A Jet Neutralizer Concept

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Abstract

When gas cell neutralizers are inadequate for large aperture ion beams, one must turn to supersonic jets to achieve a neutralizer. A transverse supersonic jet concept for neutralizing ion beams is presented. The concept eliminates the problems posed by boundary layer development in a low density nozzle flow. Operating conditions are presented for optimum neutralizers using several gases.

I. INTRODUCTION

A. Gas Cells

In using a gas stripper for a negative ion beam there are two neutralizer concepts: the gas cell and the transverse supersonic jet. For either, a controlling parameter is the "target thickness parameter", the integral of gas density along the ion beam path. Data on this parameter have been presented in Reference [1] and are used as the data base for this work. For optimum neutral yield these data can be translated into the pressure for a one meter thick neutralizer. The optimum pressures are

Neutralizer Gas	P (torr)
HELIUM	4.8
ARGON	0.22
XENON	0.058

Considering beamline pressures of 10^{-5} to 10^{-9} torr, the escape of gas from the neutralizer into the beamline represents a significant problem. In addition to the gas load on the beamline pumps, other concerns are the complexity of the system, the total gas consumption, and the beam length required.

B. Gas Jets

In terms of both concept and implementation, supersonic jets are complex. Conceptually, one is utilizing the limited lateral expansion available to a high Mach number flow. The flow is directed transverse to the beam to create a wedge of neutralizer gas. Above a Mach number of 6 the flow velocity approaches a constant value, thus the conservation of mass assures a constant target thickness parameter over the beam aperture. The total mass flow rate through the jet scales as the product of the beam aperture and the neutralizer length along the beam. Of this flow only a fraction, less than 5%, enters the beamline.

The concerns with supersonic transverse jet neutralizers are: the mass of gas required, viscous effects, and rarefied gas effects. As a measure of the importance of each of these, the following data are presented for our nominal 1 meter beam aperture:

Gas	Mass Flow (gm/s)	Reynolds No.	Knudsen No.
HELIUM	180	11000	0.0005
ARGON	26	1400	0.004
XENON	13	660	0.009

The above were based upon the optimum target thickness parameter for each gas with a gas supply temperature of 300K. The Reynolds number, which is a measure of the importance of viscous effects, is the minimum value evaluated at the Mach 1 condition in the jet. These values are low, indicating a significant viscous problem. The Knudsen number, the ratio of mean free path to neutralizer length, was evaluated in the high Mach number flow of the neutralizer volume. These values indicate the continuum assumption remains valid for purposes of analysis.

From the above one can conclude that the primary concern in the choice of a jet neutralizer concept must be with the viscous effects. It is imperative to increase the minimum Reynolds number to prevent a viscous distortion of the jet. Equally important is the reduction or elimination of the significant thickness of boundary layer which develops on the walls of conventional nozzles.

In the following, a concept is presented for achieving a well confined wedge of supersonic flow in which viscous effects can be minimized by controlling the Reynolds number at Mach 1 and eliminating boundary layers.

C. The Corner-expansion

Corner-expansion flows are common to under-expanded supersonic flows as they escape the confines of a nozzle. They are characterized by the abrupt turning

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of the streamline at the lip of the nozzle. A classic illustration of the phenomena is reproduced in Figure 1.

Here an initially uniform sonic flow has been depicted as series of streamlines emanating from the Mach 1 source cross-section and as a series of dashed constant Mach number lines radiating from the lip. The lip will be referred to as the "source lip" below.

The constant Mach lines also represent lines of constant properties and in this figure they represent order of magnitude reductions of pressure.

II. THE DOUBLE CORNER-EXPANSION JET

The concept presented in this paper, which has been termed the "double corner-expansion", can be most easily introduced by referring back to the Mach 1 source corner-expansion of Figure 1. Consider a second lip placed on a streamline, pointing in opposition to the flow, and rotated through a slight positive acute angle to the streamline. This lip will "scrape off" those streamlines above the lip streamline. These will experience compression by an oblique shock just above the scraper lip. Those streamlines below the lip will expand via a high Mach number corner-expansion originating at the scraper lip.

The streamlines above the scraper lip are referred to as the "primary flow" and those passing between the source and scraper lips compromise the "secondary flow". One can conceive of the primary flow as being that of a slightly bent wind tunnel, depicted in Figure 2, with the gas supplied by a plenum to the Mach 1 throat, which is followed by the supersonic nozzle (formed by the upper bound streamline and the lip streamline), and exiting by the diffuser (formed by the continuation of the upper-bound streamline and the scraper lip plate). The use of an appropriate dimension for the primary flow throat eliminates the throat Reynolds number problem. If we think of the primary flow path as that of a wind tunnel then the secondary flow can be thought of as a leak through a slit in the tunnel wall. The secondary flow is utilized as the jet neutralizer.

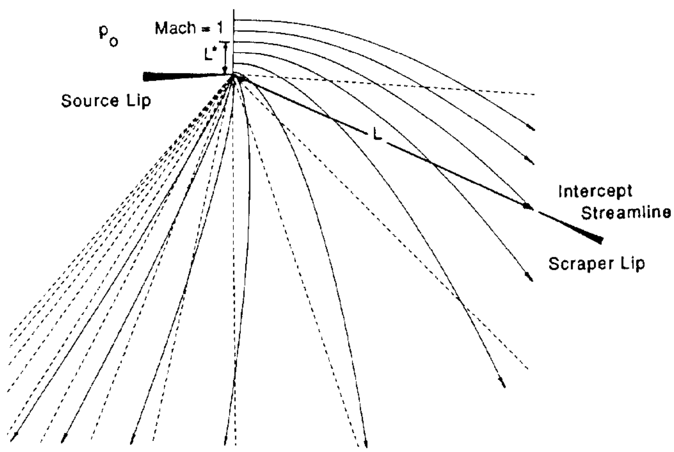


Figure 1. Corner-expansion of an initially uniform Mach 1 flow. Mach lines are dashed and shown for multiples of 10 in pressure. Streamlines are plotted with solid lines. Positioning of Scraper Lip for double expansion is shown with parameters: L—lip spacing, L*—the source layer thickness, and P_O the supply stagnation pressure.

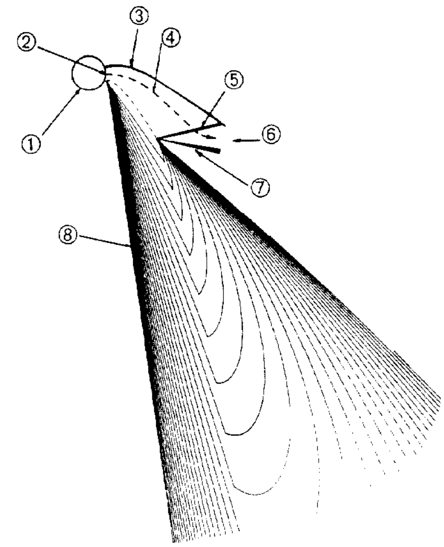
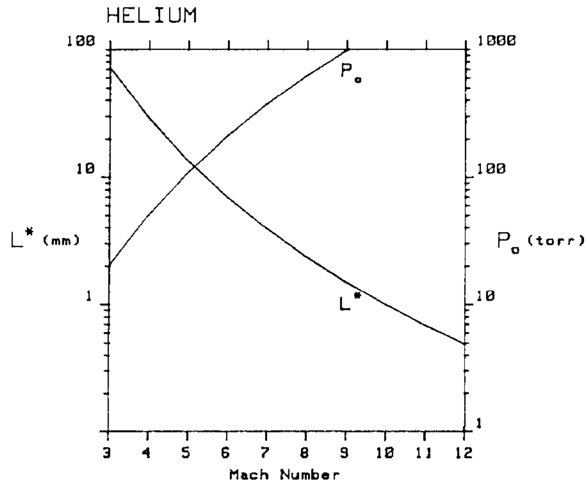
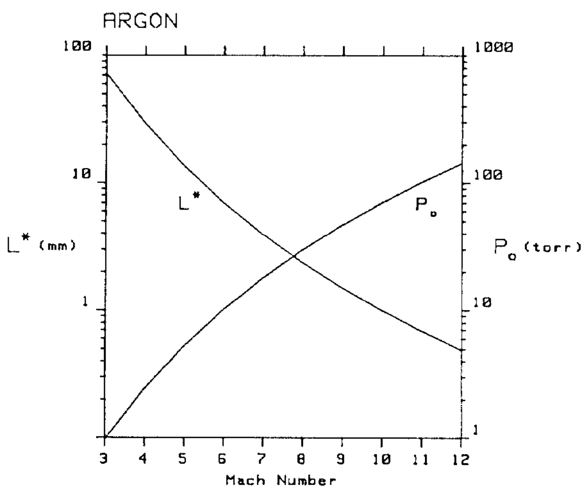


Figure 2. Possible configuration of the Primary Flow Circuit to achieve a double corner-expansion jet for a neutralizer. With: 1—gas supply plenum, 2—sonic throat, 3—upper wall of primary flow circuit, 4—a primary flow streamline, 5—oblique shock in primary flow, 6—exhaust from diffuser, 7—scraper lip, 8—secondary flow jet directed transverse to beamline.

Focusing on the secondary flow jet, consider the factors influencing the positioning of the scraper lip relative to the source lip. Clearly, high values of the intercept Mach numbers are advantageous in achieving compact jets. Recall from Figure 1 that the radial dashed lines represent constant values of Mach number and that Mach numbers increase in the clockwise direction. The intercept Mach number position also results in the skewness of the secondary flow jet to the primary flow. Increasing the radial position of the scraper lip relative to the source lip increases the mass flow in the jet and consequently the target thickness parameter.

Intercept Mach numbers below 3 result in extreme spreading of the jet. Mach numbers above 12 represent increasingly improved wedge angles but are considered to be unattainable because of condensation at the extremely low temperatures achieved in the flow. The contoured field shown in Figure 2 represents 97% of the mass flow in the jet and is for a Mach 6 intercept. The contours of the jet are unit increments of the Mach number and may be converted into pressure or density contours by the usual gasdynamic relations.





Figures 3a and 3b. Data for a lip spacing, L, of one meter. The quantity P_0 is the stagnation pressure in the gas supply plenum. The quantity L^* is the thickness of the layer of gas at sonic flow which forms the jet. As the actual parameters are P_0L and L^*/L, these data can be scaled to systems of any size.

III. OPERATING PARAMETERS

The target thickness parameter determines the scale and operating pressure. Using the optimum target thickness data with results for the double corner-expansion computations, operating parameters have been computed for comparisons of helium and argon. These data, which are a function of intercept Mach number, are presented in Figures 3a and 3b, and supplement data presented earlier in this paper.

With the elimination of Reynolds number as a primary design parameter the decisive parameter would appear to be the mass flow rate of the jet. Contrasting the 1 meter beam requirements of 180 gm/s for helium with the 26 gm/s for argon, argon would seem the better choice. However, this conclusion is based only on the mass rate of the secondary flow. A mass rate of 20 times the argon number might be circulating in the primary flow to eliminate the throat Reynolds number problem. For helium only 2.5 times the secondary flow rate is required to achieve the same throat Reynolds number. This translates into primary flow rates for argon which are over 10% greater than that of helium. Furthermore, this would translate into an argon primary flow tunnel which is 8 times the scale of that for helium.

Several questions have not been treated in this study. One concerns the asymmetry of the flow--will this create problems in designing a supersonic diffuser to recover the jet flow? Will it be allowed to escape or recovered by condensation? A metal vapor jet is considered in Reference [2].

We can conclude that the double corner-expansion concept is a viable collisional neutralizer concept for large beams. It involves the complexity of a primary flow circuit to eliminate viscous effects; however, this is more reliable and effective than a more complex system of boundary layer control on conventional nozzles at high Mach numbers.

IV. REFERENCES

[1] R. Fuehrer, *Tabulation of Electron Stripping Parameters for Various Gas and Solid Neutralizer Targets Interacting with 50 MeV H-Ion Beams*, Memorandum LANL Q-13:86:443, (1986).

[2] J.J. Guy Durocher, C.S. Bohun, and G.R. Smith, "Production of 20 to 50 MeV Neutral Hydrogen Beams", *IEEE Particle Accelerator Conference*, CH2387, 1869 (1987).