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Numerical Investigation of Various Fuel Injection Angles on Interaction in Cold Kerosene-fueled Supersonic Flow

Yin-Yin Qi[a], Lin Zhu[a,*], Wei-Lai Liu[b], Bao-Jian Xu[b], Jia-Ru Ge[a], Feng Luo[a], Tien-Chien Jen[c]

[a]*Mechanical Engineering Department, Anhui Agricultural University, Hefei, 230036, China*
[b]*Department of Precision Machinery & Precision Instrumentation, University of Science & Technology of China, Hefei, 230027, China*
[c]*Department of Mechanical Science, University of Johannesburg, Johannesburg, 2006, South Africa*

Abstract

The incident shock wave strongly affects the transversal injection field in cold kerosene-fueled supersonic flow, possibly due to its affecting the interaction between incoming flow and the fuel through various operation conditions. Optimum selection of fuel injection parameters indicates optimum interaction between incoming flow and fuel. Based on three dimensional Couple Level Set & Volume of Fluids (CLSVOF) approach, a detailed Computational Fluid Dynamics model of a cold kerosene-fueled scramjet combustor is developed in this study. Next, the effects of various injection angles on the interaction between incident shock wave and transversal cavity injection are addressed. The injection angles are specified from 45º to 135º in 45ºincrements when other operation parameters, i.e. the injection diameter, velocity and pressure drop are all constant. The CLSVOF-based predictions are focused on penetration height, span-wise expansion area, angle of shock wave and sauter mean diameter (SMD) distribution of the kerosene droplets. Our findings show that the penetration depth, span-wise angle and expansion area of the transverse cavity jet all increased with the injection angle, and that the kerosene droplets are more prone to breakup and atomization at the outlet of the combustor for the injection angle of 45º. This study demonstrates the effectiveness of CLSVOF modeling for better understanding of kerosene-fueled supersonic mixing and scramjet combustor design improvement.

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Keywords: Injection angle; Couple Level Set & Volume of Fluids (CLSVOF); Transversal scramjet combustors; Supersonic flow; Kerosene

1. Introduction

Development of an optimum supersonic combustion ramjet (scramjet) engines are pivotal for the realization of hypersonic vehicles [1]. The hypersonic vehicles are generally operated at high Mach number, e.g. 8, which indicates that the residence time of the supersonic free-stream within the combustion chamber of the scramjet is

* Corresponding author. Tel.:+86-13696544372.
E-mail address: zl009@mail.ustc.edu.cn

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extremely short, typically on the order of milliseconds [1]. Too short residence time of the fuel leads to incomplete mixing, thereby affecting the combustion efficiencies significantly [2]. Transversal fuel injection through a wall orifice has been investigated because of good fuel penetration, interaction and mixing, which is demonstrated to be one of the simplest and most conventional approaches for the scramjet engine [3-6]. Abdelhafz et al. [7] explored oblique and transverse configurations in which gaseous fuel was injected into a low-aspect-ratio supersonic combustor. They included that injecting fuel obliquely can improve mixing efficiencies. However, to the authors' knowledge, little information is available in the literature on the fuel-air mixing characteristics in a cold kerosene-fueled supersonic flow. A careful study of the foregoing issue is essential to design the optimum injection system, such as kerosene-fueled supersonic spreading and mixing as well as improving the spray strategies of the scramjet combustor.

Hence, this investigation is concerned with modeling and analysis of various fuel injection angles, in a cold kerosene-fueled scramjet combustor, on the interaction between incident shock wave and transversal cavity injection using 3D Couple Level Set & Volume of Fluids (CLSVOF) approach.

2. CFD Model and Simulation Approach

2.1. Model geometry

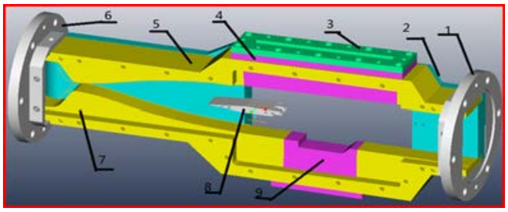

Fig.1. Schematic of a 3D scramjet combustor: 1. flange, 2. rear cover, 3. pressure pad of upper glass window, 4.upper glass window, 5. upper cover, 6. flange, 7. lower cover, 8. Strut, 9.cavity

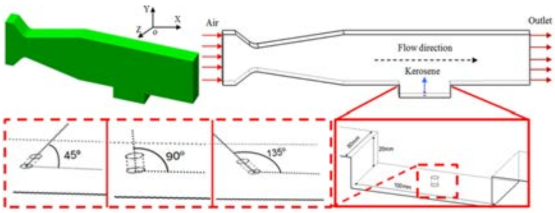

Fig.2. Schematic of the scramjet combustor geometry and computational domain

Figure 1 shows the real prototype of scramjet combustor developed by Liu [8]. For the purpose of experimental measurements, in the original design the scramjet combustor contains flange 1 and 6, pressure pad of upper glass window 3 and upper glass window 4. However, to save the calculation time, the CFD model, corresponding to Fig.1, is simplified. The scramjet combustor in this study consists of rear cover 2, upper cover 5, lower cover 7 and cavity 9. Figure 2 shows the simplified geometry of the three-dimensional scramjet combustor by using a combined feature-based modeling approach and Virtual Assembly Technique (VAT) [9]. The primary specifications used for the calculation are listed in Table.1. Note that in Fig.2, the orifice for the kerosene injection is located at the center of the cavity.

Table 1. Specifications of the scramjet combustor

Item	Dimension
Scramjet combustor	$0.6\times0.05\times0.08m^3$ (length × width× height)
Orifice	1.0×10^{-3} m (Φ),0.02m long
Injection angles	45º,90ºand 135º
Inlet & outlet	$0.05\times0.08m^2$ (width × height)

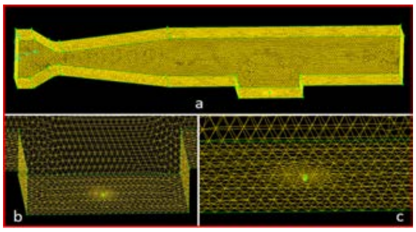

Fig.3. Details of numerical grid of the scramjet combustor

2.2. CFD modeling

Figure 3 shows the meshed CFD model of the scramjet combustor. There are totally 330,000 hexahedron cells