©Freund Publishing House Ltd. London International Journal of Turbo and Jet Engines, 14, 99-104(1997)

Twin Elliptic Jet as a Candidate for Attenuation of Jet Engine Exhaust Noise

K. Srinivasan, S. Elangovan and E. Rathakrishnan

Dept. of Aerospace Engineering, Indian Institute of Technology, Kanpur, 20816 India

Abstract

Propulsion systems of many fighter aircraft use twin nozzle configurations. When the nozzles are operated under off-design conditions, shock cell patterns occur in the jet core, resulting in jet plume interaction and consequent acoustic resonance. This could even lead to structural failure owing to increased acoustic pressure impinging on the empennage. Measurement of sound pressure level was therefore made on twin elliptic slot jets at close spacings to study their noise characteristics. A non-dimensional parameter ϕ has been identified with which the overall sound pressure level becomes a function of β only, for which functional fits have been tried. Results point out that spacing is a more crucial parameter than aspect ratio and that twin elliptic slot jets fall in between slotted and plain nozzles in noise suppression.

Nomenclature

AR	Aspect ratio of elliptic jet
D_e	Equivalent diameter of individual slot
M_j	Jet exit Mach number if it were correctly expanded
$OASPL$	Overall sound pressure level
P_0	Stagnation pressure
P_a	Ambient pressure
Pe	Perimeter of the slots
S	Spacing in between slots
β	Parameter = $\sqrt{M_j^2 - 1}$
ϕ	Non-dimensional parameter defined by $(4\,Pe\,S)\,/\,(\pi\,D_e^2)$

Introduction

Propulsion systems of many fighter aircraft use twin nozzle configurations. When the nozzles are operated under off-design conditions, shock cell patterns occur in the jet core, resulting in jet plume interaction and consequent acoustic resonance. This could even lead to structural failure owing to increased acoustic pressure impinging on the empennage. Norum *et al.* /1/ studied the dynamic loads on twin jet exhaust nozzles due to shock noise. They found that inter-nozzle spacing greatly influenced acoustic resonance. Shaw /2/ carried out experiments on screech suppression of twin jets using tabs at the exit plane of the nozzles. They concluded that lateral spacing of the nozzles played an important role in screech tone suppression. Wlezien /3/ examined the coupled interaction of jets from two nominally identical convergent-divergent nozzles as a function of nozzle spacing. His results showed that, for closely spaced nozzles coupling occurred at low jet Mach numbers. The converse was true for large spacing. In all these studies the nozzles used were axisymmetric, but in recent years non-circular jets have attracted much attention in view of their desirable mixing characteristics. In aerospace engineering rectangular jets have attracted the attention of many researchers. Gutmark *et al.* /4/ studied the near acoustic field and shock structure of supersonic jets issuing out of rectangular nozzles. But in many practical situations, manufacturing and economic expediency often dictate that the jets issue from slots with sharp edges cut in flat surfaces /5/. Even though many studies have been carried out on the acoustic characteristics of interacting twin-circular jets and single non-circular jets, similar studies on twin non-circular jets are very limited. This near absence of available literature on such an important practical problem prompted the authors to carry out the present investigation.

The study of elliptic jets is interesting for two reasons. First, it is an intermediate configuration between the two simple and extensively studied geometries – plane and circular jets. Secondly, studies have revealed that the rectangular jet structures become elliptic-like soon after their roll up in rectangular jets. Thus, a systematic study of elliptic jets is also highly relevant for an understanding of the dynamics of rectangular jets which have important practical applications. Elliptic slots, instead of contoured elliptic nozzles, have been chosen for the present study because of the following considerations: In many practical applications, expeditious manufacturing and ease of installation may necessitate the use of sharp edged slots in preference to nozzles with contoured upstream shaping /6/. Moreover, in order to study the effect of aspect ratio alone on the noise level of elliptic jets, it becomes necessary that contoured elliptic nozzles of different aspect ratios must be fabricated for comparison, in such a way that identical development of boundary layer up to the nozzle exit is ensured. This practical difficulty can be overcome if slots are used instead of nozzles as pointed out by Hussain and Husain /7/. As the plates on which the elliptic slots were made were very thin (2 mm thick), negligible growth of boundary layer at the exit was ensured.

Experimental Setup and Procedure

The experiments were carried out using a high speed jet test facility which consisted of a cylindrical settling chamber as shown in Fig. 1, which is supplied with compressed air from high pressure storage tanks. The area ratio between the settling chamber end plate and a single slot was 100. The settling chamber pressure was regulated using a pressure regulating valve. Circular plates of 2 mm thickness, over which twin elliptic slots were made, were attached to the end plate of the settling chamber as shown in Fig. 1. In all the models, each slot was of area equal to that of a 10 mm diameter circular slot. Thus, the equivalent diameter D_e of each slot was 10 mm. The aspect ratios (AR) of the

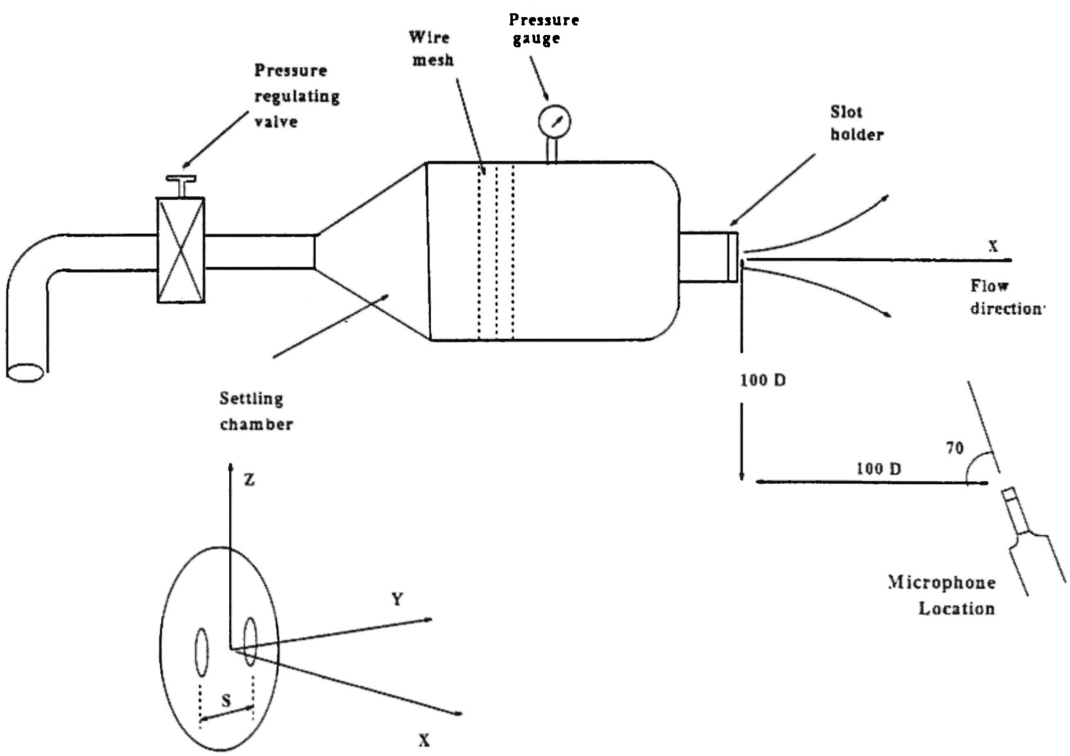

Fig. 1: The experimental setup

elliptic slots studied were 2:1, 2.5:1, 3:1 and 4:1, and the inter-slot spacings (S) used were 10 mm and 15 mm corresponding to non-dimensional spacing S/D_e of 1.0 and 1.5, respectively. The noise level measurements were carried out for sonic and underexpanded conditions in the pressure ratio (stagnation to ambient) range of 1.89 to 3.21. The overall sound pressure level (OASPL), which is a single measure indicative of the total amount of sound at a given spatial location, was measured using a model 2231 B & K sound level meter and a 1/4 inch microphone. the microphone at a fixed position was located at about 100 equivalent diameters away from the twin jet axis as shown in Fig. 1. The microphone was kept at an angle of 70° for the measurements. The distance of 100 D_e was chosen in order to compare the present results with those of Krothapalli *et al.* /8/.

Results and Discussion

A principal method of clarifying the role of turbulent mixing and acoustic shielding in the twin jet experiments is using the inter-nozzle spacing as a parameter. At larger spacings, the turbulent mixing effects will be minimal and the acoustic shielding effects will dominate. Conversely, at close spacings the turbulent mixing effects will be enhanced and acoustic shielding will be minimized /9/. As the primary purpose of the present study is to understand the effect of turbulent mixing and jet interaction on noise generation, close spacings of S/D_e = 1.0 and 1.5 were chosen for the investigation. Moreover, in the case of such closely spaced twin jets, supercritical flow conditions result in the expansion of the jets immediately downstream of the slot exit plane leading to premature merging of the jets and inhibition of acoustic shielding /9/. Hence, it may be safely presumed that the results of the present study mainly pertain to turbulent mixing and jet interaction effects only.

Figure 2 shows the variation of OASPL with level of underexpansion (represented by β, which is defined as $\sqrt{M_j^2 - 1}$, where M_j is the exit Mach number the jet would have attained if it were correctly expanded) for twin elliptic jets (AR 2:1 and 2.5:1) at spacings S/D_e = 1.0 and 1.5. It is seen that twin jets with spacing S/D_e = 1.5 have slightly lower pressure levels at lower values of β compared with those with S/D_e = 1.0, but the latter shows relatively smoother variation of OASPL with β than the former. This may be due to the effect of spacing

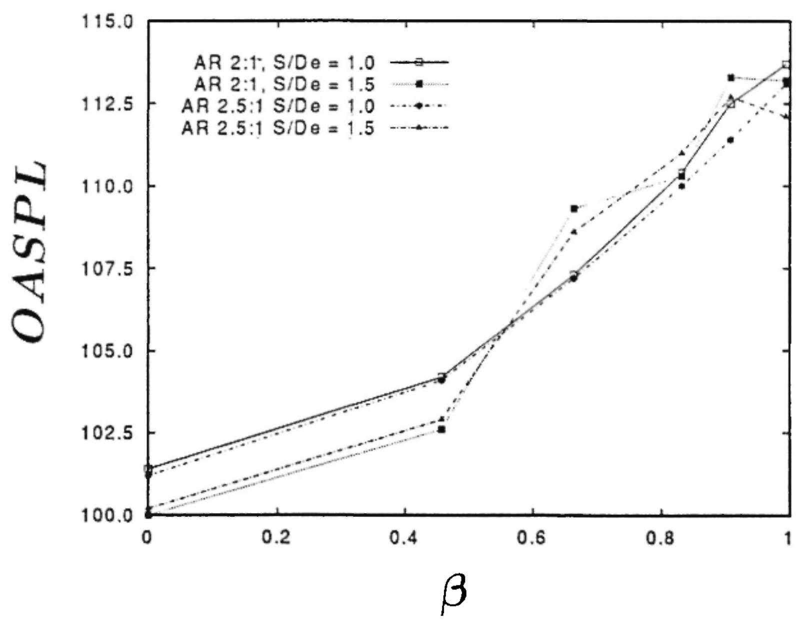

Fig. 2: Variation of OASPL with β *AR* 2:1 and 2.5:1

on the acoustic coupling. This smooth variation of very closely spaced jets compared with slightly wider spaced jets emphasizes the importance of inter-jet spacing as brought out in references /1-3/ for twin circular jets and seems to be valid for twin elliptic jets also. Thus, spacing is found to play a more dominant role than aspect ratio. But the complete understanding of the exact nature of the role of spacing on jet noise needs further experimentation for various combinations of spacings and aspect ratios.

To investigate the dependence of OASPL on aspect ratio and β, constant OASPL contours are plotted as shown in Fig. 3. As expected, β seems to be a more crucial parameter, strongly influencing the sound pressure level. To study the functional dependence of the geometrical parameters; Pe, S, D_e,, a non-dimensional parameter ϕ defined as

$$\phi = \frac{\text{Perimeter} \times \text{Spacing}}{\text{Area}} = \frac{4}{\pi}\frac{Pe}{D_e}\frac{S}{D_e}$$

has been identified. The overall sound pressure level variation with ϕ is shown in Fig. 4. It is obvious from these results that the OASPL remains almost invariant with ϕ for a given β. Hence, without loss

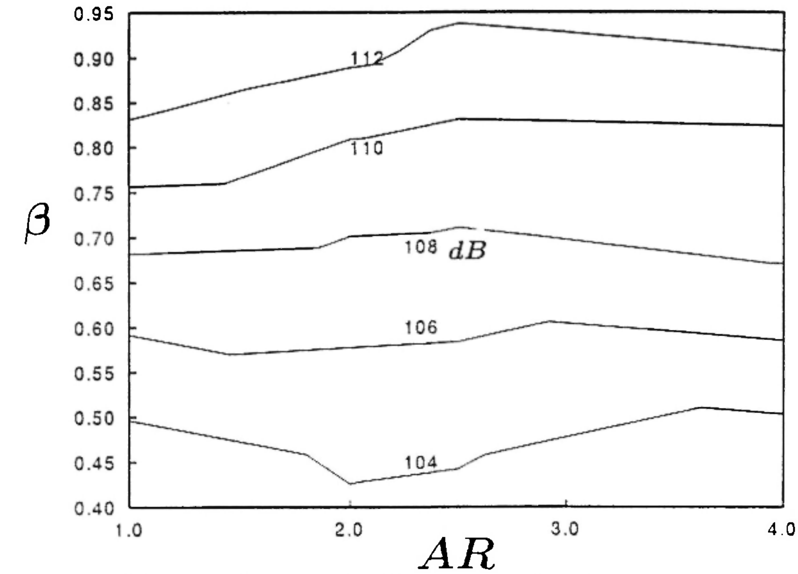

Fig. 3: Constant OASPL contours in AR-β plane

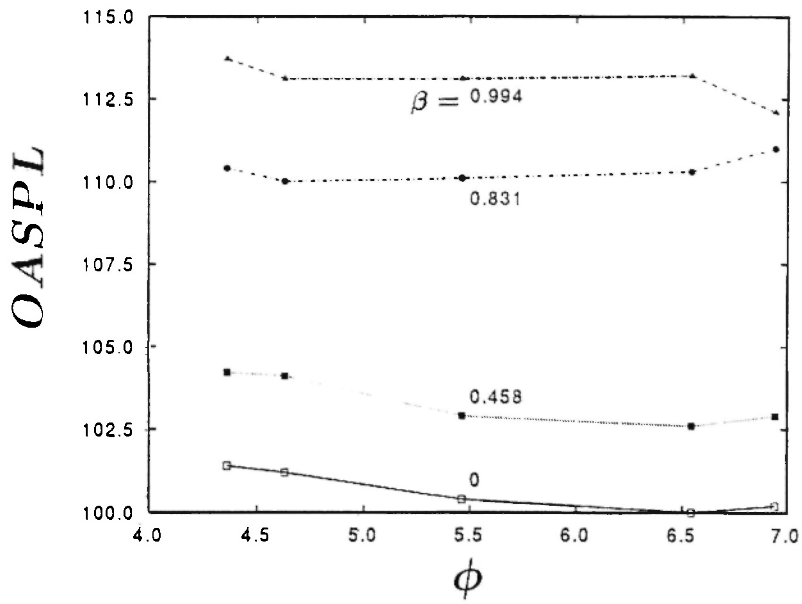

Fig. 4: Variation of OASPL with parameter ϕ

of generality, it may be assumed that OASPL is a function of β only with the introduction of ϕ. Using this assumption and the experimental data, a functional form of OASPL in terms of β has been identified as

$$OASPL(\beta) = 10.645\,\beta^2 + 3.467\,\beta + 100.36 \qquad (1)$$

where the constants were obtained by least squares technique. To authenticate the above form in which OASPL is quadratic in β, a check has been tried by assuming that OASPL varies as a real power of β and evaluating that exponent, leading to the equation

$$OASPL(\beta) = 14.069\,\beta^{1.664} + 100.31 \qquad (2)$$

The variation of OASPL with β using Eqs. (1) and (2) are plotted in Fig. 5. The experimental results are also included for comparison. From the plots it is seen that the maximum error between the fits [Eqs. (1) and (2)] and the measurements is less than 2dB. It is also seen that the two functional fits almost overlap within the present range of β. Further, it can be inferred that the results obtained with Eqs. (1) and (2) agree within 2dB even at β = 1.5, which corresponds to a pressure ratio P_0/P_a around 4.75 and within 5dB at β = 2 corresponding to a pressure ratio P_0/P_a around 10. Therefore, it may be concluded that the OASPL varies as a real power of β where the real exponent lies between 1.66 and 2 up to β = 2.

Figure 6 shows the comparison of some of the present results with those of Krothapalli *et al.* /8/ for axisymmetric nozzle jets (both plain and slotted). It is interesting to note that the under-expanded jet from a plain axisymmetric nozzle shows higher pressure levels for all β values when compared with all other cases indicating that twin elliptic jets are potential candidates for attenuation of jet noise. However, at lower values of β, noise suppression achieved through twin elliptic slot jets are not as pronounced as that achieved through slotted nozzles.

Conclusions

From the above investigations, the following conclusions are drawn:

1. In twin elliptic slot jets, spacing is found to be a more crucial parameter than aspect ratio in influencing jet noise. The OASPL variation with

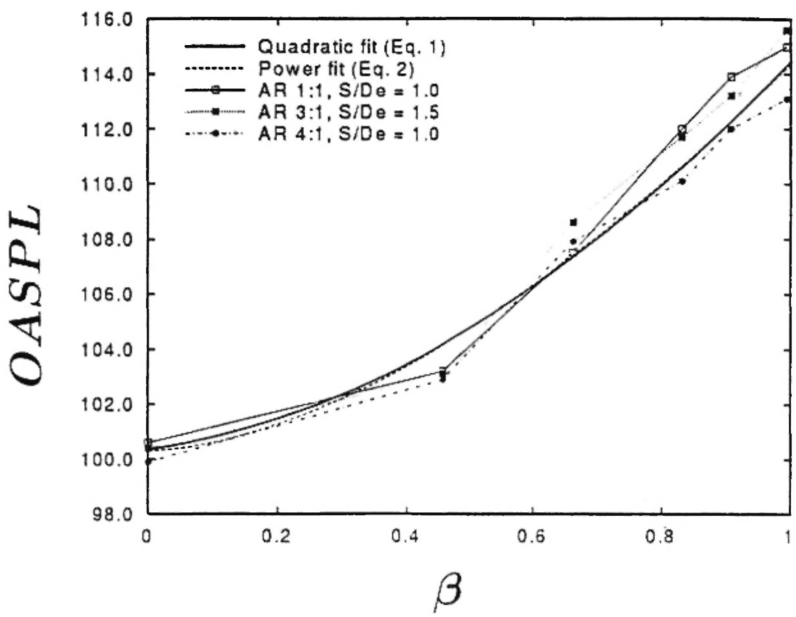

Fig. 5: OASPL variation with β - Curve fits and comparison with a few cases

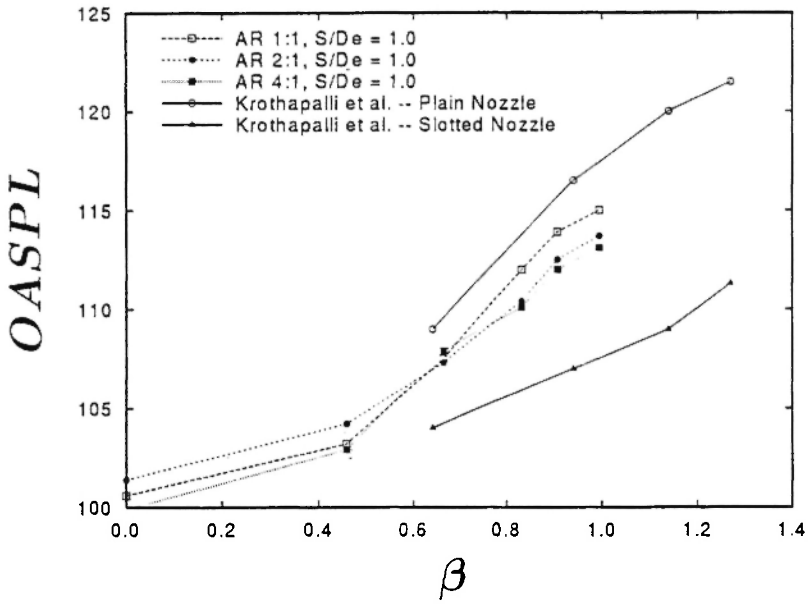

Fig. 6: Comparison of present results with plain and slotted nozzles

β for $S/D_e = 1.0$ is smoother than that for $S/D_e = 1.5$.

2. The introduction of the non-dimensional parameter ϕ renders the sound pressure level variation one-dimensional: i.e., a function of β only.
3. OASPL varies as a real power of β, where the power lies between 1.66 and 2.
4. The noise suppression achieved through twin elliptic slot jets falls in between the plain and slotted nozzles studied by Krothapalli *et al.* /8/.

References

1. Norum, T.D. and Shearin, J.G. "Dynamic loads on twin jet exhaust nozzles due to shock noise", *Journal of Aircraft*, 23 (9), 728-729 (1986).
2. Shaw, L. "Twin-jet screech suppression", *Journal of Aircraft*, 27 (8), 708-715 (1990).
3. Wlezien, R.W. "Nozzle geometry effects on supersonic jet interaction", *AIAA Journal*, 27 (10), 1361-1367 (1989).
4. Gutmark, E. Schadow, K.C. and Bicker, C.J. "Near acoustic field and shock structure of rectangular supersonic jets", *AIAA Journal*, 28 (7), 1163-1170 (1990).
5. Quinn, W.R. "Development of a large-aspect-ratio rectangular turbulent free jet", *AIAA Journal*, 32 (3), 547-554 (1994).
6. Quinn, W.R. and Marsters, G.F. "Upstream influence on turbulent jet from cruciform nozzles", *Aeronautical Journal*, 89 (882), 55-58 (1985).
7. Hussain, F. and Husain, H.S. "Elliptic jets. Part I: Characteristics of unexcited and excited jets", *Journal of Fluid Mechanics*, **233**, 439-482 (1991).
8. Krothapalli, A., McDaniel, J. and Bagaonoff, D. "Effect of slotting on the noise of an axi-symmetric supersonic jet", *AIAA Journal*, 28 (12), 2136-2138 (1990).
9. Kantola, R.A. "Acoustic properties of heated twin jets", *Journal of Sound and Vibration*, 79 (1), 79-106 (1981).
10. Tam, C.K.W. "Supersonic jet noise generated by large scale disturbance", *Journal of Sound and Vibration*, **38** (1), 51-79 (1975).