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Effect of dilution holes on the performance of a triple swirler combustor

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Abstract A triple swirler combustor is considered to be a promising solution for future high temperature rise combustors. The present paper aims to study dilution holes including primary dilution holes and secondary dilution holes on the performance of a triple swirler combustor. Experimental investigations are conducted at different inlet airflow velocities (40–70 m/s) and combustor overall fuel–air ratio with fixed inlet airflow temperature (473 K) and atmospheric pressure. The experimental results show that the ignition is very difficult with specific performance of high ignition fuel–air ratio when the primary dilution holes are located 0.6*H* (where *H* is the liner dome height)downstream the dome, while the other four cases have almost the same ignition performance. The position of primary dilution holes has an effect on lean blowout stability and has a large influence on combustion efficiency. The combustion efficiency is the highest when the primary dilution holes are placed 0.9*H* downstream the dome among the five different locations. For the secondary dilution holes, the pattern factor of Design A is better than that of Design B.

1. Introduction

Many future aircraft turbine engines are expected to operate with higher turbine inlet temperature than those typical of current technology engines. These increased turbine inlet temperature requires combustors with higher temperature rise (ΔT) capabilities than those of current technology combustors.[1,2] For high temperature rise combustors, there exist many challenges, and among them operating stably over significantly wider fuel–air ratio ranges and reducing pattern factor are of primarily important challenges. Utilizing multiple

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counter-rotating and co-rotating swirlers is considered to be a feasible approach, which could not only widen the stable combustion range, but also satisfy the other combustion performance. Mongia and his colleagues conceived, designed and demonstrated six high temperature rise combustors during 1979–1993 timeframe and multiple swirler were utilized for temperature rise combustors exceeding 1200 K. From the aspect of engineering application, Mongia has proved that a multiple swirler combustor is a promising solution for high temperature rise combustors.[3]

Triple swirler is a typical representation of multiple swirler and the topic of the present investigation. The research on triple swirler has been for many years and some valuable research results have been gained. Li et al. focused on experimental investigation of a triple annular research swirlers (TARS) which features three swirling flow passages and distributed fuel injection pattern.[4–7] In Refs.[4–6], they found that a central recirculation zone, an annular jet with internal and external shear layers characterize the flow field downstream of TARS. The central toroidal recirculation zone (CTRZ) region is axisymmetric but the jet contains imprints of the internal flow and has some nonaxisymmetric features. In Ref.[7], they studied the effects of several factors, including swirler combination, exhaust nozzle, air assist and mixing tube on NO_x and CO emissions and combustion instability. Experimental data shows that emissions and stability depend on the combination of some of these factors. Lin et al. experimentally investigated the lean blowout (LBO) limit, combustion efficiency and smoke feature of a triple swirler combustor.[8–10] In Ref.[8], experimental results exhibited that the increasing of fuel–air ratio in dome had a good effect on fuel–air ratio at lean blowout. And in Ref.[9], their experimental results show that the hybrid multi-stage swirling cup can improve combustion and enhance combustion efficiency with combustor inlet pressure ranging from 0.07 MPa to 0.11 MPa. Ref.[10] showed that the smoke number was greatly reduced (decreased by 29.4%), with lean blowout decrease by 7.3% by modificating the lip of the outer swirler which controls the mixture of oil and air. The above research results show that triple swirler combustor has the advantage of wider stable combustion range, enhancing fuel–air mixing, high combustion efficiency, extremely low emissions and so on.

Obviously, the previous efforts mainly focus on the effect of triple swirler on the performance of combustor. For a swirl stabilized combustor, dilution jets play a vital role in controlling the combustion temperature, enhancing mixing, and achieving satisfactory combustion performance. In the primary zone, primary dilution jets are required to provide more uniform mixing to promote efficient combustion. The attainment of a satisfactory temperature distribution in the exhaust gases is mainly dependent on the degree of mixing between air and combustion products in the dilution zone. Mellor[11] emphasized that interactions between swirler, primary dilution jets, and cooling flows are known to be important, but the effects of these interactions on combustion performance have not been systematically studied. Although extensive work has been carried out to study and characterize the secondary dilution jet mixing processes in the dilution zone of the combustor,[12–14] very few studies were concerned with a triple swirler combustor whose amount of secondary dilution jet was decreased greatly.

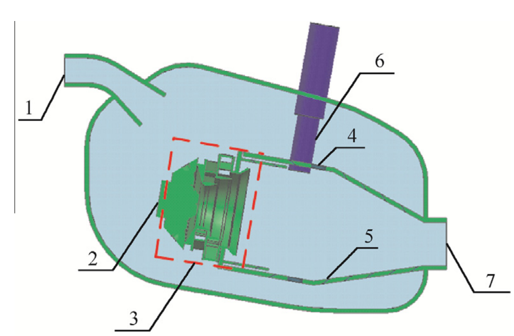
The purpose of the paper is to study the effect of dilution air jets including primary air jets and dilution air jets on the performance of triple swirler combustor. Multiple factors, including the shape and type of dilution holes, the ratio of the diameter of dilution holes to the thickness of liner, the primary dilution holes location, the arrangement of the secondary dilution, etc., affect dilution air jets. In this paper, we only discuss the effect of the primary dilution holes location and the arrangement of the secondary dilution holes on the performance of a triple swirler combustor.

2. Experimental setup

A schematic diagram of the triple swirler combustor is shown in Fig. 1. The combustion chamber is composed of four main sections: casing, liner, diffuser and the dome. The dome comprises of fuel nozzle and a fixed triple swirler. The fuel nozzle used in the experiment is a single pressure swirl atomizer instead of originally designed air blast atomizer with the purpose of ensuring good atomization at high fuel–air ratio. The pressure swirl atomizer has a cone angle of 80°. The triple swirler (see Fig. 2) consists of inner swirler, intermediate swirler, outer swirler, primary venturi, secondary venturi and flare. The fixed triple swirler has the swirl number combination of 1.5-1-0.8 and the rotational direction combination of “C-CC-C” in the order of inner, intermediate and outer swirler, where “C” and “CC” are labeled the clockwise and counter-clockwise rotating swirl direction relative to oncoming flow respectively. The airflow through these swirlers becomes swirling air jet, and the fuel sheet breaks up into droplets by the shearing action between these swirling air jets in the dome zone. The diffuser is joined with casing, which has a window on its side in order to visualize the primary zone combustion status. The liner is made of high temperature alloy with thickness of 2 mm. There are multi-rows inclined multi-holes, the first-row primary dilution holes and the second-row secondary dilution holes in the liner.

The combustor in the experiment of the present paper is designed[15–18] at design point’s fuel–air ratio of 0.033 and it is a small mass flow rate combustor. The combustion chamber has the following characteristics:

(1) A triple swirler configuration was conceived along with significantly increased combustion air with about 42.01% of the combustor air mass flow.



1—Inlet; 2—Fuel nozzle; 3—Triple swirler; 4—Primary holes; 5—Inclined multi-holes; 6—Spark plug; 7—Outlet

Fig. 1 Schematic diagram of the triple swirler combustor.