Acta Astronautica 139 (2017) 24–33

Contents lists available at ScienceDirect

Acta Astronautica

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

Experimental study of cone-struts and cavity flameholders in a kerosene-fueled round scramjet combustor

Dongqing Zhang, Wenyan Song *

School of Power and Energy, Northwestern Polytechnical University, Xi'an 710072, China

ARTICLE INFO

Keywords:
Round supersonic combustor
Kerosene-fueled
Cone-struts
Cavity
Flame stability
Damkohler number

ABSTRACT

Experimental investigations of liquid kerosene ignition and flameholding in a round supersonic combustor are presented. Three kinds of flameholders, a cone-struts structure, a cavity and the combination of the both, are studied for the kerosene ignition and flameholding. Results show that ignition and flameholding cannot be achieved by using the sole cone-struts flameholder, although flames are observed at the combustor outlet. The ignition and flameholding are achieved in a narrow range of equivalence ratios by using the cavity flameholder. This range is widened by employing the combination of the cone-struts and the cavity flameholders. It is observed that the back pressure disrupts the isolator entrance flow slightly by using the larger cone-struts (CR = 0.261). However, it does not happen when the smaller cone-struts (CR = 0.221) is employed. Then a characteristic air mass flow rate in the round combustor is redefined to calculate a modified Damkohler number that correlates the nonpremixed flame stability limits. The correlations are in good agreements with the experimental results.

1. Introduction

Reduced corner flow effects, structural, cooling and friction drag advantages are realized by employing round structures in hypersonic systems [1,2]. However, a major challenge is the penetration of the injected fuel into the flow stream in round combustors if the wall injection is used, especially for large-scale combustors. For 2D combustors, the fuel injection gap can be reduced by employing high aspect ratio designs. For round combustors, it can be accomplished by the inclusion of in-stream fuel injection elements such as struts. The closer the gap is, the shorter the combustor is [3].

An innovative solution named Core Burning was proposed by Bulman and Siebenhaar [4] to solve these problems. The Core Burning combustor consists of a pilot combustor and a main combustor [5]. The pilot flame front is provided by the pilot combustor that is located in the core of the main combustor. This design confines the combustion to the core of the combustor and away from the wall thereby reducing the heat load on the wall. The ignition and flameholding capabilities of the pilot combustor are key factors for the robust combustion in the main combustor.

Cavities are usually regarded as the promising flameholders for scramjets [6]. In addition, Cavities also play important roles in another intriguing combustion process—Deflagration-to-detonation transition (DDT) [7–10]. The presence of cavities of wider cross section in the ignition part of the tube promotes DDT and shortens the predetonation length [8]. Increasing the number of the cavities promotes the DDT whereas the velocity of turbulent flame at the exit of the last chamber is subsonic. Further increase does not promote the DDT and even delays it in the case of a high cross-section ratio [9].

Other configurations as such struts, pylons and steps are also used as flameholders. Struts and strut-cavity configurations were experimentally and numerically studied [11–17]. The shape of struts will be a compromise on mixing characteristics and pressure losses. Strut-cavity configurations must ensure that the strut does not over augment the mass-exchange between the main flow and the recirculation region flow in the cavity [15]. At the same time, the strut-cavity configuration needs to be optimized to achieve a high performance. In addition, cantilevered struts anchored by additional structures will lead to a weight penalty [1].

In order to obtain a good flameholding capability for a round pilot supersonic combustor, we studied three kinds of flameholders, a cone-struts structure, a cavity and the combination of the both, experimentally. The experiments were conducted in the air flow of Mach number 3.27, total pressure 1.5 Mpa and total temperature 1500 K by using a CH_4-combustion heated test facility that is located in Supersonic Combustion Laboratory (SCL) of Northwestern Polytechnical University (NPU). The results of the experimental investigation of kerosene ignition and flameholding are presented. In order to analyze the flameholding capabilities quantitatively, an important nondimensional parameter, Damkohler number is usually used to correlate the flame blowout limit

* Corresponding author.
E-mail addresses: zdq@mail.nwpu.edu.cn (D. Zhang), wenyan_song@nwpu.edu.cn (W. Song).

http://dx.doi.org/10.1016/j.actaastro.2017.06.025
Received 3 May 2017; Received in revised form 21 June 2017; Accepted 24 June 2017
Available online 27 June 2017

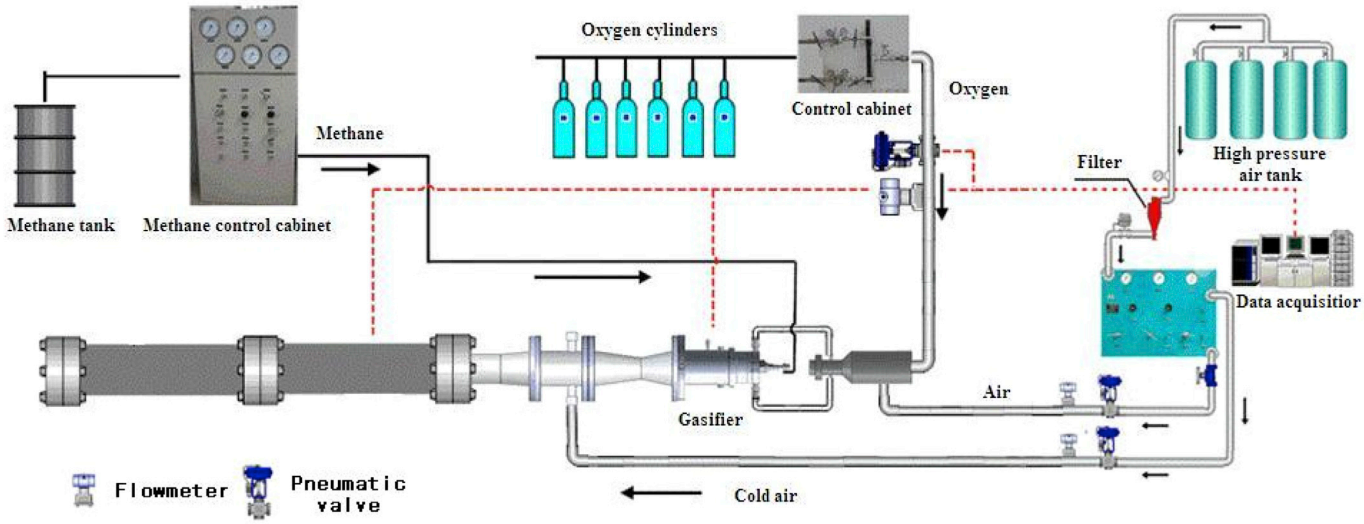

Fig. 1. Schematic of CH_4-combustion heater test facility.

[18–20]. The premixed flame blowout limits were summarized by Zukoski and Marble and by Ozawa [18,19], and the nonpremixed case was developed by Driscoll [20,21]. However, it is found that the Damkohler number of Driscoll is not suitable for the kerosene-fueled round supersonic combustor because the characteristic air mass flow rate, which is used to calculate the Damkohler number, is defined based on the rectangle structure [21]. Then the characteristic air mass flow rate is redefined for the round structure to calculate the nonpremixed Damkohler number. The correlations are in good agreements with experimental results.

2. Experimental descriptions

2.1. Supersonic facility

The experiments are conducted in a CH_4-combustion-heated direct-connect test facility that is located in SCL of NPU. Fig. 1 illustrates the facility system that mainly consists of a CH_4-combustion heater, gasses sources and control systems and etc. The facility has the capability of simulating flow conditions of stagnation temperature 800–2200 K, stagnation pressure 0.8–4.0 MPa and mass flow rate 0.5–2.5 kg/s. The

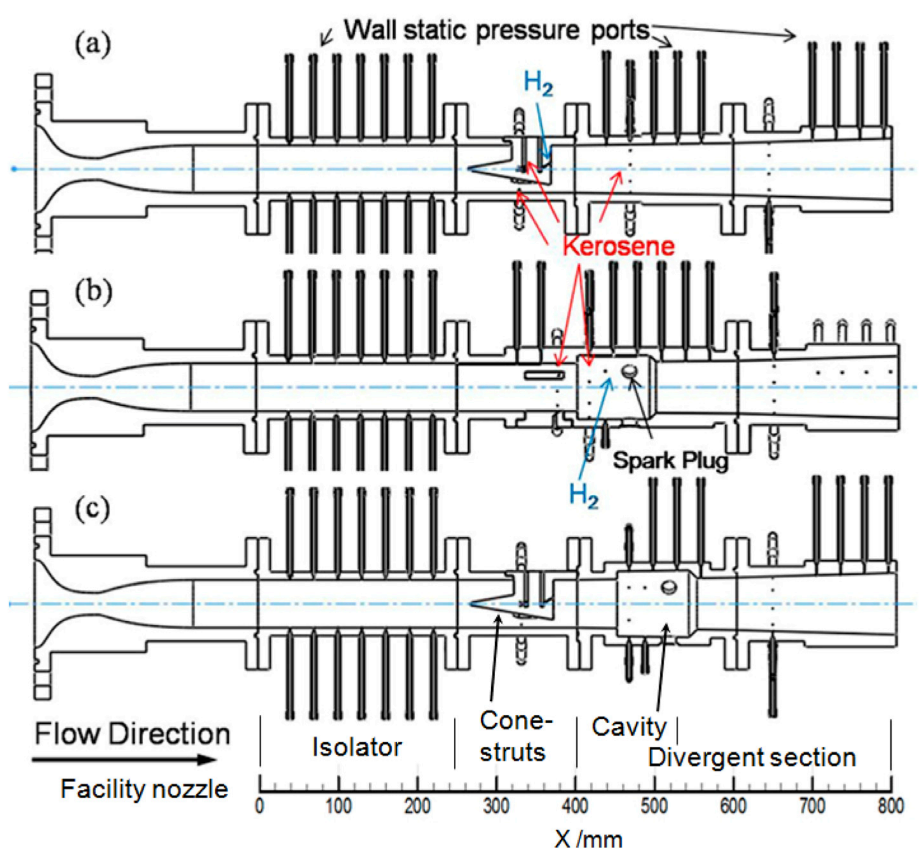

Fig. 2. Round supersonic combustor with different flameholders: (a) cone-struts (b) cavity (c) cone-struts & cavity.