The performance of dual combustion ramjet based on free-jet experiments

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Hypersonic vehicle attracts great attention in recent years and is considered as the best way to realize single-stage-to-orbit (SSTO) or two-stage-to-orbit (TSTO) because of several advantages, such as high specific impulse and high lift-drag ratio. However, considering the risks and technology readiness level, hypersonic missile is the first and practical step.

In hypersonic flight condition, scramjet shows good performance and is prosperously investigated all around the world, while Dual combustion ramjet (DCR) attracts very little attention. In fact, DCR combines the best features of a ramjet and scramjet, and has several merits: wider range of operating Mach number (3.5~6.5), easier ignition and more stable combustion, higher performance at low Mach number, and more convenient cooling of the wall. One disadvantage is that it becomes deficient when the flight Mach number exceeds 6.5 or 7. Waltrup studied the application of DCR in hypersonic tactical missile, focusing on optimal operating parameters.

DCR was firstly proposed by Billig et al. of John Hopkins University (JHU) in 1980s. DCR is mainly composed of a subsonic preburner and a supersonic combustor. Because it is difficult for liquid kerosene to combust in supersonic flow, the subsonic preburner is used to preheat the spray of liquid kerosene and to crack it into small-molecular species such as ethylene, carbon-monoxide or hydrogen. The high-temperature fuel-rich gas is then mixed with the perimeter air from supersonic inlet.

Figure 1 shows the schematic of the DCR, which is composed of intakes, preburner, combustor and nozzle. The intakes include 4 supersonic intakes (blue sectors in top figure) and 2 subsonic intakes (red sectors). Bottom figure of Fig. 1 shows internal flow path and key sections of the DCR. Section 0~5 is far field, minimum section of the intakes, inlet of the preburner, inlet of the combustor inlet, exit of the combustor and exit of the nozzle, respectively.

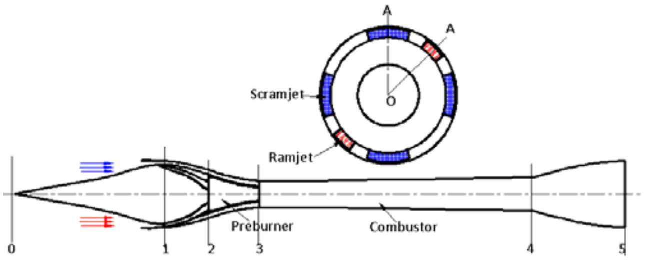

Fig. 1 Schematic of the dual combustion ramjet

Free-jet experiments of full-size DCR were conducted in National University of Defense Technology in China. The free-jet experimental setup (Fig. 2) is composed of vitiated air heater (VAH), hot-gas ejector and test cabin. The VAH generates high-temperature gas to duplicate the actual free stream stagnation conditions, including total pressure, total temperature and oxygen concentration of 23%. A convergent-divergent nozzle then brings the gas into the test cabin with the same static pressure and Mach number as that of free stream. In order to maintain the static pressure in the cabin, an exhauster system is located downstream to eject the gas into the ambient atmosphere. A unique hot-gas generator which burns oxygen and ethanol is applied to improve ejecting efficiency.

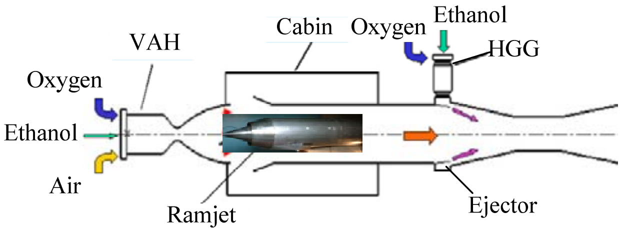

Fig. 2. Free-jet experimental setup

Figure 3 and Fig. 4 show the pressure distribution at Mach 6 and Mach 4 condition, respectively. The pressure is divided by atmospheric pressure of the flight altitude. The maximum pressure locates at the inlet of the combustor, and then decreases. The maximum pressure ratio is about 108 at Mach 6 and 40 at Mach 4. And it almost reaches the limit of the intake because the pressure at the minimum section of the intakes is almost disturbed. This means that the DCR reaches the maximum performance.

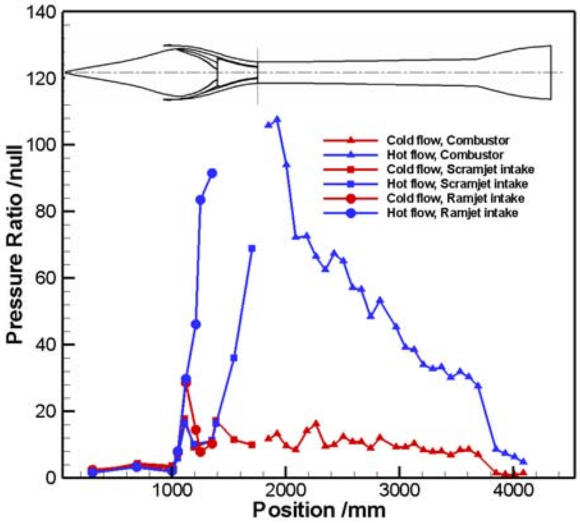

Fig. 3. Pressure distribution at Mach 6

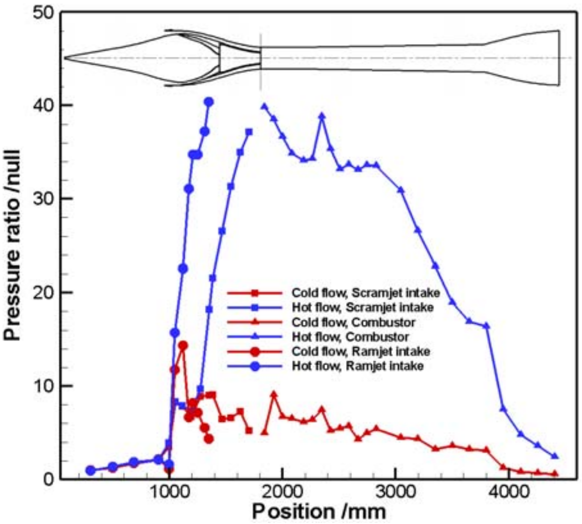

Fig. 4. Pressure distribution at Mach 4

The thrust performance is shown in Fig. 5, and the thrust coefficient is defined as:

$$C_F = \frac{F}{\frac{1}{2}\rho u^2 S} \quad (1).$$

There are three stages: (1) VAH works at 7s which simulates flight drag, and the coefficient is -0.418; (2) Only preburner is ignited, since there is no combustion in combustor, the thrust remains negative, -0.102; (3) When the combustor is ignited, the thrust becomes positive, and the thrust coefficient is about 0.15, which means that hypersonic missile powered by the DCR can overcome the drag and cruise in Mach 6 condition.

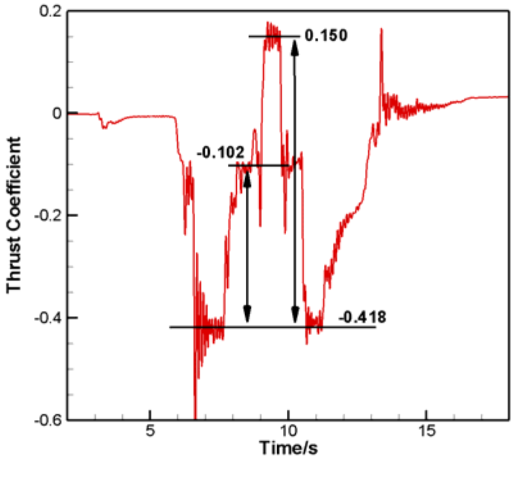

Fig. 5. Evolution of thrust coefficient at Mach 4

Several parameters that affected the performance were investigated, including flight Mach number, equivalence ratio and combustor geometry.

Results show that the performance of the DCR is good enough in Mach 4~6 condition to fulfill the requirements of hypersonic missile. Advantages and disadvantages of DCR are qualitative compared with that of scramjet.