIG. 4 SKIMMER AND PRE-SKIMMER IN AN ARGON FREE JET.  
GEOMETRY: as in Fig. 3. NOMINAL CONDITIONS: Source  
pressure and pre-skimmer Knudsen No.