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Numerical Investigation of Effect of Swirl Flow in Subsonic Nozzle

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Abstract:
This paper presents numerical investigation of swirling flow through convergent nozzle. The objective of this paper is to determine the exit velocity, thrust and mass flow of the convergent nozzle with respect to Swirl flow passes through it. In this present study swirling flow is induced by axial vane swirler before the entrance region of the convergent nozzle and it is static component which produces medium swirl flow and swirl angle is 30^0. Three dimensional models are developed using CATIA and meshed in ANASYS. Using FLUENT solver problem is solved and required results are obtained and compared. It shows a variations and increase in exit velocities compared with nozzle without swirler.

Key words: *axial vane swiler; convergent nozzle ; exit velocity;*

1. Introduction

The introduction of swirl ahead of the nozzle entrance is currently used or proposed in a variety of practical applications. Most of these applications utilize swirl to regulate the mass flow. Swirling flow in nozzles occurs in number of important propulsion applications, including the flow in turbofan and turbojet engines, spin-stabilized rockets and integral rockets, ramjets. In the first two cases, the tangential velocity component is induced by the motion of the turbine blades and by the rocket spin, respectively. Swirling flow occurs in many rockets especially spin stabilized rockets, jet engines, plasma jets to stabilize the arc, vortex valves, industrial furnaces(vortex burners), and cyclone separators and wing tip vortices, mixing equipment and number of existing or projected applications in the newer technologies. These include turbo machinery with supersonic internal flow. Particularly intriguing is the proposal to replace a mechanically variable throat area by a device which imparts swirl to the fluid, thereby varying the mass flow and the thrust sonic velocities may be reached in regions of the flow. The behavior of swirling flow is thus of some practical importance.

Despite the interest created by these applications, the mechanics of swirling flow are not clearly understood, especially with respect to the passage of the flow through the convergent nozzle. To determine the exit velocity, mass flow and thrust of convergent nozzle with respect to medium swirl flow passage through nozzle, this present study is carried out. Mainly in spin conditions rockets swirl occurs and most of study are carried out for the rocket nozzles i.e., de Laval nozzle or convergent-divergent nozzle. Swirling flow, which are highly complex, have the characteristics of both rotating motion and free turbulence encountered as in jets wake flows. Swirling flows in both reacting and non reacting conditions occur in a wide range of such as gas turbine, marine combustor, burners, chemical processing plants, rotary kilns and spray dryers, swirling jets are used as a means of controlling flames in combustion chambers. We knew and assume that the flow path through the any type of nozzle is straight and uniform or parallel to each other, to understand what happens if the path of the flow through the convergent nozzle section is rotational. In this investigation inducing swirl flow before the nozzle is important factor. Some Surveys are carried out to get an ideology. James I. Batson determined the effect of swirl on the flow field; thrust and mass flow produced by nozzled devices. Swirling flow induced by swirl flow by injecting cold gas tangentially to cylindrical chamber wall [1]. The design of vanes for the present study is also based on study of R Thundil Karuppa Raj & V Ganesan presented the details of experimental procedure and measurement made in an axisymmetric swirler. His swirler model produces good recirculation zone [3].

The selection and design of nozzle are important parts of this investigation most of papers are investigated swirl flow through the Convergent Divergent nozzle and David J Norton investigated the converge section of nozzle at three different angles and concluded that effect of swirl flow can be reduced by decreasing the contraction ratio of the nozzle [2]. And A.N.Broujerdi, A.Kerbriaee presented the boundary layer thickness depends only on nozzle angle, Reynolds number [3]. It is also found that pressure distribution decreases drastically near the outlet of the nozzle about 100 percent in average in different conditions. The nozzle with low contraction ratio is selected in present study. This investigation consists of computational method. There are two

3D models are analyzed (i) nozzle with swirler (ii) nozzle without swirler are developed and solved. Required results are obtained and compared.

2. Model Development

The whole model is designed using CATIA part workbench. The cumulative design data has been collected from various sources and designing is done. The models that considered are drawn in three dimensional, axi-symmetric nozzles. There are two three dimensional models are developed for the present study to understand the effect of swirl flow through a convergent nozzle and results are compared results, first model is nozzle with swirler also called as swirler nozzle and nozzle without swirler are developed and designed using CATIA. In the both models dimensions of cylinder and convergent nozzle are same as shown in figures (2&3). Swirl flow induced by axial vane swirler, the design details based on R Thundil Karuppa Raj & V Ganesan [3](all dimension in mm).

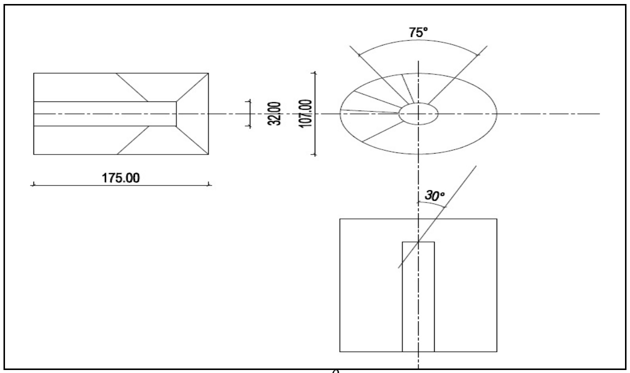

Figure: 1. Details of 30^0 Axial Vane Swirler

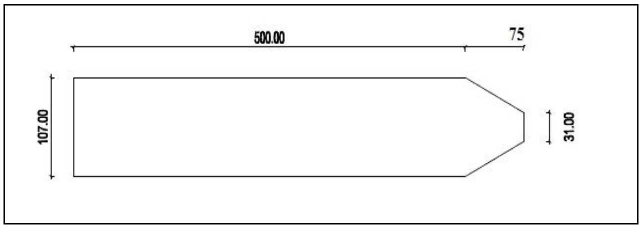

Figure: 2. Geometry of Cylinder and Nozzle

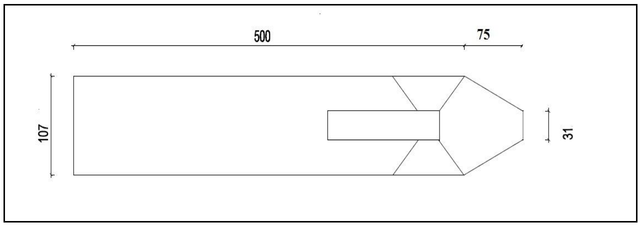

Figure: 3. Geometry of Nozzle with Swirler

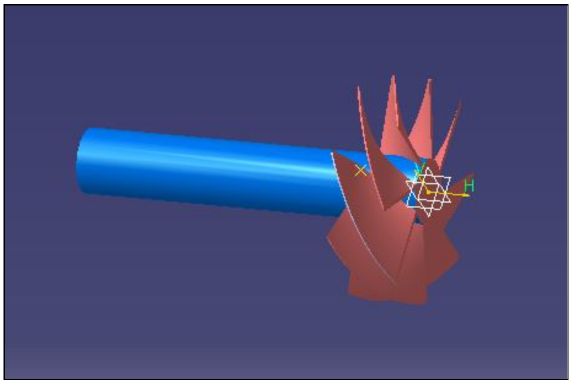

Figure: 4. Isotropic View of Axial Vane Swirler

3. Computational Method

3.1. Flow domain and grid

The flow domains are created and meshed. Grid type is unstructured. The total number of tetrahedral cells is 98,492.

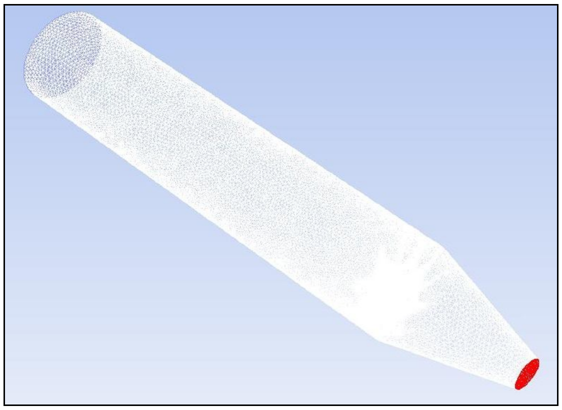

Figure: 5. Meshing Grid of Nozzle with Swirler Model

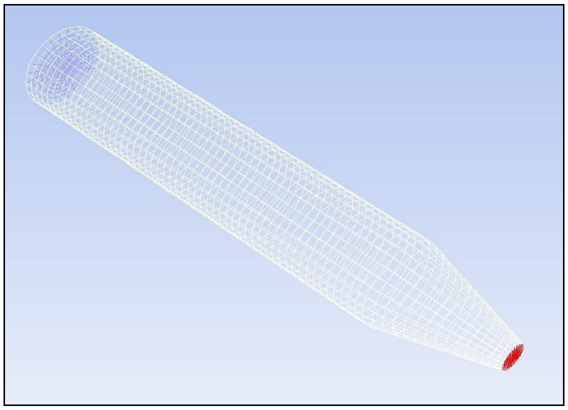

Figure: 6. Meshing Grid of Nozzle Model

3.2. Numerical method and solver features

The 3D flow was assumed to be incompressible and subsonic. The CFD code Fluent was used in order to solve the discretized governing equations. A steady state pressure based solver was used to solve the governing equations and the semi implicit method for pressure/velocity coupling. At the inlet of the computational region, the inlet boundary condition is defined as velocity inlet while the exit boundary is defined as pressure outlet. The problem is solved at 20 m/s as inlet velocity.

4. Result Discussion

A three dimensional flow field analysis is carried out using FLUENT. The two different models are analyzed and required results are obtained and compared with each other. From the comparison of both results it is observed that exit velocity of the nozzle with swirler is higher when compared with regular nozzle. Various parameters such as static pressure, exit velocity, tangential velocity, axial velocity, radial velocity and thrust are predicted at outlet of the nozzle. The following values are obtained from FLUENT results. Table shows the comparison between nozzle with swirler and nozzle of required parameters.

5. Velocity Magnitude

At the three different inlet velocities problem is solved. There is a constant increase in the velocity magnitude of the fluid as we move from the inlet to outlet for the swirler nozzle and for the nozzle. Axial velocities of both models seem to be decreasing with increase in inlet velocities. Tangential velocities of nozzle without swirler increases slightly with increase in inlet velocities. But in the case of swirler nozzle tangential velocity increase slightly at inlet velocity 25m/s and 30 m/s and drops to negative at inlet velocity 35 m/s. comparison of swirler nozzle and nozzle for the three inlet velocities are shown (table no. 1,2 & 3).

6. Thrust Calculation

The thrust is the important parameter in the nozzle. In this thrust calculation momentum thrust only considered.

Thrust = $(c_{j} - c_{i})$

Where,

$\dot{m}$ - Mass flow rate, c_{j} – Final velocity, c_{i} – Initial velocity

INLET VELOCITY AT 25 m/s			
NOZZLE		SWIRLER NOZZLE	
Axial velocity	-0.3105 (m/s)	Axial velocity	-0.1292 (m/s)
Tangential velocity	0.1066 (m/s)	Tangential velocity	0.0225 (m/s)
Exit velocity	253.347 (m/s)	Exit velocity	290.414 (m/s)
Mass flow at inlet	0.27538 (kg/s)	Mass flow at inlet	0.27538 (kg/s)
Thrust	62.88 (n/m)	Thrust	73.09 (n/m)

Table: 1 Comparison between Nozzle and Swirler Nozzle

INLET VELOCITY AT 30 m/s			
NOZZLE		**SWIRLER NOZZLE**	
Axial velocity	-0.3726 (m/s)	Axial velocity	-0.3018 (m/s)
Tangential velocity	0.1284 (m/s)	Tangential velocity	0.4060 (m/s)
Exit velocity	304.013 (m/s)	Exit velocity	349.65 (m/s)
Mass flow at inlet	0.33046 (kg/s)	Mass flow at inlet	0.33046 (kg/s)
Thrust	93.85 (n/m)	Thrust	105.63 (n/m)

Table: 2 Comparisons between Nozzle and Swirler Nozzle

INLET VELOCITY AT 35 M/S			
NOZZLE		***SWIRLER NOZZLE***	
Axial velocity	-0.4350 (m/s)	Axial velocity	-1.0122 (m/s)
Tangential velocity	0.1494 (m/s)	Tangential velocity	-0.1432 (m/s)
Exit velocity	405.93 (m/s)	Exit velocity	354.686 (m/s)
Mass flow at inlet	0.3855 (kg/s)	Mass flow at inlet	0.3855 (kg/s)
Thrust	123.25 (n/m)	Thrust	143.005 (n/m)

Table: 3 Comparisons between Nozzle and Swirler Nozzle

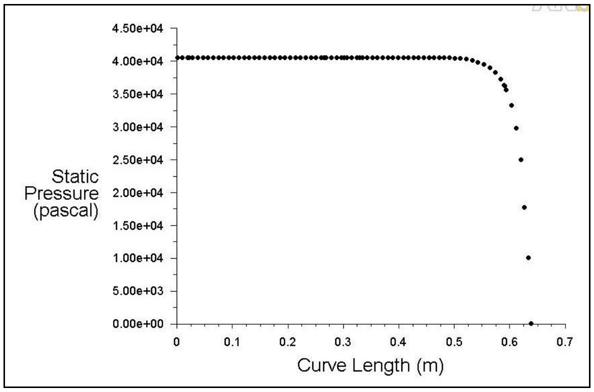

Figure: 7. Static Pressure of Nozzle 25

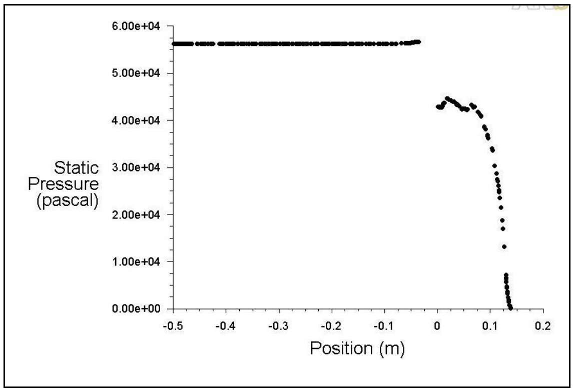

Figure: 8. Static Pressure of Nozzle with Swirler 25

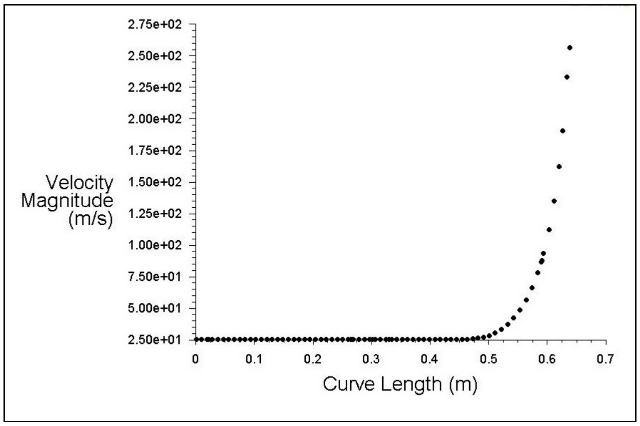

Figure: 9. Velocity of Nozzle 25

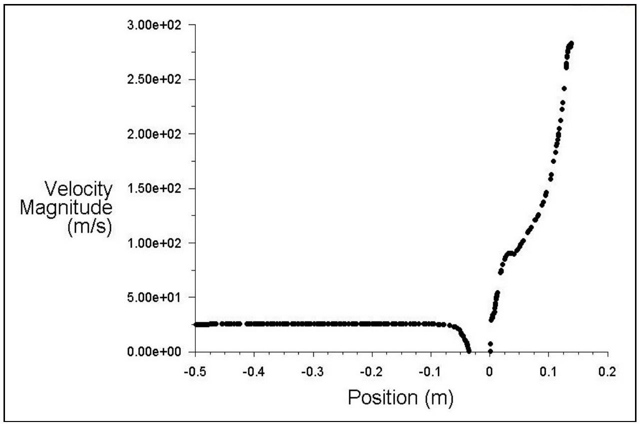

Figure: 10. Velocity of Nozzle with Swirler 25

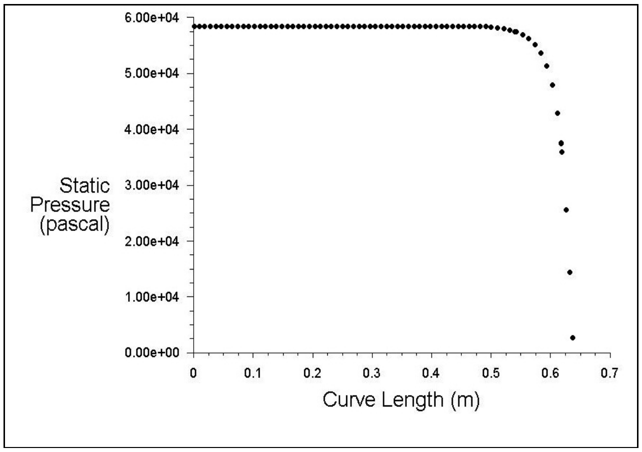

Figure: 11. Static Pressure of Nozzle 30

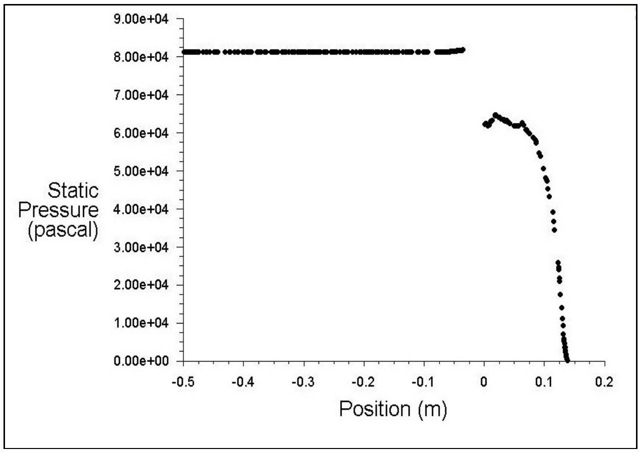

Figure: 12. Static Pressure of Nozzle with Swirler 30

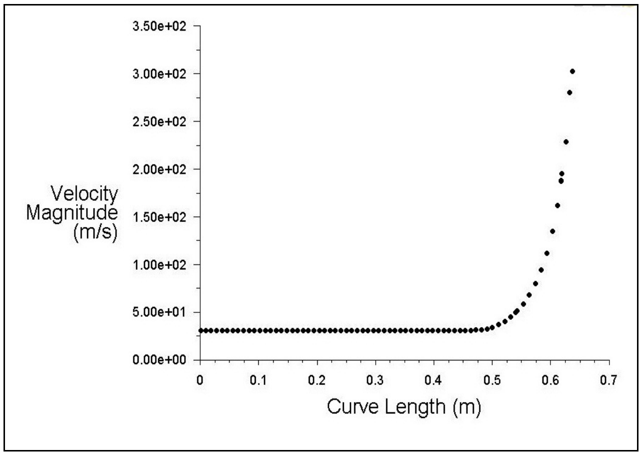

Figure: 13. Velocity of Nozzle 30

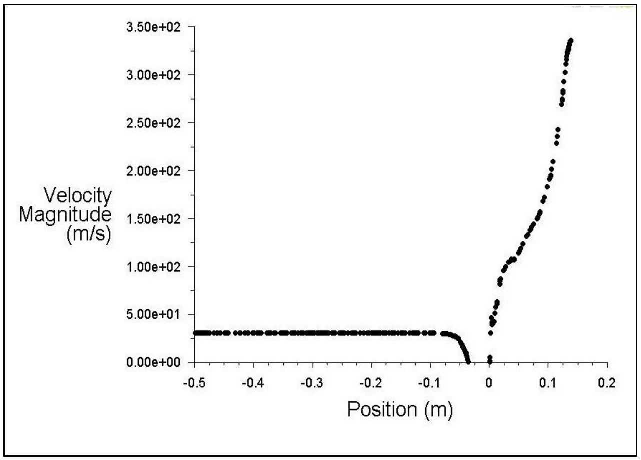

Figure: 14. Velocity of Nozzle with Swirler 30

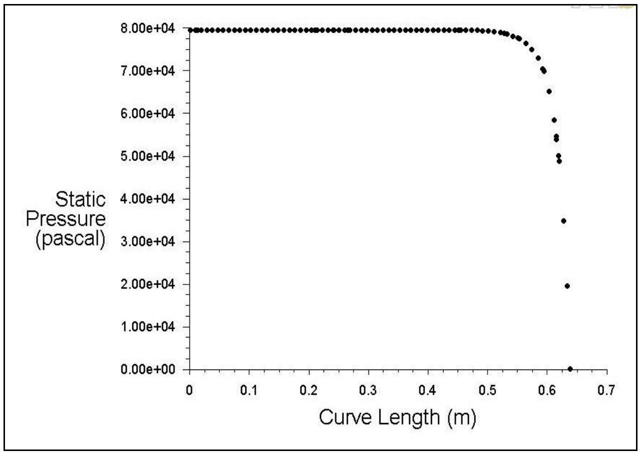

Figure: 15. Static Pressure of Nozzle 35

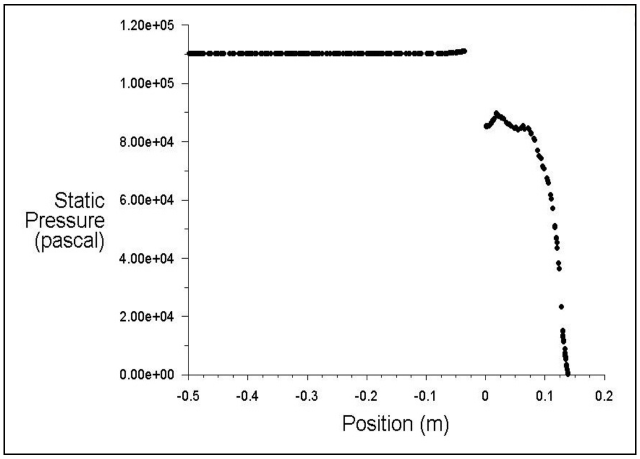

Figure: 16. Static Pressure of Nozzle with Swirler 35

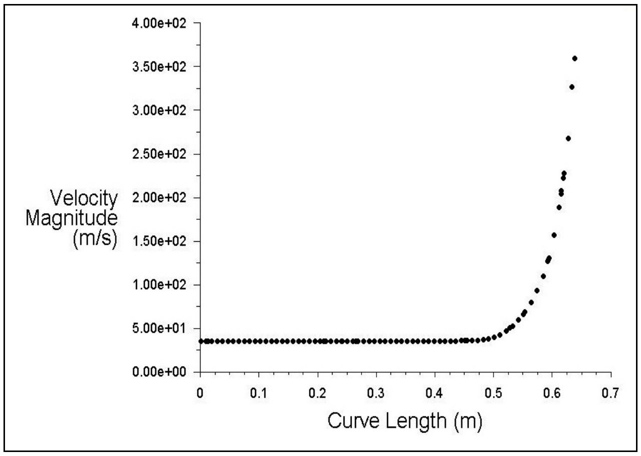

Figure: 17. Velocity of Nozzle 35

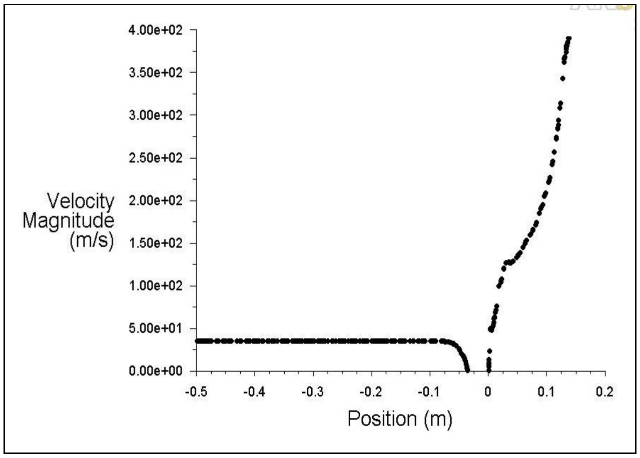

Figure: 18. Velocity of Nozzle with Swirler 35

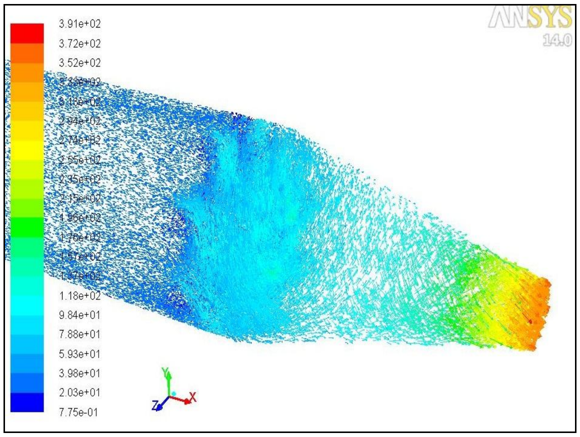

Figure: 19. Velocity Vector of Nozzle with Swirler

7. Conculsio

The effect of swirl flow through a nozzle s predicted successfully and compared with swirler nozzle and nozzle. The results show the thrust produced by swirler nozzle is higher than nozzle without swirler at medium swirl. Present study is carried out for 25 m/s, 30 m/s,35 m/s inlet velocity.

8. References

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