

# Modelling and Analysis of different Chevron Nozzles for Noise reduction in Jet Engines

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**ABSTRACT:** Chevron Nozzle has been used in the current time as a handy noise control device for noise reduction in jet engines. The main noise source in an engine is the Fan or Compressor, the Turbine, and the exhaust jet or jets leaving the jet engine. Jet exhaust noise is created or caused by the disturbed turbulent mixing of the exhaust gases with the surrounding and is influenced by the shearing action caused by the relative velocity between the jet exhaust and the surrounding. Chevron Nozzle is an effective noise control technique currently used in few of the commercial airliners. In the present work, attempt is made to understand the effect of various geometric parameters (design) of a chevron nozzle. This Paper mainly focuses on the reduction of jet noise emission in the exhaust nozzle of turbofan engines. The simulation results are evaluated in order to obtain the optimal design of the chevron nozzle with respect to the acoustic power level emitted. After assessing the chevron parameters, the chevrons design is modified in order to get maximum noise reduction. Various geometric parameters like different number of chevrons, different shape of chevrons, and their length and tip angles are employed on a 50.8 mm exit diameter nozzle.

**KEYWORDS:** Chevron Nozzle, Penetration Length, Sound Pressure Level, Acoustic Power level.

## I. INTRODUCTION

Among all the noise sources, aircraft noise is considered as one of the most disturbing. People who are very much concerned about the quality of their surroundings in urban areas are mainly concerned about the noise levels in the locality. In modern days, jet airlines are significantly more efficient with less noise compared to commercial jet airlines of the 1960s and 1970s. Even so, the goal of reducing noise from aircraft in locality surrounding airports (aerodromes) continues to exist. Aircraft manufacturers are working amidst more and stingier noise abatement regulations in airport localities. Normally, most of the noise heard from the engines is during take-off and landing. Jet exhaust noise is created or caused by the disturbed turbulent mixing of the exhaust gases with the surrounding and is influenced by the shearing action caused by the relative velocity between the jet exhaust and the surrounding, the core stream, fan stream, and free stream. Most of the previous researches have been performed on jet engine nozzles to accelerate the mixing of the shear layers without significantly reducing its performance.

Nozzles are used in gas turbine engines to increase the velocity of the flow so as to get more thrust and also to control the uniform distribution of flow the from turbine at the exit. In nozzle, the static energy (due to flow after turbine) is converted into kinetic energy because of which noise is generated in jet engines. Hence, it becomes necessary to reduce this noise from the exhaust of nozzles. Chevrons as a saw tooth pattern on the circumferential edge of exhaust nozzles are being implemented in modern jet engine nozzles so as to reduce noise from the consequent jet. Chevrons are used in jet engine nozzle to reduce the acoustic level at the exhaust by smooth mixing of exhaust with the cooler ambient air. The working of chevron nozzle is quite simple, as it ensures the smooth mixing of hot jet with the main cold air stream coming directly from the engine fan. The chevrons have a concave contour axially between the bases and apexes which promotes jet mixing through the slots. The successful application of chevron nozzle to the aircraft engine can be seen in Boeing 747-8 which is powered by GENx-2B67 engine and also ROLLS-ROYCE Trent 1000 jet engine which have a triangular saw-tooth pattern.

## II. RELATED WORK

Malay Suvagiya and Sharma [1] studied the effect of geometric parameters of chevron nozzle on generation of streamwise vortices in high subsonic jets. In this work, the authors have shown the calculation of exhaust chevron section for different nozzles with different angle in chevron models thus estimating the length of the chevron for those models. They also studied the effect of the different geometric parameters on evolution of stream wise vortices produced by the chevron in the jet flow by using ANSYS – CFX. Kaleeswaran and Shanmugasundaram [2] carried out experimental and Statistical analysis on the noise reduction of chevron nozzle in supersonic free jet. In this research paper, the authors have considers a supersonic free jet test rig with compressor & air tank. They considered nozzle as a

CD nozzle to produce supersonic flow. In the design they considered 3 models one without chevrons, the second one with 10 numbers of chevrons and the third one with 14 numbers of chevrons. They incorporated a sound level meter at the nozzle exit to measure the sound levels for various pressure conditions. A graph of NPR to NOC for various condition of noise (dB) was statistically analysed with three methods using Taguchi method, ANOVA method and multiple linear regression model. Results show that Taguchi method shows better S/N ratio for measuring the sound response of s/n ratio with respect to NPR and NOC. ANOVA technique is also employed to find statically significant parameters of noise levels. Daniel Crunteanu and Petre-Claudiu [3], performed acoustic characteristic studied on flow over different shapes of nozzle chevrons in which they analyzed four different shapes of chevrons to find the acoustic characteristics. The results show the optimum design of chevron with the most efficient shape and noise reduction. Vance Dippold [4], conducted a CFD Analysis and Jet-Noise Predictions of Chevron Nozzles with Vortex Stabilization method. In this study, the wind computational fluid dynamics code was used to perform a series of analyses on a single-flow plug nozzle with chevrons. Air was injected from tubes tangent to the nozzle outer surface at three different points along the chevron at the nozzle exit, near the chevron notch, at the chevron mid-point and near the chevron tip. Three injection pressures were used for each injection tube location, namely 10, 30, and 50 psig with injection mass flow rates of 0.1, 0.2, and 0.3 percent of the nozzle mass flow. R. Kanmaniraja et.al [5], performed 3D numerical studies on Jets acoustic characteristics of Chevron nozzles for aerospace applications where they analyzed four types of chevron nozzle and one simple nozzle. The numerical studies were carried out using a validated steady 3D density based implicit, standard, k-epsilon turbulence model using standard wall functions. This model uses a control-volume based technique to convert the governing equations to algebraic equations.

Numerical Analysis of Chevron nozzle with various configurations for noise reduction was conducted by Nevis Jenifer and Selva Preethi [6]. Here, the authors performed simulation on five different nozzle models - plain and chevron nozzles. The velocity magnitude and acoustic power level of all five types of nozzle was estimated. Usha Bharathi et.al [7] studied the effect of Chevron on Transonic Nozzle using different penetration length by keeping the diameter of exhaust & number of chevrons fixed. It is seen that the transonic nozzle with the chevron reduces the noise in the nozzle and it can be observed that by the implementation of chevron in the transonic nozzle the efficiency of the engine is also not compromised. The practical applications of chevron nozzles on full-scale engines were also investigated in this research.

### III. METHODOLOGY

In this section, the dimensional parameters like length of nozzle, inlet and exhaust diameter of nozzle, number of chevron, length of chevron for design of baseline and chevron nozzle (Any chevron nozzle) are recorded. Simple triangular chevrons are used for the present parametric study. Geometry of a chevron nozzle is defined by parameters such as number of chevrons (N), length of chevron (L), tip angle ( $\beta$ ) and penetration angle ( $\alpha$ ). Figure 1 represents the simple schematic of the chevron geometry with its shape defining parameters.

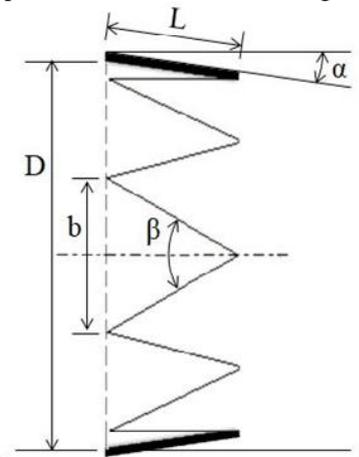


Fig.1 Schematic of Chevron Geometry

Where

b = base of the chevron

h = height of the Chevron

D = exit diameter of the nozzle

N = Number of Chevrons

$\alpha$  = Penetration angle

L = Length of the nozzle

Base of the individual chevron (b) can be calculated as,

$$b = \frac{\pi D}{N} \tag{1}$$

Relation between tip angle, base and length of chevron can be represented as

$$\tan\left(\frac{\beta}{2}\right) = \frac{b}{2L} \tag{2}$$

By combining and rearranging these equations, it gives

$$\left(\frac{L}{D}\right) \times \tan\left(\frac{\beta}{2}\right) \times N = \frac{\pi}{2} \tag{3}$$

Length of the nozzle which is dependent on the exhaust diameter of the nozzle is given as,

$$L' = 4.25 \times D \tag{4}$$

Height of the chevron

$$h = \frac{b}{2} \tag{5}$$

From these formulas it is seen that the length of the chevron depends on the number of chevron and tip angle. This relation suggests that the basic parameters defining the geometry of chevron are interdependent and hence changing any individual parameter without changing the other is not possible. Hence, chevron configurations are chosen very carefully such that the effect of individual parameter can be deduced from that.

For the designing the chevron nozzle, the exhaust diameter of nozzle is considered to be 50.8 mm, tip angle ( $\beta$ ) as  $60^\circ$ , penetration angle ( $\alpha$ ) as  $5^\circ$  and number of chevron (N) as 8 so that the chosen configuration will be N8 $\beta$ 60. Using the above relations, the base of the nozzle is estimated to be 19.54 mm and the length of chevron as 17.26 mm, while the length of the nozzle is 152.5 mm. The dimensions of the nozzle and its parameters are shown in Fig. 2.

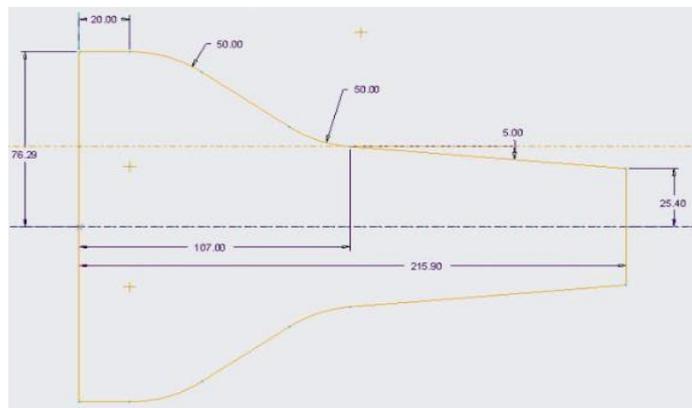


Fig. 2 Dimensions of the nozzle parameters used in the present study

#### IV. EXPERIMENTAL RESULTS

##### Nozzle Design (model):

This section shows the design of various chevron nozzles used in the present analysis along with base line nozzle. Figure 3 & 4 below shows the same.

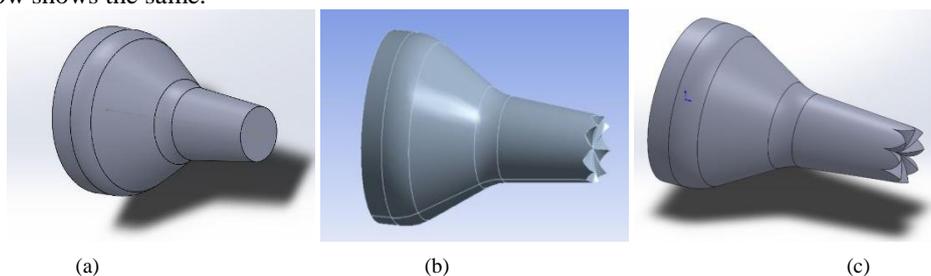


Fig. 3 (a) Design of BSL, (b) Design of Pallet and (c) Design of Inverse Pallet chevron nozzle

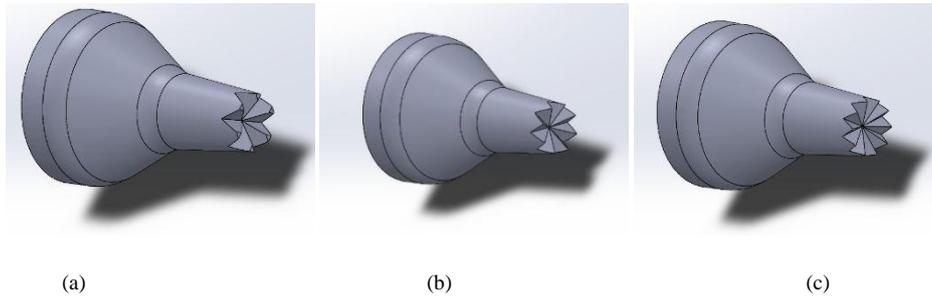


Fig. 4 (a) Design of 6<sup>th</sup> number of chevrons nozzle, (b) Design of 8<sup>th</sup> number of chevrons nozzle, (c) Design of 10<sup>th</sup> number of chevrons nozzle

**Acoustic Power Level contours**

Acoustics power level describes the amount of noise generated as shown in figures 5 & 6 below. The acoustics power level is higher at the end of nozzle because of hot and cold air mixture and strength of vortices.

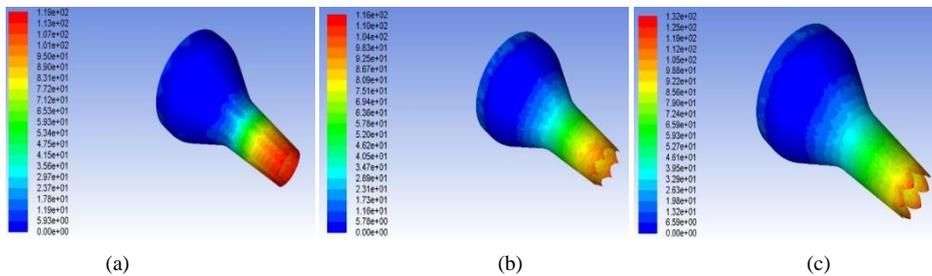


Fig.5 (a) Acoustic power level of BSL, (b) Acoustic power level of Pallet and (c) Acoustic power level of Inverse Pallet nozzles

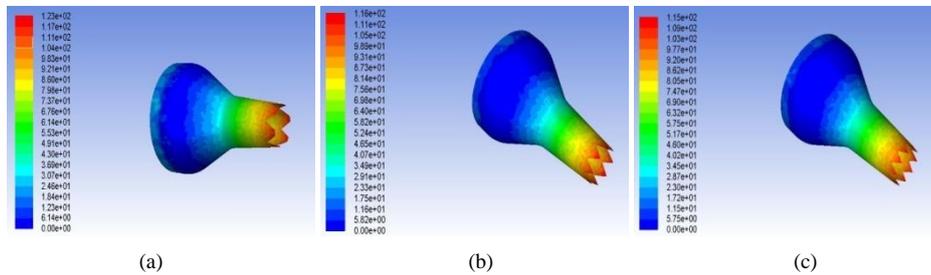


Fig.6 (a) Acoustic Power Level of 6<sup>th</sup> Number of chevrons, (b) Acoustic Power Level of 8<sup>th</sup> Number of chevrons and (c) Acoustic Power Level of 10<sup>th</sup> Number of chevrons

**Mach number contours**

In fluid dynamics, the Mach number is a dimensionless parameter which represents the ratio of flow velocities past a boundary to the local speed of sound. It denoted by M. Figure 7 & 8 shows the distribution of Mach number across the nozzle.

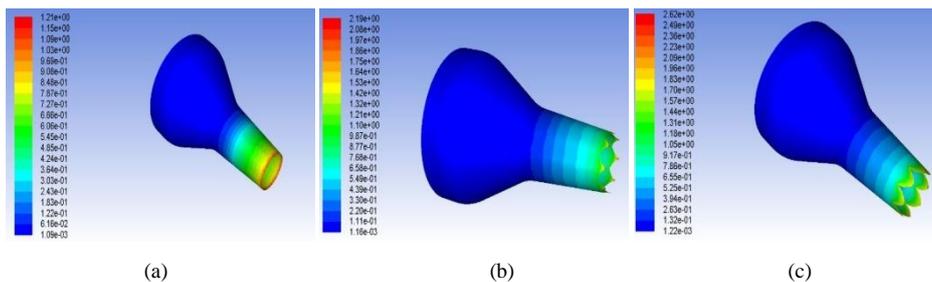


Fig.7 (a) Mach contour of BSL, (b) Mach contour of Pallet and (c) Mach contour of Inverse Pallet chevrons

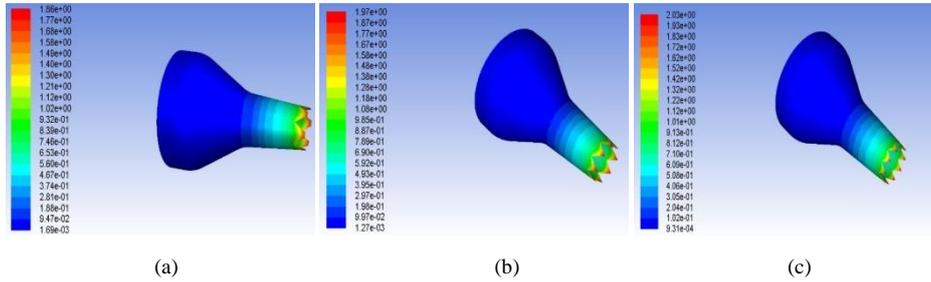


Fig.8 (a) Mach contour of 6<sup>th</sup> 10 Number of chevrons, (b) Mach contour of 8<sup>th</sup> 10 Number of chevrons and (c) Mach contour of 10 Number of chevrons

Similarly, the total pressure and total temperature profile of the nozzles analyzed are shown figures from 9 to 12 below.

**Total Pressure contours**

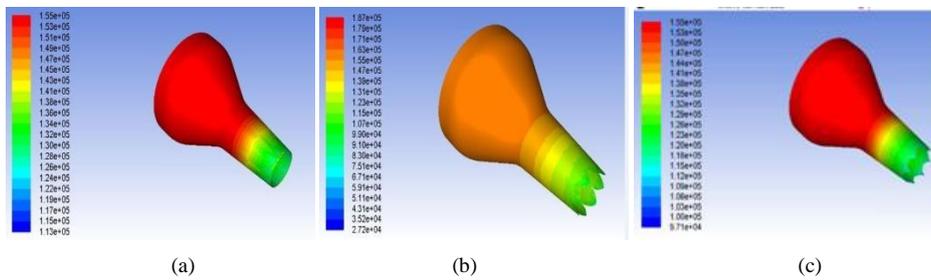


Fig.9 (a) Total Pressure of BSL, (b) Total Pressure of Pallet and (c) Total Pressure of Inverse Pallet chevrons

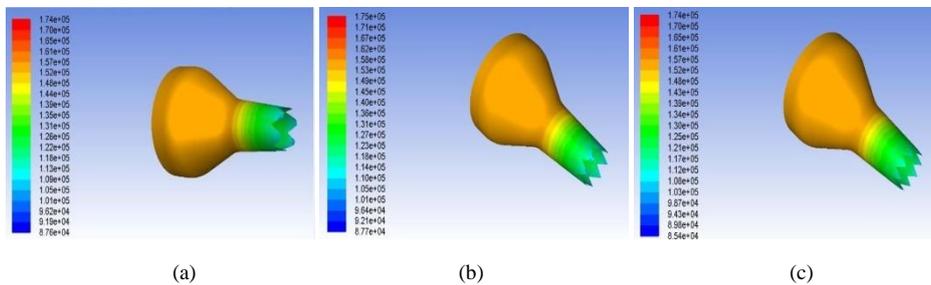


Fig.10 (a) Total Pressure of 6<sup>th</sup> Number of chevrons, (b) Total Pressure of 8<sup>th</sup> Number of chevrons and (c) Total Pressure of 10 Number of chevrons

**Total Temperature contours**

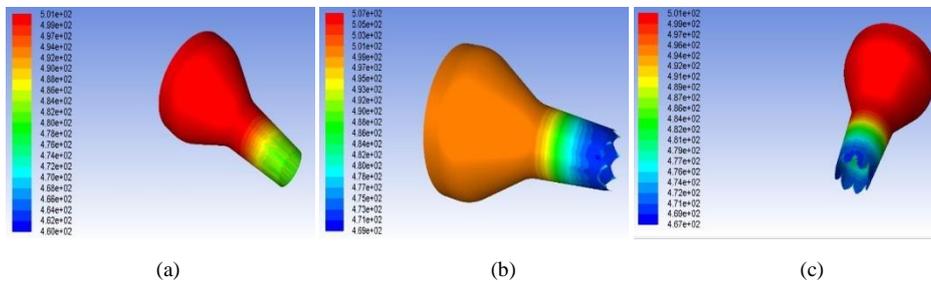


Fig.11 (a) Total Temperature of BSL, (b) Total Temperature of Pallet and (c) Total Temperature of Inverse Pallet chevrons

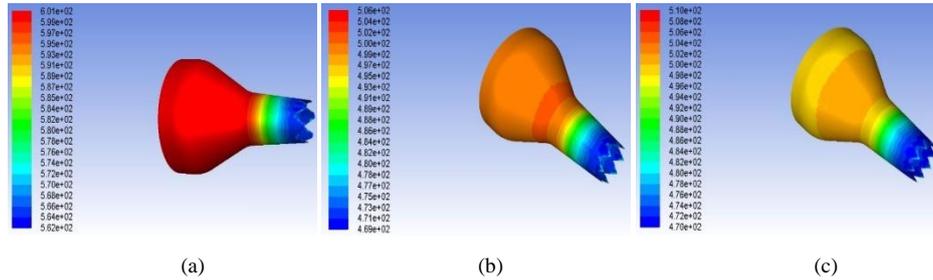


Fig.12 (a) Total Temperature of 6<sup>th</sup> Number of chevrons, (b) Total Temperature of 8<sup>th</sup> Number of chevrons, (c) Total Temperature of 10<sup>th</sup> Number of chevrons

**Acoustic Power Level graph**

This Graph below shows the comparison of Acoustic Power level of all Nozzles (BSL, Triangular chevron nozzle (NOC-6, 8, 10), Pallet and Inverse Pallet Nozzle.

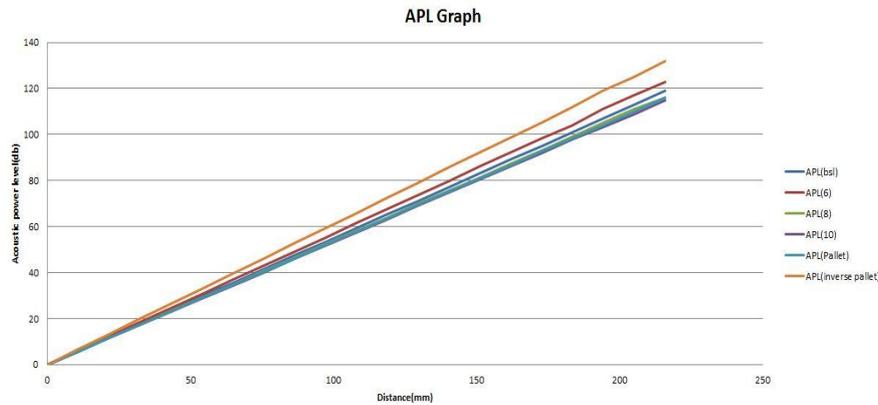


Fig.13 Acoustic Power Level

**V. CONCLUSION**

The results of the analysis are summarized in the table below

Sr.no.	Nozzle type	Number of Chevron	Acoustic power	Mach Number	Nozzle Pressure Ratio
1	Base line nozzle	0	119	1.21	15.06
2	Triangular Chevron nozzle	6	123	1.86	11.68
3	Triangular Chevron nozzle	8	116	1.97	11.69
4	Triangular Chevron nozzle	10	115	2.03	11.38
5	Pallet Chevron nozzle	8	116	2.19	12.94
6	Inverse Chevron nozzle	8	132	2.62	13.15

Table.1 Summary of analysis

From this above table it can be concluded that the increment of Number of Chevron will decrease Acoustic Power level of the nozzle and in this project the NOC = 10 giving the lowest Acoustic power level compared to other nozzles. Hence, this type of chevron nozzle helps in noise reduction.

It is observed that the static pressure of chevron nozzle attains the optimum condition similar to the baseline round nozzle with minor variation. From Acoustic power level analysis, it can be concluded that Chevron nozzle has less value at the exit compared to the baseline nozzle. It is concluded that Chevron nozzle produces less noise compared to Base line nozzle and hence can be used in Jet engines with effective noise reduction.

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