Numerical Simulations on Acoustic Characteristics of Co-flow Chevron Nozzles

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Abstract

Aircraft jet exhausts are a source of undesirable noise and continue to be an area of investigation driven by increasingly stringent regulation. The noise is produced by the unsteady mixing of the jet with the surrounding air and is dominated by the effects of the shear layer. The exhaust nozzle is an integral part of a jet engine and critical to its overall system performance. Challenges associated with the design and manufacturing of an exhaust nozzle become greater as the cruise speed of the aircraft increases. The exhaust nozzle of a supersonic cruise aircraft requires additional capabilities such as variable throat and exit area, noise suppression, and reverse thrust. In this study, a computational work of chevron nozzles with various chevron count and nozzle pressure ratio (NPR) is carried out. Chevron count with minimum nozzle pressure ratio produced reduction in noise level, whereas at high nozzle pressure ratios, chevron penetration is crucial. Co-flow analysis of perforated chevron with various count and hole dimensions with acoustic measurements are determined by computational fluid dynamics. Acoustic measurement such as overall sound pressure level (OASPL) and broadband shock noise have been made over a range of nozzle pressure ratio for sub-critical levels. The result indicates that the higher chevron count with lesser hole dimensions yields the maximum noise suppression. Acoustic level of chevron nozzle with co-flows analysis reduces 1 to 2dB of noise level compare to single flow. The result indicates by proper selection of chevron parameters substantial noise reduction can be achieved.

Keywords: Co-flow, shocks, jet mixing

1. Introduction

Aircraft noise is the second largest source of environmental noise pollution and therefore of considerable concern to urban areas surrounding most major airports, financial, and technological impact. In order to develop a technique for reducing aircraft noise we must first address the sources from which it originates. An aircraft‘s overall noise signature can be categorized into three main components: aerodynamic airframe noise, engine noise and aircraft systems noise. Airframe self-generated nose is a more significant factor during the approach phase of the aircraft and is a product of airflow over deliberately varied surfaces such as high-lift devices, engine intake and landing gear. However, during most of the aircraft‘s flight envelope it is secondary to the principle noise source, the jet engine. Noise generation is associated with sudden changes in air pressure; such situations are commonly found in and around aircraft turbojet engines where changes in pressure and temperature are required for the generation of thrust. Significant components of engine noise are generated by the compressor and turbine.

There are two main sources of noise in today’s commercial aircraft engines: fan/compressor noise and jet noise. Jet noise comprises turbulent mixing noise and, in the case of imperfectly expanded jets, shock noise. Turbulent mixing noise is very difficult to control, and so its suppression remains a challenge. It is generally agreed that turbulent shear flow mixing causes two types of noise: sound produced by the large-scale eddies and sound generated by the fine scale turbulence. The former is very intense and directional and propagates at an angle close to the jet axis. The latter is mostly uniform and affects the lateral and upstream directions. The increase in bypass ratio over the last three decades has resulted in a dramatic suppression in the jet noise of turbofan engines. Modern engines are so quiet that further reduction in noise becomes extremely challenging. The success of the high-bypass engine is offset, to some degree, by the increasing volume of aircraft operations. This creates more environmental and political pressures for quieter aircraft. Today the most successful technique for reducing jet noise from high-bypass engines involves the installation of chevron mixers on the exhaust nozzles. In field of aero acoustics has attracted much attention, with aircraft noise reduction becomes one of the most important areas of research. The International Civil Aviation Organization (ICAO) imposes regulations that limit the maximum noise exposure from aircraft at three crucial positions during its flight envelope. The noise measurement location for the approach phase is situated at ground level 2 km from the start of the runway below the approach trajectory of the aircraft. During the aircraft acceleration phase for take-off, the measurement point is 450m to the sideline of the runway, with the departure measuring point being just below the take-off path of the aircraft at approximately 6.5 km from the start of the runway.

The noise limit for each of the three measurement points varies with respect to the aircraft take-off mass, but stands at a maximum allowable limit for aircraft heavier than 270 tonnes at 108 EPNdB, which is the effective perceived noise level in decibels having taken into account the duration to its exposure and distance from its source.

2. Computational Works

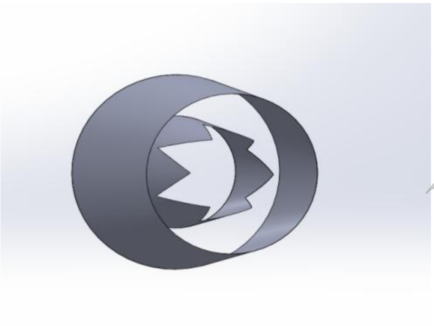


Figure 1: Conceptual design

Table 1: Nozzle Specifications

Specifications	Dimensions in mm
Inlet diameter of core	21
Outer diameter of core	16
Inlet diameter of outer cone	24
Outlet diameter of outer cone	19
Nozzle Length	25
Chevron length for four count chevron	10.88
Chevron Penetration	0°

3. Meshing

Imports the three-dimensional iges file are step file in to the Gambit software. Then do the cleanup operation if necessary. Then create the domain according to the requirement which may be rectangular brick or cylinder for our convenient. The zone height is to be 200D and length to be 250D ranges or to be greater than that too. After that we can change the model and domain in to single volume. After that go for the edge mesh followed by face mesh with appropriate interval counts. Then mesh the volume by using volume mesh option by hexahedral elements under cooper scheme. Then give the boundary conditions and export it.

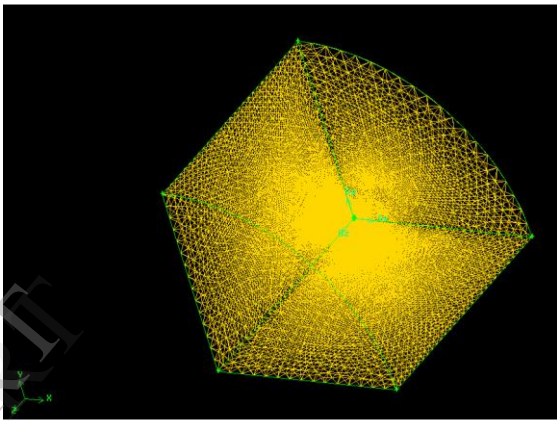


Figure 2: Chevron Nozzle Mesh

4. Result and Discussion

In this chapter we discuss about the final results from the fluent is compared with the existing journals and make sure that we are on the right path. The results are taken for single jet chevron nozzle with nozzle pressure ratio (NPR) of 3.5 and compared with shadow graph images of effect of chevron count and penetration journal (P.S.Tide 2008). The base line geometry are taken by the same paper and run at various nozzle pressure ratios. Both the computational work and the shadow graph images are matched.

Co-flow analysis of chevron nozzle with four count and eight counts are done with the help of fluent software, and the acoustic characteristics of single flow chevron and co-flow chevrons are measured. Results are shown instead of single flow nozzle co-flow nozzle yields minimum noise level, and it reduces 10db of noise level.co-flow analysis of four count chevron yields the good results. Using of k omega model in fluent we can see the turbulence exactly, where the turbulence level is more on that point noise level also high.

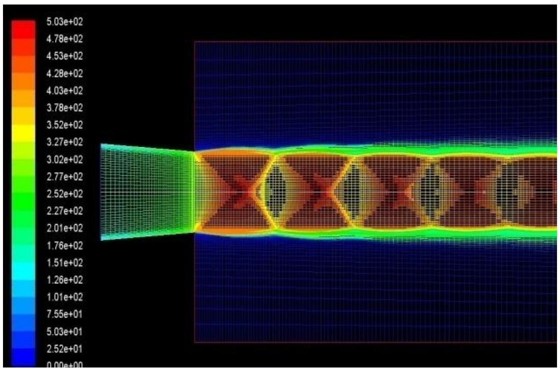


Figure 3: Velocity contour of single jet analysis with nozzle pressure ratio of 3.5

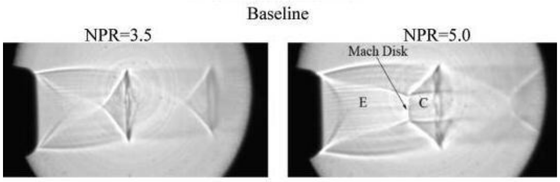
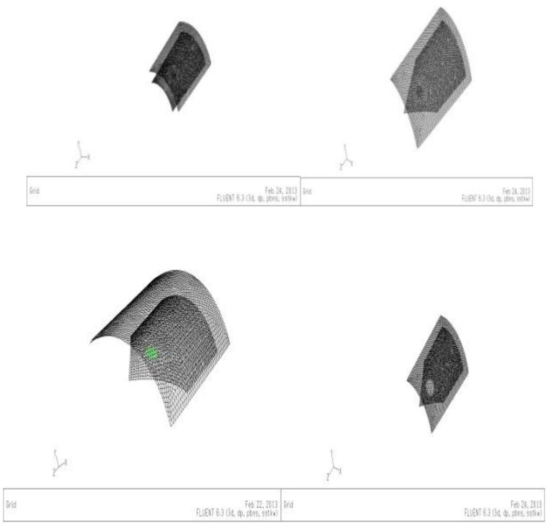


Figure 4: Shadow graph images.

As shown in the Fig 1 is the velocity contour of single jet analysis with nozzle pressure ratio of 3.5, that result is exactly matched with Fig 2 shadow graph images.

5. Co-flow Chevron Nozzle Configurations

1. Baseline
2. Chevron
3. Chevron with 2mm diameter hole
4. Chevron with 4mm diameter hole



6. Acoustic Contours

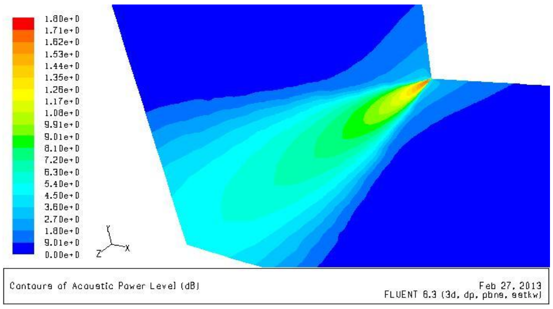


Figure 5: Baseline

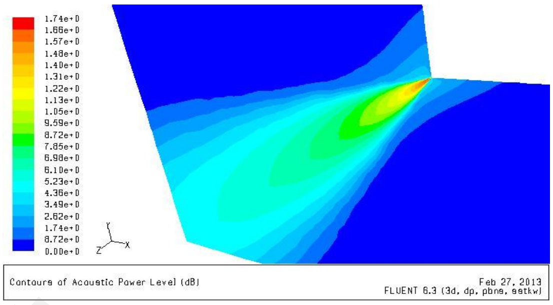


Figure 6: Chevron

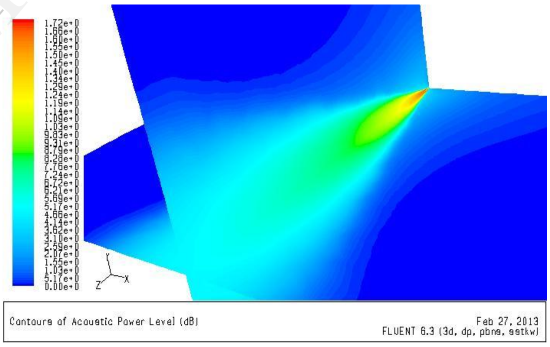


Figure 7: Chevron with 2mm ϕ hole

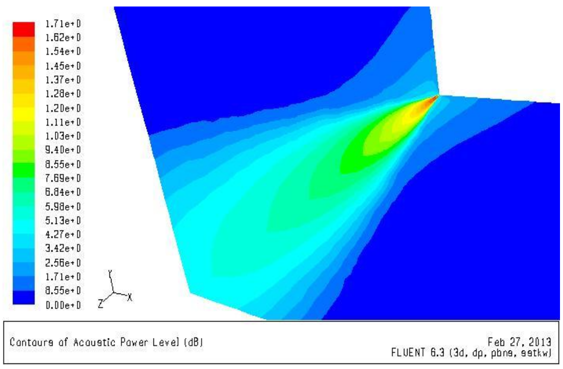


Figure 8: Chevron with 4mm ϕ hole

7. Velocity and Acoustic Plots for various configurations

The Domain is created with length of 250D in x direction, 200D in y direction. The plot is taken with angle of 45° of the plane and its gives the corresponding velocity as well as acoustic vales of the curve length.

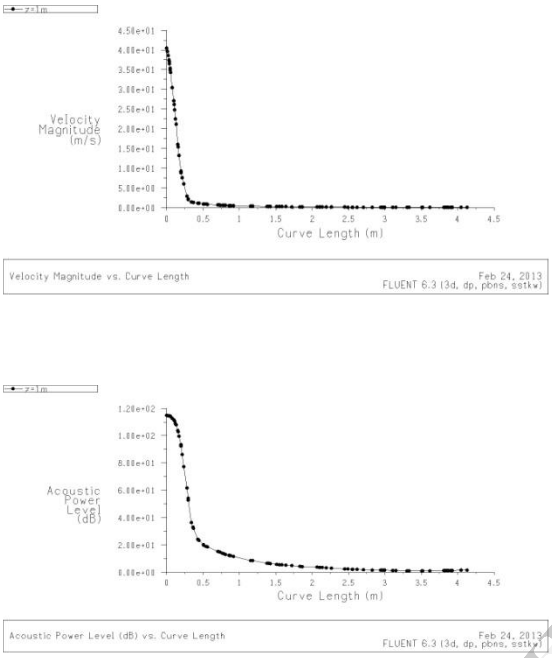


Figure 9: Baseline Graph

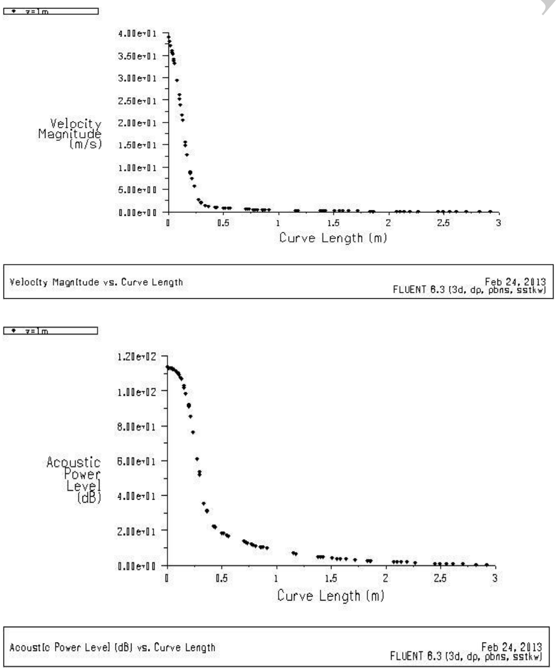


Figure 10: Chevron Graph

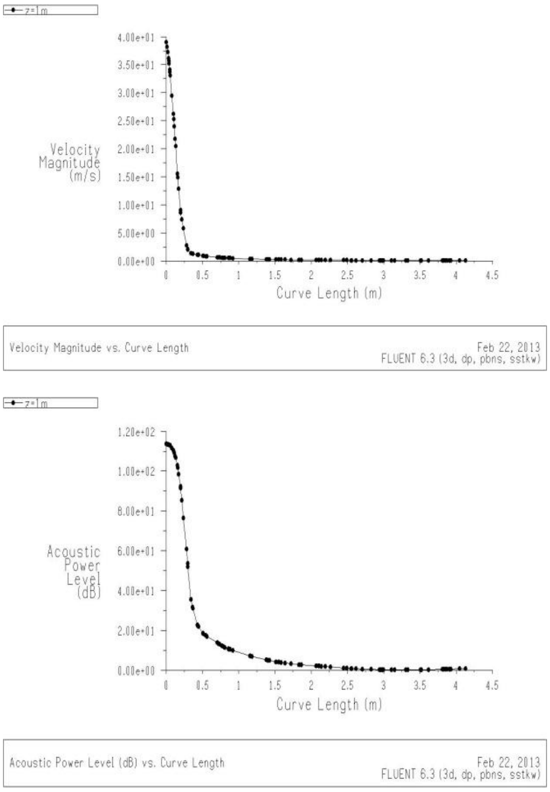


Figure 11: Chevron with 2mm ϕ hole Graph

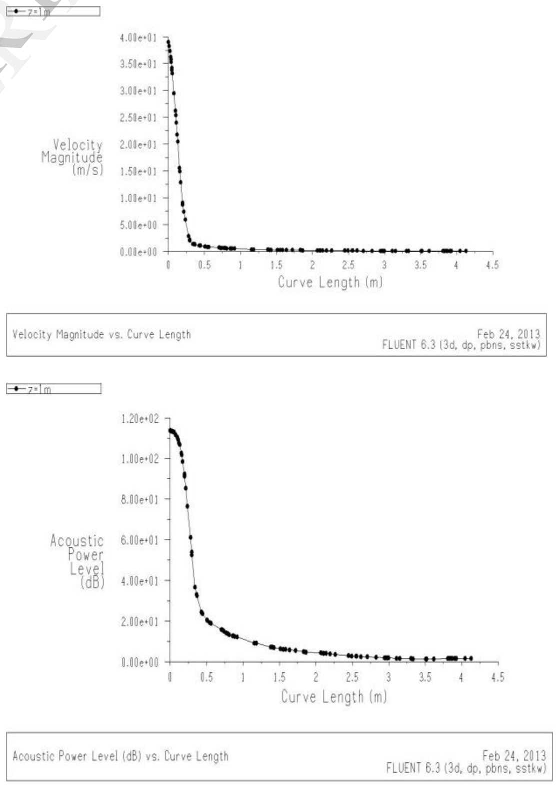


Figure 12: Chevron with 4mm ϕ hole Graph

8. Position of Receivers

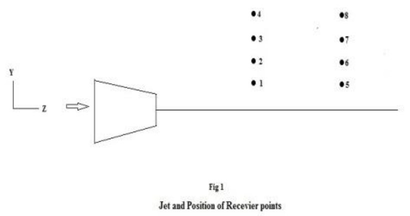


Figure 13: Position of Receivers

Table 2: Receiver- Acoustic Values(OSPL)

Receiver No.	Flow Direction Z		Radius		Acoustic Values, OSPL (dB)
	(m)	(Jet Dia)	(m)	(Jet Dia)	
1	1	53	0.5	26	27
2			1	53	7.56
3			1.2	63	5.68
4			1.5	79	3.75
5	1.5	79	0.5	26	15.38
6			1	53	4.53
7			1.2	63	2.81
8			1.5	79	1.05

9. Acoustic Values in dB

The overall sound pressure level of various configuration of chevron nozzles with above radial diameter as follows

Table 3: OSPL of various configuration

Baseline	chevron	Chevron2mm ϕ hole	Chevron4mm ϕ hole
20.26	18.733	18.7284	20.6168
8.678	7.0567	7.0522	9.222
8.4522	6.8326	6.8283	9.001
5.8048	4.22905	4.22489	6.4063

10. Concluding Remarks

The CFD results clearly indicate the overall sound pressure level (OSPL) of various configurations of chevron nozzles in dB. From that values chevron with 2mm diameter hole gives good acoustic sound pressure level. It reduces the sound level up to 2dB.

For the future commercial aircraft (Turbofan) engines the chevron nozzle produces the minimum sound level compare to other nozzles. It helps to reduce the second major problem (sound) in our country.

11. Future Work

CFD results are compared experimentally with acoustic laboratory in National Aerospace Laboratory (NAL) in Bangalore.

12. References

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