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# Design and Analysis of Single and Dual Cavity Step Type Flame Holder in SCRAMJET Engine

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**ABSTRACT:** Scramjet engine is the supersonic combustion ramjet engine that can operate even at hypersonic flow. Flameholder is the important component located in the combustion chamber which is used to achieve complete penetration of fuel into the flow results in attaining continuity of combustion. The various researchers reported that the step type flame holder is most efficient in reducing the time of combustion. The single and dual cavity step type flame holders are designed and analyzed using AUTOCAD and ANSYS-FLUENT software respectively. The comparison of both single and dual cavity step type holders for its Mach number variation and temperature has been made for better results.

**KEYWORDS:** Scramjet, Single, dual cavity, step type flame holder and analysis

## 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 formed supersonic flow must be sustained so that we can avoid dissociation of combustion products. In order to sustain this supersonic flow injectors and flame holder are very important aspects. Also to improve the performance of combustion various injectors and flame holding devices are developed and some are under research. 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.

Flame holders in combustors are mainly used for achieving continuous combustion by providing continuous free radicals and reduce ignition delay. This increases the time rate of reaction and reduces the reaction distance. Flame holding can only be possible when the resident time is more than the reaction time. Flame holding can be done by three methods namely creating recirculation area where the fuel and air can be mixed, interaction of shock waves and formation of coherent structures where the diffusion can be increased. These methods can be implemented in following ways-transverse, step followed by transverse injection and rearward step injection. The transverse injection cause high pressure loss and step with transverse increases both pressure loss and drag (1). On the other hand the rearward step injection increases plume spreading with respect to its orifice diameter(2) and this can reduce pressure loss(3).

Cavities in flame holders are found successful in recent years. These cavities create recirculation zone which enhances mixing and can keep the flow stable. As the dimensions of cavities are much smaller when comparing with the dimensions of propulsive devices, the dimensional effects of cavities can be ignored in integrated hypersonic

vehicles like scramjet(4). Dual mode cavity flame holders can reduce pressure loss and cooling requirements (5). Dual cavities can also improve combustion and give better performance than single cavity. These cavities also increase thrust. The level of fuel for obtaining same thrust as in single cavity reduces for dual cavity (6).

Cavities with short aspect ratio provides good flame holding and this short aspect ratio was present in tandem arrangement. This step arrangement gives better performance than other cavity types (7). The interaction of shock waves occurs in this rearward step type flame holders which increases the static pressure. The recirculation zones created in this type of steps improves the mixing of fuel and air and can increase combustion efficiency. Installing a rearward step type cavity improves the mixing of fuel and air and can improve the performance of combustion in scramjet (8). In this work the selected step type cavity has been placed in dual mode of flame holder and further it was analysed for its better performance.

## II. MODELING AND ANALYSIS

The Single and Dual cavity step type flame holders were drawn using AUTOCAD software. The 2D and 3D design was done using several commands like line, extrude and press pull etc. The schematic diagram of the Single and Dual cavity step type flame holders has been presented in the Figure-1.

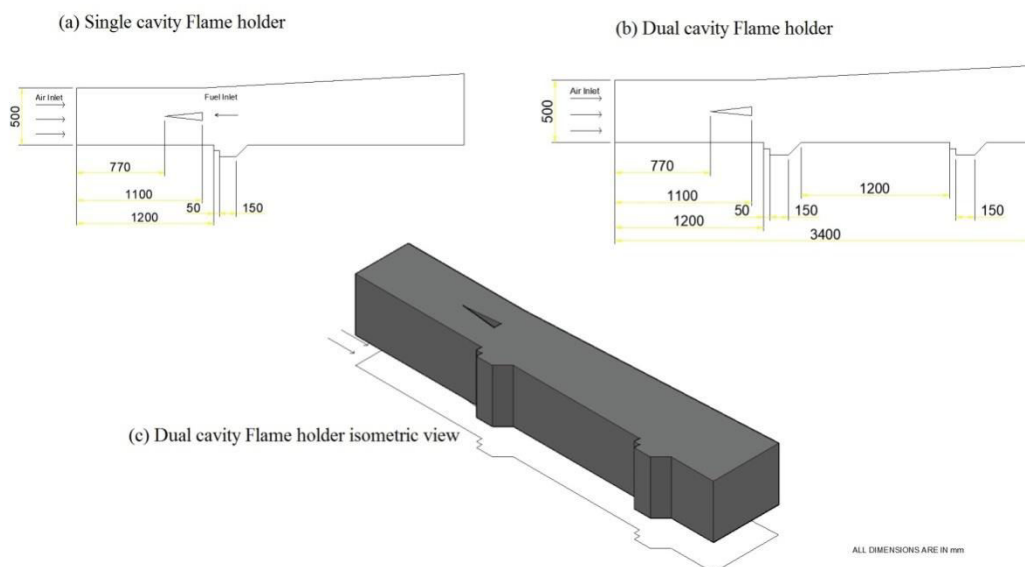


Figure-1 Schematic Diagram of step type flame holders

The AutoCAD software has the option of exporting the diagrams of step type Flame holders to ANSYS-Fluent software for flow analysis. The Computational Fluid Dynamics (CFD) analyses were carried out on 2D step type single and Dual cavity based fuel injection at Supersonic flow with the Mach number variation of 2, 3, 4 and 5. The pressure, temperature and velocity contour has been determined for Mach number 2, 3, 4 and 5 separately for identifying the better performance. In general, the quality of the mesh was checked for better optimized collection of nodes and meshing elements and so that the solution had been solved successfully. After that the simulation Grid independence test was done perfectly. Hence the computational simulations were carried out by considering the pressure inlet as the combination of air and fuel inlet and slip conditions had not applied in walls. The computational result analysis images of Single and Dual cavity flame holders at Mach No-2 and Mach no-5 has been presented in the Figure 2 & 3 respectively.

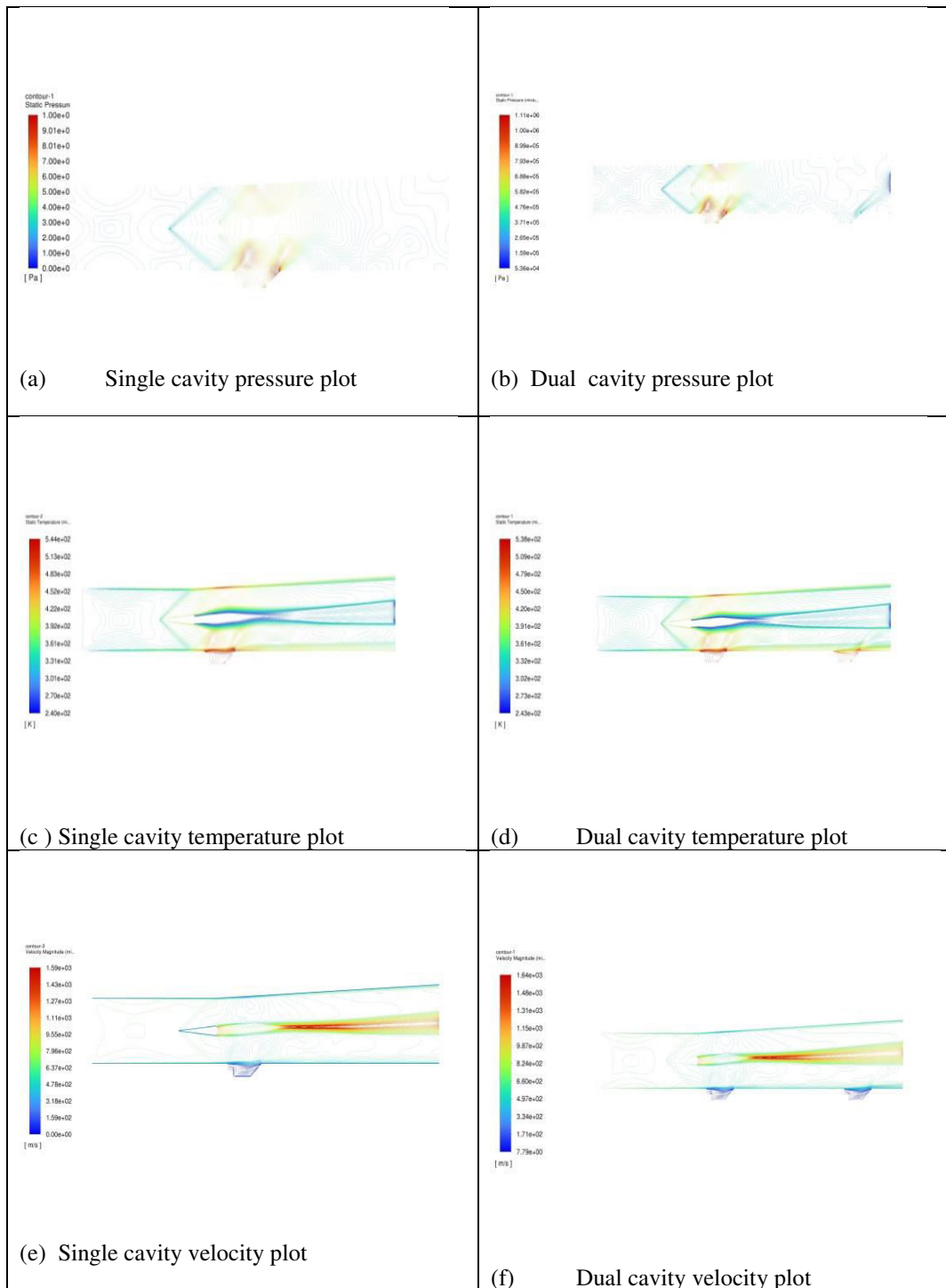


Figure-2 Analysis images of Single and Dual cavity flame holders at Mach.No-2

The input parameters like temperature and pressure were given as 1000K and 1 standard atmosphere for air, similarly the same parameters for fuel were considered as 600K and 7.57 standard atmospheres. The diameter size of the injector exit was taken as 1mm. The finite rate of eddy dissipation model was implemented to get the higher turbulence during combustion operation. The turbulent mixing process has been controlled by the reaction rate because this eddy dissipation model was set programmed depends on the hypothesis of highly infinite fast reactions.

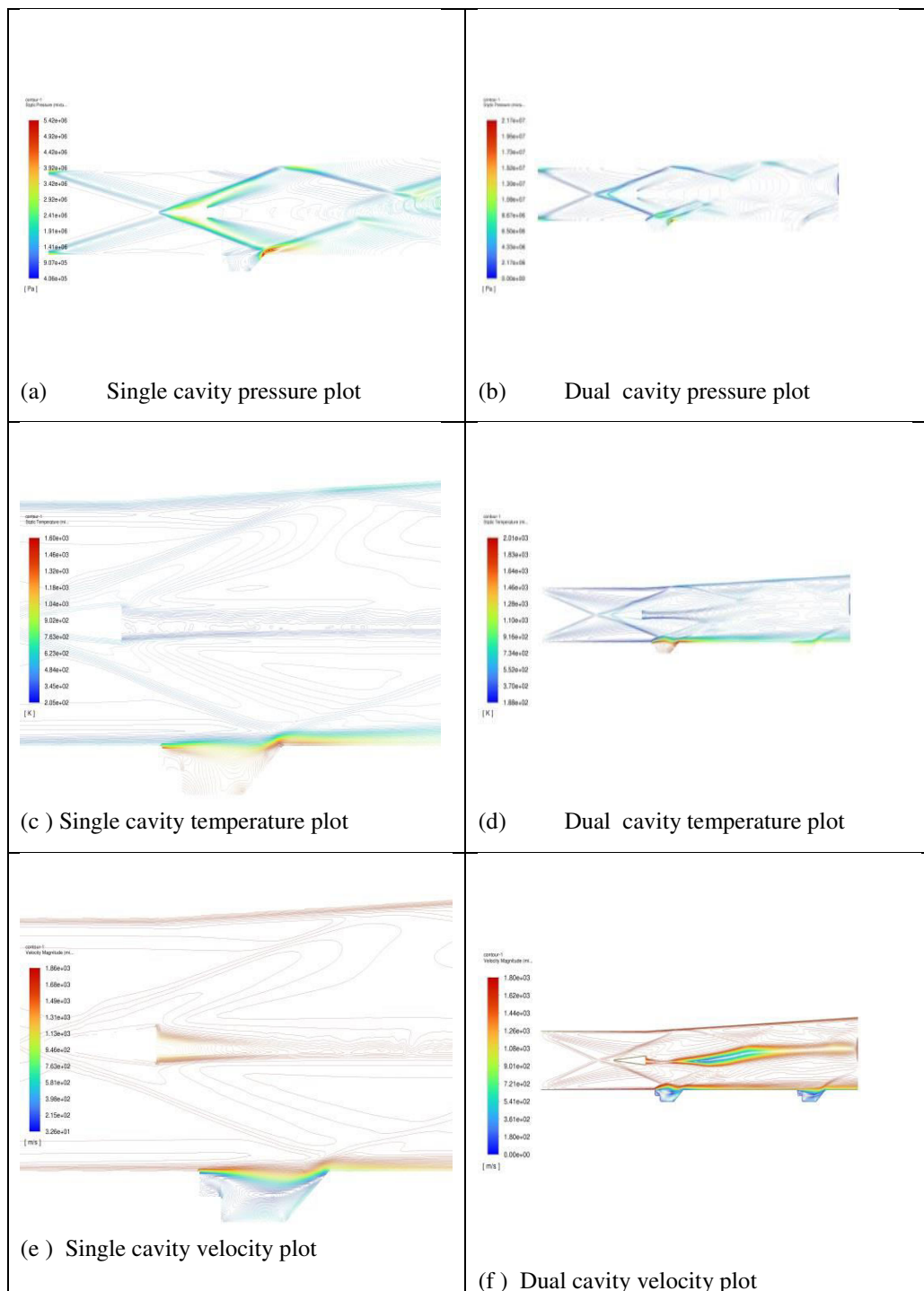


Figure-3 Analysis images of Single and Dual cavity flame holders at Mach.No-5

In order to get the continuous and steady combustion especially for supersonic flow in chamber, time consumption holds the major factor. In general, the time available for combustion was less than milliseconds. The better atomization with uniform mixture of air and fuel in the single and dual step type cavity based fuel injection was provided in the combustion chamber. The various plots with results such as Mach number, Static Temperature, velocity and Static pressure were determined.



III. RESULTS AND DISCUSSION

The pressure, temperature and velocity contours were determined from the computational results. For better comparison of results, the graphs between Mach number and pressure, temperature, velocity plotted for both single and dual cavity flame holders were discussed in the following sections.

PRESSURE PLOT

From the graph, it is clearly seen that pressure increases with Mach number. The increase of pressure is very high for dual cavity than in single cavity. The increase of pressure shows the acceleration of combustion. The pressure ranges from 3000 PA in Mach number 2 to 1910000 PA in Mach number 5 for single cavity. For dual cavity, it ranges from 53600PA to 6500000PA. Also it was observed that pressure loss is reduced in dual cavity than in single cavity.

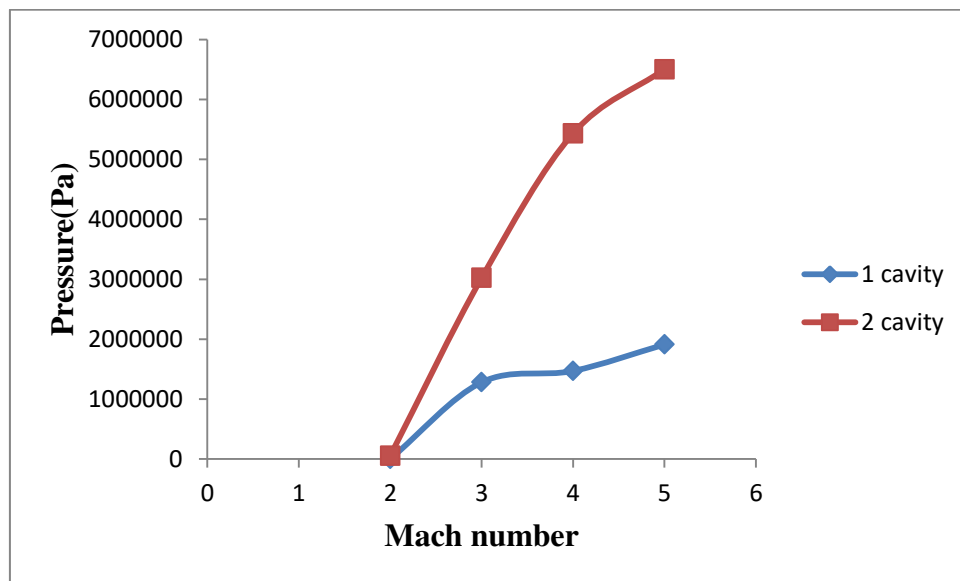


Figure-5 Mach number versus Pressure for both cavities flame holders

Hence the combustion got accelerated in dual cavity than in single cavity. The drawback noticed here is there is pressure difference found at specific areas inside chamber at some Mach number. This can be reduced by placing injectors and holders at certain angles and this needs further study.

TEMPERATURE PLOT

The temperature increases with Mach number. Also temperature increase of dual cavity is more than in single cavity. The temperature ranges from 250K to 623K in single cavity and from 391K to 734K in double cavity. But there is only slight difference of temperature increase in single and dual cavity. The increase of temperature shows the formation of shock waves. The shock waves can interact with partially mixed fuel and can improve combustion.

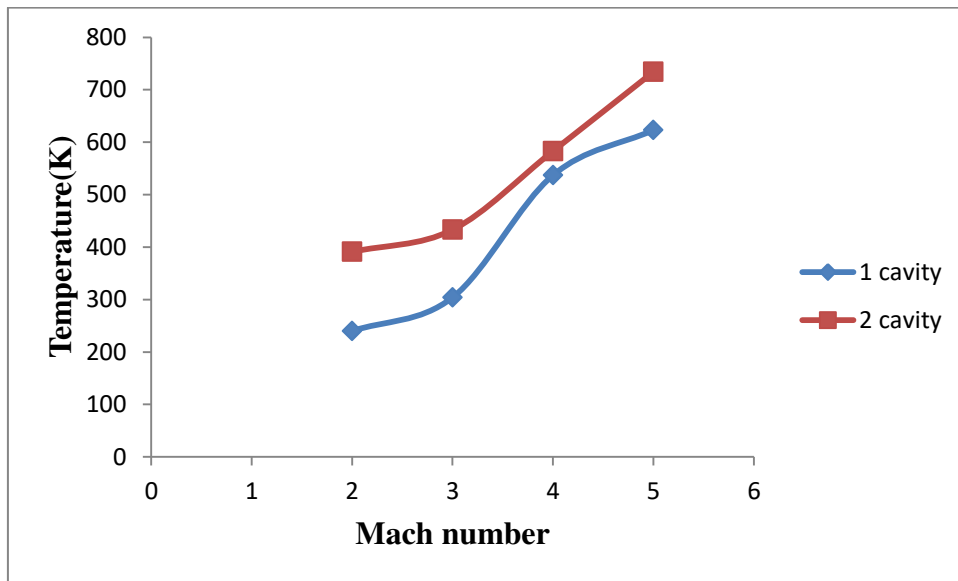


Figure-6 Mach number versus Temperature for both cavities flame holders

This interaction of fuel occurs due to the formation of free radicals and this can give continuity in combustion and increases the resident time of fuel. Thus the fuel can be ignited more and resident time of fuel can be increased in dual cavity than in single cavity. Even though the difference is small, the dual cavity can give better performance in combustion than in single cavity.

**VELOCITY PLOT**

The velocity increases with increasing Mach number. The velocity increase is more for dual cavity than in single cavity. The velocity ranges from 1110m/s to 1490m/s in single cavity and 1150 to 1800m/s in dual cavity. The increase of velocity shows the increase of thrust.

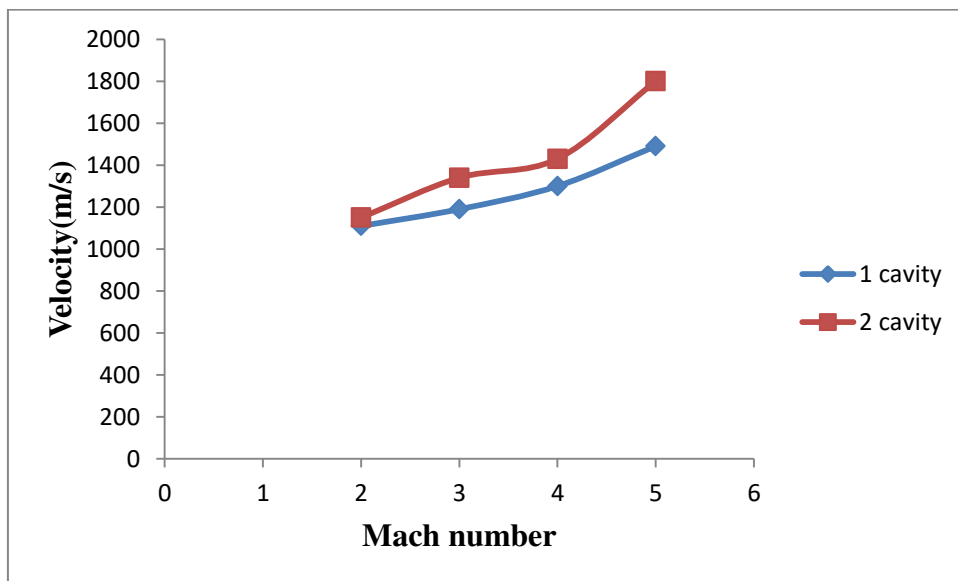


Figure-7 Mach number versus velocity for both cavities flame holders

Hence the dual cavity can give more thrust than single cavity. Even though it increases in small amount, the higher thrust was obtained in dual cavity.



For all the boundary points it defined patch and find the priority of these patches. It starts filling the target region from the highest priority patch by finding the best match patch. This procedure is repeated until entire target region is in painted.

#### IV. CONCLUSION

The CFD analysis of step type single and dual cavity flame holders were done at scramjet with variation in Mach no of 2, 3, 4 and 5. The higher pressure and temperature and notable velocities were achieved in the combustion chamber by implementing cavity based fuel injection. The analysis results proved that the pressure and temperature were highly increased in dual cavity flame holders compared to single cavity flame holders. Similarly the velocity contours for dual cavity values were higher compared to single cavity holders. The analysis results showed that there was a continuous increase of pressure, temperature and velocity with the variation of Mach no. 2, 3, 4 and 5. The Dual cavity holder's inlet pressure, temperature and velocity for Mach no. 2 to 5 were highly increased from 53600- 6500000 Pascal, 391-734K and 1150-1800 m/s respectively. This proves that the combustion chamber attains very high pressure and temperature at outlet compared to inlet. Finally as a result, we can conclude that from temperature and pressure contours, it is found that recirculation zone is created in both cavities which can increase temperature as well as pressure and can serve as ignition source. The points to be noted here are

1. Increase of Mach number, increases temperature, pressure and velocity inside scramjet.
2. Comparing 1 cavity and 2 cavity holders, 2 cavity holders recirculate more eddies and gives higher temperature, pressure and velocity.
3. Liberation of high temperature due to eddies effect forms shock waves and this increased temperatures can be helpful in increasing mixing rate and so that we can achieve continuous combustion.
4. Pressure loss was reduced in 2 cavity holders due to 2 recirculation zones.
5. Pressure variation was found in 2 cavities holder at some Mach number.

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