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Numerical Simulation of Acoustic Performance of Lobed Nozzle

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ABSTRACT

An experimental investigation of the reduction in acoustic signature in the jet mixing flows of lobed nozzles has been conducted. It is a well-known fact through the literature study that jet mixing in ejectors is affected by the shape of the nozzle exit. Hence, simulations were performed for three convergent nozzles with the same exit area. Two of these were of circular lobed configuration with six (6) and ten (10) lobes and one was a circular nozzle. The investigations gave a clear contrast in the noise signature reduction for the different configurations. The investigations also showed light upon the increase in turbulent intensity for the lobed nozzles; thereby indicating correlation of turbulence and noise intensities. For accurate predictions of the noise reductions, the flow has been simulated accordingly with the help of acoustic tools implemented in FLUENT.

Keywords-:Acoustic, Broadband noise sources, Lobed nozzle,

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1.INTRODUCTION

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight. A moving aircraft causes compression and rarefaction of air molecules resulting in their motion. This motion propagates as pressure waves. These pressure waves have a wide spectrum of frequency with some lying in the audible range. The most important noise generating sources include aerodynamic noise, engine noise and aircraft system noise. Due to the strong influence of aircraft noise on human body (civil aircrafts), detection of target (military aircrafts) there is always a need to reduce the acoustic level as far as possible. It is a well-known fact in engineering flows, that the mixing process governs the mixing rate in the combustion chambers and jet noise level of airplanes. How well a jet flow can mix with ambient flows has a major impact on the combustion efficiency, the rate of heat release and jet noise suppression.

A lobed nozzle consists of a splitter plate with a corrugated or convoluted trailing edge. It is a fluid mechanic device which is being implemented in recent times as a vortex generator, enhancing efficient mixing of co-flow streams. It has been of great interest for many researchers in the recent years. It has been applied widely in engine exhausts and ejectors for its efficient mixing performance and jet noise reduction. Continuous investigations have been made in the field of efficient jet flow mixing in a lobbed nozzle for varied shapes to determine how the complete mechanism works. Lobed nozzles have been used to reduce the jet noise while landing/take off, improve propulsive efficiency and reduce Specific Fuel Consumption (SFC). For reduction of infrared radiation signals/ thermal signature of military aircrafts; to improve their survivability, lobed nozzles have been used for enhancement of the mixing process at high temperature and high-speed gas plume from the engine with the ambient air flow.

A number of investigations have been done by researchers for efficient mixing in lobed nozzle by optimization of its geometry. Faster spreading of jet was observed in all the cases. Many of the researches are concerned with the PIV techniques, LIF techniques to study the above mentioned processes. Few investigations have been performed using the CFD analysis of the flow problem due to the difficulty in setting up the problem statement because of the complex geometry and large parameters. This experimental investigation was prompted on the basis of the few investigations performed in the CFD domain.

Lobed geometry introduces efficient mixing of two streams at different conditions of velocity, pressure and temperature. There is an increase in the interfacial area of a lobed geometry between the two streams which enhances efficient mixing. Based on the pressure, temperature and velocity measurements of a lobed nozzle, Paterson (1982) revealed the existence of large scale stream-wise vortices in lobed mixing flows which have been induced due to the optimized geometry of lobed nozzles. These large scale stream-wise vortices were said to be responsible for the enhanced mixing. Stream-wise vortices are found to follow a three step process in lobe mixing as per Werle et al (1987) and Eckerle et al (1992). They found that stream-wise vortices form, intensify, and then break down, which accounts for high turbulence resulting from vortex breakdown; thus enhancing the mixing process.

Numerical analysis of 3D airflow from a convergent nozzle along with mixing of ambient airflow was carried out by the commercial software version. An evaluation of flow results were performed by using turbulent flow characteristics (turbulent kinetic energy) and acoustic characteristics. The calculations were performed for six (6) lobed nozzle, ten (10) lobed nozzle and circular nozzle. The required results were obtained to show an effective comparison between all the three cases. The time step was chosen short in order to capture any significant variation in the acoustic signature.

The Fluent version provides the calculation of acoustic characteristics in a limited volume. The position was defined accurately to display graph of sound pressure level with dependency in position. The simulation of the aeroacoustic propagation depends on the accuracy of the applied numerical method. Practically, high order accuracy methods are required for discretization. The noise source distribution was predicted based on the Broadband Noise Source Model in Acoustics Model in Fluent. The acoustic parameters and constants were specified namely far-field density, far-field sound, reference acoustic power, number of realizations and number of Fourier modes. The Fourier modes compute the turbulent velocity field and its derivatives. The turbulent velocity field is used to compute the Linearized Euler Equations (LEE) and Lilley's source terms. This hybrid model is used to compute the acoustic far field. Lilley and Pridmore-Brown developed certain wave operators to describe acoustic propagation exactly in unidirectional sheared mean flows. Unlike the direct method and Ffowcs William-Hawking's integral method, the broadband noise source models do not require transient solutions to any governing fluid dynamics equation. Therefore, the uses of Broadband Noise Source models require the least computational sources.

I. PROBLEM FORMULATION

Computational investigations are conducted for three different configurations of nozzles. All the three nozzles have a convergent contour with a constant nozzle exit area of 1256m^2. Of the three nozzles, one is a circular nozzle which acts as the baseline case. The rest are of lobed configurations having six (6) and ten (10) lobes respectively.

The geometry was designed on CATIA V5 (Computer Aided Three-dimensional Interactive Application). The computing grid was created with the help of the software GAMBIT version using suitable size functions. Refined mesheswere generated for all the cases to analyze the investigation accurately. The number of cells in each of the case was kept in the range of ten (10) to fifteen (15) lakhs.

For solver, the turbulence model chosen is k-ω SST. Discretization schemes of time are the second order implicit. Discretization schemes of momentum are at the same order (scheme upwind). The air was defined as ideal gas with 216K temperature, calculation was run on short time step for total time of 30 seconds. At this time step, the flow conditions reached statistically steady state. The flow conditions are simulated at Mach 0.6. The temperature of nozzle inlet is at 600K. The Broadband Noise Sources model was defined for the acoustic calculation at a preferred position of flow field for proper analysis of the flow field.

Table 1: Total number of mesh elements in Gambit for various nozzle configurations

Configuration	**Mesh Cells**	**Mesh Nodes**

Circular Nozzle	1225008	212068
6 Lobed Nozzle	1308006	226286
10 Lobed Nozzle	1384212	232367

The geometry displayed in the Figure 1 shows the six (6) lobed nozzle with the troughs and peaks. The boundary conditions for the six (6) lobed nozzle and the ten (10) lobed nozzle are displayed in Figure 2 and 3 respectively. The total number of meshed elements and nodes are mentioned in Table 1.

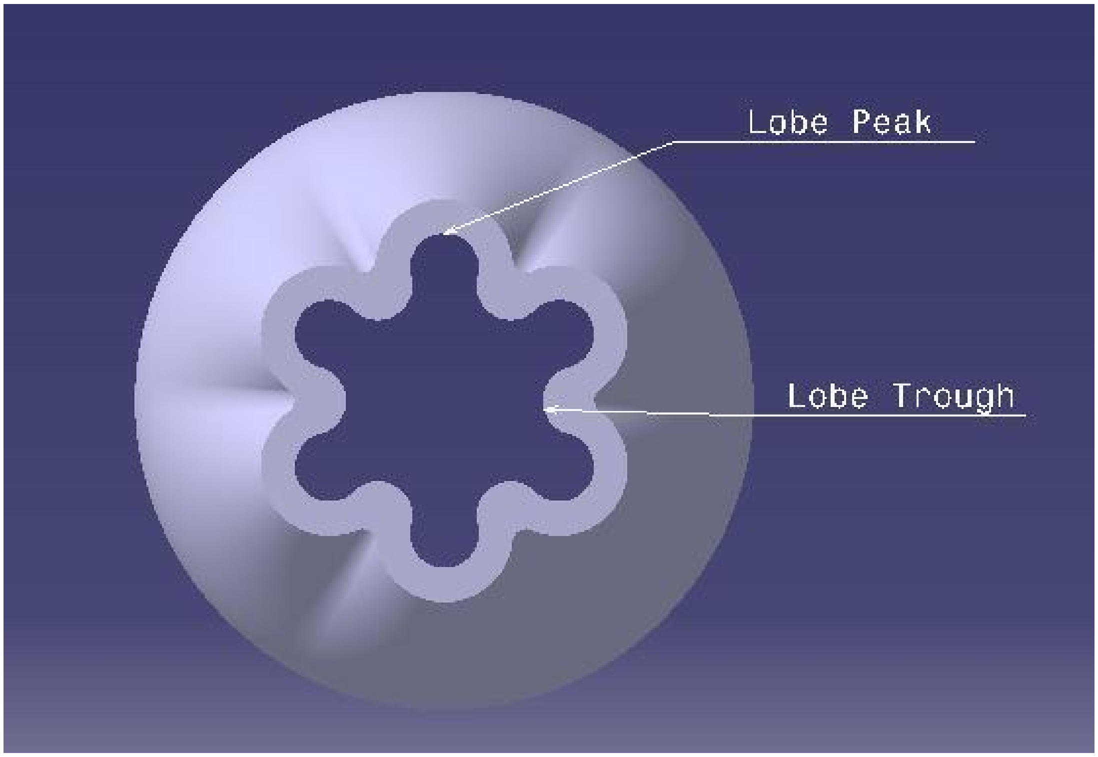
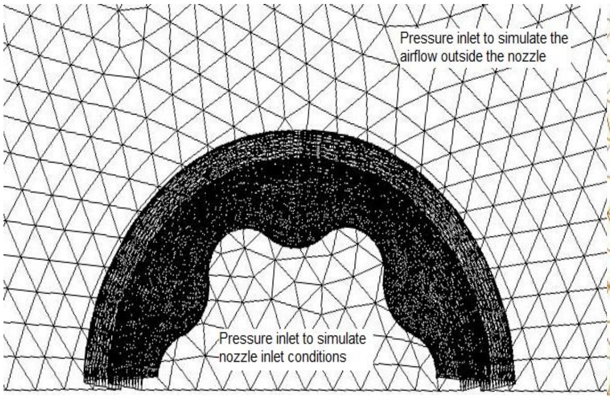


Fig 1: CAD model of six lobed nozzle



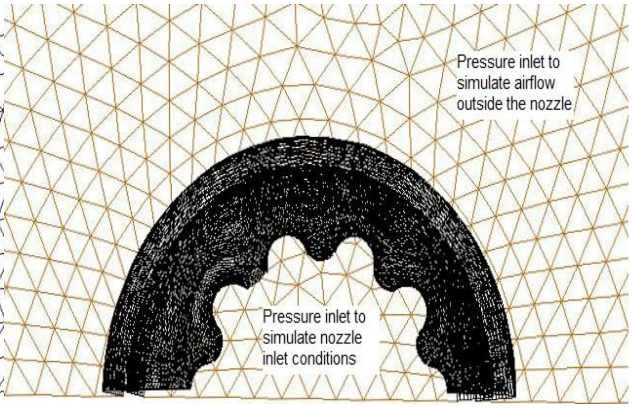


Fig 2 : Boundary conditions of six lobed nozzleFig 3: Boundary conditions of ten lobed nozzle

II. RESULTS

Figure 4(a) shows sound pressure spectra for the circular nozzle which forms the standard for the paper. Figure 4(b) shows the sound pressure spectra for the six lobbed nozzle while figure 4(c) shows that of ten lobed nozzle. Figure 5 shows the comparison of six lobed nozzle, ten lobbed nozzle with circular nozzle. For these data the supply pressure is held constant, thus, the Mach number at the exit of the jet is the same for all the cases. It is apparent that the noise level is low for all lobed nozzle cases. Increasing the number of lobes from 6 to 10 produces some additional noise benefits in the system.

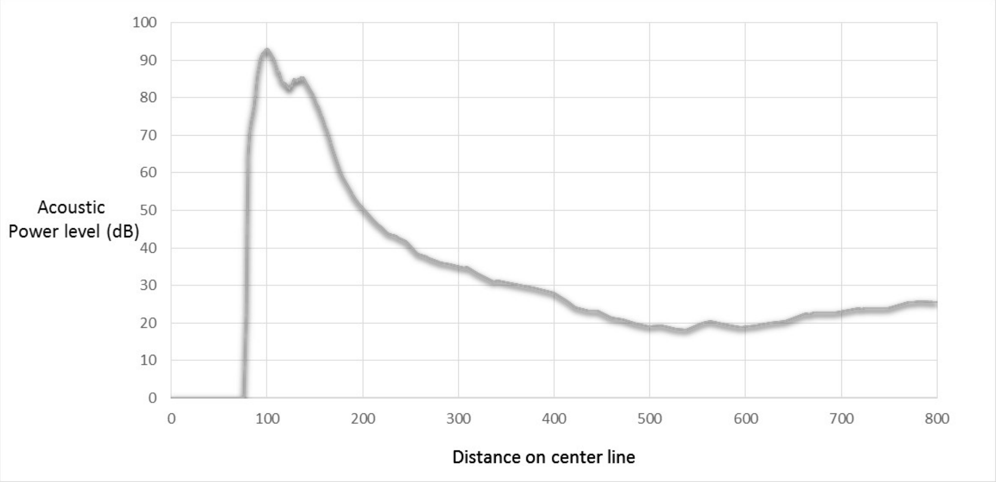


Fig 4(a): Acoustic power level of circular nozzle

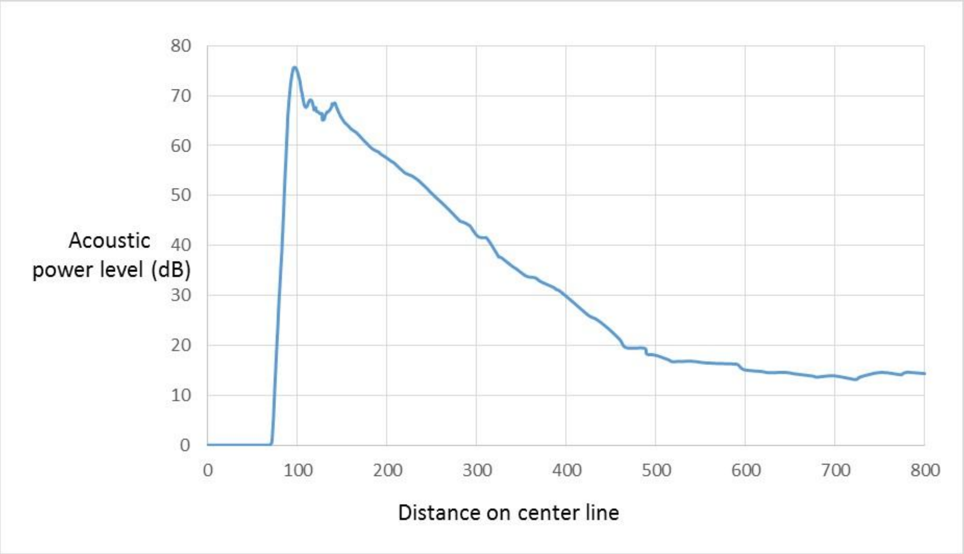


Fig 4(b): **Acoustic power level of six lobed nozzle**

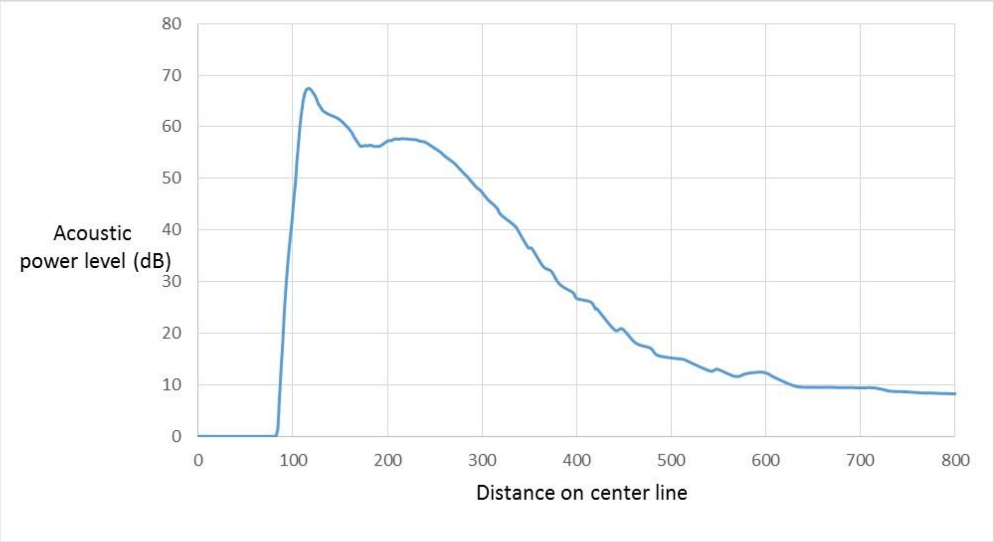


Fig 4(c): **Acoustic power level of ten lobed nozzle**

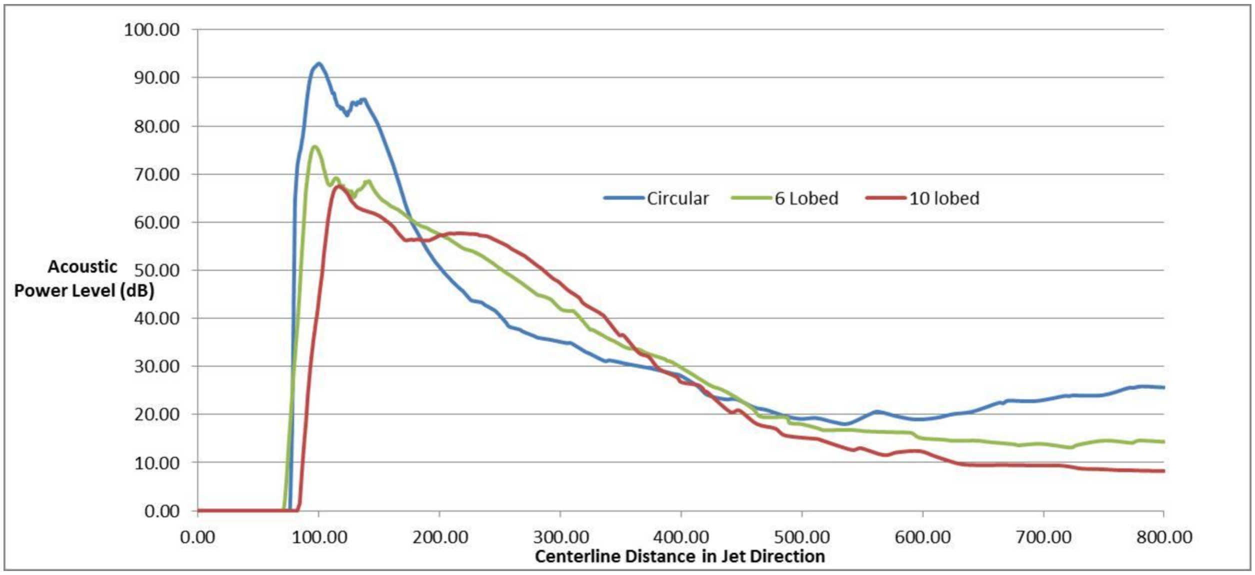


Fig 5: Comparison of six lobe, 10 lobe and circular nozzle on the basis of acoustic level

The overall sound pressure levels, obtained by the integration of the spectral data of Fig 4(a), (b) and (c) are shown in Figure 5. The data are shown as a function of number of lobes, with the circular nozzle data. The sound level is plotted at the ordinate while the position from center line is plotted at the abscissa. The amplitude decreases with increasing number of lobes, for both values of 6 and 10 of constant Mach number. For a realistic practical nozzle, the noise can be simulated by scaling the data by a large factor, assuming ‘Strouhal Number’ Scaling.

III. CONCLUSION

The results from investigations in FLUENT revealed the great differences of the turbulent structure and acoustic levels between the lobed nozzle and circular nozzle. Compared with the circular nozzle, the lobed nozzle had lower amplitudes of sound pressure levels. The lobbed nozzle was seen to accelerate the flow field and create perturbations. They involve quicker spreading of the jet from the nozzle exit as compared to the circular nozzle. Increasing the number of lobes results in progressive reduction in turbulence intensities as well as overall noise. Among the studies done, along with literature study, the six-lobbed nozzle has the optimum reduction in turbulence and noise with minimal thrust penalty.

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