

Computational analysis of hydrocarbon combustion

P Karthikeyan¹, S.Madhavan², SM Silambarasan², M.Haja Najibudeen²

¹ Assistant Professor, Department of Aeronautical Engineering, Paavai Engineering College, Namakkal, India

² UG scholar, Department of Aeronautical Engineering, Paavai Engineering College, Namakkal, India

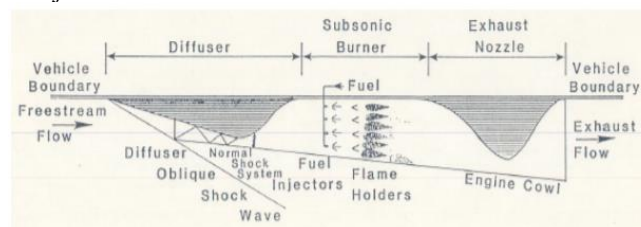
Abstract: Combustion of fuel with oxidizer provides continuous power for the vehicles to move forward. Well-designed combustor produces complete combustion, where water and carbon dioxide are the stable products. Incomplete combustion additionally produces more emission in the form of carbon monoxide and nitrogen oxides due to factors like poor mixing of the air and fuel or insufficient excess air. Therefore in order to understand the importance of various parameters which affects the combustor performance and to design the effective combustor, which delivers high combustion efficiency, it is very essential to study the combustor using CFD techniques, performed using ANSYS Fluent software. Computational or CFD methodology is used here to perform combustion simulation on the typical combustor models, where hydrocarbon like kerosene (Jet fuel) is burned with incoming air at high velocity. Computational models are created with pre-processor such as Gambit and subsequent processing and post processing with Ansys Fluent as the software. Suitable turbulent model, chemical model and physical models are enabled to analyse and plot the mass fraction of various chemical species along the length of the combustor. Fuel Additives are used to evaluate the peak temperature. The combustion efficiency of this hydrocarbon combustion is evaluated using this numerical tool.

INTRODUCTION

This chapter will provide a basic introduction to scramjet technology by presenting the definition, current status of scramjet engines. historical timeline, possible applications, and the current status of scramjet engines.

DEFINITION OF SCRAMJET ENGINE

To give the meaning of a scramjet motor, the meaning of a ramjet motor is first essential, as a scramjet motor is an immediate relative of a ramjet motor. Ramjet motors have no moving parts, rather working on pressure to ease back freestream supersonic air to subsonic velocities, in this manner expanding temperature and pressing factor, and afterward combusting the compacted air with fuel. In conclusion, a spout speeds up the exhaust to supersonic velocities, bringing about push. Figure 1 beneath shows a two dimensional schematic of a ramjet motor. Because of the deceleration of the freestream air, the pressing factor, temperature and thickness of the stream entering the burner are "impressively higher than in the freestream". At flight Mach quantities of around Mach 6, these builds make it wasteful to keep on easing back the stream to subsonic rates. Consequently, if the stream is not, at this point eased back to subsonic rates, yet rather just eased back to satisfactory supersonic rates, the ramjet is then named a 'supersonic ignition ramjet,' bringing about the abbreviation scramjet. Figure 2 beneath shows a two-dimensional schematic of a scramjet motor.

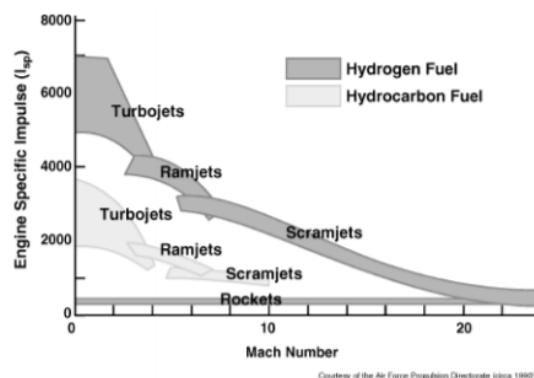


APPLICATIONS OF SCRAMJET ENGINES

There is a scope of potential applications for scramjet motors, including rocket drive, hypersonic cruiser drive, and some portion of an organized space assessments framework Figure 1.3 underneath shows the rough exhibition regarding motor explicit drive and Mach number for different sorts of drive frameworks [7]. It very well may be seen that at Mach numbers higher than roughly 6-7, the just accessible impetus frameworks are rockets and scramjets. Contrasted with rockets, scramjets have a lot higher explicit motivation levels; in this manner, it is clear why it is favourable to build up the scramjet, in the event that hence as it were. In spite of rockets, scramjets don't need that an

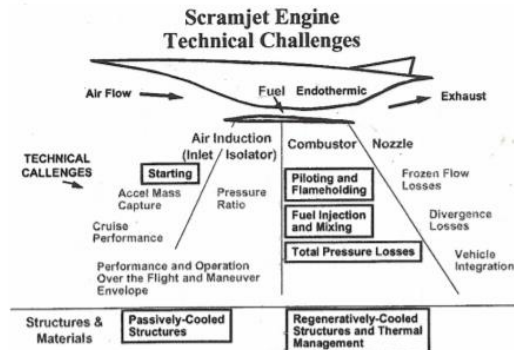
oxidizer be continued board the airplane as it is an air breathing motor, gathering oxygen from the environment [7]. This reduction the necessary load of the general impetus framework also, fuel, bringing about a higher reasonable payload weight or expanded reach. There are different reasons that the advancement of the scramjet is worthwhile also. Air breathing motors produce higher motor proficiency, have a more drawn out fuelled reach, have the capacity for push regulation to guarantee effective activity, have higher mobility, and are totally reusable [7].

Figure 1.4 showcases a subjective outline of the impetus alternatives dependent on the flight Mach number [7]. The bend addresses the inexact elevation needed to work at a given flight Mach number just as the required drive framework. Likewise appeared on this graph is a general limit between the two essential fuel alternatives for scramjets: hydrocarbons and hydrogen. However Walrus presumes that as far as possible for hydrocarbons is between Mach 9 and 10 rather than Fry's chart showing roughly 8, the overall agreement is that hydrogen fuel ought to be utilized for air breathing flight quicker than Mach 8-10, due to its "higher cooling limit" and its "quicker responses" [7]. However hydrogen can perform at higher rates over the hydrocarbon furthest breaking point, Curran states that with current abilities the hydrogenfueled scramjet will just offer "satisfactory execution to about Mach 15" [2]. Concerning the space access application for scramjet innovation, Townsend contends, explicitly, that there are numerous benefits in applying the scramjet as the drive framework for the second phase of a two-stage-to-circle (TSTO), hydrocarbon-powered aviation plane. He clarifies that it would accommodate a little TSTO vehicle just as a little single-stage-to-circle (SSTO) vehicle or military hypersonic cruiser that utilizes a hydrocarbon- filled scramjet. Fry clarifies that the reasoning for hypersonic rocket capacity lies in the way that a Mach 6-8 rocket expands the conceivable reach inside a given flight time, or comparatively, diminishes the flight time needed for a given reach [7]. In outline, the objective of scramjet advancement is to give hypersonic vehicles a more effective option in contrast to rockets. The vehicle that could most rapidly profit by current scramjet research is the journey rocket; notwithstanding, a hypersonic cruiser airplane that is an option in contrast to conventional turbojet transportation for regular citizen or military application could likewise be a not very inaccessible probability. Scramjets could likewise be utilized related to rockets for space launchers, subsequently requiring less ready oxidizer for transport to space



Current Scramjet Engine Technology Challenges

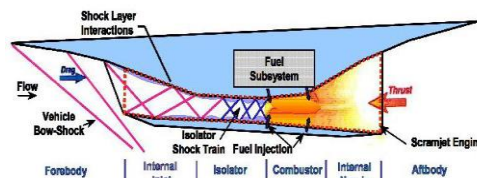
Figure 1.5 beneath is a decent rundown of the current challenges in the advancement of the scramjet motor. There are three fundamental zones that these issues lay in, specifically Air Inlet, Combustor, and Structures and Materials. Issues inside these territories fluctuate from delta beginning issues to the innate trouble of the start of the fuel in a supersonic stream, as the chance of disappointment exists anyplace from the fuel not lighting to the chance that the start could happen outside of the combustor due to the exceptional speed of the air in the motor. Furthermore, structures that can withstand the limit temperatures experienced during hypersonic flight joined with the extra temperature experienced during ignition are essential. Notwithstanding the current specialized difficulties of scramjet advancement, there is another space of scramjet improvement which merits consideration. In spite of the wide scope of uses conceivable with scramjet innovation, the vehicle should initially be pushed to a sufficiently high Mach number for the scramjet to begin. This requires, contingent upon the required



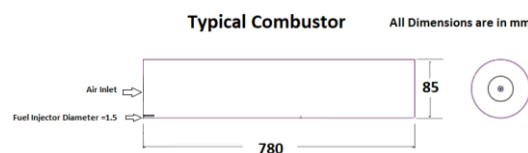
application, a couple extra impetus frameworks to drive the vehicle to the required scramjet start speed. Current scramjet plans focus on the beginning of supersonic burning to be between Mach 5 and 6 [1, 7, 8]. In request to limit the weight and intricacy of having different impetus frameworks, a double mode ramjet/scramjet is frequently proposed. Notwithstanding, if the essential scramjet beginning Mach number is decreased, a decrease in the quantity of required extra drive frameworks is conceivable, as the hole is connected between the greatest conceivable speed of the low speed engine(s) and the scramjet start speed. This would enjoy direct benefits from the coming about decrease in general vehicle weight, the lower mass portion needed for the drive framework (in this manner coming about in more accessible payload weight), and less frameworks that should work in progression dependably, in this way expanding in general vehicle wellbeing. The focal point of this undertaking is to address this issue of decreasing the beginning Mach number.

HYPERSONIC PROPULSION

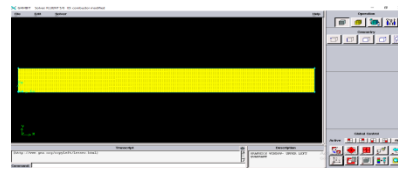
gives high push and low weight for hypersonic flight vehicles. In contrast to a traditional turbojet motor or ramjet motor, a scramjet motor has no complex moving parts. It comprises of a diffuser at delta, spout at the exit and a combustor having a fuel injector, and fire holder (as featured from Figure A) The ignition chamber comprises of various sorts of fuel infusion framework (cross over, equal or calculated infusion plot), fire adjustment component and fuel start for the maintained burning. When a scramjet motor mounted on a fast airplane, while pushing ahead, huge amounts of wind stream are drawn inside the motor through the gulf. The approaching air gets decelerated when going through the isolator area, and the unique pressing factor gets changed over into a higher static pressing factor. This high pressing factor, additionally called as slam impact works with in adding the warmth to the approaching air inside the burning chamber, without the requirement for having the different blower framework. In the burning chamber, fuel is appropriately blended in with the air at a sub-atomic level for appropriate start. Fire holders in the combustor help in settling the cycle of supersonic ignition. While consuming happens in subsonic mode in the ramjet motor ($M < 1$), it happens totally in supersonic mode ($M > 1$) in the scramjet motor. After the ignition chamber, the hot fumes gas goes through a hypersonic spout, where the stream is sped up to a high Mach number. As the spout leave speed is higher than the free stream speed, drive force is made by Newton's second law which creates push in the forward bearing.



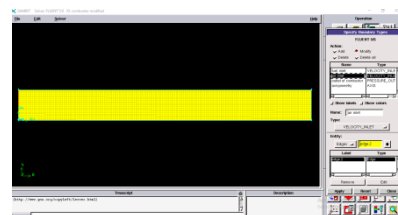
HYDROCARBON COMBUSTORCFD MODEL



CFD MESHING



Boundary Conditions



- Inlet velocity for Air : 100 m/s
- Inlet Temperature for Air : 300 K
- Species mass fraction for oxygen= 0.23
- Inlet velocity for Fuel: 80 m/s
- Inlet Temperature for Fuel: 300 K
- Species a mass fraction for
- Kerosene, C₁₂H₂₆= 1
- With additive, Ethanol =>Species a mass fraction for
 - Kerosene, C₁₂H₂₆= 0.9
- Species a mass fraction for
- Ethanol, C₂H₅OH= 0.1

ANSYS Fluent problem Setup:

- In your paper title, if the words "that utilizes" can precisely supplant Solver Type: Pressure based
- Solver Time: Steady state
- Energy condition empowered

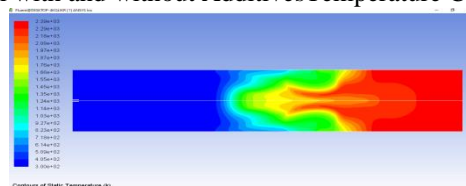
Species transport model

Volumetric combustion with Kerosene fuel as Mixture Material
Additive used: Ethanol Turbulent chemical interaction : Eddy-dissipation
Method

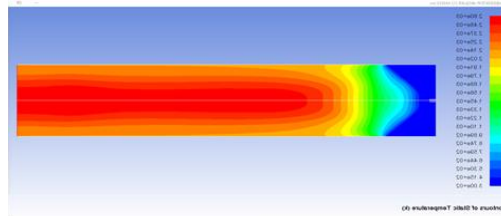
Chemical Equation:



CFD results (For both Kerosene fuel with and without Additives) Temperature Contour- Combustor without Additive

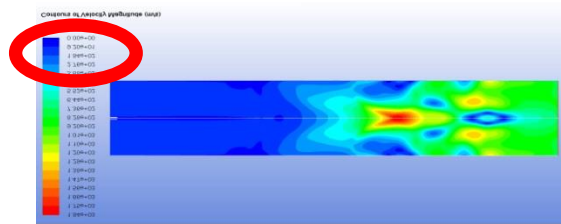


Temperature Contour- Combustor with Additives

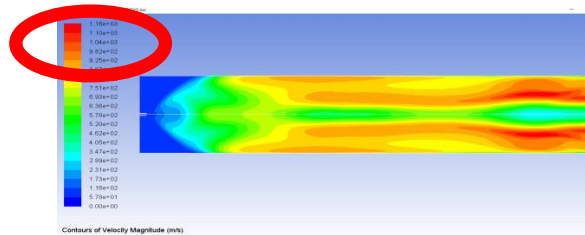


Combustor with Additive = Increase in Peak Temperature = 210 K

Velocity Contour- Combustor without Additive



Velocity Contour- Combustor with Additive



Combustor with Additive = Increase in Peak Temperature = 210 K

Combustion Efficiency

Combustion efficiency,

Mass-Weighted Average Mass fraction of c12h23	
distance-at-100-mm-length	0.077798258
distance-at-200-mm-length	0.077821775
distance-at-300-mm-length	0.076505163
distance-at-400-mm-length	0.048120209
distance-at-500-mm-length	0.029458273
distance-at-600-mm-length	0.020754921
distance-at-700-mm-length	0.015271109
fuel_inlet	1
Net	0.05961343
Flow Rate Mass fraction of c12h23 (kg/s)	
distance-at-100-mm-length	-0.81538343
distance-at-200-mm-length	-0.81567953
distance-at-300-mm-length	-0.80643774
distance-at-400-mm-length	-0.50575745
distance-at-500-mm-length	-0.32598494
distance-at-600-mm-length	-0.21750369
distance-at-700-mm-length	-0.16005434
fuel_inlet	0.81558776
Net	-2.8312134

Combustion Efficiency

Combustion efficiency, η_b

$$\eta_b = \frac{\text{Mass of Injected fuel} - \text{Mass of fuel at outlet of combustor}}{\text{Mass of Injected fuel}}$$

Mass of Injected fuel

Combustion efficiency, η_b - Combustor without Additive

At 700 mm length, (Nearly the end of the combustor)

- Mass of Injected fuel = 0.81558 Kg/s
- Mass of fuel at section 7 = 0.16005 Kg/s
- $\eta_b = \frac{(0.81558 - 0.16005)}{0.81558} = 80.37 \%$

The combustion efficiency is only 80.37 %

Combustion efficiency, η_b - Combustor with Additive

At 300 mm length, (Nearly the middle of the combustor)

- Mass of Injected fuel = 0.5811 Kg/s
- Mass of fuel at section 7 = 0.0077 Kg/sp
- $\eta_b = \frac{(0.5811 - 0.0077)}{0.5811} = 98.67 \%$

The combustion efficiency is 98.67 %

The combustion efficiency is 99.77 % at 400 mm length of the combustor.

CONCLUSION

CFD models are created using Gambit software, which is fine meshed and with defined boundary conditions (PreProcessing) Processing and Post - Processing are carried out using Ansys fluent software, with turbulent and chemical model enabled for species transport Kerosene (Jet fuel) is used in case I and Kerosene mixed with 10% Ethanol (fuel additive) is used in case II to analyse this hydro carbon combustion The peak temperature obtained in fuel with additive is higher than the case with fuel alone

Temperature obtained in combustor with kerosene only = 2390 K

Temperature obtained in combustor with kerosene + Ethanol = 2600 K

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