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A Study on the Ignition System of a Pilot Flame in a Cannon-Type-Combustor of a Turbo-Engine

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Abstract

We studied a stable pilot flame system for a cannon type combustor of turbo-engines by adding both a front chamber and a pilot flame chamber with an electric ignition system to the conventional two-stage system with two-stage combustion domains: a primary zone and a secondary zone. The electric ignition period was about 1 second with 2760V (theoretical) generated by Kochcroft-Welton circuit, and the fuel was butane gas. The inlet was 25m/sec and the pressure was about 400Pascal at the inlet of combustor. We set two cases for the outlet configuration: a converging nozzle and a turbine. The outlet temperature was 280C at the outlet velocity of 25m/sec, and the temperature was 230C at the outlet velocity of 12m/sec. A sufficiently large rotational speed and torque was obtained to rotate the compressor and fan of the turbine. We analyzed the ignition mechanism by solving two dimensional compressible Navier-Stokes equations and found that the role of the front chamber was to maintain the pilot flame after the ignition shock. We confirmed experimentally that this system can ignite and preserve a stable pilot flame with quite high probability.

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Keywords: Cannon combustor; front chamber; pilot flame; design;turbine; Kochcroft-Welton circuit

1. Introduction

The Sky-Infra project [1], which is creating a delivery service network using unmanned air vehicles (UAVs) in Mongolia, requires UAVs that can operate at high speeds and over long distances. We have been developing UAV engines that can meet these specifications, beginning with our first study on a cannon type of combustor. The

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outcomes of this first combustor design have been published in [2], and we are currently working on improving the stability and restart ability of the pilot flame in the combustor since this function is crucial for the safety of aircraft engines during flight. The pilot flame system has a complicated mechanism involving the mixing of air and fuel, evaporation, chemical reactions, and an ignition shock wave. We used a conventional annular type design [3,4] but split the combustor into two flame regions: the primary combustion and secondary zones. The role of the primary zone is combustion, while the secondary zone performs both cooling and combustion. Since the cannon type combustor has three-dimensional mixing, we needed to divide the combustor into more zones. In the present work, we have redesigned the combustor to control the pilot flame and to clarify the mechanics of the stable ignition system, as well as to find parameters that can maintain the flame and combustion.

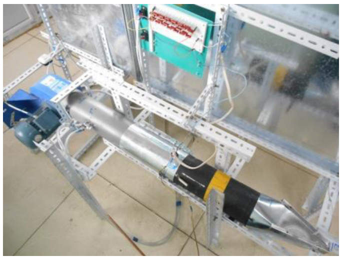

Fig.1. Experiment setup

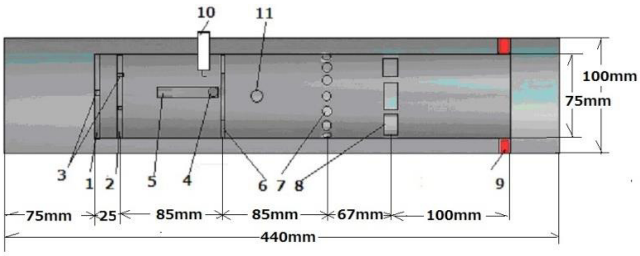

Fig.2. Design of Combustor: 1. Front room, 2. wall of front and pilot room, 3 a hole 4. pilot fuel line, 5. Pilot fuel outlet, 6, choke ,7. Holes of primary combustion, 8. Square holes for the second combustion and cooling, 9. Shield of gypsum, 10. Spark plug ,11. main fuel line

2. Experimental Method

We simplified the design by first splitting the domain into the two roles (combustion and cooling). We followed the conventional two stage (CTS) design, which gave four spaces: 1) ignition, 2) pilot, 3) main combustor, and 4) cooling zone. In the present work, we added a front chamber and a pilot flame chamber with an electric ignition system to the CTS. The electric ignition period was about 1 second with 2760V (theoretical) generated by a Kochcroft-Welton circuit (0.1microF), and the fuel was butane gas. Figure 1 shows the experimental setup. Apart from the blower and bearing, all components are handmade: these included a blower, combustor body, and convergent nozzle.

Figure 2 shows the design of the combustor. The flow enters from the left, and fresh air goes through a small hole (3 in Fig.2) and diffuses into the front chamber. The air then goes to the pilot chamber. We designed the pilot injector (4 and 5 in Fig.2) oriented to the upstream since the discharged fuel circulates toward the spark plug. The specification of the blower is 700m^3/min in the no-load condition. When we assembled it onto the combustor, the mean velocity and the pressure became 19m/sec and 800Pa, respectively, in the full open valve state, and when the valve was half closed, the mean flow velocity and pressure were 10m/sec and 400Pascal, respectively, at the combustor inlet. We supplied fuel to the primary zone at the theoretical amount of combustion (4.4g/sec). In the second mixing zone, we made square holes (8 in Fig.2) to supply a large amount of air and reduce the pressure loss. The design allowed 70% of the air pass through these holes.

In the primary design, we shielded the outlet of the channel of inner cylinder and outer cylinder with gypsum, as shown in red in Fig.2. Eventually, we removed this shield in order to cool the outer wall. We selected a larger diameter turbine (150mm) to obtain the large torque required to overcome the frictional force of the bearing. We kept a constant ignition of the spark plug NGK (10 in Fig.2) by using a Kochcroft-Welton circuit (0.1microF). The input voltage (220V and 50Hz) and the output voltage (3kV) are shown in the upper part of Fig.1. The dimensions of the convergent nozzle and turbine are shown in Fig.3 (a, b). Thermal fatigue was avoided by setting the bearing (4 in Fig. 3) away from the outlet. A choke plate (6 in Fig.2) partition was inserted between the pilot and the primary zone to produce a vortex artificially, which was the most important part.

(a) (b)

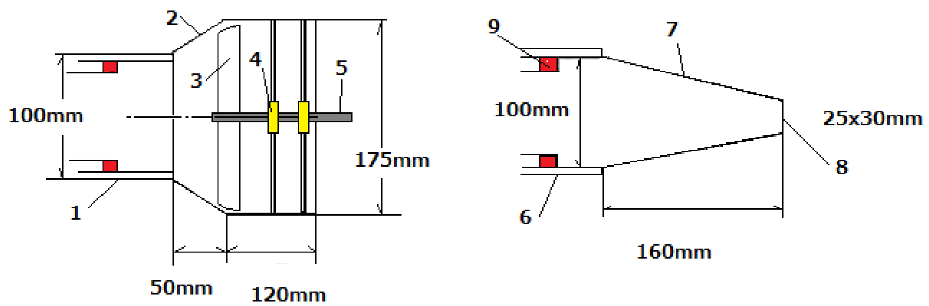

Fig.3. Design of turbine (a) and nozzle(b):1. Outer casing of combustor, 2 Shroud of turbine, 3. Turbine blade, 4. bearing, 5 10mmdiameter steel shaft, 6. Outer casing of combustor, 7. converging duct wall, 8. 20mmx30mm square jet, 9. Gypsum shield(removed)

3. Experimental results

We implemented five types of experiments.

3-1) without electric ignition: We ignited the pilot by inserting a flame from the outlet of the combustor and maintained the pilot flame. We then started the blower to test the stability. In the absence of a choke plate (6 in Fig. 2), the flame could not be sustained. 3-2) without electric ignition: We added a choke plate (6 in Fig.2) and maintained the flamed pilot as described in case 1. We then started the blower and found that the flame could be sustained. If the direction of injection was upstream and the injector was located near the center line, then the flame was sustained. 3-3) We kept the pilot at the same location as used for the electric ignition system, and then we ignited and generated a shock, but the pilot flame could not be sustained. 3-4) We added a front room. As a result, the pilot flame was ignited and its stability was successfully maintained, with or without the convergent nozzle and the turbine. In this setup, we observed that the center velocity of the jet was 25m/sec (for a cold jet) and the outlet temperature was 280C at 25m/sec and 230C at 12m/sec (for a cold jet). The stable pilot flame and stable main fuel flame were observed. Blue flames were observed in both cases. 3-5) For the turbine experiment, since the friction of the ball bearing is rather large, the blower had difficulty in rotating the turbine in a cold combustor; however, once the combustion started, the turbine also started rotating at a sufficiently fast rate to produce power for the compressor and fan. The outlet temperature was very high in both these experiments, so we removed the gypsum shield to increase the amount of cooling air around the shroud. We examined the blade for damage, but found no damage near the shaft; all damage was slight and localized at the middle and tips of the blade. This suggests that the amount of cooling air was quite sufficient.

4. Analysis using Computational Fluid Dynamics(CFD)

We obtained a more in-depth understanding of the experimental results by performing a two-dimensional compressible Navier-Stokes computation with MUSCL code [5]. We did not solve the chemical reaction, but we assumed the instantaneous discontinuity of pressure and density at the spark plug and computed the propagation of the shock wave. The initial pressure and density ratio were 3 and 2. We selected the convergent nozzle for the outlet boundary. The shocks propagated and reflected several times in the combustion chamber. The vorticity distribution of the case without the front chamber is shown in Fig. 4(a) and with the front chamber is shown in Fig. 4(b). We can see clear differences at the front chamber. There is no circulation in (a), but circulation occurs in (b). Thus, (b) has a fresh air supply.

5. Conclusion

Use of a front chamber allows us to establish a stable pilot flame system. The computation clearly shows the role of the front chamber: It acts as storage of fresh air at the ignition. Use of the front chamber and pilot room increases the length of the combustor, so we need to redesign the combustor to be shorter and to have a stable flame.

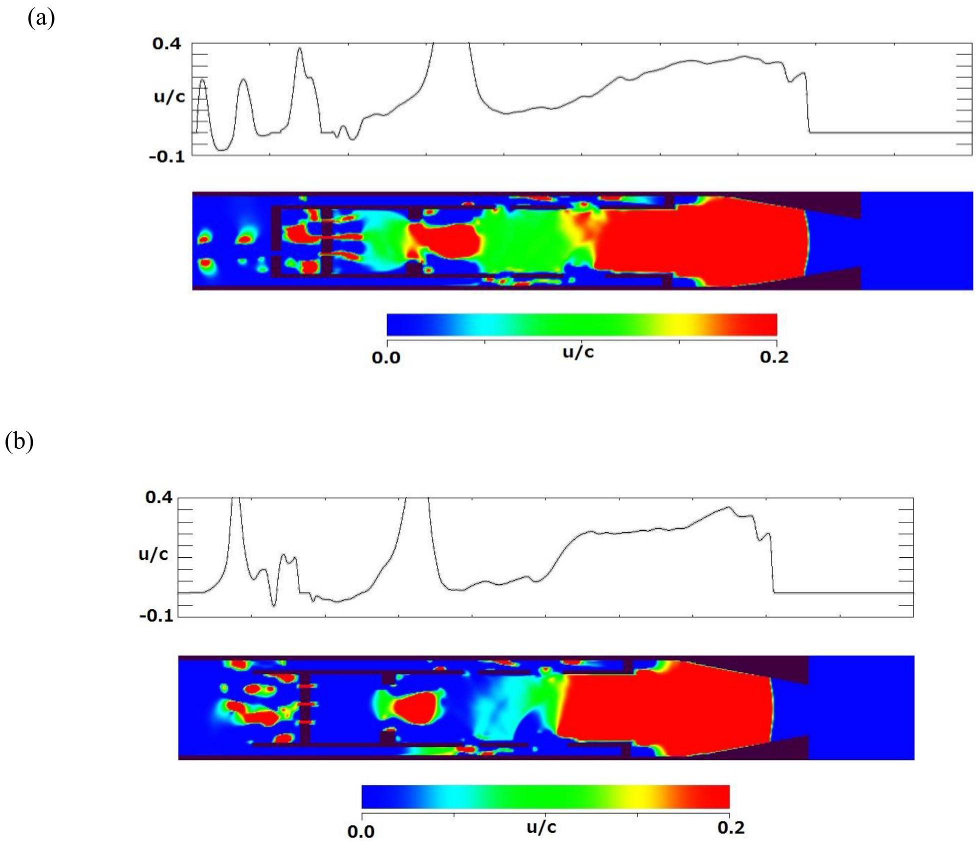

Fig.4.Shock wave analysis (a) velocity distribution with front chamber, (b)velocity distribution without front chamber where no flows in the front chamber

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