NUMERICAL SIMULATION OF HYDROGEN COMBUSTION IN GENERIC SCRAMJET COMBUSTOR

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ABSTRACT

In the present study non reactive and rsimulations of DLR scramjet combustor simplified geometry are carried out and the results are compared with experimental and CFD data. CFX solver with k-ε turbulence model and single step hydrogen air chemistry is used for present simulations. Complex flow features like shock, shock-shock interactions, shock reflections and wake flow regions are captured well in the simulation.

INTRODUCTION

Development of an efficient propulsion system is the key for the success of the hypersonic vehicle development programs. In scramjet engine, combustion must take place at supersonic speed. Scramjet propulsion system with hydrogen fuel is one of the candidates for providing thrust for these vehicles. The flow field inside a scramjet combustor is highly complex. The atomisation, evaporation, mixing of reactants, flame holding, stability and completion of combustion are major concerns in the combustion chamber design and analysis. The problem of slow lateral fuel transport in the air stream is circumvented by injecting the fuel in the core region of the flow by means of struts and or pylons. The oblique shocks generated from the struts also augment the mixing in the combustion chamber.

A good number of experimental and numerical studies are reported in the literatures which focus on various aspects of flow phenomena including mixing, combustion, etc., in a strut based scramjet combustors with hydrogen fuel. DLR single strut combustor using hydrogen fuel is extensively tested both experimentally and numerically (Ref [1,2]). Reference[1,2] provide shadowgraphs, wall pressure distribution, velocity and temperature profiles at different cross sections in the combustor for reacting and non reacting cases. In these experiments, hydrogen was injected from the base of a wedge-shaped strut at sonic speed parallel to an airstream of free stream Mach number of 2.0.

STUDY CONFIGURATION FOR HYDROGEN COMBUSTION

The scramjet configuration used in this present study is shown in Fig.1 is a modified version of DLR scramjet model, Ref [1]. A wedge shaped strut is placed in the middle of the combustion chamber at 0.077m downstream from the combustor inlet. The length and half wedge angle of the strut are 0.032m and 6° respectively. In DLR combustor model the hydrogen (H2) is injected at M =1.0 through a row of 15 ports of 1.0 mm diameter and the ports are 2.8 mm apart, in the strut base. Whereas, in the modified combustor model, only 3 ports with a diameter of 2.23mm are used and gap between ports is 10mm, these simplifications are made to reduce the computational work while maintaining the actual hydrogen mass flow rate.

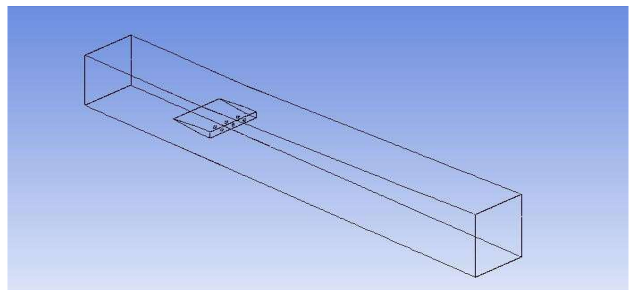

FIGURE 1: MODIFIED DLR SCRAMJET COMBUSTOR MODEL FOR HYDROGEN FUEL (REF.[1])

DETAILS OF CFD SOLVER, GRID AND SIMULATION CONDITIONS

CFX 3-D Reynolds Averaged Navier-Stokes (RANS) implicit solver with k-ε turbulence model is used for the present simulations. In-built single step hydrogen-air chemistry model is used for combustion. Local time stepping has been used for steady state simulations. Multi-block structured grid is generated using *Pointwise* grid generator. The first cell non-dimensional height, (y^+) is 1 and the grid points are distribution using hyperbolic function with a grow rate of 1.2. In the present study different boundary conditions are applied. Supersonic inflow condition has been imposed at the inlet of the combustor and the hydrogen jet inlet boundary conditions are prescribed on the ports. Supersonic outlet is imposed at the outlet of combustor. Adiabatic wall condition is imposed on walls of combustor and strut. Inlet conditions of the air and hydrogen are given in Table 1 (Ref [1]).

Variable	Air	Hydrogen Inlet
M	2	1
V(m/s)	730	1200
T(K)	340	250
p(Pa)	101325	101325

TABLE 1: FREESTREAM AND FUEL INLET CONDITIONS

RESULTS AND DISCUSSION

Non Reacting flow simulation:

Hydrogen injection adds significant complexity to the flow in the scramjet combustor which has a bearing on the mixing process and thus establishing the conditions for scramjet combustion. To validate, first a non reacting simulation is carried out and the flow features are qualitatively compared with Reference [2]. Pressure distribution on the bottom wall is also compared with both experimental and CFD data.

(i) Flow feature comparison:

Figure 2 shows the comparison of shadowgraphs on the downstream of the struts obtained from the experiment and numerical simulation. The location of the shocks, reflected shocks, wake flow and the influence of the hydrogen jet field from the numerical shadowgraph are comparable with the experimental shadowgraph.

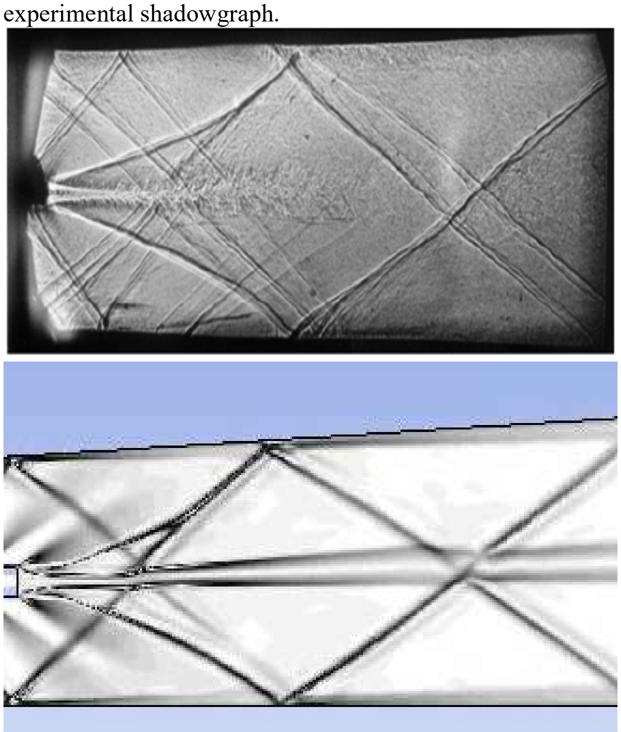

FIGURE 2: COMPARISON OF NUMERICAL AND EXPERIMENTAL SHADOWGRAPH BEHIND THE STRUT.

(ii) Static pressure comparison

Figure 3 shows the pressure palette at the mid plane of the combustor. Rise in pressure at the locations of shock impingement on the bottom and top walls at various locations in the combustor are captured. The high pressures on the top and bottoms wall are different due to the divergent angle present on the top wall. Static pressure distribution at bottom wall is compared with experimental and CFD data from Ref [2] in Fig.4. The location of the first pressure rise is correctly captured and it matches well available CFD data. But, the magnitude of the pressure rise is slightly higher for the present data. The location and the peak magnitude of pressure due to the second shock reflection are matching well with the experimental data, whereas the other CFD data is slightly under estimate the pressure rise. Figure 5 shows the Mach palette, where the wedge shocks and strut base expansion waves are reflecting from the surfaces.

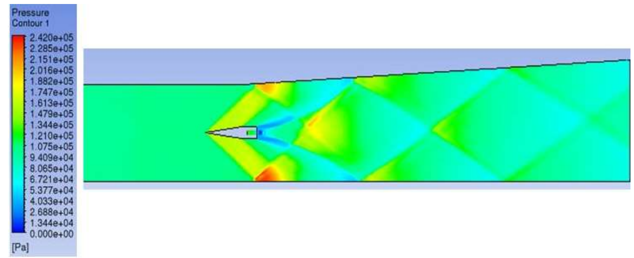

FIGURE 3: STATIC PRESSURE IN THE MID PLANE SHOW SHOCK IMPINGEMENT AND REFLECTIONS.

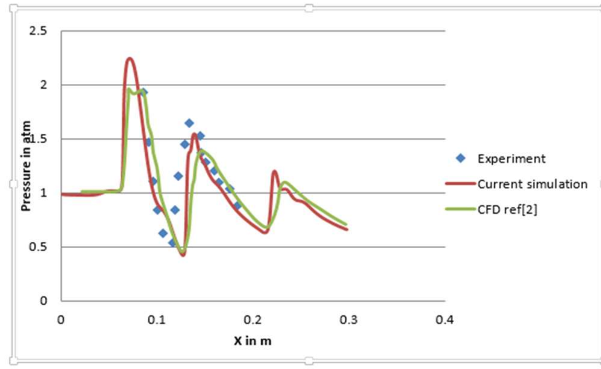

FIGURE 4: COMPARISON OF STATIC PRESSURE ON THE BOTTOM WALL SURFACE

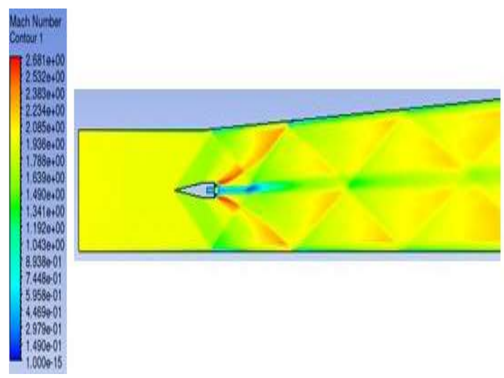

FIGURE 5: MACH PALETTE IN THE MID PLANE SHOW SHOCK IMPINGEMENT AND REFLECTIONS

REACTING FLOW SIMULATION:

Reacting flow simulation has been carried out with the reaction of hydrogen fuel in vitiated air. Single step reaction considering H2 and O2 as reactant and H2O as product are considered for the simulation. The results of the reacting flow simulations will be covered in the full length paper.

CONCLUSION

In the present study nonreactive and reactive simulations of DLR scramjet combustor simplified geometry are carried out and the results are compared with experimental and CFD data. The location of the shocks, reflected shocks, wake flow and the influence of the hydrogen jet field from the numerical shadowgraph are comparable with the experimental shadowgraph. The location of pressure rise on the bottom wall is captured well but reasonable match is seen for the magnitude of the pressure rise.

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