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Investigation of combustion process of a kerosene fueled combustor with air throttling

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ABSTRACT

An experimental and numerical study was carried out to investigate the combustion process of a kerosene fueled combustor with air throttling. The results were obtained with the inflow conditions of Mach number of 2.0, total temperature of 953 K and total pressure of 0.82 MPa, respectively. The air throttling was located 0.575 m downstream the combustor entrance, and the mass flux of air throttling was 27.2% inflow mass flux. The pilot flame was blown off by the room temperature kerosene when the kerosene supply pressure was 0.25 MPa, but the kerosene was ignited successfully when the throttling air was injected into the combustor, and the flame stabilization was achieved even when the pilot hydrogen was removed. The combustion process could be divided into four parts based on changes in the pressure monitored near the cavity: kerosene was ignited successfully by the pilot flame, and the mixture flame was stable during part-a. As the kerosene supply pressure was increasing, the flame was blown off by the room temperature kerosene in part-b. Successful ignition and flame stabilization had been achieved with the aid of air throttling in part-c, and the combustion mode was subsonic combustion. The flame was stable even after the pilot hydrogen was removed in part-d, but the combustion mode was supersonic combustion.

1. Introduction

Achieving flame stabilization is a difficult problem in scramjet combustor, because in supersonic combustor, the time available for fuel injected, vaporized, mixed with air, and combustion is very short, of the order of milliseconds [1]. This problem applies especially to hydrocarbon fuels such as kerosene that are often used in the scramjet, Which consists of long chains of hydrogen and carbon molecules with longer reaction times than smaller molecules (such as hydrogen and ethylene) and thus has long ignition delay times, often exceeding a millisecond [2]. So the flameholders should be used in the scramjet combustor in order to achieve flame stabilization. Some different kinds of flame holders, such as cavity [3–5], strut [6–9], step [10] and air throttling [11–14], have been investigated by many researchers.

Ignition transients in a scramjet engine with air throttling were investigated by Li and coworkers [13,14]. In their paper, a pre-combustion shock train was generated in the isolator due to the increased back pressure by the throttling air. The resultant increase in the temperature and pressure of the airstream in the combustor, along with the decrease in the flow velocity, lead to smooth and reliable ignition. The incidentally formed separated flows adjacent to the combustor sidewall improved fuel/air mixing as a result of enhanced flow distortion and increased residence time. Successful ignition could only be achieved with the aid of air throttling under the present flow conditions. Chemical reactions were intensified and produced sufficient heat release to maintain a flow environment conducive to flame stabilization. A self-sustaining mechanism was thus established between the flow and flame development. Stable flames were achieved even after the deactivation of air throttling. Our previous work studied the effect of air throttling on flow structure, fuel/air mixing, ignition transients and flame stabilization in the scramjet combustor [15–19]. Mathur et al. [20] conducted an experiment using air throttling to initiate combustion in a scramjet combustor. Their results showed that once the air throttling was removed after the flame establishment, the shock train was retained leading to sustained combustion if heat release was sufficient. Conversely, insufficient heat release might result in an unstable shock train and caused flame blowout. Donbar et al. [21] tested the operation sequence of ignition in an ethylene fueled scramjet combustor. Air throttling was used after a stable fuel condition was reached. Once ignition occurred by activating spark igniters, the air throttling was removed, after which sustained combustion proceeded.

From the above discussion, we found the effect of air throttling on flame stabilization had been investigated by several researchers, but most of them focused on gas (ethylene or hydrogen) fueled

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Fig. 1. Photo of the supersonic combustion facility in CARDC.

Nomenclatures

Ma	Mach number
ER	equivalence ratio
D	depth of cavity
L	length of cavity
P	wall pressure of combustor
t	time
x	distance from combustor entrance
T	mass averaged temperature

combustor. Few published papers investigated the effect of air throttling on room temperature liquid (kerosene) fueled combustor, which was our main purpose of the present paper. We used a small scaled cavity as a flameholder in the combustor in order to reduce the cavity drag, also the pilot hydrogen was used to ignite the room temperature kerosene, and air throttling was used to achieve flame stabilization after pilot hydrogen was removed.

2. Experimental and numerical simulation methods

2.1. Facility and combustor configuration

Experimental investigations were conducted on a direct-connected supersonic combustion facility (Fig. 1) in China Aerodynamics Research and Development Centre (CARDC). Hydrogen fueled heater was used to heat the air up to 1000 K and additional oxygen was added to maintain a 21% O_2 mole fraction in the vitiated air, and the mole fraction of H_2O and N_2 were 12%, and 67%, respectively. A pulse Mach 2.0 airflow was supplied via a two-dimensional nozzle which was connected to the upstream of the combustor. The total temperature and total pressure of the inflow were 953 K and 0.82 MPa, respectively.

The lab-scale combustor [19] was made of stainless steel and divided into two sections, which was shown in Fig. 2, the first section was a rectangular isolator with the length of 430 mm (350 mm straight section and 80 mm expansion section with upwall divergent angle being 1.4°) and the cross section area was 30 × $150mm^2$. The second section was the combustor which included a cavity (D: 11 mm, L/D: 11) and a four- part expansion section (range: 551mm–1070 mm). There were two fuel injected positions shown in Fig. 2, the first injector was designed for injecting room temperature kerosene and the second injector was designed for introducing pilot hydrogen, and the locations of the two injectors were 410 mm and 440 mm from the isolator entrance, respectively. The kerosene was injected at sonic speed at an angle of 90° to the airflow by fifteen 0.3 mm in diameter fuel injection holes, and the hydrogen was injected by ten 1.0 mm in diameter fuel injection holes, that of the throttling air were twenty 3 mm in diameter injection holes. The sampling frequency of pressure transducer was 1 kHz, which was used for measuring the wall pressure. Schlieren images were captured by a CCD camera, and the exposure time was 1μs and the frame rate was 10,000 fps. The chemiluminescence of CH* was used to mark the flame zones in the combustor. The luminosity from CH* was imaged by a CCD camera with ± 5 nm bandwidth interference filters centered at 430 nm and the exposure time was 1/2000 s.

The test sequence of the studying case was shown in Fig. 3 and Table 1, when hydrogen entered into the facility heater at $t = 1.80$ s, the cold flow then generated. The running time of the facility was about 600 ms (1.95s–2.57 s), when the supply pressure of hydrogen was kept as constant. The kerosene was injected into the combustor from $t = 1.95$ s to $t = 2.57$ s, and the supply pressure of kerosene was increased to 2.0 MPa (equivalence ratio: 0.3) from $t = 1.95$ s to 2.30 s. The spark in the combustor cavity was working all the test time, so the pilot hydrogen was ignited at once when it was injected into the combustor. The air throttling was started to be injected into the combustor at $t = 2.35$ s, just 0.04 s before pilot hydrogen was off. The location of air throttling was 0.575 m from the combustor entrance, and the mass flux of air throttling was about 27.2% inflow mass flux. The equivalence ratio (ER) of kerosene was 0.3, and the ER of pilot hydrogen was 0.08.

2.2. Numerical methods

In this study, the inhouse CFD code AHL3D [19,23] software which had been introduced in reference [18,19,23] was used for computation. A fully coupled form of species conservation

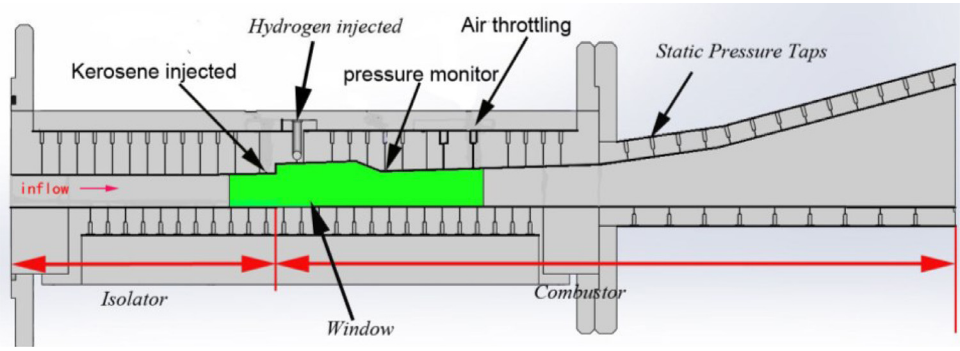

Fig. 2. Schematic illustration of the combustor.