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A novel hypersonic rarefied gas wind tunnel and its applications

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High enthalpy wind tunnels, such as shock tunnel, arc wind tunnel and Radio-frequency (RF) wind tunnel [1-3], are important ground test facilities for conducting research on the aerodynamic characteristics and thermal protection of hypersonic aircrafts. A novel hypersonic rarefied gas wind tunnel has been built in Institute of Mechanics, Chinese Academy of Sciences (CAS), where the simulated altitude is about 100 km away from the ground, the flow velocity in the test region is about 4000 m/s – 7000 m/s, which is close to the first cosmic speed, and the stably operating time is longer than 300 s.

Fig. 1 shows the schematic diagram of the hypersonic rarefied gas wind tunnel, which is mainly composed of five parts, i.e., 1) the gas heater and nozzle, which is the core part to generate the hypersonic flow and installed at the right end of the wind tunnel; 2) test chamber, which is the white chamber in figure 1, 2.5 m in diameter and 3m in length, and the test model is installed here; 3) vacuum pump system, including cryopumps, molecular pumps, roots pumps, dry pumps, and large gate valve; 4) testing and control system, including the flow field measurement system, small gas-dynamic force measurement system, and central data collecting and processing system; 5) gas supply and cooling system, which provides working gas and cooling water for the whole wind tunnel.

The altitude simulated by the rarefied gas wind tunnel is in the ultra-low orbit space, where the rarefied gas effect, high-temperature gas effect, and thermochemical non-equilibrium effect are significant. In order to obtain reliable aerodynamic force and aerodynamic heat data for aircraft ground tests, accurate measurements of wind tunnel flow field parameters are essential. In this study, emission spectroscopy method, electrostatic probe method and pressure gauge method have been applied to obtain the gas temperature, electron density and impact pressure data at different working conditions. Numerical simulation (CFD-DSMC sequential coupling) has been conducted to study the rarefied gas flow in the wind tunnel. The comparison between the numerical result and the experiment shows that the measured pressure is not the total pressure of the air flow, but is related to the viscous force.

Preliminary ground tests of an air-breathing electric propulsion model have been successfully performed in the wind tunnel. The gas collecting efficiency, thrust and specific impulse of the air-breathing electric propulsion model have been measured and analyzed. Results show that the gas collecting efficiency exceeds 55%, and the maximum specific impulse is up to 3000s.

References

[1] Zhao W, Jiang ZL, Saito T, et al. Performance of a detonation driven shock tunnel[J]. Shock Wave, 2005(14): 53-59

[2] Sagnier P, Vérant JL. Flow Characterization in the ONERA F4 wind tunnel[J]. AIAA Journal, 1998, 36(4): 522-531

[3] Mazouffre S, Caubethilloutou V, Dudeck M, et al. Operating characteristics of the SR5 hypersonic plasma wind-tunnel[J]. ESA Publications Division, 2003: 47-54.

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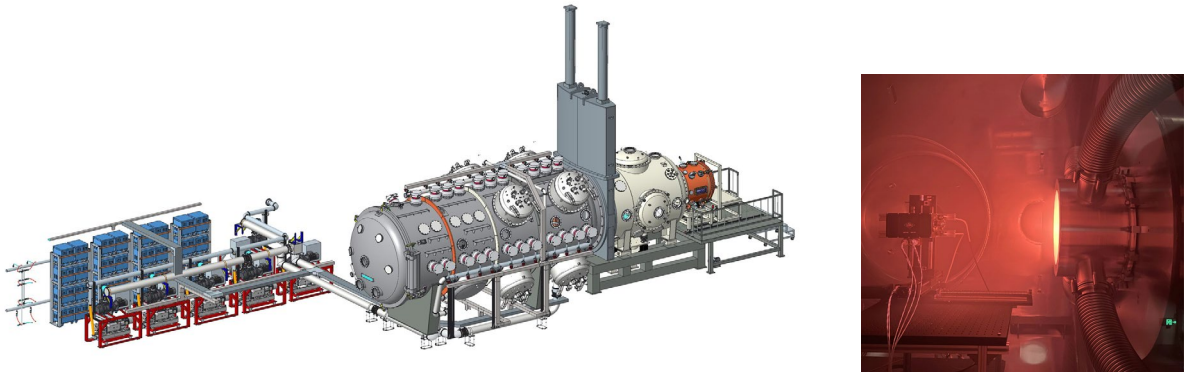

Fig. 1 the schematic diagram of the hypersonic rarefied gas wind tunnel, and the hypersonic plasma flow.