

Investigation of mixing characteristics on Convergent-Divergent Nozzle using different surface patterns.

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DEPARTMENT OF AERONAUTICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **Vaishnavi B Iyer (37260046) And Rahul Malik (37260053)** who carried out the project entitled **"Investigation of mixing characteristics on Convergent-Divergent Nozzle using different surface patterns"** under my / our supervision from SEPTEMBER 2020 to MARCH 2021.

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Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

DECLARATION

I **Vaishnavi B Iyer** hereby declare that the Project Report entitled **Investigation of mixing characteristics on Convergent-Divergent Nozzle using different surface patterns** done by me under the guidance of Prof. **VENKATESH S** and **Dr.**

VALARMATHI

is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical.

DATE:

PLACE: **Chennai**

SIGNATURE OF THE CANDIDATE

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ABSTRACT

The objective of this investigation is to study the mixing characteristics of Convergent-Divergent Nozzle using different surface patterns. This study is based on the Convergent- Divergent Nozzle by using various surface patterns. We are going to check the aerodynamic behaviour which is important in the propulsion industries. This Convergent-Divergent nozzle flow experimental analysis are done using scaled materials and CFD analysis is done using ANSYS software. Comparisons are made theoretically by getting the static variation using Bernoulli's and continuity equations and practically using the measurements. Hence the working of the convergent nozzle can be shown. This project gives guidelines and process for incorporating these requirements and the results are compared with standard numerical values. Using these two experimental and numerical simulations the best-fit patterns in the nozzle are recorded. However, the comparison was also made to meet the reliability of the work on design criteria of Convergent-Divergent nozzle which can entrench in the field of propulsion applications.

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Chapter – 1

Introduction

- Nozzle is a venturi gadget. It gives enough pressure upstream and flow conditions that results in the packed flow at the throat.
- These Nozzles have 3 different sections - Converging section, Throat section, and Diverging portion.
- The point where the radius of the nozzle is the least is known the Throat.
- The upstream section of the throat is known Converging section.
- The downstream portion of the throat is called Diverging portion.
- The converging nozzles are used to increase the fluid velocity. The kinetic energy is converted into fluid energy. These nozzles are owned for impact turbine electric generators by running turbine blades.
- The divergent nozzle is owned to shoot-up the pressure and thus produce increased thrusts like aircraft jet engines or rocket propulsion engines.
- In a Convergent-Divergent nozzle, the hot exhaust exits the chamber of combustion and converges below to the least sized space, or the **throat**, of the nozzle.
- A size of the throat is chosen to set the mass flow rate which passes through the system and **choke** these flows.
- The throat flow is sonic then that is the Mach number = one inside the throat.
- In the throat downstream, the geometry disunites and the flow enlarges isentropically to a Mach number which is supersonic and depends on the area ratio of the way-out to this throat.

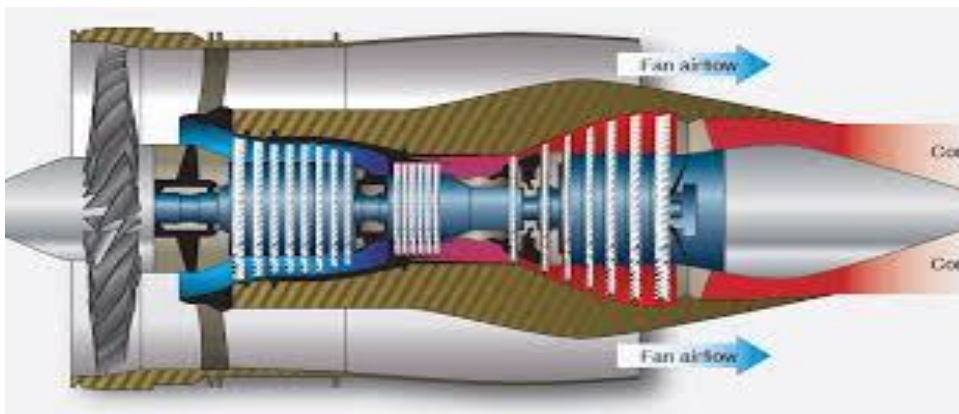


Fig. 1.1 Convergent-Divergent Nozzle

- The enlargement of the supersonic flow is the source of the temperature and static pressure to reduce from the throat to the way-out, so that the quantity of the enlargements determines the way-out temperature and pressure.
- The temperature in the exit regulates the way-out speed of sound, that governs the exit velocity.
- The exit pressure, velocity, and mass flow which passes through the nozzle decides the thrust amount processed by this nozzle.
- A nozzle is a comparatively uncomplicated device, just expressly shaped duct along which the hot gases flows.
- Rockets and ramjets customarily uses a stable converging section accompanied by a stable diverging portion for the representation of this nozzle.

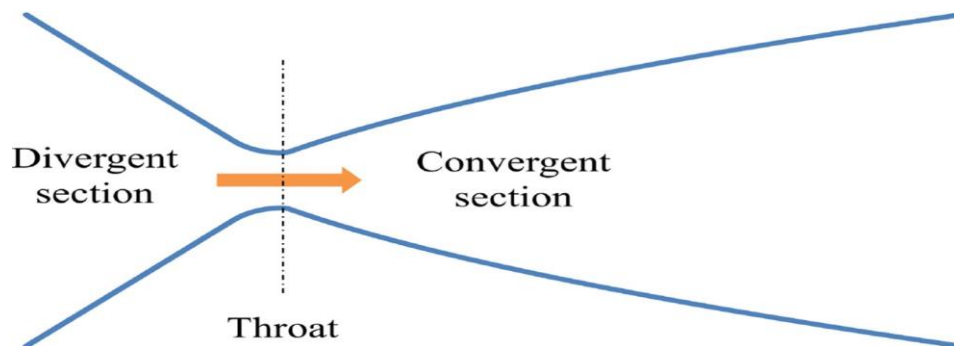


Fig. 1.2 Convergent Divergent Nozzle

- This nozzle arrangement is known a **convergent-divergent** nozzle and also called as CD noszzle.
- Nozzles are mostly used to alter the flow of fluids (i.e., rising the flow of the kinetic energy in the cost of pressure).
- **Convergent-divergent nozzles** is chiefly used for supersonic flows as it is unfeasible creating supersonic flows (Mach number $> one$) in the **convergent**

of **nozzle** and consequently that limits to controlled amount of the mass flow through the specific **nozzle**.

- In the convergent-divergent nozzles, we rise the flow velocity superior to sonic velocity that being the case of these types of nozzles have extensive implementation namely air intake for engines working at giant RPMs or propelling nozzles in jet engines.
- A positioning in which the advancing section of the nozzle is convergent, which expands the pressure of the exhaust gases, while the subsequent portion is divergent to rise gas velocity to the supersonic speed and keep away from mislaying under expansion. This ordering is not coherent below the design speed.
- For Mach number lesser of equal to 0.3, contemplate the flow to incompressible since the density difference is down 5 percentage and flows with Mach number greater or equal to 0.3, contemplate the flow, compressible as the density differences cannot be mistreated.
- Gas flow from the region of larger pressure through the nozzle (chamber) to lesser pressure (ambient).

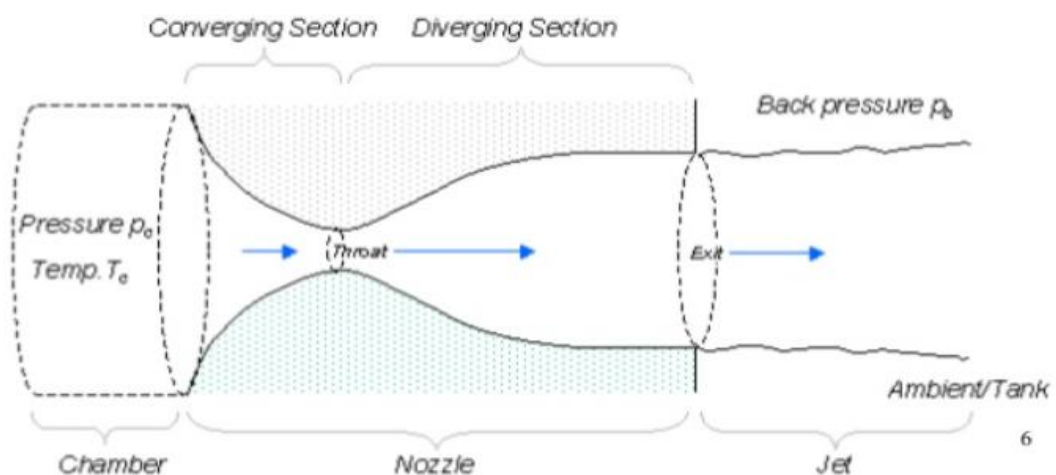


Fig. 1.3 Sections of Convergent- Divergent Nozzle

- Chamber is large and adequate in order- any flow velocities are trivial.

- Gas flows through the chamber across the converging portion of the nozzle, back in the throat, down the diverging portion, and the wear out into the ambient as jet.
- **Dimples** are the minute depressions in the cavity of a surface.
- **Mach number is narrated as-** It is the proportion of the flow speed in a channel to the sound speed in that channel.
- High velocity -Normally, the objective of the nozzle is at the cost of its pressure and internal energy to expand the kinetic energy of the flowing medium.
- Nozzles can also be reported as convergent (shrinking down from a broad diameter to a lesser diameter in the path of the flow) or divergent (enlarging from a lesser diameter to a greater one).
- A de Laval nozzle has a convergent portion continued by the divergent portion and is frequently called a convergent-divergent nozzle and is shortened as CD Nozzle. ("con-di nozzle").
- Convergent nozzles stimulate subsonic fluids. The flow will reach sonic velocity at the tapered point (that is to say, the nozzle throat). On condition that, the nozzle pressure proportion is high sufficient. In this case, the nozzle is claimed to be choked.
- Increasing the nozzle pressure proportion additionally, it will not increase the throat Mach number $> one$.
- Downstream (that is external to the nozzle) the flow is free to extend to supersonic velocities; however, Mach one can be a tremendously high speed for a hot gassince the speed of sound differs as the square root of absolute temperature.
- This is used immensively in rocketry place where hypersonic flows are needed and place where propellant mixtures are intentionally selected to additional rise in the sonic speed.
- Divergent nozzles slows' down the fluids on the condition to the subsonic flow, but they stimulated sonic or supersonic fluids.
- Convergent-divergent nozzles can consequently stimulate fluids that have tapered in the convergent portion to supersonic speeds.
- This CD process is more coherent than approaching a convergent nozzle to extend supersonic externally.

- The shape of the divergent section also confirms the path of the exhaust of gases is directly backward, as any laterally component would not grant to thrust.



Fig. 1.4 Convergent- Divergent Nozzle

Chapter – 2

Literature survey

1. CFD ANALYSIS OF CD NOZZLE AND EFFECT OF NOZZLE PRESSURE RATIO ON PRESSURE AND VELOCITY FOR SUDDENLY EXPANDED FLOWS.

Done by: SHER AFGHAN KHAN, ABDUL AABID AND MAUGHAL AHMED ALI BAIG.

A numerical work was carried out to study the effectiveness of micro-jets to control base pressure in suddenly expanded two-dimensional planar duct. Two micro-jets of 1 mm orifice diameter located at 90° intervals along a pitch circle distance of 1.5 times the nozzle exit diameter in the base region were employed as active controls. The calibrated Mach numbers at the entry to suddenly expanded duct was 1.87. The length-to-diameter ratio (L/D) of suddenly expanded duct was 10. Nozzles generating the calibrated Mach numbers were operated with nozzle pressure ratio (NPR) 3, 5, 7, 9 and 11. From the present investigation it is evident that for a given Mach number and effect of NPR will result in maximum increase/decrease of pressure and velocity. The convergent-divergent nozzle geometry has been modelled and simulated employing turbulence models: K- ϵ standard wall function turbulence model from the code was independently checked with the commercial computational fluid dynamics.

2. Investigation of High-Speed Flow Control from CD Nozzle Using Design of Experiments and CFD Methods.

Done By: Abdul Aabid And Sher Afghan Khan.

In high-speed fluid dynamics, the control of base pressure finds many engineering applications such as automobile industry and defense applications. Several studies have been reported on passive control using devices like cavities, ribs, aerospike, etc. in the last three decades. Therefore, the present research focuses on active control uses the microjets in the form of an orifice of a 1 mm diameter to inject the air in the base flows

and located at base area of 90° intervals as a control mechanism. Since the air is drawn from the main settling chamber, the NPR will be the same as the respective NPRs used for tests. Experiments were conducted in the presence and absence of the microjets for area ratio 3.24 and L/D ratios from 10 to 1 at Mach numbers 1.87, 2.2, and 2.58. The parameters were optimized using the design of experiments (DOE) approach. Three parameters have been selected for the flow and the DOE. An L9 orthogonal array, multiple linear regression, and confirmation tests were performed to analyze the experimental results. The developed models are statistically suitable and accomplished in producing reasonable predictions for both cases. Besides, a computational fluid dynamics method has been utilized and validated by the experimental results. The $k-\epsilon$ turbulent model is used to analyze the simulation results. According to the present results, it is evident that for a given parameter, an L/D ratio is the most significant impacting to a maximum increment or decrement of a base pressure.

3. Numerical Investigation of Supersonic Nozzle Flow Separation.

Done By: Q. Xiao, H. M. Tsai And D. Papamoschou.

Investigated by solving the Reynolds-averaged Navier–Stokes equations with a two-equation $k-\epsilon$ turbulence model. The focus of the study is on the structure of the fluid and wave phenomena associated with the flow separation.

Computations are conducted for an exit-to-throat area ratio of 1.5 and for a range of nozzle pressure ratios. The results are compared with available experimental data in a nozzle of the same geometry. The flow separates by the action of a lambda shock, followed by a succession of expansion and compression waves. For $1.5 < \text{NPR} < 2.4$, the computation reveals the possibility of asymmetric flow structure. The computationally obtained asymmetric flow structures are consistent with previous experimental flow visualizations studies. In addition, other flow features such as shock location

and wall pressure distributions are also in good agreement with the experimental data. The present study provides new information that confirms earlier conjectures on the flow–wave structure relevant to the instability of the separated flow in convergent–divergent nozzles of moderate expansion ratio.

4. Theoretical and experimental investigation of compressible flow through convergent–divergent nozzles.

Done By: Hocine MZAD and Mohamed ELGUERRI

The present paper is concerned with the study of compressible flow in a converging-diverging nozzle. From a theoretical and experimental investigation of the flow in an illustrative channel with convergent-divergent area variation, the behavior of the flow along the channel was found to be generally similar in trend to the flow in a stationary convergent-divergent nozzle. In compressible flows, the density and temperature variations are often significant. Therefore, the following study provides additional information on shock location, Mach number behavior and pressure distribution by varying nozzle length. The obtained curves show pressure distribution and Mach number along the two dimensioned nozzles which enable us to compare the experimental data with the theoretical calculations. Furthermore, interesting graphs are plotted which show the relationship between some nozzle parameters and flow characteristics.

5. CFD analysis of the flashing flow characteristics of subcritical refrigerant R134a through converging-diverging nozzles.

Done By: Lihong Genga, Huadong Liu And Xinli Wei.

A CFD-based numerical analysis of the choking flashing flow characteristics in R134a converging-diverging nozzles is presented in this paper. The CFD results are validated with available experimental data of R134a converging-diverging nozzles. After that, the critical mass flux and effects of geometric dimensions on the performance of converging-diverging nozzles are investigated. Furthermore, the calculated critical mass fluxes are compared to that of the classical models. Results show that the metastable state in R134a convergingdiverging nozzle is weaker than that of water at the same operating parameters and a higher choking correction factor of R134a compared to that

of water is obtained. The optimum ratio of nozzle exit diameter to the throat diameter of 2.4 is recommended among the studied nozzle geometry dimensions. Effect of the divergent length on the nozzle flow characteristics is relatively smaller than that of the nozzle exit diameter.

Chapter – 3

Aim and Scope of the present investigation

The aim of the project is to study the different flow characteristics from the nozzle of different inlet and outlet geometrical configuration. The numerical calculations were carried out with the support of standard literature. In recent years, the up-gradations of existing parts have significantly rising the performance of the system. To check the effects in the nozzle by changing different surface geometrical patterns such as a sphere, triangle, and square. By changing the geometrical surface of the nozzle with different orientations, we investigate the mixing **characteristics on Convergent-Divergent Nozzle** with different design patterns. Here, we are going to check the aerodynamic behaviour of **Convergent -Divergent** nozzle by the flow experimental analysis using scaled apparatus and CFD. Comparisons can be made by practically using the measurements. Hence, the working of the convergent-divergent nozzle can be demonstrated.

The objective of this investigation is to study the flow characteristics from the nozzle of different inlet and outlet geometrical configurations. And study the effects of geometric changes on the mixing **characteristics on Convergent-Divergent Nozzle** with design patterns through **Convergent-Divergent Nozzle**. And the study also describes the best geometrical pattern for mixing **characteristics on Convergent-Divergent Nozzle**.

Convergent-divergent nozzles has a great implementation as a propelling nozzle in the automobiles and jet industries. Examples of these application of the convergent-divergent type of nozzles in engineering are:

Greatly used in power plants called Steam turbines. They are owned for providing sufficient thrust to move upwards known as Rockets. They are enormously used for the air intake when the air requirement of the engine is high are known as The supersonic gas turbine engine.

Convergent- Divergent nozzles are also used in pump which supplies water, formula car in the intake system, and for providing sufficient thrust to propel at great speeds in jet engines greatly in supersonic jets.

Chapter 4

EXPERIMENTAL SETUP AND PROCEDURE

4.1 MODELLING

The convergent nozzle with 3 cases of surface patterns is designed using the design software which is commercially available. The model is designed with domain too.

4.2 Two-Dimensional Modelling

For our project, we modelled the nozzle by using commercial modelling software.

Using the following steps, we have drawn our model.

- Open designing software,
- Go the part model designing option.
- Entering the modelling part option, select the appropriate axes that is XY, YZ, or XZ.
- Go to the sketch workbench option by clicking the sketch toolbar for two time.
- Draw the nozzle.
- The nozzle dimensions should be as per the requirement.
- Drawing the nozzle as the axis-symmetric makes the meshing and can be solved easily.
- Further draw the domain with required calculation by taking the dimensions of the nozzle.
- Save the file as IGS.
- Step is the file formats supported by the Analysis software.

4.3 Three-Dimensional Modelling

- Enter the sketch workbench, draw a curve or a line which should be inclined based on the nozzle angle with the help of profile tool.
- Repeat to draw the line , go to the part modelling, click the exit workbench toolbar by clicking it two times.

- Create the nozzle by selecting the tool called shaft tool, to give three hundred and sixty degree rotation.
- Nozzle thickness should be given.
- The required dimensions are taken and the nozzle is structured.

4.4 Nozzle Specifications

Specifications	Dimensions
Convergent Length	35 mm
Divergent Length	12.926 mm
Inlet Diameter	28.72 mm
Exit Diameter	10 mm
Throat Diameter	8.648 mm
Mach Number	1.87

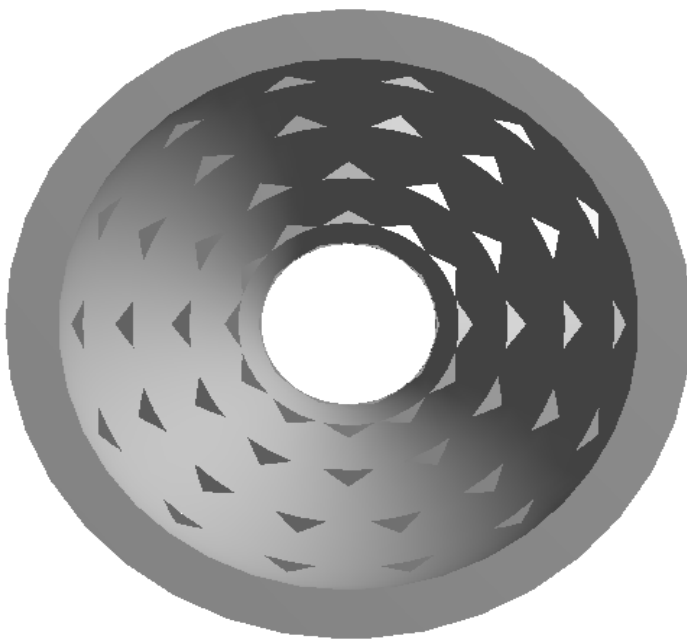


Fig. 2.1.1 Top View of a CD Nozzle with Triangular Dimples

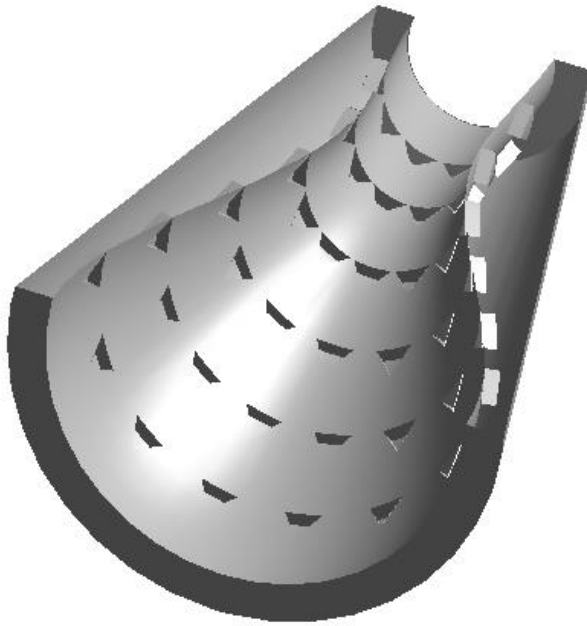


Fig. 2.1.2 Inner view of a CD Nozzle with Triangular Dimples

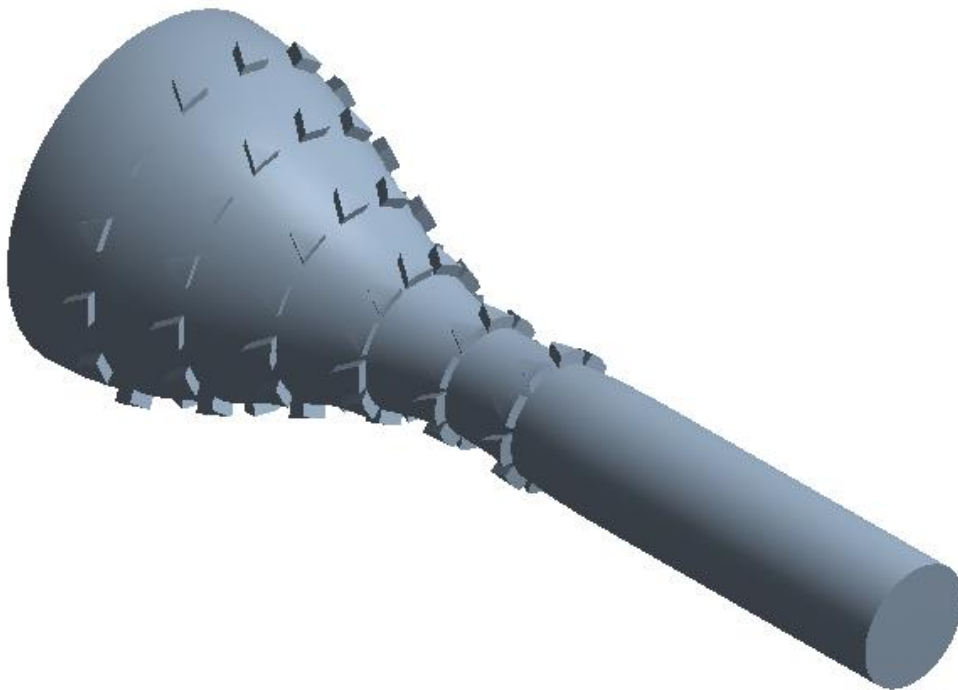


Fig. 2.1.3 Outer view of a CD Nozzle with triangular dimples.

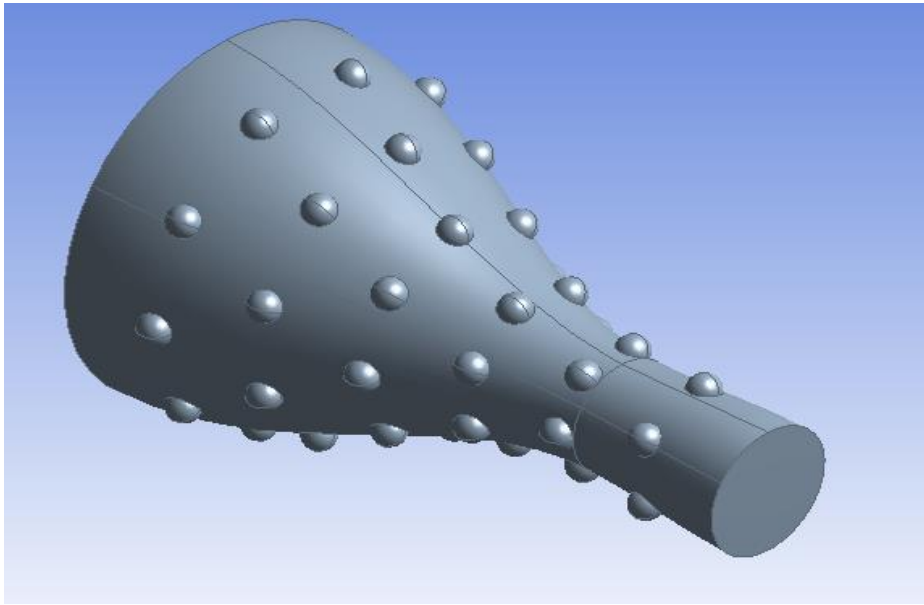


Fig. 2.2 Outer view of a Cd Nozzle with circular dimples.

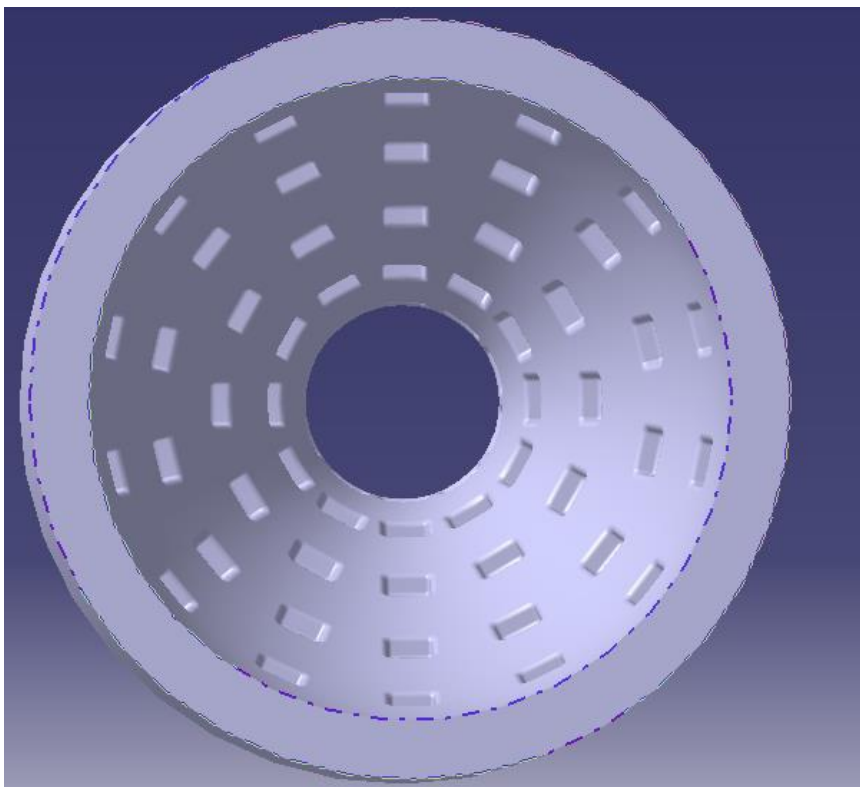


Fig. 2.3.1 Top View of Cd Nozzle with square shaped dimples.

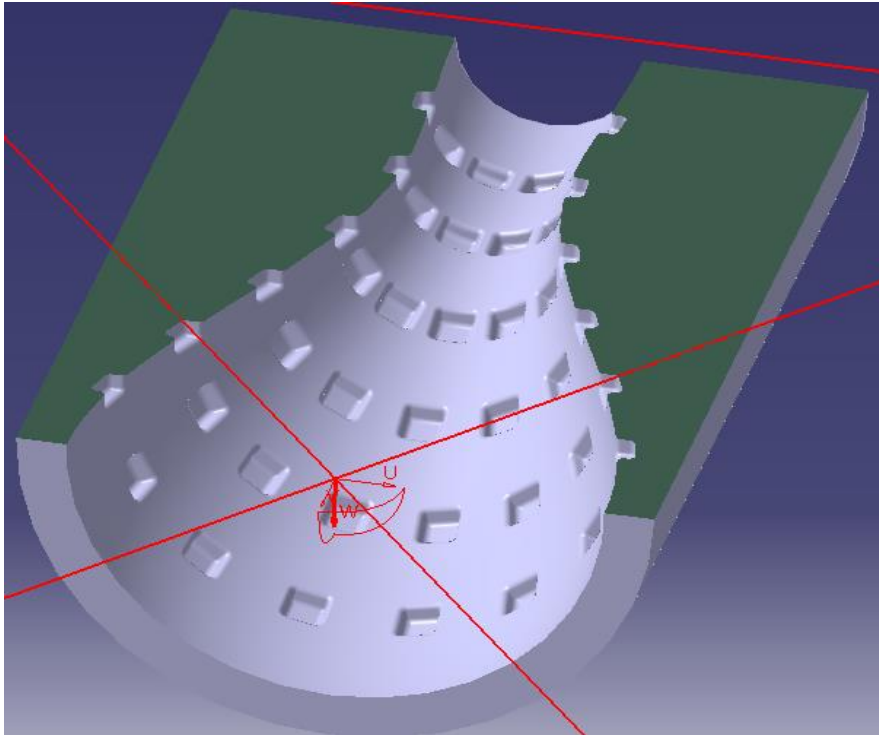


Fig. 2.3.2 Inner view of a Cd Nozzle with Square Dimples.

4.5 PREPROCESSING

For the accurate result the Commercial Analysis tools can be taken in use.

4.6 Two-Dimensional Meshing

- Open the Commercial software.
- Import the Catia model in Commercial software by using the import option.
- The Catia model cannot be directly imported to the Commercial Software.
- To import, converting the Catia file to an IGS file or Step file
- The import can be done after this conversion process.
- Importing the model with zone, change the 2d wireframe to face by using the face option.
- Mesh the edges by using the edge mesh command button.
- Mesh the face by using the face mesh option.
- According to the requirement, decompose the domain and mesh.
- Mesh the domain using quad elements under a mapping scheme.
- Give the boundary conditions and export them.

4.7 Three-Dimensional Meshing

- Import the Three-dimensional IGS file or Step file into the Ansys.
- Do any clean-up operations if necessary.
- Create the domain according to the requirement which may be rectangular brick or cylinder for our convenience.
- The zone height is to be 5D to 10D and length to be 30D to 40D range or to be greater than that too.
- Place the domain at the exit of the nozzle by using the copy option.
- Unite the two volumes as a single volume.
- The domain can be decomposed according to the requirement.
- The size of the elements can be chosen by considering the geometry and the system configuration.
- Mesh the volume by using volume mesh option by tetrahedral elements under cooper scheme.
- Give boundary conditions and export it.

4.8 Nozzle Meshing Specifications

Type of Surface Pattern	Nodes	Elements
Triangular Dimple	129331	405941
Circular Dimple	400514	1366099
Square Dimple	129331	405941

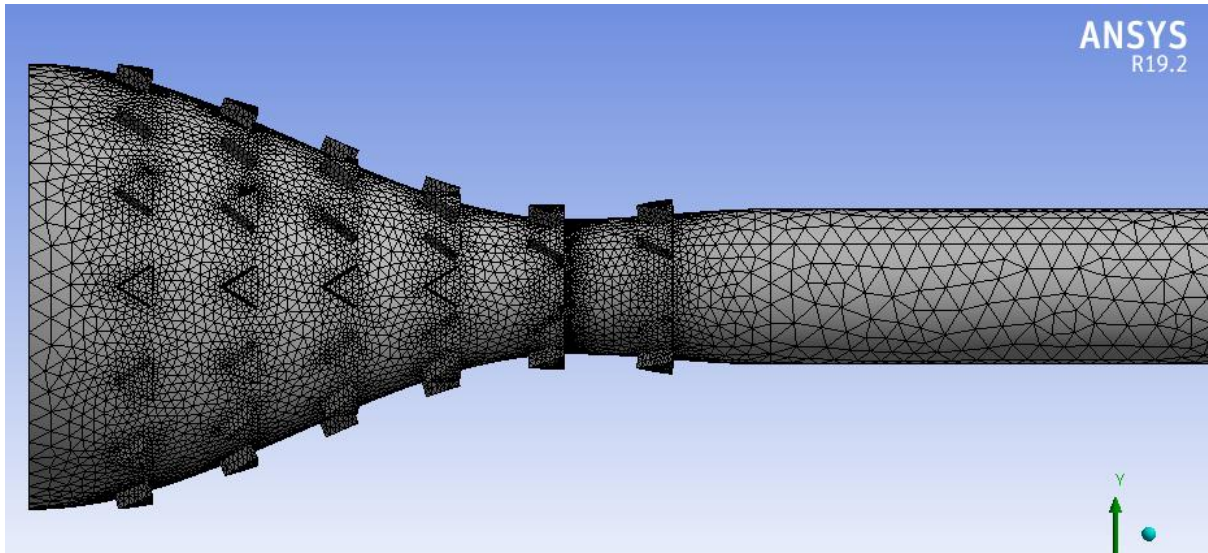


Fig. 3.1.1 3D Meshing of a Cd Nozzle with Triangular Dimples- Outer view

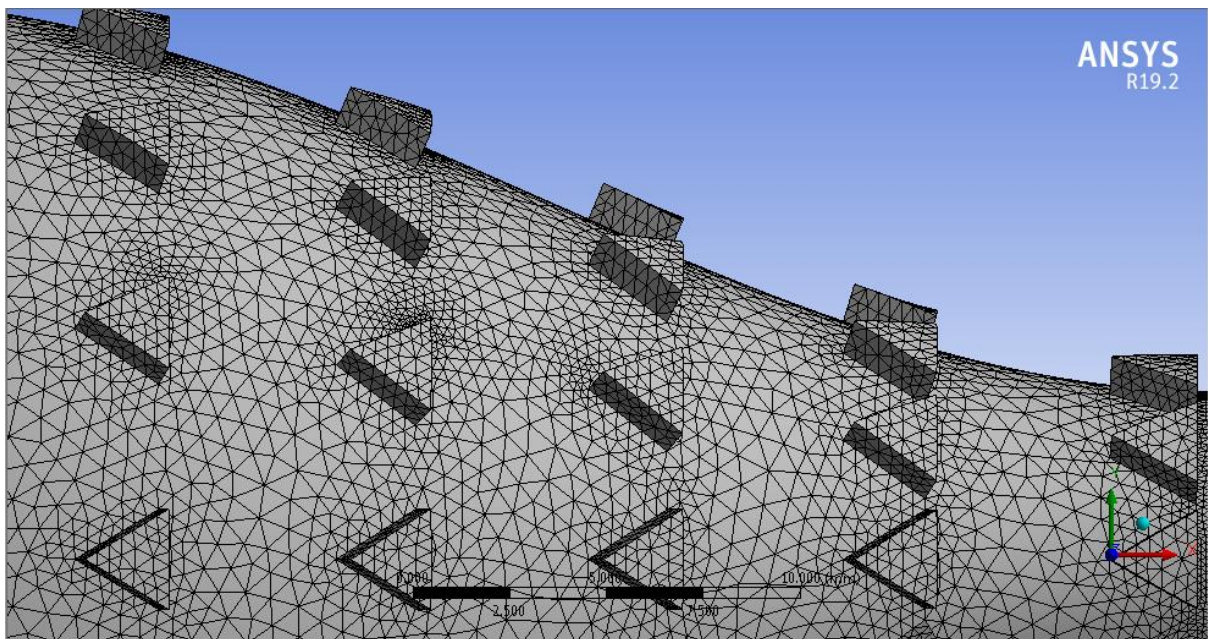


Fig. 3.1.2 3D Meshing of a Cd Nozzle with Triangular Dimples- zoomed view

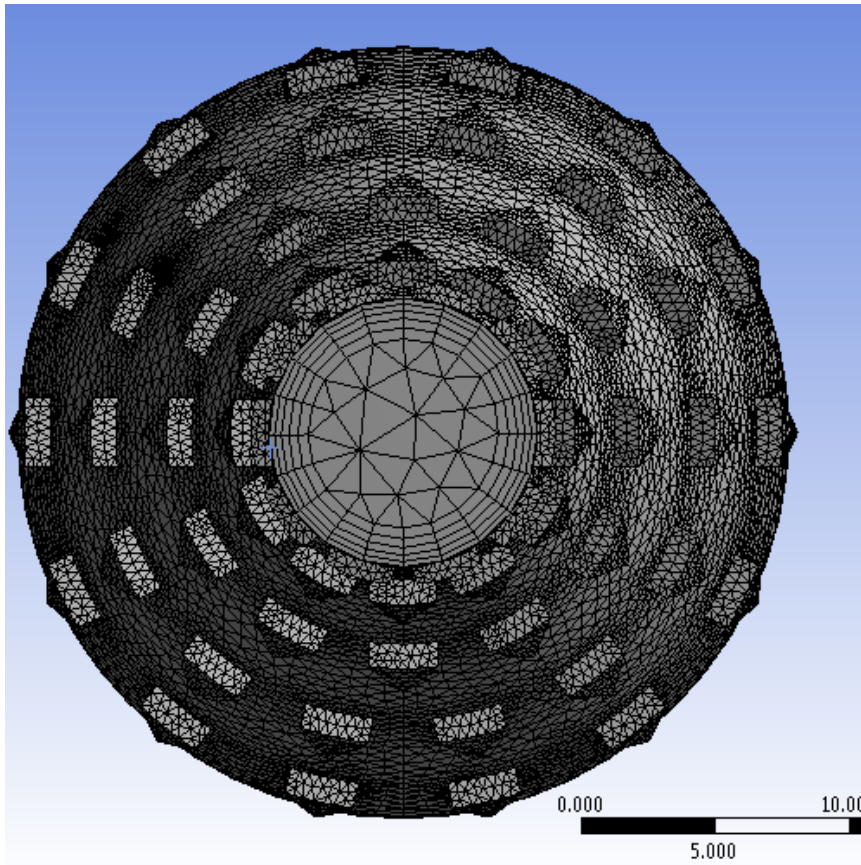


Fig. 3.1.3 3D Meshing of a Cd Nozzle with Triangular Dimples- Inner view

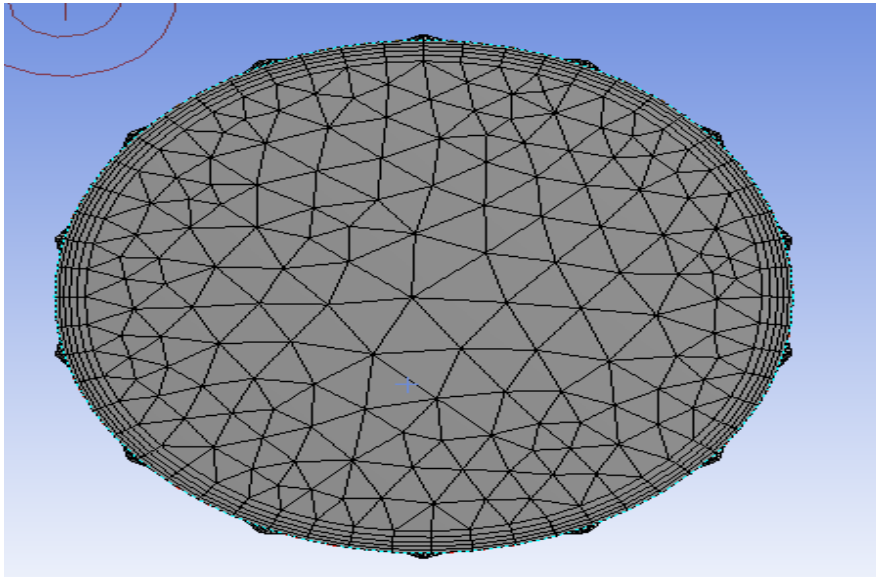


Fig. 3.1.4 3D Meshing of a Cd Nozzle with Triangular Dimples- Top view

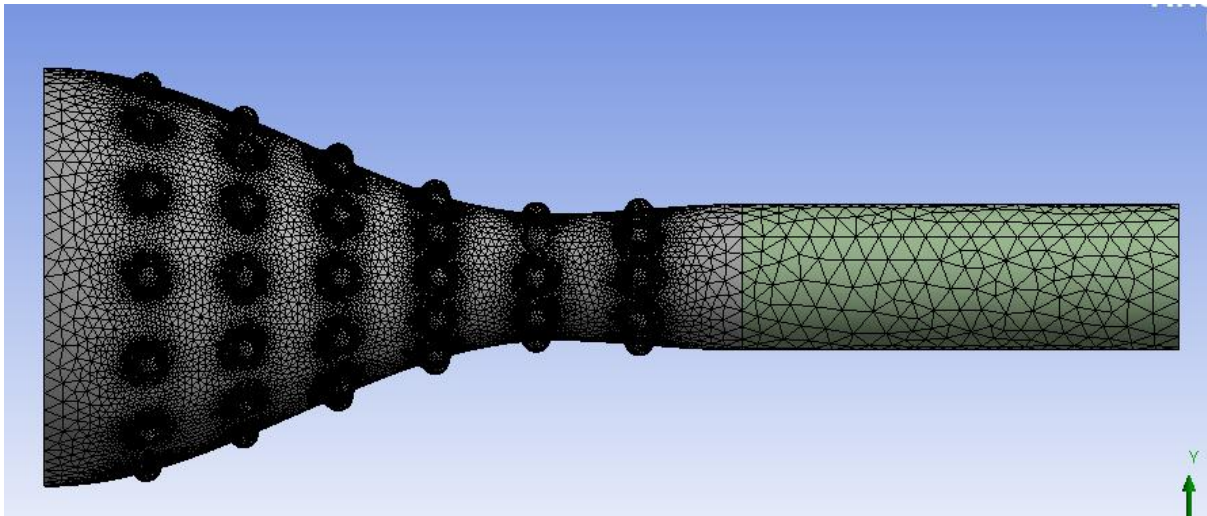


Fig. 3.2.1 3D Meshing of a Cd Nozzle with Circular Dimples- Outer view

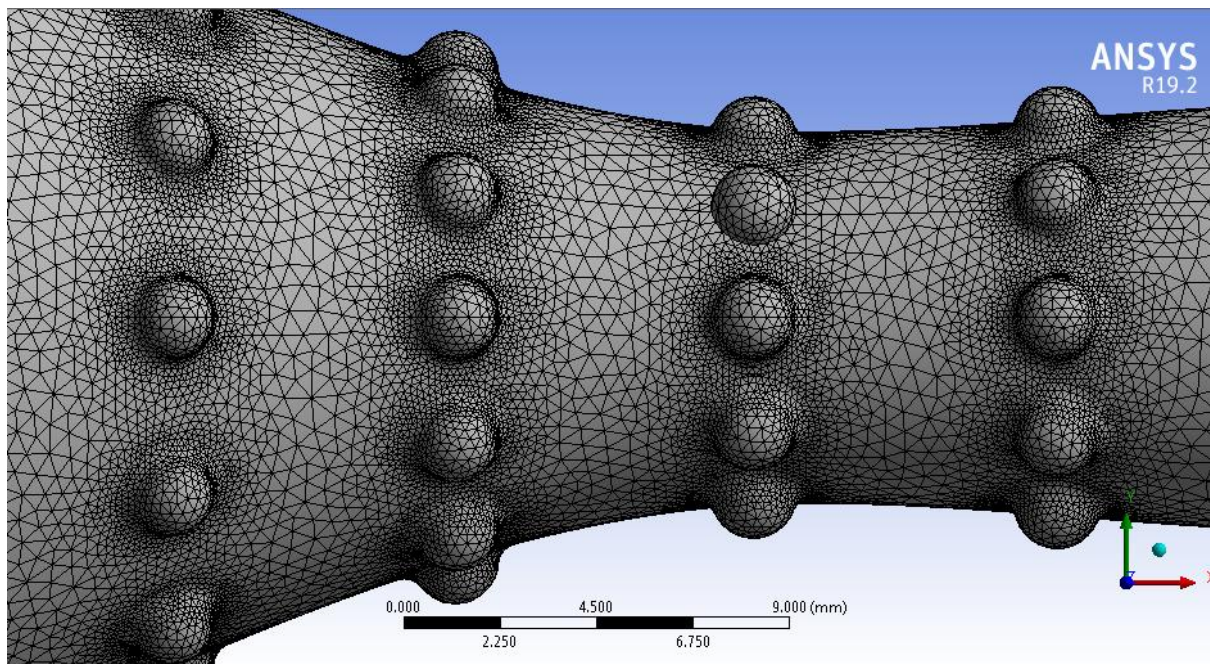


Fig. 3.2.2 3D Meshing of a Cd Nozzle with Circular Dimples- Zoomed view

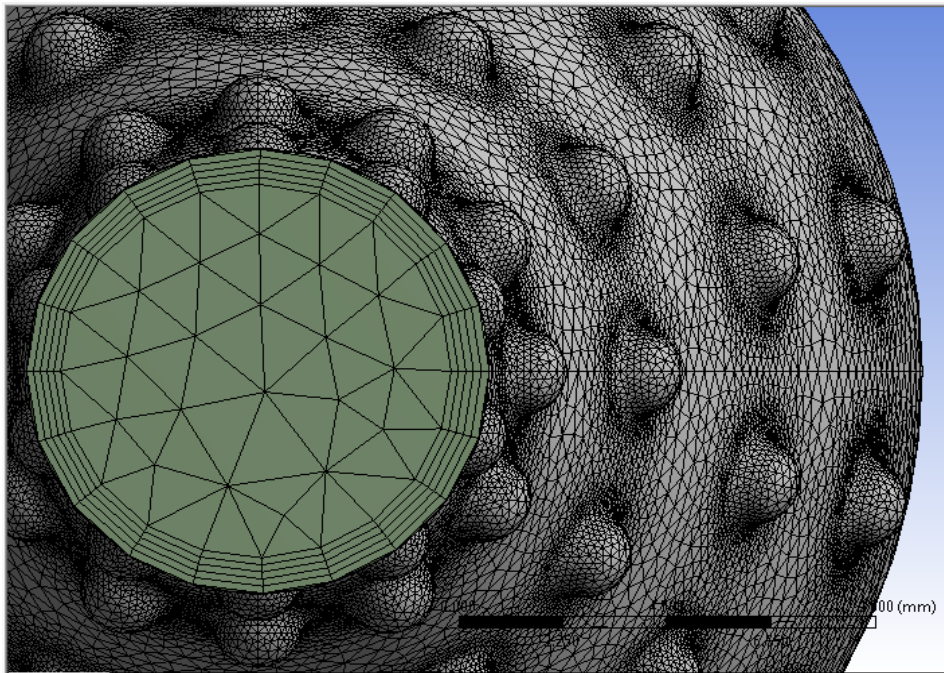


Fig. 3.2.3 3D Meshing of a Cd Nozzle with Circular Dimples- Inner view

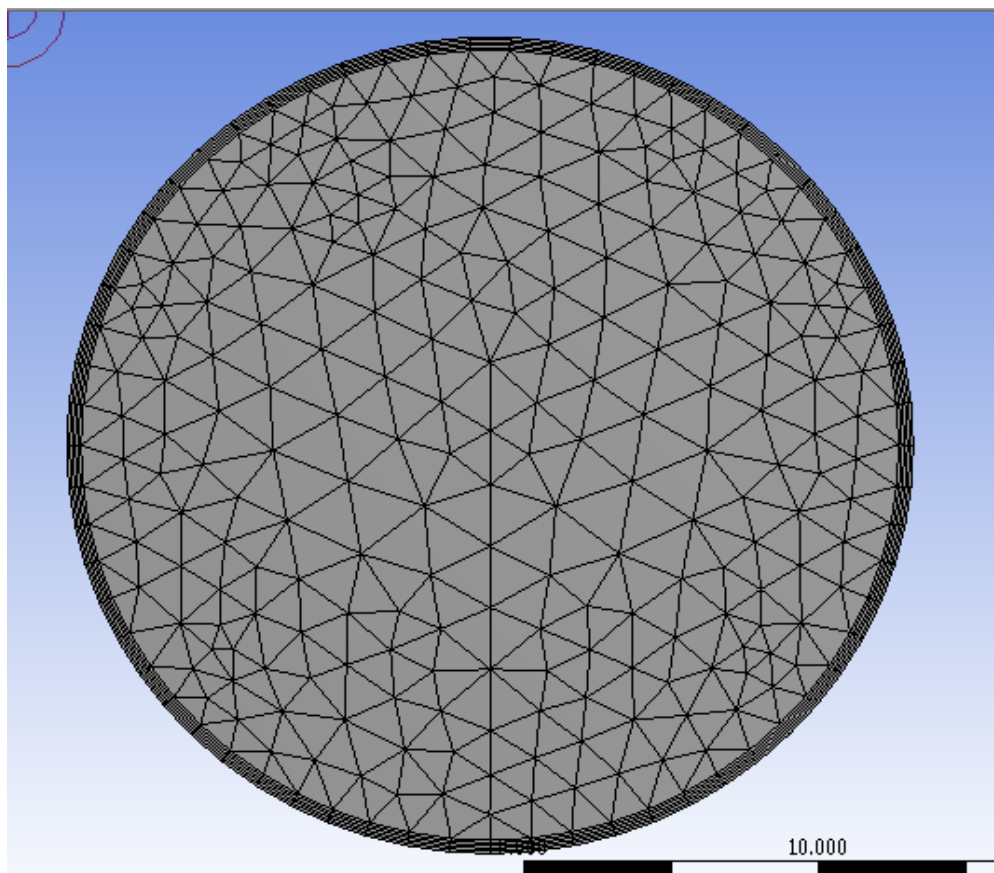


Fig. 3.2.4 3D Meshing of a Cd Nozzle with Circular Dimples- Top view

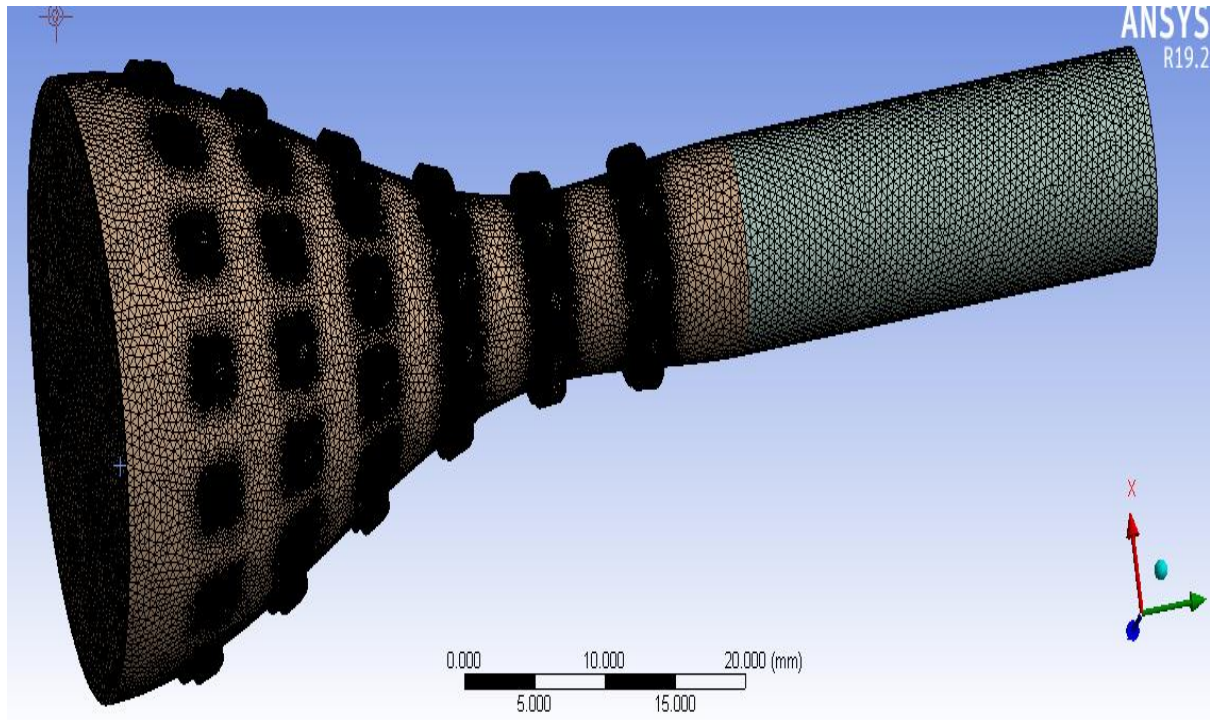


Fig. 3.3.1 3D Meshing of a Cd Nozzle with Square Dimples- Outer view

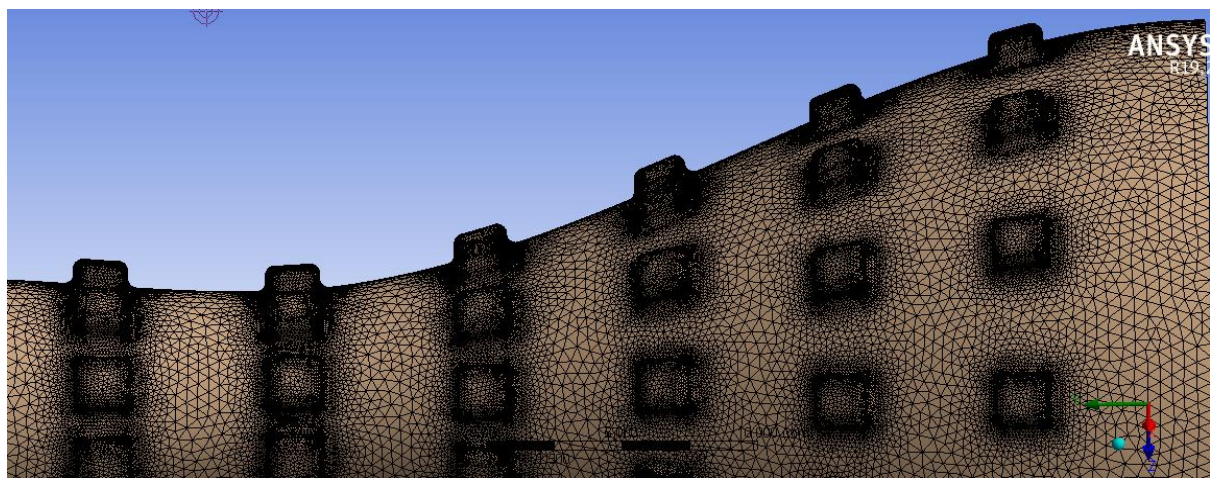


Fig. 3.3.2 3D Meshing of a Cd Nozzle with Square Dimples- Zoomed view

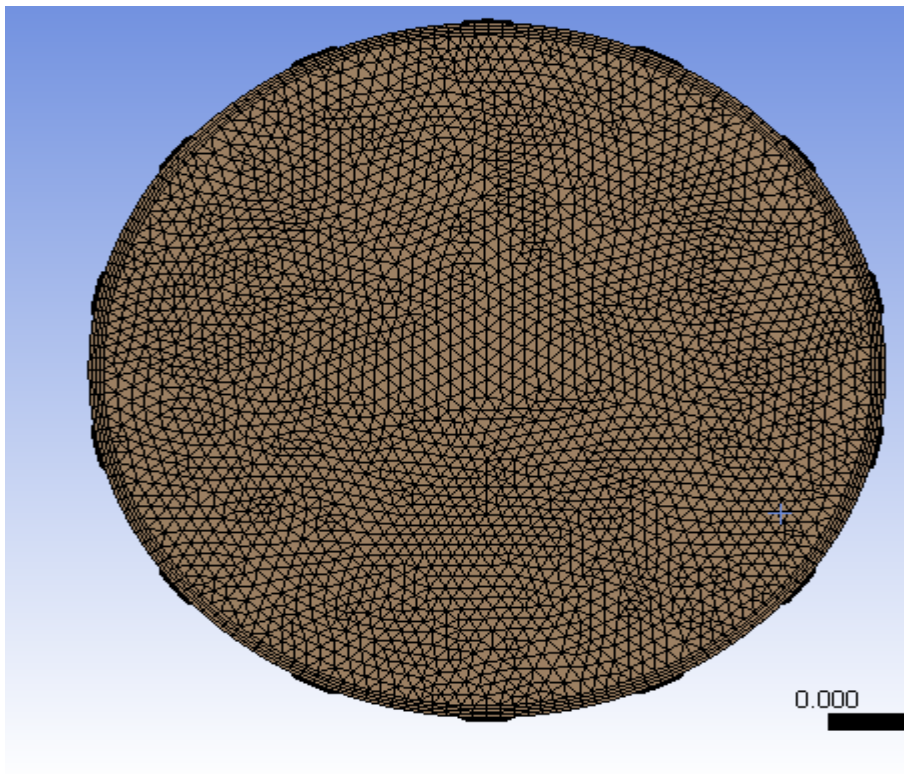


Fig. 3.3.3 3D Meshing of a Cd Nozzle with Square Dimples- Top view

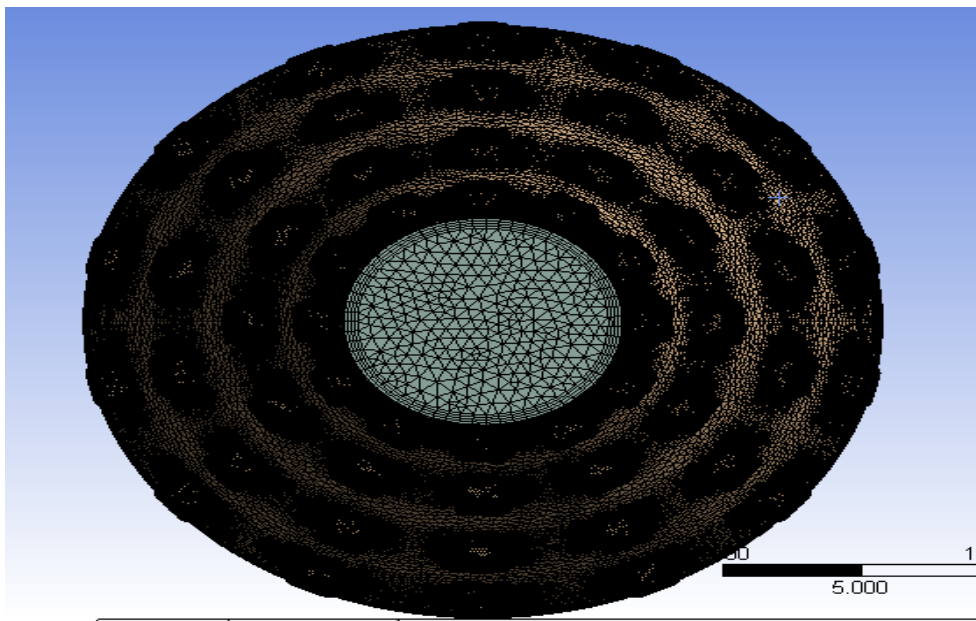


Fig. 3.3.4 3D Meshing of a Cd Nozzle with Square Dimples- Inner view

4.9 ANALYSIS

- The designed model is analysed using analytical software.
- The domain is created
- Meshing to be done.
- Post-processing is analysed and the results are obtained.

4.10 SOLVER

Fluent is a post processor or analysing software are used to simulate the model for their application.

4.11 Boundary Conditions

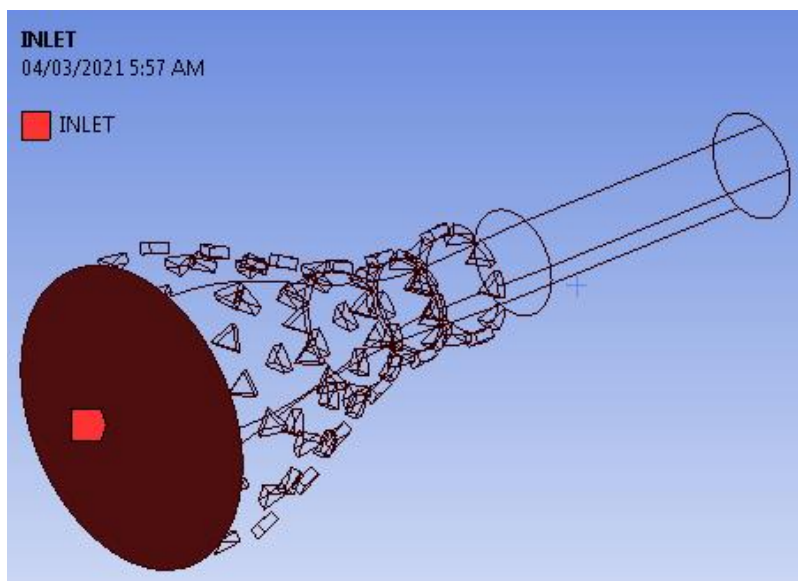


Fig. 4.1.1 Boundary Condition of a Cd Nozzle with Triangular Dimples- Inlet

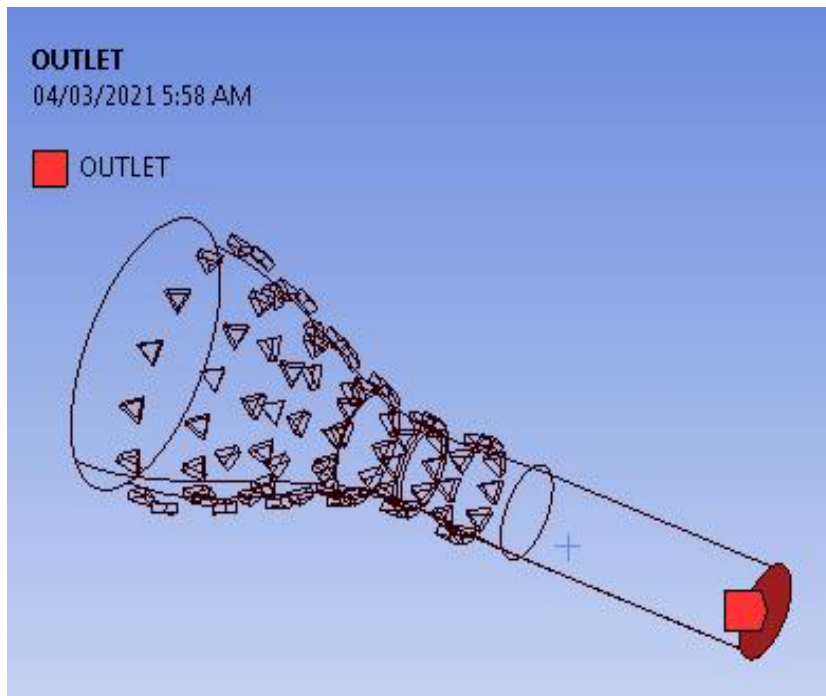


Fig. 4.1.2 Boundary Condition of a Cd Nozzle with Triangular Dimples- Outlet

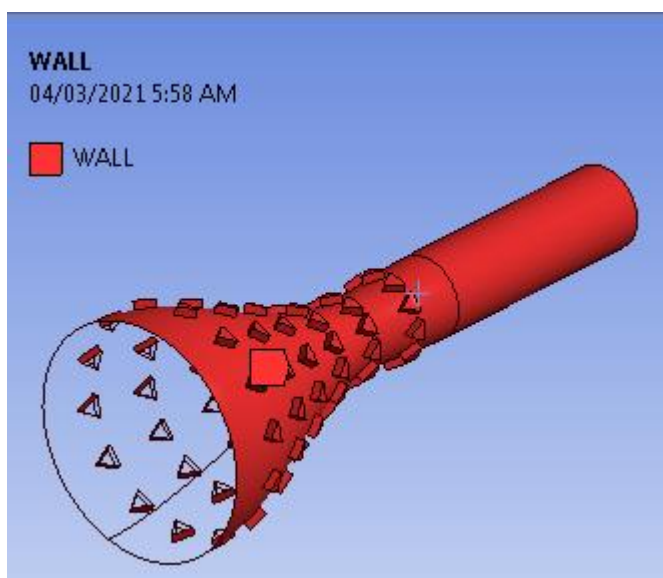


Fig. 4.1.3 Boundary Condition of a Cd Nozzle with Triangular Dimples- Wall

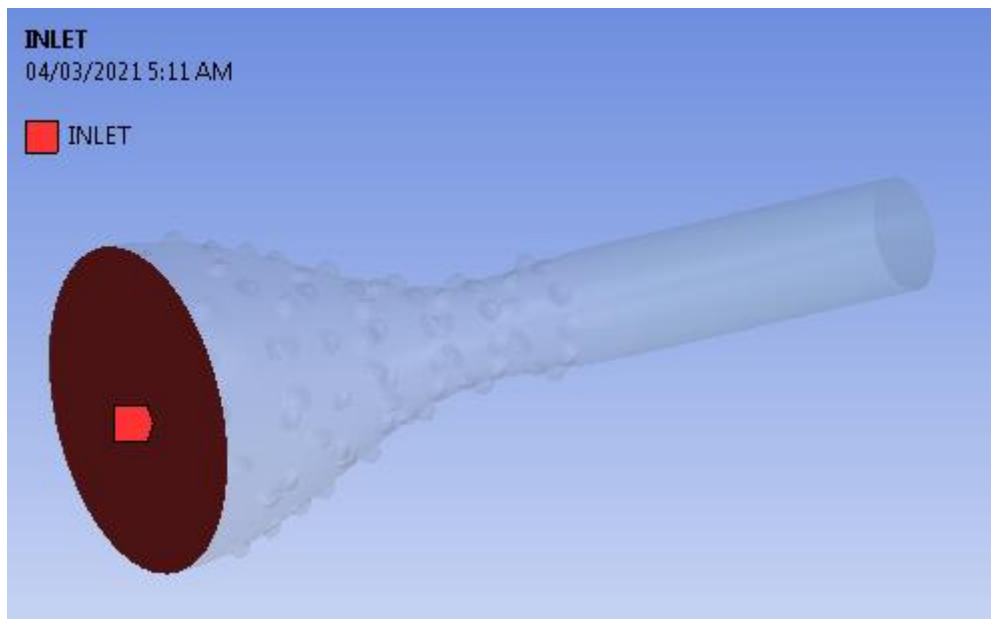


Fig. 4.2.1 Boundary Condition of a Cd Nozzle with Circular Dimples- Inlet

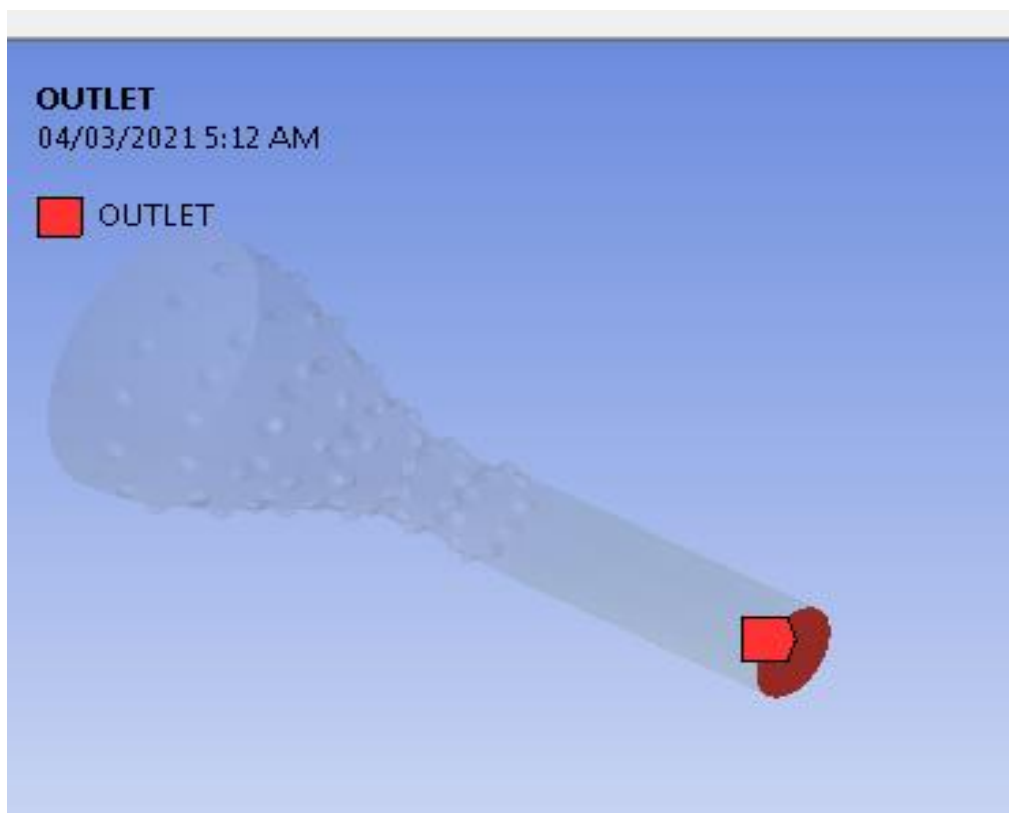


Fig. 4.2.2 Boundary Condition of a Cd Nozzle with Circular Dimples- Outlet

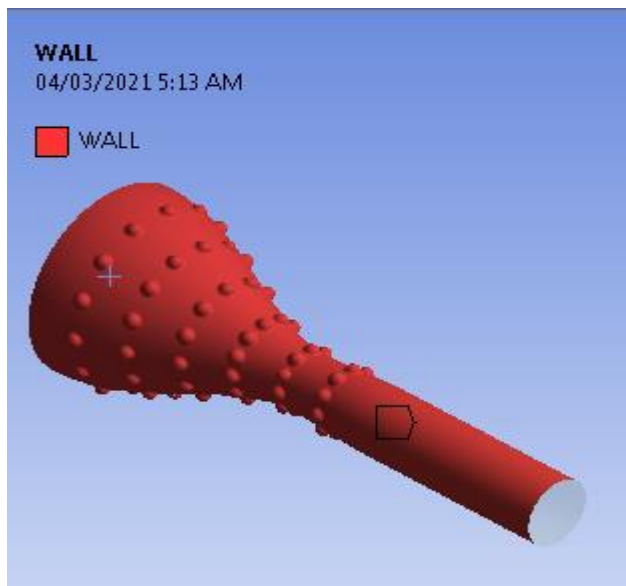


Fig. 4.2.3 Boundary Condition of a Cd Nozzle with Circular Dimples- Wall

Boundary Conditions

- INET = VELOCITY INLET (640 m/s).
- OUTLET = PRESSURE OUTLET.
- Nozzle side WALL = STATIONARY WALL, No slip Boundary condition.
- Problem type: Viscous, Standard K-e Epsilon.

Area-Weighted Average Mach Number	
outlet	1.7084485
wall	1.0882805
Net	1.1011085
Area-Weighted Average Velocity Magnitude (m/s)	
outlet	608.49893

Fig. 4.3.1 Mach No. at Inlet and Wall Velocity at Outlet of a Cd Nozzle with a Circular Dimple.

Area-Weighted Average Mach Number	
outlet	1.747174
Area-Weighted Average Mach Number	
wall	1.0555964
Area-Weighted Average Velocity Magnitude (m/s)	
outlet	618.23396

Fig. 4.3.2 Mach No. at Inlet and Wall Velocity at Outlet of a Cd Nozzle with a Triangular Dimple.

Area-Weighted Average Mach Number	
outlet	1.5887702
wall	0.88065245
Net	0.89423406
Area-Weighted Average Velocity Magnitude (m/s)	
outlet	581.23588

Fig. 4.3.3 Mach No. at Inlet and Wall Velocity at Outlet of a Cd Nozzle with a Square Dimple.

4.12 Steps to Solve

- Open the software called Fluent.
- Import the model which is meshed into the fluent software, reading the case and mesh file.
- Check the grid and zones by reading the case file.
- Change the unit as mm as required.
- Go to define.
- Select the model.
- Select the solver needed.
- Select the density, 2D or 3D, etc. in the option solver.
- Again, selecting the same solver, now click on to energy equations and give ok.
- Click the viscous model.
- Selecting the required viscous model for the problem.
- Select the option k-epsilon model(2-eqn).
- Change the material to ideal gas with the 19-constant density.
- Click the operating condition by giving the value in Pascal or any other unit.
- By click Boundary conditions give the pressure values for pressure inlet, outlet, wall etc.,
- Go to solve select the initialize option→inlet condition and click apply.
- Go to monitors in solve→ residual and click ok for printing and plotting.
- Click iterate in solve giving the value for number of iterations and proceed.
- The solution will be displayed, iteration stops then check the results.
- Go to the display→ contours and select the one to display such as velocity, pressure, etc., → click display and the contour will display in different colours for variations of values.
- The XY plot for velocity, pressure etc., can also be seen by selecting plot → XY plot→ pressure, velocity etc.
- Thus, the meshed model is analysed using FLUENT.

4.13 EXPERIMENTAL WORK

The experimental work is done with the nozzle made from commercially available materials and results are taken from jet setup.



Fig. 5.1.1 Inner View of a Cd Nozzle with Triangular Dimples



Fig. 5.1.2 Inner View of a Cd Nozzle with Circular Dimples



Fig. 5.1.3 Inner View of a Cd Nozzle with Square Dimples

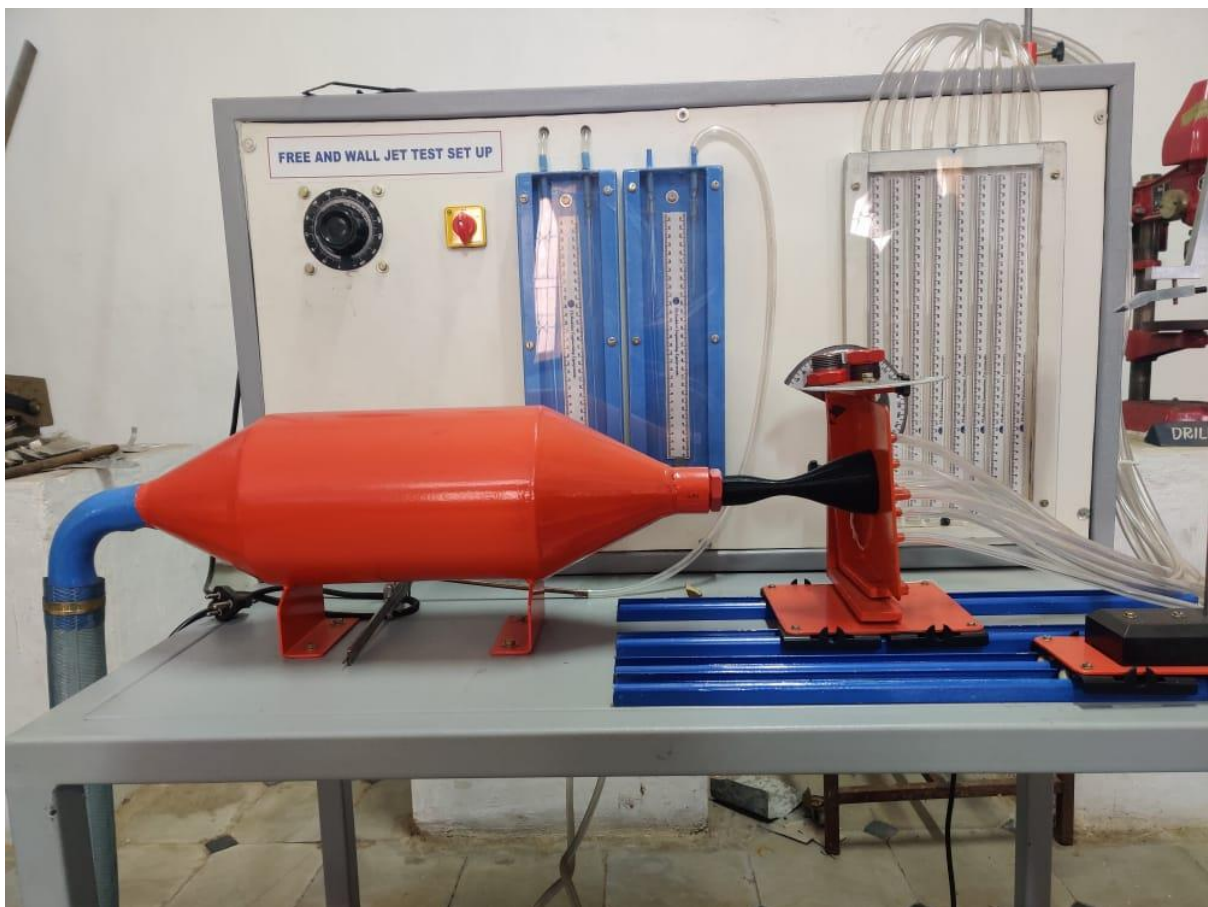


Fig. 5.2.1 Testing of a Cd Nozzle with Circular Dimples in a Free and Wall Jet Test Set Up

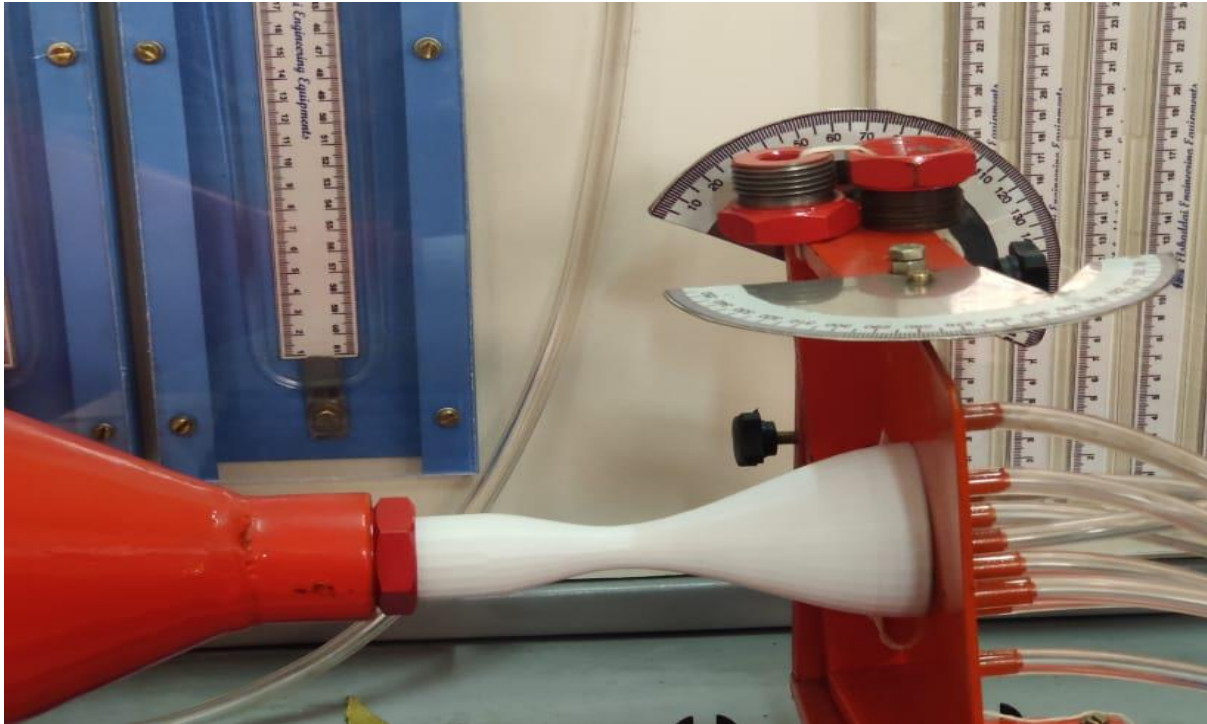


Fig. 5.2.2 Testing of a Cd Nozzle with Triangular Dimples in a Free and Wall Jet Test Set Up



Fig. 5.2.3 Testing of a Cd Nozzle with Square Dimples in a Free and Wall Jet Test Set Up

4.14 Free and Wall Jet test setup

- The experiments are conducted with the help of free and wall jet test setup that consists of a cylindrical settling chamber attached to storage tanks of greater pressure.
- The air launches in through the settling chamber, passes through the channel portion with a pressure gauge accompanied by a pressure regulating valve with a mixing length duct of 1.5 inch the radius.
- The settling chamber are attached to the mixing duct by a wide angle diffuser accompanied with 3 schemes or packly meshed grids sets 3 cm separately for minimizing turbulence at the orifice inlet.
- These screens are placed in the settling chamber.
- The settling chamber is a constant area circular portion of 150 mm inside radius and 600 mm of length.
- These settling chamber has chainings for stagnation pressure measurement and temperature measurements.
- By a slot holder positioning, the test models are attached at the last, that is a short duct like bump with implanted O-ring, above which an annular retaining sleeve with intramural threats is secured soundly.
- The total pressure(P_0), was the managing framework in this investigation, continued to be same while running by maintaining the pressure regulating valve.
- The stagnation pressure (P_0) level offers various nozzle pressure ratios (NPR), determined as the proportion of stagnation pressure to the back pressure(P_0/P_b), required for investigation.
- The settling chamber is similar to the ambient temperature and the back pressure, the chamber where the jets discharged.
- The ambient temperature of the room came almost constant within + or - 5°C in the course of 1 expermental run.
- The stagnation pressure was controlled with anprecision of + or – 0.1%.
- A the course of expermental runs, the settling chamber pressure was calculated by a U-tube manometer.
- The room temperature was measured with the help of thermometer.

- The regular changes in ambient pressure (Pa), were calculated by a mercury barometer and took a average over the duration of experiment.



Fig. 5.3 Free and Wall Jet Test Set Up

Chapter – 5

Results and Discussion, Performance Analysis

In this, we have discussed the centreline Mach number, velocity, and pressure. Here plotted the supersonic with Mach number 1.87, dimensional and non-dimensional graphs. The plots are obtained from the post-processed data.

By introducing the grooves on the surfaces of the nozzle, it generates the streamline vortices. These streamline vortices are used as effective mixing promoters.

Faster decay of plain nozzle to grove nozzle usually is the outcome of the faster mixing. The grooves gives a higher vortices in the exit along with the vortices of induced of the nozzle and the jet mixing gets higher.

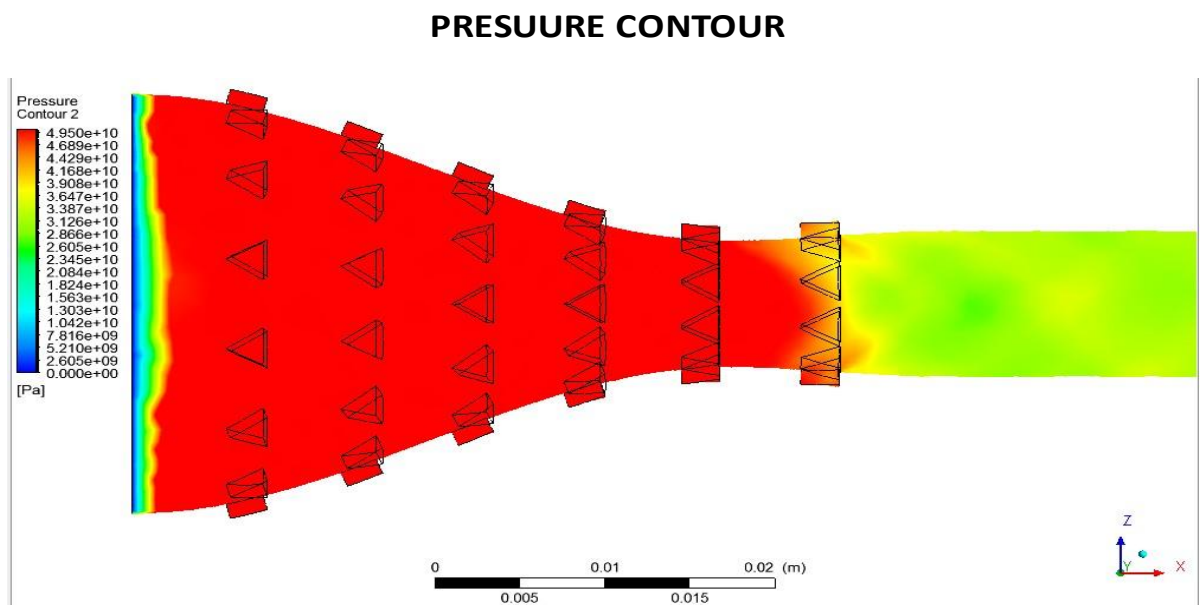


Fig.6.1.1 Pressure contour of a Cd Nozzle with triangular dimples.

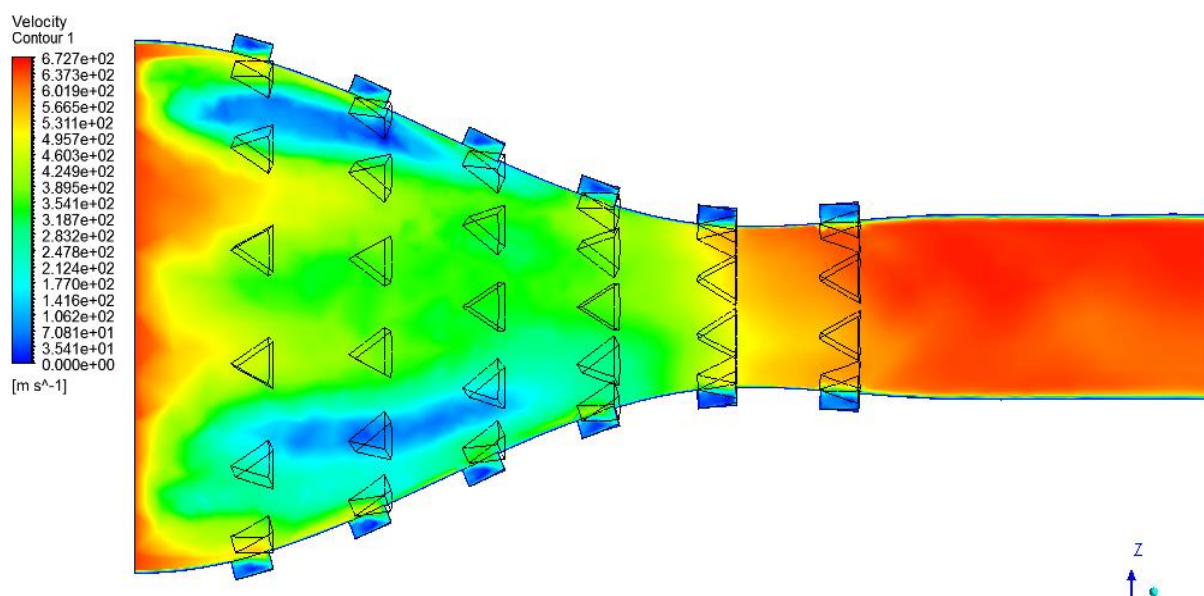


Fig.6.1.2 Velocity contour of a Cd Nozzle with triangular dimples.

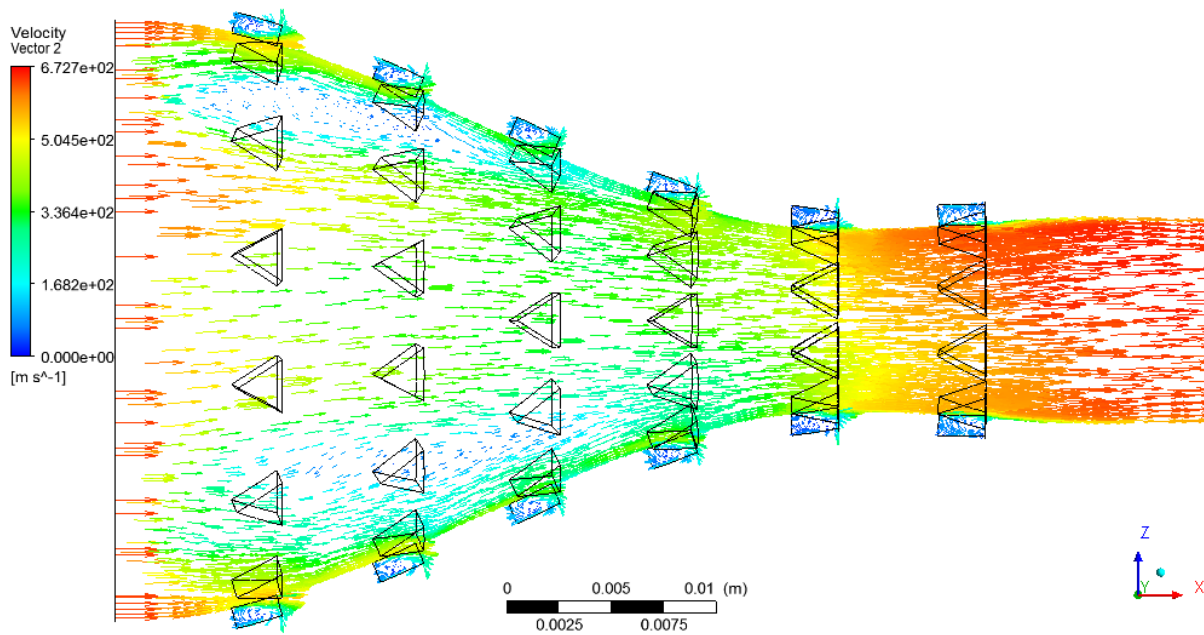


Fig.6.1.3 Velocity vector of a Cd Nozzle with triangular dimples.

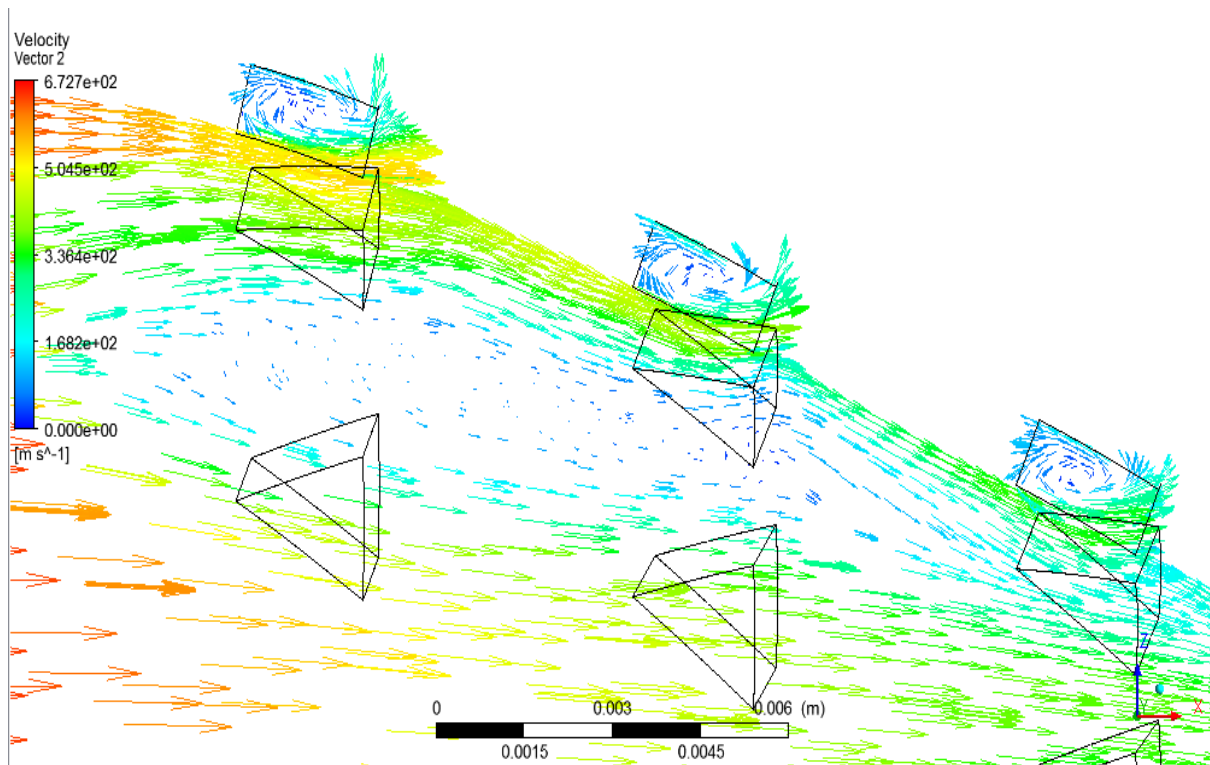


Fig.6.1.4 Velocity vector of a Cd Nozzle with triangular dimples.

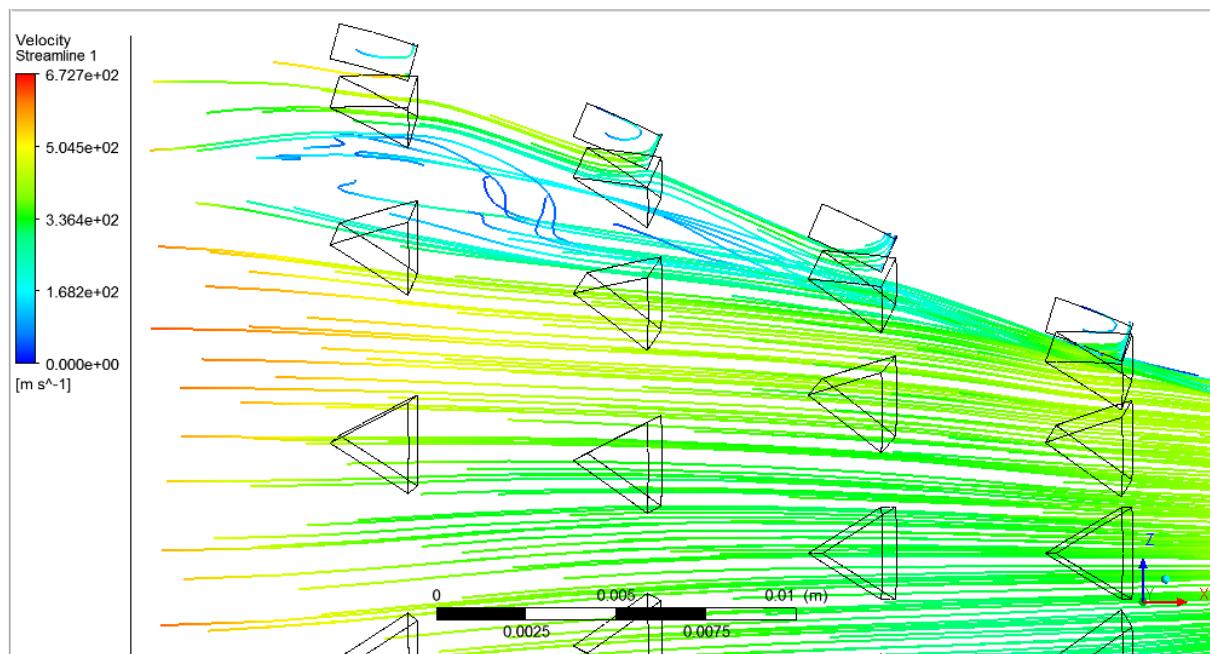


Fig.6.1.5 Velocity streamline of a Cd Nozzle with triangular dimples.

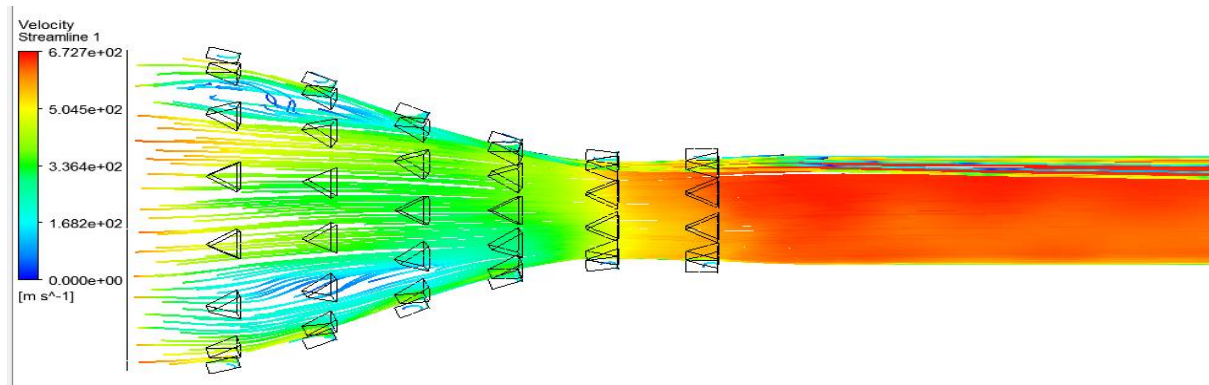


Fig.6.1.6 Velocity streamline of a Cd Nozzle with triangular dimples.

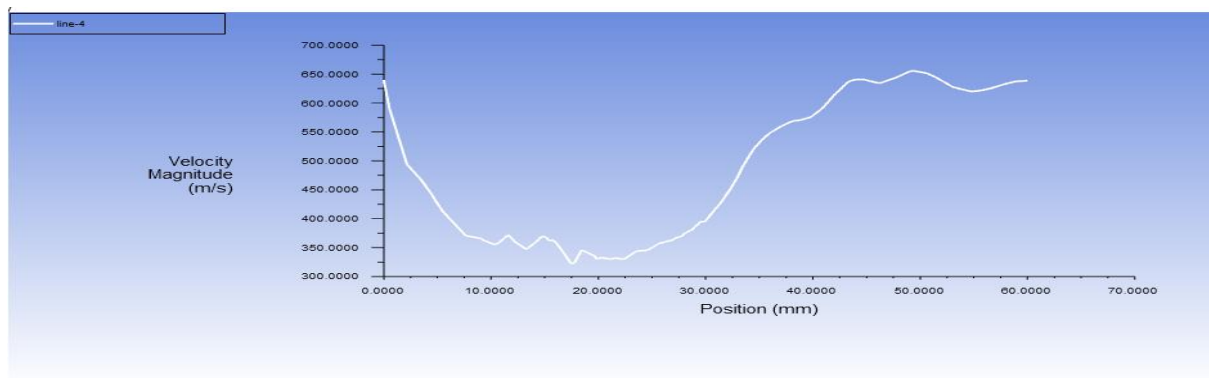


Fig.6.1.7 Velocity graph of a Cd Nozzle with triangular dimples.

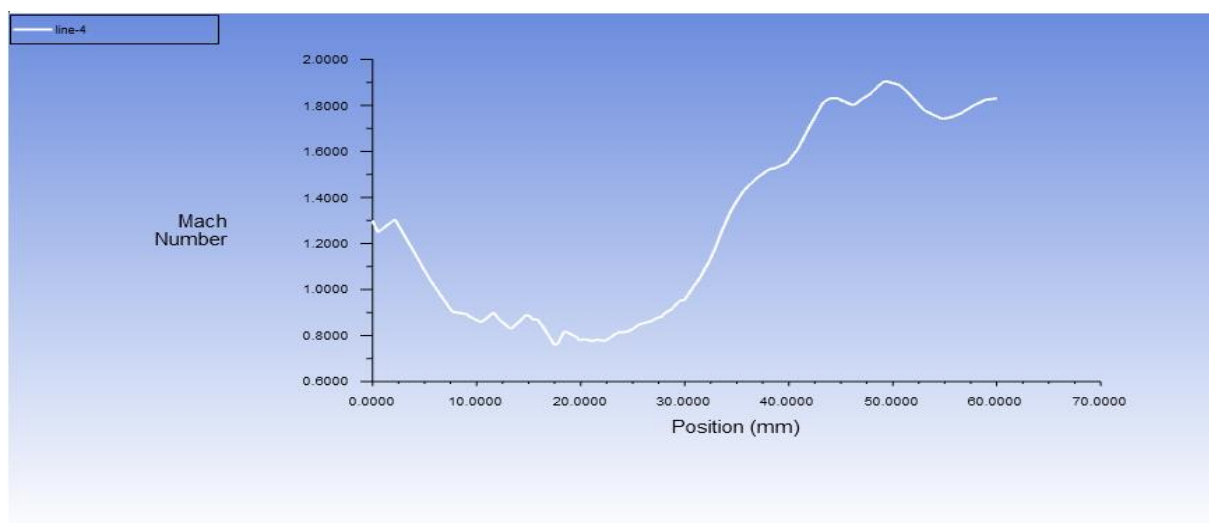


Fig.6.1.8 Mach No. graph of a Cd Nozzle with triangular dimples.

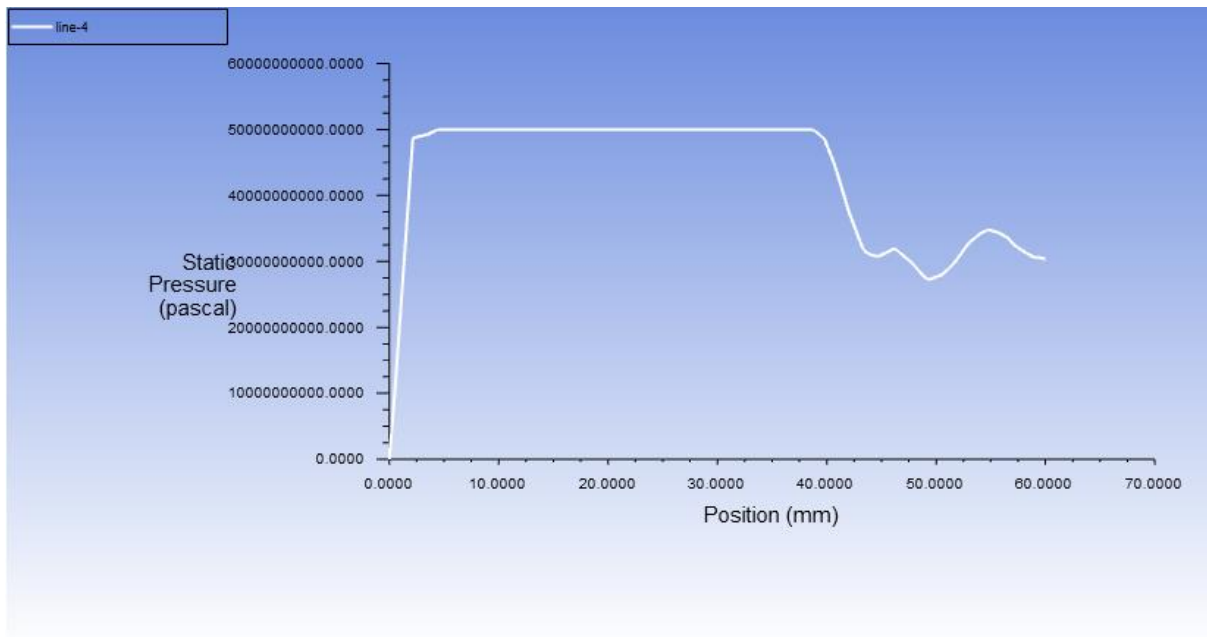


Fig.6.1.9 Static Pressure graph of a Cd Nozzle with triangular dimples.

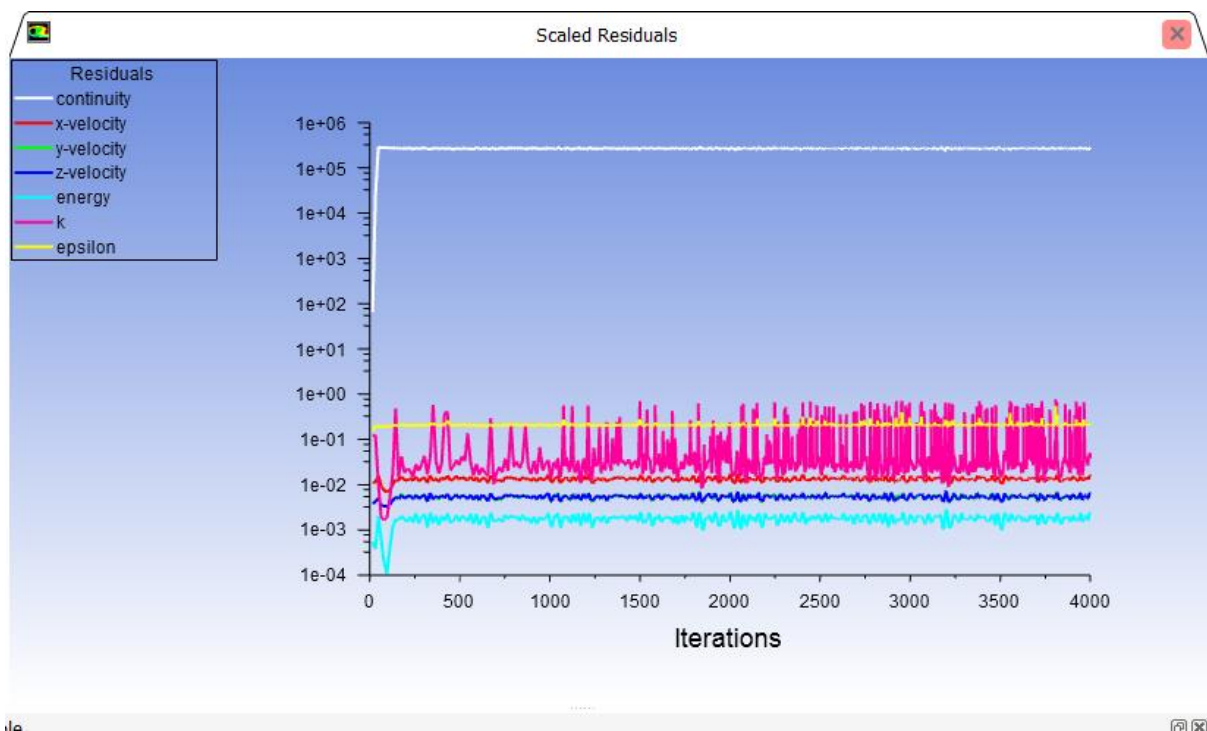


Fig.6.2.1 Convergence graph of a Cd Nozzle with Circular dimples.

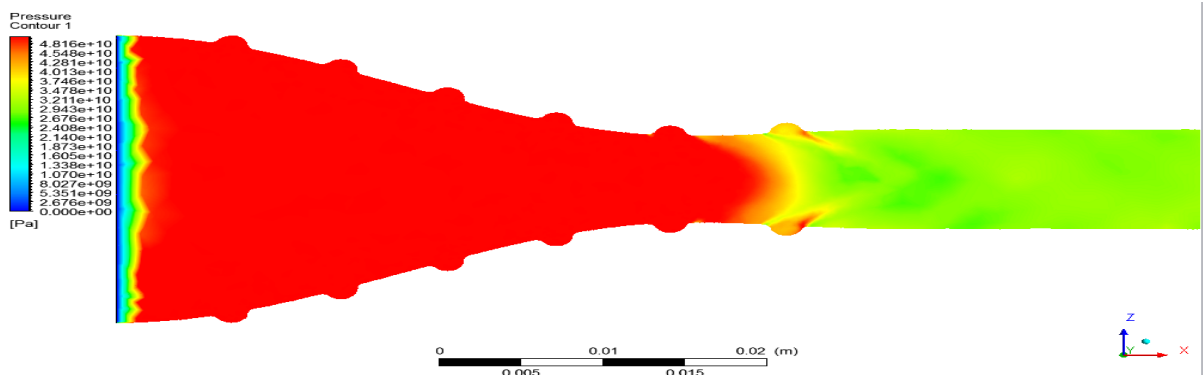


Fig.6.2.2 Pressure Contour of a Cd Nozzle with Circular dimples.

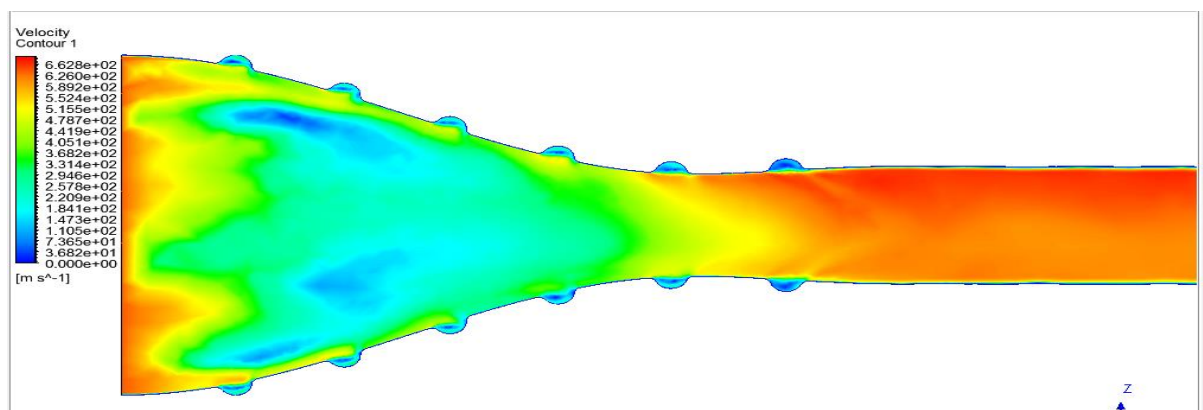


Fig.6.2.3 Velocity Contour of a Cd Nozzle with Circular dimples.

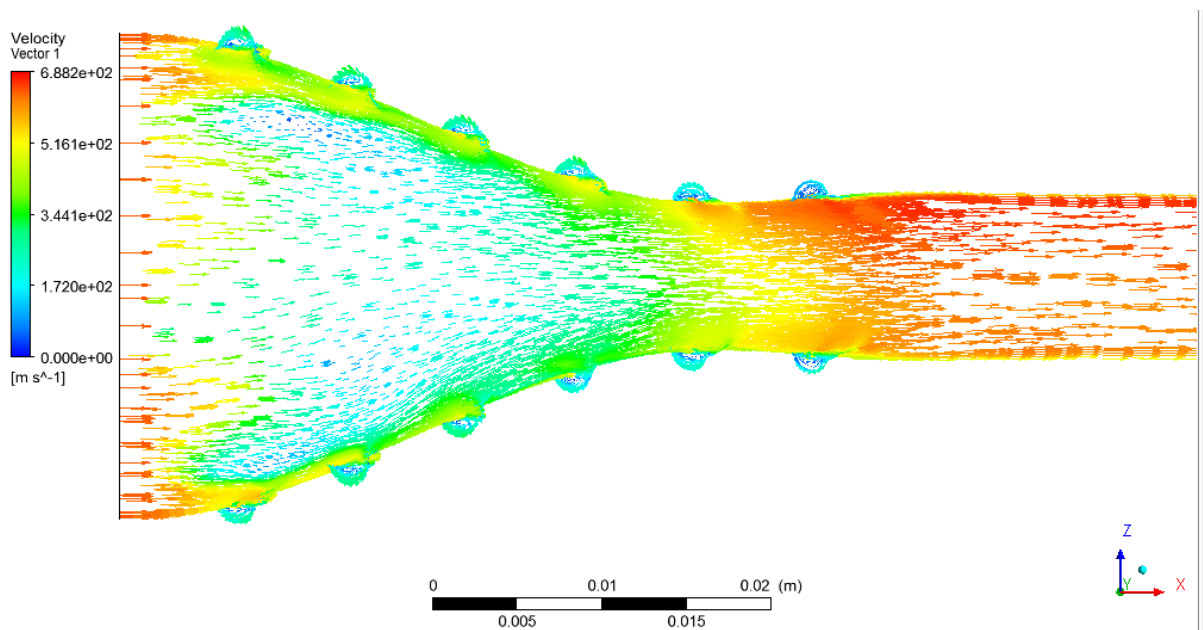


Fig.6.2.4 Velocity Vector of a Cd Nozzle with Circular dimples.

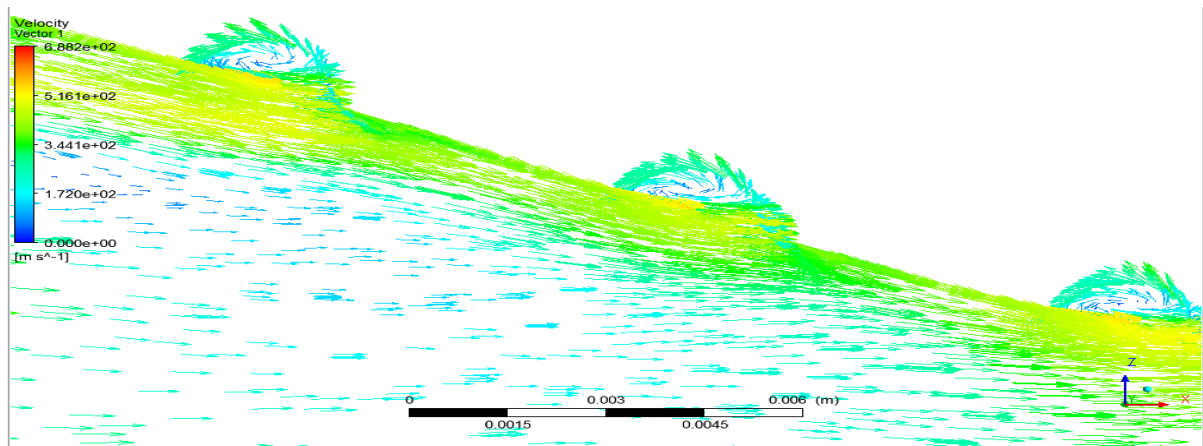


Fig.6.2.5 Velocity Vector of a Cd Nozzle with Circular dimples.

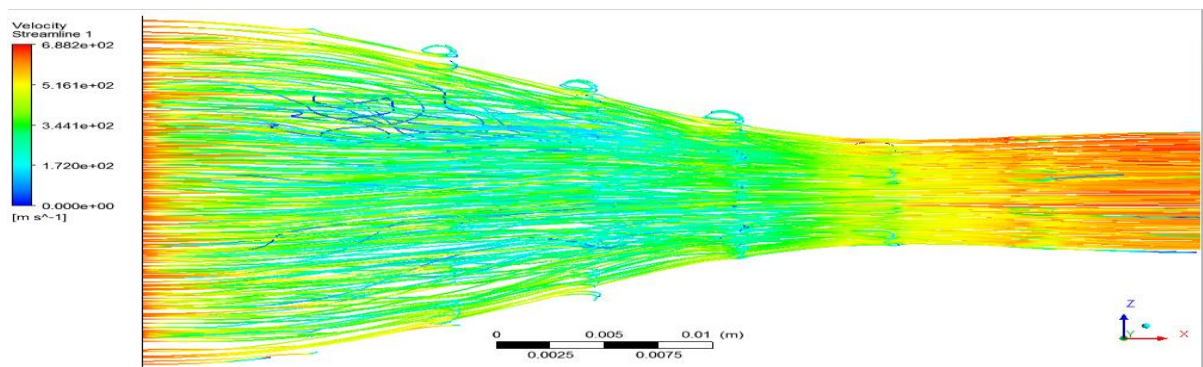


Fig.6.2.6 Velocity Streamline of a Cd Nozzle with Circular dimples.

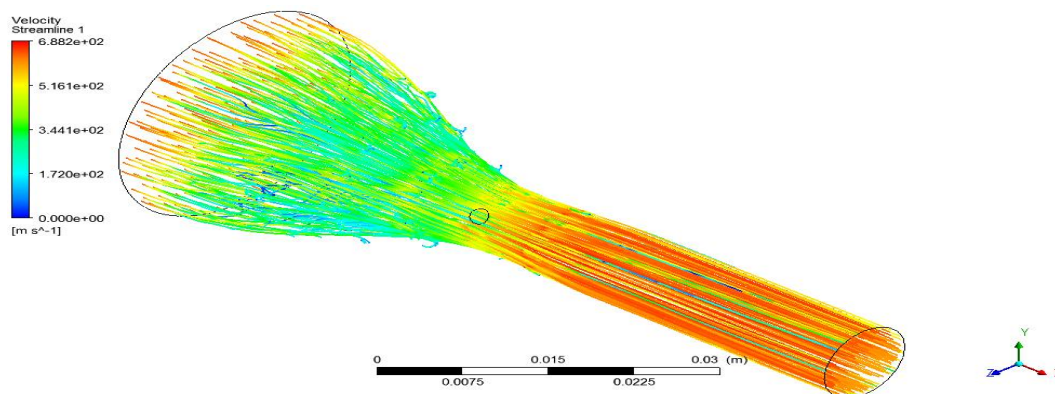


Fig.6.2.7 Velocity Streamline of a Cd Nozzle with Circular dimples.

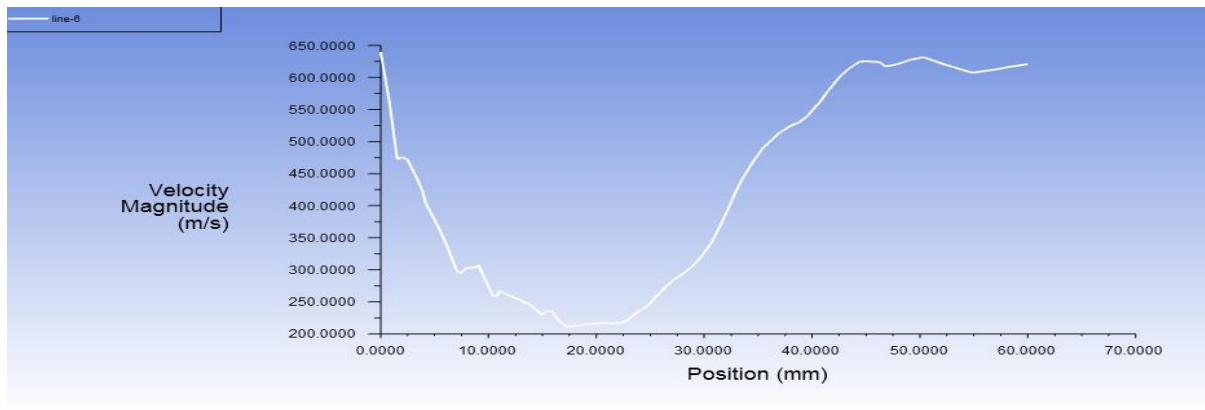


Fig.6.2.8 Velocity Graph of a Cd Nozzle with Circular dimples.

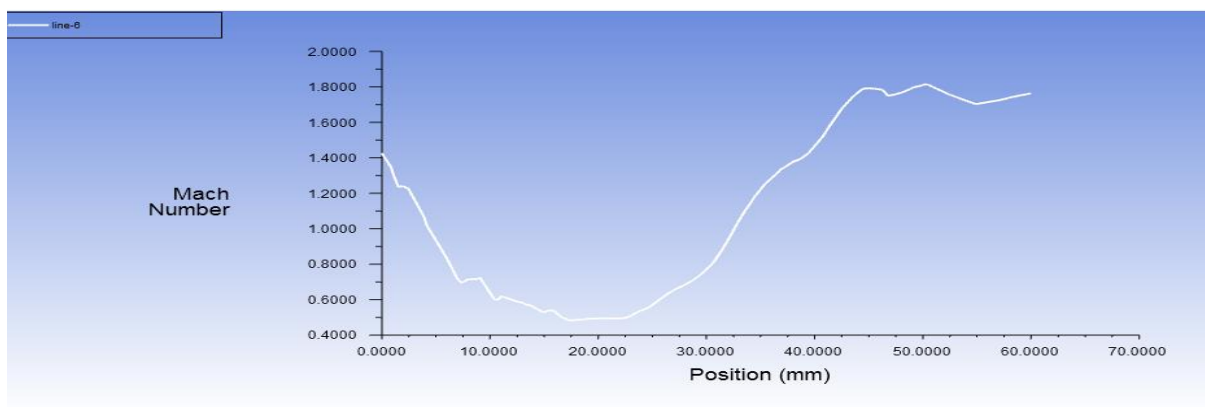


Fig.6.2.9 Mach No. Graph of a Cd Nozzle with Circular dimples.

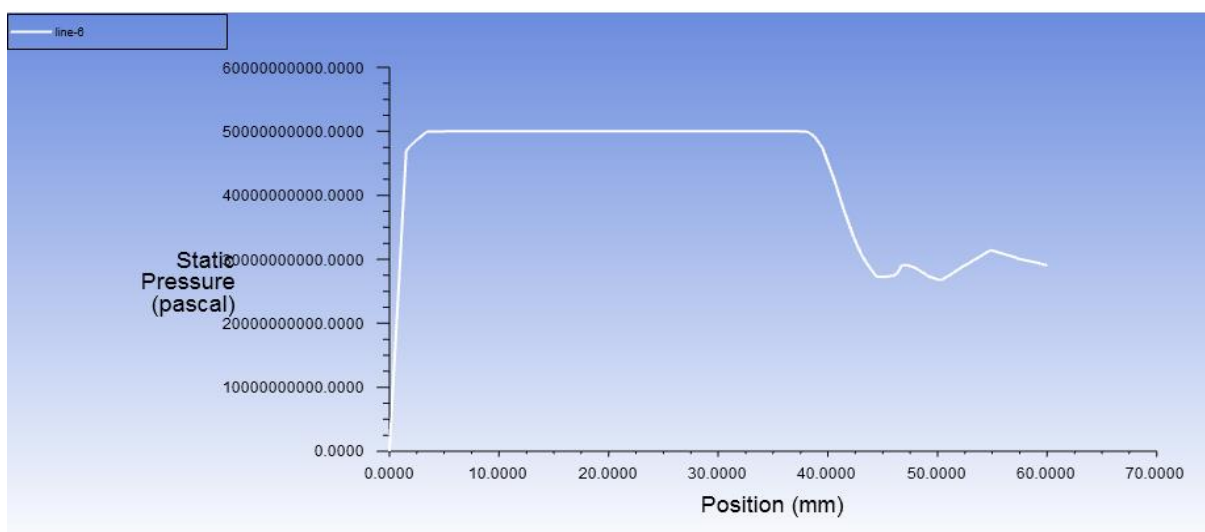


Fig.6.2.10 Static Pressure Graph of a Cd Nozzle with Circular dimples.

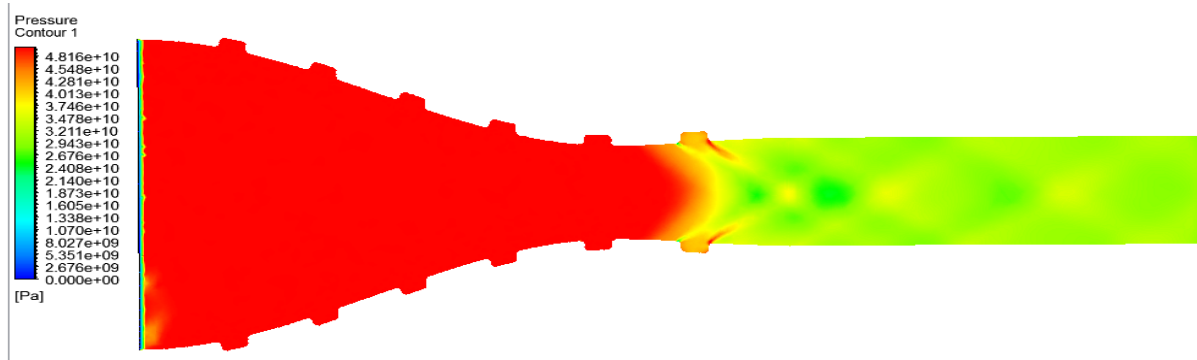


Fig.6.3.1 Pressure Contour of a Cd Nozzle with Square dimples.

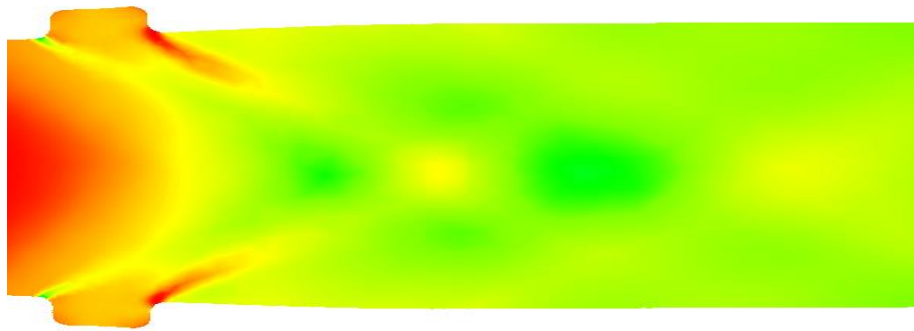


Fig.6.3.2 Pressure Contour of a Cd Nozzle with Square dimples.

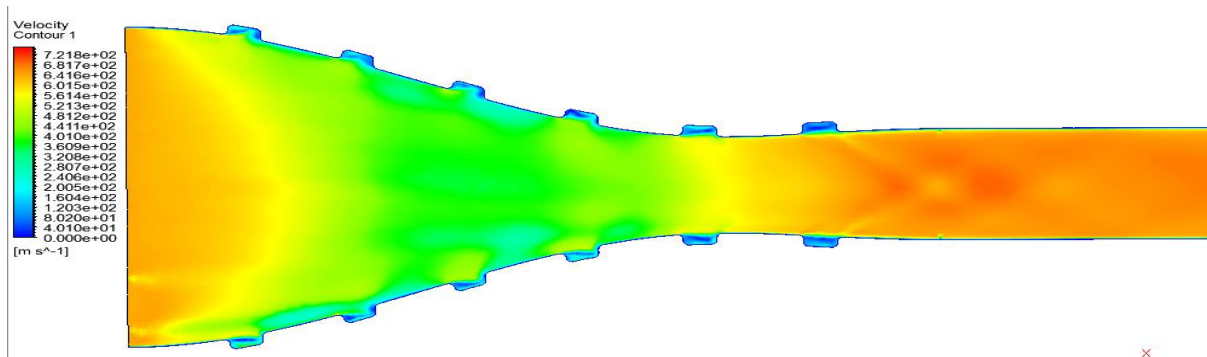


Fig.6.3.3 Velocity Contour of a Cd Nozzle with Square dimples.

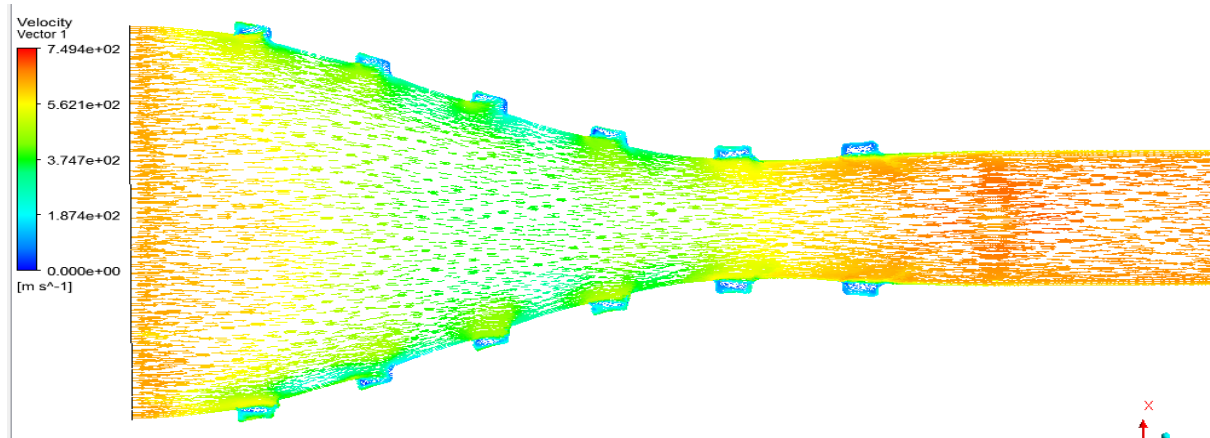


Fig.6.3.4 Velocity Vector of a Cd Nozzle with Square dimples.

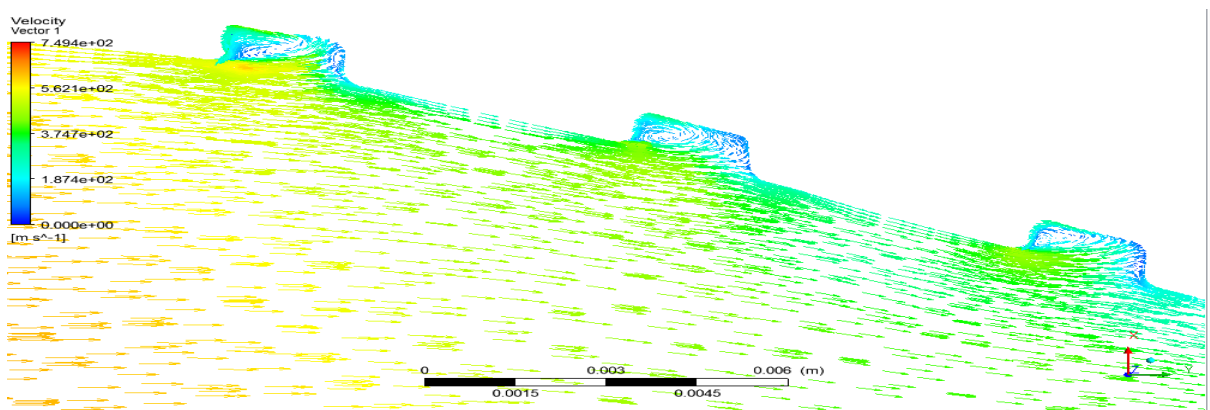


Fig.6.3.5 Velocity Vector of a Cd Nozzle with Square dimples.

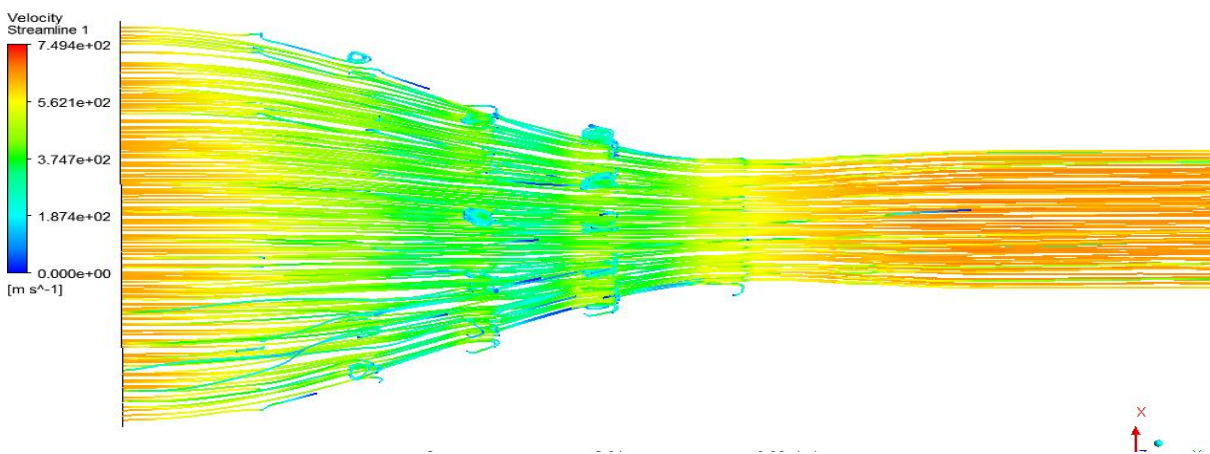


Fig.6.3.6 Velocity Streamline of a Cd Nozzle with Square dimples.

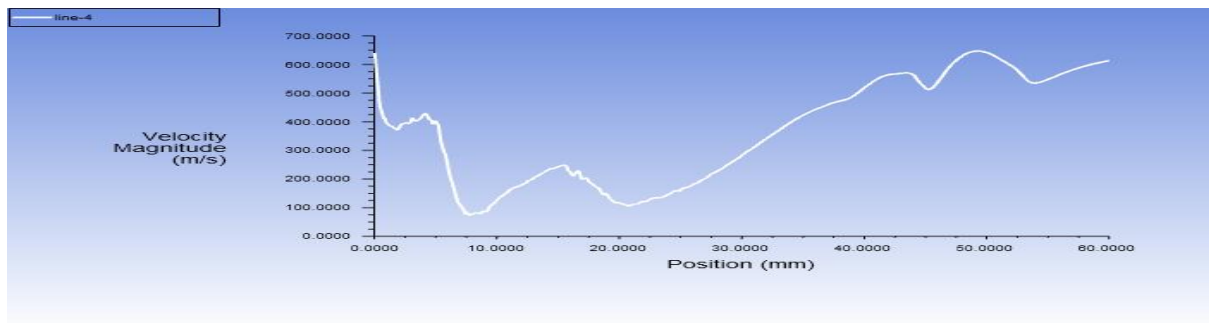


Fig.6.3.7 Velocity Streamline Graph of a Cd Nozzle with Square dimples.

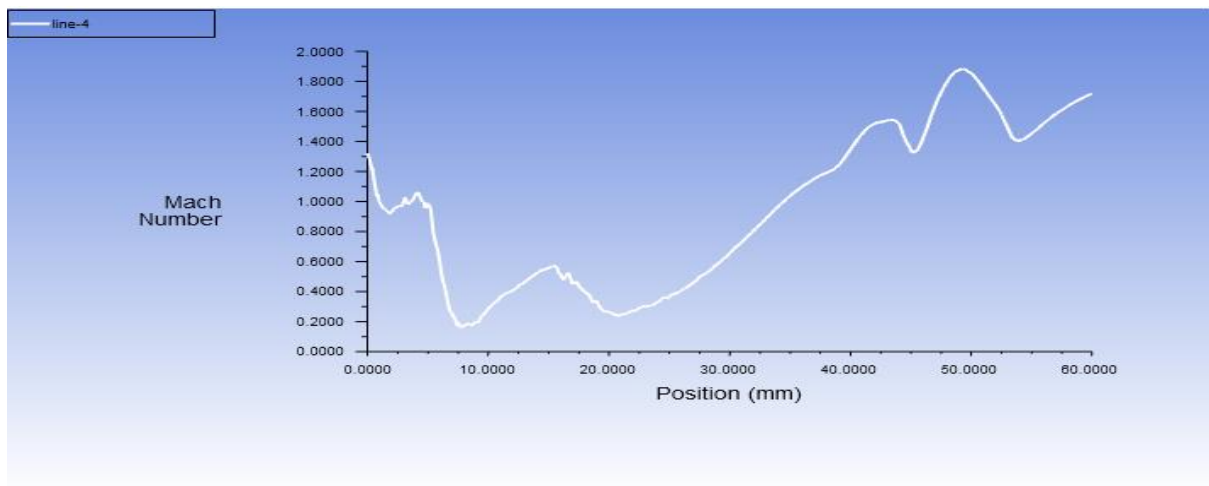


Fig.6.3.8 Mach No. Graph of a Cd Nozzle with Square dimples.

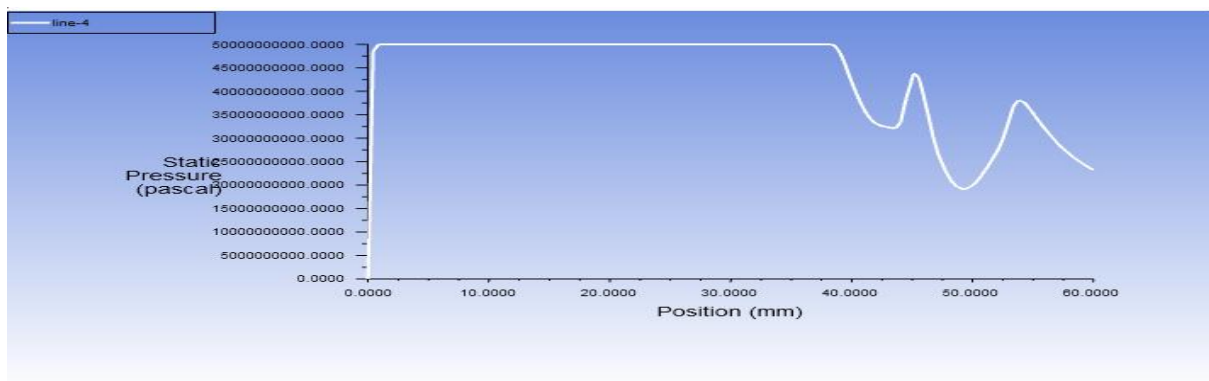


Fig.6.3.9 Static Pressure Graph of a Cd Nozzle with Square dimples.

Chapter – 6

Summary and Conclusions

The surface patterns used in this study were triangular dimples, spherical dimples, and square dimples.

Comparing all the three types of the nozzle with different surface patterns we get to know that the Nozzle with Triangular dimple has the best velocity conditions.

Again, comparing all the three types of the nozzle with different surface patterns we get to know that the Nozzle with Triangular and Circular dimple has the best Pressure conditions.

So, by comparing all three types of the nozzle with different surface patterns, the nozzle with triangular dimples works the best.

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