Numerical Simulation of Dual-Mode Scramjet Combustor with Significant Upstream Interaction

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ABSTRACT

This paper is concerned with a numerical study corresponding to experimental investigation of Chinzei and co-workers on hydrogen fueled dual-mode scramjet engine essentially to understand the key features of upstream interaction, mixing and combustion. Three dimensional Navier Stokes equations along with a $K-\varepsilon$ turbulence model and infinitely fast kinetics are solved using commercial CFD software. Reasonable agreement has been obtained between the computed surface pressure with experimental values and the results of other numerical simulations. Insights into the flow features inside the combustor are obtained through analysis of various thermochemical parameters. The comparison of surface pressure with experimental results and other numerical results demonstrated that simple kinetics and turbulence – chemistry interaction model may be adequate to address the overall flow features in the combustor. A principal conclusion is that the boundary layer at the combustor entry has a pronounced effect on the flow development in the dual-mode scramjet combustor and causes significant upstream interaction.

Keywords: Dual Mode Scramjet Combustor, Hydron Fueled Dual-Mode Scramjet Engine, Numerical Simulation, Scramjet Combustor, Upstream Interaction

1. INTRODUCTION

In recent years, a significant amount of high speed combustion research is directed towards understanding the complex flow phenomena inside a scramjet combustor over a range of operating conditions. Studies – analytical, experimental and numerical – are focused on different aspects of the flow field in the various components of scramjet engines viz., intake, combustor, nozzle etc. The components have also been coupled to make a complete scramjet engine, and the flow fields of the engine with different fuel injection systems have been subjected to numerical and experimental exploration. Curran (2001) reviewed comprehensively the status of scramjet engine in first 40 years.
and identified two emerging scramjet applications namely (1) Hydrogen fueled scramjet engine to access space and (2) Hydrocarbon fueled scramjet engine for an air launched missile. To increase the flight envelope of the air breathing vehicle, Billig (1993) and Cockrell et al. (2002) introduced Dual-mode Ramjet Scramjet (DMRJ) concept which integrate the advantageous capabilities of both ramjets and scramjets into one flow path.

In a ramjet, the flow is subsonic by the time it gets to the combustor. In a scramjet, the flow remains supersonic through the combustor. The dual mode scramjet bridges the gap between the ramjet and scramjet. It uses the same combustor geometry for both the ramjet and scramjet modes, but operates with a thermal throat in ramjet mode. This combination may enable a vehicle to operate from Mach 3 to Mach numbers approaching 20 with only minor engine geometry changes. At the lower limit of this envelope, the DMRJ operates in ramjet mode and combustion occurs at subsonic speeds. In this mode, the addition of heat can be used to drive the supersonic inflow to sonic conditions and achieve a thermal choke and a precombustion shock train forms in the DMRJ isolator. The shock train consists of a series of normal or oblique shocks, which terminate with a normal shock that drives the flow to subsonic conditions. The pre-combustion shock train aids flame stabilization by increasing the static pressure and temperature and decelerating the flow.

In the dual-mode scramjet engine, a constant area diffuser (isolator) is placed upstream of the combustor to reduce the interaction of the combustor and intake flow field and to prevent the intake un-start. The position and strength of three-dimensional pre-combustion shock train and combustor heat release distribution are strongly coupled. However, as described in Heiser and Pratt (1994), at speeds approaching Mach 6, pressure losses associated with choking the flow increase and operational efficiency decreases. At M>6, the level of heat release may be reduced by flowpath geometry modification and/or reducing the fuel-flow rate. The DMRJ operates in scramjet mode, in which combustion occurs at supersonic speeds. Transition from subsonic to supersonic combustion is obtained by controlling the heat released due to combustion such that the thermal choke is alleviated. Once the heat release is reduced by a sufficient amount, the flow is no longer choked and the flow through the combustor remains largely supersonic. The schematic of flow field in DMRJ is shown in Figure 1.

The numerical simulation of this problem is highly challenging to CFD. This is due to (i) presence of large subsonic / supersonic flow field in the combustor/isolator, (ii) the related importance of high level of turbulence modeling necessary to predict the extent and shape of the interaction and (iii) downstream mixing and combustion at lower Mach number. Recent studies by Moon et al. (2000) have indicated a
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