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"CFD ANANLYSIS & MODELLING OF A SUPERSONIC COMBUSTION IN SCRAMJET ENGINE"

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INTRODUCTION

The Supersonic Combustion Ramjet (SCRAMJET) engine has been recognized as the most promising air breathing propulsion system for the hypersonic flight (Mach number above 5). In recent years, the research and development of scramjet engine has promoted the study of combustion in supersonic flows. Extensive research is being carried out over the world for realizing the scramjet technology with hydrogen fuel with significant attention focused on new generations of space launchers and global fast-reaction reconnaissance missions. However, application for the scramjet concept using high heat sink and hydrogen fuels offers significantly enhanced mission potential for future military tactical missiles. Scramjet being an air-breathing engine, the performance of the missile system based on the scramjet propulsion is envisaged to enhance the payload weight and missile range. Supersonic combustion ramjet engine for an air-breathing propulsion system has been realized and demonstrated by USA on ground and in flight. X-43 vehicle used hydrogen fuel. Hydrocarbon fuel scramjet engine is still under study and research.

Mixing, ignition and flame holding in combustor, ground test facilities and numerical simulation of Scramjet engine are the critical challenges in the development of scramjet engine.

1.3 OBJECTIVE

This work is on scramjet engine with 3 fluids.

To model the flow inside the Scramjet engine using the Computational Fluid Dynamics (CFD) program and the combustor geometry of the Scramjet engine for maximum thrust at a single operating condition (Mach number). The configuration of the Scramjet was varied by three fluid parameters.

2. LITERATURE REVIEW

Shigeru Aso et.al worked on the topic of "Fundamental study of supersonic combustion in pure air flow with use of shock tunnel", and their findings are – The increase of injection pressure generated strong bow shock, resulting in the pressure loses. The shock generator is an effective method to accelerate the combustion. The increase of the injection total pressure raises the penetration of fuel; thus, the reaction zone expands to the center of flow field. K. M. Pandey and Siva Sakthivel. T worked on the topic of "Recent Advances in Scramjet Fuel Injection - A Review", and their findings are – Fuel injection techniques into scramjet engines are a field that is still developing today. The fuel that is used by scramjets is usually either a liquid or a gas.

Kyung Moo Kim et.al worked on the topic of "Numerical study on supersonic combustion with cavity-based fuel injection", and their findings are – When the wall angle of cavity increases, the combustion efficiency is improved, but total pressure loss increased. When the offset ratio of upper to downstream depth of the cavity increases, the combustion efficiency as well as the total pressure loss decreases. The necessary temperature level is partly achieved by the oblique shock waves in the supersonic flow with increasing combustor area ratio. K. Kumaran and V. Babu worked on the topic of "Investigation of the effect of chemistry models on the numerical predictions of the supersonic combustion of hydrogen", and their findings are – Multi step chemistry predicts higher and wider spread heat release than what is predicted by single step chemistry. The single step chemistry model is capable of editing the overall performance parameters with considerably less computational cost. A better tradeoff between thrust augmentation and combustion efficiency can be achieved through staged combustion.

T. Cain and C. Walton worked on the topic of "review of experiments on ignition and Flame holding in supersonic flow", and their findings are – Low combustor entry temperature is desirable /essential due to intake and nozzle limitations. Hydrogen and hydrocarbon the optimum temperature /pressures are in regions in which ignition delay is very sensitive to temperature, varying from 0.1ms to >>10ms. At low Mach number and static temperatures but at these conditions combustion results in free subsonic regions with very high turbulence. Chemical initiators such as silane, fluorine and OTTO can be used but there are penalties in specific impulse, system complexity and handling hazards. G. Yu, J.G. Li, J.R. Zhao, et al. worked on the topic of "An experimental study of kerosene combustion in a supersonic model combustor using effervescent atomization", and their findings are – The smaller kerosene droplet having higher combustion efficiency.

OVERVIEW OF FLUENT

There are many CFD packages in the market now, FLUENT is most widely used and this package has been used in this project for the simulation.

FLUENT, Inc. is the world's largest computational fluid dynamics (CFD) software provider, enabling solutions for a broad array of fluid flow and heat transfer phenomenon. It uses the finite-volume method to solve the governing equations for a fluid. It provides the capability to use different physical models such as incompressible or compressible, in viscid or viscous, laminar or turbulent, etc. Geometry and grid generation is done using GAMBIT which is the pre-processor bundled with FLUENT.

GAMBIT is a software package designed to help analysts and designers build and mesh models for computational fluid dynamics (CFD) and other scientific applications. GAMBIT receives user input by means of its graphical user interface (GUI). The GAMBIT GUI makes the basic steps of building, meshing, and assigning zone types to a model simple and intuitive, yet it is versatile enough to accommodate a wide range of modeling applications. It also provides tools for checking the quality of the mesh.

3.25 MODELING AND MESHING OF SCRAMJET COMBUSTOR

In the present analysis the DLR scramjet combustor with strut injection dimension is selected for simulation. A schematic of the DLR scramjet is presented in Fig 4.1. Preheated air is expanded through a Laval nozzle and enters the combustor section at Ma = 2.0. The combustor has a width of 40 mm and a height of 50 mm at the entrance and a divergence angle of the upper channel wall of three degrees to compensate for the expansion of the boundary layer. A planer wedge shaped strut is placed in the combustion chamber downstream of the nozzle. Just downstream of the nozzle the height of the 32 mm long strut is 0.295 mm. along the first 100 mm downstream of the nozzle, the side walls and the upper wall are made from quartz glass to allow optical access and to minimize the reflection of scattered light on the wall opposite the observation window. Hydrogen (H_2) is injected at Ma =1.0 through a planer strut injector with diameter of 0.295 mm, in the strut base. Typical mass flows in the experiments [33] were varied between 1.0 and 1.5 kg/s for the air and between 1.5 and 4.0 g/s for H_2, which correspond to equivalence ratios between 0.034 and 0.136, respectively. The hydrogen is injected at ambient temperature and pressure, i.e. at T = 250 K and p =105 Pa, whereas the air was injected at T = 340 K and p =105 Pa.

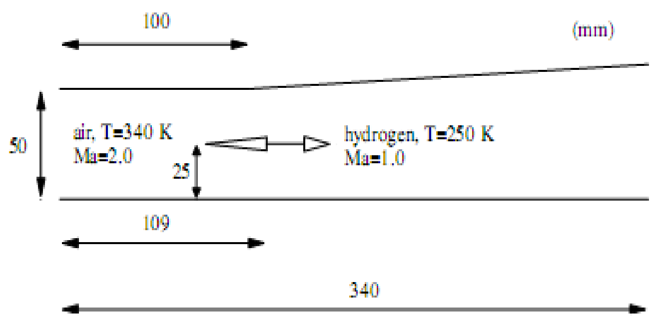


Figure 3.6 Schematic of the supersonic combustion chamber

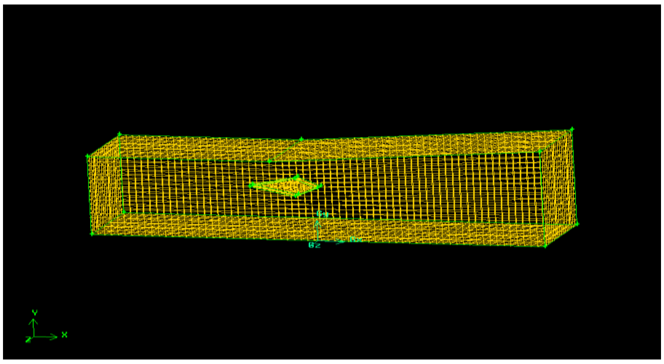
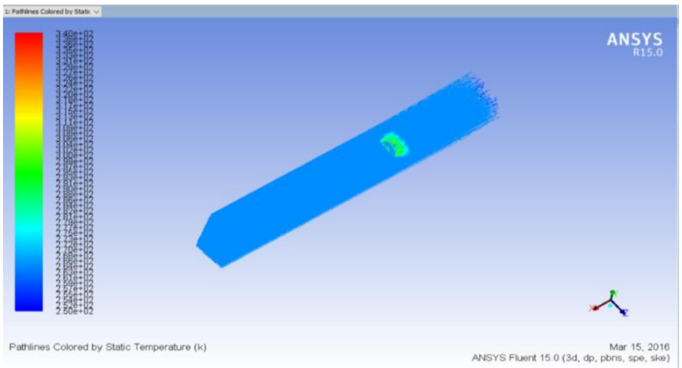


Figure 3.9 Meshing of boundary and scramjet combustor

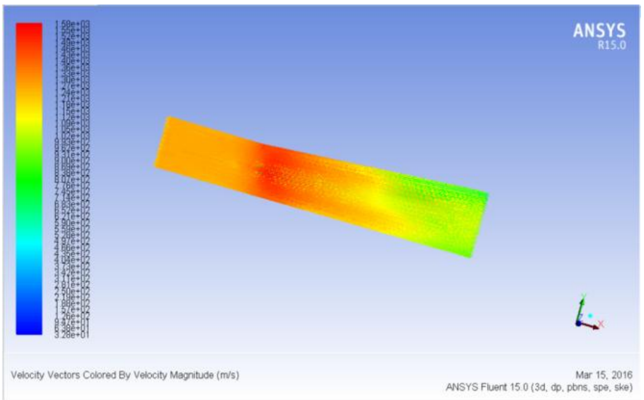
RESULTS AND DISCUSSIONS

Due to combustion the recirculation region behind the wedge becomes larger as compared to mixing case and it acts as a flame holder for the methane (CH_4), hydrogen (H_2) and diesel ($C_{10}H_{22}$) diffusion flame. It is also evident from the Fig 5.2, 5.9 and 5.18; the combustion affects the flow field significantly. The leading edge shock reflected off the upper and lower combustor walls facilitates the on setting of combustion when it hits the wake in a region where large portions of the injected fuel have been mixed up with the air. After its first encounter with the flame the leading edge shock is drastically weakened and the characteristic shock wave pattern of the cold flow cases is almost gone.

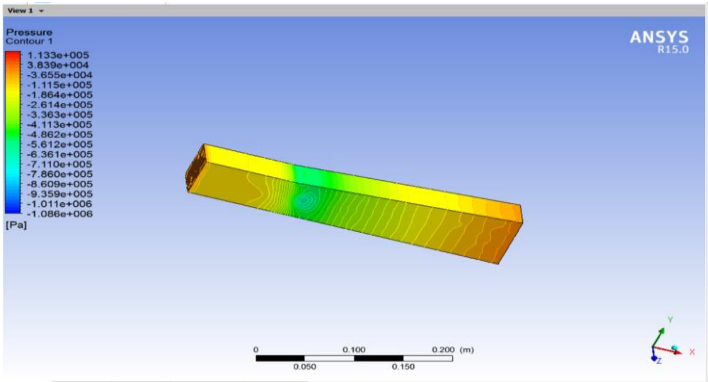
CONTOURS OF METHANE(CH_4)- AIR



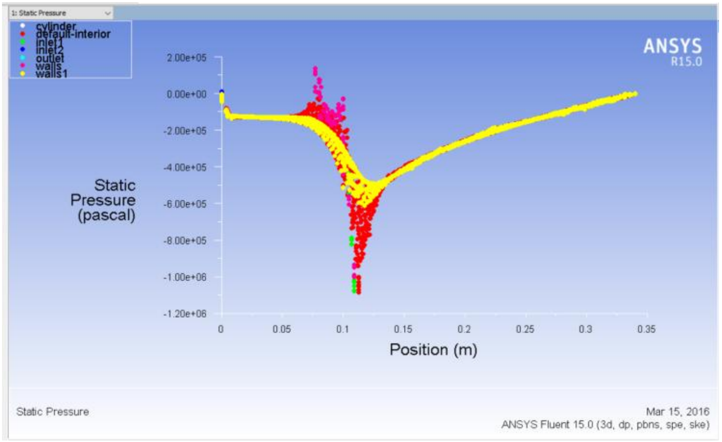
Variation of static temperature of ch_4 in scramjet



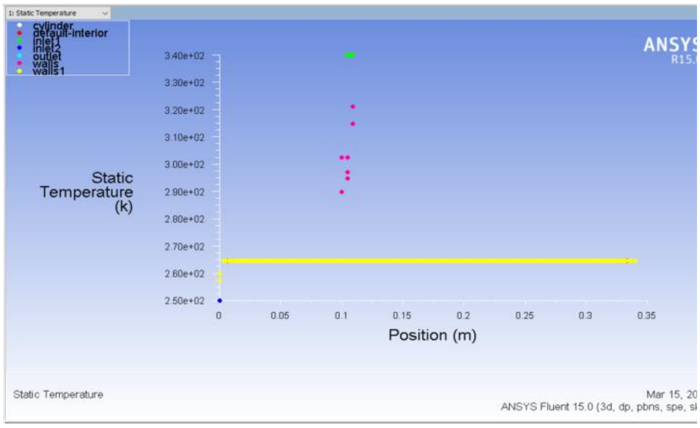
Variation of velocity magnitude of ch_4 in scramjet



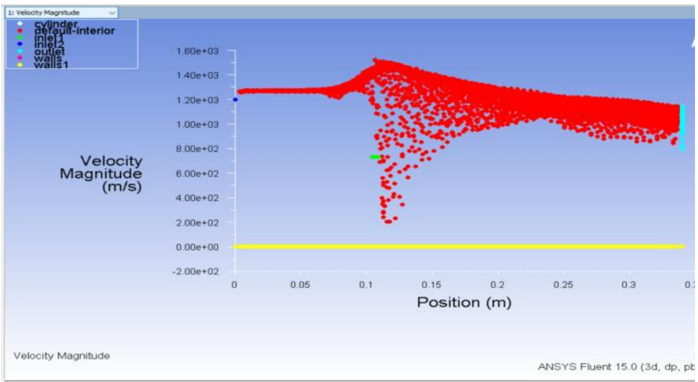
Variation of static pressure of ch_4 in scramjet



Variation of pressure from strut to outlet for inert CH_4 injection



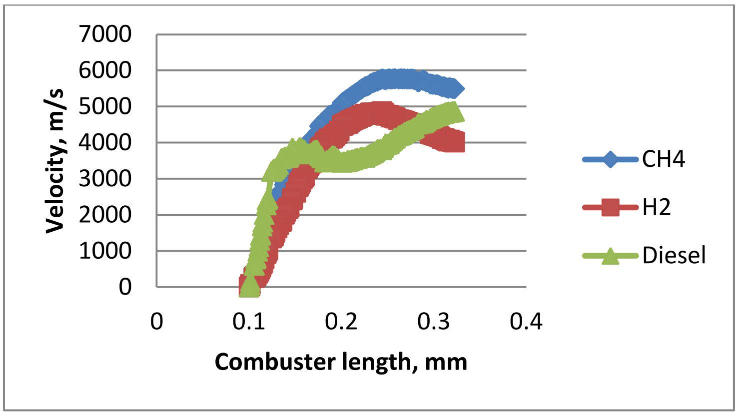
Variation of temperature from strut to outlet for inert CH_4 injection



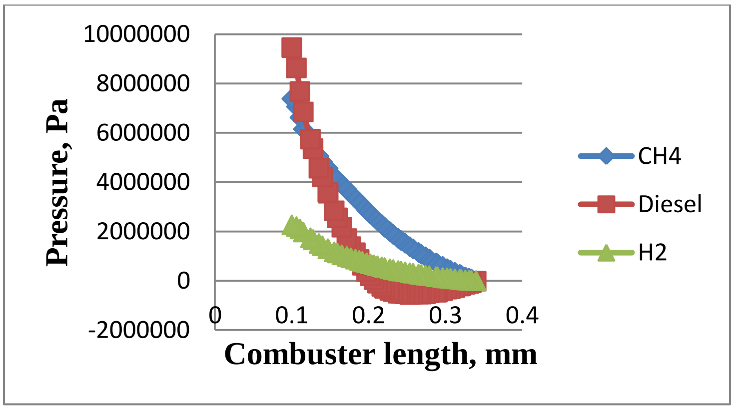
Variation of velocity from strut to outlet for inert CH_4 injection

Table 4.1 Variation of pressure, velocity and temperature

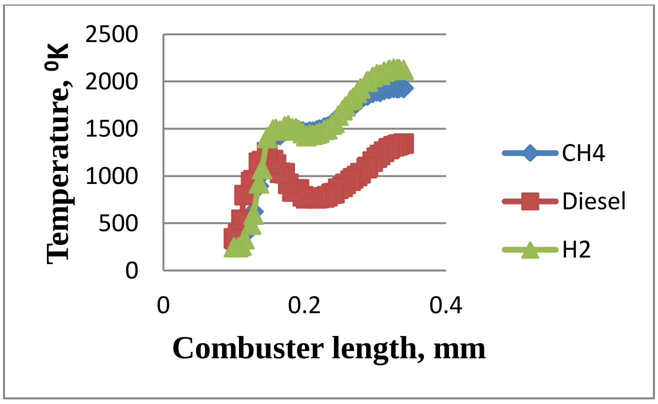
Condition	Velocity, m/s	Static pressure, Pa	Temperature, K
Methane CH_4	1.54e3	1.133e5	3.41e2
Diesel, $C_{10}H_{22}$	1.49e3	1.38e5	3.382e2
Hydrogen, H_2	1.631e6	1.227e5	3.500e2



comparision of velocity with respect to combuster length



Comparision of pressure with respect to combuster length



comparision of temperature with respect to combuster length

CONCLUSIONS

The following conclusions are drawn from the present analysis

- The numerical method employed in this work can be used to accurately investigate the flow field of the scramjet combustor with planer strut flame holder, and capture the shock wave system reasonably

- In order to investigate the flame holding mechanism of the planer strut in supersonic flow, the standard k-ε turbulence model is introduced to simulate the flow field of the hydrogen fueled, CH_4 and Diesel fuel scramjet combustor with a strut flame holder.

- The maximum static pressure, maximum velocity, and maximum temperature in the scramjet combustor with planer strut flame holder for Methane CH_4 is 8.21 e6 Pa, 6.31e3 m/s and 1900 ^{0}K respectively.

- The maximum static pressure, maximum velocity, and maximum temperature in the scramjet combustor with planer strut flame holder for Diesel, $C_{10}H_{22}$ is 1.09 e7 Pa, 5.60e3 m/s and 2070 ^{0}K respectively.

- The maximum static pressure, maximum velocity, and maximum temperature in the scramjet combustor with planer strut flame holder for Hydrogen, H_2 is 2.47 e6 Pa5.06e3 m/s and 2100 ^{0}K respectively.