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Research paper

Experimental and numerical studies on a trapped vortex combustor with different struts width

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HIGHLIGHTS

- An novel aerodynamic multi-point fueling (AMF) setup is designed for trapped vortex combustor main fueling.
- Effect of strut width on combustion and pollutant emissions is evaluated experimentally and numerically.
- Wider struts protect the tail combusting flow of struts and bluff body from being quenched by mainstream.
- Slenderer struts enhance mixing cavity flow and mainstream, and thus reduce NOx emission.

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ABSTRACT

To investigate the effect of strut width on combustion efficiency and pollutant emissions, a trapped vortex combustor with interchangeable aerodynamic multi-point fueling (AMF) setups is designed. Exhaust gas composition is measured at the exit of the combustor. Results show that lacking of protection of slenderer struts leads that the flame coming from cavity is prone to be quenched; thus combustion efficiency for cavity-only fueling conditions is relative lower. Thus, CO and HC emissions are relative higher. However, as main fueling is available, the corresponding overall combustion efficiencies become higher especially for $Ma = 0.3$. This can be attributed to larger number of struts and thus larger wet perimeter of mainstream passages. Additionally, activating of main fueling is helpful for decreasing CO and HC and thus elevating combustion efficiency. Numerical simulations of non-reacting and reacting flow are also accomplished. Although the numerical simulation results exhibit flow structure discrepancy between non-reacting and reacting simulations, the conclusion about protection of wider struts and mixing enhancement of slenderer struts are accordant.

1. Introduction

Due to increasingly deteriorated human living environment, various environment protection organizations have constituted more and more strict regulations to limit the using of the outdated technologies related to combustion [1,2]. Especially, gas turbine combustion emissions for aviation and power plant are getting more and more concerns nowadays. In order to diminish pollutant emissions produced in combustion processes, various novel combustion concept were developed [3–8].

Trapped vortex combustor (TVC) is a relatively new [9,10] and attract concept for its superior performance [11,12]. TVC concept was first evaluated by Hsu [9] and his cooperators in an Air Force Office of Scientific Research program in 1993. Since then, some different types of TVC were evolved [11]. Being different from conventional swirl-stabilized combustors, TVCs employ physical cavity to generate trapped vortex and consequently to stabilize flame. A TVC is actually a staged combustion system. The cavity flow (pilot flow) is separated from mainstream by shear layers from leading edges of the cavity, thus the cavity flow is also independent.

Abbreviations: TVC, trapped vortex combustor; AMF, aerodynamic multi-point fueling; CO, carbon monoxide; HC, hydrocarbons; NOx, oxides of nitrogen; CO_2, carbon dioxide; d, struts width, mm; L, mainstream passage length, mm; $\Phi_{overall}$, overall equivalence ratio calculated using overall air flow rate and overall fuel mass flow rate; Φ_{cavity}, cavity equivalence ratio calculated using cavity-fore air flow rate and cavity fuel mass flow rate; $\Phi_{mainstream}$, mainstream equivalence ratio calculated using main air flow rate and main fuel mass flow rate; EI, emission index, g/kg fuel; Ma, combustor inlet Mach number; m_f, fuel mass flow rate; SMD, sauter mean diameter.

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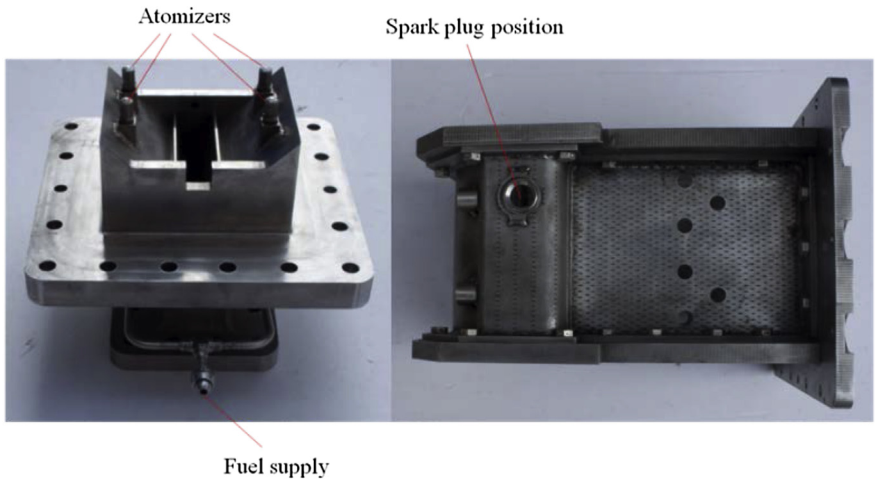

Fig. 1. Photos of the trapped vortex combustor (TVC): the left figure is assembly of diffuser and fuel system; and the right is the liner.

Owing to this feature, TVCs exhibit excellent stability. Synthetic performances of high pressure TVC sectors were tested [12]. Demonstrated results showed that the ignition, blow out and altitude re-light of the TVCs were up to 50% improved over current technology of conventional swirl stabilized combustors, and in the operating rage that is 40% wider than a conventional swirl combustor, TVC combustion efficiency could be maintained at or above 99%. Moreover, NOx emission levels were about 40%~60% of CAEP/2 standard.

A new concept that combines rich-burn, quick-mix, lean-burn (RQL) concept with TVC concept was reported by Straub [13,14]. Experiment been conducted at 10 atm and an inlet air temperature of 664 K. Also, the emission levels of this concept were predicted using the PSR-Mix-PFR model. Neglecting mixing limitations, excellent NOx and CO emissions performance (below 10 ppm) of the simplified RQL/LPP combustor model can be achieved. However, there is a large discrepancy between the experiment and the predicted results as the cavity equivalence ration increases.

Bucher and Edmonds and their colleagues [15] developed a lean-premixed TVC. Superior levels of emissions were achieved in the LP/TVC model combustor. NOx, CO and UHC are respectively 9 ppm, 9 ppm and 0 ppm. Simultaneously, the corresponding combustion efficiency is above 99.9%. Furthermore, an improved lean-premixed TVC called Advanced Vortex Combustor (AVC) has been developed and tested [16]. The AVC showed simultaneous NOx/CO/UHC emissions of 4/4/0 ppm, and even lower NOx of 3 ppm was achieved.

Agarwal [17] and his colleagues adopted some methods to enhance mixing cavity flow and mainstream. The inclined struts utilized in the compact trapped vortex combustor are is observed to produce significantly improved mixing and increased flame coverage in the main duct leading to exit pattern factor values as low as 0.1.

Merlin et al. discussed flow and flame dynamics inside a can-type TVC from large eddy simulation (LES) results compared against experimental results [18]. The results suggest that swirling motion is beneficial to the global burner stability.

According to the literatures mentioned above, few works about the effect of struts width on combustion efficiency and emissions have been conducted. The next sections will focus on this topic. A trapped vortex combustor with is designed for experimental study, and non-reacting and reacting numerical analyses are also conducted.

2. Combustor model and experimental setup

2.1. Combustor model

To reveal the effect of struts width on combustion and emissions characteristics, a trapped vortex combustor with an interchangeable aerodynamic multi-point fueling (AMF) setup is designed. Some parts of the trapped vortex combustor are shown in Fig. 1. Four simplex atomizers are employed for fuel supplying into the two cavities. As seen in the left figure, the fuel system is integrated with a single passage diffuser, and the liner comprising 0.7 mm and 20 inclined multi cooling hole as well comprising several dilution holes is showed in the right part of this figure. A movable sleeve is set at one of the cavities for spark plug fitting. The combustor assembly also comprises a casing that is not shown in Fig. 1.

The three dimensional liner of the trapped vortex combustor is schematically depicted in Fig. 2. The cavity flow form double vortexes where the burned hot mixture heats and ignites the fresh air and fuel mixture. There are two flow streams enter into each cavity, one called cavity air enters the cavities from the fore inlet near the bottom of the cavity, another is called driving air that enters the cavities from back inlet approximately at the middle of the back

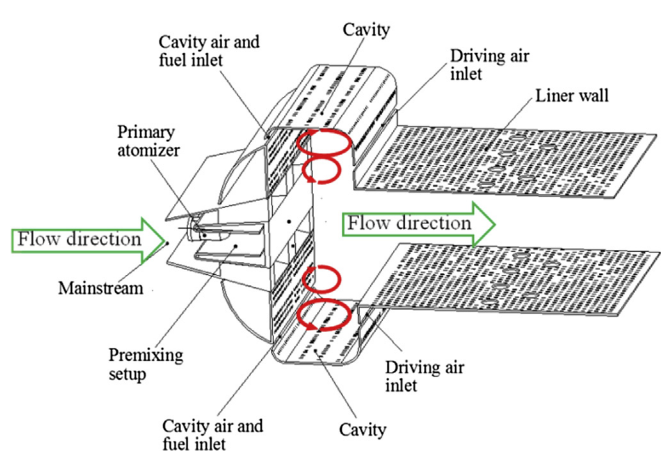

Fig. 2. Schematic of the TVC liner.