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Analysis of Step Cut on Cavity Flame Holders for Scramjet Combustors

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Abstract— Step cuts on cavity flame holders for scramjet combustors are used to propel supersonic vehicles and are known for their high-speed performance. The step cuts on cavity flame holders have been shown to improve the combustion efficiency and reduce the flame holding distance in scramjet combustors. This analysis aims to provide a detailed understanding of the effects of step cuts on cavity flame holders for scramjet combustors. The paper then delves into the design of step cuts on cavity flame holders and the different parameters that affect their effectiveness. The analysis focuses on the effects of step cut geometry, cavity depth, and cavity width on the combustion performance of scramjet combustors. The results indicate that step cuts with a sharper angle and smaller cavity width result in better combustion efficiency. Additionally, the cavity depth has a significant impact on the combustion performance, with a deeper cavity resulting in better combustion efficiency. The study also discusses the effects of operating conditions, including inlet Mach number and pressure on the combustion performance of scramjet combustors with step cuts on cavity flameholders. The results show that step cuts can improve the combustion performance over a wide range of operating conditions.

Keywords— Scramjet combustor, Cavity flame holders, Step cut.

I. INTRODUCTION

The SCRAMJET abbreviated from the words Supersonic Combustion Ramjet is a type of jet engine that can fly at hypersonic speed. This scramjet does not have any rotating parts and the main components of the scramjet are inlet, combustor and nozzle. Combustor plays an important role in achieving supersonic combustion. The major difference between the regular turbojet engine and the scramjet engine is a compressor. Scramjet engine does not carry the compressor like turbojet engine. So, work of the compressor will be done by the high-speed air and the converging inlet. This decreases the weight of the engine since it does not have moving parts.

The formed supersonic flow must be sustained so that we can avoid dissociation of combustion products. In order to sustain this supersonic flow injector and flame holder are very important aspect. Flame holder is used to hold the combustion and thus gives continuity in combustion by increasing resident time of fuel. Various configuration of flame holders like can type; gutter type and step type holders are interesting for research. Introducing cavities in these type of step holders can reduce drag and can improve performance of holders because of the formation of eddies which create circulation effect. This circulation zone also has the capability to increase mixing.

The scramjet community has proposed the use of cavity flame holders to stabilize and enhance supersonic combustion. The main purpose is to create a subsonic recirculation region inside the cavity with a hot pool of radicals, which will reduce the induction time. This will allow auto ignition of the fuel/air mixture to take place. Over recent years, the design of cavity flame holders has been extensively studied. Proper dimensions are critical to cavity performance. If deep enough, the cavity will offer a relatively long residence time for mixing and chemical reactions to take place. Cavity geometries are typically defined by their length to depth ratio (L/D).

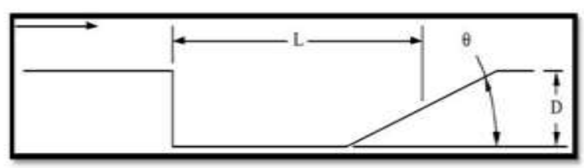

Figure 1.1: General Cavity

Types of flame holders

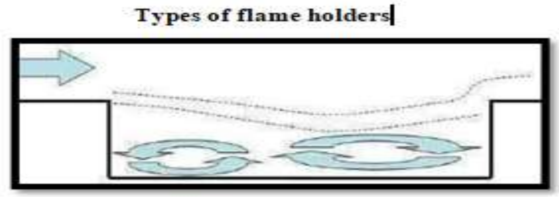

Figure 1.2: Rectangular cavity flame holder

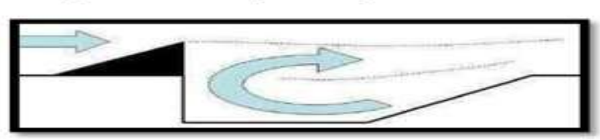

Figure 1.3: Cavity leading-edge pylon

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II. LITERRATURE SURVEY

1. "Combustion in a RAMJET Combustor with cavity flame holder" Authors: Isi Bilimi ve Teknigi DerJ. DOI: 30,2,57-68, 2010 In supersonic scramjet combustors recirculation zone plays an important role to stabilize the flame and enhances the mixing and combustion of air-fuel The transition mechanisms of combustion from ramjet to scramjet were explored numerically by Wei Huang and Li Yan [28].

2. "Combustion characteristics of a dual-mode scramjet combustor with cavity flame holder" Authors: Daniel J Micka, James F.Driscoll DOI : 10.1016/j.proci.2008.06.192 The current study focuses on combustion stabilization for conditions where auto-ignition is not expected to be dominant. The laboratory combustor studied employs basic flow elements that have been proposed for practical dual-mode combustors such as sonic wall fuel injection and a wall cavity flame holder.

3. "Effect of cavity geometry on fuel transport and the mixing in a process's scramjet combustor" Authors: Zun Cai, Mingbo Sun DOI: 10.1016/j.ast.2018.07.028 Effect of the cavity rear wall height on the non-reacting flow fields was then investigated. It was found that the vertical flow velocity of the region located right after the expansion wave starting from the cavity leading edge was increased significantly towards the cavity.

III. METHODOLOGY

Step cut cavity-based combustion chambers increases in residence time and mixing capability of the combustion process. Determining the location decide on the optimal location for the step cavity within the combustion chamber. This is typically based on factors such as the desired mixing efficiency, flame stabilization, and compatibility with other components.

IV. MODELLING OF STEP CUT CAVITY

Creating the step cut geometry in design modeler of Ansys fluent workbench, a step cut cavity geometry with appropriate dimensions and features that represent our specific step cut design. Also, we have changed the location of step cut cavity.

Defining the geometric parameters: The first step is to determine the dimensions and shape of the step cavity. This includes specifying the width, height, and length of the cavity, as well as the angles.

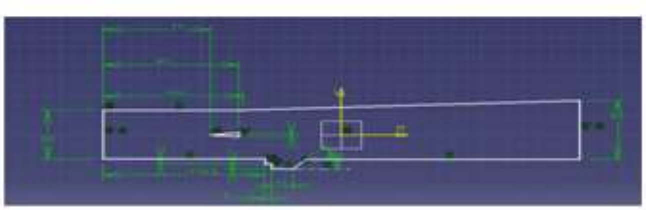
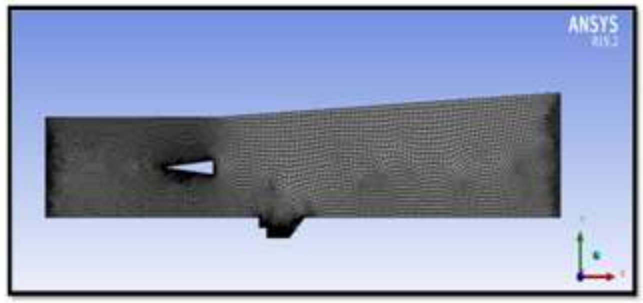


Figure 2.1: Design of step cut cavity

V. MESHING OF STEP CUT CAVITY



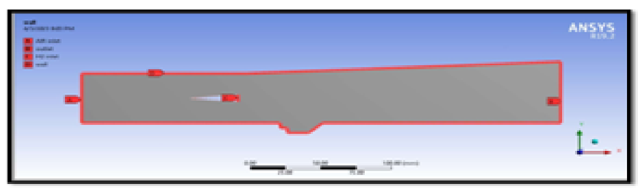
Number of Nodes	16542
Number of Elements	15873

Table 5.1: Number of nodes and elements

VI. BOUNDARY CONDITIONS

In analysis Mach number, pressure and temperature for both fuel and air for the model, Pressure far field and pressure outlet conditions were taken on the boundaries.

Boundary conditions for a step cut cavity in a combustor in ANSYS refer to the constraints or settings applied at the boundaries of the computational domain to simulate the behavior of the cavity during combustion simulations These boundary conditions typically include setting the inflow velocity, temperature, and species concentrations at the inlet of the cavity, as well as specifying the type of wall boundary condition and temperature at the walls of the cavity. Additionally, the outlet boundary conditions.



Cells	20698
Partition	1
Cell zones	1
Face zones	6

Table 6.1: Number of cells, Partition, cell zone and faces

Parameters	Air	Hydrogen
Mach	2	1
T(k)	340	250
P(Pascal)	100000	100000
$\rho(kg/m^3)$	1.002	0.097

Table 6.2: Input values of various parameters

From the researches, it was found that the residence time of compressed air in the combustion chamber plays a crucial role in combustion efficiency. From Part A, it was found that cavity-based combustion models generate a good number of shock waves, recirculation zones and vortices which can hold the air for some extra time in the combustion chamber. As a result of that, there will be enough time to mix the fuel with the supersonic air. This increases combustion efficiency. The Contours such as pressure, temperature, velocity and density also have been presented. For the present project, the mesh is going to be refined with a good number of node points than the previous mesh to get the accurate result and these results are going to compare with the previous results.

VII. RESULTS AND DISCUSSION

Counters for shock interaction over the flow (The interaction phenomenon depends on the nature, strength and orientation of shock waves, and can result in a complex flow field with mixed regions of subsonic and supersonic flows).

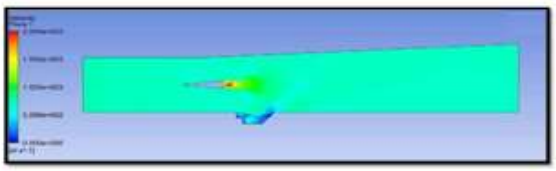


Figure 7.1: Velocity contour for representing the oblique shock

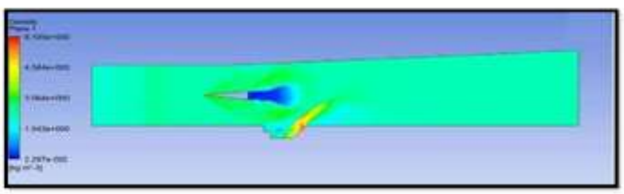


Figure 7.2: Density contour for representing the oblique shock

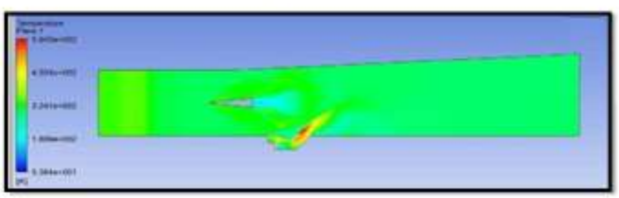


Figure 7.3: Temperature contour for representing the oblique shock

Oblique shock waves are generated from the leading edge and form a shockwave train. From above figure, the step cavity-based model combustion chambers have more recirculation zones and shock waves. These results in increasing the residence time of air in the combustion chamber which is a major parameter in mixing efficiency. These counters will justify the combustion or mixing of fuel now the maximum temperature, pressure, velocity, intensity of turbulence due to high oblique shock will give below.

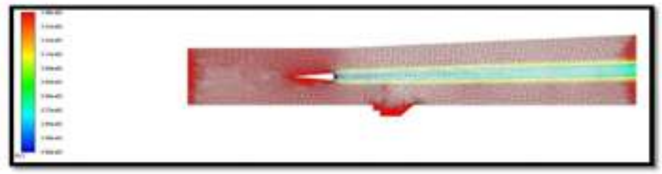


Figure 7.4: Velocity Contour

As the temperature counter shows that maximum temperature is at near the step cut cavity due the cavity section over there the fuel and air mixture will be getting the maximum time for mixing in the combustion.

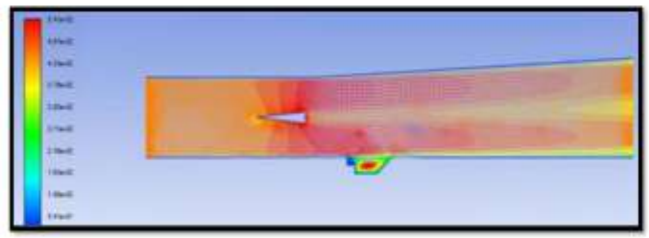


Figure 7.5: Temperature Contour

As the velocity of the airflow increases, the residence time of the air within the combustor decreases. This means that the air spends less time in the combustor, which can lead to a reduction in the efficiency of the combustion process. However, the increase in velocity also leads to an increase in the mixing of the fuel and the air. This improved mixing allows for a more complete combustion of the fuel, which can increase the overall efficiency of the engine.

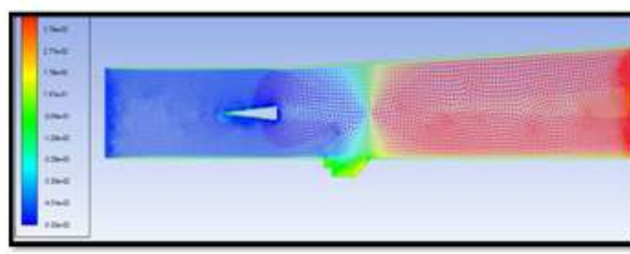


Figure 7.6: Pressure contour

The pressure is low before the step cut cavity, as the cavity creates the turbulence it increases the pressure gradually and it will increase till outlet section of the combustor the maximum pressure is shown in the counter.

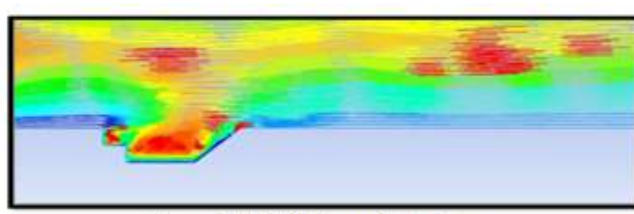
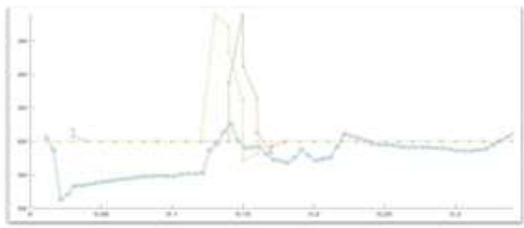


Figure 7.7: Turbulence Intensity

Turbulence creates small-scale eddies in the flow of air and fuel, which helps to break up larger pockets of fuel and air and mix them together more thoroughly. This mixing increases the contact area between the fuel and air, allowing them to react more quickly and completely.

In addition, turbulence helps to maintain a stable flame by ensuring that the fuel and air are mixed evenly and that the flame is not extinguished due to uneven mixing or separation of fuel.



Plot 7.8: Temperature vs Positions in mm

Plot 7.9: Pressure vs Positions in mm

VIII. CONCLUSION

The critical parameters which give a clear picture of the flow are pressure, density, velocity and temperature. The observation made from the part of the project is, the oblique shock waves are generated from the leading edge of the fuel struts at the walls of the combustion chamber and they were experiencing multiple reflections. By these reflections, the shockwaves form a multiple numbers of shockwave trains at the end of the strut. These trains are helpful for efficient of mixing of fuel and air.

It was clear that by using STEP CUT CAVITY-based combustion chambers there was an increase in residence time and mixing capability of the combustion process. good number of shock waves which results in getting good mixing rate.

IX. REFERENCES

1. Wu, K.; Zhang, P.; Yao, W.; Fan, X. "Computational realization of multiple flame stabilization modes in DLR strut-injection hydrogen supersonic combustor". 2019

2. Jeyakumar, S.; Assis, S.M.; Jayaraman, K. "Experimental study on the characteristics of axisymmetric cavity actuated supersonic flow". 2017.

3. Xue, C., He, X., Jiang, Z., & Ma, F. (2017). "Numerical investigation on the flow and combustion characteristics of a dual-mode scramjet combustor with a step-cavity flameholder". 2017

4. Navin Kumar Mahto and Gautam Choubey and Lakka Suneetha and K.M.Pandey, "Effect of variation of length-to-depth ratio and Mach number on the performance of a typical double cavity scramjet combustor" (2016)

5. Gautam Choubey and K.M. Pandey, "Investigation on the effects of operating variables on the performance of two-strut scramjet combustor" (2016)

6. Wei HUANG, Ming-hui LI, Feng DING, Jun LIU "Supersonic mixing aug-590 mentation mechanism induced by a wall-mounted cavity configuration" (2016)

7. Rabadan, E.; Weigand, B. "Numerical investigation of a hydrogen-fueled scramjet combustor at flight conditions". 2013

8. Wei Huang and Zhen-guo Wang and Li Yan and Wei-dong Liu "Numerical validation and parametric investigation on the cold flow field of a typical 490 cavity-based scramjet combustor" (2012)

9. Luo, S.B.; Huang, W.; Qin, H.; Wang, Z.G.; Liu, J.; Xia, Z.X.; Lei, J.; Pourkashanian, M.; Ma, L.; Ingham, D.B.; et al. "Investigation of Turbulent Models for the Flow Field from a Typical Strut Based Scramjet Combustor". June 2011.

10.Huang, W.; Wang, Z.G.; Luo, S.B.; Liu, J. "Parametric effects on the combustion flow field of a typical strut-based scramjet combustor". 2011.

11.Yuan, M., Yan, C., & He, G. (2019). "Effects of step-cavity flame holders on combustion characteristics in scramjet engines".

12.Ben-Yakar, A.; Hanson, R.K. "Cavity Flame-Holders for Ignition and Flame Stabilization in Scramjets" 2001.