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Subsonic Jet Noise Mitigation using Distinct Nozzle Configuration

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Abstract: Harmful noise effect produced by an aircraft in flight is an issue of enormous environmental, financial and technological impact. A significant contributor to the overall noise of an aircraft is the jet noise induced by high turbulence downstream the nozzle leading to flow instability due to pressure fluctuations. With the growing demand of high thrust output from the aircraft engine in addition to the minimal fuel input jet noise is one of the major restricting factors for aircraft operation since it has a profound influence on the communities surrounding the airport. However the challenge in reducing jet noise is to actually reduce noise while attaining tolerable impacts on performance, weight, operability and manufacturability of the engine.

This project mainly focuses on jet noise reduction by implementation of chevron nozzle. Chevrons are the saw tooth patterns placed circumferentially along the nozzle exit and they enhance the acoustic performance of the nozzle. Parameters that reveal the acoustic characteristics of the flow are Turbulent kinetic energy (TKE) and mean axial velocity. Acoustic results obtained with chevrons are compared with the conventional convergent nozzle. In the present context, the conventional axisymmetric single flow nozzle without an external plug is analyzed. The dimensions of this nozzle are taken from an acoustic study carried out at the NASA John H. Glenn Research Center.

Keywords: TKE(Turbulent kinetic energy), chevron, Acoustic power level, ANSYS-Fluent, Noise Reduction, Jet Noise.

1 Introduction

Sound is the energy produced due to vibration of objects. This energy travels outward from the sound source in the form of a wave, making the objects and the air around vibrate. However, Noise is unwanted sound that may result in disturbance and annoyance. Aircraft noise can be defined as the aggregate of noise produced by various components of the airframe and engine of the aircraft and the aircraft itself. It is a highly technical and complex subject matter which has been studied for decades and is only getting worse with the continuing growth in air travel.

Aircraft noise is caused by wake turbulence created by the airflow around the aircraft fuselage and wings and noise generated from engine components such as rotor blades, exhaust nozzle etc. Dominant sources of aircraft noise can be can be grouped into two main categories mainly airframe noise and engine noise. Airframe noise can be defined as the aerodynamic noise generated by all the non-propulsive components of an aircraft. The components that contribute to the engine noise are turbo-machinery present inside the engine i.e. fan, stator, rotor, mechanical shaft etc. and turbulent mixing of exhaust gases that results in jet noise. When a fluid flows as a jet into a stagnant or relatively slower moving background fluid, the shear formed between the moving and stationary fluids results in a fluid-mechanical instability that causes the interface to disintegrate into vortices. Passive control can be accomplished by modifying the shape of the nozzle that results in enhancement of jet mixing by generating stream-wise vortices.

The flow pattern within the conventional convergent nozzle depict large pressure fluctuations which can be minimized by implementation of chevron. Chevrons are, triangular serrations, placed circumferentially along the nozzle that aim to reduce low speed noise. These patterns strengthen stream-wise vortices, ensure fast mixing of fan, core and ambient air, reduce peak turbulent energy which ensure reduction of jet noise.

Here, we have used some types of different chevrons configurations at trailing edge of the subsonic nozzle in order to reduce the maximum possible noise.

2 Objective

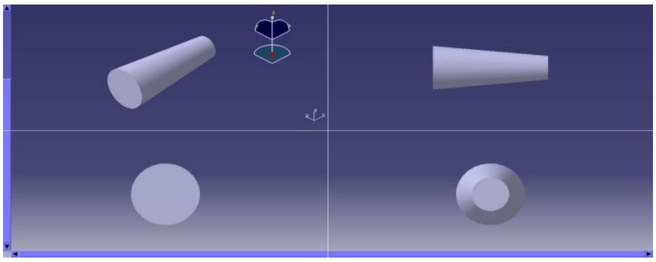
Several studies have been done to understand how the geometric characteristics of chevrons affect the resulting noise from the nozzles. While these have shown how chevron penetration into the flow and the number chevrons, and different designs of the chevrons together affect the turbulence in the jet flow.

3 METHODOLOGY

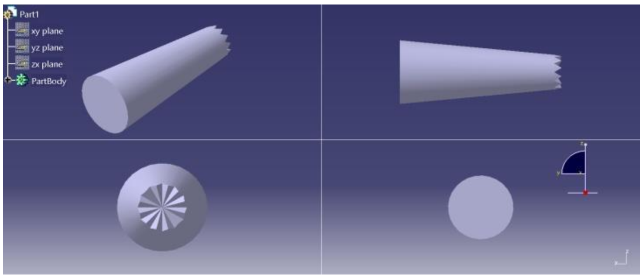
Extensive study of existing literature on experimental analysis of reduction of noise through convergent nozzles has been done. Nozzle geometry, flow and boundary conditions have been drawn on the basis of the literature survey. Creation of three-dimensional geometry of the nozzle is done using CATIA V5R17 and meshing has been done using ICEM CFD. Simulation is carried on ANSYS FLUENT 14.5 software. Mesh quality has been checked. Post processing features of ANSYS FLUENT 14.5 are used to generate static pressure, and velocity, turbulent intensity, acoustic power level contours for all cases.

3.1 3-D models

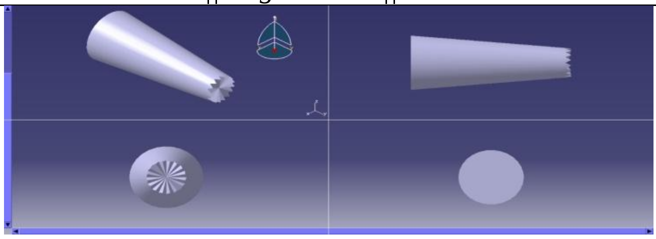
Particulars	Dimension
Inlet width (Diameter) (mm)	55.035
Exit width (Diameter) (mm)	30
Convergent Length (mm)	130.6
Convergent angle (degree)	5.5
Nozzle length (mm)	130
Chevron Length (mm)	10.64
Chevron Penetration (degree)	2.5
Chevron Apex Angle (degree)	30

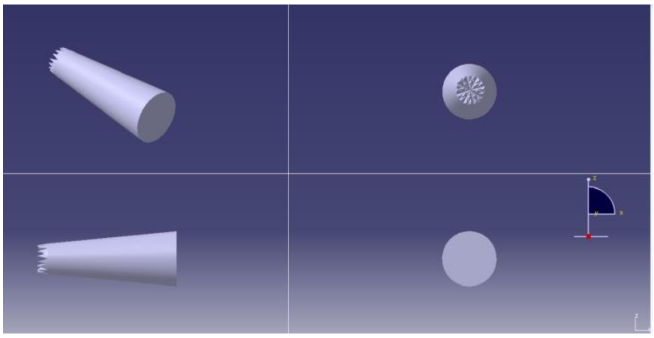


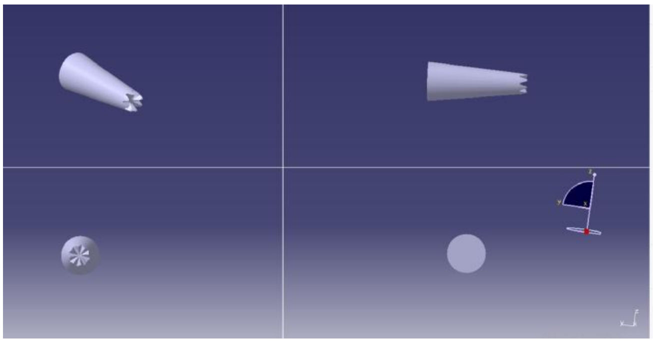
Model of No_Ch_130



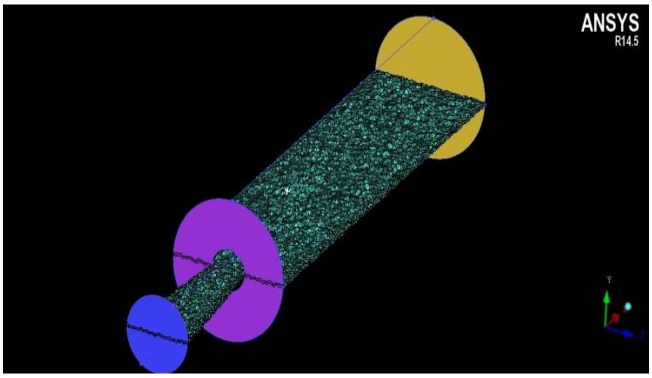
Model of Ch_130_12


Model of Ch_130_16


Model of Ch_130_8_M-Lobbed

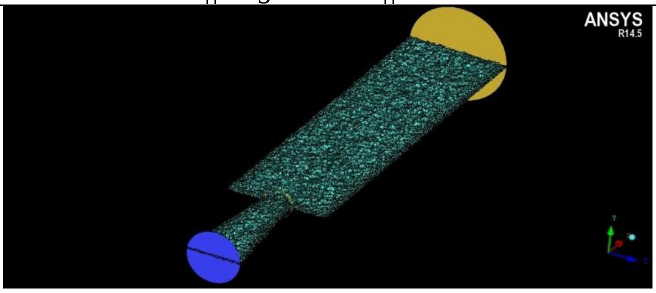

Model of Ch_130_8_Sino

3.2 volumetric mesh



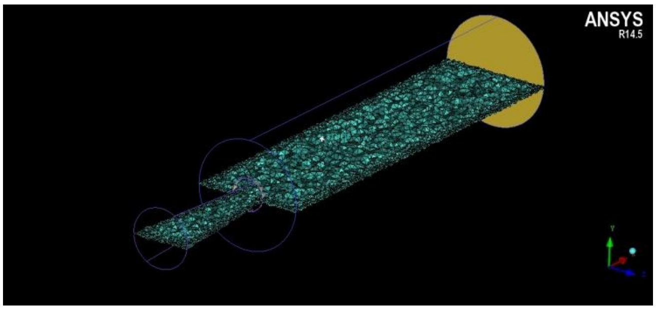
Volumetric Meshing of No_Ch_130

Total number of nodes: **217083**
Total number of elements: **1247936**



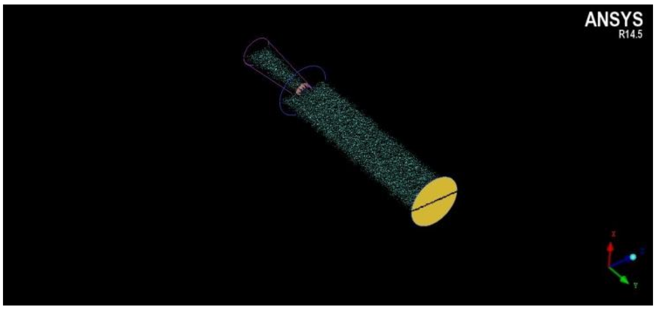
Volumetric Meshing of Ch_130_12

Total number of nodes: **199283**
Total number of elements: **1142141**



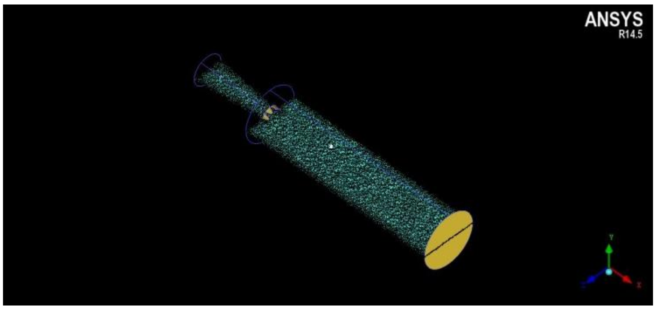
Volumetric Meshing of Ch_130_16

Total number of nodes: **193317**
Total number of elements: **1106130**



Volumetric Meshing of Ch_130_8_M-Lobbed

Total number of nodes: **198357**
Total number of elements: **1136423**



Volumetric Meshing of Ch_130_8_Sino

Total number of nodes: **184970**
Total number of elements: **1056277**

4 Boundary Conditions

Inlet – Pressure inlet boundary conditions are used at the inlet of the nozzle.
Wall – Stationary Wall with No Slip Condition is used at the wall.

Outlet - Pressure outlet boundary conditions are applied to the outlet.

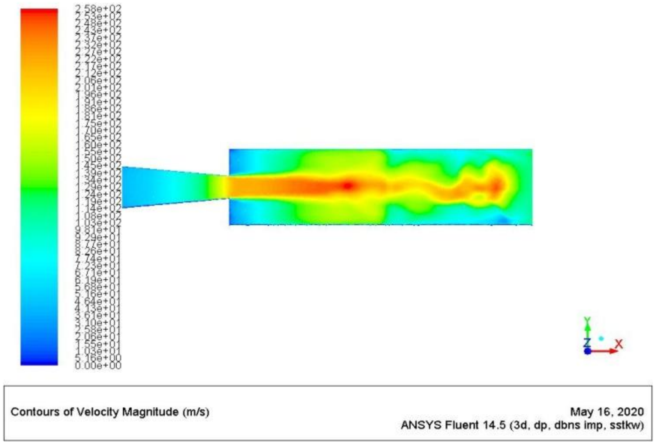
The boundary conditions described for flow through the Convergent nozzle in the process are as given below:

The Nozzle inlet is taken as the pressure inlet,
Gauge Total Pressure (Pa):500000 Pa
Temperature (Ti) =300 K

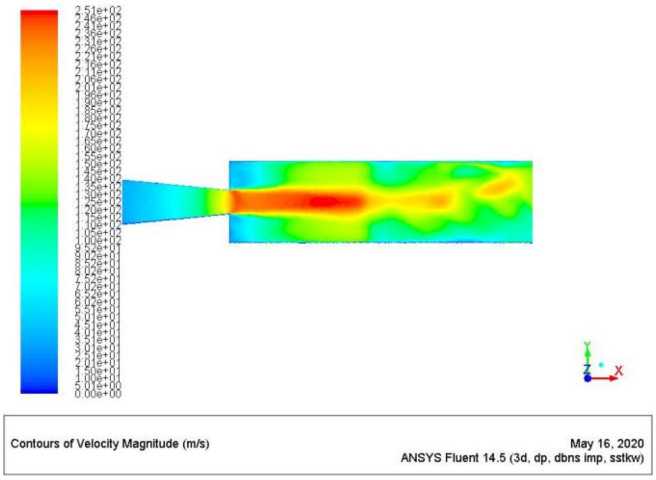
Implicit method we have used here ,since it is much more stable and longer time step can be implemented.

5 Result and Analysis

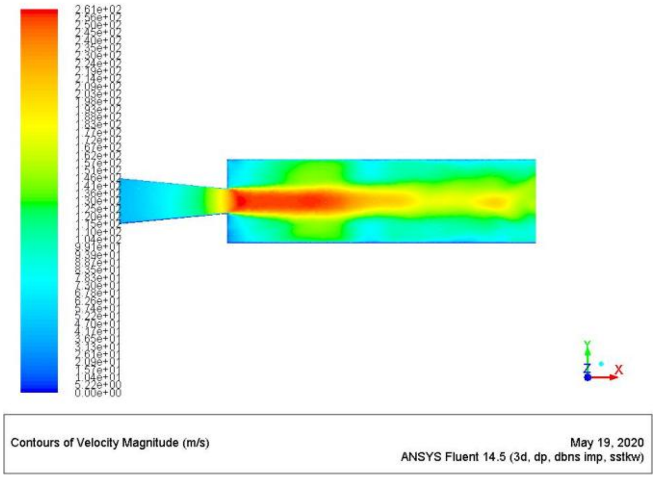
5.1 velocity contours



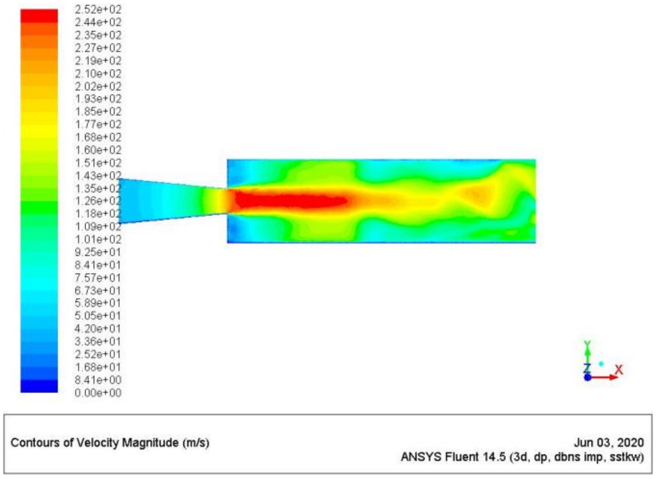
Velocity Contour of No_Ch_130 Nozzle



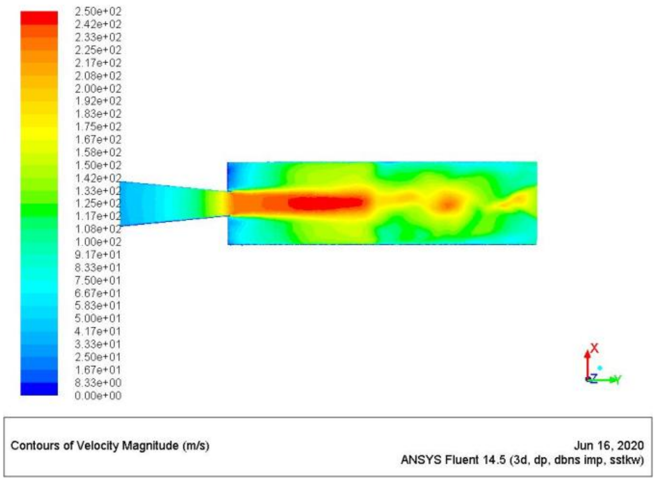
Velocity Contour of Ch_130_12 Nozzle



Velocity Contour of Ch_130_16 Nozzle

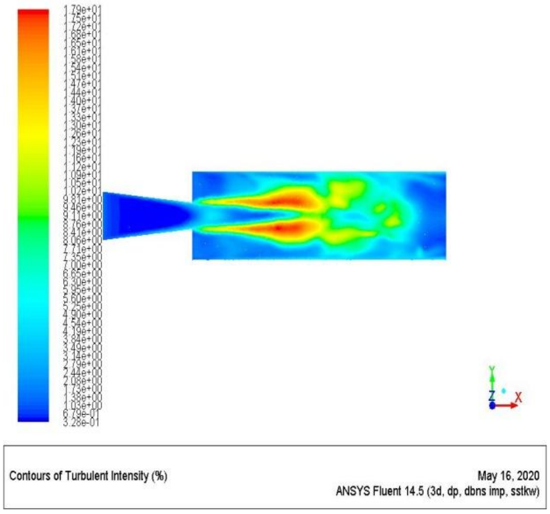


Velocity Contour of Ch_130_8_Sino Nozzle

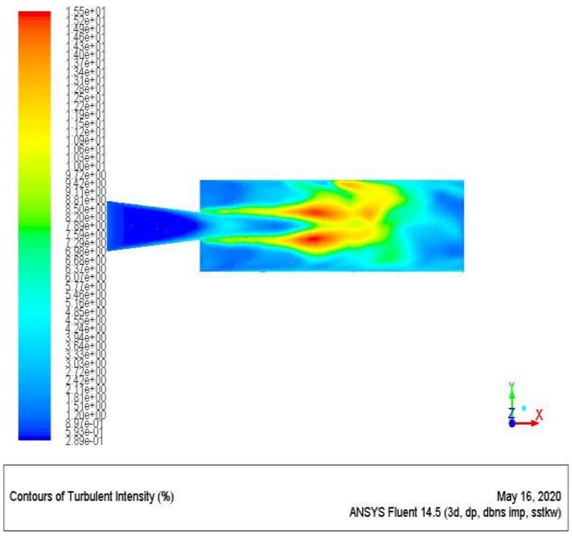


Velocity Contour of Ch_130_8_M-Lobbed Nozzle

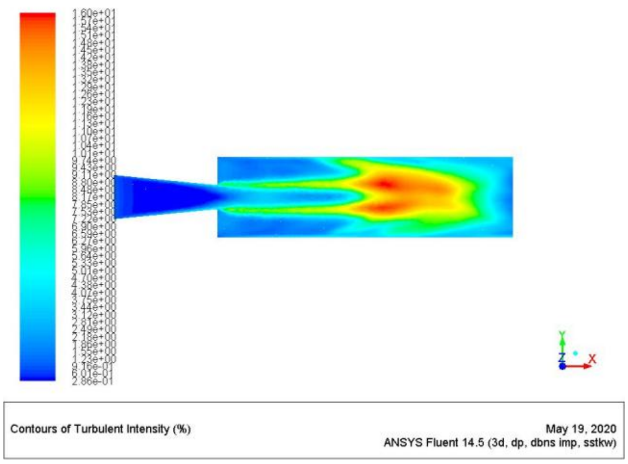
5.2 Turbulent Intensity Contours



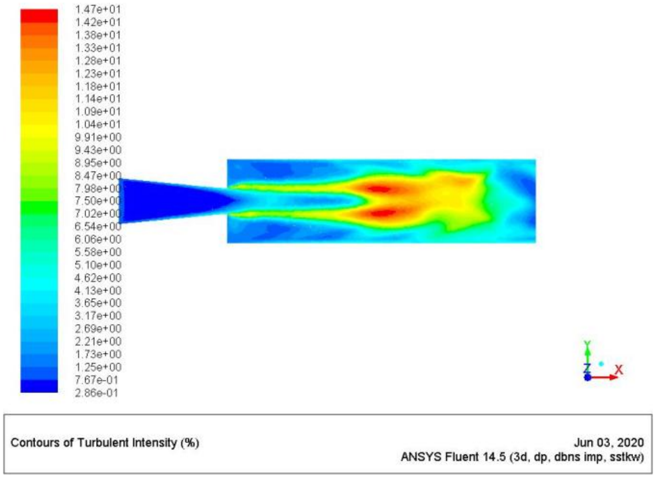
Turbulent Intensity Contour of No_Ch_130 Nozzle



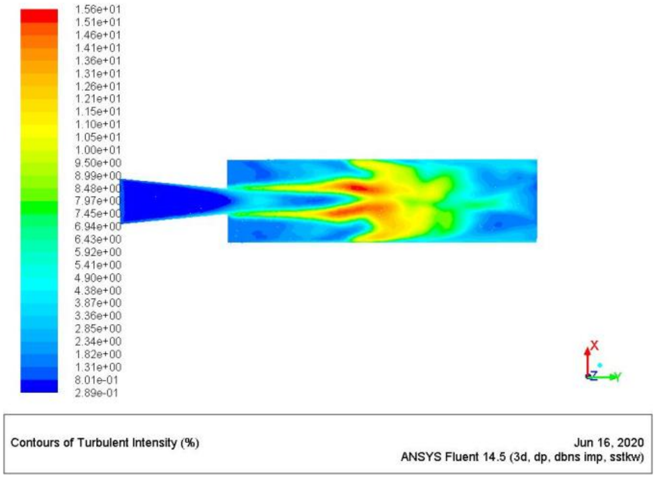
Turbulent Intensity Contour of Ch_130_12 Nozzle



Turbulent Intensity Contour of Ch_130_16 Nozzle

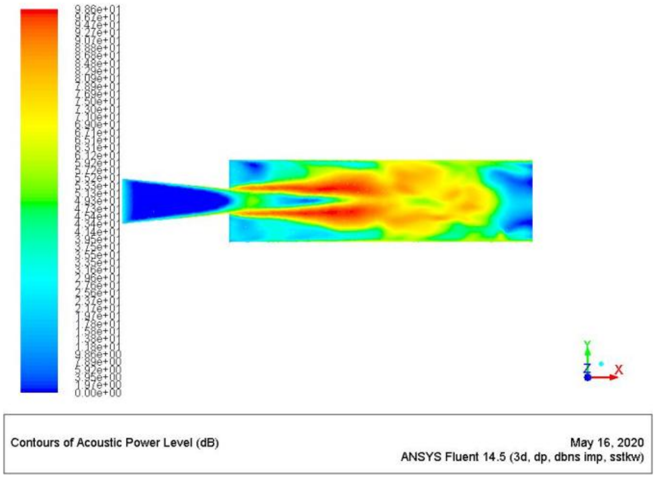


Turbulent Intensity Contour of Ch_130_8_Sino Nozzle

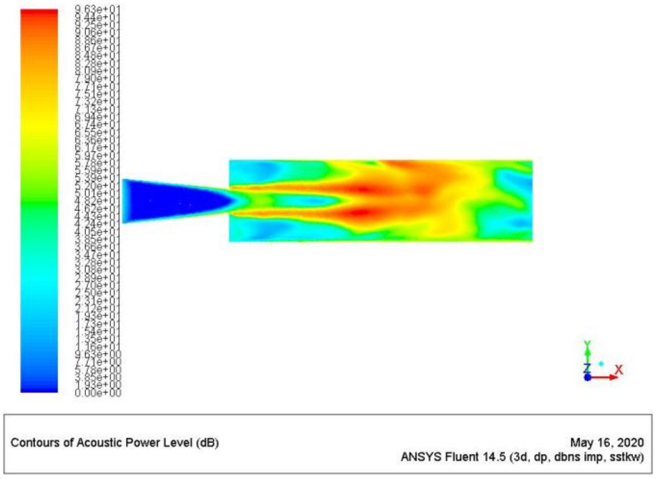


Turbulent Intensity Contour of Ch_130_8_M-Lobbed Nozzle

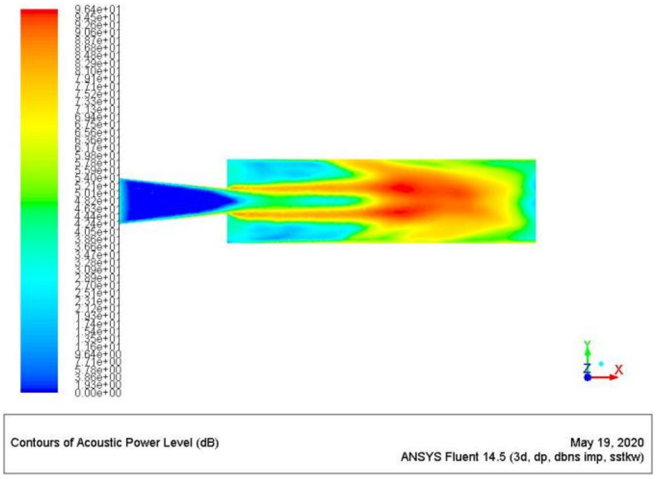
5.3 ACOUSTIC POWER LEVELS (dB) CONTOURS



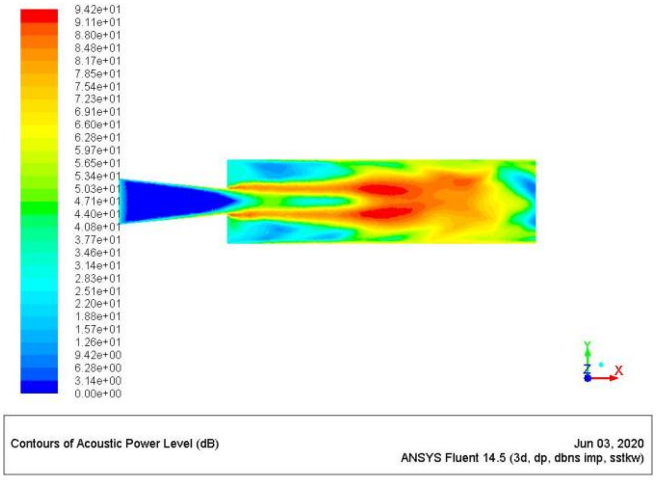
Acoustic Power Levels of No_Ch_130 Nozzle



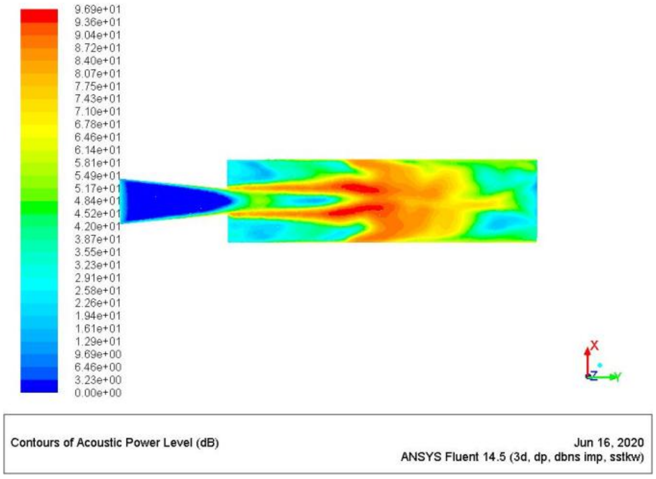
Acoustic Power Levels of Ch_130_12 Nozzle



Acoustic Power Levels of Ch_130_16 Nozzle



Acoustic Power Levels of Ch_130_8_Sino Nozzle



Acoustic Power Levels of Ch_130_8_M-Lobbed Nozzle

6 Conclusion

It is very difficult to reduce jet noise without impacting engine performance negatively. Chevrons are unique, as a jet noise reduction technology, in that they can have a relatively small impact on weight and performance. From the velocity contours, it is evident that addition of chevron configuration to the nozzle does not significantly impact the nozzle exit velocity, hence there is minimal impact on nozzle performance.

It is evident from the contours of Turbulent Intensity that the Turbulent Intensity of chevron nozzle is less than the baseline nozzle, this is due to proper mixing of hot air from the nozzle and relatively cold air of the atmosphere.

The acoustic power level of different type of nozzle is shown by below table:

Nozzle type	Acoustic Power Level in dB
Baseline(NO_CH_130)	98.6
Nozzle with 12 chevrons(CH_130_12)	96.3
Nozzle with 16 chevrons(CH_130_16)	96.4
Nozzle with sinosoidal type of chevron(CH_130_8_SINO)	94.2
Nozzle with M-lobbed type of chevron(CH_130_8_M-LOBBED)	96.9

Table 6.1: Acoustic Power Level of Different Types Of Nozzle

From obtained data we can say that among all nozzle the most effective nozzle is nozzle with sinosoidal type of chevrons, because nozzle with sinosoidal type of chevrons is producing about 94.2 dB of noise which is 4.4 dB less than that of baseline nozzle, that is 98.6 dB.

Hence we can say that adding the chevron configuration to the nozzle results in reduction in significant amount of noise with minimal or no effect on engine performance.

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