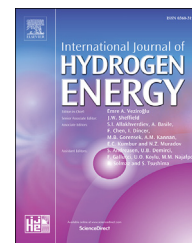




ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Numerical study on supersonic combustion of hydrogen and its mixture with Ethylene and methane with strut injection

Sugang Ma ^{a,b}, Fengquan Zhong ^{a,b,*}, Xinyu Zhang ^{a,b}

^a State Key Laboratory of High Temperature Gas Dynamics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

^b School of Engineering Science, University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:

Received 13 December 2017

Received in revised form

28 February 2018

Accepted 1 March 2018

Available online 23 March 2018

Keywords:

Detached eddy simulation
Reduced kinetic mechanism
Supersonic combustion
Hydrogen
Hydrocarbon

ABSTRACT

In this paper, supersonic combustion and flow field of hydrogen and its mixture with ethylene and methane from strut injections in a Mach 2 supersonic flow are studied numerically. The fuel mixture of hydrogen, methane and ethylene represents the major products of pyrolysis of hydrocarbon fuels with large molecules such as kerosene as it acts as coolant and flows through cooling channels and absorbs heat. Detached Eddy Simulation with a reduced kinetic mechanism and steady flamelet model are applied to simulate turbulent combustion. The calculated temperature profiles of hydrogen are compared to the experimental results of DLR supersonic combustor for validation of the present numerical method. The supersonic combustion flows associated with shock waves, turbulent vortices and flame structures are studied. With addition of methane and ethylene, the flame zone moves further downstream of the strut and the maximum flow temperature at chamber exit decreases by 200 K. With analysis of total temperature ratios, it is found that combustion efficiency for hydrogen combustion is 0.91 and it decreases to 0.78 for the fuel mixture. The calculation of ignition delay time and flame speed reveals that fuel mixture of hydrogen and hydrocarbons has considerably larger delay time and smaller flame speed, that contributes to the weakened flame zone and lower combustion efficiency.

© 2018 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Introduction

Combustion characteristic of hydrocarbons is a key issue in the design of air-breathing engine system. For long-run engines, hydrocarbon fuels (e.g., kerosene) are often used as coolant to absorb heat from the engine structure in a regenerative cooling system [1,2]. When hydrocarbon fuel with large molecules flows through the cooling channels, it absorbs

heat from the combustor wall and its temperature may exceed the cracking point and pyrolysis occurs. The fuel is then decomposed into small molecular products such as methane, ethylene and hydrogen and so on before being injected into the combustor [3,4]. Many of previous works focused on combustion characteristics of single fuel components and fuel mixture, particularly representing products of pyrolysis is rarely studied. Therefore, it is necessary to investigate combustion characteristics of fuel mixture of hydrogen and small

* Corresponding author. No.15 Beisihuanxi Road, Institute of Mechanics, Chinese Academy of Sciences, Beijing, 100190, China.

E-mail address: fzhong@imech.ac.cn (F. Zhong).

<https://doi.org/10.1016/j.ijhydene.2018.03.007>

0360-3199/© 2018 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Nomenclature

C_{DES}	Calibration constant used in DES model
D	Coefficient of mass diffusivity
L_t	Turbulent length scale
\dot{m}_F	Mass flow rate of fuel
Ma	Mach number
n	Normal vector of cross section
T	Static temperature
$T_{0,1}$	Total temperature at the inlet
$T_{0,2}$	Mass-averaged total temperature at the outlet
T_{ad}	Adiabatic flame temperature
t	Flow time
V	Velocity vector and
Y_F	Mass fraction of fuel
Y_O	Mass fraction of oxidant
Y_{OH}	Mass fraction of OH species
Y_k	Dissipation of k
∇	Hamiltonian
η	Combustion efficiency
η_{mix}	Mixing efficiency
ρ	Density
k	Turbulent kinetic energy
ω	Specific dissipation rate
$\chi_{F,O}$	Cross-scalar dissipation rate

molecular hydrocarbons for applications of realistic engine operation.

To study details of reaction flow in supersonic combustor, optical methods such as Schlieren Imaging or Laser Induced Fluorescence are attempted. However, the present optical methods are mainly applied in qualitative illustrations with limited visualization zones. Alternatively, numerical simulation with high order of accuracy is effective for the study of flow and reaction mechanism of supersonic combustion. Detached Eddy Simulation (DES) originally proposed by Spalart [5] combines advantages of Reynolds averaged N-S method (RANS) in the turbulent boundary layer and Large Eddy Simulation in the outer flow region and is considered an efficient method for resolving turbulent structures with relatively low computational costs. For example, Choi et al. [6] studied flow and combustion process of a scramjet combustor with hydrogen fuel via DES. The details of flow fields and characteristic frequencies are provided. It is concluded that comparing with RANS method, the DES is a very useful tool for scramjet studies and presents more detailed information of supersonic combustion. Vyasaprasath et al. [7] simulated planar mixing and turbulent combustion of hydrogen and air using DES model and obtained consistent results with the experimental data. The DES method is able to resolve the dynamics of reactive turbulent flow. Wang et al. [8] simulated reacting flow of the DLR supersonic combustor using a 19-step reaction model of hydrogen and a flamelet/progress variable model. The DES model can better simulate the turbulent transport processes and hence improve the accuracy of combustion simulation. Kummitha et al. [9–11] conducted the

simulation of mixing and combustion of fuel and air in the DLR supersonic combustor. The authors used different passive technologies to improve the mixing and combustion efficiency.

Using DES method and a reduced kinetic mechanism, supersonic combustion of hydrogen and its mixture with methane and ethylene are considered in present works in order to compare the combustion properties for fuel mixture with pure hydrogen. The reduced mechanism with 25 species and 131 reaction steps is obtained from a detailed mechanism proposed by Wang [12] via a reduction method of directed relation graph with error propagation and sensitivity analysis (DRGEPSA) [13,14]. The present numerical method is validated by comparison of temperature profiles of hydrogen combustion with the experimental data reported by Gucorra et al. [15] for the DLR supersonic combustor. The supersonic combustion of mixture fuel of hydrogen, methane and ethylene is simulated and the effects of hydrocarbon components on flow and combustion properties are discussed. The present numerical work is expected to provide insights into combustion properties of fuel mixture of hydrogen and hydrocarbons with small molecules and to obtain better understanding of mechanisms of supersonic combustion.

Computational method

The computational domain

Fig. 1 gives configuration of a supersonic model combustor that has been experimentally tested at the German Aerospace Center (DLR) [15] as called as DLR supersonic combustor in many of previous literatures [16,17]. The channel has an inlet cross section of $40 \text{ mm} \times 50 \text{ mm}$, and the air has an inlet Mach number of 2.0 and an inlet static temperature of 340 K. There is a wedge-shaped strut placed at the center of the combustor and is located 35 mm downstream of the combustor entrance. The strut has a length of 32 mm and a height of 6 mm, where fuel is injected into the supersonic airflow at sonic velocity and with a static temperature of 250 K.

The airstream and the fuel inlet boundary conditions are fixed with pre-given pressures and total temperatures. Slip wall is applied for the top and the bottom walls of the combustor to avoid resolving wall boundary layer as used in previous numerical work of [18,19]. The strut walls are treated as adiabatic and no-slip wall. The boundary conditions at the combustor outlet is set to be non-reflection since supersonic flow is assumed at the outlet. For the present study, several mesh sizes (500×300 , 600×400 , 700×500) are tested for the study of grid independency. As shown in Fig. 2, the time averaged temperature profiles at a streamwise distance of $x = 125 \text{ mm}$ calculated with the mesh of 600×400 and 700×500 are very close to each other. Therefore, a mesh of 600×400 with a minimum grid spacing of $1.0 \times 10^{-6} \text{ m}$ near the wall is chosen for the present study.

The Turbulence closure is achieved by means of DES (Detached eddy simulation) approach based on SST $k-\omega$ model [20,21]. The dissipation of k is given by

Download English Version:

<https://daneshyari.com/en/article/7706649>

Download Persian Version:

<https://daneshyari.com/article/7706649>

[Daneshyari.com](https://daneshyari.com)