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Effect of variation of angle of attack on the performance of two-strut scramjet combustor

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ABSTRACT

Computational simulation of Scramjet combustor at Mach 2.5 through two struts and with three angle of attack ($\alpha = -3^\circ$, $\alpha = 0^\circ$ and $\alpha = 3^\circ$) have been presented and discussed in the present research article. Here the fuel which is injected through two struts is placed parallel to the air stream. The geometry and model used here is slight modification of the DLR (German Aerospace Center) scramjet model. Steady two and three dimensional (2D and 3D) Reynolds-averaged Navier–stokes (RANS) simulation and SST k-ω turbulence model is used to predict the shock structure and combustion phenomenon inside the scramjet combustor. All the simulations are done by using ANSYS 14-FLUENT code. Eddy dissipation along with finite rate chemistry model is used as combustion model for the present geometry because of the absence of Arrhenius calculations where turbulence controls the reaction rate. The effect of variation of angle of attack on the efficiency of two-strut scramjet combustor is also discussed in the research article. Present results show that the geometry with zero angle of attack i.e. $\alpha = 0^\circ$, have smallest ignition delay and it improves the performance of scramjet combustor as compared to geometry with $\alpha = -3^\circ$ and $\alpha = 3^\circ$. The combustion phenomena as well as efficiency is also found to be highest in case of geometry with $\alpha = 0^\circ$. In order to validate the results, the numerical data for single strut injection is compared with experimental result which is taken from the literature.

Introduction

The Supersonic Combustion Ramjet (SCRAMJET) combustor has been perceived as the most encouraging air breathing drive framework for the hypersonic flight (Mach number over 5). Lately, the innovative work of scramjet combustor has advanced the investigation of combustion in supersonic streams. Broad exploration is being completed over the world for understanding the scramjet innovation with hydrogen fuel with noteworthy consideration concentrated on new eras of space launchers and worldwide quick response surveillance missions. In present years, study of combustion phenomenon in supersonic flows creates and promotes a huge interest in the further research and development of scramjet engine [1]. In most of the countries, the research on scramjet technology is still going on with mainly hydrogen fuel for space related research applications. Many researchers are working on the development of the scramjet engine due to its applications in the military missiles, low cost space access, and space tourism in particular [2,3]. Pandey et al. [4,5] performed a computational study on mixing characteristic of scramjet combustor.

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They observed that in order to achieve efficient combustion, it is necessary to enhance and accelerate the mixing between the fuel and the air as well as to reduce the pressure losses in the combustion. K. Kumaran and V. Babu [6] in their work found that multi step chemistry model predicts higher and more extensive spread heat discharge than what was anticipated by single step chemistry model. The single step chemistry model is able to predict the overall performance parameters with significantly less computational expense.

One of the spearheading experimental results of scramjet combustion with hydrogen fuel in a basic geometry at the Institute for Chemical Propulsion of the German Aerospace Center, DLR, was published by Waidmann et al. [7–9]; these results and outcomes were viewed as a kind of perspective in literature for the advancement of the computational fluid dynamics (CFD) model of scramjet combustors. Fuel jets and compressible shear layers are characteristic features of any scramjet. Mixing these shear layers are characterized by large scale eddies that form due to the high shear between the fuel and air streams [10]. Other than the greater part of this, different test and computational examinations were performed to discover the result of isolator lengths on execution of scramjet inlet by Reinartz and Hermann [11]. The idea of investigation on the combustion performance of a typical single strut scramjet combustor by the variation of strut configurations and locations was mainly approached by Wei Huang [12]. In his work, he observed that when overlapping occurred in single strut injector between the leading shock wave and upper wall, the combustion efficiency increased. Recently Wei Huang and Li Yan [13] also investigated the ram–scram transition mechanism in a strut-based dual-mode scramjet combustor computationally and found that with the increment of jet-to-cross flow pressure ratio; there was an upstream expansion of the separation zone. This phenomenon was mainly influenced by the movement of the shock wave train in the isolator. Computational study of Scramjet combustor along with two-stage and alternating wedge injection struts was finished by C. Fureby et al. [14]. In their work they found that there was a significant difference between two stage and alternating wedge scramjet combustor in terms of stream and flame structure where rotating wedge delivered the longitudinal vorticity which would help in expanding the combustion efficiency and decreasing the flame steadiness. However, in the event of two-stage injection struts, auto-ignition zones helped in combustion procedure. An improved investigation on high angle of attack characteristics of hypersonic space vehicle was again performed by Huang et al. [15] and they observed that when the angle of attack was 20°, the high pressure did not leak from around the leading edge to the upper surface of hypersonic space vehicle. Further Parametric effects on the combustion flow field of a typical strut-based scramjet combustor was also investigated by Huang et al. [16]. They found that when there was a variation in the injection conditions, a transition took place from the shock wave to the normal shock wave and there was also a formation of separation zone in double near the walls of the combustor.

M Deepu [17] in his work found that for all kinds of jet, jet penetration to free stream value increased with the increment of jet to free stream momentum flux ratio. The strength of the bow shock was significantly depending on the injector position. The shock generated by the transverse injector is strong enough as compared to oblique injector. Effective air-fuel mixing and lessening of combustor length is a vital parameter in fitting advancement of scramjet combustor [18]. The idea of variation of angle of attack on Scramjet combustor was mainly approached by Edder Rabadan Santana and Bernhard Weigand [19]. They mainly worked on Numerical Investigation of Inlet-Combustor Interactions for a Scramjet Hydrogen-Fueled Engine at a Flight Mach Number of 8 and observed that for single strut injector with negative angle of attack has the lowest ignition delay [19]. But the importance of variation of angle of attack on the performance of multi-strut scramjet combustor was not discussed earlier. Hence this has been the foremost inspiration for the present analysis.

The objective of the present work is to study numerically the flow phenomena in two struts scramjet combustors for different angle of attack ($\alpha = -3^\circ$, $\alpha = 0^\circ$ and $\alpha = 3^\circ$) by modifying the DLR scramjet model. The presence of variation of angle of attack and its impact on the performance of scramjet combustor is also discussed in this paper. The generation of shocks by different geometry and its effect on combustion efficiency is also reported. It is found that modified scramjet combustors with two struts and zero angle of attack $\alpha = 0^\circ$ have improved the combustion efficiency and it has lowest ignition delay.

DLR experimental details

A schematic diagram of DLR scramjet model [7–9] is given in Fig. 1. The air enters into combustion chamber at M = 2.0 whereas hydrogen fuel (H_2) is injected parallel to the air stream at M = 1.0.

The width and height of the combustor section at the entrance is 40 mm and 50 mm respectively which is then diverged at an angle of 3° on the upper wall of the combustor. The strut is 32 mm long and a height of 6 mm which are located at a distance of 77 mm from the inlet. For the purpose of validation only in case of single strut, we used boundary conditions of Waidmann et al. [7–9]. Regarding the remaining operating conditions and detailed phenomena about experiment are given in Waidmann et al. [7–9].

Flow modeling and simulation

Geometry, grid generation and grid convergence study

To diminish the computational time as much as possible without changing the relevant physics of scramjet combustor,

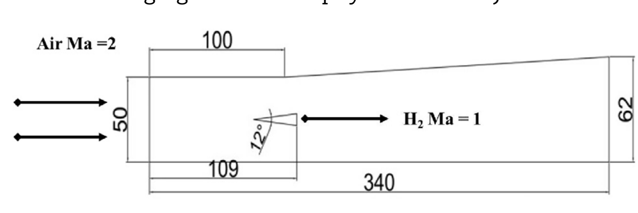

Fig. 1 – Schematic diagram of DLR supersonic combustion chamber [7–9].