ISSN 2395-695X (Print)
ISSN 2395-695X (Online)

International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

Computational analysis of co-flow jets from elliptical nozzle

G Kavitha[1], Rajeswary Gopal[2], Dr. S. Thanigaiarasu[3]
[1, 2, 3] Department of Aerospace Engineering
Madras Institute of Technology, Chennai, India
Kavithakrishnan9295@gmail.com, Rajeswary09.g@gmail.com, sthanigaiarasu@mitindia.edu

Abstract— **The study has been motivated by the increasing interest in the usage of non-circular geometries in modern applications such as propulsion and combustion chambers, power-producing gas turbines and industrial mixing appliances. In this paper, the coaxial circular nozzle and nozzle with primary as elliptical and secondary as circular has been designed and analysed using CATIA V5 and ANSYS V15.0 software for a Mach number range of 0.6 to 1 with secondary sub-sonic flow. The Mach number contours for both the models were investigated along the flow. The primary elliptical nozzle results in more turbulence which in turn decreases the potential core length when compared to the primary circular nozzle.**

Index terms - co-axial nozzle, subsonic flow, potential core

NOMENCLATURE

D	Nozzle exit diameter
X/D	Axial position
R/D	Radial position
M	Local Mach number
M_e	Jet Mach number at primary nozzle exit

I. INTRODUCTION

A jet is a coherent stream of fluid that is injected into a surrounding medium, usually from some nozzle, aperture or orifice. A co-flow jet is formed by flow issuing from a nozzle into a medium which is also moving in a certain velocity. The outer secondary flow protects the central inner flow from being dissipated easily. Instead of dissipation of the inner jet the outer jet dissipates protecting the central jet. So because of this phenomenon, the potential core of the Co-flow nozzle is longer than that of a single jet.

Coaxial jets are utilised in a number of devices throughout the world. The hot supersonic jets exhausting from the engines of high speed aircraft are powerful noise generators, especially during takeoff which is one of the major technological hurdles facing the supersonic air transport. In general, today's aircraft engines possess dual stream jets in which a hot high speed primary flow is surrounded by a cold secondary flow.

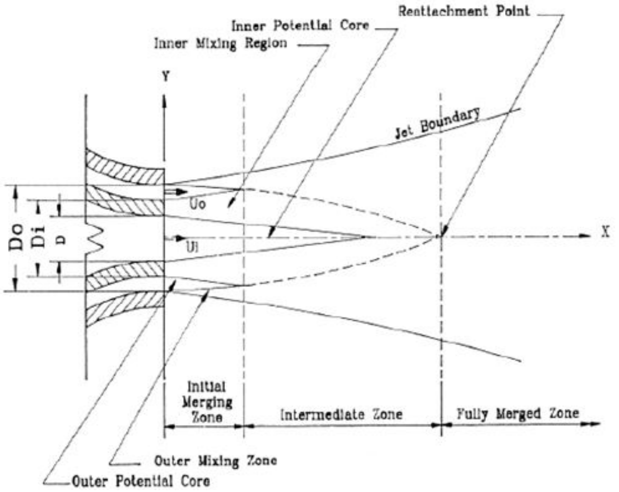

Fig 1.1 Structure of Co-flow jet

In many industrial applications, especially in ejectors and propulsive jets, most of the dynamical behavior of the system is strongly influenced by the mixing efficiency of the jet. This is particularly the case when dilution of hot propulsive jets is required, for example to reduce the infra red signature of military aircraft. Many control strategies have been proposed to improve the mixing efficiency of free shear flows, from the very simple but higher mixing rate pressure loss is higher. In order compensating these mixing rate with minimum pressure loss non circular geometry have been used.

II. LITERATURE SURVEY

[1]**E. Rathakrishnan & Pinnan Lovaraju (2011)** has done **"Experimental studies on subsonic and supersonic co-flow jets"**. It is found that the co-flow retards the mixing of the primary jet, leading to potential core elongation. The characteristics decay of the jet is also retarded in the presence of co-flow. With co-flow core length elongation of 40% and 80% were achieved for correctly expanded and under expanded (NPR 7) sonic jets, respectively. Shadowgraph pictures shows that the co-flow is effective in preserving the shock-cell structure distance of the inner jet,

making the jet to propagate to a greater axial distance which otherwise would have decayed faster.

[2]**Erina Murakami and Dimitri Papamoschou** have worked on the **"mixing layer characteristics of coaxial supersonic jets" (AIAA Journal, 2001-0668, Jan 2001)**. They have tried on the experimental results on mean flow development and mixing layer characteristics of single and dual-stream compressible air jets. The results are relevant to noise emission and mixing enhancement of high-speed turbulent jets. In the dual-stream jets, the primary flow was fixed at Mach number 1.5 and the secondary stream was supplied at various subsonic Mach numbers and from a variety of nozzles. Coaxial and eccentric nozzle configurations were investigated. In the coaxial arrangements, the secondary flow reduces the growth rate of the primary shear layer and elongates the primary potential core and the supersonic region of the jet. The eccentric configuration shows substantial improvement in mixing over the coaxial case and achieves an entrainment rate comparable to that of the single jet when the thickness of the secondary flow is relatively small. In the eccentric case, the maximum observed elongation of the primary potential core was 20% relative to the single jet case. An empirical model for predicting the primary and secondary potential core lengths of a coaxial jet is proposed.

[3]**Abel Vargas and Ahsan R. Choudhuri** together has done a work on **Characteristics of elliptic co-axial jets.** They have studied the effects of an elliptic co-flow on a circular inner jet, the near-field flow characteristics of a turbulent elliptical coaxial jet. A dependence on the outer structures with different velocity ratios is observed in the elliptical co-flow jet. Observed that a non-axi-symmetric coaxial nozzle exhibits distinct flow characteristics in the minor and major plane. These flow characteristics produce more intense mixing which is favourable in combustion processes and propulsion applications.This paper numerically investigates the effect of elliptical primary nozzle on co-flow characteristics for sunsonic and sonic Mach numbers.

III METHODOLOGY

A. *GEOMETRY*

CIRCULAR COAXIAL NOZZLE

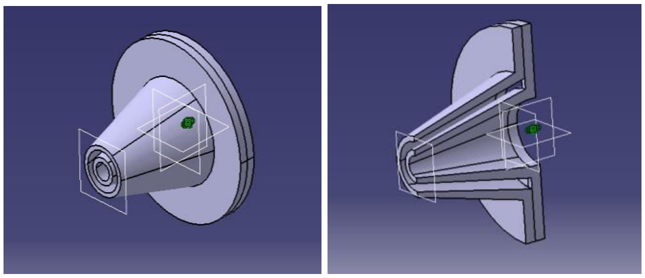

Fig. 3.1 Isometric view and cut section view of circular coaxial nozzle.

	Inlet Diameter(mm)	Exit Diameter (mm)
Primary Nozzle	30	10
Secondary Nozzle	32	22.5

Table 2.1 Circular nozzle specification

ELLIPTICAL COAXIAL NOZZLE

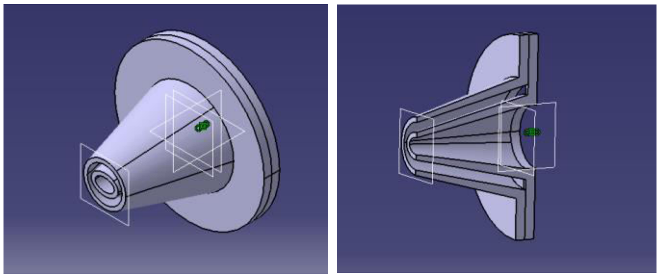

Fig 3.2 Isometric view and cut section view of circular co-axial nozzle.

	Inlet Diameter(mm)	Exit Diameter(mm)
Primary Nozzle	30	Major axis = 12.5 Minor axis = 8
Secondary Nozzle	32	22.5

Table 2.1 Elliptical nozzle specification

B. *COMPUTATIONAL METHODS*

Computational fluid dynamics is the science of predicting fluid flow, heat and mass transfer, chemical reactions and related phenomena by solving numerically the set of governing mathematical equations such conservation of mass, momentum, energy, species etc., Headway in the field of CFD simulations is strongly dependent on the development of computer related technologies and on advancement of our understanding and solving ordinary and partial differential equations (ODE and PDE). These equations are together represented as a Navier-Stokes Equation which can effectively be used to depict any single phase fluid flow problem.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}[\rho u_j] = 0$$

$$\frac{\partial}{\partial t}[\rho u_i] + \frac{\partial}{\partial x_j}[\rho u_i u_j + p\delta_{ij} - \tau_{ji}] = 0$$

$$\frac{\partial}{\partial t}[\rho e_o] + \frac{\partial}{\partial x_j}[\rho u_i e_o + u_j p - q_j - u_j \tau_{ji}] = 0$$

Where, x_j indicates Cartesian co-ordinates (j =1, 2, 3), u_j indicates Cartesian velocity components, p is pressure, is density, indicates viscous stress terms, e0 is the energy term, qj indicates heat flux, and is the Kronecker delta term.

CFD analysis also reduces the total effort required in the experiment design and data acquisition. The future relevance of CFD will depend on how accurate complex flows can be calculated. Since many flow of engineering interest are turbulent, the appropriate treatment of turbulence will be crucial to the success of CFD. Solving CFD problem usually consists of four main components: Geometry and grid generation, setting up a physical model, solving it and post processing the computed data.

The three steps involved in CFD, are pre-processing, processing and post-processing,

- **Pre-processing**: The physical setup of the model is created along with the specification of the different boundaries, their nature and fluid types. It can be sub-divided into

– Volume creation, where the physical dimensions of the model are defined. In this problem volume creation is done using CATIA design tool and then it is imported to pre-processing.

– Meshing of the volume, where the domain is divided into cells for solving the discretised problem. In this study meshing is done using ICEM-CFD and solved using cfx.

C. MESHING

The modelled flow domain is then taken for meshing where the domain is divided into cells for solving the discretized problem. ICEM CFD is used to mesh the geometry. For an accurate representation of the flow field, sufficient grid density must be provided in the mixing region.

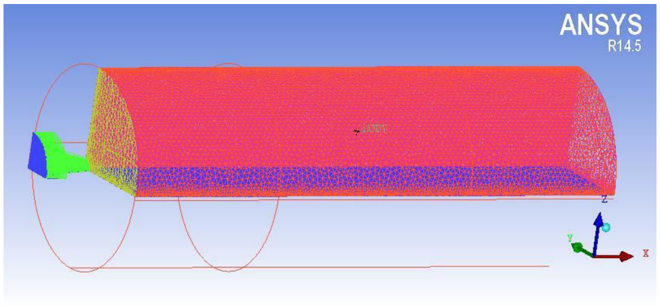

Figure 3.3 Meshed model of circular nozzle

- **Processing**: The simulation is initiated and the PDEs are solved as a steady state or as an unsteady flow problem, as required. In this study the problem is steady state.
- **Post-processing**: The solution thus obtained is then analysed, generally by exporting the data for further calculations.

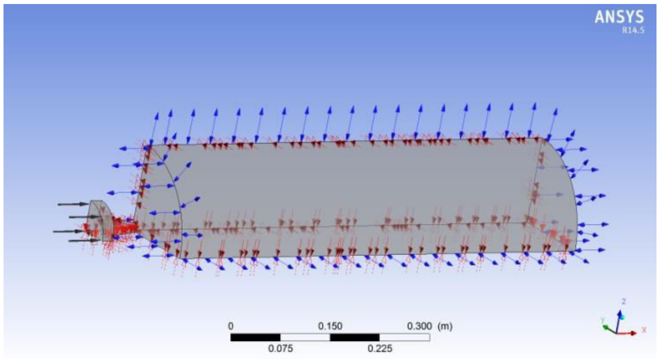

Figure 3.4 Isometric views of boundary conditions given

IV. RESULTS AND DISCUSSION

Centre line pressure decay or velocity decay or Mach number decay can be taken as an authentic measure for the analysis. The results for various configurations have been discussed here. From the analysis it has been noticed that the potential core length has been reduced. Moreover the mixing of the jet has been enhanced. The central core of jet where the exit velocity is preserved up to some axial distance is called as potential core length. The formation of potential core length is visualised in the non dimensionalised Mach number plot as shown in figures 4.1-4.3.

The analysis was carried out for Mach numbers 0.6, 0.8 and 1 till the solutions get converged. The model analysed were used to study the effect of potential core length by varying the primary flow Mach number.

The Mach number decay along the radial and central line has been studied and the reduction in potential core length has observed. The obtained results are comparison of Mach number variation along the central line and radial decay along y and z axis results for the models.

The Mach profile of the flow by varying the Mach number between 0.6 and 1 are shown in the figures 4.1-4.3. It may be observed that for all subsonic and sonic primary jets, the circular jet - primary, exhibits inhibited potential core whereas the jet issued from the non-circular nozzle reduction in potential core. For example, potential core for circular jet for Mach 0.6 is about six times the nozzle diameter whereas for non circular jet, the potential core was reduced to four times the nozzle diameter and decay also seems to be faster for the non-circular jets as compared to circular jets.

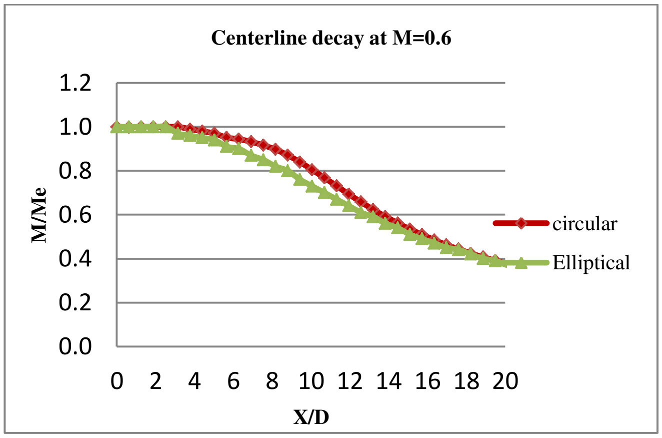

Figure 4.1 Centreline decay comparison along jet axis for Mach number 0.6

Similar trend was observed for other two Mach numbers 0.8 and 1.0. This may be due to the fact that, elliptical nozzle , The irregularities along the perimeter of these non-standard jets can lead to strong self-induction and instability of vertical structures, which in turn alter the development of the jet as it interacts with the secondary. This means that a structure with variable curvature will have different downstream velocities at different points along its perimeter, and will thus deform out of its original plane. The initial process of deformation will further alter the curvature of the structure, feeding back into the local velocities. In the case of an isolated elliptical vortex ring, the velocity is thus initially higher at the major axis ends of the ring. These inabilities lead to enhanced mixing and reduction in potential core for non-circular jets, in particular elliptical jets.

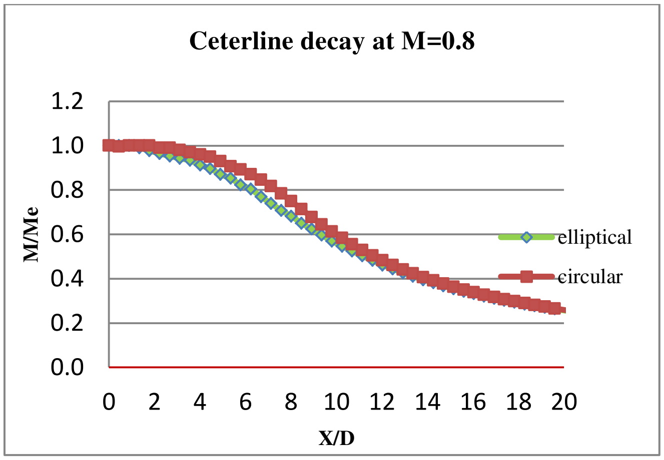

Figure 4.2 Centreline decay comparison along jet axis for Mach number 0.8

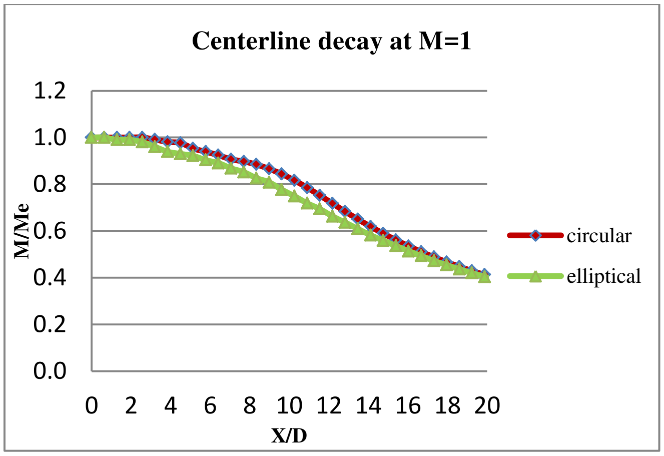

Figure 4.3 Centerline decay comparison along jet axis at Mach 1

From figure 4.4 to 4.9 shows the radial decay of elliptical nozzle at various radial locations along y and z axis. The potential core decay is visible along both the axis. For elliptical nozzle shows the variation in decay different in y and z axis.

For 0.6 Mach number the variation along y and z shows difference in decay due to the non circular geometry. Similar tread in followed along y and z axis. Similar trends are followed in 0.8 and 1 Mach.

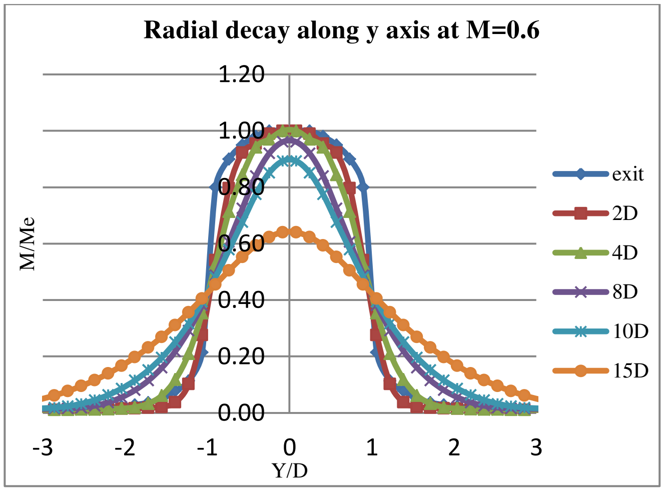

Figure 4.4 Radial decay of elliptical nozzle along y axis at Mach 0.6

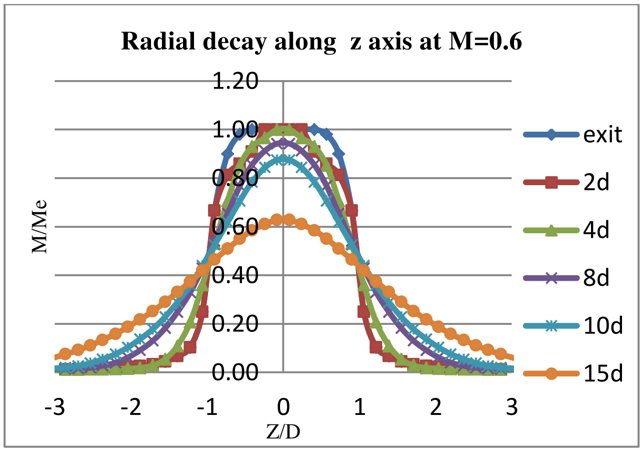

Figure 4.5 Radial decay of elliptical nozzle along z axis at Mach 0.6

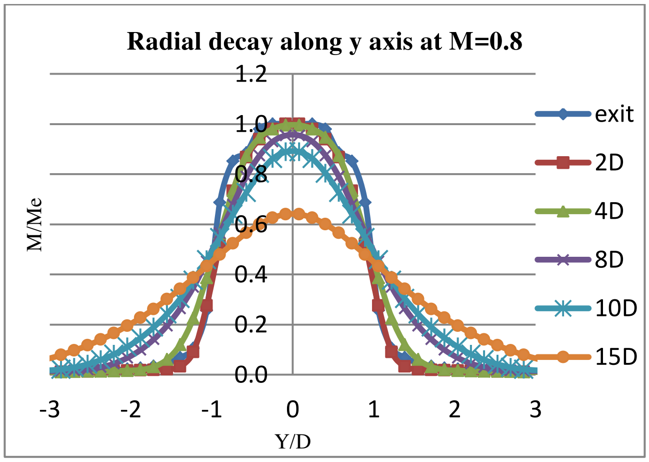

Figure 4.6 Radial decay of elliptical nozzle along y axis at Mach 0.8

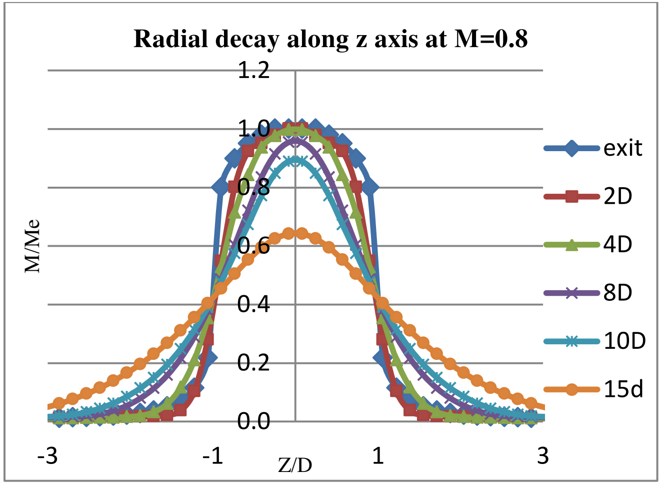

Figure 4.7 Radial decay of elliptical nozzle along z axis at Mach 0.8

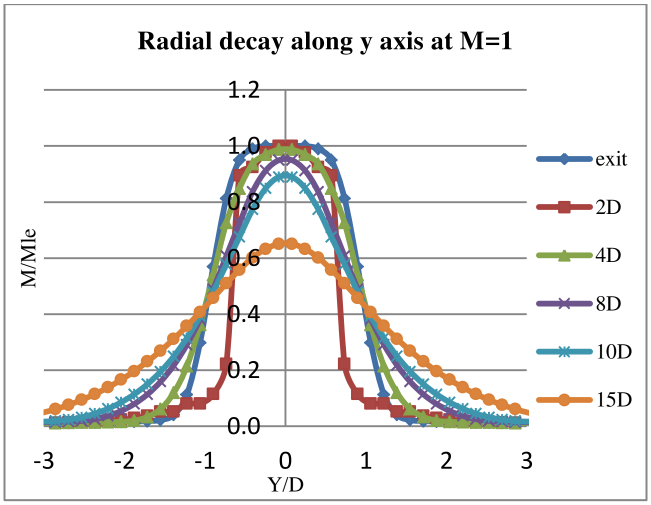

Figure 4.8 Radial decay of elliptical nozzle along y axis at Mach 1

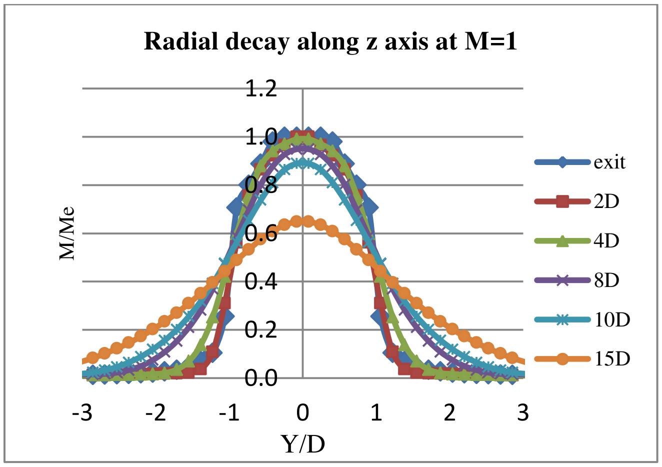

Figure 4.9 Radial decay of elliptical nozzle along z axis at Mach 1

VELOCITY CONTOURS FOR VARIOUS CO-FLOW MODELS

Iso-Mach contours for various subsonic and sonic Mach numbers are shown in the Figure 4.4 to 4.6 for circular jets and from Figure 4.7 to 4.9 for non-circular jets. It was observed that for circular primary nozzle the potential core is predicted to extend as the outer jet protects the inner jet as seen from the figures 4.4 to 4.6. It is observed from the figures 4.7 to 4.7 for non-circular elliptic nozzle that the Mach contours appears at the earlier stages as compared to the circular nozzles. This is attributed to the fact that vortical structure formed at the elliptical nozzle is stronger as compared to the circular nozzle which is responsible for enhanced mixing.

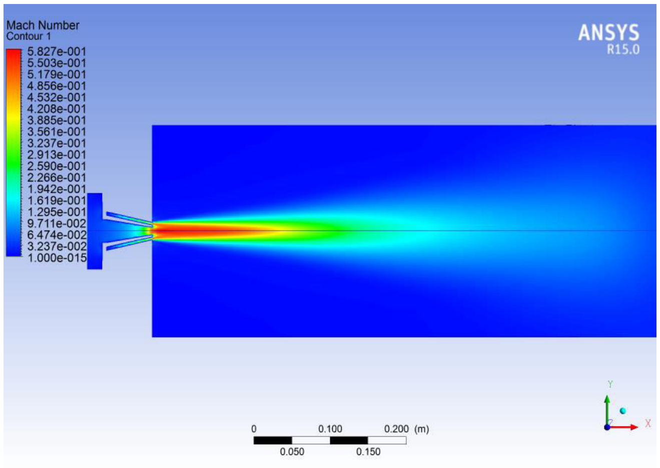

Figure 4.4 Mach number contour of Circular co-axial nozzle at Mach number 0.6

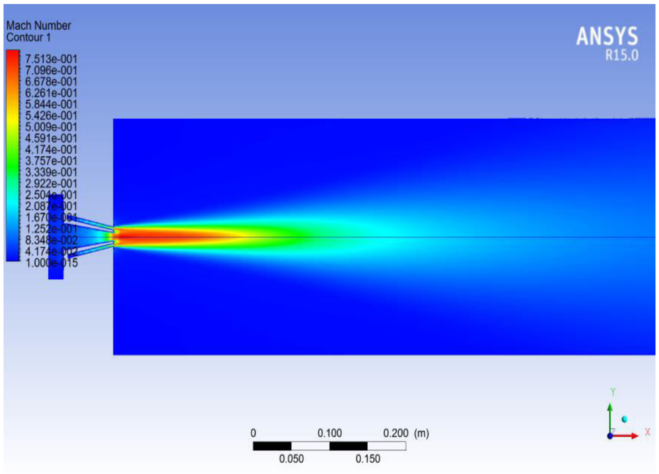

Figure 4.5 Mach number contour of Circular co-axial nozzle at Mach number 0.8

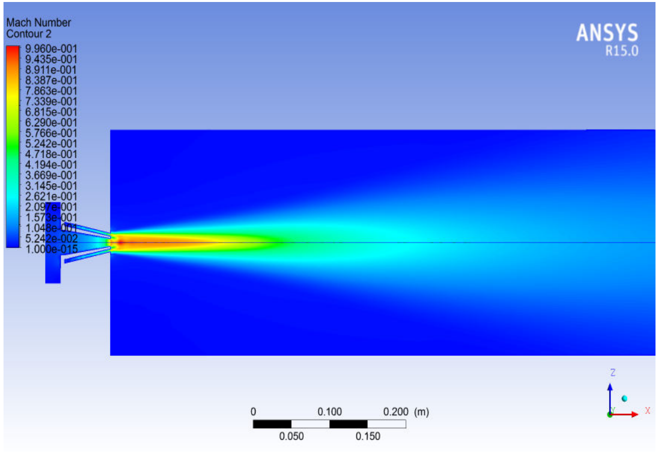

Figure 4.6 Mach number contour of Circular co-axial nozzle at Mach number 1

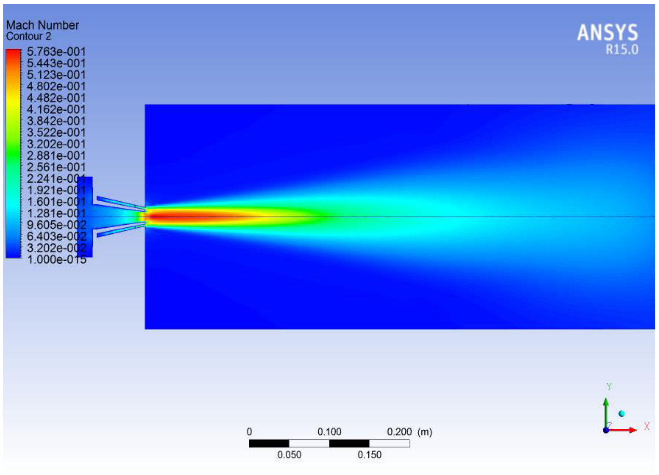

Figure 4.7 Mach number contour of Elliptical co-axial nozzle at Mach number 0.6

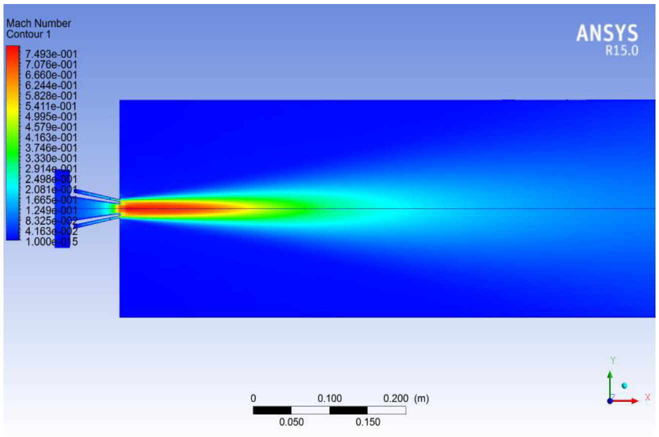

Figure 4.8 Mach number contour of Elliptical co-axial nozzle at Mach number 0.8

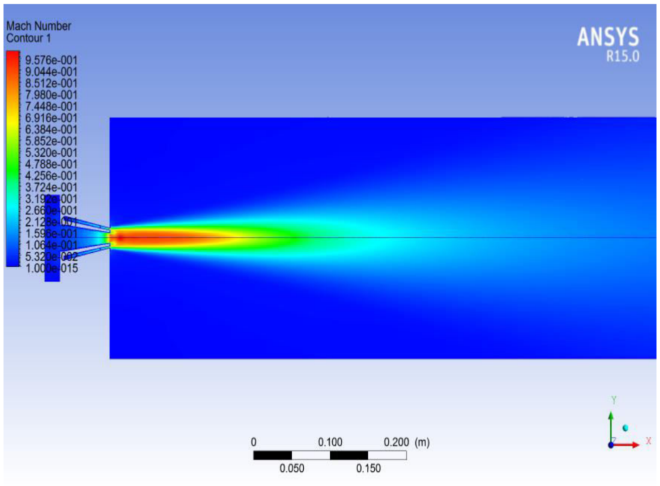

Figure 4.9 Mach number contour of Elliptical co-axial nozzle at Mach number 1

V. CONCLUSION

The overall inference obtained from the above results is, introducing elliptical as primary nozzle affects the jet characteristics. The potential core length decreases for non circular primary nozzle than a circular nozzle. The potential core length for the co-flow with elliptical primary nozzle is lesser than the circular one for the same total pressure. The effects are visible along the z and y axis of elliptical nozzle. Reduction in potential core length a measure of enhanced mixing which is due to the effect of non circular geometry introduced at primary nozzle in the co-flow jet arrangement. The geometry of the primary nozzle play crucial role in dictating the co-flowing jet characteristics.

REFERENCES

[1] Pinnam Lovaraju · E. Rathakrishnan “Experimental Studies on Co-flowing Subsonic and Sonic Jets” Flow Turbulence Combust.,Springer Science+Business Media B.V. 2011
[2] Erina Murakami and Dimitri Papamoschou.,”Mixing layer characteristics of co axial supersonic jets”AIAA Journal 2000-2060
[3] Abel Vargas and Ahsan R. Choudhuri “Characteristics of elliptic co-axial jets”Electric Power 2003
[4] Erina Murakami and Dimitri Papamoschou.,”Mean flow development in dual stream compressible jets”AIAA Journal Vol.40 No.6,June 2002
[5] P. Manivannan, P.K.Dash, B. T. N. Sridhar, “An Experimental Study on comparison of Non-circular Co-flow Jet with Co-axial Jets and Computational Verification”, (Space Research Journal 4 (2): 60-70, 2011)
[6] Erina Murakami and Dimitri Papamoschou.,” Eddy Convection in Coaxial Supersonic Jets” AIAA journal Vol. 38, no. 4, april 2000

N.W.M. Ko and A.S.H. Kwan, Experimental Investigation of Subsonic Coaxial Jets. Fifth Australasian Conference, December 1974

.