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NOISE REDUCTION AND THRUST ENHANCEMENT IN VARIOUS MODIFIED CHEVRON NOZZLE

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ABSTRACT

The aircraft jet noise drop a crucial problem in aero-acoustics research. Acoustic studies tell that addition of chevrons to the nozzle reduces the sound pressure level reasonably with acceptable decrease in performance. In this paper complete numerical studies on acoustic characteristics of different types of chevron nozzles have been carried out with non-reacting flows for the shape optimization of chevrons in supersonic nozzles for aerospace applications. The numerical studies have been carried out using a validated steady 3D density based, k-ε turbulence model. In this paper chevron with sharp edge, flat edge, round edge and U-type edge are selected for the jet acoustic characterization of supersonic nozzles. We observed that compared to the base model a case with round-shaped chevron nozzle could reduce 4.23% acoustic level with 0.7% thrust loss. We accomplished that the prudent selection of the chevron shape will enable a visible reduction of the aircraft jet noise without compromising its overall performance. It is evident from the present numerical simulations that k-ε model can expect reasonably well the acoustic level of chevron supersonic nozzles for its shape optimization.

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INTRODUCTION

The firm noise principles around major airports due to environmental concern have made jet noise a key problem in present day aero-acoustics research. The three main acoustic sources in aircraft are aerodynamics noise, noise from aircraft systems and engine and involuntary noise. Among these noise cradles engine noise contribute more noise pollution to environment. Although high bypass-ratio turbofans do have large fan noise, the majority of engine noise is due to the jet noise coming out from the exhaust nozzle. Although many studies have been carried out during the last few decades a complete understanding of the jet noise mechanisms is still a scary task (Bridges *et al*., 2004; Zaman, 2010; Saiyed *et al*., 2000; Hao Xia, 2013; Fan Shi Kong, 2013; Khalid, 2010; "Ejector/Engine/Nacelle Integration for Increased Thrustminus Drag, 2010; Gregory *et al*., 2011; Callendar *et al*., 2005; Callendar *et al*., 2008). It is well known that the high velocity jet leaving back of the engine has intrinsic shear layer instability and rolls up into ring vortices. This later breaks down into turbulence sources of jet noise at the exit of nozzle.

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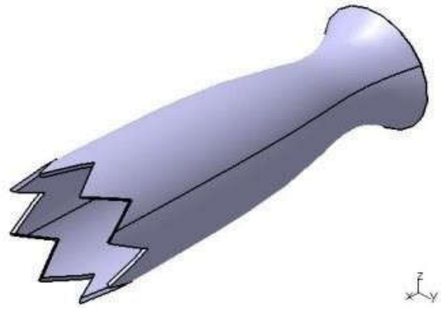
There are many methods report in the literature to reduce the jet engine noise without compromise other design parameters of propulsive system. Among these, the popular methods are variable area jet nozzle using the shape memory alloy actuators, fan flow deflectors and chevrons nozzles (Bridges *et al*., 2004). Zaman *et al*. (2010) reported that 'Chevrons', a saw tooth pattern on the rambling edge of exhaust nozzles, are being implement on modern jet engine nozzles that help reduce noise from the ensuing jet (see Fig. 1). It has been known from past experimental studies with laboratory-scale jets that miniature protrusion at the nozzle lip, called 'tabs', would suppress 'screech' tone. In the 1980's and 1990's the tabs were explored extensively for mixing enhancement in jets. These studies advanced the understanding of the flow mechanisms and suggested that the technique might have a potential for reduction of 'turbulent mixing noise' that is the dominant component of jet noise for most aircraft. These are succinctly reported by Zaman *et al*. (2010). Literature review reveal that the noise drop nozzles are of great interests to the aerospace industry, such as the saw-like (or chevron) nozzle (Bridges *et al*., 2004) The comprehensives experimental studies of Saiyed *et al*. (?), (Saiyed *et al*., 2000) at NASA expose that the chevron modification to the round nozzle can bring as much as 3 dB reduction in peak noise during take-off with less than 0.5 % thrust loss during cruise. For high frequencies and large angles to the jet, the use of chevrons may also direct to about to 2 dB noise increase. This naturally leads to the chevron design optimization problem in which eddy resolving numerical simulations and acoustic modeling techniques for jet noise prediction play an important potential role. Hao Xia (2013) carried out numerical study of chevron jet noise using parallel flow solver. Author performed cross large-eddy type simulations for chevron nozzle jet flows at Mach 0.9 and Re ~ 10^5. Many researchers carried out studies on chevron nozzles for various applications. Fan Shi Kong, Heuy Dong Kim, Yingzi Jin and Toshiaki Setoguchi (Fan Shi Kong, 2013) reported a new class of nozzle with chevrons was installed inside the supersonic ejector- diffuser system. Literature review further reveal that the nozzle with chevrons was widely used in the aerospace science and aircraft engine, because it has many advantages such as jet noise drop infrared signature control and enhancement of conventional converging-diverging nozzle or convergent nozzle (Khalid *et al*., 2010). Gregory A. Blaisdell *et al*. (2011) also view that the conventional nozzle features were improved as a result of installing the chevrons.

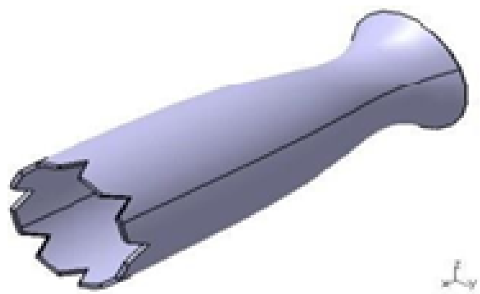
.Note that the chevron nozzles have the flexibility in controlling acoustic and thrust performance. Admittedly, the previous studies reveal that the potential of chevron nozzles (or serration) for aircraft engines noise drop is promising owing to the fact that the jet noise continues to be the dominant noise component, especially during take-off. Acoustic studies tell that addition of chevrons to the nozzle reduces the sound pressure level sensibly with acceptable reduction in performance. Although many studies were carried out by the earlier investigators the understanding of the fundamental mechanisms responsible for the acoustic advantange and the influence of various geometric parameters of chevrons are not clear. Parameters such as, the number of chevron lobes, the lobe length and the level of penetration of the chevrons into the flow have been investigated over a variety of flow conditions. Although experiment are necessary and offer useful data for validating the computations, they are expensive and can supply relatively limited amount of information. Hence it is enviable rather inevitable to have reliable CFD capabilities to quickly evaluate beginning designs for noise reduction. In this paper comprehensive numerical studies on acoustic characteristics of various types of chevron nozzles have been carried out with non-reacting flows for the shape optimization of chevrons in supersonic nozzles for aerospace applications, which are discussed in the ensuing sessions.

NUMERICAL METHODOLOGY

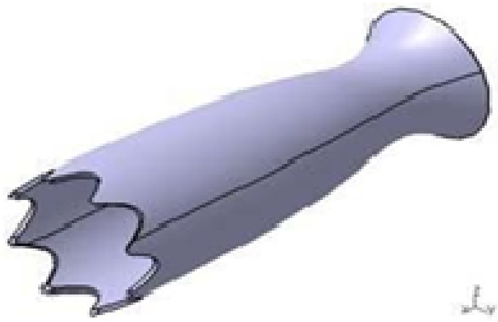
The numerical studies have been carried out using a validated steady 3D density based couched standard, k- epsilon turbulence model using standard wall functions. This model uses a control-volume based method to convert the governing equations to algebraic equations. The viscosity is determined from the Sutherland formula. The nozzle geometric variables and material properties are known *a priori*. Initial wall temperature and inlet temperature are specified. At the exit, far field boundary condition is prescribed. At the solid walls no-slip boundary conditions imposed. The Courant- Friedrichs-Lewy number is chosen as 0.5 in all of the computations. The turbulent kinetic energy and the specific dissipation rate are taken as 0.8. Ideal gas was selected as the working fluid. Fig. 2 shows the base model of the nozzle.



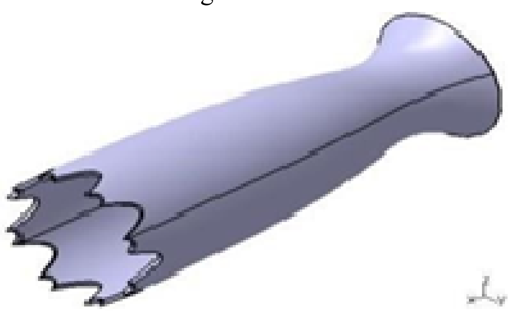
a. Chevron with sharp edge



b. Chevron with flat edge



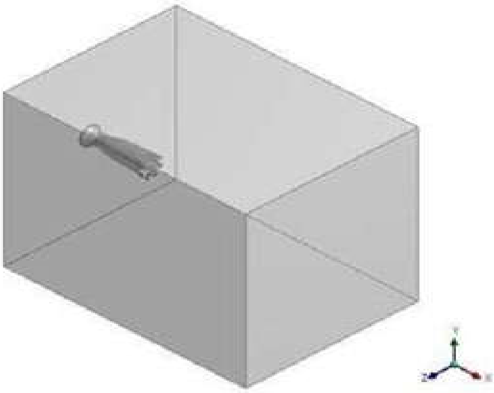
c. Chevron with round edge



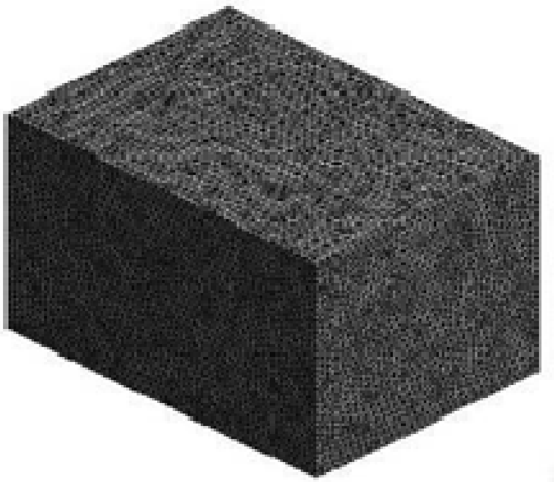
d. Chevron with U-type edge

Figs. 1 (a)-(d) Different types of Chevron nozzles

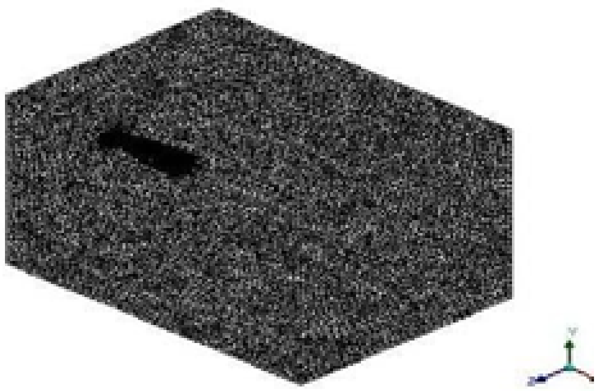
The base model was designed with an area ratio (Ae/At) of 2.6814 with an exit Mach number of 2.6 at the given inlet conditions. The match up points for the divergent portion of the nozzle were selected based on a typical shock-free convergent-divergent (CD) nozzle. Figs. 3 (a)-(d) show four different types of idealized chevron nozzles selected for the parametric analytical studies. In all the cases the number of chevron selected was 8. A shapeless grid with tri angular elements was used for all the cases. Grid system in the computational domain is selected after detailed grid alteration exercises. Fig. 4 shows the chevron nozzle with round edge in the computational domain.



a. 3D model in the computational domain



b. 3D grid system in the computational domain



c. Model with wireframe meshes

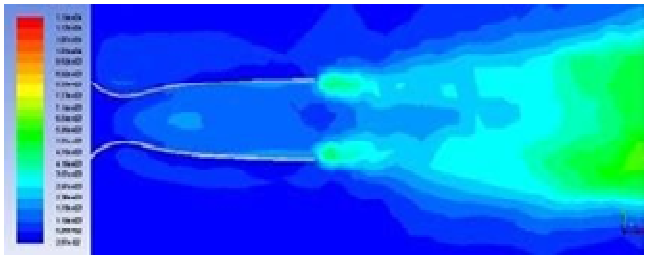
Figs. 2 (a)-(d) Different types of Chevron nozzles

RESULTS AND DISCUSSION

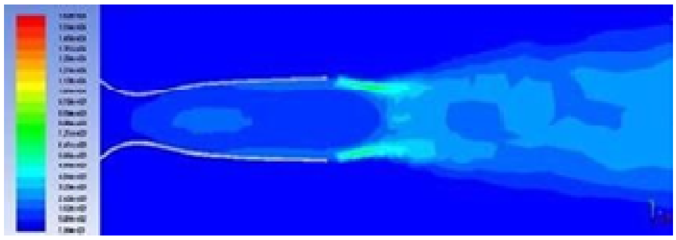
In this paper comprehensive geometric studies on acoustic characteristics of four different types of chevron nozzles have been carried out with non-reacting flows and compared each other and also with the base model for the shape optimization.

Due to the lack of fixed correlation between jet noise and the chevron shape and its dispersion distance it was difficult for choosing types of chevron for parametric studies. However, authors made an challenge to idealize the shapes of various chevron nozzles using empirical techniques for throwing light for its shape optimization. In this paper chevron with sharp edge, flat edge, round edge and U-type edge are selected for the jet acoustic characterization and association with the base model.

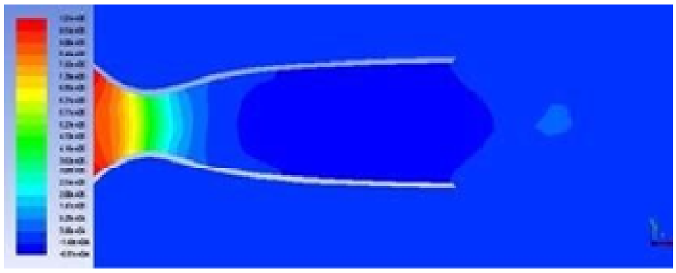
Note that the 2d analyses for the aforesaid four types of chevron with different dimensions having one chevron were carried out by the earlier investigators and found that chevron with round edge exhibit less acoustic level (20). In this 3d analyses an inlet Mach number of 0.35 is imposed in all the cases having 8 chevrons for a rational estimation of the jet noise reduction.



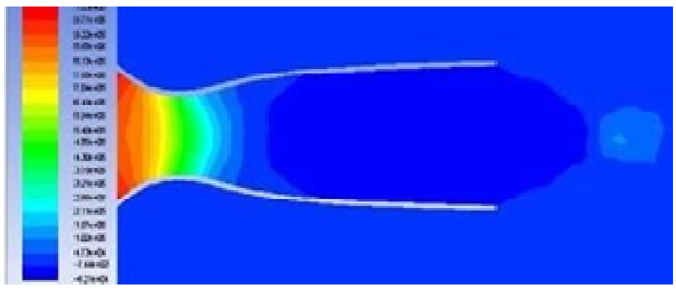
a. Base model of the CD nozzle



b. Chevron with flat edge

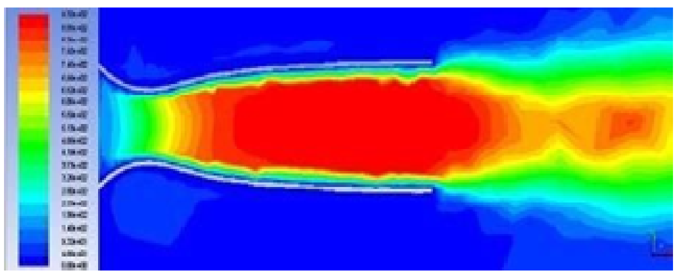


c. Chevron with round edge

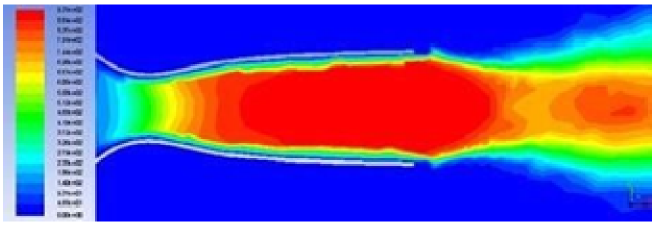


d. Chevron with U-type edge

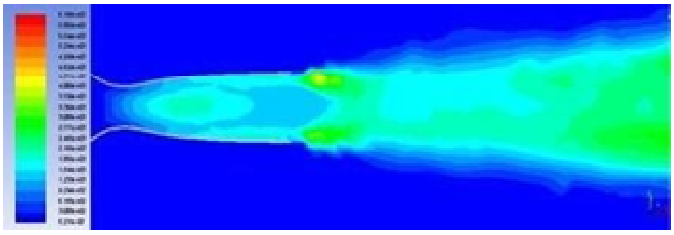
Fig. 3 (a)-(e) Static pressure contours of five different cases



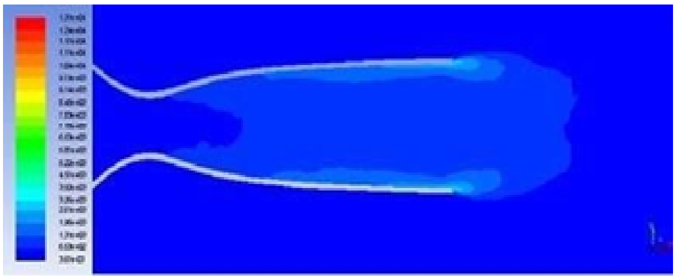
a. Base model of the CD nozzle



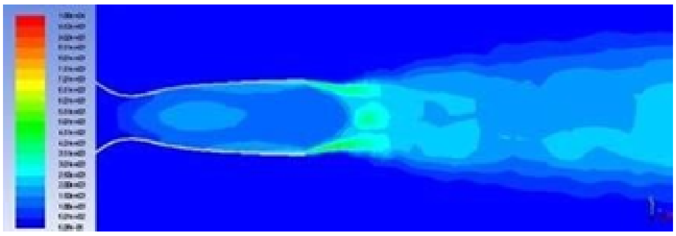
b. Chevron with sharp edge



b. Chevron with flat edge

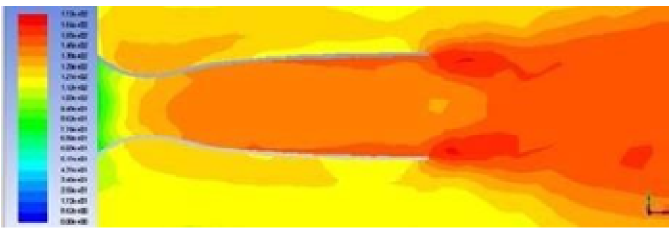


c. Chevron with round edge

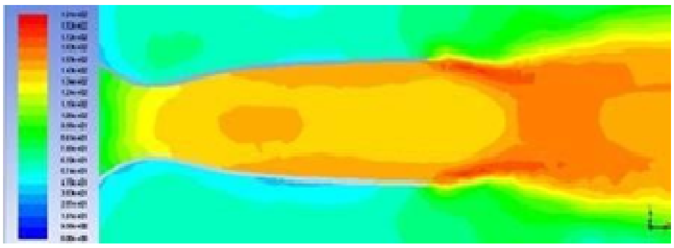


d. Chevron with U-type edge

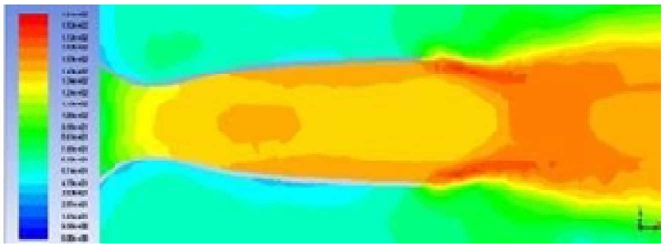
Fig. 4 (a)-(e) Turbulent kinetic energy of five different cases



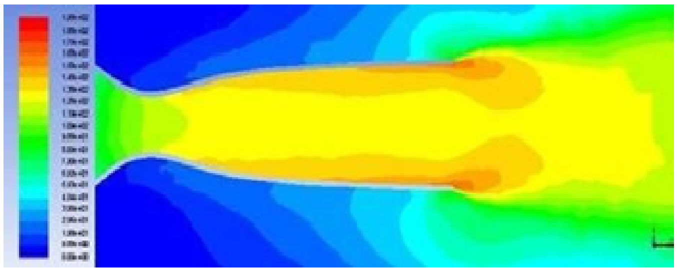
a. Base model of the CD nozzle



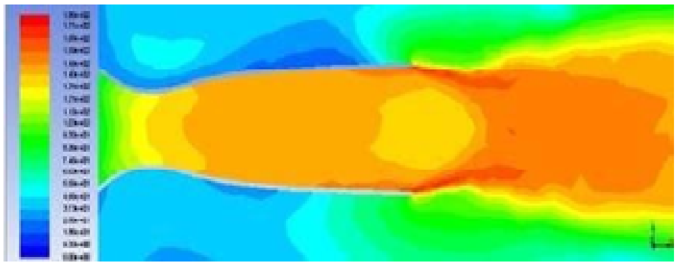
b. Chevron with sharp edge



c. Chevron with flat edge



d. Chevron with round edge



e. Chevron with U-type edge

Fig. 5 (a)-(e) Acoustic power level contours of five different cases

Conclusion

We concluded that the shape optimizations of chevron nozzle have a potential for drop of turbulent mixing noise further, which is believed to be the leading component of jet noise for most aircraft. It is emphasized that jet noise remains a major component of engine noise. The Chevron technology has provided a modest relief for jet noise drop in aerospace applications. As the result of analysis, comparison was carried with baseline CD nozzle and four different types of chevrons. Finally we concluded that the chevron with round edge is the best selection for the sound reduction, of the acoustic power plane of the base model of the nozzle, on the order of 6 dB. We also concluded that the wise selection of chevron will enable the designer to reduce the sound level ~5%.

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