CFD Modelling of Scramjet Combustor

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1. INTRODUCTION & OBJECTIVE

Scramjet engine is a promising propulsion system for safe and sustained flight in the hypersonic regime. Scramjet differs from a ramjet in the combustion process, in a scramjet combustor combustion takes place in supersonic airflow thus reducing the losses that occur due to normal shock wave formation in ramjet. However, there are many challenges associated with scramjet combustors. Because of very high speeds, the fuel residence time in combustor is very small. In such short span, the fuel has to be mixed with air sufficiently and burn completely. Flame stability, flame holding and minimizing total pressure loss are the most challenging problems. The design of the fuel injector plays a very important role in the overall performance of the combustor. In this paper, different strut fuel injectors are compared along various performance parameters. Mainly 2 types of strut are considered, Symmetric and Asymmetric. Different geometries of the symmetric strut were obtained by varying the wedge angle of the strut and different geometries of asymmetric strut were obtained by varying the angle of asymmetry.

a. In symmetric strut case (Fig. 1), the wedge angle 'X' was varied between 12, 15 and 17 degree.

b. In asymmetric strut case (Fig. 2), the wedge angle was fixed at 17 degree (because 17 degree symmetric strut gave the best results), the angle of asymmetry 'X' was varied between 10, 18 and 25 degree.

The effect of these changes on the flow were studied. The combustor geometry used for present study is shown in fig. 3. The model combustor used here is same as the combustor used at DLR (German Aerospace Centre)[1]. Hydrogen is injected from the base of the strut, from a 1mm×40mm planar surface.

Commercial CFD software ANSYS Fluent was used to model the flow inside the supersonic combustor. Mesh was made in Gambit. SST k-w model is used for turbulence modeling[3,4]. Combination of Eddy Dissipation (ED) model and Finite Rate Chemistry (FRC) model is used for combustion model. The reaction rate is calculated by using single step chemistry[4,5]. CFD methodology was verified and validated by comparing CFD results for 12 degree symmetric strut with the experimental data from ref. [1]. The results matched to a good accuracy.

Mixing and Combustion efficiencies were the primary parameters to compare the struts. The mixing efficiency is defined as that fraction of the least available reactant (fuel or oxidiser) which would react if the fuel-air mixture were brought to chemical equilibrium without additional local or global mixing. The efficiency of the combustion is being calculated based on mass fraction of water vapour created in the combustor (For the sake of brevity, mathematical expressions for these parameters are not shown in the abstract)

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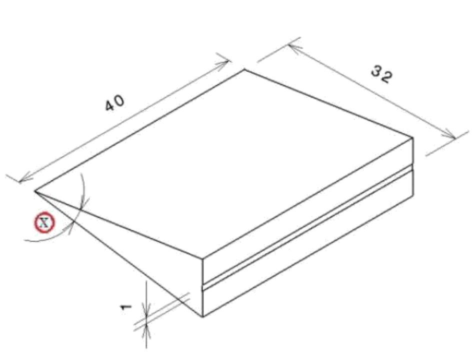

Fig. 1: Symmetric Strut

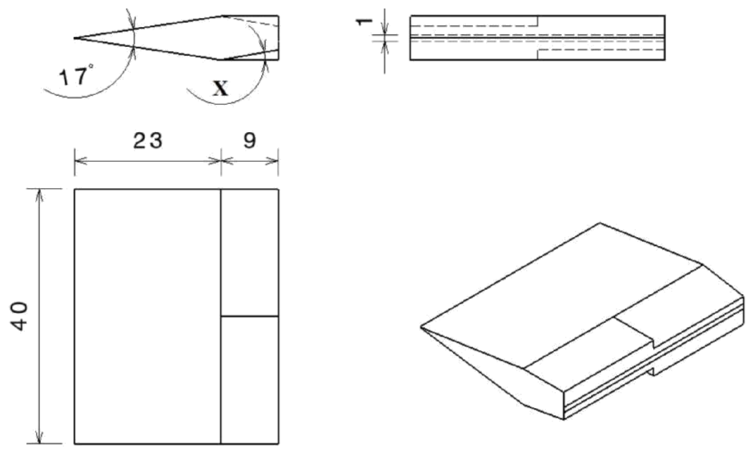

Fig. 2: Asymmetric Strut

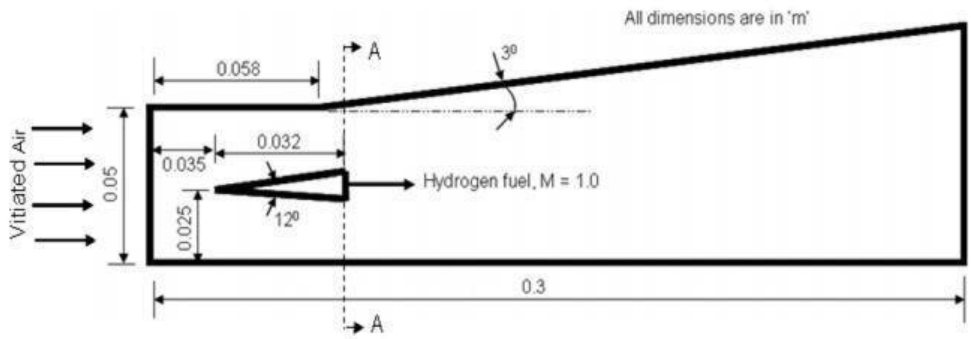

Fig. 3: Geometry of Scramjet Combustor

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

1. Symmetric Strut Results –

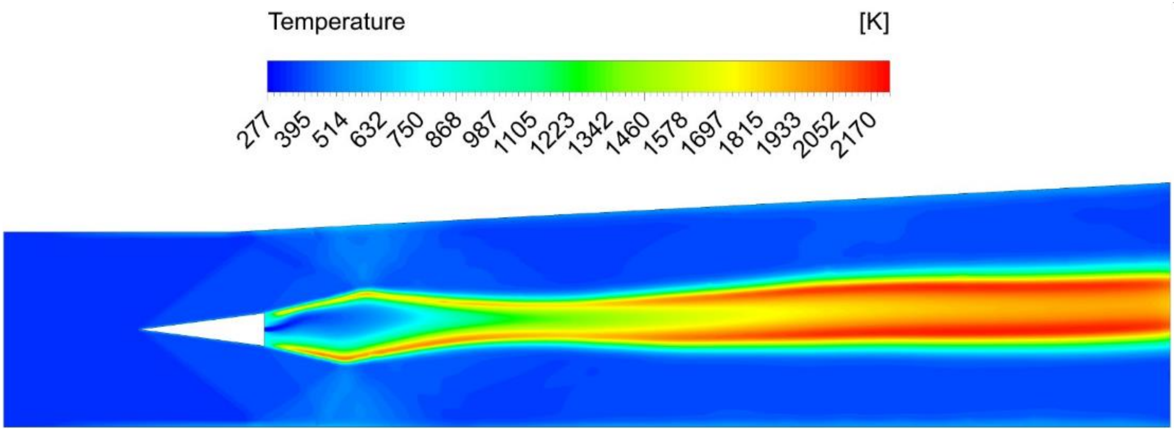

Fig. 4: Temperature Contours (15 degree symmetric strut)

Fig. 4 shows the temperature contours for the 15 degree wedge angle symmetric strut. The temperature profile clearly depicts the reaction zone in the combustor. The combustion is occurring only in the narrow zone from the base of the strut and has not spread enough in the lateral direction. Combustion is initiated in the shear layers leaving the edges of the wedge. Performing similar simulations for various wedge angle shows that higher the wedge angle, higher will be the height of the strut and wake region created by strut will be larger which helps hydrogen in mixing more rapidly. Total Pressure loss increases with increase in wedge angle, because higher wedge angle creates stronger oblique shocks and provide larger obstruction for the incoming flow. Thus drag will also be high for high wedge angles.

2. Asymmetric Strut Results –

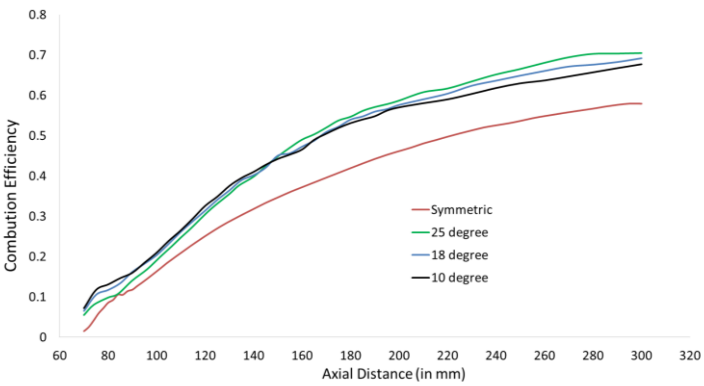

Fig. 5: Combustion efficiency

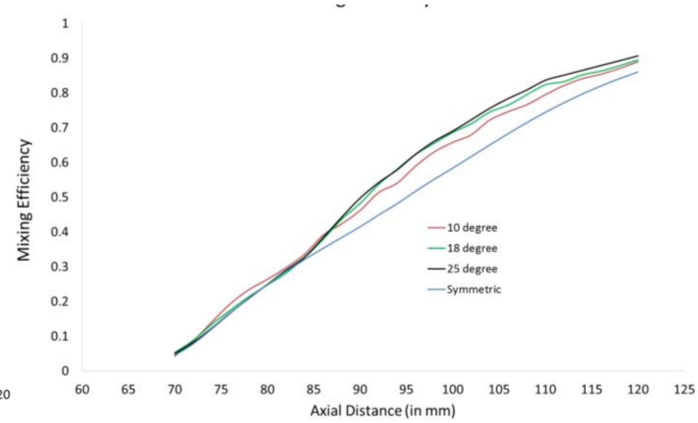

Fig. 6: Mixing Efficiency

The Asymmetric strut gives better mixing and combustion efficiency as compared to symmetric struts as shown in figures 5 and 6. In Asymmetric Strut, circulation is created well before the end of strut which continues for longer period in the downstream (divergent portion) of the combustor. The presence of circulation before fuel injection increases air fuel mixing significantly. Asymmetric strut with higher angle of asymmetry have better mixing and combustion efficiencies, because larger angle creates bigger circulation regions and enhance the performance of the combustor.

REFERENCES

1. Waidmann, W., Alff, F., Brummund, U., Bohm, M., Clauss, W., & Oschwald, M. (1994). Experimental Investigation of the Combustion Process in a Supersonic Combustion Ramjet (SCRAMJET) Combustion Chamber. *DGLR-Jahrestagung 1994*, (March), 10.
2. Seiner, J. M., Dash, S. M., & Kenzakowski, D. C. (2001). Historical survey on enhanced mixing in scramjet engines. *Journal of Propulsion and Power*, *17*(6), 1273–1286.
3. Kumaran, K., & Babu, V. (2009). A comparison of the numerical predictions of the supersonic combustion of hydrogen using the S-A and SST k-w models. In *Progress in Computational Fluid Dynamics, Vol.9, No. 8* (pp. 475–489).
4. Chandra Murty, M. S. R., Mishal, R. D., & Chakraborty, D. (2010). Numerical simulation of supersonic combustion with parallel injection of hydrogen fuel. *Defence Science Journal*, *60*(5), 465–475.
5. Kumaran, K., & Babu, V. (2009). Investigation of the effect of chemistry models on the numerical predictions of the supersonic combustion of hydrogen. *Combustion and Flame*, *156*(4), 826–841.
6. Dharavath, M., Manna, P., & Chakraborty, D. (2013). Thermochemical exploration of hydrogen combustion in generic scramjet combustor. *Aerospace Science and Technology*, *24*(1), 264–274.
7. Mao, M., Riggins, D. W., & McClinton, C. R. (1991). Numerical simulation of transverse fuel injection. *NASA Lewis Research Center Computational Fluid Dynamics Symposium on*