DESIGN AND ANALYSIS OF COMBUSTION CHAMBER IN RAMJET ENGINE

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Abstract - *Today's aircraft are powered by a variety of engines that generate thrust depending on the application. Each aircraft jet engine has its own collection of benefits and drawbacks. Each aircraft has a different type of engine depending on its intended use. One of the most important sources of supersonic flight power is the ramjet. In the near future, missiles powered by Ramjets, rockets powered by Ramjets, and supersonic fighters supported by Ramjets will lead the aviation market. Ramjet combustion has a variety of issues, including combustion instability and enhanced fuel mixing. The modeling, software analysis, and fabrication of a subsonic ramjet engine are all part of this project. The existence of a ventilated disc after the diffuser is a novel concept for ensuring proper fuel and air mixing. The diffuser, ventilated disc, combustion chamber, ignition system, and nozzle of the subsonic ramjet engine were all modeled and analysed in software before being manufactured according to our specification. The measurement programme tests and calculates temperature, velocity, and pressure distribution along the engine's longitudinal axis.*

Key Words: Ramjet engine, Thrust, analysis, Pressure distribution

1. Introduction

The act of altering the motion of the body is referred to as propulsion in a general sense. When a body is moved through a medium, propulsion mechanisms provide a force that pushes bodies that are initially at rest, shifts momentum, or overcomes retarding forces.

1.1 Aircraft Propulsion

Jet propulsion is a mode of locomotion in which the momentum of expelled matter imparts a reaction force to a body.

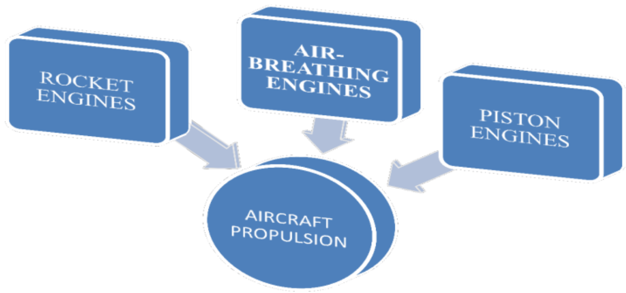


Fig.1. Aircraft Propulsion

A jet engine is a reaction engine that generates thrust by discharging a fast-moving jet of fluid in accordance with Newton's laws of motion. The force that propels every aircraft through the air is known as thrust. Thrust is generated by the aircraft's propulsion system. Different propulsion systems generate thrust in different ways, but all thrust is generated by applying Newton's third law of motion in some way (For every action there is an equal and opposite reaction). A working fluid is accelerated by the system of any propulsion system, and the reaction to this acceleration creates a force on the system. There are several different types of jet engines, all of which use the theory of jet propulsion to achieve forward thrust.

2. Literature Survey:

In this paper, the numerical output of three separate ramjet inlets as well as an entire ramjet is investigated. It is assumed that the fluid is viscid. SCRAMJET inlet 1 has been selected from the literature. Instead, Inlets 2 and 3 are based on the Oswatitsch theorem. Inlet 2 and 3 deliver a series of oblique shocks that converge at the engine cowl lip, followed by a typical shock that terminates just downstream of the inlet throat. The combustion in ramjet is modeled using a non-uniform volumetric heat source distributed across the combustor.[1]. The scramjet engine has piqued the interest of many researchers as one of the most promising propulsion systems in the future. The flow field of a hydrogen fuel scramjet combustor with a planer strut flame holder has been numerically simulated using the two-dimensional coupled implicit NS equations, the regular k-e turbulence model, and the finite-rate/eddy-dissipation reaction model under two separate working conditions, namely cold flow and engine ignition. The results show that the numerical method used in this paper is capable of simulating the scramjet combustor's flow area. The static pressure distribution along the top and bottom walls of the case under engine ignition is much higher than the static pressure distribution along the top and bottom walls of the case under cold flow. On the top and bottom walls of the scramjet combustor, there are three distinct pressure increases. The eddy created in the strut acts as a flame keeper in the combustor, allowing the mixture to stay in the supersonic flow for longer.[2]. Scramjet (scramjet) engine (Scramjet). For the L/D ratio of 10, the CFD study of the combustion phase of a scramjet engine with wall injectors at various locations on the wall of the combustion nozzle and single and double cavities. The main goal of this project is to use GAMBIT software to develop a combustion chamber model and to investigate the combustion processes of an Air-Fuel mixture for wall injector models with inlet air at Mach 1.4 and inlet fuel at Mach 1.4. When designing an efficient combustion chamber for a rocket engine, there are several important factors to consider. The primary goal of this investigation is to compare the different two-dimensional cavity-based models. The numerical results obtained with the fluent programme indicate that the duel cavity based combustor model has strong overall agreement with literature review results. The flow is viewed as non-reacting to isolate the purely fluid dynamic effects. In addition, a grid-independent test was performed for more precise outcomes The static pressure and temperature profiles at different locations in the flow field are presented.[3,4]. In this analysis, a liquid fuel ramjet system with a subsonic side-dump combustor is simulated, and the results are compared to available experimental evidence. A probability density function (PDF) method was used to study the complex combustion process in a ramjet combustor. The uncertainty emerges from the mixing of fuel and air sources, as well as the eventual combustion of the resulting mixture, all within the limits of the combustion chamber. For a two-dimensional case, the expected numerical results were validated with open literature results, and for a three-dimensional case, with in-house experimental data. The technique enables quantitative evaluation of various designs based on performance metrics such as combustion efficiency, flame stability, and so on.[5-8]. The theoretical combustion of a solid fuel under supersonic cross flow conditions was studied. Numerical solutions were found for a two-dimensional, axisymmetric, turbulent (k -), global one-step reaction model. FLUENT software was used to run numerical simulations of combustor geometries posing solid fuel regression situations. The inlet airflow had a Mach number of 2, a temperature of 1200 K, and a total pressure of 30 atm in the combustor. The HTPB fuel was used, as well as a global one-step reaction system. The results of non-reacting calculation show that with solid fuel boundary regression, airflow velocity decreases in the majority region of the combustor.[9-11].

Table .1 Comparisons of different types of Jet engines:

Type	Description	Advantages	Disadvantages
Water JET	For propelling water rockets and jet boats; squirts water out the back through a nozzle	In boats, can run in shallow water, high acceleration, no risk of engine overload (unlike propellers), less noise and vibration, highly manoeuvrable at all boat speeds, high speed efficiency, less vulnerable to damage from debris, very	Can be less efficient than a propeller at low speed, more expensive, higher weight in boat due to entrained water, will not perform well if boat is heavier than the jet is sized for
Turbojet	A tube with a compressor and turbine sharing a common shaft with a burner in between and a propelling nozzle for the exhaust. Uses a high exhaust gas velocity to produce thrust.	Simplicity of design, efficient at supersonic speeds.	A basic design, misses many improvements in efficiency and power for subsonic flight, relatively noisy
Ramjet	Intake air is compressed entirely by speed of oncoming air and duct shape , and then it goes through a burner section where it is heated and then passes through a propelling nozzle	Very few moving parts, Mach 0.8 to Mach 5+, efficient at high speed (> Mach 2.0 or so), lightest of all air- breathing jets (thrust/weight ratio up to 30 at optimum speed), cooling much easier than turbojets as no turbine blades to cool	Must have a high initial speed to function, inefficient at slow speeds due to poor compression ratio, difficult to arrange shaft power for accessories, usually limited to a small range of speeds, intake flow must be slowed to subsonic speeds, noisy, fairly difficult to test
Pulsejet	Air is compressed and combusted intermittently instead of continuously. Some designs use valves.	Very simple design, commonly used on model aircraft	Noisy, inefficient (low compression ratio), works poorly on a large scale, valves on valved designs wear out quickly

3. Ramjet engine

The ramjet is a type of air breathing jet engine that compresses incoming air using the forward motion of the engine rather than a rotary compressor. Ramjets can't generate thrust at zero airspeed, so they can't get an aeroplane moving. As a result, ramjets need another propulsion device to get the vehicle to a speed where the ramjet can start producing thrust. Ramjets perform well at supersonic speeds of around Mach 3. Ramjet engines can reach speeds of up to Mach 6. Ramjets are particularly useful in high-speed applications that require a small and simple mechanism, such as missiles or artillery shells. Armor designers are looking to integrate ramjet technology into artillery shells to improve range; a 120-mm mortar shell with a ramjet could achieve a range of 22 miles (35 km). The inlet of a ramjet is built around it. A high-speed projectile travelling through air creates a high-pressure zone upstream. The high pressure in front of the engine is used by a ramjet to push air through the tube, where it is heated.

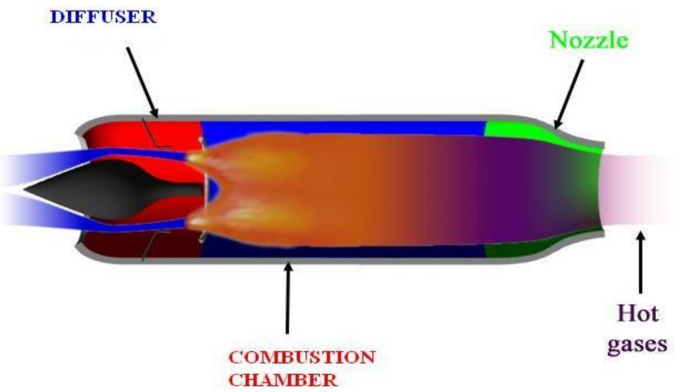


Fig 2.Ramjet engine

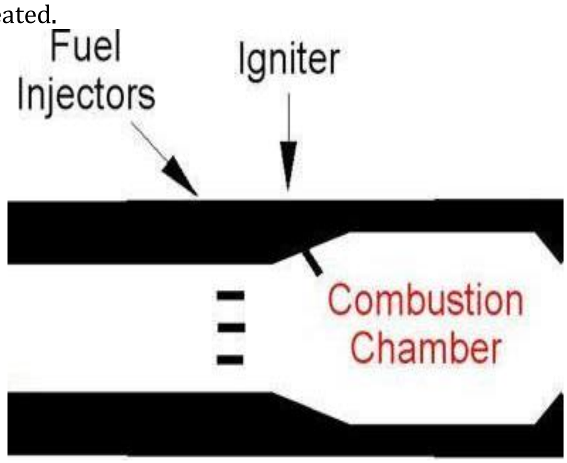


Fig.3.Combustion Chamber:

The combustor's function, like that of other jet engines, is to generate hot air by burning a fuel with basically constant air pressure. Since the airflow through a jet engine is normally very high, sheltered combustion zones are provided by using 'flame holders,' which prevent the flames from blowing out. A ramjet combustor can safely work at stoichiometric fuel: air ratios since there is no downstream turbine, suggesting a combustor exit stagnation temperature of the order of 2400 K for kerosene. Normally, the combustor must be able to work at a variety of throttle settings and for a variety of flight speeds and altitudes. When the vehicle intake experiences high yaw/pitch during turns, a sheltered pilot region normally allows combustion to begin. Flame holders, which range in design from combustor cans to basic flat plates, are used in other flame stabilization techniques to shield the flame and maximize fuel mixing. The usual shock caused by overfueling the combustor will result in a significant reduction in engine airflow and net thrust.

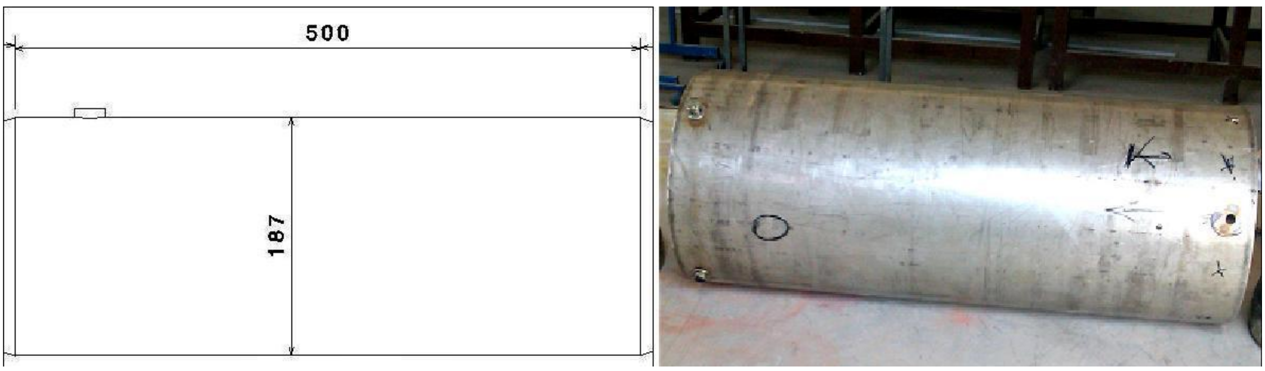


Fig .4 Flame holders

4. CFD Approach

CFD is a computational tool for measuring heat transfer and fluid flow. Its primary use at the moment is as an engineering tool for providing data that complements theoretical and experimental data. Commercially accessible codes and in-house codes at large organizations fall under this category. CFD may also be used for pure scientific analysis, such as researching turbulence fundamentals. Academic universities and government research facilities are more likely to do so. Codes are typically created to investigate a particular issue. Computational fluid dynamics (CFD) is the science of using a computational method to solve the mathematical equations that control these processes in order to predict fluid flow, heat transfer, mass transfer, chemical reactions, and other phenomena. CFD analyses generate valuable engineering data that can be used in concept studies for new designs, comprehensive product creation, troubleshooting, and redesign. Testing and experimentation are improved by CFD research. Reduces the overall amount of effort needed in the lab.

4.1 Three Main Elements Of CFD Software

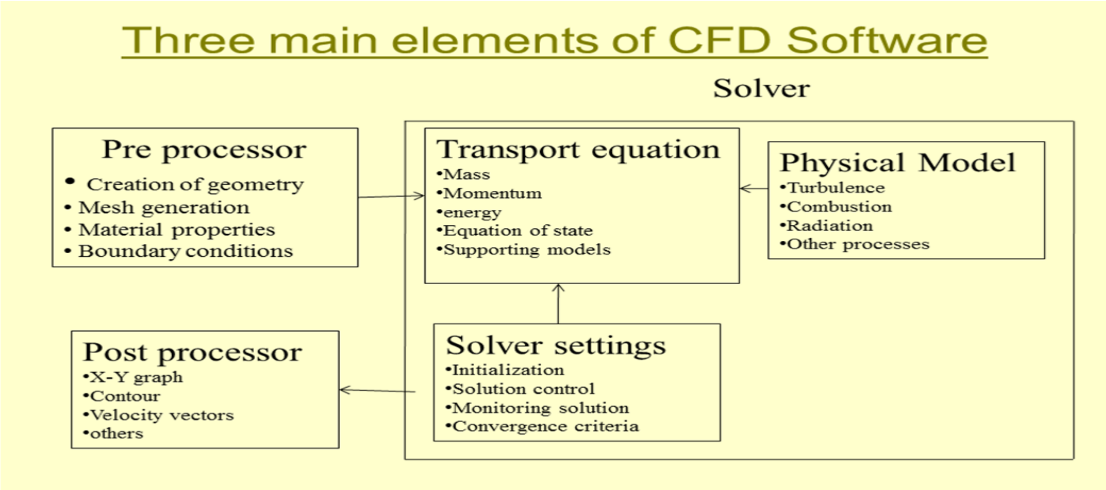


Fig.5.Three main elements of CFD Software

5. Modeling:

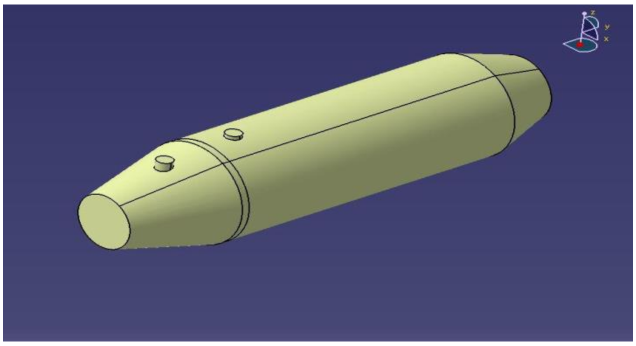
Dassault Systems developed CATIA (Computer Aided Three-dimensional Interactive Application), a multi-platform CAD/CAM/CAE commercial software suite. CATIA is a 3D Product Lifecycle Management software suite that supports various stages of product creation (CAx), including conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). CATIA helps engineers collaborate across disciplines, such as surfacing and shape design, mechanical engineering, and equipment and systems engineering. To build, alter, and validate complex innovative shapes, CATIA offers a suite of surfacing, reverse engineering, and visualisation solutions. From subdivision, styling, and Class A surfaces to mechanical functional surfaces, there's something for everyone. From 3D sketches, sheet metal, composites, forged or tooling components, to the concept of mechanical assemblies, CATIA enables the production of 3D parts. It includes methods for completing product specification, including functional tolerances and kinematics. It simplifies the design of mechanical, electrical, and distributed systems like fluid and HVAC systems, as well as the development of manufacturing documents. Via a systems engineering approach, CATIA provides a solution for modeling complex and intelligent products. It involves the concept of specifications, device design, behavior modeling, and the development of a virtual product or embedded software. Application programming interfaces (APIs) allow CATIA to be configured (API). CAA (Component Application Architecture), a component object model (COM)-like interface, can be used to adapt CATIA V5 using Visual Basic and C++ programming languages. CATIA V5 provides a parametric solid/surface-based kit that uses NURBS as the core surface representation and includes several KBE-compatible workbenches. Other software, such as Enovia, Smarteam, and various CAE Analysis applications, can be used with V5.

5.1. Boundary Conditions:

- Energy equation is used for heat transfer. Pressure based
  steady flow
- Mixture material: Kerosene-air
- Turbulence Chemistry: Eddy Dissipation
- Reaction: Eddy Dissipation
- Specific heat: constant (1000 J/Kg-K) Density: 1.225 Kg/m3
- Viscosity: 1.789 x 10-5 Kg/m-s.
- Inlet air velocity: 198 m/s(0.8 mach) Inlet air
  Temperature: 300K
- Velocity contour at 0.2mach

5.2. Solver

Fluent is a computational fluid dynamics computer code developed and marketed by Fluent Inc. The code solves the equations for conservation of mass, momentum, energy and other relevant fluid variables using a cell-centred finite-volume method. First the fluid domain is divided into a large number of discrete control volumes (also known as cells) using a pre-processor code which creates a computational mesh on which the equations can be solved. Once the fluid domain has been meshed, the governing equations (in integral form) are applied to each discrete control volume and used to construct a set of non-linear algebraic equations for the discrete dependent variables. Fluent then offers the user a number of choices for the algorithm used to solve these equations, including coupled explicit, coupled implicit, and segregated solvers. In all the calculations reported here only the segregated solver has been used. In this approach the governing equations are solved sequentially. Since these equations are non-linear they are first linearized using an implicit method.



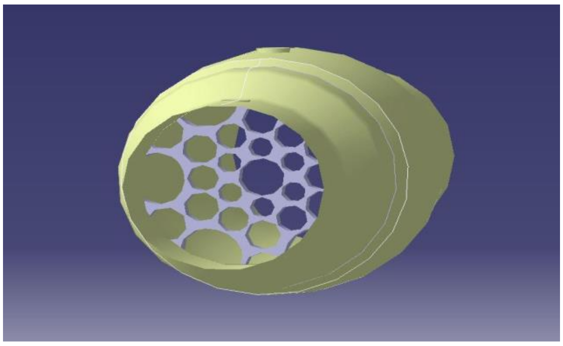
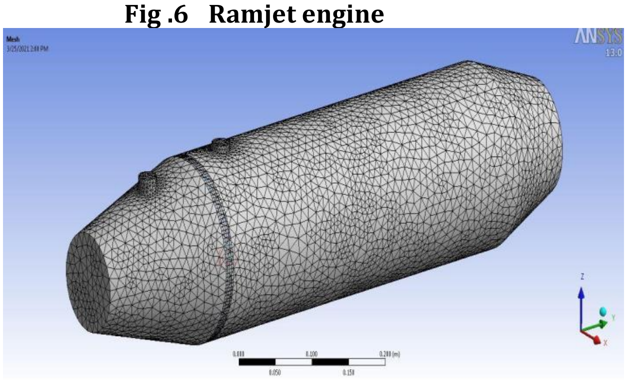


Fig .6 Ramjet engine **Fig.7.Ventilated Disc design**



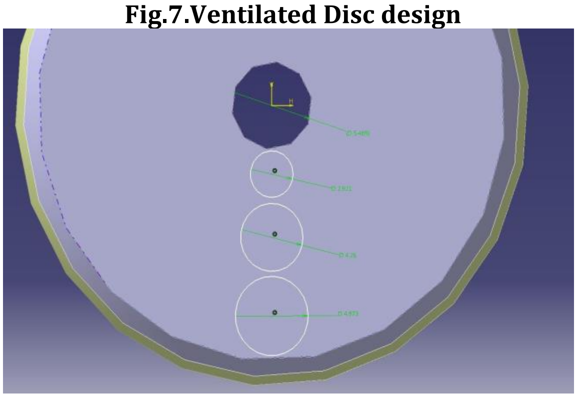


Fig.8. Meshing of combustion chamber **Fig.9. Dimensions of Holes in Ventilated Disc**

6. Result& Discussion:

6.1 Theoretical Calculations

Inlet air velocity v1 =137ms-1

Inlet air pressure p1 =po1=1/2ℓv 2

=1/2*1.225*1372

=11496.0125 n/m2

P =0.11496 bar

Inlet air temperature T = 300k

T0=800k [from analysis]

Assumptions:

Diffuser efficiency ηd=0.8

Combustion efficiency ηc = 0.8

Nozzle efficiency ηn=0.9

Cp=1.005 kj/kg-k

$H1+v_1^2/2=h2$

$c_pT_1+v^2/2=c\ T$

$T_2=T_1+V^2/2c$

$=300+137^2/2*1.005$

$N_d^1 =h_2\ \_h_1/h_2^1-h_1=T_2\ -T_1/T_2-T_1$

$N_d =T_2^1-(300/309.34-300)=0.8$

$T_2^1=307.472k$

$P_{o2}/p_{01}=(T_2^1/T_1)^{(\gamma/\gamma-1)}$

$=(307.472/300)^{3.5}$

$P_{o2}/p_{01}=1.0899$

$P_{o2}=0.1253$ bar

Assume pressure loss in the combustion chamber=4%of p_{02}

Δp=0.04*0.1253bar

$\Delta p=5.012*10^{-3}$

$P_{03}=p_{02}-\Delta p_b$

$=0.1253-5.012*10^{-3}$

$P_{03}=0.120288$bar

$P_{03}/p_{04}=0.120288/1.013=0.1187$

$T_4^1/T_3=(P_{04}/P_{03})^{\gamma-1/\gamma}=(1/0.1187)^{0.2857}$

$T_4^1=1.838*T_3=1.838*800$

$T_4^1=1470.68K\ \eta_J=h_3-h_4/h_3-h_4^1$

$0.9=800-T_4/800-T^1$

$T_4=1403.61k$

Exit gas velocity $c_j=c_i\sqrt{T_4/T_1}$

$=137\sqrt{1403.61/300}$

$C_j=296.33ms^{-1}$

Thrust $=ma(c_j-c_i)$

=1.318(296.33-137) Thrust =210N

Where

T_0 = Initial air Temperature

P_1 = Initial air pressure V_1= Initial air velocity C_j = Exit gas velocity

Fuel consumption

C_V Value of petrol=47,300kj/kg $f*c_v=h_{03}-h_{02}/\eta_b$

$c_p(T_3-T_2)/\eta_b$

$f*c_v=h_{03}-h_{02}/\eta_b=c_p(T_3-T_2)/\eta_b$

$f*c_v=1005(800-309-34)/0.8$

$f*47.300*10^3=616391.625$ $f=616391.625/47300*10^3$

f=0.013

Fuel mass flow rate mf=ma*f=1.318*0.013

Mf =0.0171kg/s

TSFC=mf/thrust

=0.0171*9.81*3600/210

TSFC=2.875N/N-h

Where

C_V =Calorific value of fuel, TSFC= Thrust Specific Fuel Consuption, Mf = Fuel mass flow rate

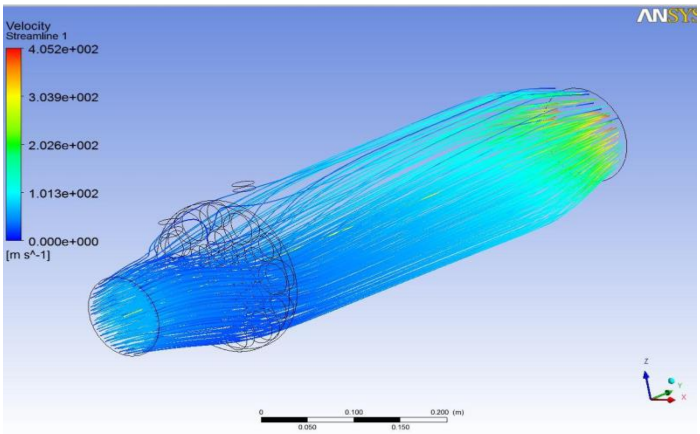


Fig.10. Velocity Stream Line

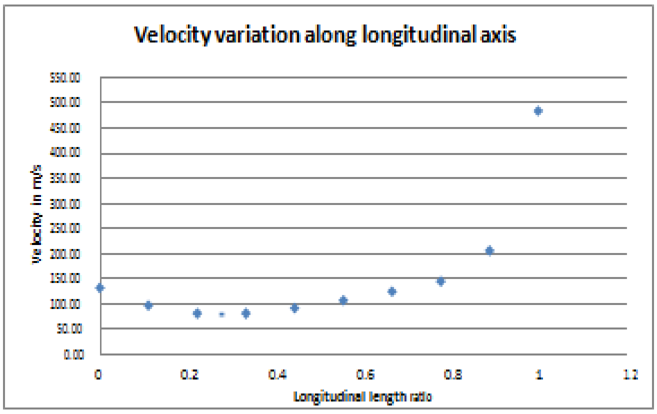


Fig.11.Velocity variation along longitudinal axis

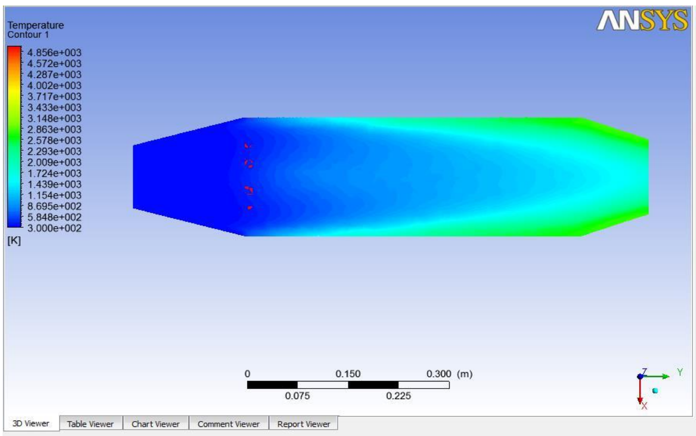


Fig.12. Pressure Variation along Longitudinal Axis

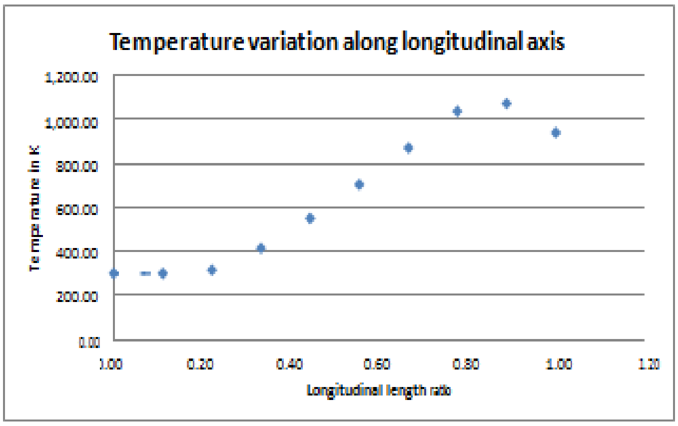


Fig.13 Temperature variation along longitudinal axis

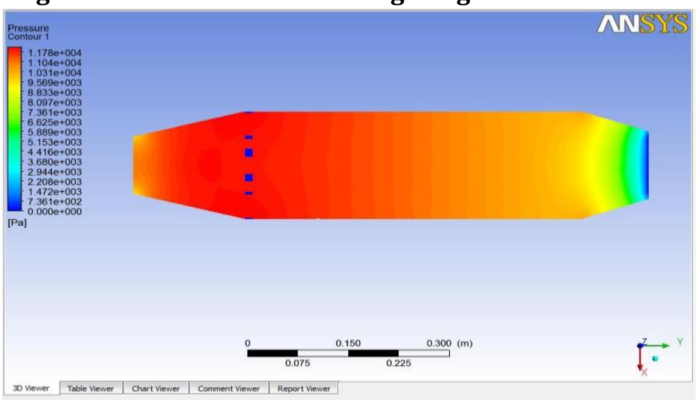


Fig.14.Pressure in small hole

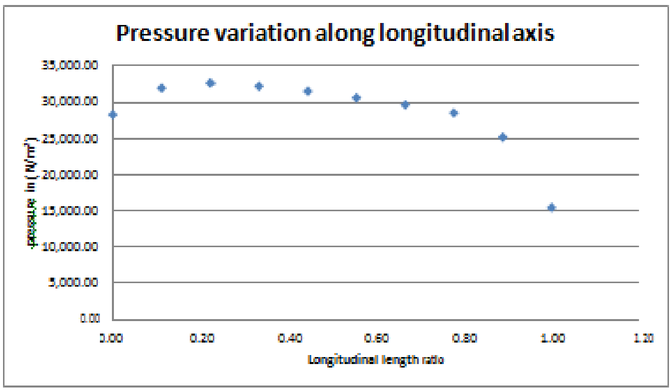


Fig .15.Pressure variation along longitudinal axis

The fig.10 &11 velocity stream line shows, After the solution is initialized then the program is said to run calculation which solves continuity, momentum, energy equations at each nodes of the ramjet engine model. After solving these equations then the interactions will continue to a converge value. The solution is converged at 250 iterations. Then the flow properties like velocity, pressure, temperature are taken along different longitudinal length ratio of the engine and it is plotted as follows: Taken inlet air velocity =132 m/s(0.4 mach). The flow properties are taken and plotted as following fig 10-15 .the above presented graphs correspond to the experimental working conditions of our Subsonic Ramjet Engine. During the testing, the inlet velocity was 0.4 Mach and the above presented graphs are of the same operating condition & they were obtained from the analysis done in ANSYS-FLUENT software. The graphs presented below are also obtained from the FLUENT software at various other operating conditions of the Subsonic Ramjet Engine. At each operating velocity the pressure and temperature variations were determined from the software and compared to the normal working condition of Subsonic Ramjet engines in general. Thus the various graphs corresponding to the various operating conditions were obtained from the analysis software FLUENT. The behavior of the ramjet engine could be easily understood from these graphs mentioned above. From these graphs we can conclude that the Ramjet Engine works efficiently from the software analysis. However, the behavior of the Subsonic Ramjet Engine experimentally was observed and the advantages as well as a few drawbacks which occurred are mentioned below in this report which will be useful for further improvisations in the near future.

Conclusion

In this project we have design and analyse the ventilated disc having different sizes of holes in combustion chamber of ramjet engine for better air-fuel mixing which increasing the velocity and thrust power. The CFD analysis for this combustion chamber is studied and gives the results of velocity, pressure, turbulence . From these results the thrust produced by our ventilated disc is quit high from the existing design.

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