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Research paper

Experimental and numerical investigations on liner cooling characteristics of a trapped vortex combustor

Zhang Jingyu [a, b, *], He Xiaomin [a, b], Wang Lu [a], Jin Yi [a]

[a] College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 210016, PR China
[b] Jiangsu Province Key Laboratory of Aerospace Power System, Nanjing, Jiangsu 210016, PR China

HIGHLIGHTS

- The highest wall temperatures were obtained in the injector plane.
- The cooling effectiveness increases as the *Ma* increases.
- The cooling effectiveness decreases as the inlet temperature increases.
- The cooling effectiveness increases as the excess air ratio increases.
- The impingement/effusion geometry achieves the lowest wall temperature.

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ABSTRACT

Experimental and numerical investigations have been carried out to examine the cooling effect of the liner wall of the cavity zone and the dilution zone in a trapped vortex combustor. The flow field and heat transfer characteristics of three cooling schemes are examined by numerical simulations. Experimental efforts focus on two of the three schemes investigated by numerical simulation, the effects of the inlet temperature, the inlet Mach number and the excess air ratio on the dilution wall temperature are obtained. The results show that, the numerical data agree well with the experimental results. The lowest wall temperature, the highest surface heat transfer coefficient, the highest cooling efficiency are achieved with the impingement/effusion cooling scheme.

1. Introduction

The trapped vortex combustor (TVC) concept has been investigated for about 20 years ever since it was proposed in 1993 [1–4]. Previous studies have proved that TVCs offer significant improvements in lean blowout, altitude relight, operating range and NOx emissions as compared with conventional swirl stabilized combustors [5–7]. Recently, as the TVC concept becomes more and more feasible to be employed in actual aero engines, effective liner wall cooling has accordingly become an important issue.

State of the art cooling techniques include film cooling, effusion cooling, impingement/effusion cooling, multi-perforated plate, floating tile and ceramic-matrix composite liner [8–12]. In this paper, various cooling schemes are designed for the cooling of the liner walls both in cavity zone and in the dilution zone. The cooling characteristics of these cooling schemes are examined under high-temperature, high-pressure inlet conditions both numerically and experimentally. In addition, the effect of the flow and combustion on the wall temperature and the heat transfer characteristics are also evaluated.

2. Liner cooling schemes

2.1. Trapped vortex combustor model

The trapped vortex combustor model, as depicted in Fig. 1, is comprised of a diffuser, casing and liner. The zone within the liner can be divided to the cavity zone , the primary zone and the dilution zone.

* Corresponding author. College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 210016, PR China. Tel.: +86 13851691671; fax: +86 25 84893666.
E-mail address: zjyhxm@nuaa.edu.cn (Z. Jingyu).

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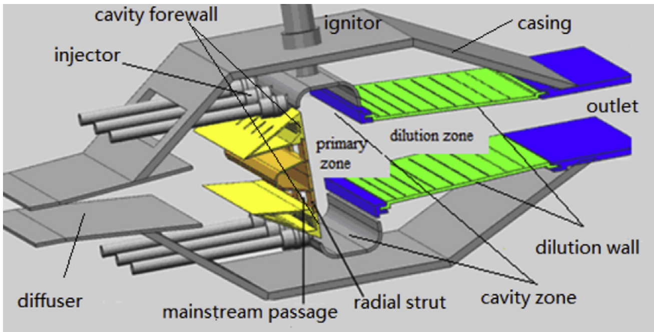

Fig. 1. Schematic of the TVC model.

2.2. Cooling geometries

The cooling geometries are designed based on the requirement that the amount of the coolant is no more than 25% of the total combustor inlet air (about 5% for the cavity forewall, about 20% for the dilution wall).

1) Cavity forewall

In the cavity forewall, the cooling air is introduced through five rows of 1 mm-diameter effusion hole, the films are then formed on the hot side to protect the wall. The inner two rows of holes are inclined at the angle of 45° pointing inwardly to the centerline of the combustor, the outer three rows of holes are inclined at the same angle with that of the inner two rows, however, pointing the outwardly to the bottom wall of cavity. The flow of the cooling air in the cavity forewalls is expected to be incorporated with the vortical flow pattern in the cavities. The geometry of the cavity forewall is shown in Fig. 2.

2) Dilution wall

Numerical results of the models which are not arranged cooling structures reveal that the local adiabatic wall temperature in

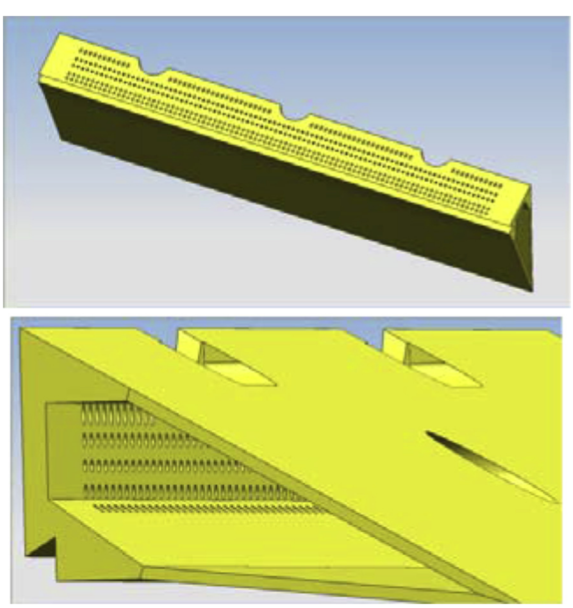

Fig. 2. Schematic of the cavity forewall.

Table 1
The geometry of the dilution wall.

Cooling geometry	D_m (mm)	D_j (mm)	H (mm)
Geometry 1 effusion wall	1.5	–	–
Geometry 2 effusion wall	1.0	–	–
Geometry 3 impingement/effusion	1.0	1.0	1.0

D_m: diameter of film hole.
D_j: diameter of impingement hole.
H: impingement height.

dilution wall can reach as high as 2000 K, and that the adiabatic wall temperature in the upstream dilution wall is noticeably higher than that in the downstream dilution wall. Based on the results, three cooling schemes are designed for the dilution wall. The configuration and geometrical parameter of the three cooling schemes can be seen in Table 1.

The cooling hole's arrangement of effusion wall configuration is shown in Fig. 3. Nine rows of cooling holes are set in the streamwise direction, and the inclination angle for all the holes are 45°, the amount of the cooling air is under control to be 15%–20% of the total air flow. The relative projection position of the impingement holes and the effusion holes is schematically shown in Fig. 4. All the ratios of the effusion hole-area to the area of the whole liner wall are fixed as 0.0302. So the amount of holes is different for different diameters. The smaller the diameter of holes is, the smaller the pitch of holes is. And the amount will correspondingly increase.

3. Experimental investigations

3.1. Experimental setup and test conditions

The schematic of the experimental setup can be seen in Fig. 5. The experiments system were conducted with an air supply maximum mass flow rate up to 2 kg/s, and the air can be heated to temperatures ranging from room temperature to 200 °C by an electric heater. NI PXIe-1082 data acquisition system was employed for temperature measurement. Table 2 shows the experimental condition for the measurement. The fuel of the experiment is kerosene (RP-3).

Fig. 6 shows locations of the 9 K-type thermocouples (marked from 1 to 9 respectively). The number1, 4 and 7 are in the injector plane, the number3, 6 and 9 are in the middle plane between two adjacent injectors, and the number2, 5 and 8 are in the middle plane between the two planes discussed above. A 9-element B-type thermocouple rake is set at the outlet of the combustor to measure the burnt gas temperature.

3.2. Experimental results and analysis

The cooling effectiveness is defined [13] as

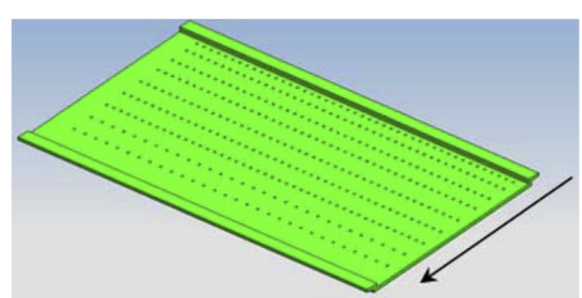

Fig. 3. Cooling hole arrangement of the dilution wall.