Jet Noise Abatement Using Elliptical Ring Tabs

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Abstract: - Aero-acoustic characteristics of a high-speed jet with elliptical ring tabs fitted at the aft of the nozzle in diametrically opposite to the exit is experimentally investigated at a Mach Number of 1.8. The Main focus is to examine the effects of the extent of elliptical ring tabs, its position in the mixing layer and also to study the characteristics of supersonic nozzle with and without elliptical ring tabs. The elliptical ring tabs are found to produce vortices, thereby increasing the surface area of the jet, particularly in the close vicinity of the nozzle, which increases the mixing and reduces the potential core length. The overall noise levels registered along the jet edge immediately downstream of the nozzles are higher, but further downstream they are reduced in comparison with the plain baseline nozzle. A pair of dimensionally optimized elliptical ring tab placed diametrically opposite at the exit of the nozzle with blockage area of 5% without effecting the loss of thrust. The mixing enhancement caused by the tab will be studied at nozzle pressure ratio 5.75. The reduction in Sound Pressure Level (SPL) in dB is compared to that of plain nozzle.

Keywords: - Jet mixing, passive control, supersonic, vortex generator.

1. INTRODUCTION

High speed jets are of great importance to aerospace as well as other industries. To enhance mixing in jet flows, a passive control method, using vortex generators [1] in the form of mechanical tabs or small protrusions at the exit of a nozzle has been under investigation for the past several years. A tab [2-8] is kept normal to the flow direction which can produce a pair of counter-rotating stream wise vortices, which can offer a considerable reduction of potential core length as well as suppresses the noise level. In order to achieve the reduced potential core length at the cost of minimum thrust loss, dimensionally optimized elliptical ring tabs was used. Jet mixing can be achieved by two methods. They are Passive jet mixing and Active jet mixing. The active jet mixing involves energized actuators to dynamically manipulate the flow. Active jet mixing involves the external power source. The passive control is preferable since no external power source is required for its action. Passive controls mainly rely on geometrical modification of the nozzle, which generates the jet or introduction of a secondary body, which can shed mixing promoting small-scale vortices. Placing elliptical ring tabs (Fig. 1,3) at the ft of the C-D Nozzle (Fig 2,4) is one such passive control, which generates counter rotating vortices all along its sides, which become stream wise soon after shedding.

2. EXPERIMENTAL SETUP

The experiments were conducted in the open jet facility at the aerodynamics laboratory, Rajalakshmi Engineering College, Chennai, India (Fig 5). The facility consists of air supply system which consists of compressor and storage tanks and an open jet test facility. The test facility used consists of a settling chamber, with a provision to mount the jet nozzles on its end plate. The settling chamber is fed with compressed dry air at high pressure through a pressure regulating valve, which controls the settling chamber pressure at any desired level before expansion through the jet nozzle. Pressures were measured with 8 port pressure transducers with DAS.

The Data Acquisition System (DAS) is a digital storage directly attached to the computer to evaluate the values of pressure recorded by pressure transducers. All the jet noise related experiments were performed in the free- field conditions to facilitate usage of scaling laws. A semi anechoic chamber (Fig 4) has dimensions of 2.8 X 2.5 X 2.15 m (from wedge tip to tip).

Strong gypsum boards were used as outer and inner walls of chamber, each 12.5mm thick and in between a glass fibre (of density 48 kg/cm^2) hasbeen placed. The inner walls of chamber was covered with noise absorbing foam made up of Polyurethane with an NRC of 0.95 and in pyramid form. This pyramid shape attenuates the possible reflections in the chamber. Accordingto ANSI Standard, any measured background noise within 15dB below any measured noise source spectra at a specified frequency is corrected using a semi-anechoic chamber

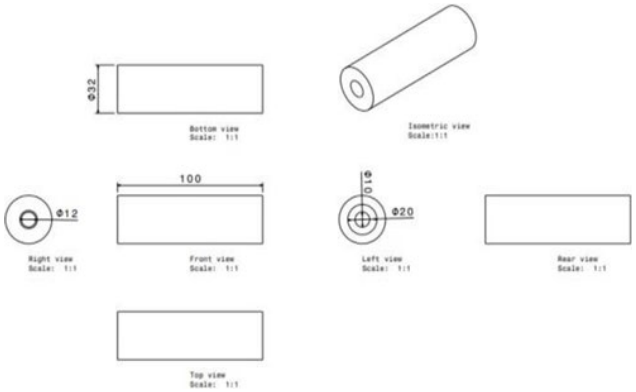

Figure 1. Draft of Baseline Nozzle

Figure 2. Elliptical Ring Tabs

Figure 3. C-D Nozzle with elliptical ring tabs

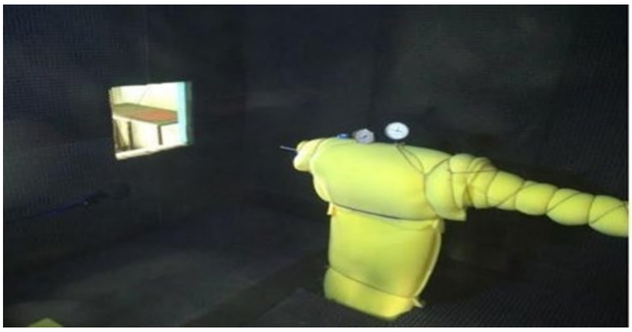

Figure 4. Anechoic Chamber Jet Setup

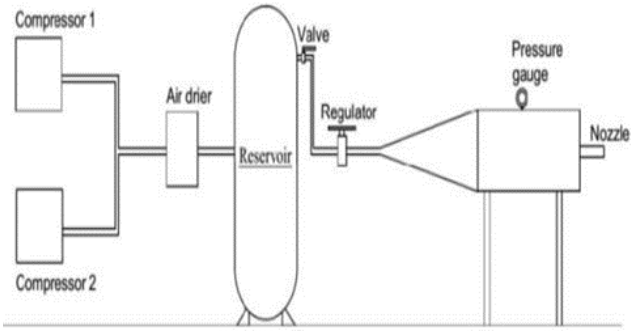

Figure 5. Experimental setup

Table 1. Analysis Of Elliptical Ring Tabs

Design Mach number (M)	1.8
Inlet diameter ($d1$)	20 mm
Throat diameter ($d2$)	10 mm
Outlet diameter ($d3$)	12 mm
Inlet area ($a1$)	314.15 mm^2
Throat area ($a2$)	78.54 mm^2
Exit area ($a3$)	113.04 mm^2
Length of the nozzle	100 mm
Convergent length (l_c)	50 mm
Divergent length (l_d)	50 mm

3. CALCULATION OF ABSOLUTE PRESSURE

$$P/P_0 = \left[1+\left(\left(\Gamma-1\right)/2\right)\left(M\right)^2\right]^{(\Gamma/\Gamma-1)} \tag{1}$$

$$\Gamma = 1.4M = 1.8P_0 = 1 \tag{2}$$

$$P/P^0 = [1+((1.4-1)/2(1.8)^2]^{(1.4/1.4-1)} \tag{3}$$

$$= 5.75bar \tag{4}$$

$$P_{absolute} = P_{gauge} + 1 \tag{5}$$

$$5.75 = P_{gauge} + 1 \tag{6}$$

$$P_{gauge} = 4.75 \tag{7}$$

$$A_e / A^* = \left(\left(\pi d_e^{\,2} / 4\right) / \left(\pi d^{*2} / 4\right)\right) \quad (8)$$

$$A_e / A^* = (\pi\left(0.0122 / 4\right) / \left(\pi\left(0.012\right) / 4\right) \quad (9)$$

4. STEPS FOR OASPL CALCULATION

A. Find the corresponding pressure value of SPL

The expression for Sound level Pressure (SPL) isgiven by

$$SPL = 20_{log}(P / P_{ref})\ (dB) \quad (10)$$

Here, the normal human hearing pressure is taken as the reference pressure, i.e., $P_{\text{ref}} = 0.00002$ Pa.

From the above, find the pressure value,

$$P = \left(10^{(SPL/20)}\right) * P_{ref}\ (dB) \quad (11)$$

B. Find the Root Mean Square (RMS) value of entire spectrum

(Square the pressure values, sum up, find the average value, and then take square root)

C. Calculate the OASPL value

The OASPL value can be calculated from equation (12) bysubstituting the estimated RMS value.

$$OASPL = 20_{log}(P_{rms} / P_{ref})(dB) \quad (12)$$

5. RESULTS AND DISCUSSIONS

To assess the jet symmetry in the presence of tabs, the non-dimensional pressure, p_{0t}/p_0 in the directions along and normal to the tabs at specified axial locations from 0.5D to 18D, at NPR 5.75 are presented. Pressure profiles of the uncontrolled supersonic jet, at NPR 5.75 (Fig 6) is plotted. It is seen that at 0.5D the vortices generated at the jet periphery introduces some asymmetry to the jet. This is because the vortices formed have their own frequency and amplitude. Even a marginal asymmetry in the nozzle or a small variation in the smoothness of the nozzle inner surface or a mild perturbation in the atmosphere to which the jet is discharging and so on is enough to trigger the vortices to form in a staggered sequence. This kind for formation is natural since avoiding the above features responsible for causing asymmetry to not possible in practice. Pressure profiles for the controlled supersonic jet at NPR 5.75 with tabs at exit (Fig 7) is also plotted. From these results it is seen that the propagations of the flow in the direction along and normal tothe tab are considerably different. This difference persists even at 18D, but the vortices shed by the tab can make the jet too propagate in the planes along and normal to the tab. The experimental model is tested in supersonic Mach number of 1.8 at NPR of 5.75.

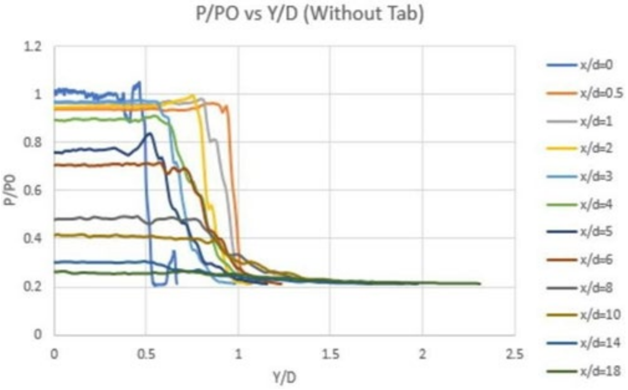

Figure 6. Pressure Profile along Radial direction WithoutTab

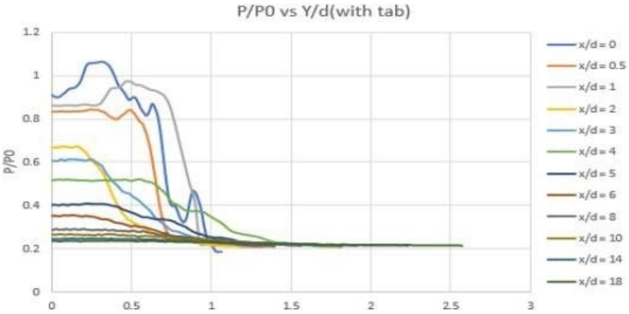

Figure 7. Pressure Profile along Radial direction With Tab

The jet width has been reduced drastically in comparison with uncontrolled jet. The pitot readings are taken both streamwise direction (X/D) and radial direction (Y/D). The calibrated values of nozzle with and without tabs are compared with each other. The graph is then plotted between (P/P_0) and (X/D) for different NPRs and tab combinations. Supersonic core length is defined as the distance from the nozzle exit up to which the supersonic flow prevails. The supersonic core length can be estimated from Centre line pitot pressure surveys. The plot ofpitot pressure ratio for NPR extends up to X/D = 18 in case of nozzle without tab (Fig 7).

The core is the axial extent up to which supersonic flow prevails. The core of the uncontrolled jet (without tab) extends to about 5.9D (Fig 8). The reductions in jet core lengths were observed as 17% for controlled jet at NPR 5.75 in comparison to uncontrolled jet. The plot of pitot pressure ratio for NPR 5.75 up to X/ D = 16 (Fig 9). This is due to expansion waves reflected as strong compression waves to reduce the pressure and bring the equilibrium with ambient. The core of the controlled jet extends to about 4.9D.

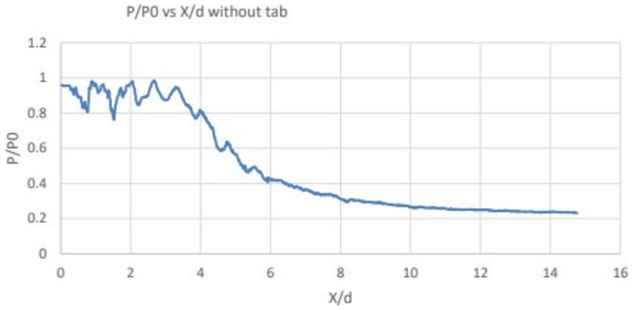

Figure 8: Pressure Profile along axial direction Without Tabs

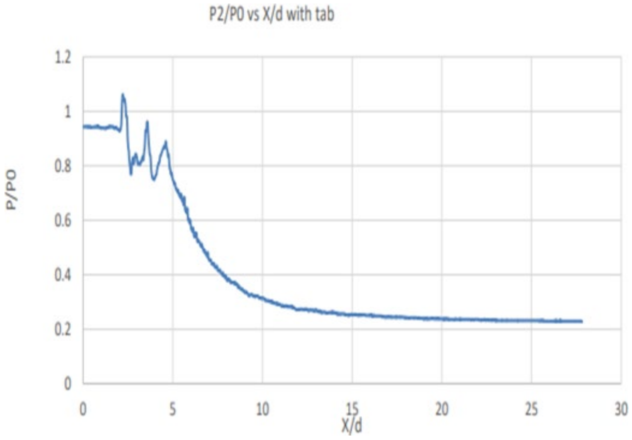

Figure 9. Pressure Profile along axial direction With Tab

The elliptical ring tabs essentially divide the jet into two smaller jets. Because of this bifurcation and the associated initiation of enhanced transverse momentum exchange, the flow along the centerline behind the tabs gain momentum rapidly, attains a peak followed by characteristic decay, typical of a free jet. Therefore, the axial extent at which characteristic decay begins can be justifiably taken as the core length for the jet from a nozzle with elliptical ring tabs. It is seen that the controlled jet core has only mild oscillations in the centerline pitot pressure. This implies that the shocks prevailing in the jet core are very weak. This reveals that there are no waves of significant strength along the jet centerline downstream of the tabs. After the core, the jet with tabs experiences a faster decay than the jet without tabs. It should be noted that all mentioned differences in the jet behavior are taking place within 6D axial distance. Beyond 6D, jets from nozzles with tab and without tab are behaving moderately. It is well established that, weakening the shocks in the jet core will result in reduction of shock associated noise, hence enhance the jet. For all the tabs thejet becomes fully developed at about 5D itself. Whereas the uncontrolled jet shows a tendency to become fully develop only beyond 15D.

Schlieren visualization and observation of shock cell length of supersonic jet for uncontrolled and controlled jets (Fig 10). Schlieren image and top view of controlled supersonic jet for NPR 5.75 (Fig 11). Schlieren image of uncontrolled supersonic jet for 5.75.

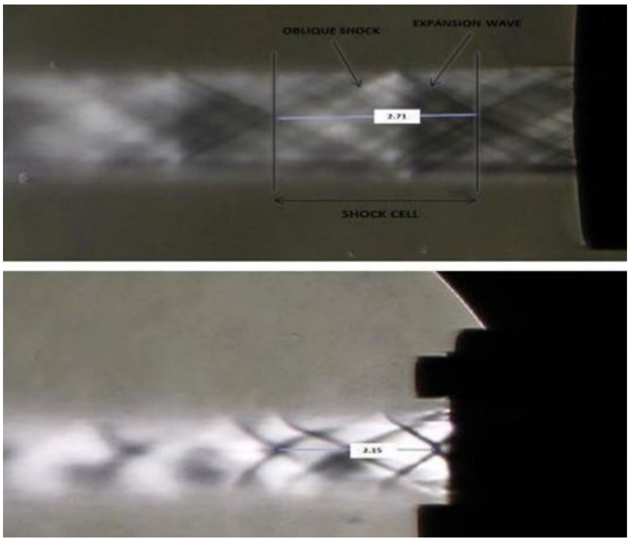

Figure 10. Schlieren Image of controlled & uncontrolled jet at NPR 5.75

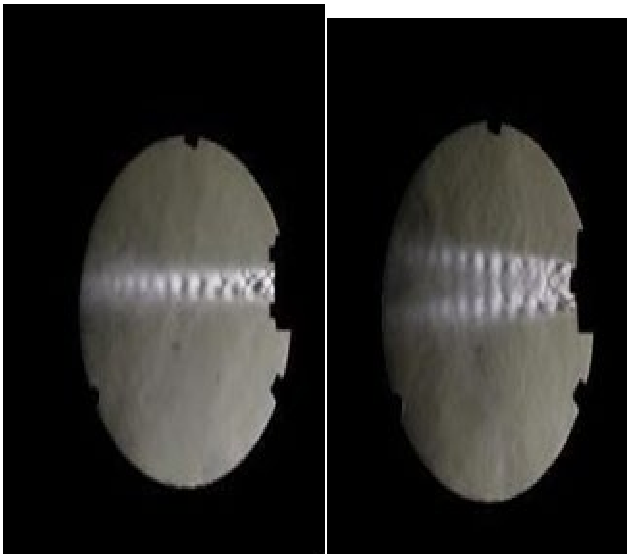

Figure 11. Flow Pattern at NPR 5.75

6. SPL VS FREQUENCY (5.75 bar, major axis)

The graphs are plotted using MATLAB software. The microphone is placed at different azimuth angles at a farfield distance of R/D= 70. The above case P_0 = 5.75bar corresponds to correctly expanded jet.

At 60^0 for Supersonic C-D nozzle with elliptical ring tabs minimal overtones were found, for C-D nozzle model shock noise are likely to exist. Hence Supersonic C-D nozzle with elliptical ring tabs is found to work better (Fig 12). At 90^0 for Baseline nozzle model 3 overtones were found, for Supersonic C- D nozzle with elliptical ring tabs 2 overtones were found. This shows that Supersonic C-D nozzle with elliptical ring tabs suppress better (Fig 14, Fig 15).

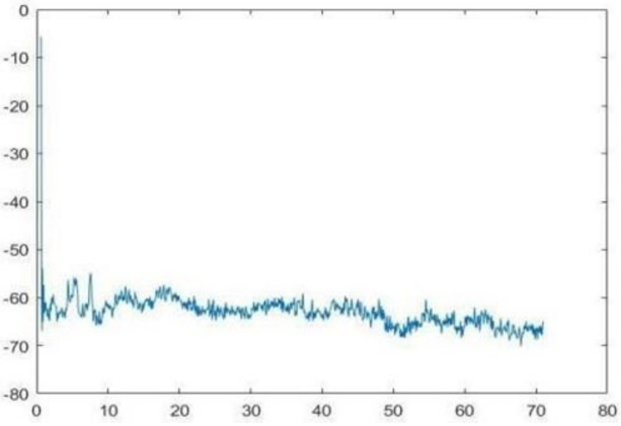

Figure 12. SPL vs Frequency (with tabs 60 deg) at major Axis

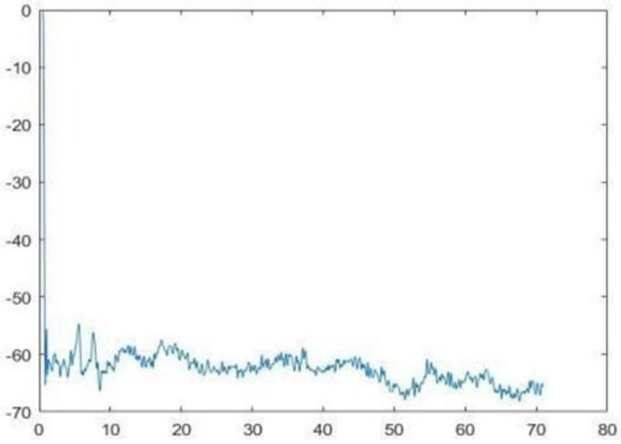

Figure 13. SPL vs Frequency (without tabs 60 deg) at major axis

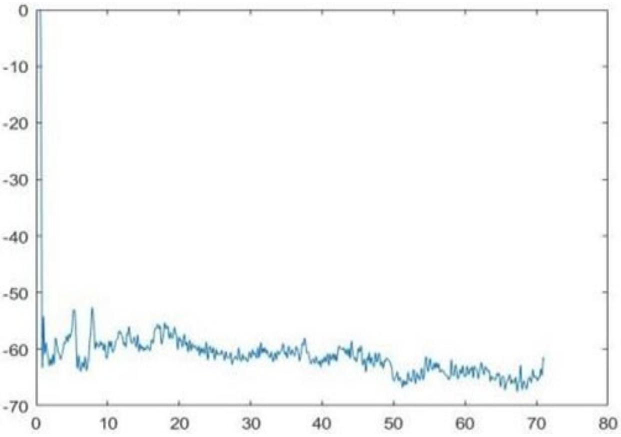

Figure 14: SPL vs Frequency (with tabs 90deg) at major axis

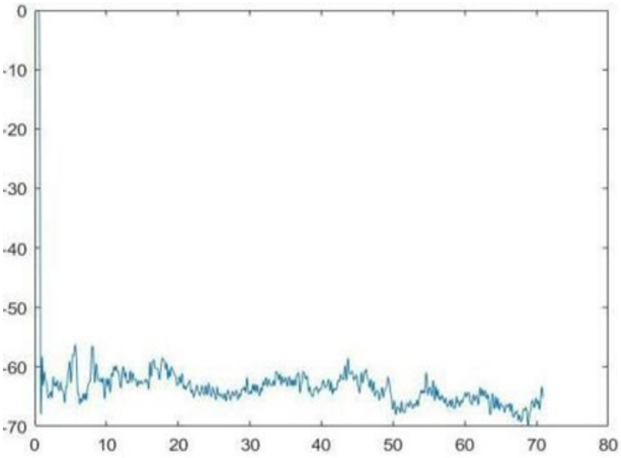

Figure 15. SPL vs Frequency (without tabs 90 deg) at major Axis

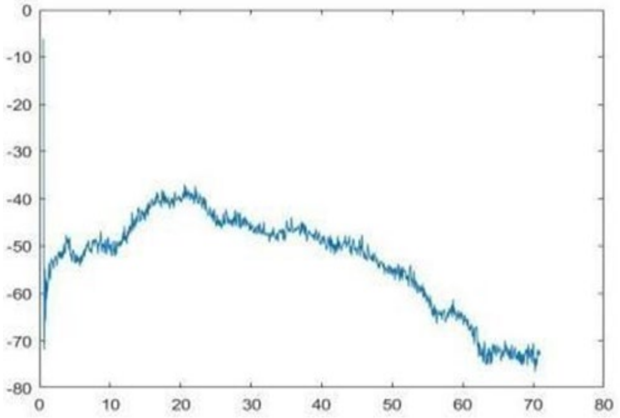

Figure 16. SPL vs Frequency (with tabs 120deg) at major Axis

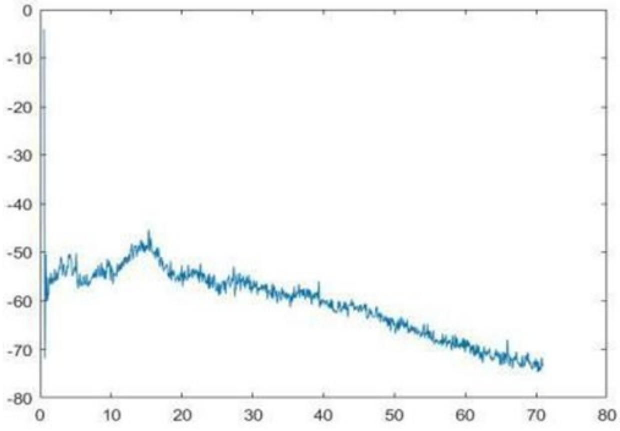

Figure 17. SPL vs Frequency (without tabs 120deg) at major Axis

At 120^0 for C-D nozzle model 3 overtones were found to exist, for Supersonic C-D nozzle with elliptical ring tabs 1 over tone is found to exist.

Hence Supersonic C-D nozzle with elliptical ring tabs found to work better. Hence from the above discussion with Supersonic C-D nozzle with elliptical ring tabs is found to suppress noise effectively at correct expanded condition along the major axis (Fig. 16, Fig. 17).

7. CONCLUSION

The acoustic characteristics of the supersonic jets with and without elliptical ring tabs were studied experimentally. It is found from pressure profiles that the propagations of the flow in the direction along and normal to the tab are considerably different. This difference persists even at 18D.

It is found from Schlieren images that the weaker shocks are noticed in the controlled jets compared to uncontrolled jets. For controlled jets the supersonic core has multiple weaker shocks and shock length gets reduced. The wave reflection of controlled jets is not continued to downstream as uncontrolled jets. This indicates the reduction of supersonic core length when compared to uncontrolled jets. These results are proved fromSchlieren images.

It is found from spectrum plots that supersonic C-D nozzle with elliptical ring tab model has a smaller number of overtones which means that they are less prone to screech compared with nozzle without tab. Thus, when screech is suppressed, shock associated noise is also found to be reduced. This is due to the nature of disturbance created by the elliptical ring tabs where the disturbance is spread uniformlythroughout the exit cross section. From the OASPL results it is found that the noise level is decreased upto 4 dB in both azimuth angle of 60º, 90º and 120º.This clearly shows that noise level is decreased while using supersonic C-D nozzle with elliptical ring tabs when compared to the nozzle without tab. When comparing OASPL value of azimuth angle there is not much difference in noise level reduction.

Table 2. Nomenclature

$P_{absolute}$	$AbsolutePressure$	$[p_{as}]$
p_{gauge}	$GaugePressure$	$[P_g]$
$p_{atmosphere}$	$AtmosphericPressure$	$[P_{atm}]$
SPL	$SoundPressureLevel$	$[pa]$
$OASPL$	$OverallSoundPressure$ $Level$	$[Pa^2]$
F	$Frequency$	$[Hertz]$

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