Edge Tones in High-Speed Flows and Their Application to Multiple-Jet Mixing

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Abstract

THIS paper reports the results of an experimental investigation on edge tones generated with a high-speed subsonic air jet issuing from a rectangular nozzle and impinging on a wedge shaped edge. Experiments were also made to determine the influence of these tones on the mixing of multiple rectangular jets. For exit Mach numbers ranging from 0.2 to 1.0, the minimum breadth required for a tone to be generated increases linearly with Mach number. At distances of the wedge beyond the minimum breadth, the narrow-band spectrum of the near field pressure signals indicate the simultaneous existence of several discrete frequencies, and the amplitude dominant frequencies show different stages. Improved mixing of the multiple jets has been observed when a wedge is placed in one of them.

Contents

Several experimental studies aimed at understanding the fluid mechanics underlying edge tone generation have been carried out over a period of time at Stanford University. A description of the main features of the edge tone phenomenon and a review of the various experimental and analytical investigations were given by Karamcheti et al.[1] The discussion was mainly concerned with the results of experiments on an incompressible jet having a parabolic-type exit mean velocity profile. The main purpose of this paper is to present and discuss the results of experiments on edge tones generated with a compressible subsonic air jet issuing from a rectangular nozzle having a top hat mean exit velocity profile and impinging on a wedge shaped edge. As part of an ongoing program to study the mixing processes of single and multiple rectangular jets, we are interested in a mechanism which can enhance the mixing of multiple jets. As a result, an attempt has been made to study qualitatively the mixing processes of multiple jets with a wedge present in one of them.

The main parameters governing the problem are the Mach number M and Reynolds number Re of the jet near the exit, the state of the flow at the exit of the nozzle, the geometry and disposition of the wedge with respect to the nozzle exit, and the condition of the ambient medium into which the jet is issuing. In the present investigation, the exit Mach number varies from 0.2 to 1.0. The Reynolds number employed is based on the width D (small dimension) of the nozzle and is given by $Re=MaD/\nu$, where a and ν are the speed of sound and kinematic viscosity of the ambient medium, respectively. The Reynolds number varies from 1.8×10^4 to 6.3×10^4 in the experiments. From the measurements of mean velocity at the nozzle exit, not shown here, top hat mean velocity profiles are observed for the range of exit Mach numbers considered here.

A blowdown air supply system is used to provide the airflow to a rectangular nozzle. The dimensions of the rectangular exit of the nozzle used are 50 mm long by 3 mm wide. The nozzle used for the edge tone investigation is one central lobe of the multilobe nozzle employed in a multiple-jet investigation. The experimental facility and model are described in detail by Krothapalli et al.[2] A 20-deg wedge has been selected. A conventional schlieren system is used for flow visualization. The near acoustic field measurements are made using a standard B&K ⅛-in.-diam microphone.

One of the main features of the edge tone is the "minimum breadth," which is the minimum distance h_0 required for a tone to be first generated. The variation of h_0 with exit Mach number M and/or Reynolds number is shown in Fig. 1. The distance h_0 is normalized with the nozzle width D. Included in the figure are the data from the low-speed ($M\simeq0.02$) edge tone investigation of Woolley.[3] These low-speed tones were generated with a jet having a top hat mean velocity profile at the nozzle exit and impinging on a 20-edg wedge. For the case of a low-speed jet, h_0 decreases with increasing jet exit velocity or Reynolds number, while for a high-speed ($0.2\leq M\leq1.0$) jet, h_0 increases linearly with Mach number, as shown in the figure. As suggested by Karamcheti et al.,[1] an explanation of the effects of Mach number or Reynolds number on the minimum breadth lies to a large extent in the stability characteristics of the jet.

Narrow-band spectral analysis of the pressure signals has been carried out, and frequencies of spectral peaks obtained for a jet at an exit Mach number of 0.87 are shown in Fig. 2a. The data indicate the simultaneous existence of several frequencies which are not harmonically related. Generally, only the frequencies associated with maximum amplitude are presented in plots such as Fig. 2a, and the dark symbols in the figure represent those frequencies (also referred here as stage frequencies). The higher frequencies present during the first-stage operation belong to one or the other stages that will arise

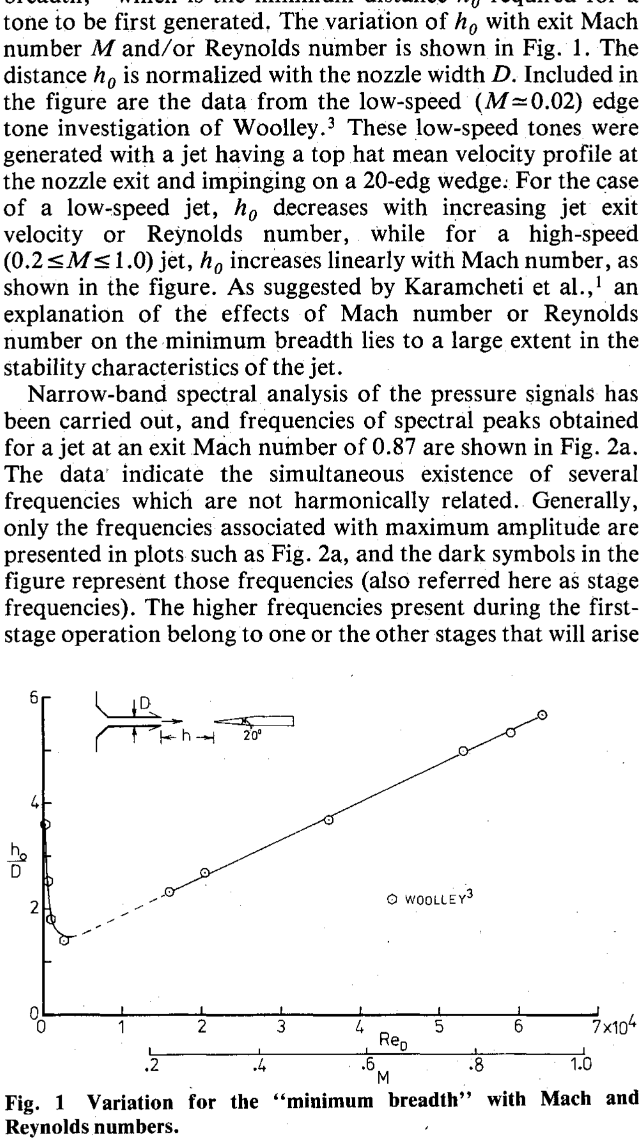

Fig. 1 Variation for the "minimum breadth" with Mach and Reynolds numbers.

Presented as Paper 82-0120 at the AIAA 20th Aerospace Sciences Meeting, Orlando, Fla., Jan. 11-14, 1982; submitted Jan. 22, 1982; revision received Nov. 2, 1982. Full paper available from AIAA Library, 555 W. 57th Street, New York, N.Y. 10019. Price: Microfiche, $4.00; hard copy, $8.00. **Remittance must accompany order.**

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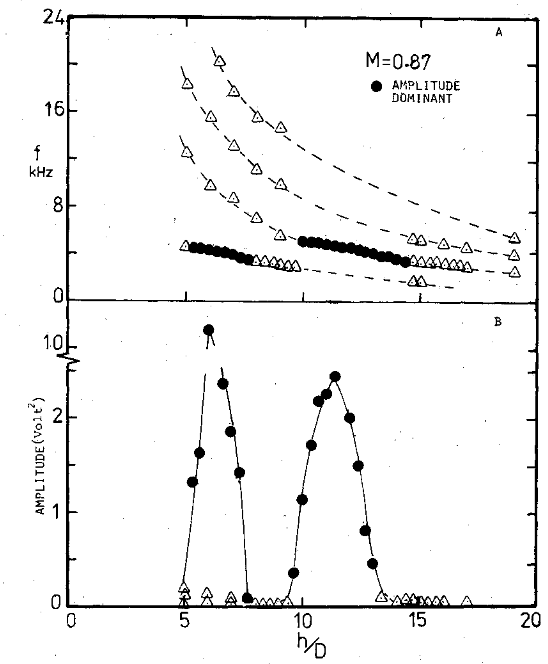

Fig. 2 Frequency and amplitude variation with edge distance.

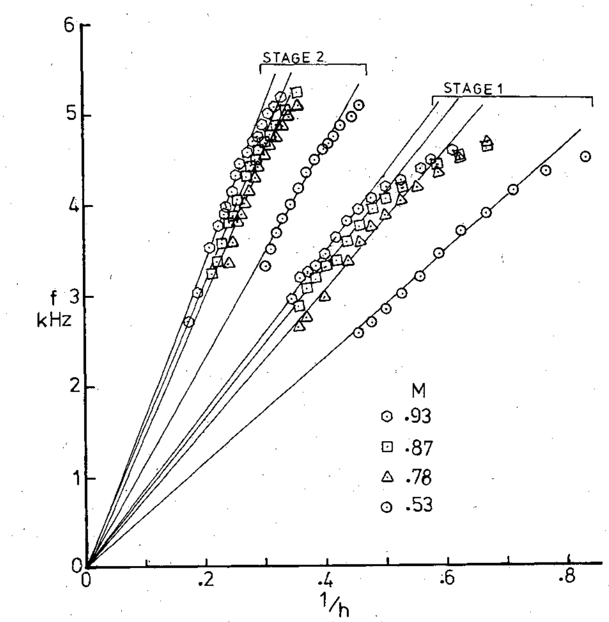

Fig. 3 Variation of frequency with edge distance at different Mach numbers.

at large distances h, of edge. The amplitudes of the corresponding frequencies are shown in Fig. 2b. As before, the dark symbols correspond to stage frequencies. The amplitude distribution of stage frequencies during each stage shows a sharp rise followed by a drop during the end of the stage. The peak amplitude during the first-stage operation is much higher (note the break in the scale) as compared to that in the second stage. Between the stages, the amplitudes of all the frequencies are almost equal. The variation of the amplitude dominant (stage) frequencies at different Mach numbers in a plot of frequency f, against $1/h$, are shown in Fig. 3. The frequency at a given Mach number is found to be inversely proportional to the breadth h during each stage of operation when the frequencies concerned have the dominant amplitude.

During the course of the experimental study, it was found that the edge tones can be utilized to promote mixing in rectangular jets. Consequently, experiments were conducted with a linear array of five rectangular jets with and without a wedge placed in one of them. A typical schlieren picture of the flow, with four jets in view, is shown in Fig. 4a. The exit Mach number of each nozzle is equal to 0.87. Figure 4b depicts the multiple-jet flowfield with the same conditions as in Fig. 4a except for a wedge placed in one of the jets. The wedge in this case is located at a distance from the nozzle exit of 1.9 cm ($h/D=6.33$). The edge tone here is in stage 1 mode of operation. We now observe that the neighboring jets show distinct vortex structures quite similar to that observed in a jet edge system. The phase-locked schlieren movie of this flowfield shows that the frequency of oscillation of individual jets is the same. However, some changes in phase are apparent from the position of the respective vortices in each of the jets. Enhanced mixing due to the external excitation of these jets is quite evident from these pictures.

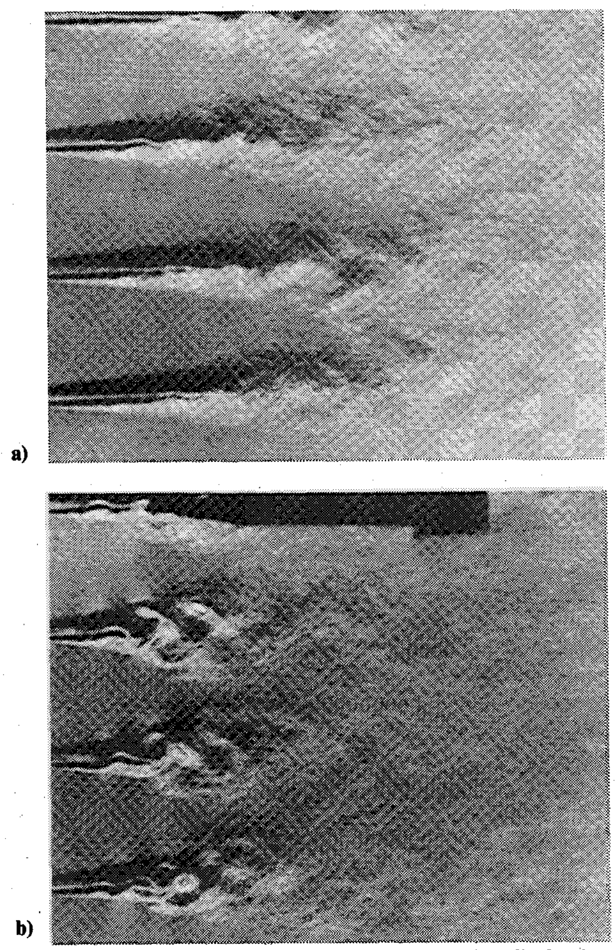
Fig. 4 Schlieren pictures of the multiple-jet flowfield with and without the edge.

The present studies are not complete enough to enable a detailed understanding of the various features of the high-speed edge tones flowfield. All the implications of the results obtained are not yet fully understood. Further detailed investigations are underway at this time.

Acknowledgment

This work is supported by AFOSR under Contract F49620-79-0189.

References

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[3]Woolley, P.J., "An Investigation of Edge Tones and the Role of Flow Field Instability in their Generation," Ph.D. Thesis, Stanford University, Stanford, Calif., 1973.