Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Computational and Experimental Analysis of Optimized Dual Throat Fluidic Thrust Vectoring Nozzle Configurations

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ARTICLE INFO

Received: 03 Nov 2024

Revised: 17 Nov 2024

Accepted: 12 Dec 2024

ABSTRACT

Dual-throat Nozzle (DTN) is known as one of the most effective approaches of fluidic thrust-vectoring. It is flourishing into a promising technology to implement supersonic and hypersonic thrust-vector control in aircrafts. The main objective of the study is numerical investigation of the effects of secondary injection geometry and the cavity angles on the performance of a planar dual throat thrust-vectoring nozzle. The main contributions of the study is to consider the rate of secondary injection and cavity section with different angle configuration of the DTN, and the impacts is examined. 2-D compressible reacting simulations have been conducted in order to resolve the flow field in a dual throat nozzle with Nozzle pressure ratio of 5. The RANS equation, Energy equation is solved along with the standard k – ε model for the turbulence closure. Parameters such as convergence angle in the cavity & secondary injection angle are invoked to analyze the better thrust vectoring angle. Results reveal that a maximum vector angle of 10.96 degrees is a secondary injection rate equal to 20% of primary flow rate with a cavity convergence angle of 30 degrees. Findings suggest that the higher thrust vectoring is offered by a DTVN with higher cavity convergence angle with lesser percentage of secondary inlet.

Keyword: Dual throat nozzle, Secondary Fuel injection, Cavity convergence angle, Thrust-vector angle

Introduction

The concept of thrust vectoring is an advancing technology in the field of propulsion. Thrust vectoring is used to manipulate the direction of thrust for an effective maneuvering of the aircraft. The need for an efficient and reliable thrust vectoring in supersonic, and aerospace vehicles is very much evident in the growing phase of propulsion field. The two methods of employing thrust vectoring are fluidic and mechanical. In mechanical thrust vectoring, additional moving mechanical parts are attached in the nozzle to direct the thrust off axis. Fluidic Thrust Vectoring eliminates the usage of any moving mechanical parts by having a fixed geometry through which a secondary injection is given inside the nozzle which manipulates or control the primary exhaust flow, this approach makes the system simpler, light weight and capable of being implemented with stealth capabilities. The primary fluidic nozzle methods include shock vector control, throat shifting, co-flow, counter-flow, and Dual Throat Nozzle (DTN). Different techniques for fluidic thrust vectoring have been studied and experimented and among these The Dual Throat fluidic thrust vectoring Nozzle (DTN) has received wide attention due to its excellent thrust vectoring efficiency and minimal thrust loss.[1] The potential benefits of fluidic thrust vectoring was estimated by NASA, it reported that employing fluidic thrust vectoring nozzles could result in a 43%–80% weight reduction and a 37%–53% reduction in nozzle procurement and life cycle costs.[1][4] The research demonstrated that Dual throat nozzle was capable of achieving higher thrust-vectoring efficiency than other fluidic techniques without sacrificing thrust efficiency. [4]

Dual Throat Nozzle uses the approach of shock thrust vector control and fluidic throat skewing. Dual throat

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Nozzle is composed of two throats, injecting secondary flow in the vicinity of the upstream throat, the secondary flow induces flow separation in the cavity between the two throats, which will skew the sonic line and vector the exhaust flow. The dual throat nozzles concept have been the subject of several experimental and theoretical studies, there remains a significant gap in understanding how to fully harness their potential in fluidic thrust vectoring systems for supersonic vehicles. Specifically, the relationship between nozzle geometry, secondary injection parameters, and the resulting thrust vector angle has yet to be thoroughly explored. This study addresses the need to refine these configurations to achieve maximum performance.
The study is focused on understand the different parameters that influence the thrust vectoring capability of the dual throat nozzle. Among many such parameters, the injection rate, angle of injection, and geometry of the dual throat nozzle are explored, and their effect on the thrust vectoring is presented. The primary focus was to design and develop a dual throat nozzle that was suitable for the supersonic jet facility at Mangalore Institute of Technology and Engineering and conduct a computational study. The DTN was approached with fluidic throat skewing, and the study focused on understanding the parameters that determine the thrust efficiency of the dual throat nozzle and determining which combined parameter configuration provided a higher thrust vector angle. The design approach focused on trying to increase the efficiency of the dual throat nozzle by changing the parameters that played a major role in determining the vectoring efficiency of the dual throat nozzle. The major parameters governing the efficiency of DTN, which are considered for the study are cavity convergence angle, secondary injection rate, and angle of secondary injection.
The problem this study seeks to address is the challenge of determining the ideal configuration of dual throat nozzles to achieve superior thrust vectoring efficiency in supersonic regimes. The study focuses on understanding the influence of nozzle design and secondary injection and convergence cavity effect on the resultant thrust vector angles, aiming to provide a methodology for optimizing fluidic thrust vectoring systems in future aerospace applications. The study also focuses on advancing the dual throat nozzle concept, which holds significant potential for improving aerodynamic control in high-speed flight regimes.

OBJECTIVES

The main objective of the present study is to design, develop and analyze the Dual Throat fluidic thrust vectoring Nozzle for testing in a supersonic jet facility and obtain a better thrust vectoring angle for an air-injected dual throat nozzle, by examining cavity angle, secondary injection rate and angle of secondary injection. By systematically analyzing its performance under various governing parameters of thrust vectoring efficiency and design configuration's, the study will generate critical insights into the design process and vectoring efficiency of fluidic thrust vectoring. The study is aimed to determine the optimal configuration of dual throat nozzles to enhance thrust vectoring efficiency in supersonic regimes. It aims to analyze the impact of nozzle design parameters, secondary injection, and the convergence cavity effect on the resulting thrust vector angles, and it seeks to provide a methodology for optimizing fluidic thrust vectoring systems, with the goal of improving aerodynamic control in future high-speed aerospace applications. The outcomes of this work are intended to contribute to future experimental work and technological advancements in supersonic jet propulsion, space launch vehicles, and reusable-launch vehicles.

Materials and Methodology:

To investigate the parameters governing the thrust vector angle of DTN with a secondary injection, the convergent- divergent nozzle with dual throat was conceptualized and designed using SolidWorks and the computational study and analysis was performed in ANSYS FLUENT, providing a detailed and accurate digital representation of the design.
The principle of a Convergent-Divergent (CD) nozzle is based on the principles of fluid dynamics and thermodynamics to accelerate gases to supersonic speeds. The nozzle's shape, consisting of a converging section, a throat, and a diverging section, enables the controlled expansion and acceleration of the gas. In the convergent part of the nozzle, the cross-sectional area decreases. According to the continuity equation, for a subsonic flow, as the area decreases, the velocity of the gas increases. At the same time, Bernoulli's principle

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implies that as the velocity increases, the static pressure and temperature decrease. The flow continues to accelerate until it reaches the throat. The throat is the narrowest part of the nozzle, where the cross-sectional area is the smallest. For a given upstream pressure, the flow velocity reaches the speed of sound (Mach 1) at the throat. This condition is known as "choked flow." The mass flow rate through the nozzle becomes limited and cannot increase further by decreasing downstream pressure once the flow is choked. After the throat, the nozzle diverges, and the cross- sectional area increases. In the divergent section, the flow becomes supersonic. For supersonic flow, the relationship between area and velocity is reversed compared to subsonic flow. As the area increases, the velocity of the gas also increases. Simultaneously, the static pressure and temperature of the gas continue to decrease. This acceleration to supersonic speeds occurs due to the conservation of mass, momentum, and energy in the flow. The operation of a CD nozzle relies on several key principles:

1. Continuity Equation**:** Ensures mass conservation throughout the nozzle

$$\rho 1 A 1 V 1 = \rho 2 A 2 V 2$$

2. Bernoulli's Equation**:** Relates pressure, velocity, and elevation in a flowing fluid, applicable to the converging section

$$P_1 + \frac{1}{2}\rho g V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho g V_2^2 + \rho g h_2$$

3. Isentropic flow relations (1),

$$1.\quad \frac{P}{P_t} = ((1 + \frac{\gamma - 1}{2} M^2)^{\frac{-\gamma}{\gamma - 1}})$$

$$2.\quad \frac{\rho}{\rho t} = (1 + \frac{\gamma - 1}{2} M^2)^{\frac{-1}{\gamma - 1}}$$

$$3.\quad \frac{T}{T_t} = (1 + \frac{\gamma - 1}{2} M^2)^{-1}$$

Methodology

Using the above isentropic flow relations and the governing equations the dimensions of the CD nozzle was calculated through iterative process. The calculation of the nozzles design involves several key steps based on fluid dynamics and thermodynamics. Initially the inlet conditions were defined as per the reservoir conditions. The inlet conditions were defined to be, Total pressure (P0) = 500000 Pa, Total temperature (T0) = 473.23 K, Gas constant (R0) = 273, the study is based upon the characteristics of an ideal gas and hence the specific heat ratio (γ)
=1.4, (The nozzle design conditions were initially specified based on the jet facility available at MITE), the exit conditions were defined in accordance. The nozzle pressure ratio (NPR) is a key parameter in the design and analysis of nozzles, especially in aerospace and propulsion applications. It is defined as the ratio of the total (stagnation) pressure at the inlet of the nozzle to the static pressure at the nozzle exit. The nozzle pressure ratio indicates the expansion level of the gas within the nozzle and is crucial for determining the exit velocity and thrust produced by the nozzle. The DTNs with an NPR greater than 3 exhibited improved and better performance efficiency in vectoring control at supersonic range [5], therefore NPR 5 was chosen for the study and accordingly
and the exit conditions for the nozzle were designed. The NPR is defined as $\frac{P0}{Pe}$, using the relation of Mach number
and NPR, eqn (2), the Mach number for NPR 5 is calculated.

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$$M_e = \sqrt{\frac{2}{\gamma - 1}\left[\left(\left(\frac{P_0}{P_e}\right)^{\frac{\gamma-1}{\gamma}}\right) - 1\right]} \quad (2)$$

From the equation (2), the exit Mach number for an NPR of 5 is 1.7, therefore Me = 1.7 , and using isentropic relations, the area ratio and pressure ratio were determined for compressible flow at a Mach number of 1.7. The throat conditions are calculated using the area ratio eqn (3).

$$\frac{A}{A^*} = \left(\frac{\gamma - 1}{2}\right)^{\frac{-\gamma+1}{2(\gamma-1)}} \frac{\left(\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{-\gamma+1}{2(\gamma-1)}}\right)}{2} \quad (3)$$

The area ratio is a crucial parameter for determining the exit area (A) and the throat area (At) of the nozzle. Using the Mach number and area relation formula, the area ratio is calculated. $\frac{A}{A*}$ = 1.33. The nozzle conditions were defined to obtain a choked flow. Choking occurs when the exit plane velocity is at sonic conditions; i.e., at a Mach number of 1. To achieve choked flow in the converging section, the following conditions were maintained, At= A* (A* the throat area of nozzle where the flow is sonic, Mach = 1), and Pt = P*, P*/P0 = 0.53 (For M = 1) and the pressure values is calculated from eqn (4),

$$\frac{A^*}{A_e} = \left(\frac{\gamma + 1}{2}\right)^{\gamma-1} \left(\frac{P_e}{P_0}\right)^{\frac{1}{\gamma}} \sqrt{\frac{\gamma + 1}{\gamma - 1}\left|1 - \left(\frac{P_e}{P_0}\right)^{\frac{k-1}{k}}\right|} \quad (4)$$

The throat condition are At= A*= 50.26 mm² Throat diameter = 8 mm
From the area ratio the exit area = 66.84 mm² Exit diameter = 9.22 mm
Therefore, the conditions are defined:

P0 = 5, 00,000 Pa

Pe = 1, 00,000 Pa

P* = 2, 65,000 Pa

Hence the flow is choked as Pe < Pt, and the Mach number at the throat is 1. The mass flow rate remains constant regardless of further decreases in pressure.

Nozzle design

The Dual Throat Nozzle are designed on concept of isentropic flow conditions, according to the analytical calculations, [5] The study initiated with the calculation of the geometrical parameters of the DTN, the geometrical parameters were to be determined using isentropic flow relations. The main consideration for the geometrical parameter was the supersonic jet facility at Mangalore Institute of Technology Engineering, based on the configuration of the facility, the preliminary design of the DTN was designed. This iterative process resulted in the finalization of three main designs, each tailored to showcase specific performance requirements in analysis, highlighting the importance of both computational tools and analytical methods in the development of efficient nozzle geometries. Initially the primary design of the convergent-divergent nozzle was designed in SOLIDWORKS.

The study is focused on DTNs with three different cavity convergence angle and seven different injection rate for the respective DTNs. The area ratio Eq.2 is a crucial parameter for determining the exit area (A) and the

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throat area (At) of the nozzle. The inlet diameter for all the nozzle configurations were set constant and the throat and exit diameter was designed according to the calculated values. Inlet diameter = 27 mm, throat diameter = 8 mm, and the exit diameter = 9.22 mm. The ratio of throat area and secondary exit area was maintained 1.

Secondary Throat

To design the secondary throat of the dual-throat nozzle, the secondary convergence θ2 is determined, and the ratio of the throat diameter to the secondary exit diameter is set to 1.
The convergence angle θ2 for the cavity is selected for the dual-throat nozzle. The secondary convergence angles **θ2** determined are as follows:

1. 10 $^{\theta}$
2. 20 $^{\theta}$
3. 30 $^{\theta}$

A C-D nozzle with 10° divergence angle was the most optimum configuration for a Dual throat nozzle with better performance efficiency [5]. The divergence angle θ1 is set constant **θ1 = 10 °.**
The final three designs were finalized, Figure (1), (2), and (3), illustrate the finalized designs of DTN

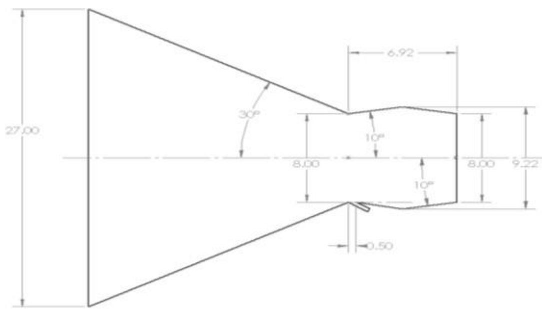

Figure 1: Engineering drawing of DTN for θ2=10

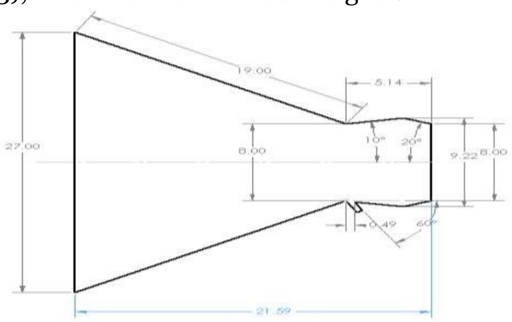

Figure 2: Engineering drawing of DTN for θ2=20

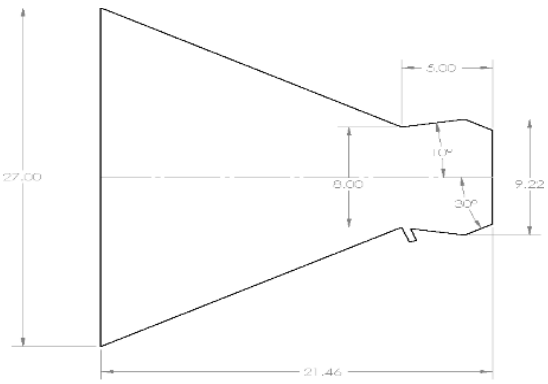

Figure 3: Engineering drawing of DTN for θ2=30

Computational study

The computational fluid dynamics (CFD) analysis was conducted for three distinct dual-throat vectoring nozzle (DTVN) configurations, each evaluated under six different secondary inlet velocity conditions. This paper presents the highest thrust vector angles achieved by each of the three models, offering a comparative assessment of their performance. The findings highlight the impact of secondary inlet velocity variations on thrust vectoring efficiency and provide valuable insights for optimizing nozzle design for practical applications.
The computational study and analysis for DTN was done in ANSYS FLUENT.
For the two-dimensional planar DTN, the unsteady compressible Reynolds-Averaged Navier- Stokes (RANS)

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compressible equations are solved in accordance with the finite volume method to investigate the dynamic characteristic. The realizable k-ε turbulence model is employed. In addition, a second-order upwind scheme is used to discretize the turbulence transport equation. Quadrilateral grids of DTN are generated in this study and the length of the domain was extended further the exit of nozzle. The grids of the nozzle surface and vicinity of secondary injection are refined, velocity- inlet boundary condition is imposed on the secondary injection of the DTN.

Computational geometry and grid

The 2D flow analysis for the different DTNTV models was performed using ANSYS FLUENT tool and initially the geometry deigned in Soliworks was imported to the Fluent and meshing is done. The model created using the above dimensions was meshed in the mesh mode of ANSYS FLUENT 2024. It was done to create a suitable numerical domain over the geometric feature in which the solver solves the required equations Edge Sizing has been used with varying numbers of divisions, from 80 in the throat section, which has a small length, to 200 in the diverging section of the nose. Then, Face mesh was used to create the structured mesh with all quadrilateral cells, as shown in Figures below. The meshing was done denser at nozzle wall and divergence section where we expect the flow separation and shock wave formation. The physical preference for mesh generation was CFD, and the solver preference was Fluent, the figure (4), depicts the meshing and the domain for the analysis of the dual throat nozzle.

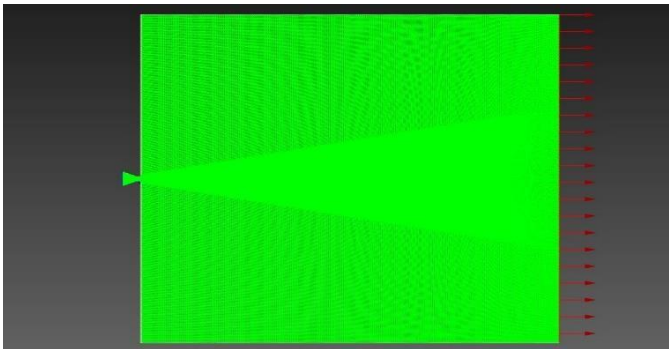

Figure 4: Computational Domain

Energy equations are turned on for the simulation of compressible flow to solve the vast effect of temperature variation due to the nature of the nozzle. The material chosen was Air, Ideal gas density model was used to get the respective behavior. The detailed boundary condition used are, The pressure inlet boundary condition is applied to the nozzle inlet boundary, Gauge total pressure of 500000Pa because of the combustion would produce the respective pressure according to the throat geometry, supersonic/initial gauge pressure of 499000Pa, and constant temperature of 472.23 K are used for all the cases. The nozzle wall is specified by the wall boundary condition with the adiabatic and no - slip conditions used. To make a computationally economical numerical investigation, the computational domain is Planar. The pressure outlet boundary condition is specified for the domain boundary layer. The outlet pressure is kept same as the ambient pressure i.e., 100000Pa. The important parameter is choosing the secondary inlet velocity, the values of secondary inlet taken for analysis is mentioned in Table (1).

Velocity(m/s)	Pressure (Pa)	Temperature(K)
60	99120	286
70	98323	285
100	95200	283
150	87543	277
175	82567	272
200	76825	268

Table 1 Parameters for Secondary Inlet

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The following images represent the results obtained from each analysis conducted during the study. Figure (5) illustrates the thrust generation at Mach 1.8 for a convergent-divergent (C-D) nozzle without secondary injection

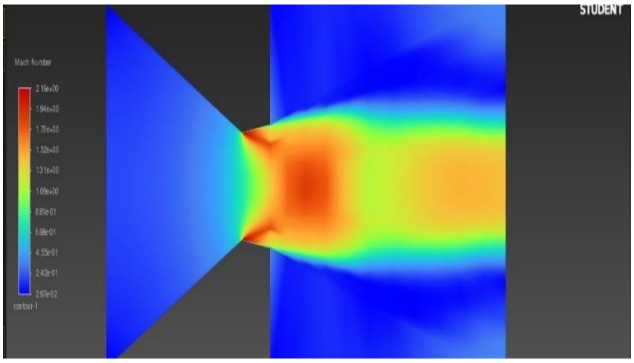

Figure 5: Thrust generation without secondary injection

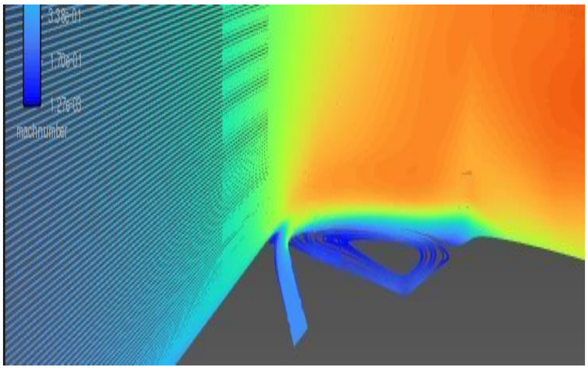

Figure 6: Separated flow region at the cavity of DTN

Figure (6) illustrates the separated flow region within the cavity of the dual-throat nozzle, which serves as a critical factor for achieving thrust vectoring.

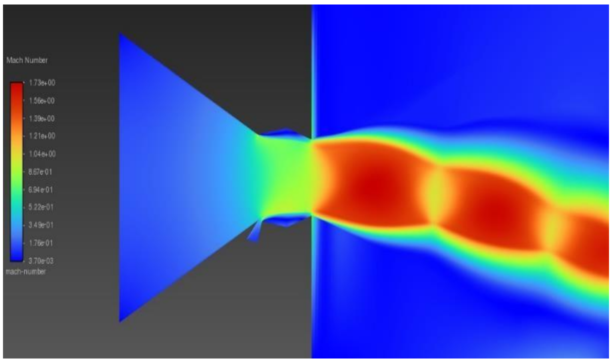

Figure 7: Thrust vectoring of DTN for θ2=10⁰

Figure (7) depicts the thrust vectoring for the DTN with convergence angle **θ2=10⁰,** the maximum Mach number achieved at the exit of the nozzle is Mach 1.8.

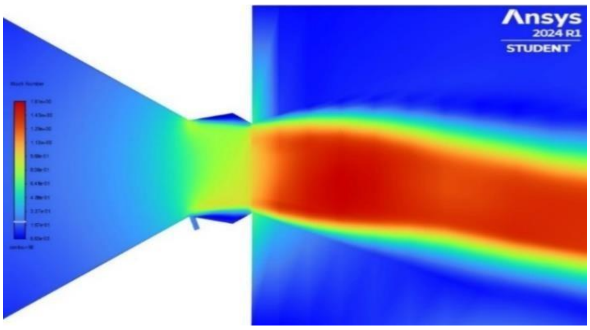

Figure 8: Thrust vectoring of DTN for θ2=20⁰

Figure (8) depicts the thrust vectoring for the DTN with convergence angle **θ2=20⁰,** the maximum Mach number achieved at the exit of the nozzle is Mach 1.65

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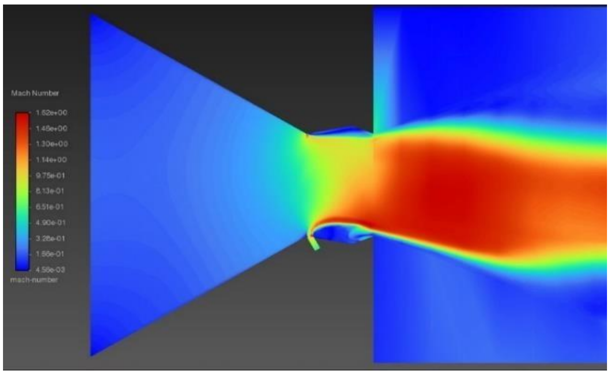


Figure (9): Trust vectoring of DTN for θ2=30°

Figure (9), (10), depicts the thrust vectoring for the DTN with convergence angle **θ2=30°,** the maximum Mach number achieved at the exit of the nozzle is Mach 1.79, this configuration of the DTN achieved the highest thrust vector angle with better performance.

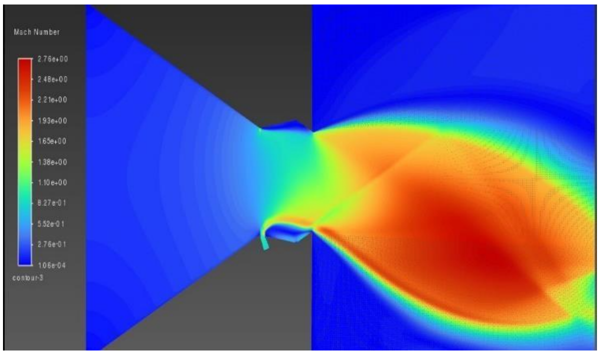
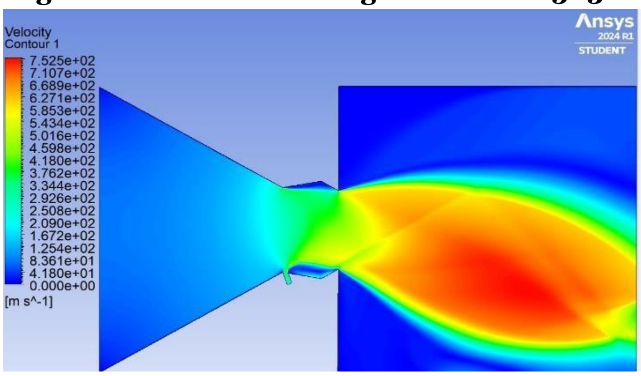


Figure 10: Thrust vectoring of DTN for θ2=30°

POST PROCESSING

The post - processing is done in ANSYS CFD - POST for contour plots option for various parameters like pressure, velocity, density, and temperature. At the same time, plots for those variables were made in both CFD posts MATLAB is used for better normalization, comparisons of various parameters and derive the desired results by formulation. ANSYS allows to define paths or surfaces on the model to evaluate results along those specific areas. The figure (11) shows the final post processed simulation of the DTN with **θ2=30°**.

Figure 11: Thrust vectoring of DTN for θ3=30°



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Journal of Information Systems Engineering and Management
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CFD COUNTOUR ANALYSIS

The computational analysis conducted in ANSYS FLUENT on the dual throat nozzle with three different design configurations, based on the convergence angle (**θ2**), yielded the following results. The figure (12) depicts the plots of the thrust vector angle for three distinct configurations, namely **θ2 =10°**, **θ2 =20°**, and **θ2 =30°,** under various secondary inlet flow conditions and the Table (2) shows the final consolidated results of this study. Angle. The results clearly demonstrate that the dual-throat nozzle (DTN) with a convergence angle of θ_3 = 30° achieves the highest thrust vector angle at an injection rate of 120 m/s. This DTN configuration is suitable for further experimental testing.

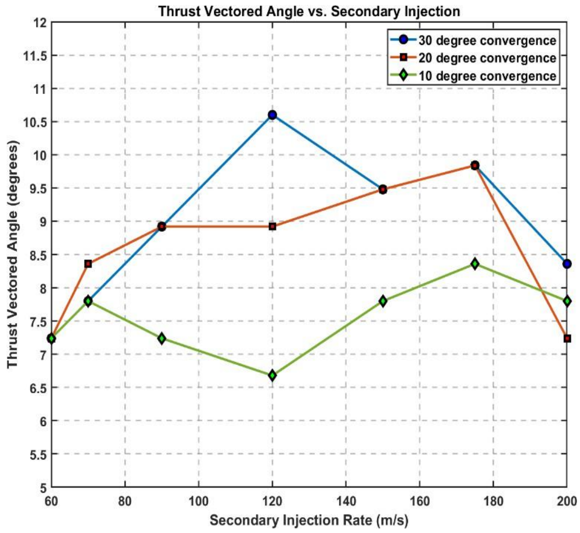

Figure 12: Thrust vectored angle vs Secondary velocity Plot

Secondary injection in m/s	Vectored angle for θ 2=30	Vectored angle for θ2=20	Vectored angle for θ 2=10
60	7.45	7.23	8.71
70	7.97	8.6	8.89
90	9.38	8.34	7.89
120	10.96	8.64	7.51
150	8.66	8.73	8.73
175	8.73	9.13	8.96
200	8.82	7.8	8.82

Table 2 Parameters for Secondary Inlet

APPARATUS AND EXPERIMENTAL METHODS

The study was conducted at the MITE Supersonic Jet Exit Test Facility. The following sections will discuss the test facility, secondary injection setup, model hardware, test conditions, and data acquisition methods.

JET EXIT TEST FACILITY

The supersonic jet facility in our aerodynamic laboratory is designed to support high-speed flow experiments. The facility is equipped with a primary compressor that can deliver up to a maximum pressure of 15 bar, which is used as the primary airflow for generating the supersonic jet through the nozzle. A secondary compressor with a maximum pressure of 8 bar supplies the required secondary airflow to induce jet deflection for thrust vectoring experiments. The main components of the facility are a settling chamber that stabilizes the flow and reduces turbulence to establish uniform conditions before entering the nozzle. The necessary pressures required to produce both primary and secondary flows are produced by high-speed compressor. The other elements consisted of a moisture and dust filter that further guarantees cleaner flow,

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
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and an air vertical reservoir, which keeps the compressors' compressed air at a pressure, hence being at steady supply for the entire course of experiments. The system further comprises an air filter that will trap all the remaining contaminants before entering the nozzle. The facility well-structured ensures that precise and controlled conditions are present to study complex flow dynamics and optimize performance of supersonic nozzles.

(a)

(b)

(c)

Figure 13: Supersonic Jet Facility (a), Compressor, filter and storage tank (b), 8 bar compressor (c)

SECONDARY INJECTION SETUP

In the dual throat fluidic thrust vectoring nozzle, the secondary inlet configuration creates a controlled secondary flow for introduction into the throat region of the nozzle. This configuration plays the most important role in manipulation to control the primary jet flow resulting in thrust vectoring without a mechanical actuation mechanism. The injection of air through the secondary inlet changes the pressure distribution within the nozzle, creating asymmetric flow patterns that deflect the exhaust jet. This deflection allows for precise control over the thrust vector, enhancing maneuverability and reducing the need for traditional movable control surfaces. The secondary injection was given with the 8-bar compressor.

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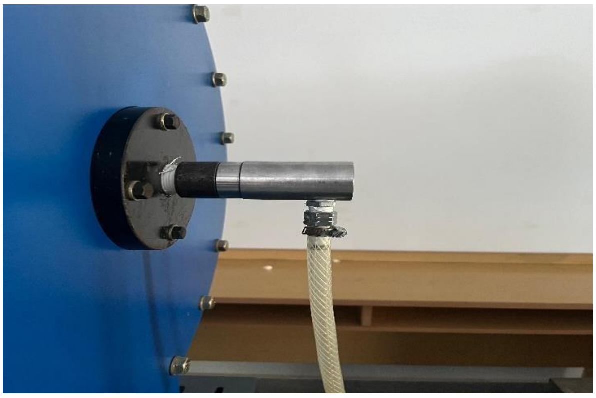

Figure 14: Secondary Inlet Setup

MODEL DESCRIPTION

The dual throat fluidic thrust vectoring nozzle is designed with precision for experimental analysis of fluidic thrust vectoring. The inlet diameter provided in the nozzle is of 26 mm, which favours efficient intake of high-pressure air from the supply system to generate a high-velocity supersonic jet during operational activities. The outlet diameter presented is 9.2 mm. The critical throat diameter of 8 mm controls the Mach number and characteristics of the flow; it is located between the convergent and divergent sections of the nozzle.

The nozzle has an overall length of 55 mm, a connector length of 25 mm is integrated into the design to ensure proper alignment and secure attachment to the supply and experimental setup. The convergent angle of 30 degrees and divergent angle of 10 degrees are optimized for efficient flow acceleration and expansion, facilitating the formation of a supersonic jet while minimizing losses. High pressure is used in the operation of the nozzle, having a tank pressure of 15 bar, which is equal to 1,519,875 Pascals. This high-pressure supply can ensure the required flow energy in order to achieve supersonic velocities and supports effective vectoring when combined with secondary flow injection. The precise geometric parameters and robust construction characterize the design of the nozzle, which is integral in the study of advanced thrust vectoring mechanisms and validation of CFD models.

(a) **(b)**

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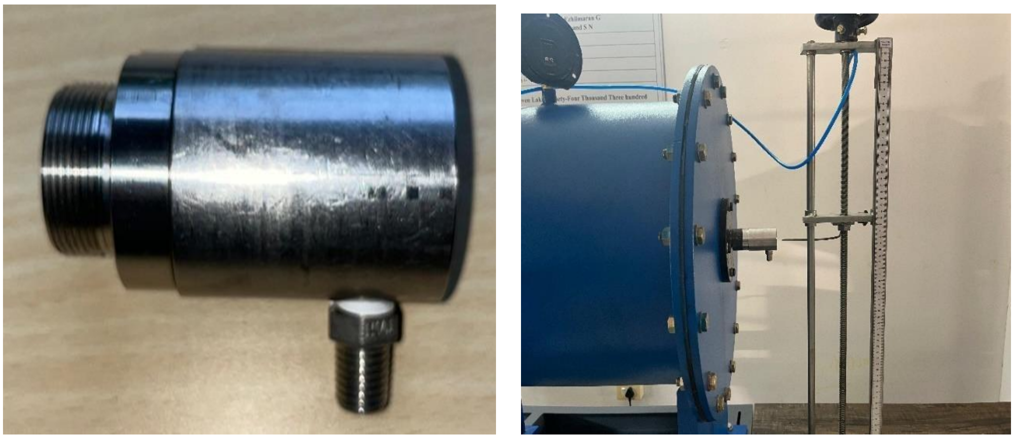

(c)

Figure 15. DTN Inlet (a), DTN outlet (b), Dual throat nozzle with secondary injection setup (c).

INSTRUMENTATION

Measurement of Pressure

Using an Arduino driven data acquisition system, pressure changes at the nozzle exit and the settling chamber were taken. A pitot tube was strategically positioned at the nozzle exit to be able to measure the pressure of the exhaust jet. The data was sent to Microsoft excel in real time through the data streamer plug-in for accurate logging and easy handling of data.

Flow Visualization

Using the shadow graph technique, flow visualization at the nozzle exit was performed. The plan consisted of providing a lie source of high intensity and a camera which would be able to focus on the shadow pictures of supersonic flow emanating from the nozzle. The arrangement of the shadow graph provided reasonable contrast and clarity of the flow features including the shock waves and or expansion fans.

Image Processing

The shadowgraph visualization images obtained were processed through MiT's chosen graphics software to improve their visualization quality to a more acceptable standard. Furthermore, they were on order processed to enhance their contrast and also sharpen the shadows in order to be closer to the geometric standards used for flow visualization. So a thorough qualitative assessment of the structure of the flow patterns was possible.

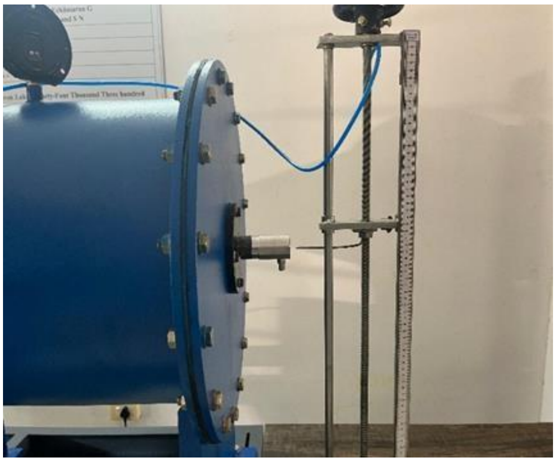

Figure 16: DTN Instrumentation setup

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
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EXPERIMENTAL PROCEDURE

In the experimental evaluation of the dual throat fluidic thrust vectoring nozzle, the designed setup successfully demonstrated to achieve jet deflection through secondary flow injection. The experiments were conducted under controlled conditions using the supersonic jet facility, with a primary flow pressure of 5 bar and a secondary injection pressure of 7 bar.
The experiments were conducted to analyze the behavior of the dual throat fluidic thrust vectoring nozzle under varying primary and secondary pressure conditions.

Primary Flow Conditions

The primary flow was introduced into the nozzle at three different stagnation pressure levels:

- **3 bar**,
- **4 bar**, and
- **5 bar**.

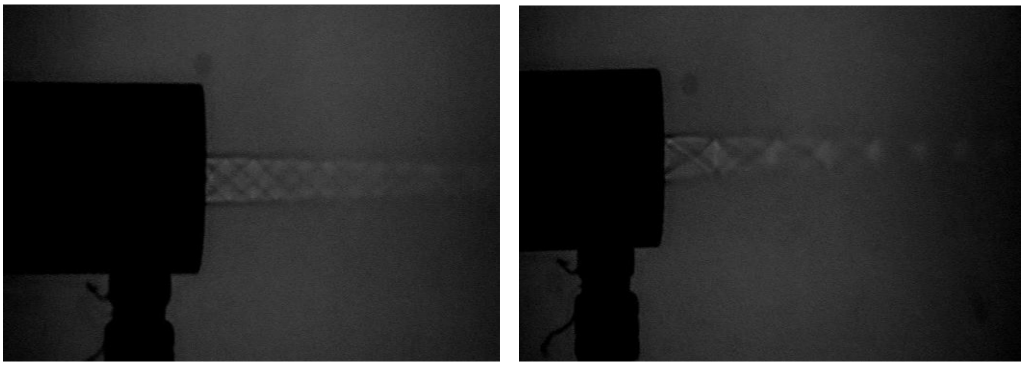
These pressure levels were chosen to observe the nozzle's performance across a range of typical operating conditions, ensuring comprehensive characterization of the flow behavior.

SECONDARY FLOW INJECTION

To evaluate the thrust vectoring capability of the nozzle, a secondary flow at a stagnation pressure of **7 bar** was injected. The injection was positioned to influence the primary flow, with the objective of inducing deflection in the exhaust jet. This approach aimed to assess the effect of secondary flow on altering the thrust vector angle and verifying its feasibility in practical applications.

RESULTS AND DISCUSSION

The experimental trails the thrust vectoring was conducted for three different primary inlet conditions, and it was observed that for a primary flow of 5 bar and secondary injection of 7 bar, a clear change in the trajectory with a slight deflection of the exit thrust was observed at this trial, the change in angle was measured to be 6.350. The exit thrust jet flow without secondary injection can be seen in figure 17 (a), and the thrust vectoring of the exit thrust with secondary injection can be observed from figure 17 (b).
All other experimental trials with primary inlets at 3 bar and 4 bar respectively showed no observable vectoring for 7 bar of secondary injection. The figure 18(a), figure 18 (b) show the exit jet flow for 3 bar and 4 bar respectively.



(a) **(b)**

Figure 17. Exit thrust flow at 5 bar inlet without secondary injection (a), Exit thrust flow at 5 bar inlet with secondary injection at 7 bar (b).

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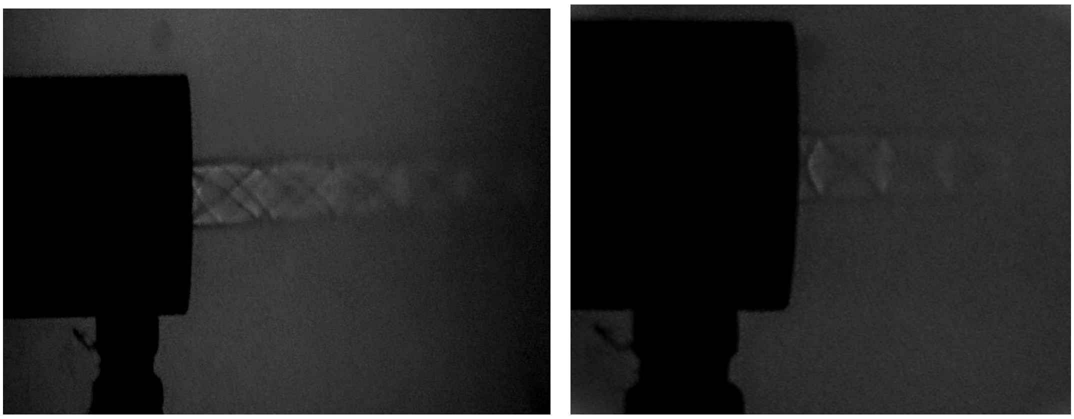
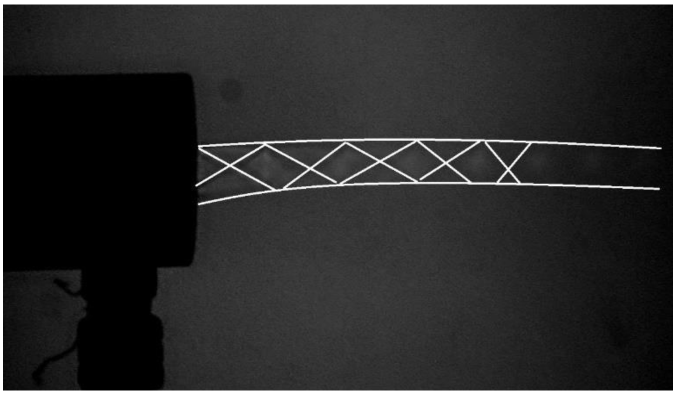


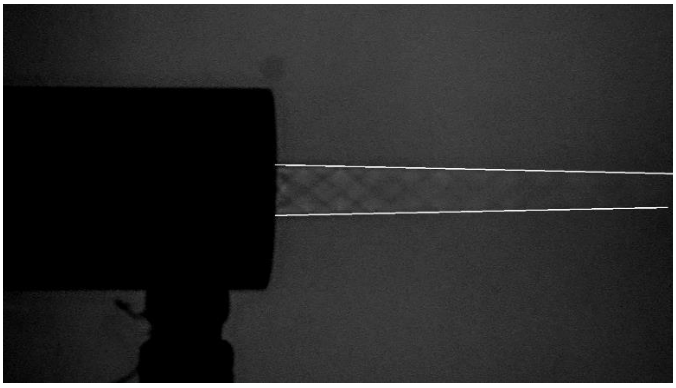
(a) **(b)**

Figure 18. Exit thrust flow at 3 bars (a), exit thrust flow at inlet 4 bar (b).

The flow trajectory, reflected shock waves, Mach angles and Mach cones have traced for better visualization



(a)



(b)

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
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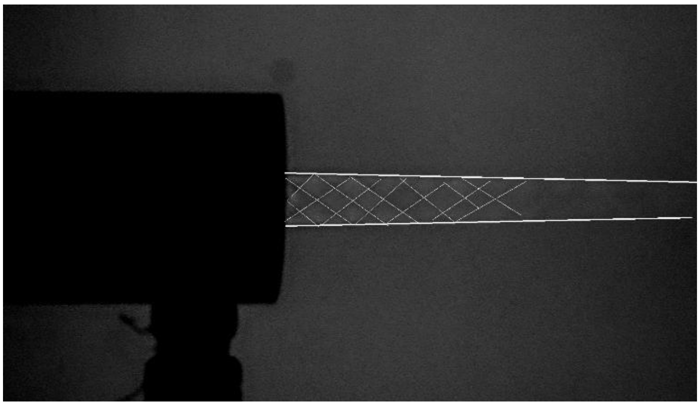

(c)

Figure 19. Exit thrust vectoring at 5 bar inlet with secondary injection (a), Exit thrust flow trajectory at inlet 5 bar (b). exit thrust flow with reflected shock waves at inlet 5 bar (c).

An error percentage of 42.06% is calculated, which shows how far apart the experimental results are from the analytical ones. This can be due to several sources such as flow turbulence, limits of measurement, and even assumptions in the CFD modeling process. However, the experimental results validated overall performance and thrust vectoring capability of the nozzle. The study underlined the significance of secondary flow injection and the influence on jet deflection, which provides critical insight for optimizing fluidic thrust vectoring mechanisms.

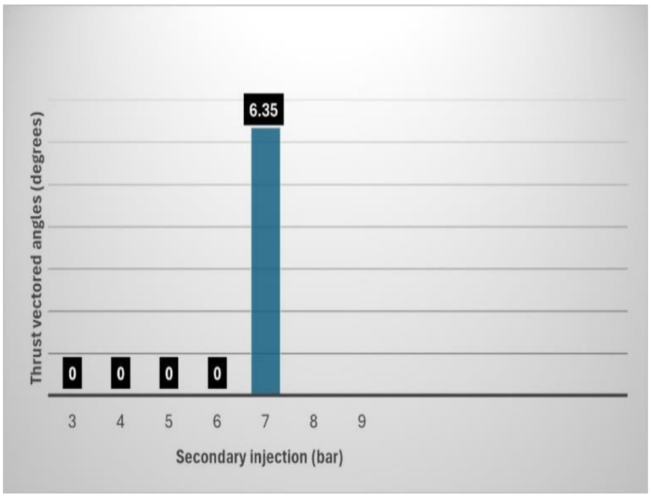

Figure 20: EXP-Thrust Vectored vs Secondary Injection for 30-degree Convergence

CONCLUSION:

The project on Fluidic Thrust Vectoring Nozzle with Modified Geometry successfully demonstrated the potential of fluidic thrust vectoring for enhancing maneuverability in supersonic propulsion systems.

Without secondary flow injection, the Nozzle produced a steady flow along the centerline, as expected. When we applied secondary flow of 7 bar pressure using secondary compressor for a 5 Bar pressure from primary compressor, a clear deflection in the flow path was observed, confirming effective thrust vectoring.

Minor differences in deflection angles compared to research results can be attributed to the compact size and specific geometry of our nozzle. The compact and precise fabrication of the nozzle highlights its potential for applications in scenarios where size, efficiency, and accuracy are critical.

The result validates the design functionality and potential as a reliable alternative to the mechanical thrust vectoring system, with application in advanced aerospace propulsion.

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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REFERENCES

[1] Karen A. Deere, Bobby L. Berrier, Jeffrey D. Flamm NASA Langley Research Center, Hampton, -A *Computational Study of a New Dual Throat Fluidic Thrust Vectoring Nozzle Concept*
[2] Elisa Capello Politecnico di Torino, Italy-*CFD-based Fluidic Thrust Vectoring model for fighter aircraft*
[3] Jeffrey D. Flamm, Karen A. Deeret, Mary L. Mason, Bobby L. Berrier, and Stuart K. Johnson NASA Laniley Research Center, Hampton, Virginia, 23681-*Design Enhancements of the Two-Dimensional, Dual Throat Fluidic Thrust Vectoring Nozzle Concept*
[4] Michele Ferlauto, Roberto Marsilio (2017) - *Numerical investigation of the dynamic characteristics of a dual- throat-nozzle for fluidic thrust-vectoring*
[5] Buxian XUa, Dongping Hub, Lihao FENGa,- *Dynamic characteristics and application of dual throat fluidic thrust vectoring nozzle* (2024)
[6] Roshan Vignesh Baskaran, & Ukeshkumar Harisrinivasan (2018) - *Geometry Optimization of a Pintle Nozzle for Augmented Thrust Vectoring and Steering using Expansion Waves*-American Institute of Aeronautics and Astronautics.
[7] Kenrick A. Waithe and Karen A. Deere (2003) - *Experimental and Computational Investigation of Multiple Injection Ports in a Convergent-Divergent Nozzle for Fluidic Thrust Vectoring* - American Institute of Aeronautics and Astronautics.
[8] Vladislav Emelyanov, Mikhail Yakov Chuk & Konstantin Volkov (2021) - Title: Multiparameter Optimization of Thrust Vector Control with Transverse Injection of a Supersonic Underexpanded Gas Jet into a Convergent Divergent Nozzle - Journal:
[9] VladetaZmijanovic, Luc Leger, & EricDepussay (2016) - *Experimental–Numerical Parametric Investigation of a Rocket Nozzle Secondary Injection Thrust Vectoring* - Propulsion and Power.
[10] Kavi Prasath S, Prasanth C, Rakesh Kumar P, Abinaya R (2020) - *CFD Analysis Of Dual Throat Thrust Vectoring With Chevron Nozzle* - International Research Journal of Engineering and Technology.
[11] Karen A. Deere (2003) - *Summary Of Fluidic Thrust Vectoring Research Conducted At Nasa Langley Research Center* - American Institute of Aeronautics and Astronautics.
[12] Emanuele Resta, Roberto Marsilio & Michele Ferlauto (2021) - *Thrust Vectoring of a Fixed Axisymmetric Supersonic Nozzle Using the Shock-Vector Control Method* - MDIP.
[13] Vladeta Zmijanovic, Luc Leger & Viviana Lago (2021) - *Experimental and Numerical Study of Thrust-Vectoring Effects by Transverse Gas Injection into a Propulsive Axisymmetric C-D Nozzle* - American Institute of Aeronautics and Astronautics.
[14] Erich A. Wilson, Dan Adler & Pinhas Bar-Yoseph (2003) - *Thrust-Vectoring Nozzle Performance Modeling*- Propulsion and Power.
[15] Flamm, Karen A. Deere, Bobby L. Berrier, Stuart K. Johnson, & Mary L. Mason (2005).

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