Computational and analytical study of flow through a nozzle

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Abstract

Computational and analytical study of flow through a nozzle is done in this research article. It is found that both the study predicts same results which has an industrial and scientific applications. In this research article, it is found when fluid flows through a nozzle then total pressure head converted into a kinetic head, as a result, the velocity of fluid increases and pressure decreases where area of cross-section is minimum or at a nozzle. The important application of nozzle is in rocket, engines of two and four-wheeler vehicle.

Key words: Nozzle, pressure head, kinetic head, Bernoulli equation, continuity, fluid

1. Introduction

In this research paper, fluid flow through a nozzle is studied analytically and verified with the computational solution. Primary nozzle geometry is studied by Natthawut et. al [1] and used Fluent 6.3 to analyze the flow through eight different nozzles and found that primary streams mixing quality changes if the angle of expansion of nozzle varies. Balaji Krushna et. al [2] studied the dual bell nozzle for knowing about the static pressure, temperature variation and different type of velocity variation radially and along the flow horizontally. They found that velocity of fluid increases radially and along the flow at nozzle. At low altitude, dual bell nozzle works better and gives good performance, as a result, efficiency increases from 25-30% and saves the consumption of fuel. The mechanics of nozzle in rocket propulsion was studied [3] and found the quality of working nozzle which was able to maintain the velocity of liquid fuel so that it was burning well. Advance rocket propulsion mechanics using nozzle was studied [4] and found the satisfactory results. The design aspect like wall inflection, nozzle extension and performance of dual-bell nozzle was discussed [5] and they found expected results. Nozzle plays a very important role when the velocity of fluid/fuel is needed to increase to get complete combustion of fuel that is why the concept of advance rocket nozzle was studied [6] and shown that it really plays an important role to increase the velocity of fuel that is required and the aim of our study. This study is different from other previous scientific studies because here, analytical results were compared with computational results and found good agreement.

2. Problem formulation

Consider Newtonian and incompressible fluid flows through a nozzle whose density is ρ and viscosity μ and the nozzle connected with the pipe that is converging by an angle of α with the nozzle at the point of minimum cross-section area. Here, the diameter of pipe is much greater than the diameter of nozzle that is why fluid flows with a higher velocity at nozzle than pipe. The fluid enters from lift side in pipe and leaves at nozzle with high velocity.

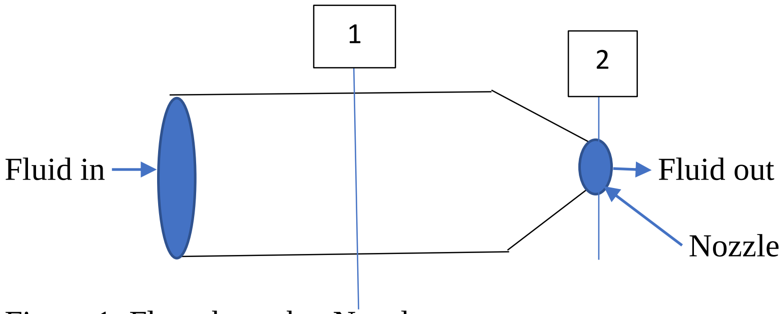

Figure 1: Flow through a Nozzle

Mainly the Navier-Stokes and continuity equations are used by software FLUENT and GAMBIT to generate the data. Additionally, we also used Bernoulli and continuity equation together to analyze the results analytically. The equations which are used to analyze the results analytically.

Bernoulli's equation

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant} \qquad \text{----------------------------- (i)}$$

Where, p, v and z are the pressure, velocity and elevation respectively. ρ and g are the density of fluid and acceleration due to gravity.

Continuity equation

Av = constant -----------------------------(ii)

Where, A is the area of the pipe or nozzle.

3. Result and discussion

When the Newtonian and incompressible fluid flows through a pipe and nozzle then velocity and pressure vary with varying the area of cross-section.

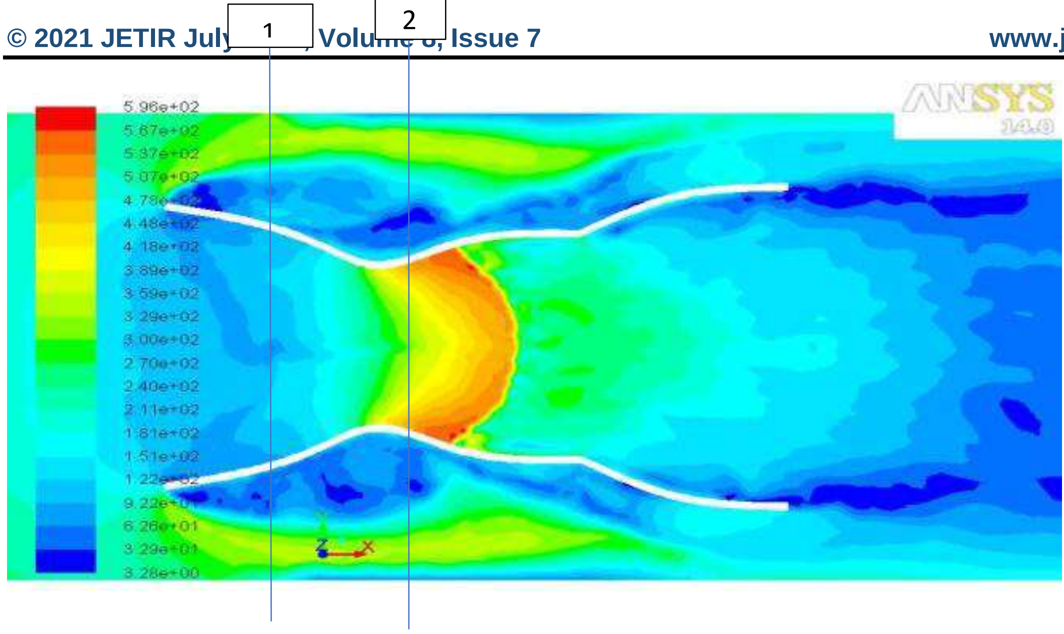

Figure 2: velocity variation at pipe and nozzle (ref. 2).

Our analytical results are matching very well with the computational results (ref. 2). From equation (ii) [v $\propto 1/A$], it is clear when area of cross-section increases then velocity of fluid decreases (figure 2, section 1) and from Bernoulli's equation pressure energy increases because Bernoulli's equation says that the total energy (pressure energy + kinetic energy + elevation energy) remains constant. As per Bernoulli's equation, if elevation does not vary and kinetic energy decreases then pressure energy will increase to maintain total energy constant in section 1. When the same fluid flows through a nozzle (figure 2, section 2) then velocity of fluid increases and it is shown by red type color (red color shows high velocity region and light blue color shows low velocity region but high-pressure region), it is also verified by equation (i) and (ii) when these equations are used simultaneous. When area of cross-section decreases at section 2 (nozzle) then from equation (ii) velocity increases that is also shown by computational results.

4. Conclusion

When the incompressible fluid/fuel flows through a nozzle then pressure energy decreases and kinetic energy increases at nozzle. Due to increasing the kinetic energy at nozzle, the velocity of fluid/fuel increases, as a result, complete combustion of fuel occurs and the efficiency of engine also increases. Our analytical results are matching well with computational results (ref.2).

References

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