International Journal of Applied Engineering Research ISSN 0973-4562 Volume 18, Number 1 (2023) pp. 17-20
© Research India Publications. https://dx.doi.org/10.37622/IJAER/18.1.2023.17-20

A Numerical Investigation on Flow Characteristics of Jets Emerging from a Multi-Lobed Nozzle with Pointed Corrugations

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Abstract

One of the significant properties of fluids in motion is that they adjust to succumb to their environments. The various dynamic physics are merely the outcome of these adjustments. Nozzles transform pressure energy of fluids into kinetic energy using their peculiar geometry. Numerous studies on nozzle profiles have proven to be fruitful in light of their contributions in the field of aerospace, fluid transport and many other applications. Here we investigate the dynamic characteristics of a jet emerging from a lobed nozzle with sharp ended corrugations numerically by utilising tools of computational fluid dynamics. For validation purposes, the numerical investigation has been compared to numerical study by Kriparaj et al. (2018) and experimental findings by Anderson et al. (2005). The results suggest that velocity decay associated with multilobed nozzles with pointed corrugations are higher than conventional nozzles and smoothly corrugated designs. The centerline velocity appears to increase downstream as expected, but the radial velocity profiles at corresponding axial sites reported by Kriparaj et al. (2018) appear to have shifted to locus points that lie between characteristic profiles of conventional circular nozzles and smooth corrugated lobed geometry.

Keywords– Pointed corrugations, Centerline velocity, Radial velocity, Computational fluid dynamics

NOMENCLATURE

X	=Axial distance from reference point
R	=Radial distance from reference point
D_o	=Exit diameter of Nozzle
L	=Lobe length
$U\infty$	=Maximum jet velocity
U	=Velocity at any point in flow field
P	=Lobe penetration
D_i	=Inlet diameter of Nozzle

I. INTRODUCTION

A corrugated nozzle, by means of its geometric identity has itself proven to be an efficient mixer of emanating jets. Apart from this function, the wide transformation of physics of flow occurring during operation has benefited the scope of study of nozzles into many other domains such as aero acoustics. They find diverse applications in fields such as jet noise suppression, duct designs etc. Hence academic progression and contributions in this domain are of significant relevance.

A numerical study was carried out by Kriparaj *et al.* (2018) to investigate the jet characteristics in lobed nozzles. They performed simulations for three different configurations of nozzles by varying lobe length as the parameter. The results resembled experimental work by Anderson *et al.* (2005) on a conventional round nozzle. The investigation reported that centerline velocity at nozzle exit was less compared to round nozzles. However, the value increased with lobe length. Also the decay rate of velocity in the axial direction was reported to be higher compared to rounded nozzles.

The present work determines the jet profile and exit characteristics of a corrugated 4 lobed nozzle with sharp-pointed exit profile. The outcomes acquired from the simulations are compared with results reported by Kriparaj *et al.* (2018). The 3D model of the nozzle was designed in Autodesk Inventor Professional 2017 and imported to Ansys 16.2 for further proceedings. The analytical CFD tool used was Fluent and later the results were post processed for comparison purposes.

II. PROBLEM FORMULATION

Figure 1. Illustration of Multi Lobed test nozzle

The test model is illustrated in Fig. 1. The geometrical parameters were as enlisted in the table below. A 4 lobed design with 10 mm penetration and pointed corrugations as in Fig. 1 was imported to Design modeler and a computational domain of dimensions $30D_o$ x $16D_o$ was constructed to capture the physics of flow. The solid model of the nozzle was then subtracted from the entire domain using Boolean operations.

Table 1. Geometrical Parameters of lobed nozzle

Dimensional Parameter	Units (m)
D_o	0.04
P	0.01
L	0.05
Di	0.05

The fluid domain assumes the shape of a cylinder truncated along the central plain lengthwise for ease of computation. The corresponding surface formed was defined as “Wall-Symmetry” in solver setup.

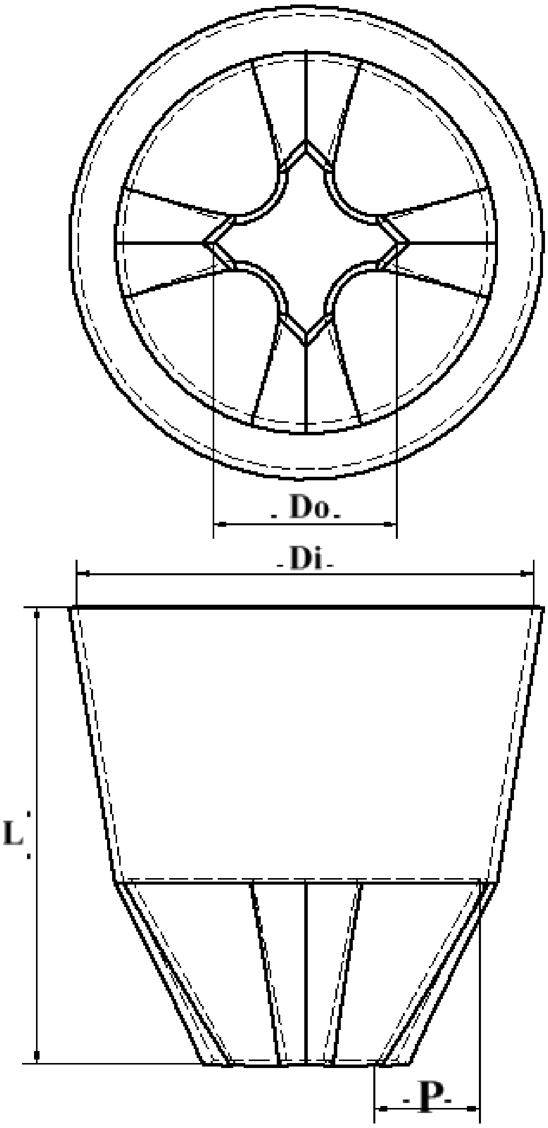

Figure 2. Nozzle parameters

The computational mesh was generated as tetragonal with “Proximity and Curvature” as the adaptive size function so that finer adapted cells can be brought closer by default to the sections where geometrical mismatches occur in the domain. The domain consisted of 3.5 million elements.

Since the flow under investigation was subsonic, the steady state pressure based solver was used for analysis by formulating the case as viscous-turbulent. To characterize the flow behaviour, RANS equation with SST *k-ω* model was chosen. The reference condition was set as ambient and the nozzle inlet was defined as pressure inlet with a gauge value of 50 kPa by keeping reference conditions for inlet and exit boundaries. To compute gradients in the flow field, Green-Gauss node based evaluation technique was followed. The setup was hybrid initialized before computation.

III. RESULTS AND DISCUSSION

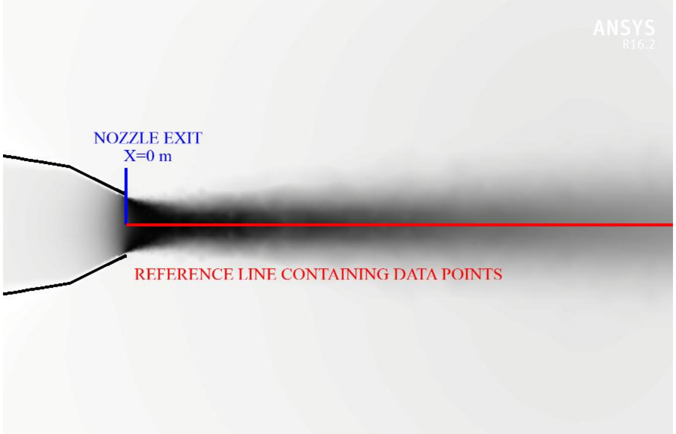

Figure 3. Reference lines for data acquisition

The results of the simulation were post-processed in CFD-post for developing graphs. Fig. 3 shows the reference line that contains data points to report numerical output of each variable under investigation. The line indicated in red travels along the centerline axis of the nozzle, hence providing centerline data values. The blue line is meant to report radial numerical outputs. The exit section of the nozzle as marked in Fig. 3, where the red and blue line intersects, is defined as the reference point with X=0 and r=0.

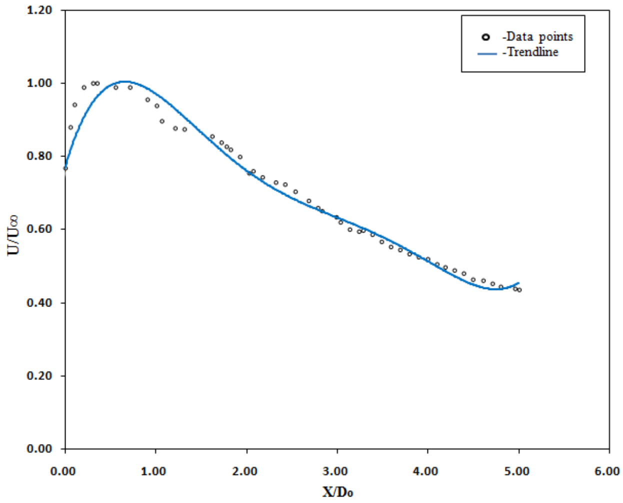

Figure 4. Variation of axial velocity along nozzle centerline

Fig. 4 shows the variation of axial velocity corresponding to different X/D$_o$ locations along the centerline. By comparing the output plot with findings of Kriparaj *et al.* (2018), it can be observed that the velocity decay is much higher for the present case. A sharp gradient is observed in the slope which is an indication of enhanced turbulent mixing due to sharp corrugated boundary at exit.

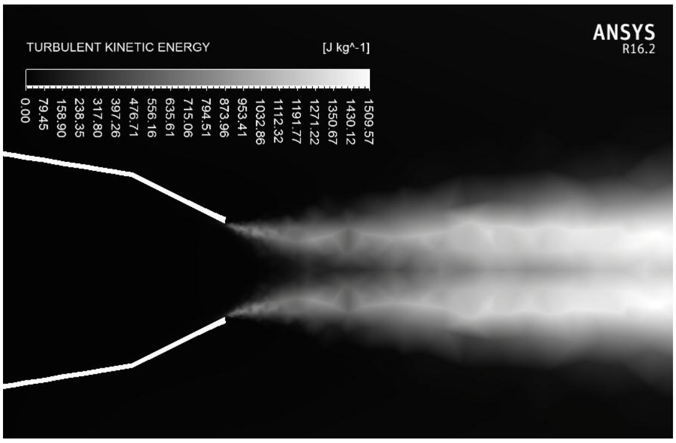

Figure 5. Contour of Turbulent Kinetic Energy

The contour of turbulent kinetic energy is demonstrated in Fig. 5, where the localised formation of turbulent structures can be observed. The emanating jet immediately interacts with the turbulent eddies and suppression of momentum occurs as a result of enhanced momentum exchange. This effectuates a sharp velocity decay rate.

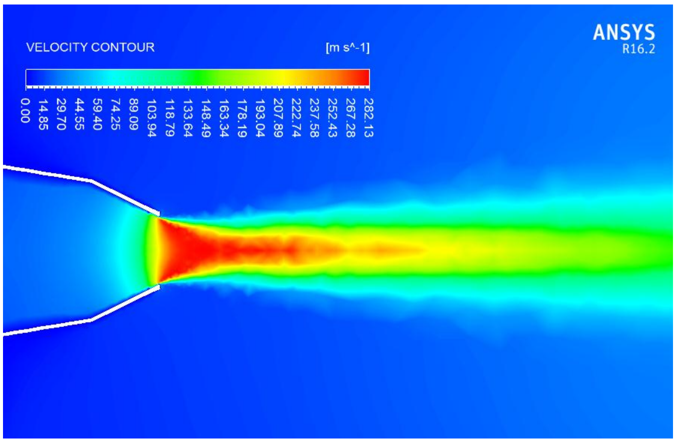

Figure 6. Contour of Velocity along central plane

Fig. 6 shows the distribution of velocity along the central plane at steady state. It is a clear indication that radial velocity variation at the nozzle exit follows an unexpected profile in reference to the behaviour obtained in conventional nozzles. This deviation is well conveyed in Fig. 7. The numerical data for the plot is derived from the post processing interface in Ansys. The emerging pattern appears to deviate from radial velocity profiles in conventional rounded nozzles at exit section. This is an attribute to the lobed design.

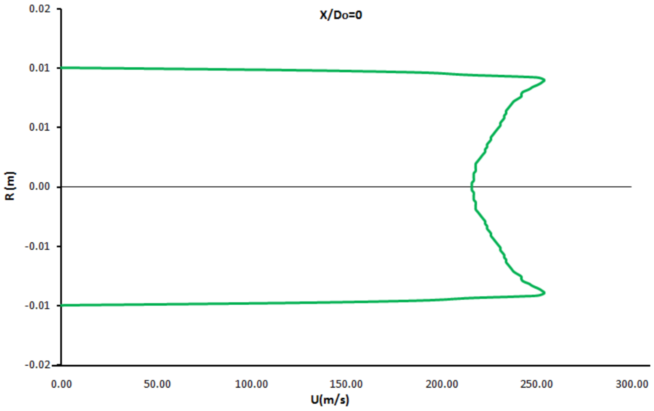

Figure 7. Variation of radial velocity at nozzle exit

Fig. 7 indicates the radial variation of velocity at location X/D$_o$=0. Comparing the graph with numerical results of Kriparaj *et al.* (2018), it is observed that the pattern emerges similarly. The centerline velocity is less compared to outer edge velocity as expected. However, the width of the jet where the reasonable spike in velocity occurs appears to be less.

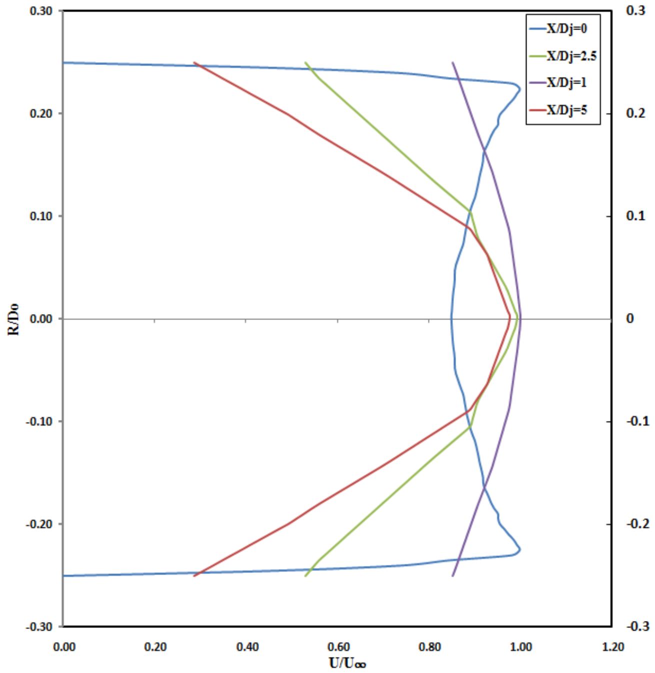

Figure 8. Variation of radial velocity along centerline

This variation in radial velocity profile remarks a significant deviation compared to that of a jet emanating from rounded nozzles near the exit section. This contrasting behaviour is furthermore demonstrated in Fig. 8. Upon observation, it is evident that the anomaly mentioned before diminishes as the jet proceeds further downstream. The centerline velocity appears to increase downstream compared to outer edge velocity of the jet and finally assumes a profile analogous to results of conventional rounded nozzles. This is due to turbulent interactions and the momentum acquired from the surrounding streams. The pattern of variation downstream is an indication that radial degradation of velocity is severe further from nozzle exit. It can be inferred that the characteristic curves in Fig. 8 fit between numerical results reported by Kriparaj *et al.* (2018) and experimental results by Anderson *et al.* (2005).

IV. CONCLUSION

The characteristics of a jet emanating from a 4 lobed pointed nozzle were carried out using computational fluid dynamics approach. The results were comparable to works by Kriparaj *et al.* (2018) and Anderson *et al.* (2005). The velocity decay near the nozzle exit is comparatively more in the axial direction when compared to smooth corrugated design. However, the radial velocity profile emerges analogous in both cases with a little variation. The centerline velocity improves downstream as a consequence of momentum gain from surrounding streams. The radial velocity profiles at different locations as described in Fig. 8 lies between curves reported in smooth corrugated 4 lobed nozzles and conventional rounded nozzles.

ACKNOWLEDGEMENT

The authors would like to thank the reviewers for their suggestions and declare that they have no conflicts of interest.

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