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A Review on 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 review on 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.

Fig 1. Chevron nozzle in jet engine.

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].

II. WORKING PRINCIPLE OF CHEVRON NOZZLES

Aircraft noise is a major problem that has an effect on the environment, the economy, and technology today. The noise produced by an airplane's engine may be broken down into two categories: compressor/fan noise and jet flow noise. The primary source of noise is the result of the rotor's viscous wakes interacting with guiding vanes at the fan's outlet or the stator. Even the clattering of gears and cogs within the engine itself. Turbulent mixing of the jet and insufficient jet expansion both contribute to the jet noise. Research on the difficult problem of turbulent mixing in a jet is ongoing.

Increased thrust may be achieved by increasing the velocity of the fluid flow, which is achieved with the help of nozzles. Nozzles are noisy because they transform static energy into kinetic energy. As a result, quieting the exhaust nozzle is essential. It's the nozzle design that uses a chevron at its outlet to combine cold and hot air without turbulence. The chevron pattern first appeared in prehistoric pottery and rack carving. The primary reason for adding chevron to the jet engine of an airplane is to lessen the noise produced by the plane and hence lessen its effect on the neighborhood. The edges of a chevron help to smooth out the mixing of the hot air from the exit with the cooler air, reducing the turbulence that causes noise.

The Boing747-8, powered by saw-toothed GEnx-2B67 engines, is a good example of how chevron nozzles may be successfully used to aircraft engines. The degree to which chevron penetration affects centerline decay and noise is rather high [1]. For low and medium nozzle pressure ratios, the most effective noise suppression is achieved with a larger chevron count and a lower level of penetration. And discovered, in contrast to standard nozzles, the chevron nozzle produces no scream [4]. When the number of chevrons and their penetration were held constant, James and Brown [1] reported that the chevron length had no discernible effect on flow or sound. At both cold and hot jet conditions, the effect of chevrons on the azimuthal structure of the fluctuating axial velocity is shown to be negligible by James and Brown [5].

The aft margins of certain jet engine nozzles include a sawtooth design called chevrons. The hot air from the engine core and the cool air from the engine fan are more easily blended according to the rounded corners. The Chevron Nozzle is a relative invention. The Boeing 787's engines implement this concept. Alternately, a sawtooth pattern can be used instead of a straight line when cutting the engine's circumferential end (trailing edge).

Explaining Chevron Nozzle's operating concept without being too technical might be challenging. Visualize the flow of COLD air from the fan being channeled in a sawtooth fashion by the Chevron Nozzle. In contrast to a conventional nozzle, where the redirected airflow is continuous throughout its entire circumference, the chevron nozzle's design forces the airstream to converge at the apex of each saw tooth, creating a space between them. According to the theory, the hot air fills these spaces instead of violently interacting with the cold air at the back of the engine, reducing turbulence. Although it is not an ideal approach, noise can be reduced by making the mixing a little less turbulent. The performance of an engine is believed to be diminished by less than 0.25 percent when using a Chevron Nozzle.

III. NOISE REDUCTION IN JET ENGINE USING CHEVRON NOZZLE

Aircraft noise has profound consequences for environments, economies, and technologies. Compressor noise and jet noise are both of the most common types of engine noise in passenger planes. This is because the jet shear generates a structure with a lot of turbulence. The flow instability brought on by the pressure variation in the nozzle is usually to blame for the formation of these turbulence formations. By accelerating the mixing of the fan, core, and ambient streams, the Chevron nozzle can reduce jet noise with minimal effect on performance.

There are significant ecological, economic, and technical consequences associated with aircraft noise. Modern commercial airplane engines generate a great deal of noise from two sources: fan/compressor noise and jet noise. Turbulent mixing noise and, in the case of inadequately inflated jets, shock noise make up what is known as "jet noise." Eddy creation owing to the mixing of air streams at varying temperatures and velocities causes turbulent mixing, which in turn causes noise that is exceedingly difficult to suppress. Eddies are caused by the interaction of the outside air with the fast-moving exhaust gases from the engine.

Chevrons, also known as zigzags or raw their teeth, taking are being used on contemporary jet engines. Their pointed ends are ever-so-slightly angled into the flow of air. The method has the potential to lessen the most noticeable aspect of jet noise, which is caused by turbulent mixing. Stream-wise vortices are induced into the shear layer by the triangular cut outs along the nozzle's trailing edge, which improves mixing and shortens the jet plume. As a result, the chevrons increase mixing appropriately, and the total jet noise is diminished. When there is too much interaction, the chevrons increase the volume. No noise-reduction advantages are achieved with insufficient mixing. The nozzle creates a miss between the core and bypass flows, which dampens the low-frequency noise associated with very turbulent flows.

The idea of reducing jet noise by chevron-induced flow-mixing augmentation has received a lot of interest recently. It is generally accepted that jet noise originates in the completely turbulent mixing zone located downstream of the jet potential core and in the jet shear layers. The frequency of the noise caused by the turbulence is determined by the length and time scales of the turbulence in various parts of the jet flow. Scales that produce noise at higher frequencies are thought to be found in the jet flow's thin shear layers, while those producing noise at lower frequencies are thought to be positioned downstream of the jet's possible core end. For some time, scientists have been trying to figure out how to manage and reduce jet noise by employing specialized flow-mixing improvement devices.

The major focus of this research is on chevrons, which are one of the most widely used jet noise-reduction technologies today. The chevrons create an axial vorticity that increases mixing in the jet's shear layers, which can either reduce or increase noise at specific frequencies. At aft angles, chevrons tend to dampen low-frequency noise while enhancing high-frequency noise at broadside angles to the jet [1]. In chevron design, the ultimate objective is to minimize low-frequency noise while avoiding an appreciable rise in high-frequency noise. The number of chevrons, the depth of the chevrons, and the length of the chevrons are all variables that may be played with in order to find an optimal solution. The number of chevrons determines the separation of the axial vortices they create, the depth to which they penetrate determines the intensity of the axial vorticity, and the length of the chevrons determines the distribution of vorticity inside the axial vortices themselves [1]. Therefore, in order to achieve the highest level of noise reduction using chevron nozzles, an optimization study of numerous factors is required.

IV. PAST STUDIES

Cican and Deaconu (2021) discussed research on lowering turbojet engine noise, in particular tiny turbojet engine jet noise. Following the presentation of the measurement campaign results is an analysis of the test bench's performance based on the data it collected. The testing included a baseline nozzle as well as two nozzles with chevrons. The first type of nozzle predicted has eight triangular chevrons, with an immersion angle of I = 0 deg and a length of L = 10% of the corresponding diameter. The second nozzle is identical to the first in terms of length and immersion angle; the 16 chevrons are the sole difference. The tiny turbojet engine has been put through its paces in four distinct velocity ranges.

Fuel flow, turbine inlet temperature, air intake rate, compression ratio, thrust, and compressor inlet temperature were all measured to track engine performance. In addition, axial and radial vibrations were observed during testing, both of which are consistent with a well-functioning engine during the chevron nozzles' evaluation. It was determined that the use of chevron nozzles had no effect on noise at low regimes, but does result in a 2-3 dB(A) decrease at high regimes. There was a decline of a few percent in propulsion force in addition to reductions in intake air and fuel flow, compression ratio, and temperature in front of the turbine.

Devipriya (2017) Installing chevrons with specific characteristics in the nozzle section can significantly lower airplane exhaust noise. In order to assess the significance of the Chevron parameters, including the number of Chevrons and the mixing properties of the jet, numerical studies have been conducted on chevron Nozzles. After analyzing the Chevron characteristics, we install the triangular wedge to change the Chevron forms at the exit and achieve optimum noise reduction with little loss of thrust. Finally, the results of the CFX CFD study of the free jet Nozzle with the Chevron and the Chevron with the wedge are compared, and the potential core decay of both Nozzles is assessed.

Kumaran (2015) There are significant ecological, economic, and technical consequences associated with aircraft noise. Modern commercial airplane engines generate a great deal of noise from two sources: fan/compressor noise and jet noise. With NASA's crucial help, an in-house R&D effort was launched to find ways to quiet the jets without negatively affecting their performance, use, manufacture, weight, etc. The result was the chevron nozzle, an exhaust system component that improves performance while simultaneously decreasing jet noise by increasing the rate at which the fan, core, and ambient streams are mixed.

Chevrons, also known as zigzags or raw jaws, are being used on contemporary jet engines. Their pointed ends are ever-so-slightly angled into the flow of air. Most jets' loudest noise comes from turbulent mixing, which might be mitigated with this new technique. The purpose of this project is to compare and contrast the effectiveness of various chevron configurations. CATIA V5R20 is used to model many chevron nozzle designs, and ANSYS CFD is used to analyze their acoustic performance. To determine the most effective chevron form, its acoustic features were examined alongside the primary flow parameters of pressure and velocity. Nozzle, Jet Noise, and Chevrons are Some Related Words.

Kong (2013) When it comes to ejector-diffuser systems, the supersonic nozzle is the most crucial component. It is challenging to establish the best operating state and appropriate construction of supersonic nozzle due to the complex turbulent mixing, compressibility effects, and flow unsteadiness created near the nozzle extent. In order to induce longitudinal vortices within the Chevron lobes and activate the shear actions between the main and secondary streams, this study modified the primary stream nozzle to employ a convergent nozzle. A geometrical model illustrating the ejector-diffuser system was built to ensure the reliability of the experimental results. Both the Chevron nozzle and a standard convergent nozzle were tested as the principal stream in an ejector system and their operational characteristics were evaluated.

The ejector's internal supersonic flows and shock waves have been simulated using CFD. Primary numerical analysis findings demonstrate that the Chevron nozzle has a beneficial influence on the performance of the supersonic ejector-diffuser system by altering the flow structure and shock system. More secondary stream may be entrained with the same mass flow rate of primary stream by using an ejector with a Chevron nozzle.

Bridges (2002) Turbulence data from three different flow nozzles, two of which include mixing improvement features on their core nozzle, demonstrating how the mixing enhancement features affect turbulence to minimize jet noise. Three nozzles with different degrees of symmetry were evaluated: the axisymmetric baseline nozzle 3BB, the alternating chevron nozzle 3A12B, and the flipper tab nozzle 3T24B. The results given highlight the turbulence features of importance in jet noise that are different from those created by the nozzles' geometric variations. Most notably, the mixing devices drastically change the ratios of turbulence components, and the integral length scales do not fit any previously established turbulence model. These results should aid in better predicting jet noise through the use of models that account for the statistical features of turbulence.

Massey et al. (2006) The primary processes for both the flow and the noise were discovered. The compressible Reynolds-averaged Navier-Stokes equations are used to model the flow on a structured grid, and they are assumed to be asymptotically stable. The parallel, multi-block, structured grid code PAB3D is used to compute flows. The Jet 3D algorithm, which combines the Light hill Acoustic Analogy with anisotropic Reynolds stress modeling, was used to digitally map and incorporate local noise sources. Predictions of decreasing noise levels were confirmed by this research. Noise source maps were generated in Jet3D and afterwards connected to regional flow characteristics. Flow analyses reveal that the asymmetric merger of the fan and core shear layers is greatly slowed down due to the longer fan chevrons' involvement in dampening the intensity of the secondary flow created by the pylon itself. As a result, the kinetic energy of the peak turbulence is reduced and shifted downstream, leading to less noise. The physics of a fan chevron nozzle built to incorporate the impacts of propulsion airframe aeroacoustics interaction have been well-understood thanks to this integrated and noise prediction technique.

V. CONCLUSION

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.

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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.

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