Proceedings of the ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels
FEDSM-ICNMM2010
August 1-5, 2010, Montreal, Canada

FEDSM-ICNMM2010-30472

SCREECH TONE SUPPRESSION IN NON CIRCULAR TWIN JET

V.Boopathi sabareesh, K.Srinivasan, T.Sundararajan
Indian Institute of Technology Madras
Chennai , Tamilnadu, India

ABSTRACT

The acoustic characteristics of twin jet screech tone is studied for various jet configurations such as both square and diamond. The measurement is carried out along the jet direction for various angles at two different planes using a microphone and the jet flow visualization is done by the shadowgraph technique. It is observed that the screech tone suppression is taken place for diamond jet configuration for the small jet spacing S = 0.5. By comparing the directivity pattern of twin jets with single jet, it is found that the twin jet behave as a single jet at higher nozzle pressure ratio.

1. INTRODUCTION

The twin jet arrangement is employed in various fields such as aviation, automotive, agriculture and engineering applications like spraying, cleaning and cooling. The mixing enhancement and noise suppression is very important in all jet problems. The mixing enhancement is attained by stimulating higher level of interactions between small and large scale flow structures. This is achieved by the non circular jet, due to the growth in fine scale turbulence, and also the interaction and self induction happened in between the axial and azimuthally vortices which lead to the axis switching.

The jet noise components are generally classified into turbulent mixing noise and shock associated noise. Further the shock associated noise is divided into screech and broad band shock associated noise. These shock associated noise is generated due to the imperfect jet expansion in the nozzle exit causing the series of shock cell structure in the flow field. When the interaction takes place in between the shock cell structure and the downstream convected large coherent structures, then there will be a generation of series of acoustic pulse. Then the resulting acoustic pulse propagates upstream and stimulates the coherent structure in the shear layer at the nozzle lip. This feedback process causes the screech tone generation. This screech tone is found as a discrete tone in the measured noise spectra.

When two jets are placed close enough to each other then the coupling happened in between the plumes leads to the great amplification of screech tone and higher dynamic pressure in the inter nozzle region. This will induce the structural damage and fatigue failure to the nozzle. So the suppression of screech tone will lead to the great noise reduction in twin jet arrangement.

2. LITERATURE REVIEW

Gutmark and Grinstein [1] reported that the increased entrainment and enhanced fine scale mixing obtained with the non circular jet were due to the complex interaction between the azimuthal and streamwise vortices. Quinn and militzer [2] observed that the free jet issuing from square geometry has faster spread rate than the circular jet. Quinn [3] showed that the square jet provides faster mixing in the near field region. Grinstein and Devore [4] numerically simulated the dynamics and topology of large scale coherent structure emerging from the vortex sheet.

Srinivasan and Radhakrishnan [5] studied that the lower order polygonal jet showed better mixing. Alvi *et al*. [6] observed the insignificant effect of streamwise vorticity on the mixing and noise generation. Jothi and

Srinivasan [7] documented the detailed report on noise characteristics of the non circular jet and found that triangular and square jets are quieter than the single jet.

Seiner *et al.* [8] reported that the higher dynamic pressure in the inter nozzle region can be associated with the phase coupling of each plume's jet flapping mode. The investigation on the various suppression method revealed that the small tab mounted on the nozzle exit provided the substantial noise reduction compared to the small notch at the nozzle exit. Shaw [9] explored the effectiveness of various noise suppression techniques. It was concluded that except axial spacing, all other techniques such as tab, lateral spacing and secondary jet are very effective in the suppression of noise. Raman and Taghavi [10] provided the correlation parameter to determine the mode of coupling in the rectangular twin jet. Raman [11] documented the coupling of the screech instabilities in the twin jets of complex geometry. Srinivasan *et al.* [12] performed the experiment on the twin elliptic jet and showed the importance of aspect ratio in the twin jet on the noise reduction. Panicker *et al.* [13] have studied the coupled twin jets of single beveled geometry for both arrowhead and V shaped configuration. They found that the coupling occurred only in the V shaped configuration but not in the arrowhead.

The literature review shows that there is sustained interest in understanding the noise characteristics of non circular twin jet emanating from the sharp corners and flat edges. It also reveals that noise emission from such geometries is highly unexplored. So the present study is conducted to find out the effect of nozzle geometry (such as sharp corner faced twin jet and flat edge faced twin jet) on the twin jet noise. The equivalent circular jet is taken to be the reference for this whole jet noise study.

3. EXPERIMENTAL SET UP AND PROCEDURE

3.1 Test Facility

Figure 1 shows the schematic view of the experimental set up. All the experiments were completed within a simplified anechoic chamber of dimensions 2.5 m x 2 m x 2 m. The settling chamber having an inner diameter of 380mm and the traversing system for the directivity measurement are placed inside the anechoic chamber. The flow conditioning meshes with progressive fineness has kept inside the settling chamber to diminish the initial turbulence level. The disk nozzle is attached to the converged end section of the settling chamber having a diameter of 43.5 mm by the use of a disk holder. To control the stagnation pressure of the settling chamber, one needle valve is used. The settling chamber was supplied with compressed air at pressures up to 7 bar from two tanks of capacity 10 m^3 capacity storage tank.

3.2 Disk Nozzle Configuration

The schematic views of the slot or disk nozzle configuration used in this experiment are shown in Figure.2. The twin jet disk nozzles were fabricated for the different topology (both square and diamond cross section) with various jet spacing (s/d = 0.5 to 2) using a circular mild steel plate of diameter 73mm and 2mm thickness. The twin slot jets are designed for constant area equivalent to that of the circular single jet area.

3.3 Flow Visualization And Data Acquisition

The shadowgraph technique is used for flow visualization. The present shadowgraph apparatus include a high resolution camera with 1280x1024 pixel (Mikrotron Model No. 1302 CMOS Type) digital video camera, high intensity light source and Bi-Convex lens (75mm diameter). A pin hole is made in front of the projector to make that light source as a point source. Then one fiber-optic link is used to connect the camera to its controlling computer, upon which the results are viewed. Using the camera, the shadowgraph images are captured by allowing the light rays to pass through the jet flow, then the images are acquired by the use of Sapera LT 5.2.

A quarter inch condenser microphone (PCB Piezotronics, Model No. 377A01) is used for the entire acoustic measurement. The microphone is attached to the rotating arm of the automatic angular traversing system in which a stepper motor is employed to achieve the required angular movement for the directivity measurement. The arrangement of this traverse mechanism and the microphone position are shown in Fig.3 & 4. The synchronization of traversing system with data acquisition system provides the custom designed automated data measurement. The low pass filtered signal at 70 KHz by analog filter (Krohn-Hite Model No.3364), sampled at the rate of 150 Sa/s is acquired for one second by an eight channel simultaneous sampling card (National Instruments, Model No. NI-PCI-6143). Both data acquisition and traverse motion is automated and controlled by LABVIEW software 7.1.

4. RESULTS AND DISCUSSIONS:

4.1 Noise Spectra Of Non Circular Twin Jet

The SPL spectra corresponding for both single and twin jet configuration at Ø = 90**º** and Ø = 0**º** are shown in Fig. 5a and Fig. 5b. The screech tones are observed around 10 kHz from the single jet and edge faced twin jet configuration at Ø = 90**º** plane (Fig.5a). However due to the variation in the shock cell spacing in between the single and twin jet configuration, resulting a slight difference in the screech tone frequency. But there will be no screech tone found for the vertex faced twin jet configuration. The single jet screech tone amplitude is 4dB higher than that of the edge faced twin jet configuration. The coupling between the jet plumes of the edge faced twin jet causes the jet screech tone generation mechanism. Since each jet in twin jet would become a barrier between the observer and other jet, there would be no screech tone found in Ø = 0**º** plane (Fig.5b) for both the edge faced and vertex faced twin jet.

The shadowgraph was used to visualize the jet plume coupling. The uncoupled and coupled jet plumes are shown in Fig. 6.

It is observed from Fig. 6a that there will be no distortion in the shock cell system of two jet plumes of vertex faced twin jet, whereas Fig. 6b displays crucial shock cell distortion in edge faced twin jet due to jet plume coupling. Perhaps this kind of jet plume coupling occurring at very close spacing (S/d = 0.5), and higher NPRs (≥ 6) induce a screech tone with very high amplitude. The screech tone suppression is observed at higher NPRs (≥ 5) for wide jet spacing (> 0.5) irrespective of the geometry either it will be an edge faced twin jet or a vertex faced twin jet. Usually the screech tone presence is detected for NPRs from 4 to 5 for all jet spacing. Above and below this range, the screech tone is suppressed at all jet spacing except the close jet spacing S/d = 0.5. Thus the screech suppression could be obtained at higher NPRs (≥ 5) by increasing the jet spacing (> 0.5).

Even though the spacing is same (S/d = 0.5) for both an edge faced twin jet and vertex faced twin jet, the jet plume coupling is taking place in the edge faced twin jet. Because of faster growth rate in the flat side of the jet and 45-deg rotation of jet cross section leads to decrease in the jet spacing below S/d = 0.5 , obviously cause shear layer interaction of edge faced twin jet . But for the vertex faced twin jet, the jet spacing increased by the 45-deg rotation of jet cross section causes no interaction in-between the jet shear layer.

The shadowgraph results for both the edge and vertex faced twin jet for the jet spacing s/d = 0.5 & 1 are presented in Fig.7. Since the acoustic level in the inter nozzle zone was very much affected by the spacing between the jet, the spacing plays an important role in the noise suppression mechanism in the twin jets. From the shadowgraph it appears that the coupling between the two jet is possible only when the spacing between the two jet is small s/d = 0.5 for the edge faced twin jet. When the spacing between the edge faced twin jets was increased from 0.5 to 1, it can be seen that there can be no coupling happened in between the jet. But for the vertex faced twin jet, the coupling is not happened even for the small jet spacing s/d =0.5.

4.2 Directivity Pattern Of Non Circular Twin Jet

The OASPLs of the single jet and twin jet of both configuration edge faced and vertex faced are compared in Fig.8. Both single and edge faced twin jet follows the same trend with 4dB difference. This reveals that the phenomenon of jet plume coupling make twinjet as a single jet with the same directivity pattern of single jet. The screech suppression in the vertex faced twin jet exhibits lower OASPL than the other two jets. It is observed that the twin jets are quieter than that of the single jet at higher NPRs. The observed noise reduction by the twin jets may be due to the effect of enhanced mixing between the two jets and acoustic shielding such as reflection, refraction, absorption and scattering. Even though both fine and large turbulence structures are employed in the jet flow, the dominant sources for the turbulent mixing noise are the large turbulence structure.

Since the non circular twin jet highly issuing the fine turbulence structures from the sharp corners leads to the generation of low turbulent mixing noise compared to noise generated by the large turbulence structure in the case of single jet. This may also be the reason for the reduction in OASPLs for the twin jets compared to the single jet. The trend of the directionality curve may be due to the presence of quadropole sources in the jet. The aft quadrant in Fig.7 shows gradual decrease in OASPL, whereas the fore quadrant shows increase in OASPL.

Fig.9 shows the waterfall spectra for both the edge and vertex faced twin jets. The presence of screech tone throughout the angles 27º to 145º by the edge faced twin jet is seen in Fig.9a and also the absence of screech tone by the vertex faced twin jet is observed from Fig.9b. From Fig.8a, it is noticed that the screech tone amplitude at the downstream end of the edge faced twin jet is one order higher than that of the screech tone amplitude at the upstream end of the twin jet. The sub harmonics are found over a range of angles 85º to 95º.

5. CONCLUSIONS

From the experimental observations the following conclusions are drawn.

(i) The screech tone was suppressed in diamond (vertex faced) twin jet, due to the absence of coupling achieved in between jets.

(ii) If we use square (edge faced) twin jet instead of using single jet, a 4dB noise reduction was attained in the screech tone.

(iii) Each one of the jet in twin jet acts as a barrier between the observer and the other jet, there was no screech tone found at Ø = 0**º** plane.

(iv) The directionality of square (edge faced) twin jet follows the same behavior as that of the single jet due to the presence of coupling in jets.

REFERENCES

1. E.J.Gutmark, F.F.Grinstein: Flow control with noncircular jets. Annual Review of Fluid Mechanics **31** (1999) 239-272.
2. W.R.Quinn, J.Militzer: Experimental and numerical study of a turbulent free square jet. Physics of Fluids **31** (1988) 1017-1025.
3. W.R. Quinn: Streamwise Evolution of a square jet cross section. AIAA Journal **30** (1992) 2852-2857.

4 F.F.Grinstein, C.R.DeVore: Dynamics of coherent structures and transition to turbulence in free square jets. Physics of Fluids **8** (1996) 1237-1250.

5 K.Srinivasan, E.Radhakrishnan: Studies on polygonal slot jets. AIAA Journal **38** (2000) 1985-1987.

6 F.S.Alvi, A.Krothapalli, D.Washington: Aeroacoustic properties of a supersonic diamond-shaped jet. AIAA Journal **34** (1996) 1562-1569.

7 T.J.S.Jothi, K.Srinivasan: Acoustic characteristics of non-circular slot jets. Acta Acustica united with Acustica. **94** (2008) 229-242.

8 J.M. Seiner, J. C. Manning, M. K. Ponton: Dynamic pressure loads associated with twin supersonic plume resonance. AIAA Journal **26** (1988) 954-960.

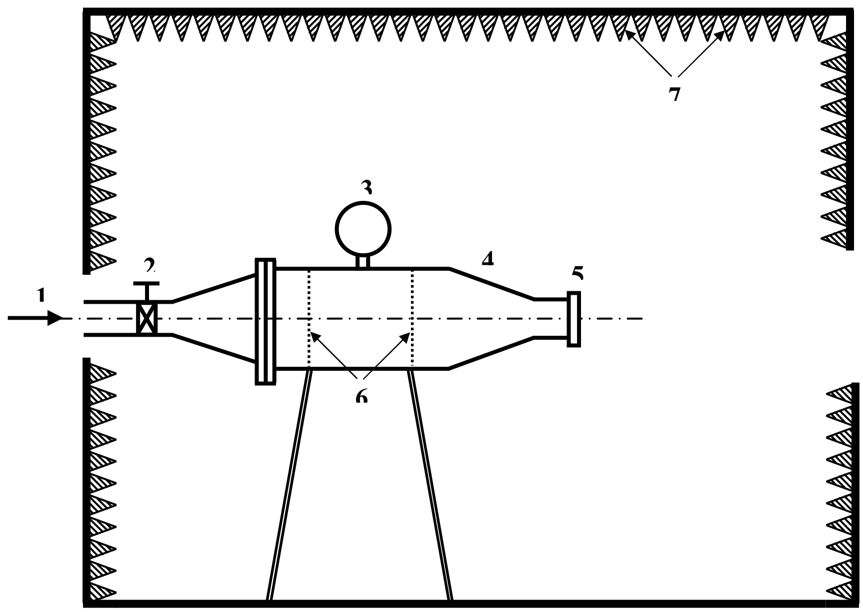
9 L.Shaw: Twin-jet screech suppression. Journal of Aircraft **27** (1990) 708-715.

10 G.Raman, R.Taghavi: Coupling of twin rectangular supersonic jets. Journal of Fluid Mechanics **354** (1998) 123-146.

11 G.Raman: Coupling of twin supersonic jets of complex geometry. Journal of Aircraft **36** (1999) 743-749.

12 K.Srinivasan, S.Elangovan, E. Radhakrishnan: Twin elliptic jet as a candidate for attenuation of jet engine exhaust noise. International Journal of Turbo and Jet Engines **14** (1997) 99-104.

13 P.Panicker, K.Srinivasan, G.Raman: Aeroacoustic features of coupled twin jets with spanwise oblique shock-cells. Journal of Sound and Vibration **278** (2004) 155-179.



1. Air inlet
2. Pressure regulating valve
3. Pressure gauge
4. Settling chamber
5. Disk holder
6. Wire meshes
7. Wedges

FIG.1 SCHEMATIC VIEW OF ANECHOIC CHAMBER

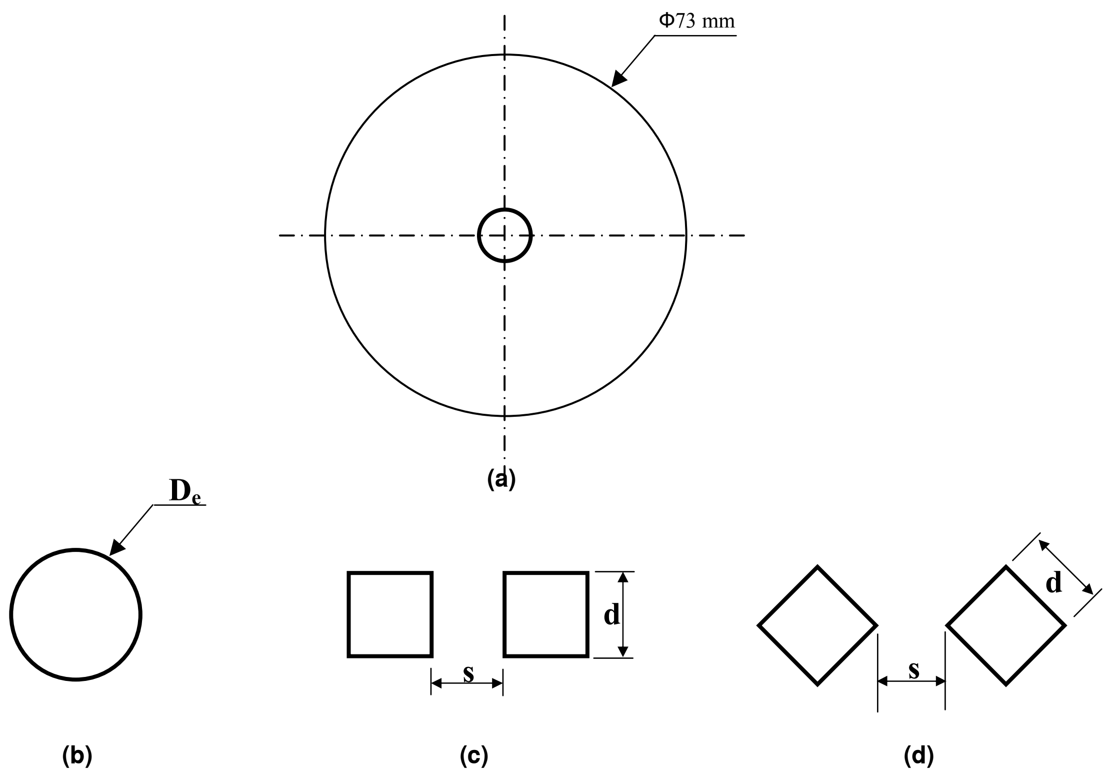


FIG.2 DISK NOZZLE CONFIGURATION; (a) DISK NOZZLE (b) EQUIVALENT SINGLE JET (c)EDGE FACED TWIN JET (d) VERTEX FACED TWIN JET

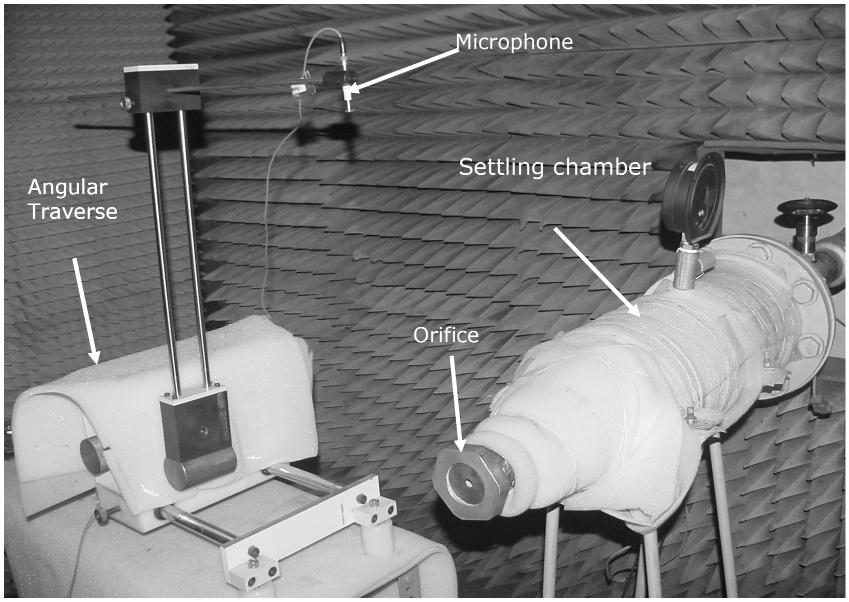


FIG.3 PHOTOGRAPH SHOWING THE ARRANGEMENT OF TRAVERSE MECHANISM

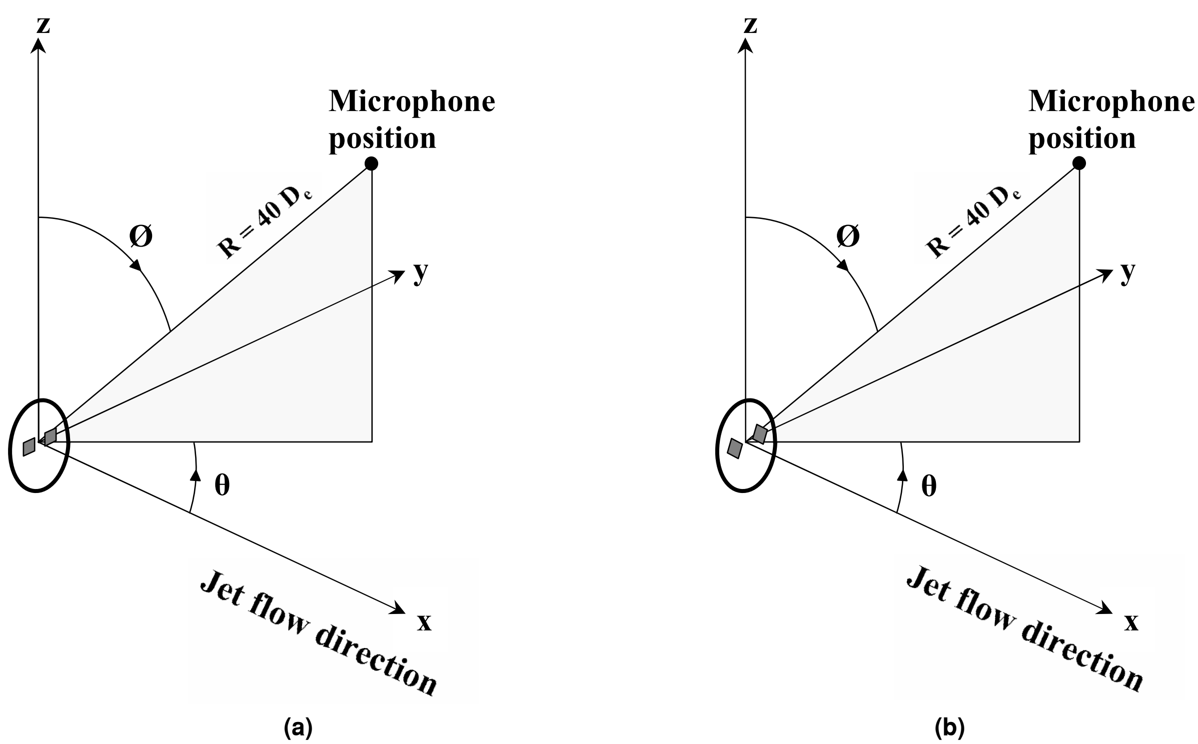
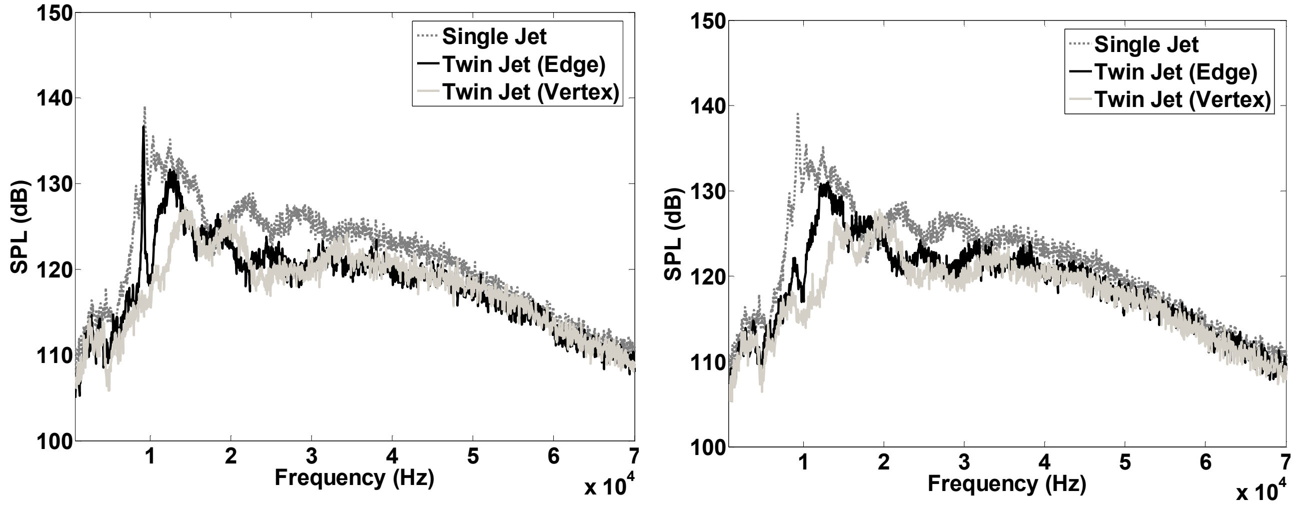


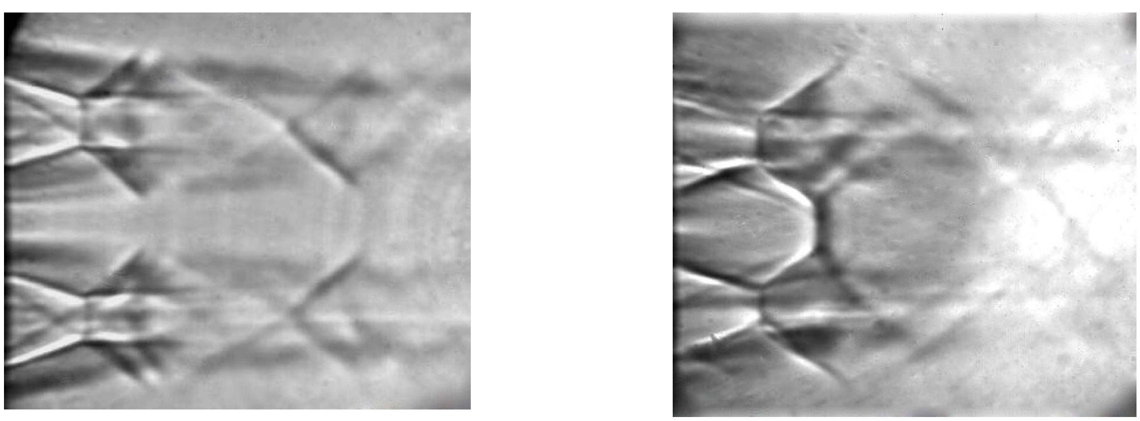
FIG.4 MICROPHONE POSITION IN THE FAR FIELD MEASUREMENT; (a) EDGE FACED TWIN JET

(b) VERTEX FACED TWIN JET



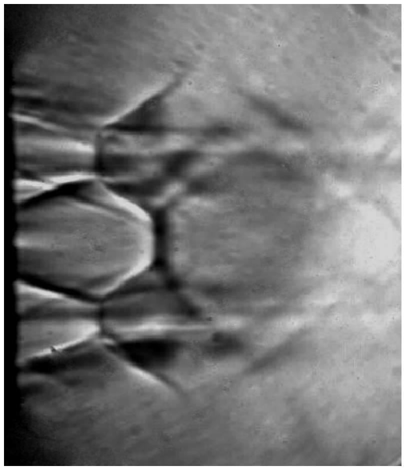
(a) (b)

FIG.5 SPECTRA FROM SINGLE AND TWIN JETS FOR NPR = 7, S/D = 0.5 (a) Ø = 90º; (b) Ø = 0º.

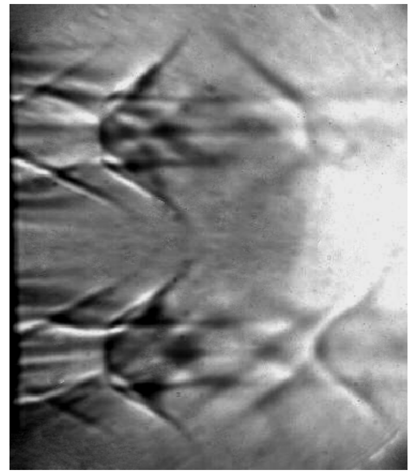


(a) (b)

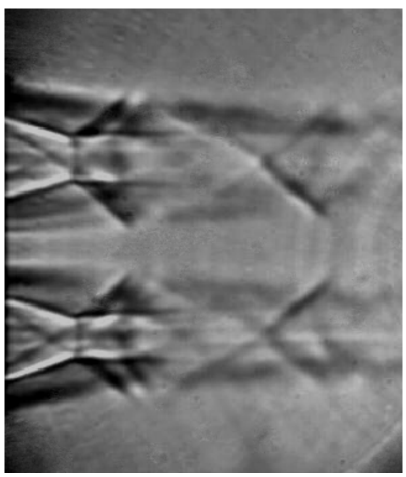
FIG. 6 SHADOWGRAPH IMAGES OF PLUME COUPLING: a) NO COUPLING; b) COUPLING



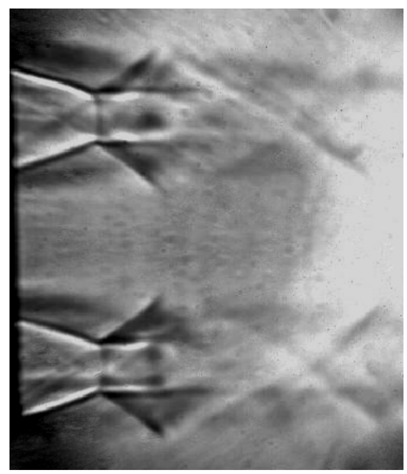
(a) S/d = 0.5



(b) S/d = 1



(c) S/d = 0.5



(d) S/d = 1

FIG.7 SHADOWGRAPH IMAGES OF TWIN JET FOR VARIOUS SPACING. EDGE FACED TWIN JET (a & b) AND VERTEX FACED TWIN JET (c & d) FOR NPR = 7.

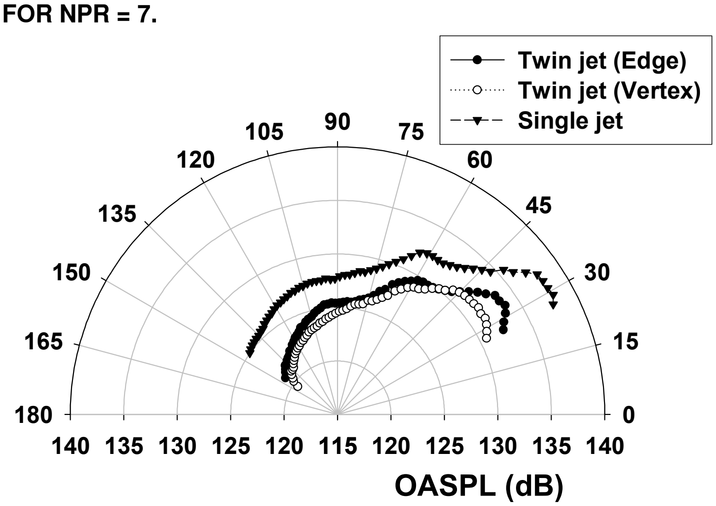
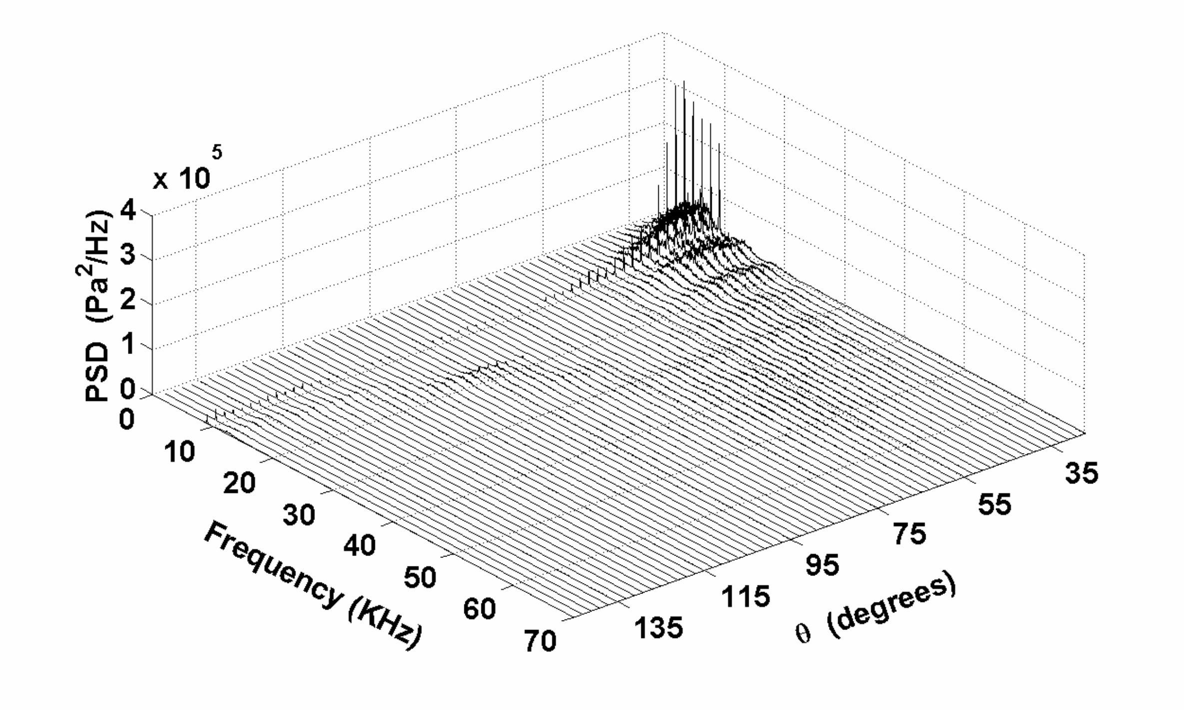
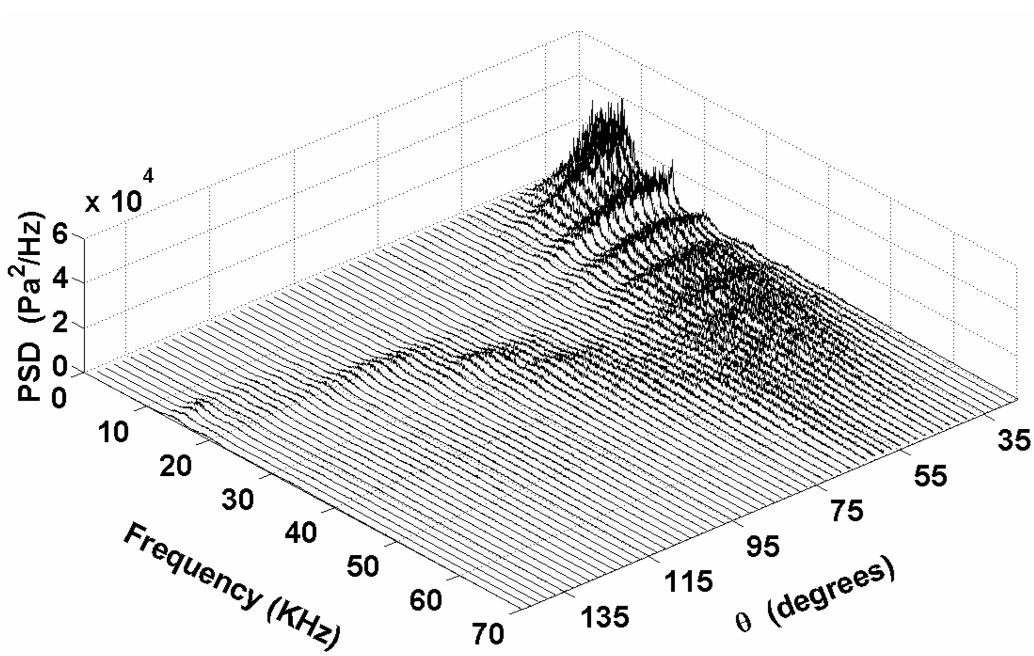


FIG. 8 OASPL OF SINGLE AND TWIN JETS FOR NPR = 7, S/D = 0.5



(a)



(b)

FIG.9 WATERFALL SPECTRA FOR (a) EDGE FACED TWIN JET AND (b) VERTEX FACED TWIN JET FOR NPR = 7, S/D = 0.5