International Journal of Future Engineering Innovations

Effect of Convergent Angle on Flow Characteristics in a Converging-Diverging Nozzle

John Akpan John [1*], **Nkanang Bassey D** [2], **Eyakeno Emmanuel Isaac** [3]
[1-3] Department of Mechanical Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria

* Corresponding Author: **John Akpan John**

Article Info

ISSN (online): 3049-1215
Impact Factor (RSIF): 8.25
Volume: 03
Issue: 02
March-April 2026
Received: 17-01-2026
Accepted: 15-02-2026
Published: 13-03-2026
Page No: 87-93

Abstract

The convergent section of a converging-diverging (C-D) nozzle plays a fundamental role in accelerating subsonic flow to sonic conditions at the throat, directly influencing the overall efficiency of energy conversion in propulsion systems. This study investigates the effect of convergent angle on flow behavior using Computational Fluid Dynamics (CFD). A 2D axisymmetric C-D nozzle model was analyzed in ANSYS Fluent under steady, compressible, and near-isentropic flow assumptions. Simulations were conducted for convergent angles of 15° and 30°, while maintaining constant divergent angle (6°), throat diameter (0.404 m), and other geometric parameters. Results demonstrate that the convergent angle significantly influences inlet and centerline flow characteristics. The 15° convergent angle consistently produced higher velocities at the inlet and along the centerline, accompanied by sharper reductions in pressure, temperature, and density, indicating more effective energy conversion from thermal to kinetic energy. Conversely, the 30° convergent angle resulted in higher inlet pressure, suggesting milder acceleration but improved inlet pressure stability. Importantly, the convergent angle showed negligible influence on exit flow properties, as the exit conditions were primarily governed by the divergent section geometry and the overall pressure ratio. The study concludes that a smaller convergent angle (15°) is favorable for achieving higher flow acceleration and efficient energy conversion in C-D nozzles, providing valuable design guidelines for aerospace and industrial applications.

DOI: https://doi.org/10.54660/IJFEI.2026.3.2.87-93

Keywords: Convergent angle, compressible flow, nozzle, CFD, ANSYS Fluent, flow acceleration

1. Introduction

In the field of fluid dynamics, the converging-diverging (C-D) nozzle, also known as the de Laval nozzle, is a fundamental device for accelerating compressible fluids to supersonic speeds [1]. Its application spans rocket engines, supersonic jet engines, steam turbines, and industrial gas systems [2]. The nozzle consists of three distinct sections: the convergent section, where subsonic flow is accelerated; the throat, where the flow reaches sonic velocity; and the divergent section, where supersonic expansion occurs [1, 3].

The convergent section is critical because it determines the efficiency with which the high-pressure gas is accelerated to the throat. The geometry of this section, particularly the convergent angle, influences the velocity distribution, pressure drop, and the uniformity of flow entering the throat [4, 5]. An improperly designed convergent section can lead to flow separation, non-uniform velocity profiles, and increased losses, which ultimately degrade the performance of the entire nozzle [6, 7].

While previous studies have acknowledged the importance of the convergent angle, detailed parametric investigations focusing exclusively on its isolated effect are limited [8, 9]. Many studies combine the analysis of convergent and divergent angles, making it difficult to isolate the specific contribution of the convergent section. This study addresses this gap by employing Computational Fluid Dynamics (CFD) to systematically analyze the isolated effect of convergent angle on flow behavior in a C-D nozzle. By quantifying its influence on velocity, pressure, temperature, and density, this research aims to provide clear design guidelines for optimizing the convergent section for enhanced flow acceleration and energy conversion [3, 10, 11].

2. Materials and method:

2.1. Numerical Implementation

CFD analysis was conducted using ANSYS Fluent software, selected for its robust solver capabilities and accuracy in modeling compressible flow phenomena.

2.2. Geometry and Mesh

A 2D axisymmetric model of a C-D nozzle was created in ANSYS DesignModeler. The geometry was based on the area-Mach number relation, with a throat diameter of 0.404 m, convergent length of 2.02 m, and divergent length of 4.04 m. Two convergent angles were investigated: 15° and 30°. To isolate the effect of convergent angle, the divergent angle was held constant at 6°, the throat diameter was fixed at 0.404 m, and the throat length was set to 0.0 m. A structured mesh with a face meshing method and element size of 1 mm was generated, with refinement at critical regions to ensure accuracy.

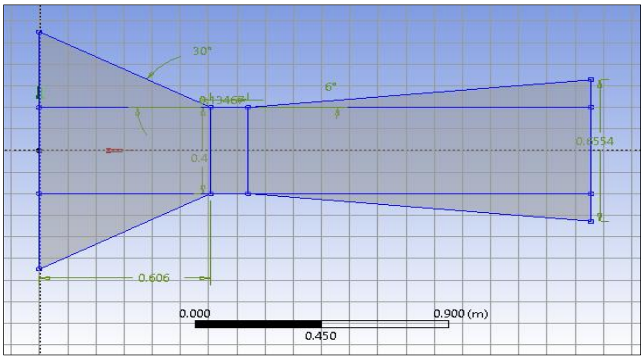


Fig 1: 2-D model of the Nozzle

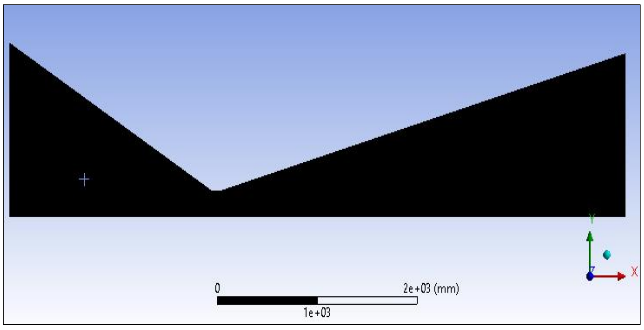


Fig 2: 2D Mesh Generation

2.3. Boundary Conditions and Solver Setup

The solver was configured as a density-based, steady-state solver. The energy equation was enabled to account for thermal effects in the compressible flow. The SST k-ω model was selected for turbulence modeling due to its ability to handle adverse pressure gradients and near-wall phenomena accurately.

Air was used as the working fluid, modeled as an ideal gas with Sutherland's law for viscosity. The boundary conditions were set as follows: pressure inlet at 528,000 Pa (5.28 bar) and 340 K; pressure outlet at 101,325 Pa (1.01325 bar) and 300 K. Adiabatic no-slip walls were applied. The analysis setup is summarized in Table 1.

Table 1: Analysis setup in ANSYS

Category	Parameter	Value / Setting
General	Solver Type	Pressure-based
	Velocity Formulation	Absolute
	Time	Steady
	2D Space	Axis-symmetric
Model	Energy	On
	Viscous Model	k-epsilon
	k-epsilon Type	Realizable
Material	Fluid	Air
	Density	Ideal Gas
	Viscosity	Sutherland
Boundary Conditions	Pressure Inlet	528,000 Pa
	Temperature Inlet	340 K
	Pressure Outlet	101,325 Pa
	Temperature Outlet	300 K
Reference Values	Compute From	Inlet
Initialization	Method	Standard
Solution Scheme	Scheme	Coupled

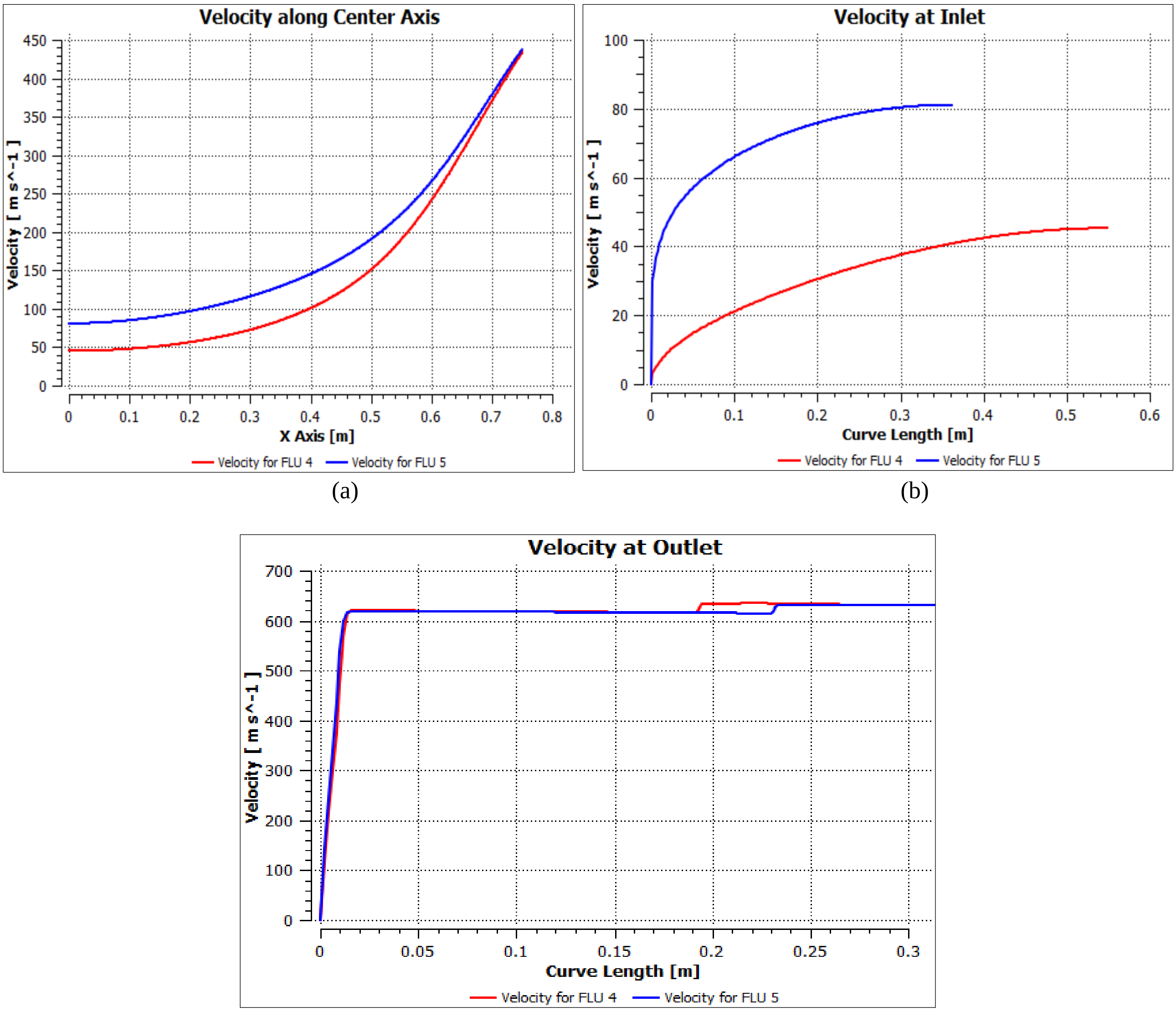
3. Results a Discussion

3.1. Effect of Convergent Angle on Flow Characteristics

The analysis revealed that the convergent angle significantly influences the upstream flow characteristics up to the throat, while having a negligible effect on the exit flow properties.

3.1.1. Velocity

As shown in Figure 1, the 15° convergent angle (blue line) consistently produced higher velocities along the centerline compared to the 30° convergent angle (red line). At the inlet section (Figure 1b), the 15° angle resulted in a sharper velocity increase, reaching approximately 80-90 m/s, while the 30° angle produced a more gradual increase to about 50-60 m/s. This difference is attributed to the more rapid area reduction in the 15° convergent section, which causes stronger flow acceleration according to the continuity equation. At the throat, the 15° angle achieved a higher velocity, indicating more efficient conversion of pressure energy into kinetic energy. However, at the outlet (Figure 1c), the velocities for both angles converged to nearly the same supersonic value (approximately 600-650 m/s), confirming that exit velocity is independent of convergent angle under the given pressure ratio.



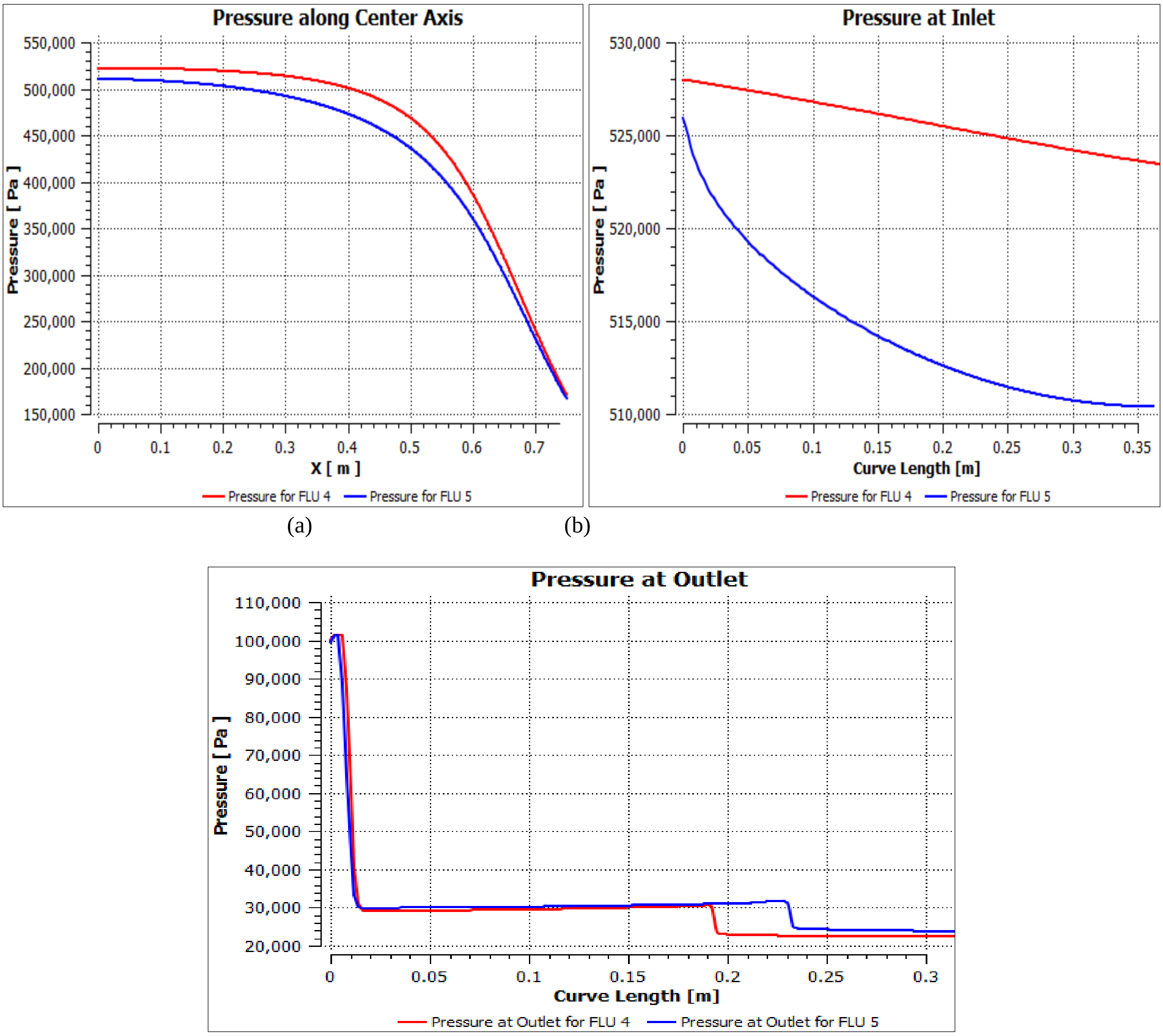
(a) (b)

(c)

Fig 3: Effect of converging on velocity at (a) Center Axis of the nozzle (b) Inlet curve length and (c) Outlet Curve length

3.1.2. Pressure

The pressure distribution, shown in Figure 2, exhibited a trend inverse to that of velocity. The 15° convergent angle produced a sharper pressure drop at the inlet (Figure 2b), dropping from approximately 528,000 Pa to about 450,000 Pa within the convergent section, while the 30° angle maintained a higher pressure throughout the inlet region. This sharper pressure drop corresponds to the higher velocity achieved, consistent with Bernoulli's principle for compressible flow. The 30° angle, by contrast, showed a more gradual pressure reduction, indicating milder acceleration but potentially better pressure stability. At the outlet (Figure 2c), both angles reached nearly identical static pressures (approximately 20,000-30,000 Pa), confirming that exit pressure is governed by the divergent section and the backpressure condition.



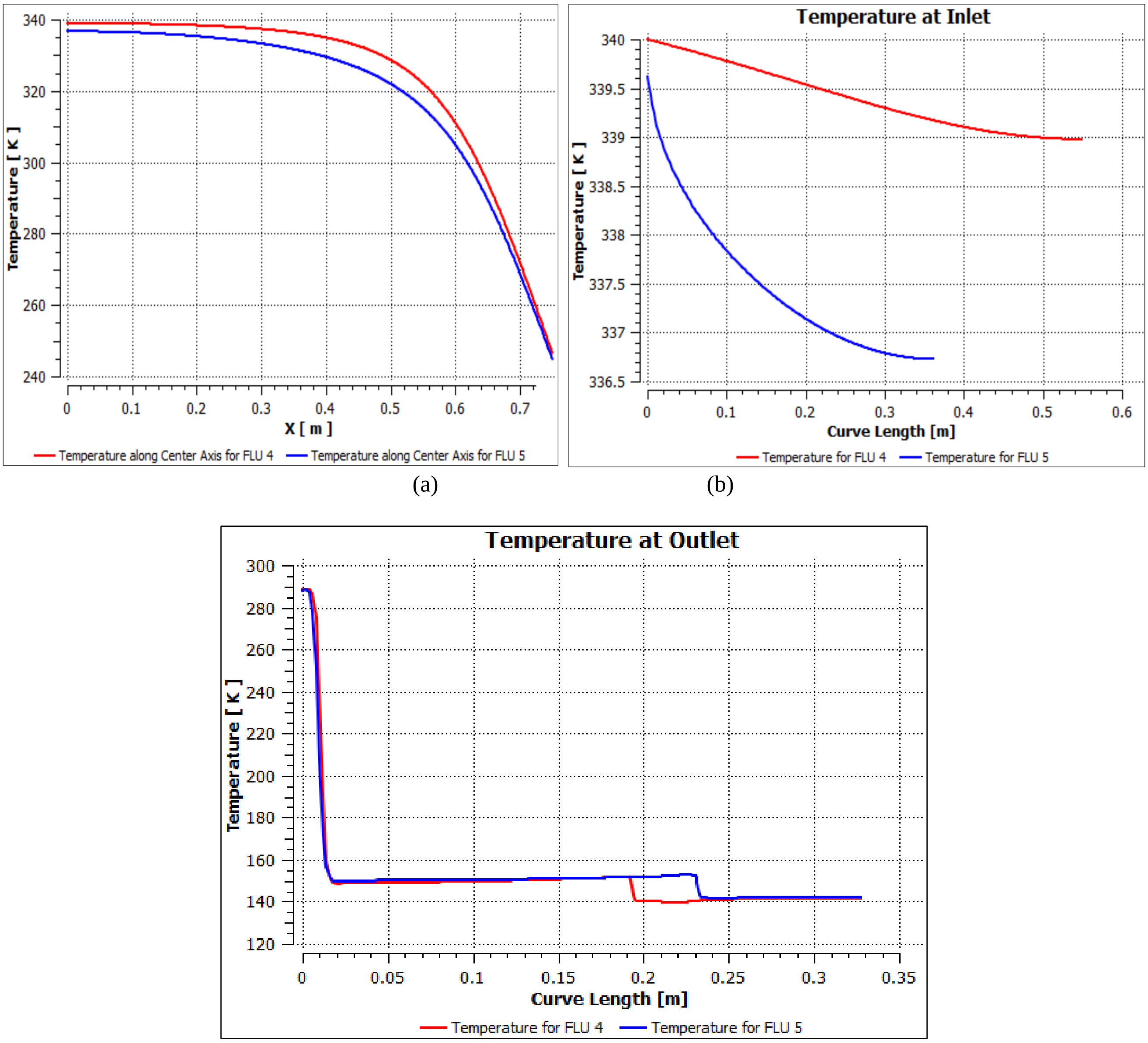
(a) (b)

(c)

Fig 4: Effect of converging on pressure at (a) Center Axis of the nozzle (b) Inlet curve length and (c) Outlet Curve length

3.1.3. Temperature

The temperature distribution, presented in Figure 3, mirrored the pressure behavior. The 15° convergent angle resulted in a more pronounced temperature drop along the centerline (Figure 3a) and at the inlet (Figure 3b), decreasing from 340 K to approximately 310 K within the convergent section. This reflects the conversion of thermal energy into kinetic energy, as described by the energy equation for adiabatic flow. The 30° angle showed a milder temperature reduction, indicating less thermal energy conversion. At the outlet (Figure 3c), both angles achieved nearly identical exit temperatures (approximately 140-160 K), further confirming that exit thermal conditions are dominated by the expansion process in the divergent section.



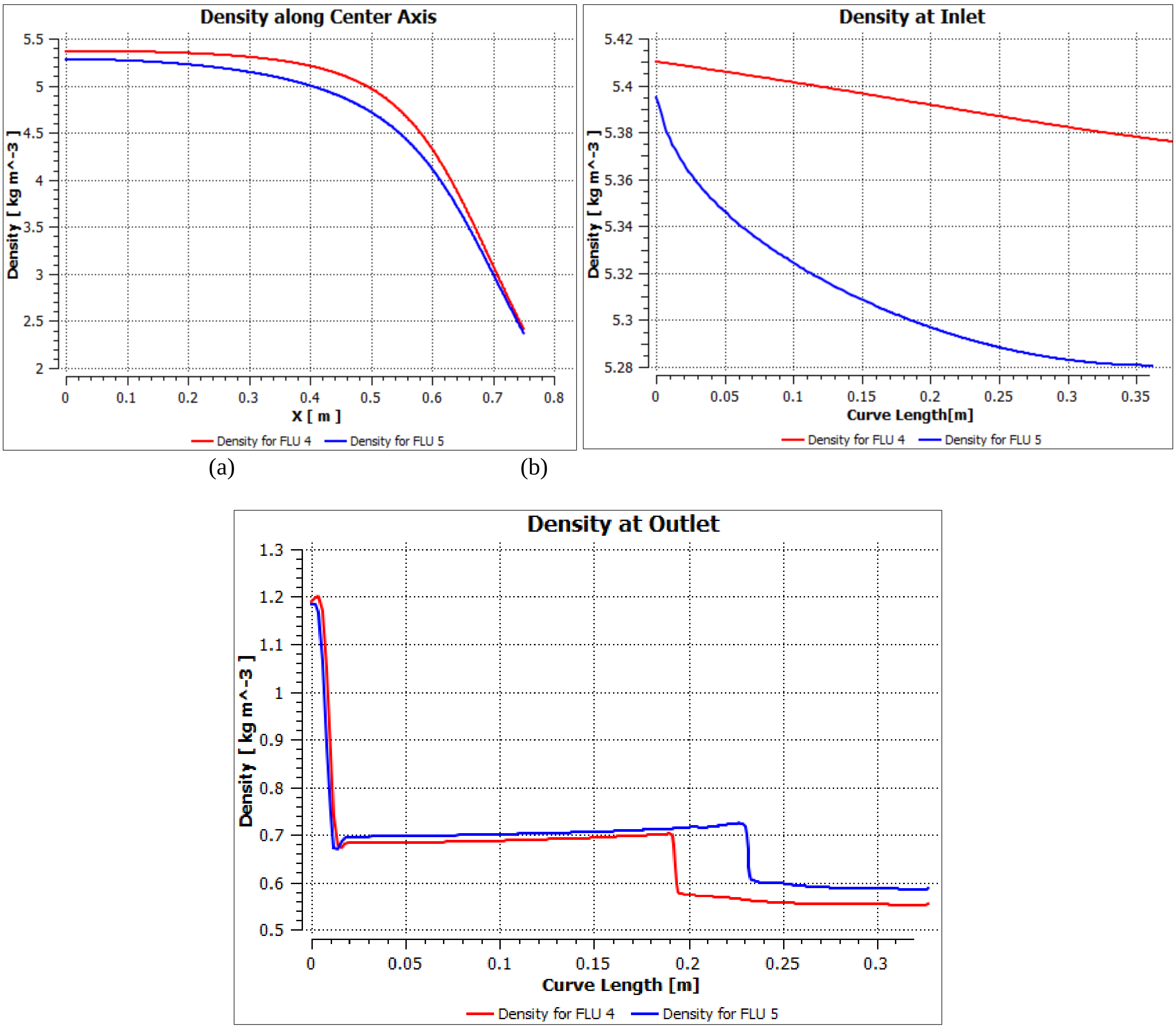
(a) (b)

(c)

Fig 5: Effect of converging on temperature at (a) Center Axis of the nozzle (b) Inlet curve length and (c) Outlet Curve length

3.1.4 Density

The density distribution, shown in Figure 4, followed the same pattern as pressure and temperature, as expected from the ideal gas law (P = ρRT). The 15° convergent angle produced a sharper density reduction along the centerline (Figure. 4a) and at the inlet (Figure 4b), decreasing from approximately 5.5 kg/m³ to about 4.8 kg/m³ within the convergent section, while the 30° angle exhibited a more gradual decrease. At the outlet (Figure 4c), both angles achieved nearly identical exit densities (approximately 0.6-0.8 kg/m³), confirming that the convergent angle does not influence the final density after expansion.



(a) (b)

(c)

Fig 6: Effect of converging on density at (a) Center Axis of the nozzle (b) Inlet curve length and (c) Outlet Curve length

3.2. Summary of Findings

The results clearly demonstrate that the convergent angle is a significant parameter for upstream flow development but has a negligible influence on exit flow properties. The 15° convergent angle provides superior flow acceleration and energy conversion, making it ideal for applications where maximizing velocity is the primary objective. The 30° convergent angle, while offering milder acceleration, maintains higher inlet pressure, which may be beneficial in applications requiring pressure stability or when the inlet conditions are sensitive to pressure fluctuations.

4. Conclusion

This CFD-based study has successfully characterized the isolated effect of convergent angle on the flow behavior of a C-D nozzle. The key conclusions are:

1. The convergent angle significantly influences inlet and centerline flow characteristics. A 15° convergent angle produces higher velocities and sharper reductions in pressure, temperature, and density, indicating more efficient energy conversion from thermal to kinetic energy.
2. A 30° convergent angle results in higher inlet pressure and milder acceleration, which may be advantageous for applications requiring greater inlet pressure stability.
3. The convergent angle has a negligible influence on exit flow properties, as the exit conditions are primarily governed by the divergent section geometry and the overall pressure ratio.
4. For applications where maximizing flow acceleration and energy conversion is the primary objective, a smaller convergent angle (15°) is the preferred design choice.

These findings provide valuable design guidance for optimizing the convergent section of C-D nozzles in aerospace propulsion and industrial fluid systems.

References

1. White FM. Fluid mechanics. 8th ed. New York: McGraw-Hill Education; 2016.
2. Anderson JD. Fundamentals of aerodynamics. 6th ed. New York: McGraw-Hill Education; 2017.
3. Yadav V, Tiwari P. A review on CFD analysis of effects of convergence and divergence angles on the

performance of a nozzle. Int J Sci Res Eng Trends. 2020;6(1):33-5.

4. Flack RD. Fundamentals of jet propulsion with applications. Cambridge: Cambridge University Press; 2005. (Note: The provided author "Almeida P" appears to be an error; the standard reference for this title is Ronald D. Flack.)
5. Oboh AE, Akpan UE, Nkanang BD, Attah JE. Nonlinear vibration analysis of cracked rotating shafts using Matlab-based simulation framework. Int J Adv Eng Manag. 2025;7(8):384-90.
6. Nair R, Kumar S, Patel V. Numerical study of flow separation in divergent ducts. J Appl Fluid Mech. 2020;13(2):547-56.
7. Nkanang B, Abam F, Ndukwu M, Ugwu H, Oboh A. Comparative analysis of biodiesel produced from blends of palm kernel shell and cocoa pods oils with conventional diesel fuel: Characterizations. ABUAD J Eng Res Dev. 2024;7(2):372-90.
8. Malik NM, Zaheer MA, Farooq MA. Effect of convergent angle on different flow parameters of a convergent-divergent nozzle. In: Proceedings of the ... (Hammamet, Tunisia). EDP Sciences; 2024. p. 01001.
9. Roy S, Ghosh A, Banerjee D. Optimization of converging-diverging nozzle using Taguchi method. Aerosp Sci Technol. 2016;55:121-30.
10. Meena L, Niranjan M, Kumar G, Zunaid M. Numerical study of convergent-divergent nozzle at different throat diameters and divergence angles. Mater Today Proc. 2021;46:10676-80.
11. Edem IF, Balogun VA, Nkanang BD, *et al*. Surface roughness optimization in turning using Taguchi approach. ABUAD J Eng Res Dev. 2020;3(1):147-53.

How to Cite This Article

John JA, Bassey ND, Isaac EE. Effect of convergent angle on flow characteristics in a converging-diverging nozzle. Int J Future Eng Innov. 2026;3(2):87–93. doi:10.54660/IJFEI.2026.3.2.87-93

Creative Commons (CC) License