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CFD analysis of De Laval Nozzle Geometry & Reverse Flow Cavitation Phenomenon

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Abstract*: De laval nozzle is a convergent divergent type nozzle which has the ability to convert the chemical energy with high pressure in to kinetic energy with high velocity and low pressure. In other words the device takes in minimal power and delivers tremendous amounts of output power used in jet and rocket engines. The pressure and velocity distribution across the nozzle are very important and they entirely depend on the cross section or the geometry. Reverse flow is caused in the negative pressure gradient region and reverse flow Cavitation is very much useful in under water applications. The present study is focussed on analysis of de laval nozzle geometries and reverse flow phenomenon. The nozzle is designed and analysed in Ansys fluent. Pressure distribution and velocity values are noted down and these are compared with the theory of gas dynamics. The case of reverse flow is also simulated and contours are drawn to the available geometry.

***Keywords*: De laval nozzle , Gas Dynamics , Ansys Fluent , Reverse flow , Jet engines**

I. INTRODUCTION

The de laval nozzle contains throat where the multiplication of velocity takes place due to the minimum flow area and inlet area and exit area. The velocities attained by the jet engines are expressed in terms of Mach number and de laval nozzle should facilitate minimum pressure drop and high velocity. The flow goes from subsonic (M- Mach number <1) to Sonic (M=1) and then to the supersonic (M>1). The back pressure when lowered to a value equal to the pressure at the exit of the nozzle offers a uniform super sonic flow. When the air enters the inlet the high pressure fluid expands over the chamber and reduce its pressure to the pressure existing outside the nozzle . This is design consideration for the nozzles.

A. GOVERNING THEORY

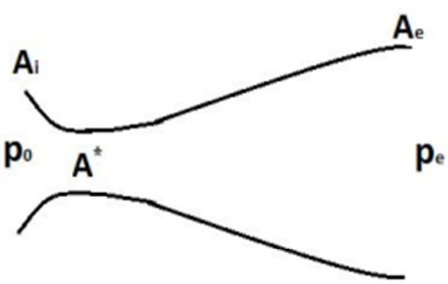

Fig. 1 Flow through convergent divergent duct.

$$\dot{m} = \rho^* u^* A^*$$

Where, ρ^*, A^* and u^* are geometric and flow properties at the throat.

For the steady flow, mass flow rate at any cross-section having geometric and flow properties as ρ, A and u will be equal to the mass flow rate of the throat. Hence,

$$\rho u A = \rho^* u^* A^*$$

$$\frac{A}{A^*} = \frac{\rho^* u^*}{\rho u} = \frac{\rho^*}{\rho_0}\frac{\rho_0}{\rho}\frac{u^*}{u} = \frac{\rho^*}{\rho_0}\frac{\rho_0}{\rho}\frac{a^*}{u}$$

$$\left(\frac{A}{A^*}\right)^2 = \left(\frac{\rho^*}{\rho_o}\right)^2\left(\frac{\rho_o}{\rho}\right)^2\left(\frac{a^*}{A}\right)^2$$

$$\frac{\rho_0}{\rho} = \left[1 + \frac{(\gamma-1)}{2}M^2\right]^{\frac{1}{(\gamma-1)}}$$

$$\frac{\rho_0}{\rho^*} = \left[\frac{(\gamma+1)}{2}\right]^{\frac{1}{(\gamma-1)}}$$

$$\left[\frac{u}{a^*}\right]^2 = M^{*2} = \frac{\frac{(\gamma+1)}{2}M^2}{1 + \frac{(\gamma-1)}{2}M^2}$$

Hence the area relation can be written as,

$$\left[\frac{A}{A^*}\right]^2 = \frac{1}{M^2}\left[\frac{2}{(\gamma+1)}\left(1 + \frac{(\gamma-1)}{2}M^2\right)\right]^{\frac{(\gamma+1)}{(\gamma-1)}}$$

COMPUTATIONAL MODELLING USING ANSYS

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B. Cad modelling

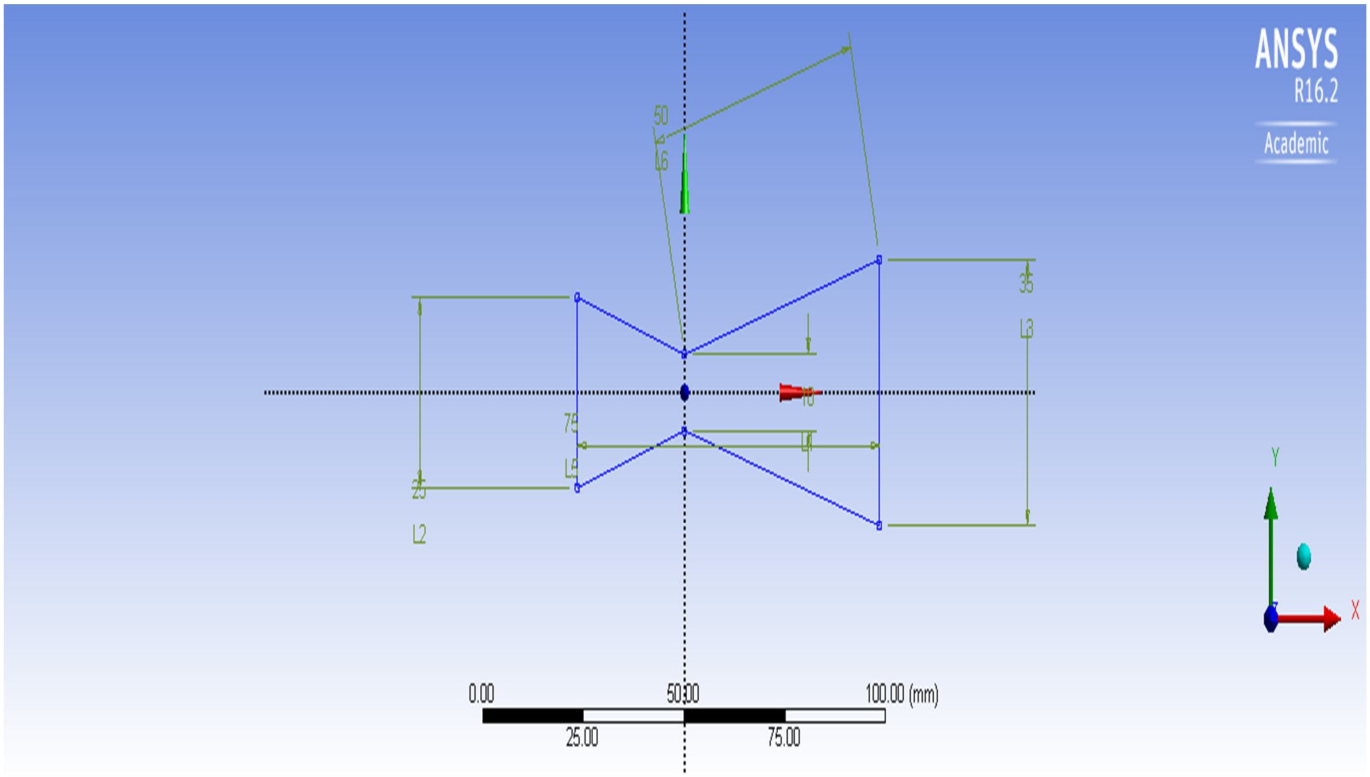

Fig 2. Cad modelling of nozzle

C. MESHING

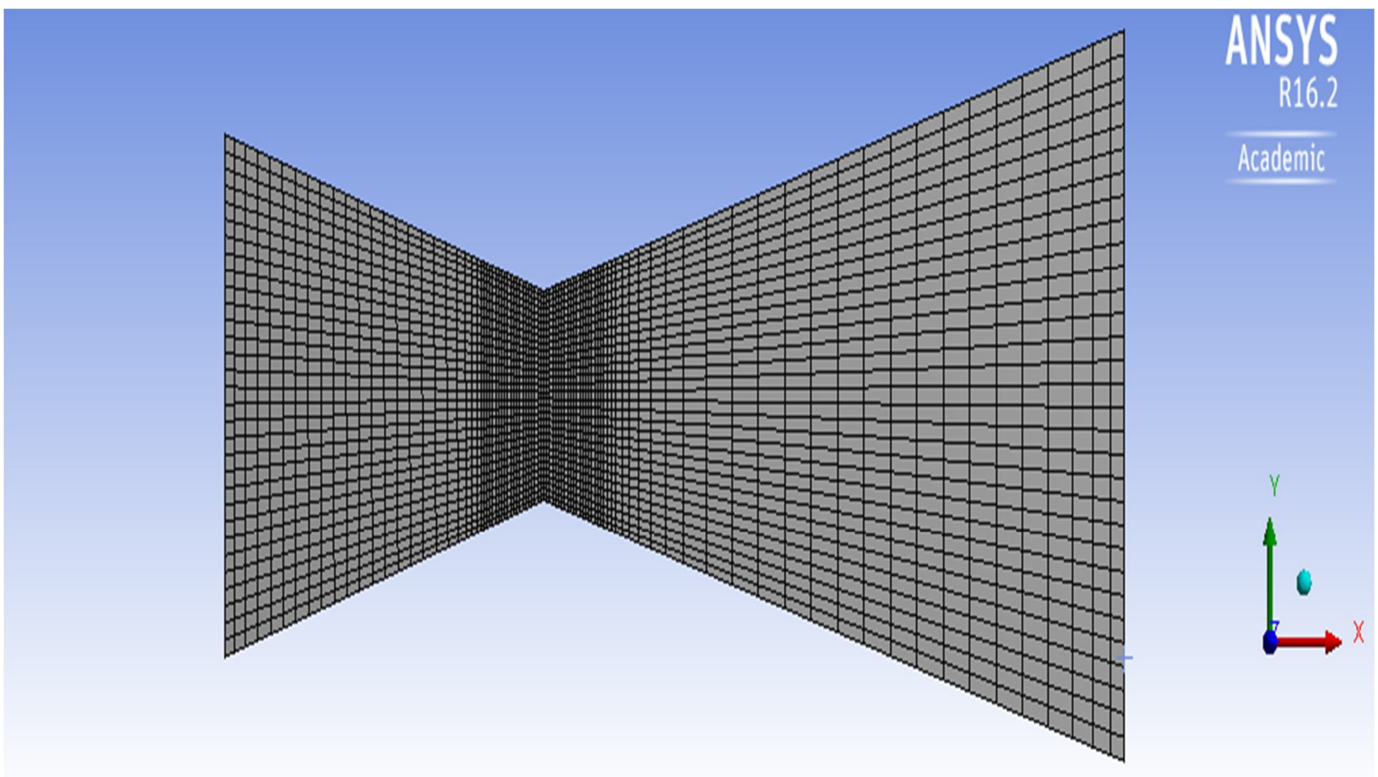

Fig 3 Meshing of C D nozzle

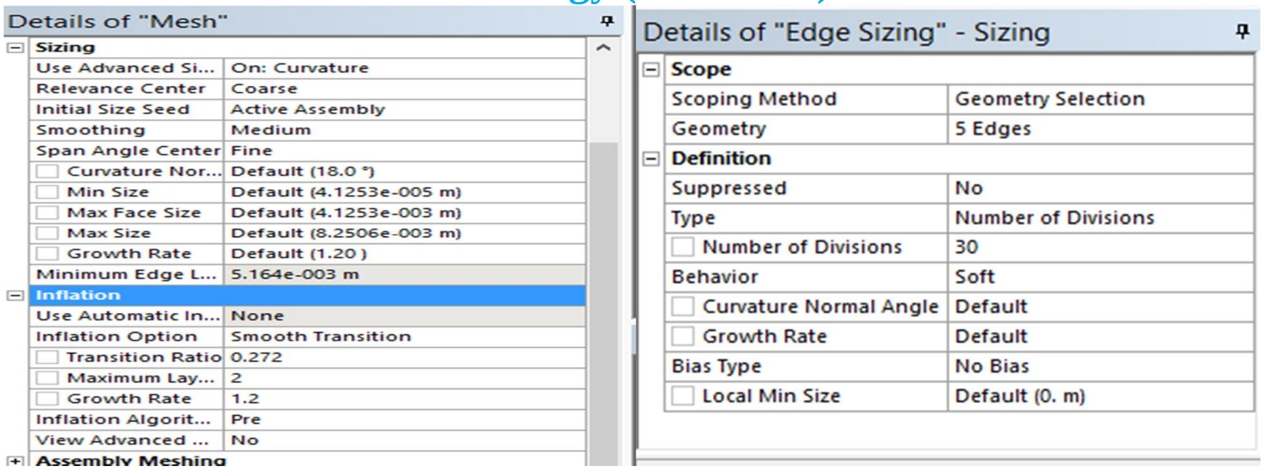

Fig 4 Meshing attributes of the nozzle

D. PRE-PROCESING

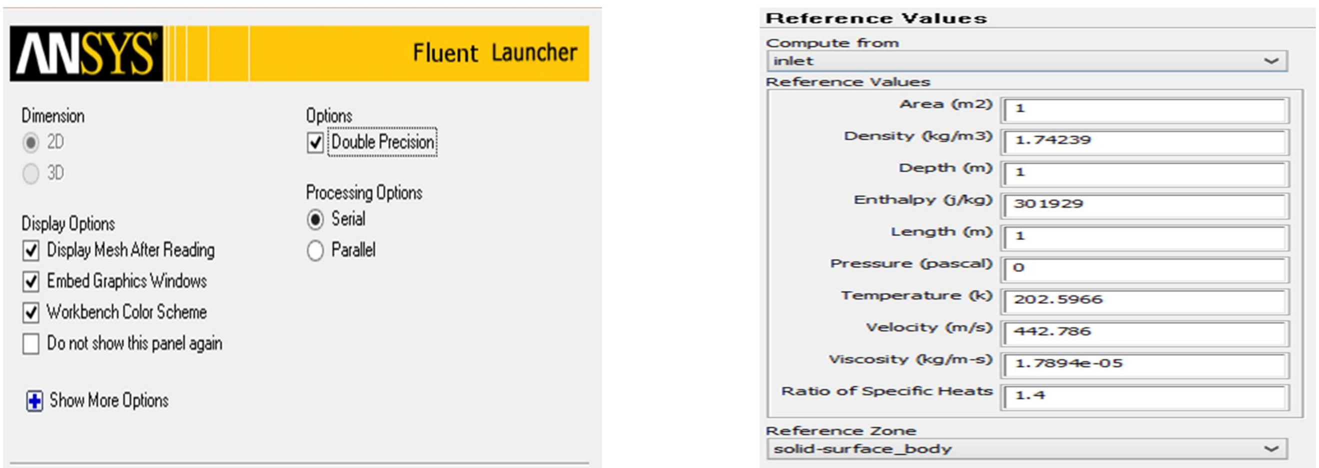

Fig 5 Input values to the model

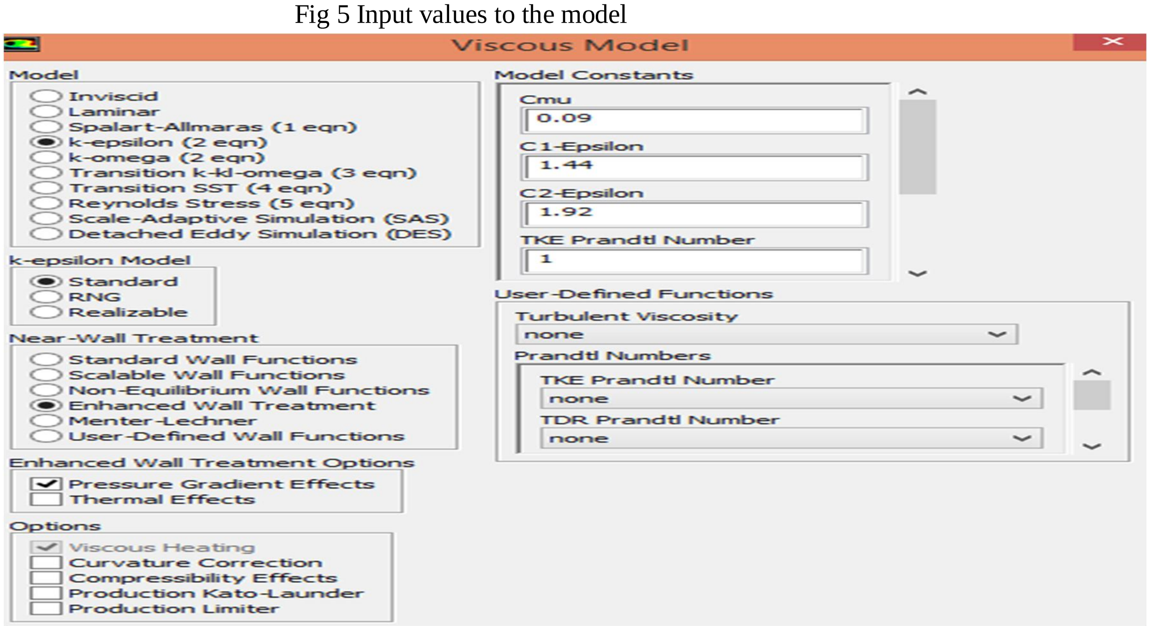

Fig 6 Mathematical modelling

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II. SIMULATION RESULTS

A. Convergence

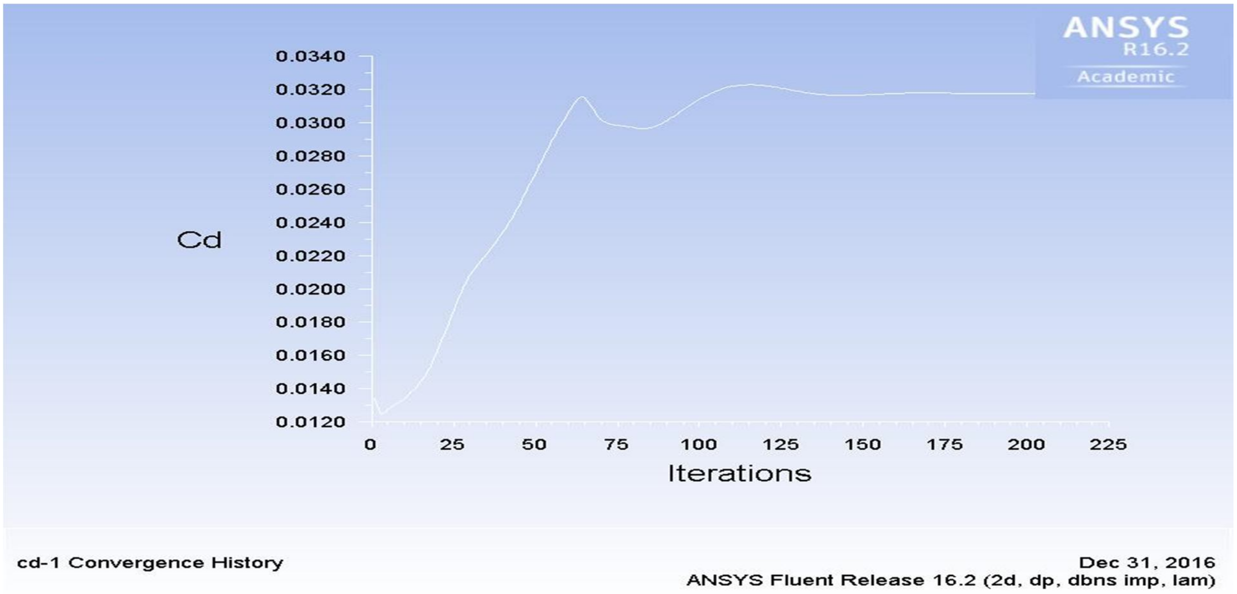

Fig 7 cd-1 Convergence plot

B. Velocity distribution

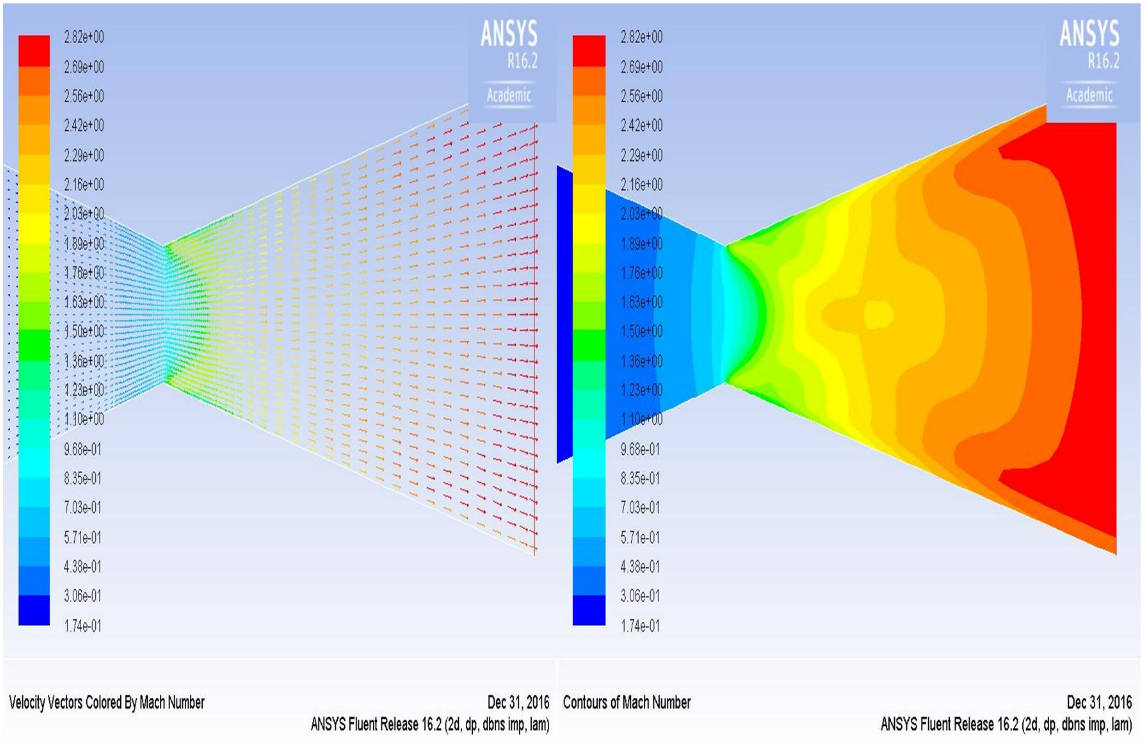

Fig 8 Contours and vectors of Mach number – Velocity

The velocity is maximum with Mach no = 2.82 at the exit of the nozzle. The throat has a Mach – 0.98 approaching the sonic flow and. This is also called as choking at the throat. The red color contour indicates the exit region velocity and the blue region indicates the low velocity profile at the inlet.

C. Pressure distribution

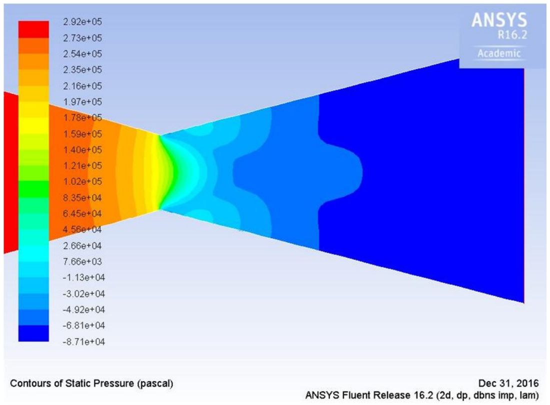

Fig 9 Static pressure contour

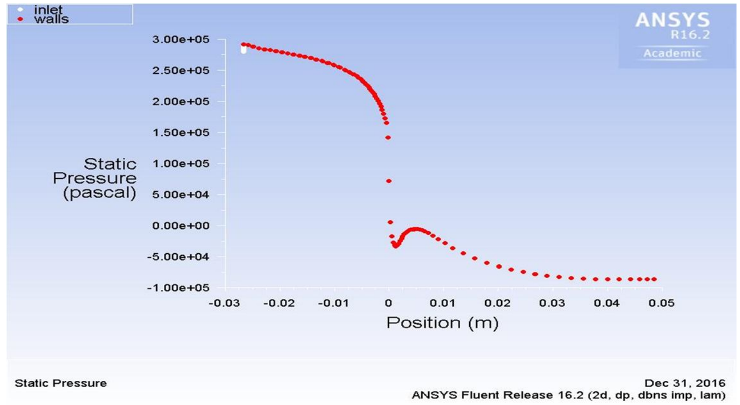

Fig 10 static pressure plot

The inlet pressure is 3 bar and outlet pressure is almost equal to the atmospheric pressure indicated by the blue contours that the pressure is decreased drastically. The plot also indicates a fall in the pressure. This is the design consideration and this is met successfully.

D. Wall shear and Reverse flow phenomena

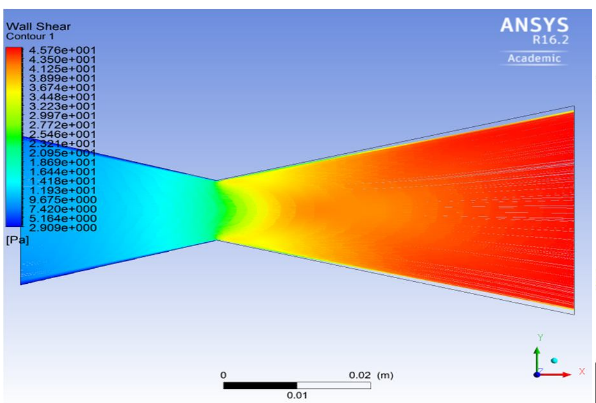

Fig 11 Wall shear contour

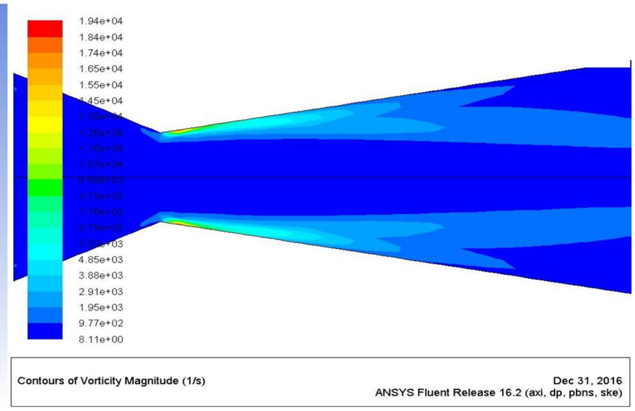

Fig 12 Reverse flow

III. CONCLUSION

The results obtained suggest that the geometry considered is fail safe and can produce maximum power from basic input. The design is also suitable for submerged conditions which is analysed from the reverse flow contours. The design behaves accordingly to the theoretical assumptions with subtle deviations which can be considered negligible in the present scenario. The meshing was robust and separate sections for the chamber and throat are designed keeping the focus entirely on the throat region. The flow conditions considered here are standard and still there is scope for testing the nozzle in extreme real time conditions with appropriate parameters.

IV. ACKNOWLEDGMENT

I feel ecstatic to be part of this work along with Arjun Singh who delivered his best towards completing this analysis on time. The Ansys platform user guide provided all the necessary concepts needed to perform simulations matching the real time conditions. I thank each and everyone for providing various inputs and their valuable time in to this paper.

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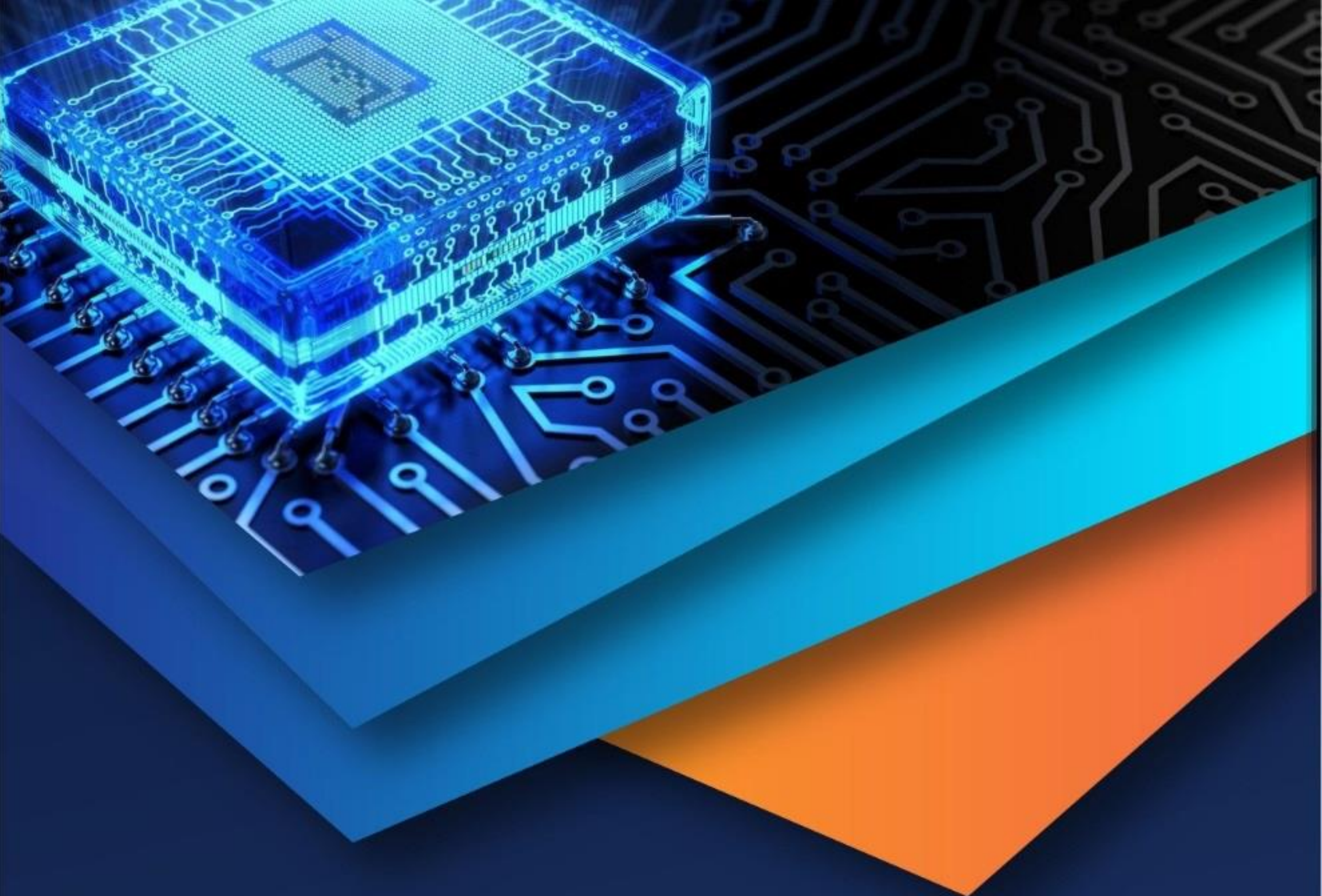

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