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Thermal Analysis and Optimization of Chevron Nozzle using Taguchi Method

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Abstract- One of the most pressing issues in aviation today is noise pollution and the imperative to significantly lessen the noise exposure of communities in close proximity to airports. The most significant times of noise production in aircraft occur during takeoff and landing. The engines of a commercial airliner are typically the loudest parts of the plane. The secondary source is found in the surrounding airflow (aerodynamic source). In this paper thermal analysis and optimization of chevron nozzle using Taguchi method has been done.

Keywords- Chevron nozzle, optimization, Taguchi method, thermal analysis.

I. INTRODUCTION

The Experiments with small, laboratory-scale jets featuring rectangular protrusions near the nozzle output were conducted in the 1980s. 'Tabs' were protrusions that were bent into the flow to reduce the screaming noise made by supersonic planes.

According to Bradbury and Khadem [18], the possible core length of the exhaust was cut down to around two diameters due to the tabs, and then the centerline mean velocity decreased precipitously. The tabs acted as vortex generators, creating pairs of vortices that spiraled streamwise and improved the blending of the jet stream with ambient air. They worked just as well in hypersonic as in subsonic flight [19]. Lighthill's eighth power law predicts that better mixing will lead to slower jets and less jet noise.

The noise produced by jet can be greatly reduced by installing chevron nozzles. Triangular serrations are used at the trailing edge of traditional chevron nozzles. New chevron ideas include asymmetrical chevrons and protrusions with a sinusoidal form. “Jet noise is a critical issue in modern aeroacoustics because to growing environmental awareness and severe noise limits near major airports. During takeoff, when the exhaust conditions may become under expanded, jet noise remains the major noise component.” Improvements in noise prediction methods, deeper knowledge of the mechanics that generate noise, and the exploration of noise reduction technologies are the primary focuses of current jet noise research. There are costs connected with implementing noise reduction measures, and they must be taken into account throughout the design process. Using a chevron nozzle is appealing in this context because of its low cost and easy assembly. Research shows that putting chevrons on the nozzle significantly lowers the SPL with just a little hit to performance. For medium and high bypass turbofan engines, the current state of the art in jet noise reduction technology is Chevron nozzles. Triangular serrations along the nozzle's trailing edge create a whirlpool effect in the shear layer.

The length of the jet plume is shortened as a result of increased mixing. It has been shown by Bridges and Brown [1] that the number of chevrons determines the distance in azimuth between axial vortices, the depth of chevrons determines the intensity of axial vortices, and the length of chevrons determines the distribution of vorticity inside axial vortices. Slope of the chevron edge normal to the jet diameter in the plane normal is the criterion for the vortex strength. If the radius 'r' as a function of arc length's' at the chevron's midpoint describes the chevron edge projected onto the axial plane, then the chevron's local deflection is proportional to = r/s.

The vortex strength parameter is denoted by the value. The flow field, and therefore the creation of noise, is dominated entirely by turbulent mixing for idealized enlarged subsonic and supersonic axisymmetric jets. By reducing the potential core and encouraging more effective mixing of the high-velocity inner jet, chevron nozzles are known to lower peak jet noise. While a number of geometric features, including asymmetry and chevron lobe profile, have been identified, their importance is not yet fully understood.

One of the most pressing issues in aviation today is noise pollution [1] and the imperative to significantly lessen the noise exposure of communities in close proximity to airports. The most significant times of noise production in aircraft occur during takeoff and landing. The engines of a commercial airliner are typically the loudest parts of the plane. The secondary source is found in the surrounding airflow (aerodynamic source) [2].

Fig 1. Chevron nozzle in jet engine.

II. PARAMETERS AND THEIR LEVELS

The Taguchi method uses three processing parameters—tip angle, penetration angle, and number of chevrons—to provide nine different design permutations. One strategy for achieving the target level of performance is optimizing process parameters. The chevron nozzle design is analyzed and improved with the use of the Finite Element Method (FEM). Table 1 displays the recommended values for tip angle, penetration angle, and the number of chevrons based on a literature assessment.

Table 1. Parameters and their levels.

Parameters	Levels		
Tip angle, °C	60	65	70
Penetration angle, °C	5	7	7
Number of chevrons	8	10	12

The number of components and their proper level are specified by the orthogonal array. The design array size is calculated by dividing the entire number of possible factors with the desired number of repetitions. Table 2 displays the nine possible orthogonal arrays that were chosen using the L9's three parameters and three levels.

Table 2. Simulation run layout.

Tip angle	Penetration angle	Number of chevrons
60	5	8
60	6	10
60	7	12
65	5	10
65	6	12
65	7	8
70	5	12
70	6	8
70	7	10

Nine simulations were conducted run in ANSYS CFD with varying parameters based on the simulation design.

III. FEM MODELLING OF CHEVRON NOZZLE

Recent efforts in the field of research have concentrated mostly on finding ways to reduce aircraft noise pollution. The aircraft's engine and nozzle are major contributors to ambient noise levels. The chevron nozzle, with its saw-toothed tip, is widely used in industry to reduce noise levels. The length of the jet plume is shortened thanks to the triangular cutouts at the nozzle's trailing edge. Whereas chevron helps provide optimal mixing and lessens jet noise.

Especially at takeoff, jet noise remains the most noticeable disturbance. There has been a lot of work put into creating effective passive flow control methods for jet noise reduction. There has to be a significant reduction in the associated thrust penalty before these designs can be used in commercial aviation engines.

The addition of chevrons to the nozzle, according to acoustic tests, significantly lowers the sound pressure level while causing just a marginal drop in performance. There is a lack of clarity on the effect of different geometric features of chevrons and the underlying mechanisms responsible for the acoustic advantage they provide. Various flow regimes are being analyzed in terms of chevron lobe number, lobe length, and chevron penetration. Experiments are costly and can only offer a limited amount of information, but they're vital and provide important data for confirming the computations. Therefore, it is preferable to have dependable CFD abilities to rapidly assess prototype ideas for noise abatement.

Solid works was used to create nine different chevron CAD models with varied tip angle, penetration angle, and number of chevrons, which were then imported as IGES files into ANSYS for simulation. Below are 9 CAD Models for your perusal:

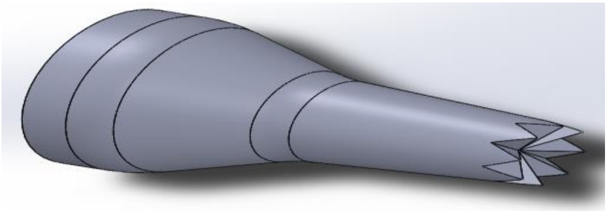

Fig. 2. CAD Model.

1. Meshing:

Meshing is crucial to obtaining an excellent result from your FEA simulation. A mesh is constructed from elements, each of which has nodes (variable coordinate positions in space used to define the form of the geometry). Mesh refinement is performed in order to make the issue amenable to Finite Element analysis. By meshing, the domain may be partitioned into smaller regions, with each region standing in for a different element. Mesh refinement is performed in order to make the issue amenable to Finite Element analysis.

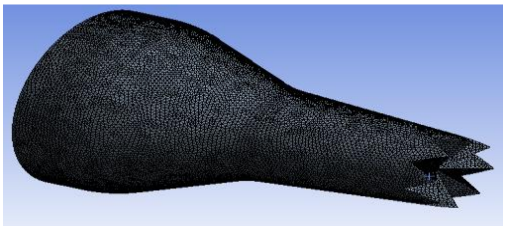

Fig 3. Mesh model.

The CAD model is partitioned into smaller regions called elements using the finite element mesh, and then a set of equations is solved over these elements. By defining a collection of polynomial functions over each element, these equations approximate the governing equation of interest.

2. Boundary condition:

Boundary conditions (b.c.) are requirements for finding an answer to a boundary value problem. Differential equations (or systems of differential equations) in a domain whose boundary conditions are known are called boundary value problems. Boundary conditions can be classified as either essential if they are imposed explicitly on the solution or natural if they are met automatically after a solution is found.

Boundary conditions play an essential part in computational fluid dynamics and are crucial for problem definition. That's because how things are handled numerically may have a huge impact on whether or not numerical methods can be used, and on the quality of the calculations that result.

The value that a solution must have in some region of space is what the boundary condition states, and it does not change over time. A solution needs to satisfy the original condition at exactly one point in time. Boundary conditions define the parameters that may be entered into the simulation model. Conditions like a fluid's velocity and volumetric flow rate govern how it enters or departs the model. The film coefficient and heat flow are two additional parameters that describe the manner in which the model transfers energy to its surroundings. In this analysis, we use the inlet, the outlet, and the wall as boundary conditions.

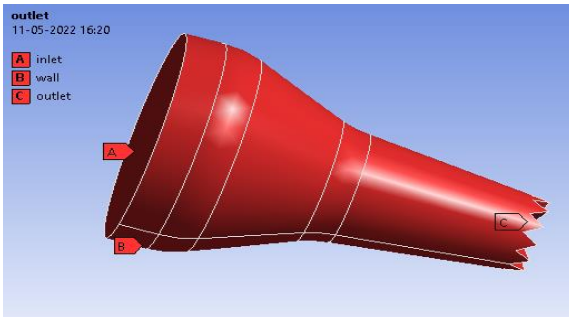

Fig 4. Boundary condition.

IV. ACOUSTIC POWER LEVEL CONTOURS

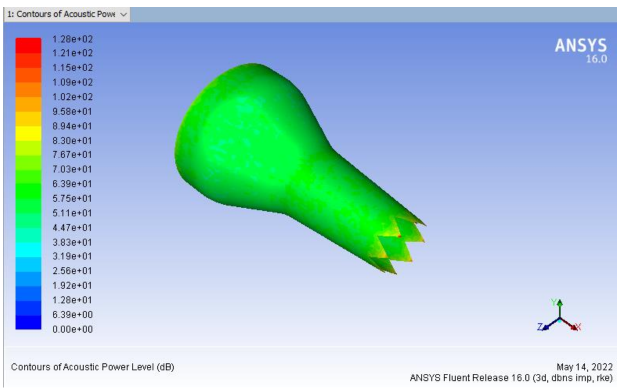

Fig. 5. Acoustic Power Level.

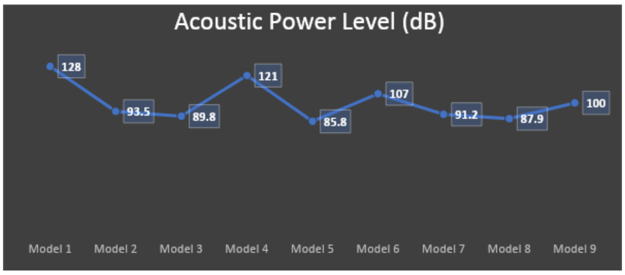

Fig. 6. Acoustic power level.

As can be seen in the figures below, the acoustic power level provides an estimate of the total noise level. a combination of the strong vortices and the mixing of hot and cold air near the nozzle's tip, the acoustic power is greatest there. Model 1 has a greater acoustic power level, while Model 5 has the lowest. The aft margins of certain jet engine nozzles include a saw tooth design called chevrons.

The curved edges help to smooth the mixing of hot air from the engine core and cold air from the engine fan, reducing turbulence and noise. It has been clear from an acoustic study of a chevron nozzle that noise reduction is achieved by using chevrons to direct airflow.

V. CONCLUSION

The purpose of this research was to determine which chevron nozzle design provides the best performance. So, researchers resort to ANSYS CFD-based theoretical study to measure the chevron nozzle's acoustic efficiency. Setting the tip angle at 1 (60 acoustic power level), the penetration angle to 3 (7°C), and the number of chevrons to 12 is optimal for achieving a minimum Mach number. When the tip angle is set to 2 (65 acoustic power level), the penetration angle is set to 1 (5 ° C), and the number of chevrons is set to 1 (8), the minimum acoustic power level is achieved.

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