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Numerical Investigation of Lobe Design in Modification in Chevron Nozzle for Noise Reduction

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Abstract: This research study is focused on the design optimization of aircraft engine nozzle to reduce noise intensity by modifying the lobe design in chevron and has been made in this research study to investigate the flow field in lobes by varying the nozzle designs. The project mainly focuses on the reduction of jet noise emission in the exhaust nozzle of turbofan engines. Numerical analyses have been carried out on various configurations of chevron nozzle to assess the importance of chevron parameters. The sound pressure level can be calculated, from that we determined the noise level at nozzle exit section. After assessing the chevron parameters, we are going to modify the chevrons in order to get maximum noise reduction along with very negligible thrust loss. ANSYS-Fluent is a commercial Computational Fluid Dynamics code which will be used for performing the simulation with five different nozzle models-plain and chevron nozzle. The simulation results are evaluated in order to be able to discover the design of chevron nozzle regarding the acoustic power level emitted.
Keywords: Chevron Nozzle, Acoustic Power Level, Sound Pressure Level, ANSYS-Fluent, Fluid Dynamics

I. INTRODUCTION

Aircraft noise is a huge environmental, financial, and technological problem. In today's commercial aircraft engines, there are two primary sources of noise: fan / compressor noise, and jet noise. Flight noise consists of turbulent mixing noise, and shock noise in the case of imperfectly extended jets. Turbulent mixing noise is very difficult to regulate and due to the mixing of air streams at various temperatures and speeds turbulent mixing is induced by eddy formation. Outside air and high velocity engine gasses normally result in eddies. Today's jetliners are slightly more powerful and quieter compared with 1960s and 1970s commercial jet liners. Jet noise involves turbulent mixing which is very hard to monitor. It is caused by air stream mixing at dissimilar velocity and temperature. The ambient air and the high speed of gas around the engine appear to increase the creation of the eddy. Aircraft noise pollution is a noxious effect created during the various phases of a flight by any aircraft or its components. Sound processing is composed of three categories:

A. Engine and other industrial emission
B. Emission from aviation devices

A moving aircraft like the jet engine or propeller causes air friction and rarefaction, allowing air molecules to pass. This movement propagates like waves of energy through the air. If these pressure waves are intense enough and a sensation of hearing is produced within the audible frequency spectrum. Different types of aircraft have different noise and frequency levels. The noise comes from three primary sources:

1) *Engine And Other Mechanical Noise:* Most of the noise in propeller aircraft comes from the aerodynamics and propellers alike. Helicopter noise is noise from the main and tail rotors that is aerodynamically induced and mechanically induced from the main gearbox and various transmission chains. The mechanical sources emit high-intensity narrow band peaks related to the rotational speed and movement of the moving pieces. Engines are the primary source of noise from aircraft. The Pratt & Whitney PW1000 G gearbox helped to minimize the noise levels of the Bombardier C Series, Mitsubishi MRJ and Embraer E-Jet E2 narrow body aircraft: the gearbox enables the fan to rotate at maximum speed, which is one third of the LP turbine speed., for slower fan tip speeds. It has a noise footprint 75 per cent smaller than traditional equivalents. The Power Jet SaM146 in the Sukhoi Super jet 100 features 3D aerodynamic fan blades and a nacelle with a long mixed duct flow nozzle to reduce noise.

2) *Aerodynamic Noise:* Aerodynamic noise occurs from the airflow and control surfaces around the fuselage of an aircraft. Because of the air density this form of noise increases with aircraft speed and even at low altitudes. Jet-powered aircraft produce powerful aerodynamic noise. Military low-flying, high-speed aircraft produce especially noisy aerodynamic noise. The shape of an aircraft's nose, windshield, or canopy influences the sound produced.

a) *Bluff Body Noise:* The alternating vortex shedding from either side of the bluff body produces low-pressure regions (at the center of the shed vortices) that manifest as pressure (or sound) waves. The separate flow across the bluff body is very chaotic, and the flow "rolls up" into ring vortices — which then break down into turbulence

b) *Edge Noise:* As turbulent flow reaches an object's end or gaps in a structure (high lift system clearance gaps) the resulting pressure waves are heard as the sound propagates from the object's edge (radially downward).

3) *Noise From Aircraft Systems:* Cockpit and cabin ventilation and cooling systems are also a significant contributor inside civil and military aircraft cabins. Nonetheless, one of the most important sources of commercial jet aircraft cabin noise, other than engines, is the Auxiliary Power Unit (APU), an on-board generator used by aircraft to fuel the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Certain internal aircraft systems, such as advanced electronic equipment, can also apply on certain military aircraft. Aircraft engines are the key source of noise during take-off, which can reach 140 decibels (dB).

4) *Technological Advances:* Modern high bypass turbofans are not only more fuel efficient but also much quieter than older turbojets and turbofan engines with low bypass. On newer engines noise- reducing chevrons further decrease the noise of the engine while on older engines the user of hush kits is used to help reduce their unnecessary noise.

a) *Acoustic Liner*: One effective method of further minimizing noise is to absorb the sound produced inside the engine, also in ultra-high bypass ratio engines. Acoustically absorbent material or acoustic liners may be mounted on the engines' interior surfaces. The use of acoustic liners is possibly the most common passive approach for noise reduction. The liners absorb the radiated acoustic energy, thereby raising the noise levels on the far field.

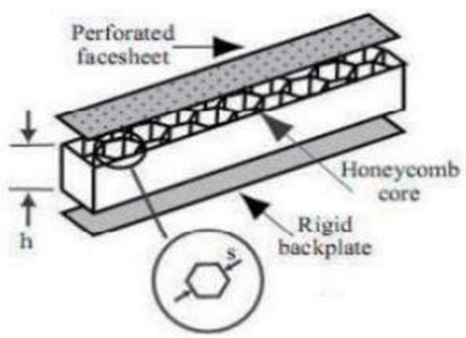

Fig 1.4.1: Schematic of Acoustic Liner

b) *Nano Technology:* It is one of the biggest inventions and has brought drastic change to all kinds of industry. Nano material is also used in various sectors of the aviation industry due to its multifunctional characteristics such as low weight, availability, eco-friendly and lower fuel consumption. Nano material also has other properties such as highly sensitive communication network, minimum repair criteria. Nano material is very useful in reducing noise in an aircraft's exhaust nozzle given all of the above properties. Nano materials have a high density (high strength) property along with very low weight, so if an aircraft's exhaust nozzle is made of the material Nano, And there is a risk that full noise would be absorbed inside the aircraft nozzle.

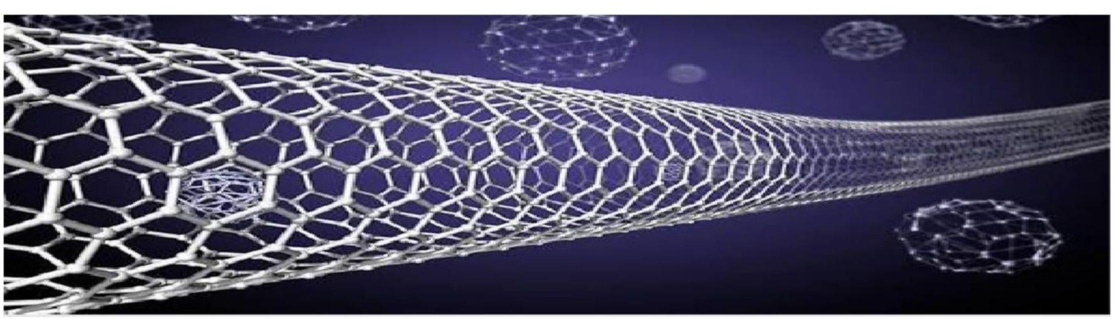

Fig 1.4.2: Nano Technology

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c) *Aircraft Engine Configuration:* If we further increase the length of the tail pipe longitudinally in an aircraft's engine after the nozzle portion then the exhaust jet will not be exposed directly to the atmosphere but will pass through the extended section. The density of the extended part will suppress much of the noise when going through this section. In turbofans both the hot jets and bypass air receive the thrust. Hot jet travels through the traditional jet engine and via annular nozzle into the cold wind. If the bypass ratio ((β=c / alpha) is increased by a certain amount and combined with the hot stream collected from the generator, the total exhaust gas energy can be decreased by a few, then the overall energy of exhaust gas can be reduced by some amount so that the jet noise of the aircraft can be reduce.

d) *Implementation Of Chevron Nozzle:* At the end of the nacelle, Chevrons are zigzag or raw tooth shapes, with tips that bend very slightly into the flow, and are introduced on modern jet engines. The technology has the potential to reduce turbulent mixing noise, which for most aircraft is the dominant component of jet noise; The triangular cut outs made along the trailing edge of the nozzle induce stream-wise vortices into the shear layer leading to increased mixing and reduced jet plume length, Hence the chevrons enhance mixing by the right amount and the total jet noise reduces. The chevrons make the sound increase, if the mixing is too much. No noise reduction benefits are achieved when mixing is too low. The nozzle allows the core and bypass flows to miss in a way that reduces low frequency mixing noise from highly turbulent flows.

5) *Theoretical Back Ground Of Trailing Edge Serration:* Serrations of seven owl species were examined on the full wings and on the tenth primary remiges. Small, medium, and large owl species were studied, as were species that were more active during the day and owls that were more active during the night. Serrations occurred in the outer parts of the wings, mainly at the 10th primary remiges but also in most species on more wing feathers. Serration tips were focused away from the feather rachis so they faced in during flight into the air stream. The serrations of nocturnal owl species were formed higher, as shown by a wider angle of inclination (the angle between the base of the barb and the rachis), a wider angle of displacement of the tip

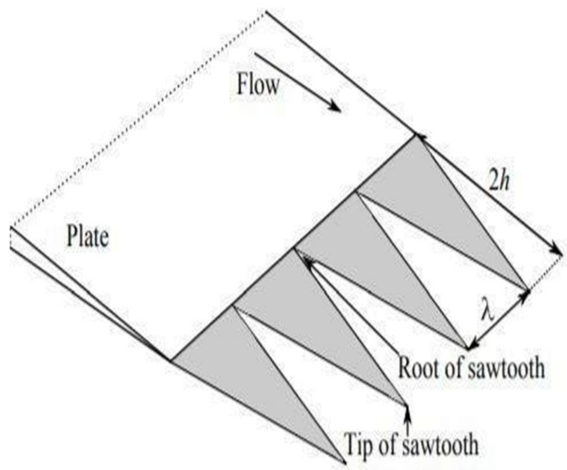

Fig 1.5.1 Trailing edge serration

II. DESIGNING PROCESS

A. CATIA

CATIA is an acronym for Three-Dimensional Interactive Machine Aided Use. It is one of the leading 3D applications companies using in various industries from aerospace, automotive, to consumer goods. CATIA is a multi-platform 3D software suite developed by Dassault Systems which includes both CAD, CAM and CAE. Dassault is a French airline, 3D modeler, 3D digital mock-up and product lifecycle management (PLM) software engineering firm. CATIA is a powerful modeling tool which combines 3D parametrics with 2D tools and addresses any design-to-production process.

CATIA also provides spell, sectional, auxiliary, isometric and 2D drawing views for generations during the construction of solid models and assemblies.

It is possible to establish the model dimensions and to define reference dimensions in the drawing views. CATIA's bidirectional associatives ensure that the improvements made to the layout are reflected in the views of the drawings and vice versa. CATIA provides the ability to display 3D prototypes.

This idea was groundbreaking when implemented. As Dassault Systems lacked marketing skills, it had a sales-sharing relationship with IBM, which was extremely successful for both companies to sell CATIA.

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B. Designing Parameters

1) Design 1: Base Line Nozzle (The Existing Nozzle Design)

Baseline nozzle without any serrations is taken as the base model for comparison. A simple convergent nozzle design with the required dimensions as specified is designed in Catia. Most of the modern commercial aircrafts such as Airbus A320,A321,A350,A380 and Boeing 747,777 are still using such a nozzle design.

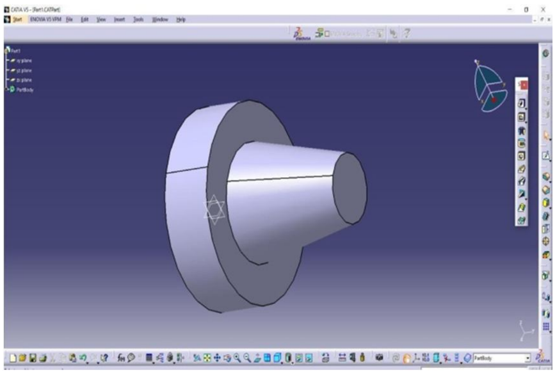

Fig 2.2.1.A: Base Line Nozzle (The Existing Nozzle Design)

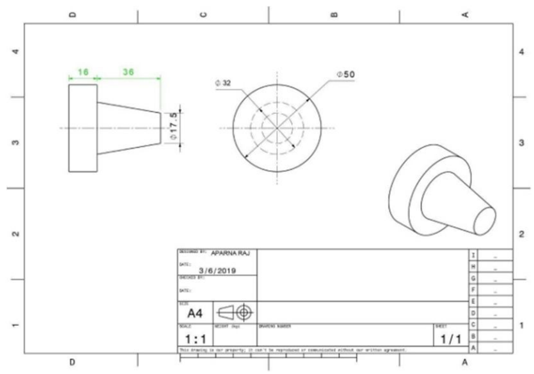

Fig 2.2.1.B: Isometric View of design 1

2) Design 2: Chevron Nozzle With V-Shaped Serration

The existing chevron nozzle design with V shaped serrations are designed with 6 lobes each with a lobe length of 8.87 mm and lobe angle 40^0

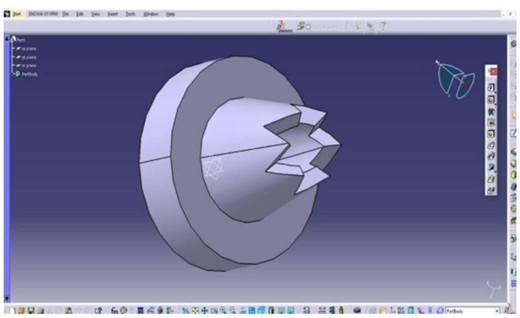

Fig 2.2.2.A: Chevron Nozzle With V-Shaped Serration

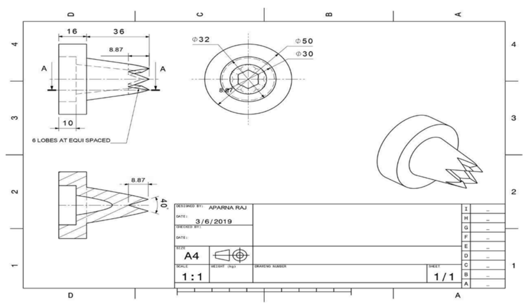

Fig 2.2.2.B: Isometric View of design 2

3) Design 3 Chevron Nozzle With Sinusoidal Serration

Chevron nozzle with sinusoidal serrations are most commonly used in passenger aircrafts such as Boeing 747-8,787 8Max for noise reduction purposes. They produce comparatively lesser sound decibels than the existing baseline nozzle design.

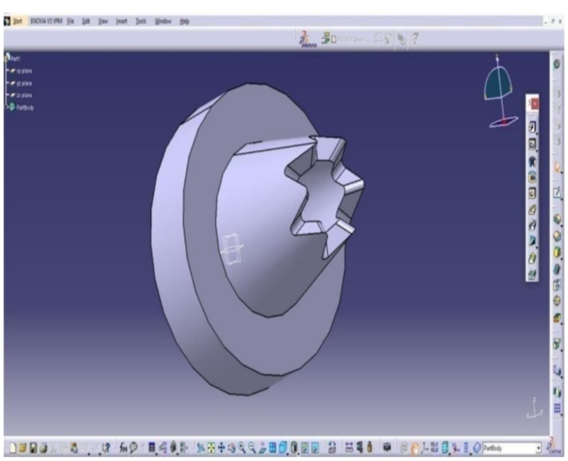

Fig 2.2.3.A :Chevron Nozzle With Sinusoidal Serration

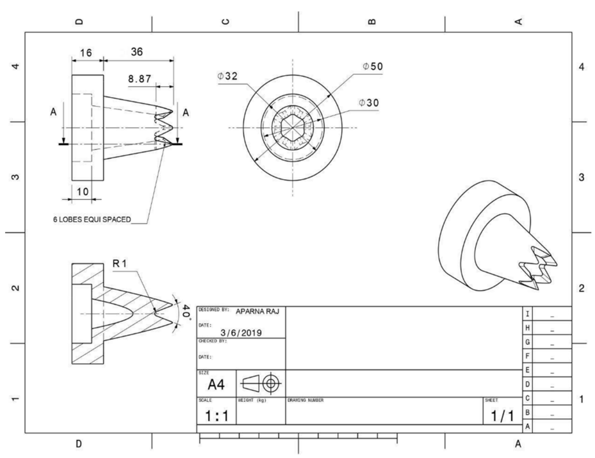

Fig 2.2.3.B : Isometric View of design 3

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4) Design 4 :M-Lobed Chevron (Sharp Edged)

M-shaped chevron with sharp edge cuts is the newly designed model with a lobe angle of 40 degrees and lobe length 8.87 mm. M shaped lobe with sharp edge patterns contains larger pressure accumulating points than the existing nozzle design.

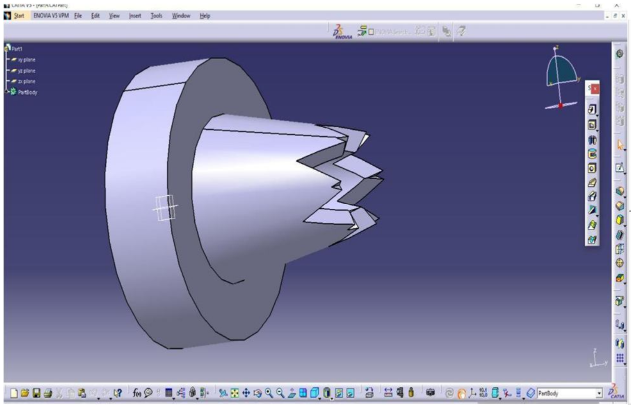

Fig.2.2.4.A: M-Lobed Chevron with Sharp Edged

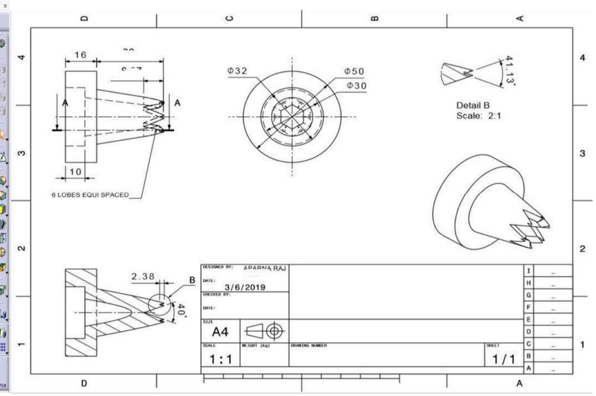

Fig 2.2.4.B : Isometric View of design 4

5) Design 5 :M-Lobed Chevron With Sinusoidal Curve

M-shaped chevron with sinusoidal curves is the new adopted design modification implemented through the project for the detailed study of acoustic level performance and to carry out the comparative study of different nozzle designs with reduced noise level performance.

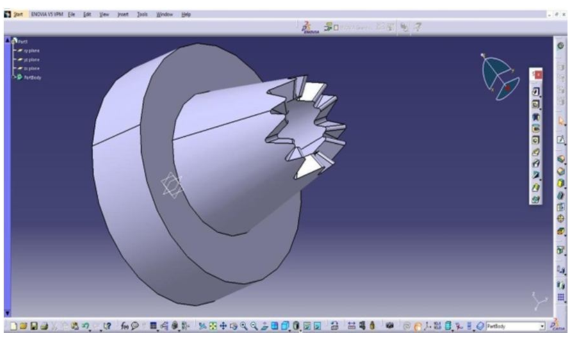

Fig.2.2.5.A: M-Lobed Chevron with Sharp Edged

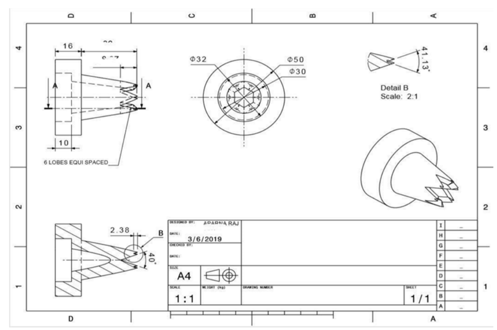

Fig 2.2.5.B : Isometric View of design 4

III.MESHING AND ANALYSIS

A. ANSYS

Ansys Inc. is a Canosburg, Pennsylvania-based public company. It designs and markets engineering simulation software. Ansys software is used to design materials including semiconductors, including simulations that check the longevity, temperature distribution, and electromagnetic properties of a component.ANSYS is a solid collection of computer fluid dynamic devices included in the Ansys CfD Package, simulation of the fluid flow and other physical events associated with it. Ansys develops and markets tools to model engineering problems for end-to-end aspect analysis. The software creates virtual computer models of structures, electronics or device components to simulate strength, resilience, elasticity, temperature distribution, electro magnetism, the liquid flow and other attributes. Ansys is used to determine whether a product can work without test goods manufacturing or crash testing with specific specifications.. For instance, Ansys software may simulate the best way to process salmon in a canery to minimize wastage, or how to create a diapositive that uses less material without compromise security after years of traffic..

B. Meshing

Ansys meshing is a smart, digital, general-purpose tool. It provides the most suitable mesh for accurate, effective multiphysical solutions. A well-suited mesh can be created in all sections of a model by a single mouse click. The professional user who wants to change the mesh is able to take full control over the options used to create the mesh. Parallel processing power is used to decrease the time you need to anticipate mesh generation.

The foundation of engineering simulations is to build the most suitable mesh. ANSYS Meshing knows what technologies the project must employ, and has the right standards for producing the most suitable mesh. Within the ANSYS Workbench framework ANSYS Technology is automatically integrated with each solver. A functional mesh can be generated with one click of the mouse for a fast review, or for the new and infrequent user. ANSYS Meshing uses the most appropriate solutions, based on model form of analysis and geometry. ANSYS Meshing is aware of the type of solutions to be used in the project and has the correct standards for making the most suitable mesh. Inside the ANSYS Workbench environment, For a fast analysis, or for the new and infrequent user, a functional mesh can be created with a single click of the mouse. ANSYS Meshing's ability to automatically take advantage of the available cores on the device to use parallel processing and thereby dramatically reduce the time to create a mesh is especially handy. Parallel meshing is possible without extra criteria for costs or licenses.

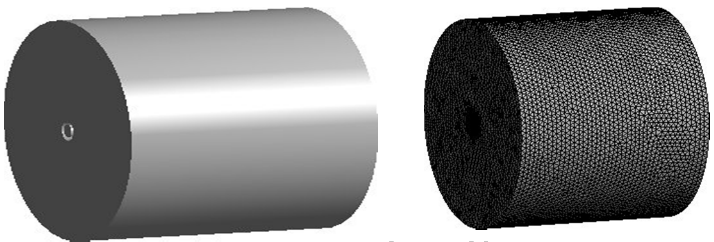

Fig 3.2 : Flow Field Domain

IV.RESULTS AND DISCUSSION

ANSYS CFX, a CFD software kit, practically analyzed the baseline nozzle model and the chevron nozzle models produced by CATIA V5R20. Tests are obtained in ANSYS CFX applications on the orkbench platform. As convergence is an iterative process, the CFX solver conducted successive iterations to obtain the distribution of pressure, the distribution of velocity. Acoustic characteristics have been studied for the main flow parameters namely strain, velocity to find the most efficient chevron form. The result of the CFX solver was taken from the CFX-post (test) in the CFX method, namely the pressure distribution and the velocity distribution.. The process is repeated for further simulation of the successive four versions. Pressure distribution of the four types of nozzle models is shown below in Figure From the above pressure and velocity distribution of the four types of nozzle models as shown in Figure 1 and Figure 2, it is apparent that speed is approximately the same for all nozzles with different pressure values at the end of the nozzle due to the lobe design modification.

1) *Model 1:* The contours of pressure magnitude for model 1(Base line nozzle) as shown below.

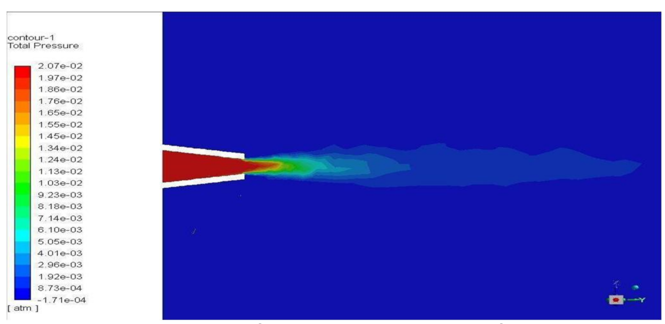

Fig 4.2 : The contour of acoustic power level for model 1

2) *Model 2:* The contour of pressure magnitude for model 2 (Chevron nozzle with V- shaped serration) as shown below.

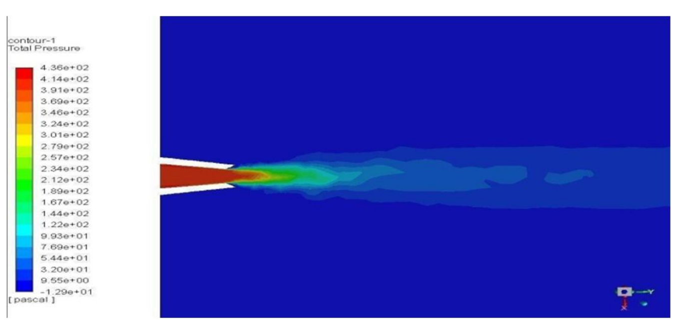

Fig 4.3 : The contour of pressure magnitude for Model 2

3) *Model 3:* The contour of pressure magnitude for model 3(V-shaped Chevron nozzle with sinusoidal serration) as shown below.

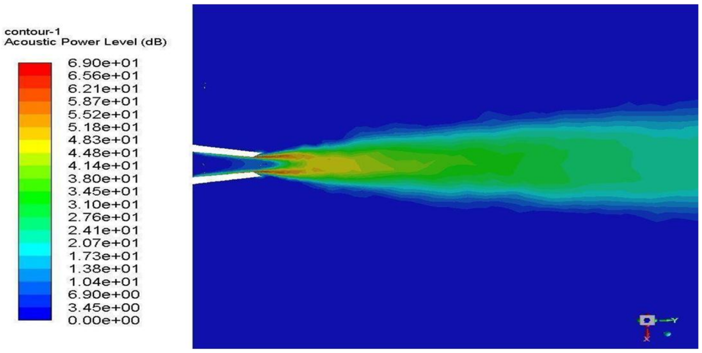

Fig 4.4 : The contour of acoustic power level for model 3

4) *Model 4:* The contour of pressure magnitude for model 5 (M-lobed Chevron nozzle with sinusoidal serration) as shown below.

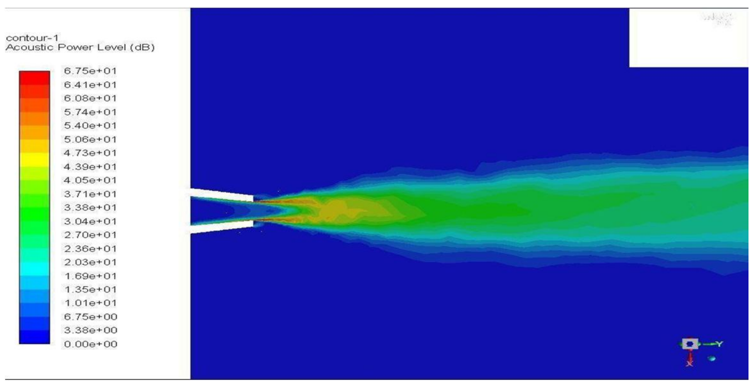

Fig 4.5: The contour of acoustic power level for model 4

V. CALCULATION

MODEL 1
Acoustic power level obtained (SWL) : 89dB
Sound pressure level (SPL) = 89- [10 log(1/4ε1)] = 99.99 dB

MODEL 2
Acoustic power level obtained (SWL) : 74.2dB
Sound pressure level (SPL) = 74.2- [10 log(1/4ε1)] = 85.19 dB

MODEL 3
Acoustic power level obtained (SWL) : 69 dB
Sound pressure level (SPL) = 69- [10 log(1/4ε1)] = 79.99 dB

MODEL 4
Acoustic power level obtained (SWL) : 74.11 dB

Sound pressure level (SPL) = 74.11- [10 log(1)] = 85.10 dB

MODEL 5
Acoustic power level obtained (SWL) : 67.5 dB

Sound pressure level (SPL) = 67.5- [10 log(1)] = 78.49 dB

VI. CONCLUSION

Acoustic power level values and sound pressure levels of all five nozzle designs are calculated and it is found that M-shaped lobe with sinusoidal curve is the most efficient nozzle design in terms of noise performance level. M-shaped sinusoidal lobe produces comparatively lesser noise as compared to other design modifications taken under the specified conditions. M shaped sinusoidal lobe produced 21.5 dB lesser noise in terms of SWL and 21.5 dB lesser noise in terms of SPL, as compared to the existing baseline nozzle. The percentage reduction in sound was found to be around 24.15. Chevron nozzle with sinusoidal curve was found to be the second efficient design in terms of noise reduction. They created 20 dB less sound than the baseline model, and proved to be the most effective model for noise reduction strategies among existing nozzle designs in the aviation industry. M-shaped sinusoidal lobe displays better acoustic efficiency than the current chevron nozzle which is commonly used in Boeing 787 Dreamliner, B777X, B747-800 and B737 max 8. M lobe with sinusoidal serration decreases the sonority by 2,17 percent compared to the current chevron nozzle configuration

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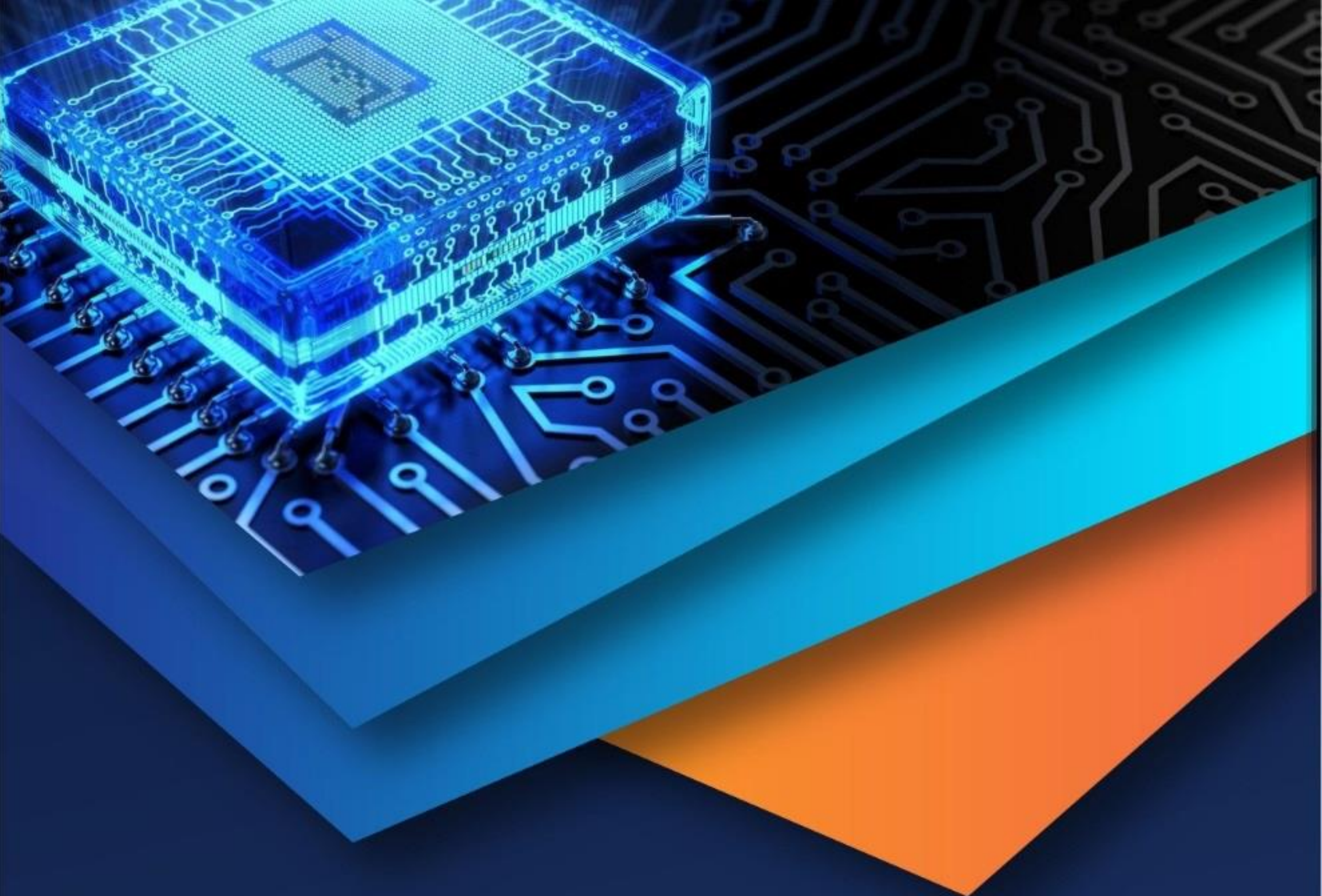

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