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# Analysis of Scramjet Engine Flow Phenomenon with Model Configurations of Cavity Injector - A Review

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***Abstract*: Human desire for faster response and cheap access to space continues to push the envelope in terms of altitude and airspeed. The advancement in space vehicles and high speed flights critically depends on the development of engines capable of delivering thrust to attain wide range of Mach numbers. As Turbofan and Ramjet engines are unsuitable for high supersonic and hypersonic Mach numbers, the only alternative is the Scramjet in which the flow through the combustor remains supersonic. Due to the very short residence time, an efficient and rapid mixing of fuel/air is hard to achieve. In supersonic flows a rapid fuel/air mixing, additionally suffers from inherently low mixing rates due to compressibility effects at high convective Mach numbers. Cavity injectors are used in Scramjet combustor for fuel injection, fuel air mixing, flame holding and ignition. Vorticity is the main driving mechanism for rapid near-field mixing. Strength and size of the vortices depends on the cavity geometry. The increase in height/width of the cavity from the baseline value exhibits an increase in the total pressure loss across the combustion section. This total pressure loss is correlated with the low pressure region created by the flow displacement caused by the cavity geometry. This paper presents a review on the effect of cavity geometries in scramjet using is available data's.**

**Key Words: cavity injector, scramjet**

## 1. Introduction

Scramjet engines are used to power hypersonic flights which are an active area of research and development today. A scramjet combustor should be capable for a good flame holding and fuel distribution. Combustion must occur within a very short time. Wall-based flame holders such as cavities, enable the engine to sustain combustion with less drag than in-stream devices, [1] resulting in a shorter and lighter engine. Normally the cavities are placed near to combustor walls. [2] Intrusive geometry modification schemes near the cavity can produce shear layer instabilities and it's improving the turbulence, but less is known about optimizing this combination. Motivated by previous studies at the Air Force Institute of Technology (AFIT) and Air Force Research Laboratory (AFRL), this paper discusses a review study of a cavity with different geometry configurations. Non-reacting or reacting supersonic flow analysed on Cavity flame holders.

## 2. Review based on Available Data and Information

Fuel injection techniques into scramjet engines are a field that is still developing today. The fuel that is used by scramjet is usually either a liquid or a gas. The fuel and air need to be mixed to approximately stoichiometric.3 proportions for efficient combustion to take place. The main problem of scramjet fuel injection is that the air flow is quite fast, meaning that there is minimal time for the fuel to mix with the air and ignite to produce thrust (essentially milliseconds). Hydrogen is the main fuel used for combustion. Hydrocarbons present more of a challenge compared to hydrogen due to the longer ignition delay and the requirement for more advanced mixing techniques. Enhancing the mixing, and thus reducing the combustor length, is an important aspect in designing scramjet engines. There are number of techniques used today for fuel injection into scramjet engines.

### A. Experimental Analysis

Eunju Jeong et al. [11] conducted an experiment In Seoul National University, Seoul, Korea. The supersonic combustion experiments are carried out using the T3 free-piston shock tunnel. Different shock tube fill pressures have various inflow conditions. Hydrogen fuel injection is located with a 15° slope before the cavity. Oblique shock is generated at the trailing edge of the cavity and reflects off the top and bottom wall. For non-reacting flow, floor static pressures for low equivalence ratio are similar to those for no fuel injection. As equivalence ratio is increased, static pressures are increased in the duct. For similar equivalence ratio, static pressures increase when total enthalpy is decreased. For reacting flow, the flame occurs near the cavity and the cavity acts as a flame-holder. The combustion is weak locally in the middle of the duct. The up-and-down pressure distribution in the duct means that the supersonic combustion is generated [3].

### B. Numerical Analysis

In this case SST is used as the turbulence model. SST model was the need for the accurate prediction of aeronautics flows with strong adverse pressure gradients and separation [4, 5]. Over decades, the available turbulence models had consistently failed to compute these flows. In particular, the otherwise popular k-ε [6] model was not able to capture the proper behavior of turbulent boundary layers up to separation [7]. The Johnson-King model [8] was the first formulation, which allowed the accurate prediction of separated airfoil flows. Unfortunately, the model was not easily extensible to modern three-dimensional Navier-Stokes codes due to its algebraic formulation. The k-ω model is substantially more accurate than k-ε in the near wall layers, and has therefore been successful for flows with moderate adverse pressure gradients, but fails for flows with pressure induced separation [4]. In addition the ω-equation shows a strong sensitivity to the values of ω in the free stream outside the boundary layer [9]. The free stream sensitivity has largely prevented the ω-equation from replacing the ε-equation as the standard scale-equation in turbulence modelling, despite its superior performance in the near wall region. This was one of the main motivations for the development of the zonal BSL and SST models. The zonal formulation is based on blending functions, which ensure a proper selection of the k-ω and k-ε zones without user interaction. The main additional complexity in the model formulation compared to standard models lies in the necessity to compute the distance from the wall, which is required in the blending functions. This is achieved by the solution of a Poisson equation and is therefore compatible with modern CFD codes. The SST model was originally used for aeronautics applications, but has since made its way into most industrial, commercial and many research codes. This is in agreement with the present authors experience that the need for accurate computations of flows with pressure induced separation goes far beyond aerodynamics. The SST model has greatly benefited from the strength of the underlying turbulence models. In particular, the accurate and robust near wall formulation of the Wilcox model has substantially contributed to its industrial Turbulence, Heat and Mass Transfer 4 usefulness. As well, all the model additions developed by Wilcox for rough walls and surface mass injection etc. can be used with minor modifications [10]. Robustness optimization has brought the model to the same level of convergence as the standard k-ε model with wall functions. An improved near wall formulation has reduced the near wall grid resolution requirements, which has resulted in a substantial improvement for industrial heat transfer predictions. Finally, the zonal formulation of the model has been beneficial in the formulation of an industrial Detached Eddy Simulation (DES) model. A large number of model validation studies and applications can be found on the internet.

### *C. Experimental and Numerical Analysis*

M. R. Gruber, *et al.* [23] discussed about the Fundamental Studies of Cavity-Based Flameholder Concepts for Supersonic Combustors. Experimental and computational investigations of the flow. Field associated with several cavity-based • flameholders in a no reacting supersonic flow is described. All cavity flows were of the open type, that is, length-to-depth ratio L/D<10. Two values of L/D were studied with several offset ratios (OR) and aft ramp angles μ. Results indicate that the aft ramp angle plays an important role in determining the character of the shear layer that spans the cavity. For a rectangular cavity with OR= 1 and μ = 90 deg, a compression wave forms as the flow separates from the cavity's upstream corner. A strong recompression occurs at the aft wall, and the flow is visibly unsteady. The pressure on the cavity before wall decreases steadily and the recompression process occurs more gradually with decreasing aft ramp angle. Higher drag coefficients and shorter residence times are found in cavities with shallower ramp angles.

Adela Ben-Yakar and Ronald K. Hanson [24] had done an overview Cavity Flame-Holders for Ignition and Flame Stabilization in Scramjets. Here describes ongoing research efforts in the scramjet community on cavity flame holders, a concept for flame holding and stabilization in supersonic combustors. During the last few years, cavities have gained the attention of the scramjet community as a promising flame holding device, owing to results obtained in • flight tests and to feasibility demonstrations in laboratory-scale supersonic combustors. However, comprehensive studies are needed to determine the optimal configuration that will yield the most effective flame holding capability with minimum losses. The flow field characteristics of cavities and research efforts related to cavities employed in low and high-speed flows are summarized. Open questions impacting the effectiveness of the cavities as flame holders in supersonic combustors are discussed.

Eunju Jeong, *et al.* [11] conducted and experimental analysis on cavity flame holder with different fuel condition. Here the important of the stagnation enthalpy is explained. Supersonic combustion experiments are carried out using the T3 free-piston shock tunnel. Different shock tube fill pressures have various inflow conditions. Hydrogen fuel injection is located with a 15° slope before the cavity. Oblique shock is generated at the trailing edge of the cavity and reflects off the top and bottom wall. For non-reacting flow, floor static pressures for low equivalence ratio are similar to those for no fuel injection. As equivalence ratio is increased, static pressures are increased in the duct. For similar equivalence ratio, static pressures increase when total enthalpy is decreased. For reacting flow, the flame occurs near the cavity and the cavity acts as a flame-holder. The combustion is weak locally in the middle of the duct. The up-and-down pressure distribution in the duct means that the supersonic combustion is generated. This study describes experiments formed on the static pressure and OH-PLIF measurements in a scramjet combustor using cavity injection. The main flow generates the oblique shock wave at the trailing edge of the cavity and this shock reflects off the up and down wall. Even if the total enthalpy of the main flow is different, the shock structure in the duct is generated similarly. For non-reacting flow, the static pressure in low equivalence ratio is close to that in no fuel injection. As the equivalence ratio is increased, the static pressures rise. For similar equivalence ratio, the static pressure is increased when the total enthalpy of nitrogen flow goes down. This is most likely due to the increase in Mach number in the flow at the lower enthalpy conditions. For reacting flow, the static pressure in the cavity rises up due to the combustion near the cavity. This, along with the fact that OH is apparent within the cavity itself, indicates that the cavity can act as a flame-holder. But in the total enthalpy, the static pressure in the cavity is similar to that of non-reacting flow so that the combustion becomes weaker near the cavity in this condition and this fact can be checked by the OH-PLIF signal. For high equivalence ratio, the static pressures are increased up to 50% and this happens more significantly as the total enthalpy is decreased. The fluctuation of the static pressure along the duct means that the supersonic combustion is occurring in the tests, and appears to be stronger at conditions of low stagnation enthalpy, provided ignition occurs, and .higher equivalence ratio.

A B Freeborn *et al*. [14] are done a study that's explores the effect of adding a pylon to the leading edge of a cavity flame holder in a scramjet combustor. The data were obtained through a combination of wind-tunnel experimentation and steady-state computational fluid dynamics. Wind tunnel data were collected using surface pressure taps, static and total probe data, shadowgraph flow visualization and particle image velocimetry (PIV). CFD models were solved using the commercial fluent software. The addition of an intrusive device to the otherwise low-drag cavity flame holder offers a potential means of improving combustor performance by enabling combustion products to propagate into the main combustor flow via the low pressure region behind the pylon. This study characterized the flow field effects of adding the pylon as well as the effect of changing Reynolds number over the range of approximately 33 x $10^6$ $m^{-1}$ to 55 x $10^6$ $m^{-1}$ at a Mach number of two. The addition of the pylon resulted in approximately three times the mass flow passing through the cavity compared with the cavity with no pylon installed. Reynolds number effects were weak. The addition of the pylon led to the cavity fluid traveling up to the top of the pylon wake and significantly increasing the exposure and exchange of cavity fluid with the main combustor flow.

The addition of the pylon caused the expected shock and expansion waves. The low pressure resulting from the expansion around the back of the pylon led to a strong flow upward from the cavity. This upward flow into the pylon wake increased mass exchange between the main flow and the flame holder. The larger mixing surface due to the pylon wake combined with increased mass exchange should enhance flame holder performance. These effects provide an avenue for the reacting products in the cavity flame holder to extend into the main flow at least as far as the top of the pylon. While research must continue, the pylon-cavity flame holder described here should provide the designer with an additional tool for optimizing the scramjet flow-path. Knowledge of the flow features discussed here should improve fuel/air injector designs and lead to improved performance.

Jeong-Yeol Choi and Vigor Yang [15] carried out a computational fluid dynamics analysis on the cavity flam holder a series of computational simulations have been carried out for non-reacting and reacting flows in a supersonic combustor configuration with and without a cavity. Transverse injection of hydrogen, a simplest form of fuel supply, is considered in the present study with the injection pressure varying from 0.5 to 1.5 mPa. The corresponding equivalence ratios are 0.167-0.50. The work features detailed resolution of the flow and flame dynamics in the combustor, which was not typically available in most of the previous studies. In particular, oscillatory flow characteristics are captured at a scale sufficient to identify the underlying physical mechanisms. Much of the flow unsteadiness is related not only to the cavity, but also to the intrinsic unsteadiness in the flow field. The interactions between the unsteady flow and flame evolution may cause a large excursion of flow oscillation. The role of the cavity, injection pressure, and amount of heat addition are examined systematically.

The reacting flow dynamics in a scramjet combustor was carefully studied by means of a comprehensive numerical analysis. The present results show a wide range of phenomena resulting from the interactions among the injector flows, shock waves, shear layers, and oscillating cavity flows. As a conclusion of the present study, new findings can be summarized as follows. Strong unsteady flow characteristics were identified for a scramjet combustor. The work appears to be the first of its kind in the numerical study of combustion oscillations in a supersonic combustor. Large flow disturbances can be generated by shear layer instability that may be triggered by the interactions with shock waves. For all the cases studied herein, instability caused by the cavity seems to override the shear layer instability caused by the shock-wave/shear-layer interactions when both instabilities are present. Transverse injected jet may remain stable without disturbance, but can be triggered to become unstable with disturbances from a shear layer or a cavity. Disturbed transverse injected jet has deeper penetration and improved fuel/air mixing than the stabilized one. A more careful study is necessary to characterize the stability of transverse injection jets. The roles of the cavity as a source of disturbance for the transverse jet, fuel/air mixing enhancement, and flame holder were clarified. Unstable flow characteristics for the reacting cases are similar to that of non-reacting flows except for the cases where pressure builds up rapidly. When the combustion takes place throughout the entire chamber, an unstable Mach reflection is formed above the injector and the pressure builds high enough for propulsion applications. The Mach reflection is unstable due the flow unsteadiness and results in a strong pressure fluctuation on the upper wall. As an extreme case of high pressure build up, thermal choking of the combustor was observed, which resulted in the combustor unstart by the forward running strong shock wave. The present study can be extended to a more realistic combustor configuration, but further investigations are necessary to achieve better understanding of detailed fluid and flame a scramjet combustor.

Hongbin Gu, *et al.* [16] are done Experimental Investigation of Cavity-based Scramjet Model. The configuration of scramjet engine is important to organize combustion with the kerosene fuel. Cavities and struts are usually used to enhance mixing and hold flame. The present work focused on the performance of the model engine with the different inlets and combustors. The models were tested in a free-jet wind tunnel that typically provides the testing flow with Mach number of 5.8, total temperature of 1800K, and total pressure of 4.5MPa and mass flow rate of 4kg/s. Strut as effective techniques were used in a kerosene-fueled scramjet. The integration of strut/cavities also had the important effect to make the combustion more stable than the model without strut. The one dimensional analysis method has been used to analyze the main characteristics of the models.

This study investigated the scramjet model with different configurations, evaluated the cavities and strut effect on the supersonic combustion. The results can be concluded as the strut is an effective technique for the kerosene fueled scramjet. The strut functioned not only as a device for the mixing enhancement, but also as an isolator to avoid the pressure raise in the combustor transmitted upstream to the inlet. In addition, the strut could serve as the fuel mixing enhanced way to improve the engine performance. The strut shown the merit to generate more thrust than drag. The integration of strut/cavities also had the important effect to make the combustion more stable than the model without strut. One dimensional analysis show that model MCM01 had more reasonable heat release distribution and higher combustion efficiency. It also indicates that the coupling of fuel injection and flow field is critical to obtain the better performance.

Kyungjae Lee, *et al.* [17] are Effects of Fuel Injectors and Cavity Configurations on Supersonic Combustion. In this study, the effects of the diameter and quantity of fuel nozzles combined with various cavity type flame holders for supersonic combustion were investigated empirically and numerically. Although increasing the quantity of fuel nozzles yields a greater fuel-to-air interface area, which results in a higher fuel–air mixing rate, smaller nozzle diameters yield a lower penetration depth, which results in a lower combustion performance at the top wall region. This study adopts the cavity shapes of fuel injectors from previous research studies to design new injector configurations with different sizes and quantities of fuel nozzles. The diameter and quantity of nozzles are determined to have the same equivalence ratio and momentum ratio as were used in previous research under a given fuel pressure. A comparison of results from the present tests with previous research shows that the plain cavity and zigzag cavity have distinct characteristics. Configurations using these cavity types were investigated via three-dimensional numerical analysis. It is concluded that a configuration consisting of a larger number of small fuel nozzles improves combustion performance significantly when installed without a cavity and slightly when installed with a plain cavity. However, combustion performance is degraded when a zigzag cavity is used.

The effects of fuel nozzle configuration with various cavity-type flame holders for supersonic combustion were investigated using experimental and numerical methods. The tests were conducted at a blow down wind tunnel equipped with a vitiated air heater. The test model was designed to switch fuel injector configurations. The cavity shapes of the fuel injectors were the same as those used previously, with the exception of new fuel injectors that had a large number of small fuel nozzles. The test results were compared with previous research. In addition, a three-dimensional numerical analysis was performed using FLUENT for a more detailed investigation of the combustion characteristics and internal flow behavior of a plain cavity and a zigzag cavity, which provided interesting results. The following conclusions were drawn from the present study. When there was no additional flame holder such as a cavity, a large number of small fuel nozzles enhanced the fuel–air mixing rate, resulting in significant improvement in combustion performance. When combined with a plain cavity, larger numbers of small fuel nozzles increased the fuel–air mixing rate and combustion pressure at the bottom wall. Furthermore, ignition delay was shortened. Reducing the ignition delay yielded a shorter combustor and, consequently, a better combustion performance. However, as the penetration depth of the injected fuel decreased, the combustion pressure decreased at the top wall. The overall performance of the plain-cavity fuel injector was improved, but the improvement was insignificant in comparison with the no-cavity case. Conversely, when combined with the zigzag cavity, the larger quantity of small fuel nozzles degraded combustion performance. This was due to the resulting reduction in eddy size and consequent reduction in transverse-directional pressure non uniformity, one of the favorable effects of the zigzag cavity. The reduction in transverse directional pressure non uniformity also led to a reduced fuel–air mixing rate inside the cavity. In addition, because the distance between injection nozzles was reduced, the larger number of small fuel nozzles caused interaction between the bow shocks induced by the injected fuel. This interaction increased total pressure loss and consequently caused thrust loss. In summary, a larger number of small fuel nozzles significantly improved the combustion performance in the absence of an additional flame holder. However, the performance improvement was insignificant when combined with the plain cavity, and performance was degraded when used with the zigzag cavity. From the findings of the present study, it was concluded that, to achieve maximum performance from a fuel injector with a zigzag cavity, the number of fuel nozzles and their arrangement should be optimized.

The idea about operability of scramjet engine defined by Kuo-Cheng *et al.* [18] Performance and operating limits of an ethylene-fueled recessed cavity flame holder with various cavity lengths were investigated both experimentally and numerically, using an AFRL research scramjet flow path at Wright-Patterson Air Force Base. Flush-wall low-angled injectors were used as main fuel injectors. Discrete flight conditions from Mach 3.5 to 5 at flight dynamic pressures up to 2000 psf were simulated with Mach 1.8 and 2.2 facility nozzles. Cavities with length-to-depth ratio (L/D) of 4, 5, and 6 were tested. Each recessed cavity features an array of fueling ports on the aft ramp for direct cavity fueling. The cavity operating conditions include 1) direct cavity fueling, 2) direct cavity fueling with back pressurization, and 3) fueling from main injectors with direct cavity fueling. It was found that the L/D=6 cavity exhibits the poorest performance among the three cavities, in terms of the lean blowout limit at cavity-only operation. With back pressurization, both the lean ignition limit and the lean blowout limit increase as compared to the case without back pressurization. The L/D=6 cavity also has a poorer lean operability when back pressurized with air throttle. Despite the poorer LBL observed above, the flow path equipped with the L/D=6 cavity actually performs better in terms of overall combustor operability and thrust generation. The flow path equipped with the L/D=4 cavity performs worst among these three cavity configurations both experimentally and numerically. The measured dominant frequency for acoustic pressure oscillation lies between 100 and 300 Hz, which agrees with the previous measurements inside the same flow path equipped with the L/D=5 cavity. The acoustic oscillation does not depend on the cavity length or the injector location for the present flow path. The L/D=6 cavity exhibits better RBL while the L/D=4 cavity exhibits worse RBL, probably due to the difference in cavity volume.

Operating limits of recessed cavity flame holders with various cavity lengths were investigated both experimentally and numerically, using an AFRL research scramjet flow path at Wright-Patterson Air Force Base. This flow path features a recessed cavity flame holder on the body wall and flush-wall low-angle injectors on both body and cowl walls. Cavities with L/D of 4, 5, and 6 were designed and fabricated for testing. The recessed cavities feature an array of independent fueling ports located at the aft cavity ramp. The flight conditions of interest were simulated with Mach 1.8 and 2.2 facility nozzles to cover Mach 3.5 to 5.0 flight conditions. Unheated ethylene was selected as the fuel for both main injector and independent cavity fueling ports. The cavity operating conditions include cavity fuel only, cavity fuel with a shock train established from air throttling, and main fuel with and without cavity fuel. The rich blowout limit for cavity- only operation was not obtained due to an under-sized flow meter for the cavity fuel. The major conclusions of the present study are as follows. With direct cavity fueling from the cavity ramp, both the lean ignition limit and the lean blowout limit increase with the characteristic air flow rate. The measured lean blowout limit is lower than the lean ignition limit, probably due to the presence of hot combustion products and the effect of cavity wall temperature. The L/D=6 cavity exhibits the poorest performance among the three cavities, in terms of the lean blowout limit. For a fueled cavity with back pressurization, both the lean ignition limit and the lean blowout limit increase from the fueled cavity without back pressurization, indicating a reduction in cavity lean operability under back pressurization. This reduction is due to unfavorable changes in air entrainment characteristics. Both lean limits are fairly insensitive to the shock train location. Air entrainment into the cavity is relatively constant once the shock train is established. The L/D=6 cavity has poorer lean operability when back pressurized. Despite the slightly poorer LBL observed above, the flow path equipped with the L/D=6 cavity actually performs better in terms of overall combustor operability and thrust generation. The L/D=4 cavity performs worst among these three cavity configurations both experimentally and numerically. The measured dominant frequency for acoustic pressure oscillation lies between 100 and 300 Hz, which agrees with the previous measurements inside the same flow path equipped with the L/D=5 cavity. It appears that the acoustic oscillation does not depend on the cavity length or the injector location for the present flow path. The rich blowout limit with main fuel injection was found to increase with the body-side fuel flow rate, due to reduced fuel entrainment into the cavity from deeply penetrating fuel plumes. Consequently, the rich blowout limit for a cavity operated with both main and cavity fuel injection is lower than that for a cavity operated with cavity fuel alone, due to fuel entrainment from main fuel plumes. The L/D=6 cavity exhibits better RBL while the L/D=4 cavity exhibits worse RBL, probably due to the difference in cavity volume. The overall flow structure within the cavity flame holder is highly three dimensional and varies with the cavity configuration. The link between cavity operation in full duct fueling and the cavity operability under cavity fueling only and cavity fueling plus back pressurization from air throttling should be investigated in the future.

Sivabalan Mani, *et al.* [19] is carried out a study on 3D Flow Visualization and Geometry Optimization of Cavity based Scramjet Combustors they used k-ω turbulent model. Here numerical studies have been carried out to examine the intrinsic flow features of cavity based scramjet combustors with backward facing step and forward ramp using 3D, density-based, implicit, SST k-omega turbulence model. The preliminary results show a wide variety of flow features resulting from the interactions between the injector flows, shock waves, boundary layers, and cavity flows. In all the cases the $C_2H_6$-$CO_2$-$H_2O$ fuel is injected at three different jet angles for the optimization of the jet orientation. Through the 3D numerical simulation we have corroborated that an optimized cavity is a good choice to stabilize the flame in the scramjet combustor as it generates a benign recirculation zone in the scramjet combustor. We comprehended that the cavity based scramjet combustors have a bearing on the source of disturbance for the transverse jet oscillation, fuel/air mixing enhancement, and flame-holding improvement. We concluded that the cavity shaped combustor with backward facing step and 45$^o$ forward ramp having an injector location of 1.6 times of its hydraulic diameter from the inlet facilitating at an angle of injection of 45$^o$ opposing the inlet flow is a good choice to getting relatively higher temperature at the exit.

While concluding the experiment a successful attempt has been made numerically for the 3D design optimization of a scramjet combustor. Note that the flow field within the combustor of scramjet engine is very complex and poses a considerable challenge in the design and development of a supersonic combustor with an optimized geometry. In this paper comprehensive numerical studies on flow field characteristics of cavity based scramjet combustors with different angles of injectors are reported. The $C_2H_6$-$CO_2$-$H_2O$ fuel is injected at three different jet angles for the optimization of the jet orientation. The results show a wide variety of flow features resulting from the interactions between the injector flows, shock waves, boundary layers, and cavity flows. We have conjectured that an optimized cavity with a suitable location and angle of injection can stabilize the flame in the hypersonic flow, and it generates a recirculation zone in the scramjet combustor. We comprehended that the cavity based scramjet combustors having a bearing on the source of disturbance for the transverse jet oscillation, fuel/air mixing enhancement, and flame holding improvement. We concluded that the cavity shaped combustor with backward facing step and 45$^o$ forward ramp having an injector location of 1.6 times of hydraulic diameter facilitating at an angle of injection of 45$^o$ opposing the inlet flow is a good choice to get higher temperatures at the exit compared to other models considered in this study.

Pan Yu, *et al.* [20] discussed about the Cavities installation schemes effect on the scramjet ignition. Investigations on room temperature kerosene ignition and combustion using six cavity based flame holder installation positions and two fuel injection schemes were conducted in a model combustor of cross section 54.5mm×75mm.The entry Mach number was 2.64, the total pressure and stagnation temperature was 1.84Mpa and 1300K respectively. Room temperature liquid kerosene were vertically injected into the supersonic channel flow through wall mounted 4× ϕ 0.5mm holes, ignited by pilot hydrogen ignited by spark plug. The ignition and flame stabilization ability were tested by installation cavities in some of the six positions. Different combinations of the positions installed cavities and kerosene injection methods lead to different ignition and flame stabilization results. Cavity configuration with deeper height have better ignition and flame stabilization ability. It was also showed that the combination of cavities in the little expansion angle section have higher ignition ability.

The cavities intersected installation and more cavities lead to better ignition and flame holding ability. But two cavities installed closer were not beneficial for ignition and flame stabilization.

The hydrogen ignited by spark plug, pilot hydrogen ignite liquid kerosene, steady combustion flame ignite more kerosene and kerosene flame holding ability were investigated by install different cavities at different position of supersonic combustion combustor, with the inflow M=2.64, total pressure Pt=1300K and static pressure P=83.3KPa. Results reveal it was more easy to get successful ignition at the little expansion section; opposite cavity without fuel injection also enhanced the ignition ability; too closer two cavities in tandem worse for ignition; more cavities leads to better ignition ability.

## 3. Conclusion

In the conclusion, the finding is scramjet engine mainly facing two problems; First problem is that the combustion in short residence time and the second problem the requirement of rapid air fuel mixing. From the reviews there we can provide some types of flam holders like cavity flam holder, alternative struts etc. to hold the flame and to produce turbulence, high mass exchanges. Among the flame holders cavity flame holder is simple in design and principles. When there we do computer numerical analyses using cfd softwares like OpenFOAM or Fluent SST two equation models where used. SST model helps to find the solution for both the boundary and internal field flow problems. The optimization of parameters of cavity flame holder is done by varying some parameters like L/D ratio, aft angles, fuel injection angle, fuel nozzle diameter etc. In the results the aft angles value is optimized into 22.5 degree, the L/D ratio is less than 10. L/D ratio affects the drag force inside the cavity. Commonly the experiments were carried out using the test sections and supersonic flow producer like T-3 piston shock tube. Sometimes the fuel injection may transverse or opposite direction to the inlet flow. To increase the mixing of air and fuel there we add some obstacle like leading edge pylon or trailing edge obstacles. This modification helps to increase the mass exchange inside combustor and to increase the surface area inside the test sections. Also the shock and expansion waves will produce; it also helps to increase the mass exchanges. When mass exchange increases the rapid air fuel mixing is take in place. The commonly use fuels are, Hydrogen, Helium, Kerosene. To attain easy and complete combustion spark plugs also used. From the Review the combustor details and optimization concept were found. There is a scope of future works in numerical analysis of the scramjet engine with grid independent study.

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