International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 07 | July 2022 www.irjet.net p-ISSN: 2395-0072

COMPUTATIONAL ANALYSIS OF FLAME STABILIZATION IN RAMJET ENGINE COMBUSTION CHAMBER

Manikandan C[1], Ramesh K[2], Shoban Babu[3], Kulandaivel.D [4]

[1] *Department of Mechanical Engineering- PG, M.E. Thermal Engineering, Government College of Technology, Coimbatore -641 013, Tamil Nadu, India,*
[2] *Professor- Department of Mechanical Engineering, Government College of Technology, Coimbatore -641 013, Tamil Nadu, India.*
[3] *Department of Mechanical Engineering, Government College of Technology, Coimbatore -641 013, Tamil Nadu, India.*
[4] *Assistant Professor- Department of Mechanical Engineering, Government College of Technology, Coimbatore -641 013, Tamil Nadu, India.*

---***---

Abstract – *This work involved the numerical simulation of an integrated ramjet engine that included a nozzle, a subsonic combustor, and supersonic diffuser. The results are reported in this paper. These findings include analyses of cold flow and the addition of heat to the combustion chamber and nozzle. These results include cold flow studies, heat addition in the combustion chamber along with the nozzle. This study uses computational fluid dynamics to quantitatively predict the combustion characteristics of a ramjet engine used with a symmetric inlet (CFD). For a 15:1 air-fuel ratio with kerosene as the fuel, two examples of combustor layouts are examined. The blockage ratio is kept between 30 and 40 percent in all setups. While the combustion efficiency and other performance characteristics remain the same, Case 1 reduced blockage ratio results in a pressure loss of about 2%. It is advised to use the Case 2 configuration, which has a combustion efficiency of about 80 and a lower blockage ratio, in the ram jet combustor design.*

Key Words: **Ramjet engine, air intake, combustor, numerical simulation, internal flow, air/fuel ratio**

1. INTRODUCTION

Propulsion, in a broad sense, is the act of modifying the motion of the body. Propulsion mechanisms supply a force to move a body across a medium. That changes originally resting bodies by pushing them. Overcomes restraining forces, or gains velocity. In a gas turbine cycle, the combustion process is crucial. The reason for this is that throughout this process, the chemical energy of the fuel is transformed to heat energy, which the turbine then uses to produce work [1]. It is first important to combine fuel and air in the gas turbine combustion system in such a way that the resulting flame can sustain itself. As a result, the design of the combustor includes the creation of a turbulence zone with the complexity of both aerodynamic and thermo-chemical effects. Therefore, despite the extensive research on combustion, flame stability in constant flow could still be improved. A ramjet is a type of air-breathing jet engine that compresses incoming air without the use of a rotary compressor by moving the engine forward [2]. Ramjets are unable to generate thrust at zero airspeed, hence they are unable to start an aircraft moving. Ramjets need a lot of forward speed to function properly, and this class operates at its best efficiency around Mach 3. Ramjet can be especially helpful in applications like missiles that call for a tiny, straightforward engine for usage at high speeds.

1.1 COMPONENTS OF RAMJET ENGINE

Diffuser of the ramjets attempt to take advantage of the extremely high dynamic pressure in the air as it approaches the intake lip. Most of the freestream stagnation pressure, which is needed to promote the combustion and expansion process in the nozzle, will be recovered by an effective intake. The combustor, like other jet engines, burns fuel and air at nearly constant pressure to produce hot air. Since the airflow through a jet engine is typically rather high, "flame holders" are used to prevent the flames from blowing out, creating shielded combustion zones. Since it speeds up exhaust flow to provide thrust, the propelling nozzle is a crucial component of the ramjet design [2]. Exhaust flow is accelerated through a converging nozzle for a ramjet running at a subsonic flight Mach number. Acceleration for supersonic flight is often accomplished using a convergent-divergent nozzle.

1.2 FLAME HOLDERS

In order to sustain continuous combustion, ramjet engines use a part called a flame holder. A flame holder is required for every continuous-combustion jet engine [3]. An engine's low-speed eddy is produced by a flame holder to keep the flame from being blown out. A stable eddy and drag must coexist in harmony for the flame holder's design to work. The can-type flame holder is the simplest design; it is made of a can with a few tiny holes in it. The H-gutter flame holder, which has a curve that faces and opposes the flow of air and is formed like a letter H, is much more efficient.

2. RAMJET COMBUSTION PROCESS

In this paper, the numerical investigation of different ramjet combustion chamber as well as an entire ramjet is investigated. It is assumed that the fluid is viscid. RAMJET combustion chamber has been selected from the literature. G. Raja Singh Thangadurai et al. [1]. The combined analysis of the supersonic air intake, combustion chamber, and nozzle aids in the investigation of the relationship between the air intake and the combustion chamber.

The significance of ramjet combustion was noted by Gordon L. Dugger et al. in [2]. Ramjet engines are employed in research aircraft and missiles that are expected to have a significant impact in the next years. The increased temperature rise will affect the combustor material and overall engine performance even if hypersonic flying speed vehicles are still being developed. Ramjet propulsion could be utilized to power up, according to recent trials and analysis.

Many researchers are interested in the ramjet engine as one of the most useful propulsion systems of the future. It moves field of a ramjet combustor Utilizing numerical simulation, the V-gutter flame holder the connected explicit NS equations in two dimensions, the Under two independent operating conditions, the conventional k-e turbulence model and the finite-rate/eddy dissipation reaction model for capture the cold flow and engine ignition are two examples of circumstances. On various dump combustor geometries without a central jet, Shahaf et al. [3] studied two-dimensional liquid fuel combustion phenomena analytically and empirically. Jones and Whitelaw went into great length about how to calculate turbulent reacting flows. The system of vortices in the head area is essential for the steady operation of the combustor, according to Roy et al [4] experiential's testing of the combustor performance of a gas generator ramjet with four side air inlets but no central injection. Liquid fuel injection was used by Stull, et al. [5] to investigate the dual-side-air-inlet dump ramjet combustor. By altering the position of the dome plate, Stull et al. statistically examined the flow-field properties of a three-dimensional side-air-inlet dump combustor.

Yen et al. studied the impact of side-inlet angle on the flow field of a three-dimensional dump combustor where the side jets are completely opposite to one another [6]. Inamura, et al., conducted an experimental study on the combustion characteristics of a ramjet combustor [7]. The spray-combustion flow in a side-dump ramjet combustion chamber attached with four symmetric inlets was numerically investigated by Jiang et al. in [8]. In order to anticipate the overall performance of the four-stage ramjet combustion chambers, Grohens et al. [9] used a novel numerical method. First, a non-reactive Reynolds averaged Navier-Stokes (RANS) calculation was done, then a liquid phase Lagrange calculation (fuel). The transport equation was then solved, and a chemical kinetic model was used to determine the combustion efficiency for any equivalency. A flow model that may predict the impacts of fuel droplets on combustion, flame holders, and diffuser form in the case of a three-dimensional axisymmetric combustor has been created in the current study.

3. VARIOUS INLET OPERATION OF A RAMJET ENGINE:

Ramjets are a particular kind of air-breathing jet engine that compresses incoming air by moving forward as opposed to using a rotary compressor. Because they can't generate thrust at zero airspeed. Moving the ramjet therefore require an additional propulsion system to increase the vehicle's speed so that the Ramjet can begin to generate thrust. Ramjets are effective at Mach 2 or faster supersonic speeds. According to the heat released in the combustor, as indicated in figure 1.1, there are three various situations under which a ramjet engine diffuser can operate. The operation is considered to be critical when the heat released in the combustor is just sufficient to allow the normal shock to be positioned at the inlet throats due to the back pressure at the subsonic diffuser's exit section; this is the design condition.

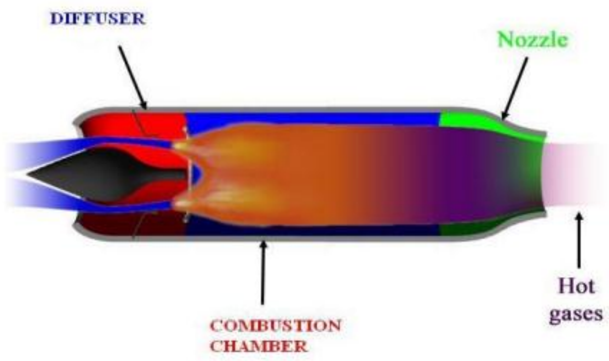


Fig 1. Ramjet engine

4. CFD APPROACH:

The science of numerically resolving the equations governing these processes to predict heat transfer, fluid movement, mass transfer, chemical reactions, and other phenomena is known as computational fluid dynamics (CFD). Important engineering data from CFD simulations can be applied to conceptual design studies, problem-solving, in-depth product development, and redesign. To minimize the total amount of work required in the lab, CFD analysis is utilized in conjunction with research and testing. The study of utilizing a computational approach to solve the equations that control fluid flow is known as computational fluid dynamics (CFD). Various procedures to forecast heat transfer, fluid flow, and phenomena such as mass transport, chemical reactions, and others.CFD analyses produce useful engineering information that can be utilized in concept research for fresh designs, thorough invention, troubleshooting, and redesign of products.

4. MODELLING:

Computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM, and 3D are all applications included in the multi-platform SolidWorks software suite. It provides a way to build, alter, and validate complex, novel shapes from industrial design to Class-A surfacing using the ICEM surfacing technologies. It also offers solutions for shape design, styling, surfacing workflow, and visualization. Whether the product design process is initiated from scratch or from 2D sketches, SolidWorks enables various stages. An symmetric inlet is present in the ramjet engine combustion chamber. Therefore, CFD analyses for cold flow simulations are performed using a two-dimensional model. Regarding diffuser design and flame holder layout, various changes were done. Ultimately, 3 layouts were chosen based on a few factors, including: The velocity must be uniform at least 400 to 500 mm from the diffuser end. There should be little total pressure loss over the combustion.

4.1 BOUNDARY CONDITIONS:

- Energy equation is used for heat transfer. Pressure Base steady flow
- Model Energy Viscous – Realizable K-ϵ Standard
- Mixture material: Kerosene- Air – ideal gas
- Turbulence Chemistry: Finite rate/Eddy Dissipation
- Mass flow inlet, Inlet Temperature: 300K
- Pressure outlet
- SIMPLE Pressure-velocity Coupling Discretization scheme.
- Inlet Pressure and outlet temperature are monitored.

Following table 1,2 and 3 shows the inlet, outlet and wall boundary conditions used in this study.

Table 1: Inlet Boundary conditions

Parameter	Value
Flow Regime	Subsonic
Mass and Momentum	Total Pressure
Turbulence	Zero gradient
Heat Transfer	Static Temperature = 300K

Table 2: Wall Boundary conditions

Parameter	Value
Mass and Momentum	No Slip Wall
Wall Roughness	Smooth Wall
Heat Transfer	Adiabatic

Table 3: Outlet Boundary conditions

Parameter	Value
Flow Regime	Supersonic
Mass and Momentum	Opening pressure = 1atm
Turbulence	Medium Intensity = 4.5%
Heat Transfer	Static Temperature = 300K

4.2 SOLVERS:

FLUENT, one of the most flexible solvers for Hypersonic flow, is used to compute the aforesaid model because it has a well-validated physical modelling capability to give quick, accurate results across the broadest spectrum of CFD and multi physics applications. A wide variety of physical flow problems and other physical phenomena can be solved using the ANSYS Fluent software, including heat transfer, external flow over a contour, internal flow in a cylinder or pipe, dynamic flow problems like acoustics, and complex geometry flows like those in turbine and compressor blades. Analyses for the 60-degree model were conducted while taking the periodicity of the geometry into consideration. To represent the entire model, asymmetry model is applied to this sector. All of these combustors underwent reacting flow evaluations for the Sea Level altitude condition and a matching flying Mach of 2.6. At the combustor's input, the mass flow inlet condition is set. At the nozzle's exit, the flow is still chocked, or supersonic, therefore the pressure is determined by the upstream flow values. In the previous section provides the corresponding boundary condition values. Fuel is injected from the primary injector in the first two cases at a pressure of 15 bar. In this approach equations are solved sequentially. Since these equations are non-linear, they are first linearized using an explicit method.

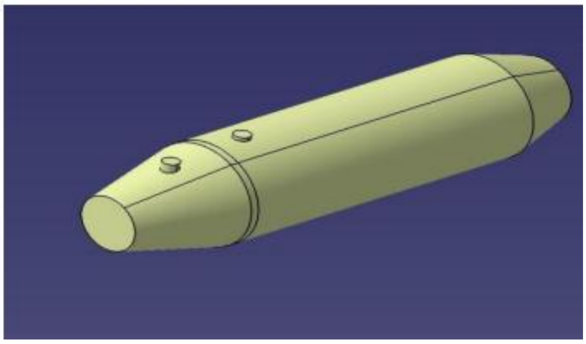


Fig .2 Ramjet engine

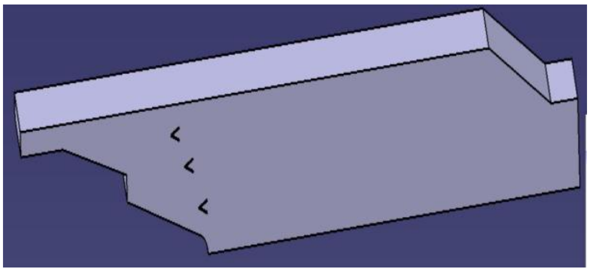


Fig .3 3D combustor

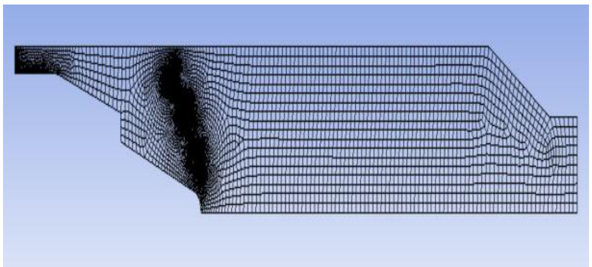


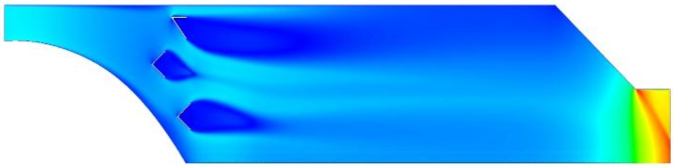
Fig .4 Meshing of combustion chamber

5. RESULT AND DISCUSSION:

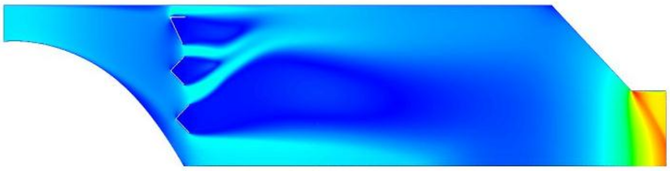
The outcomes of the two-dimensional cold flow analyses performed using the solver input conditions outlined in chapter 4 are shown. Mass imbalance and exit pressure were observed during the convergence. Results from these analyses are discussed in terms of Mach number distribution.

5.1 COLD FLOW ANALYSIS:

Figure 5 shows the Mach contours of few configurations 2D design modifications which are analyzed for cold flow conditions. The problems identified with this design is the formation of low velocity region over the diffuser which will lead to damage in material when combustion occurs. Also, the deflector presents in the inlet produce recirculation zones behind it but difficult to construct and not desired for Ramjet engine. This led to change in diffuser shape to cone type and elimination of flame holder as shown in config. 1. These two configurations satisfies the following conditions for desired combustor and are chosen for reactive flow analysis among 2 cases.



Case 1



Case 2

Fig: 5 Mach contour of various 2D combustor configurations

From Figure 6, It is seen that even without the combustion process occurring the engine was able to accelerate the exit flow to a higher value than the inlet. This implies that the design of the ramjet meets the standard requirements.

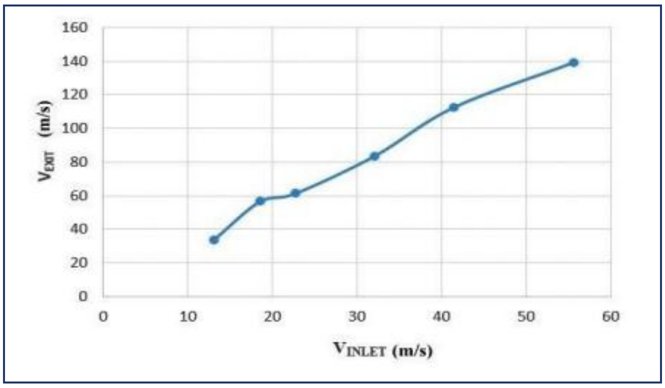


Fig: 6 Cold Flow Analysis Velocity Plot

5.2 REACTIVE FLOW ANALYSIS:

The analyses produced second order correct results. We kept an eye on the convergence's inlet pressure and exit temperature. The design is created in a way that the complete mixing of air and fuel is accomplished at the conclusion of the assembly. The igniter is therefore placed behind this to begin combustion mixing area.

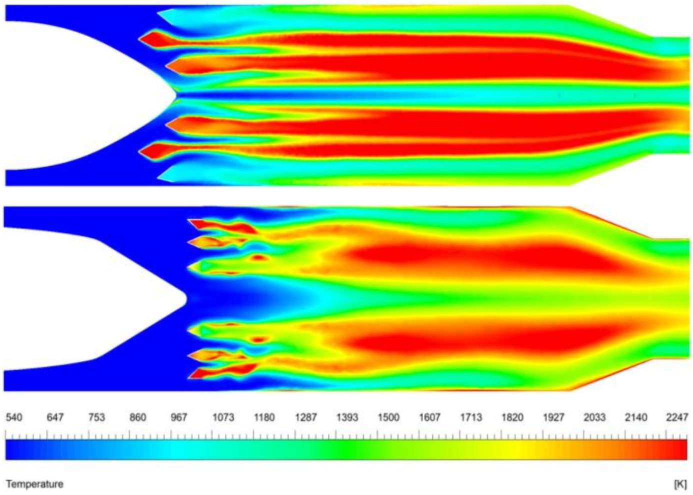


Fig: 7 Contours of static temperature at mid plane

To determine the mass proportion of exhaust products following the combustion event, a plane is constructed at the ramjets exit. Figure 7 static temperature contour demonstrates there is no unburned fuel because the fuels are totally burned in the ramjet's exit. Finished combustion is characterized by the presence of water and carbon dioxide. This ramjet accomplishes this design. The carbon dioxide and methane mass fraction contours. Figure 6 displays the water vapor from the combustion model that the amount of carbon in the exhaust emissions is at its highest dioxide and vaporized water. These preceding diagrams make it simple to understand how the ramjet engine behaves. These graphs show We can therefore say that the Ramjet Engine operates effectively. However, the process in which the experimentally, a subsonic ramjet engine was presented and a few different consequences that occurred are listed in this report's summary, which will be helpful for future study.

6 Conclusion:

Through comprehensive engine simulations, the overall performance of a ramjet engine that includes the air intake, combustor, and nozzle has been studied. The relationship between the air-intake and combustor is intensely highlighted by the coupled study. Several factors affect the air intake performance, including both by its geometry and the amount of heat release during combustion. The flow model that was created in the probable use of the current study Ramjet's design and development tool programmes for development. With the reduction in the blockage ratio in Case 1, around 2% pressure loss is obtained while the combustion efficiency and other performance parameters remaining same. Finally, it can be stated that Case 2, configuration with reduced blockage ratio is recommended for implementation in the ramjet engine combustor configuration.

REFERENCES

[1] G. Raja Singh Thangadurai, B.S. Subhash Chandran, V. Babu and T. Sundararajan., May 2008, "Numerical Analysis of Integrated Liquid Ramjet Engine", Defense Science Journal, Vol. 58, No. 3, pp. 327-337.

[2] Gordon L. Dugger., 2009, "Recent Advances in Ramjet Combustion", ARS Journal, Vol. 29, No. 11), pp. 819-827.

[3] O. Dessornes., M. Bouchez., 2005, "Combustion Experiments of Liquid Kerosene and Hydrogen/Methane Mixing in a Dual Mode Ramjet Engine"- AIAA/CIRA 13th International Space Planes and Hyper sonics Systems and Technologies.

[4] Senapthi Krishnamachary., S. Krishna Mohan., Jayaraman Desingou., Sunita Devi Jena., R. Vivek., Trivedi Darshan Kuma., and V. Ramanujacharic., 2014, "Polycyclic alkanes based high density hydrocarbon fuels preparation and evaluation for LFRJ application", RSC Advances.

[5] Shahaf, M., Goldman, Y. & Greenberg, J.B., March 1980, "An investigation of impinging jets in flow with sudden expansion". Proceedings of the 22nd Israel Annual Conference on Aviation and Astronautics, Israel Ministry of Transport, Tel Aviv and Haifa, Israel, pp.100-106.

[6] Jones, W.P. & Whitelaw, J.H., 1982, "Calculation methods for reacting turbulent flows: A review", Combustion and Flame, 48, 1-26.

[7] Roy, P.; Schlader, A.F. & Odgers, J., 1982 "Combustor modelling studies for ramjets. Ramjets and RAM rockets for Military Applications", pp. 31-1 to 31-10. Report No. AGARD-CP- 307.

[8] C.W. Foley, I. Chterev, J. Seitzman and T.Lieuwen, "Flame Configurations in a Lean Premixed Dump Combustor With an Annular Swirling Flow", AIAA 30332-0150, USA

[9] Adi Surjosatyo & Farid nasir, "A study of enhancing the swirl burner performance on a small scale bio mass gasification", International journal of engineering & technology, Vol.11 No. 04, pp. 20-29.

[10] Claypole, TC & Syred, "The effect of swirl burner aerodynamics on NOx formation', proceeding of the combustion institute", Eighteenth symposium (International) on combustion, the combustion institute. pp.81-89.

[11] G.L. Morrison, M.T. Schobeiri, K.R. Pappu, "Five-hole pressure probe analysis technique", Mechanical Engineering Department, Texas A&M University, College Station, TX 77843-3123, U.S.A.