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# Experimental and computational study on combustion performance of a kerosene fueled dual-mode scramjet engine

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ABSTRACT

Dual-mode scramjet has a good thrust performance in the wide range of flight Mach number. The effect of equivalence ratio and fuel distribution on combustion performance of the dual-mode scramjet engine was investigated by numerical simulations and experiments in this paper. The results were obtained under the inflow condition with Mach number of 2.0, total temperature of 1100 K, and total pressure of 1.0 MPa. When the total equivalence ratio was 0.6, there were large differences in combustion performance of different fuel distribution cases, the combustion performance was better when kerosene was injected in front of the first cavity (defined as K1), the position of thermal throat was different in each case. When the total equivalence ratio was 0.8, there were little differences in combustion performance of the same fuel distribution cases, but the position of thermal throat was at the same location. The position of thermal throat was also at the same location when the equivalence ratio of K1 was increased, the size of separation zone in the isolator was increasing. The flow structure of this dual-mode scramjet was stable when the combustion mode was subsonic combustion. The thrust increased as the total equivalence ratio was increased.

## 1. Introduction

The scramjet engine has become one of the most important candidates for hypersonic flight propulsion systems. When the flight Mach number is bigger than 3, in order to obtain the best combustion performance, both subsonic and supersonic combustion should be obtained by a fix-shaped dual-mode scramjet combustor. When the flight Mach number is between 3 and 6, the combustion mode should be subsonic combustion, when the flight Mach number is larger than 6, the combustion mode should be supersonic combustion. Thus, it is a significant work to study the combustion performance of a dual-mode scramjet engine.

Dessorness et al. [1] studied on the influence of equivalence ratio on combustion mode transition, they found that the combustor changed from supersonic combustion mode to subsonic combustion mode as the equivalence ratio became larger. Sunami et al. [2] studied on the mechanism of the mode transition from the weak combustion to the intensive combustion. In the weak combustion mode, the ignition and combustion of fuel occurred within the boundary layer in the combustor. The pressure and temperature increased as the fuel flow rate was increased for the fuel heat release. The reaction region propagated upstream through the boundary layer or through its separation when the pressure rose largely, the intensive combustion mode with separation of the boundary layer was obtained. Kanenori et al. [3] investigated the downstream combustion ramjet-mode operation in a dual-mode engine combustor. Subsonic combustion was attained in the downstream straight-duct section without a geometrical throat in the downstream combustion. Better thrust performance and combustion were observed in the upstream combustion ramjet mode than in the usual upstream combustion ramjet mode. In the case of the downstream combustion ramjet mode, injection of a larger amount of fuel was possible and a large impulse function was attained, for the separation region did not go far upstream.

The above researches are focused on the dual-mode combustor associated with cavity flameholding, while a series of research on combustion performance and combustion mode transitions were conducted by Harbin Institute of Technology using the dual-mode combustor associated with center strut flameholding. Firstly, the flush wall supersonic combustor equipped with center strut flameholding was studied experimentally by Refs. [4–8]. The center strut flameholding with the flush wall is a novel supersonic combustor

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**Nomenclature**

| | | | |
|---|---|---|---|
| *Ma* | Mach number | *K2* | Injector K2 |
| $T_t$ | Total temperature | *K3* | Injector K3 |
| $P_t$ | Total pressure | $P_{wall}$ | Pressure of wall |
| $Ht_{add}$ | Total enthalpy added | $P_{in}$ | Inflow static pressure |
| *K1* | Injector K1 | *ER* | Equivalence ratio |

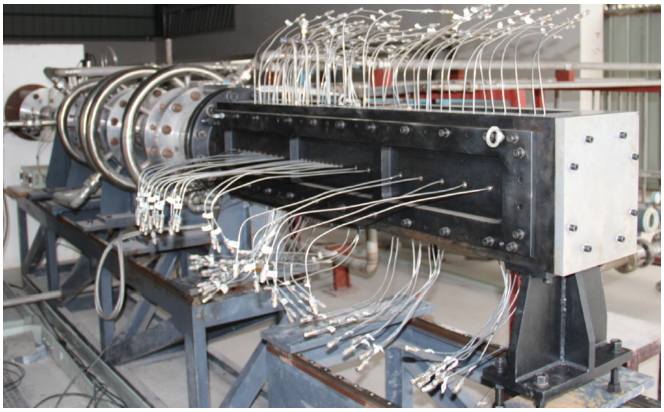

**Fig. 1.** Photo of the CARDC's supersonic combustion facility.

in contrast with the cavity [4,5], and the fuel injection strategy between the strut and the wall was conducted by experiment [6], and the effects of upstream strut on the combustion of liquid kerosene in a model cavity scramjet was discussed [7,8]. For the novel supersonic combustor with flush wall, the combustion mode transformation characteristic needs to be investigated deeply. Some novel characteristics were found, and these can provide some beneficial references for the current research. Based on the flush wall supersonic combustor, the flame transition characteristics at different combustion modes [9], the dynamics characteristic at different combustion mode transitions [10], the effect of combustion modes on the performance of scramjet engine [11], the analysis of combustion mode and operating route for scramjet engine [12] were discussed respectively. Beside of the experiment results, the mechanism of combustion mode transition [13,14] was explained from the viewpoint of thermodynamics cycle analysis. From the above investigation, we know, many factors would influence on the combustion mode in the combustor. In this paper, the effect of the equivalence ratio and fuel distribution on combustion performance in dual-mode scramjet combustor was studied by CFD and experiments.

## 2. Numerical simulation and experimental methods

### 2.1. Facility and scramjet configuration

The dual-mode scramjet engine was directly connected to China Aerodynamics Research and Development Center (CARDC)'s supersonic combustion facility (Fig. 1). A $H_2/O_2$ vitiated air heater was used to generate high enthalpy airflow supplied into the combustor. Oxygen was fed into the heater to obtain test gas with its mole fraction of oxygen being equal to that of standard air. The mole fraction of $O_2$ was 21%, that of $H_2O$ was 12%, and that of $N_2$ was 67%. Total temperature ($T_t$) of the test gas was 1100 K and total pressure ($P_t$) was 1.0 MPa. The test gas was accelerated by the nozzle to Mach 2.0, the running time of the facility was about 5.0 s.

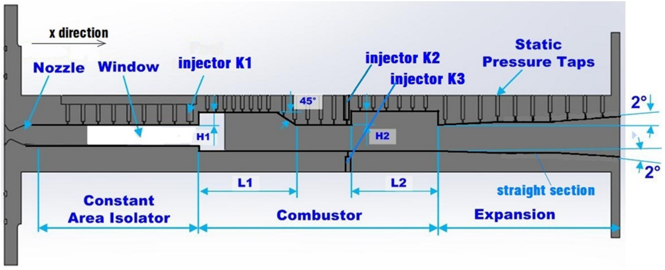

**Fig. 2.** Schematic illustration of a dual-mode scramjet.

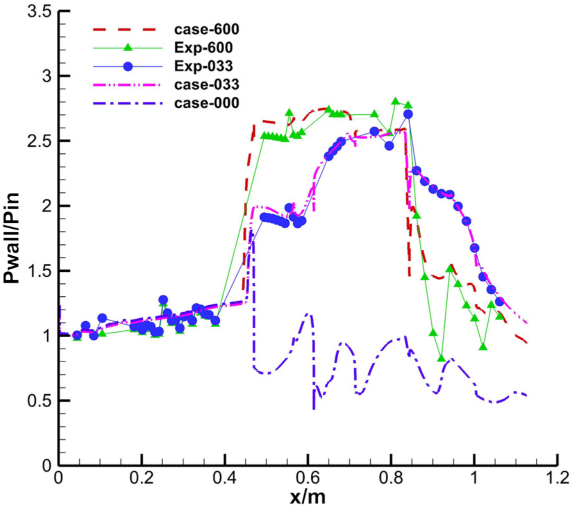

**Fig. 3.** Distribution of nondimensional wall pressure of total ER 0.6 and 0 cases. (upwall: upwall of the dual-mode scramjet; case-600: computational results of case-600; Exp-600: experimental results of case-600; case-033: computational results of case-033; case-000: computational results of case-000; Exp-033: experimental results of case-033).

A schematic illustration of the combustor model was shown in Fig. 2, the model consisted of a constant area isolator, a combustor, and an expansion section. The cross-sectional area was $30 \times 150\ mm^2$ in the isolator, the isolator length was 0.47 m. The combustor length was changed from 0.47 m to 0.84 m, which included three sections: first cavity ($L1/H1 = 11$, $H1 = 10$ mm), straight part (range: 0.58 m–0.72 m) and second cavity ($L2/H2 = 12$, $H2 = 10$ mm). There were three fuel-injected locations (K1, K2, and K3) shown in Fig. 3. The first injector K1 was located 15 mm upstream of the first cavity. There were 10 fuel injection holes (0.5 mm in diameter, 13.2 mm interval in span wise direction) at stream wise location of $x = 455$ mm from the entrance of isolator ($x = 0$ mm) on the upwall. The injector K2 was located 8 mm upstream of the second cavity. The injector K3 was the same position with the injector K2 in the flow path, opposite wall to the location of K2. There were 8 fuel injection holes (0.5 mm in diameter, 13.3 mm interval in span wise direction) at stream wise location of $x = 717$ mm on both sidewall. The expansion section consisted of three parts: first expansion (range: 0.84 m–0.90 m), straight part (range: 0.90 m–1.0 m), and second expansion (range: 1.0 m–1.13 m). The location of pilot $H_2$ was 10 mm upstream of K1 position. There were 10 $H_2$ injection holes (1 mm in diameter, 12.7 mm interval in span wise direction) at stream wise location