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The effect of kerosene injection on ignition probability of local ignition in a scramjet combustor

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ABSTRACT

The spark ignition of kerosene is investigated in a scramjet combustor with a flight condition of Ma 4, 17 km. Based plentiful of experimental data, the ignition probabilities of the local ignition have been acquired for different injection setups. The ignition probability distributions show that the injection pressure and injection location have a distinct effect on spark ignition. The injection pressure has both upper and lower limit for local ignition. Generally, the larger mass flow rate will reduce the ignition probability. The ignition position also affects the ignition near the lower pressure limit. The reason is supposed to be the cavity swallow effect on upstream jet spray near the leading edge, which will make the cavity fuel rich. The corner recirculation zone near the front wall of the cavity plays a significant role in the stabilization of local flame.

1. Introduction

Reliable ignition in supersonic flow is a key technology for scramjet engines. Since the scramjet engine cannot start from ground takeoff, it must be boosted by another propulsion system to a high-speed, approximately Mach 4. Therefore, the ignition of scramjet engine should mainly base on low Mach flight condition [1].

For the scramjet engines whose flight Mach is under 8, kerosene is more promising than hydrogen fuel due to its high enthalpy, high density and easy storage under condition. However, compared with hydrogen fuel, kerosene is liquid in room temperature, which makes the mixing, ignition and combustion process inside the scramjet combustor more complex. Moreover, the chemical reactivity of kerosene is much weaker than hydrogen, which will affect the minimum ignition energy and ignition delay time. Normally, in scramjet ground tests fueled with kerosene, small amount of H2 is added as piloted ignition of source [2,3]. This method needs to use additional storage, control and delivery system for hydrogen and makes the flight system complexity. Li [4] employed a plasma to ignite the liquid kerosene in Ma 4 flight condition. However, the plasma igniter need an 1.5 kW electric energy source, which is too large for the aircraft system. To simplify the ignition system of the kerosene-fueled scramjet engine, the possibility of high-energy spark ignition has been explored by our research group [5,6]. Although spark ignition can be successful in some situations, but plenty of misfire still remain. In order to ensure the reliability of kerosene spark ignition in scramjet engine, more careful researches still need to be accomplished.

An ignition event can be judged from both flame light emission and pressure rise owing to heat release. Masumoto [7] has observed four combustion modes, namely non-ignition, weak combustion (with little pressure rise), supersonic combustion, and dual-mode combustion. In the weak combustion mode, reaction was active in the mixing layer between the airflow and fuel jet. Accordingly, Xi [1] introduced the concepts of local ignition and global ignition. In a local ignition event, the pressure rise in the combustor is insignificant and the flame is self-sustained and trapped only in circulation zones, but failed to spread into the primary flow. On the other hand, in the global ignition event, the pressure rise in the combustor owing to combustion is high and the flame propagation into the primary flow with flame convection down stream [8]. However, in our previous work [6], local ignition is much easier to realize than global ignition, and local flame produced by local ignition can transfer to global flame after some sequences. So it is meaningful to investigate the formation condition of local ignition.

In this present work, the spark ignition of kerosene are studied at Ma 4, 17 km flight condition. The high-speed camera and pressure scanner are used to record the characteristics of local ignition. The ignition probabilities have been measured based on wall pressure evolution. The effect of upstream injection setups on ignition probability has been acquired, and the reason of misfire has been analyzed.

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Table 1
Conditions Simulated by air heater.

Parameter	Value
Air (g)	1173.75
Oxygen (g)	91.98
Alcohol (g)	30.66
Total pressure (MPa)	0.86
Total temperature (K)	880
Mach number	2.03
Oxygen mass fraction	0.2337

2. Experimental facility

2.1. Air heater system

The direct-connected test facility consists of four parts, including the vitiated air heater, supersonic nozzle, isolator and scramjet combustor model. By combusting alcohol with oxygen continuously, the air heater can provide high pressure and high temperature vitiated air. The standard mass flux of three components and the theoretical results of air heater is shown in Table 1. As the ignition results are sensitive to the oxygen mass fraction of the vitiated air, throttling devices are used to ensure the stabilization of mass flux. In order to ensure the reliability of experimental results, we only choose the experiments whose oxygen mass fractions are between 0.231 and 0.235. As a result, the total pressures of the vitiated air are between 0.8427 MPa and 0.885 MPa, and the total temperatures are between 861 K and 893 K.

2.2. Model combustor

Fig. 1 shows the configuration of the two-dimensional combustor and wall pressure measuring points. The height and width of the isolator entrance are 40 mm and 50 mm. The below side of combustor has an expand angle of 2.25. Two cavities are installed on the up side of combustor. The upstream cavity (T1) was 20 mm in depth and 100 mm in length, with aft angle of 45, while the downstream cavity (T2) was 25 mm in depth and 175 mm in length, with aft angle of 45.

An injection model is installed upstream against to cavity T1. The injection model has two sets of injection orifices, named as A and B. As the injection is rectangle, the injection model can be turned around to change the distance between the orifices and T1 cavity leading edge. The mass flow rates of the two injections have been measured during the experiments and the results are shown in Fig. 2. The experimental data match well with the fitted curves. According to the fitted curves, the orifices of injection A are bigger than the orifices of B.

2.3. Measuring method

Fast images of the spark sequence and the subsequent ignition event are acquired with a Photron FASTCAM-Ultima APX. In this experiment, the camera is set to 1000 fps with a region of 1024*512 pixels. The wall pressure distributions are measured by Intelligent Pressure Scanner Model 9116. A high-energy spark is adopted in ignition tests. According to the product specification, the energy of the spark is 4.5 J per lighting, with impulse frequency of 50 Hz. In the present work, we concern the effect of kerosene injection on spark ignition, so the installation site of spark plug is fixed as shown in Fig. 3. The ignition probability test operation sequences are shown in Fig. 4. The sequences have four repeated ignition events. In each ignition events, spark work with injections for 300 ms.

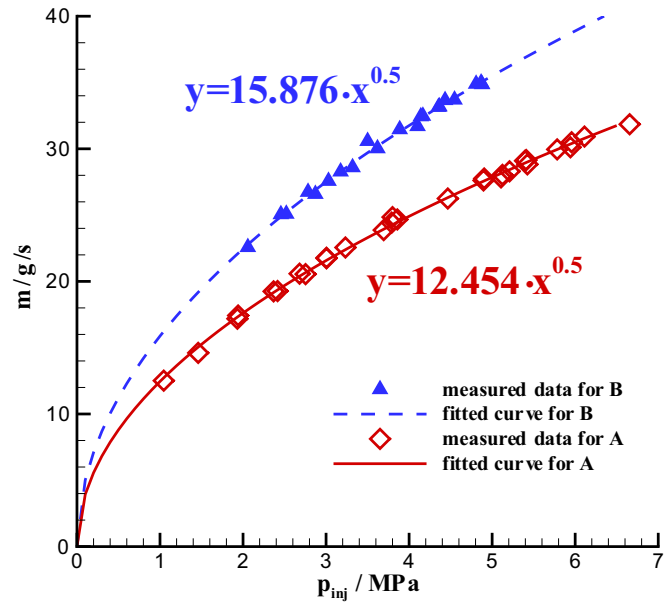

Fig. 2. The mass flow rate of two injection sets.

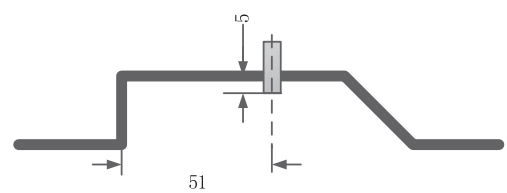

Fig. 3. Location of spark plug.

3. Results and discussion

3.1. Ignition judgement

The process of local ignition is illustrated in Fig. 5, and the wall pressure during ignition is shown in Fig. 6. In Xi [1] article, the local ignition can be observed by high-speed camera, but don't have pressure response. However, in the present investigation, when a local ignition is observed by the camera, the wall pressure inside T1 or downstream near the aft edge of T1 (namely the pressure site 6, 7, 8 and 9) will rise obviously, while other wall pressure sites do not change significantly. This characteristic can be the criterion to distinguish local ignition from non-ignition instead of by optical observation. The local flame produced by local ignition can be self-sustained. An unstable process of local flame is shown in Fig. 7. The local flame seems to be blown out in the first six images, and the flame draw back to the corner recirculation zone near the front wall of T1. In the last six images, the flame in the corner recirculation zone expands back to the whole cavity recirculation zone and forms a local flame again. The corner flame near the front wall seems to be the key point of local flame stabilization.

3.2. The treatment process for ignition probability

Sparking a turbulent non-premixed flow need extra spark energy to

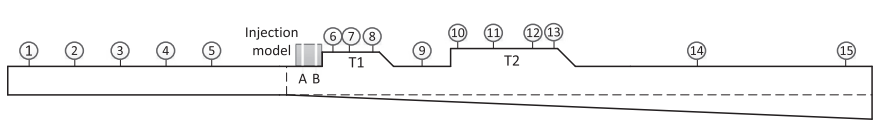

Fig. 1. Schematic diagram of combustor with cavity.

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