Effects of Mach Number on the Development of a Subsonic Rectangular Jet

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Abstract

A SUBSONIC jet of air emanating from a rectangular nozzle of intermediate aspect ratio has been investigated using hot-wire anemometry. The purpose of this investigation was to extend our knowledge of a rectangular jet from incompressible to compressible flow. Results of the hot-wire measurements show that a compressible subsonic rectangular jet behaves in a manner similar to that of an incompressible jet. It exhibits three distinct regions characterized by the decay of the mean axial velocity along the axis of the jet. These three regions are a potential core region, a two-dimensional type region, and an axisymmetric type region. The principal effect of increasing the Mach number of the rectangular jet was found to be the extension of the two-dimensional type region, and the jet behaves more nearly like a two-dimensional jet at higher Mach numbers.

Contents

The experiment was carried out on a rectangular nozzle, 50 mm long (L) and 3 mm wide (D), which was preceded by a 40 mm long smooth channel (50×3 mm). A Cartesian coordinate system was used with its origin located at the center of the nozzle and the X axis oriented along the centerline of the jet. The Y and Z axes are parallel to the long and short dimensions of the nozzle, respectively. Four exit Mach numbers ($M_e = 0.18$, 0.3, 0.5, and 0.8) were studied in this experiment. The corresponding Reynolds numbers based on the width of the nozzle were 12,000-52,000. For all the Mach numbers studied, a top-hat mean velocity profile with a centerline turbulence intensity of about 0.4% was obtained at the nozzle exit. Measurements were made with standard constant temperature anemometer system (DISA 55P11, 55M10, and 55M25). The mean hot-wire output voltage was linearized for a velocity range of 20-280 m/s, with the voltage directly proportional to the velocity.

The variation of the (squared) normalized mean velocity along the centerline of the jet for four exit Mach numbers is shown in Fig. 1. The centerline mean velocity U_c is normalized with respect to the mean velocity at the center of the nozzle exit U_0. The three regions of an incompressible rectangular jet as described above can be identified in this figure. It appears that the jet decay rate has a fairly weak dependence on the Mach number.

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Figure 2 shows the distribution of mean velocity U in the central X, Y plane at different downstream locations, ranging 20-100D for various Mach numbers. The mean velocity U is normalized with respect to U_c at the corresponding downstream location, while the distance Y is normalized by the distance X to the station in question. A similarity profile of a

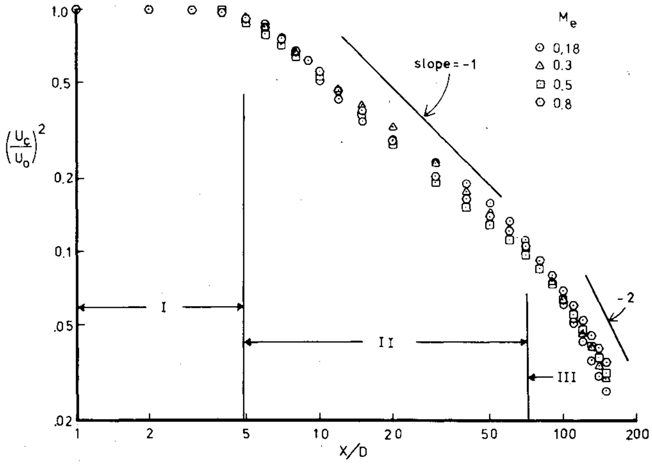

Fig. 1 Normalized centerline mean velocity decay.

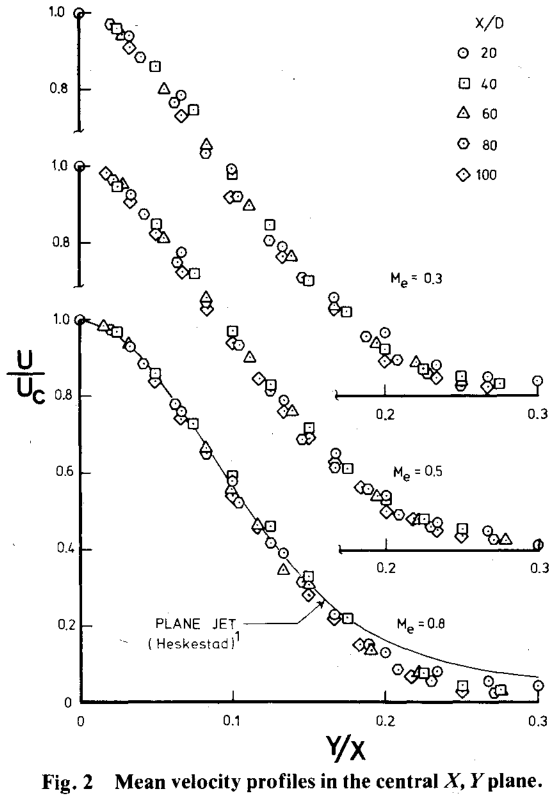

Fig. 2 Mean velocity profiles in the central X, Y plane.

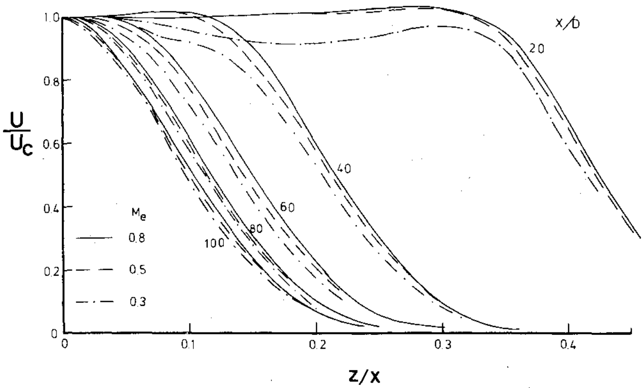

Fig. 3 Mean velocity profiles in the central X,Z plane.

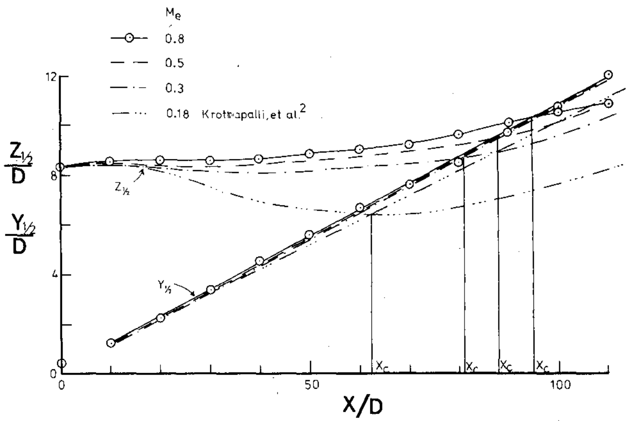

Fig. 4 Growth of the rectangular jet with downstream distance.

plane turbulent jet from Heskestad[1] is included in the figure. Within the limits of error for the experiment, at each Mach number the profiles are geometrically similar. The shape of the similarity profile is nearly independent of the exit Mach number and similar to that of a two-dimensional (plane) jet.

Figure 3 shows normalized mean velocity profiles in the central X,Z plane at five downstream locations for various exit Mach numbers. At each corresponding downstream location, the profile shows only a slight variation with M_e. At $X=20D$, a saddle shape profile is observed in the jet for M_e equal to 0.3. This type of profile was also observed in the two-dimensional type region of an incompressible rectangular jet.[2] As the exit Mach number increases to 0.5 and 0.8, the saddle shape becomes less pronounced. These mean velocity profiles suggest that in the two-dimensional type region the jet behaves more nearly like a planar jet at higher subsonic Mach numbers.

The growth of the jet with downstream distance in the central X,Y and X,Z planes can be represented by the half-velocity widths $Y_{1/2}$ and $Z_{1/2}$, respectively, as shown in Fig. 4 for different exit Mach numbers. The half-velocity width is defined as the distance from centerline of the jet to the point where the axial mean velocity is equal to one-half of its centerline value. The jet in the X,Y plane spreads linearly with X. The exit Mach number seems to have very little effect on the growth of the jet in the X,Y plane. However, in the central X,Z plane the variation of the half-velocity width with X shows some changes with exit Mach number. For M_e equal to 0.3, 0.5, and 0.8, $Z_{1/2}$ varies only slightly with X. But in an incompressible jet $(M_e=0.18)^2$, $Z_{1/2}$ first decreases with downstream location X and then increases. At some intermediate location the half-velocity widths in the two central planes cross over. This location corresponds to the onset of the axisymmetric region. The distance from the nozzle exit to the crossover point along the X axis (X_c) increases with increasing Mach number. This effect is solely due to the variation of $Z_{1/2}$ with M_e.

The development of the turbulence intensity profiles with downstream distance in the central X,Y and X,Z planes for a compressible subsonic jet shows an insignificant variation with exit Mach number. The profiles are quite similar to those found in an incompressible jet.[2]

Acknowledgment

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References

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