Combustion of Hydrogen Jet with the Introduction of Shock Wave

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Abstract

Experiment and analysis on the interaction between shock wave and combustion in a supersonic flow field of a hydrogen jet were performed. Supersonic combustion facility at the Institute of Fluid Science, Tohoku University (Fig.1) was used to make the present experiment in a supersonic airflow. The main flow conditions were the Mach number of 1.5, total pressure 0.25 MPa and total temperature 520 – 840 K. Figure 2 shows the schematic layout of the injection wall and the shock generator. We set up a preburner before hydrogen injection, because self-ignition of hydrogen was difficult under these conditions. Injected gases contain much unburned hydrogen of high temperature since the preburner temperature is lower than

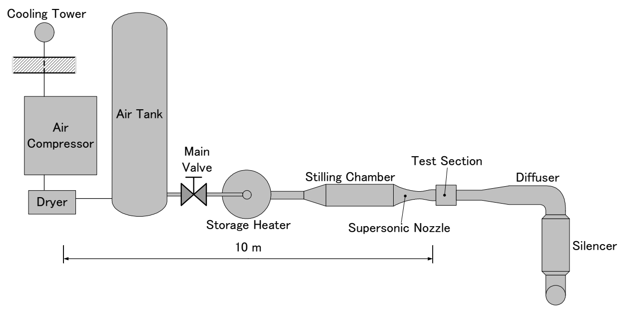

Fig.1 Supersonic combustion facility at the Institute of Fluid Science, Tohoku University

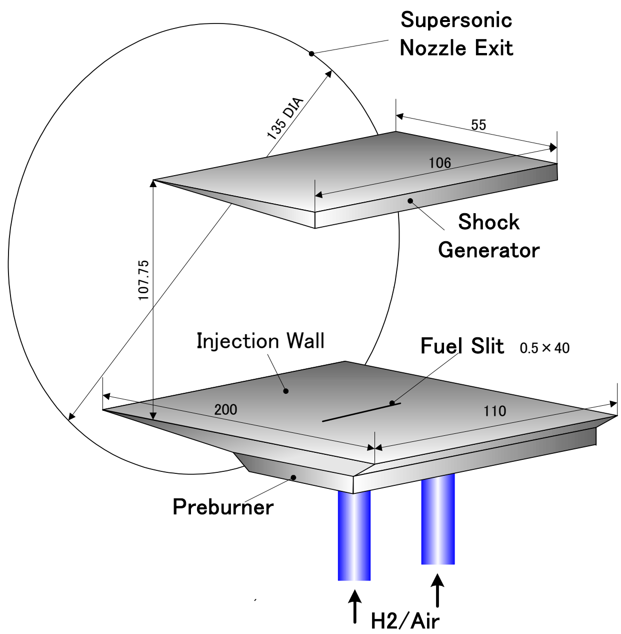

Fig.2 Schematic layout of the injection wall and the shock generator

the adiabatic temperature of H_2/Air premixed flame. The flow field is two-dimensional and hydrogen is injected from a rectangle slit with the size of 0.5 mm × 40 mm. The total pressure of injection was 0.5 MPa. Schlieren imaging and video camera were used to visualize the flow field and to check flame-holding, respectively. The turning angle of shock generator was kept constant 6 degrees and the pressure rise by the generated shock wave was 1.44 times.

Figure 3 shows experimental points of success or failure obtained by changing the total temperature of the main flow and the equivalence ratio. Without shock generator, we did not make sure of flame-holding. When the incident point of the shock wave was on the upstream side of the hydrogen injection slit, flame-holding was successful. In these cases, the start point of the separation shock wave in front of the injection point moved to the upstream side, so that the separation region expanded. On the other hand, when the incident point was on the downstream side, the separation region did not change appreciably in comparison with that without the shock generator. Therefore, when the shock wave was introduced into the downstream side of injector, the flame-holding succeeded only at high total temperatures of the main flow, although the performance of flame-holding was improved in comparison with

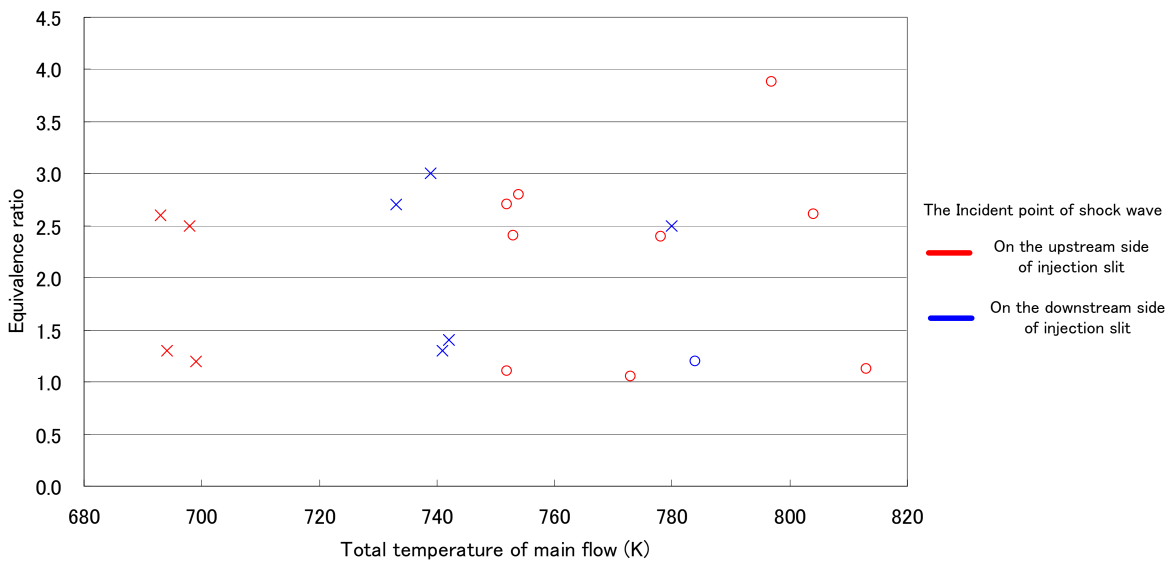

Fig.3 Success or failure against total temperature of the main flow and equivalence ratio

the case without the shock generator. This means that the improvement of flame-holding could not be explained only by the size of recirculation zone in the separation region. For instance, the acceleration of mixing may be the other mechanism of the effect of induced shock wave.

We also performed a numerical analysis by 2-D CFD. Because CFD for a supersonic combustion requires much memory and calculation time, some techniques were needed to solve within a practical calculation time. Therefore, we used LU-SGS method and Domain Decomposition Method by MPI, so that the present CFD code achieved a very high parallel performance, as shown in Fig.4.

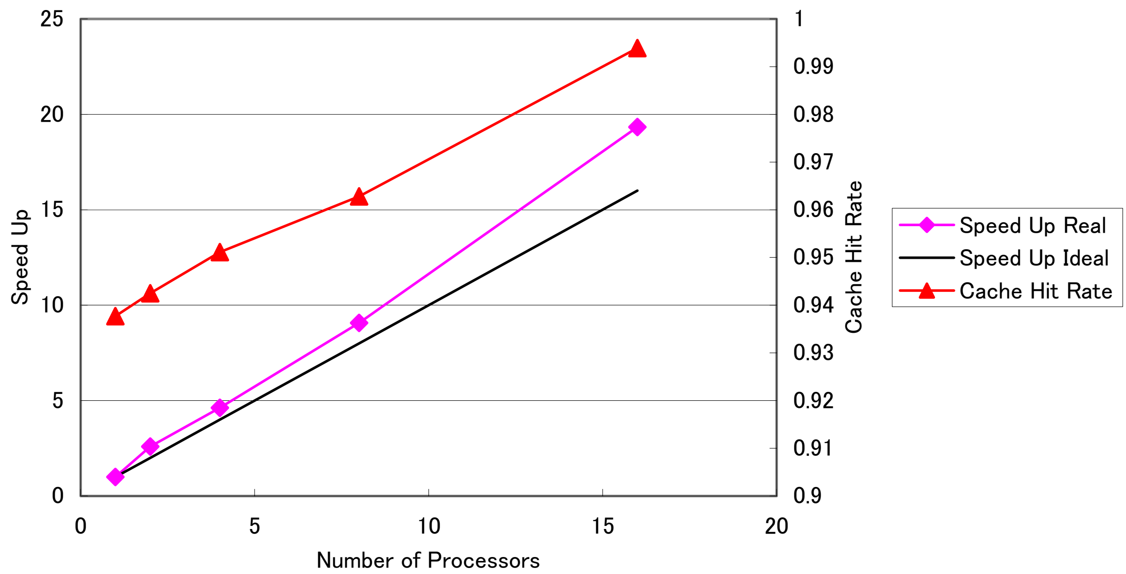

Fig.4 Parallel performance

The calculated density distribution was sufficiently equivalent to schlieren images in experiments, as shown in Fig.5, but only the start point of separation was different from experiment. In the case of low equivalence ratio and high injection temperature, combustion was promoted even by the incident shock wave introduced into the recirculation region on the downstream side, because the reaction in this region, activated a little by high temperature injection although the reaction did not occur by low temperature injection, promoted the flame-holding. On the other hand, in the case of high equivalence ratio and low injection temperature, the calculation could not show flame-holding because the turbulent diffusion model used for the recirculation region might not fully describe the present phenomenon exactly.

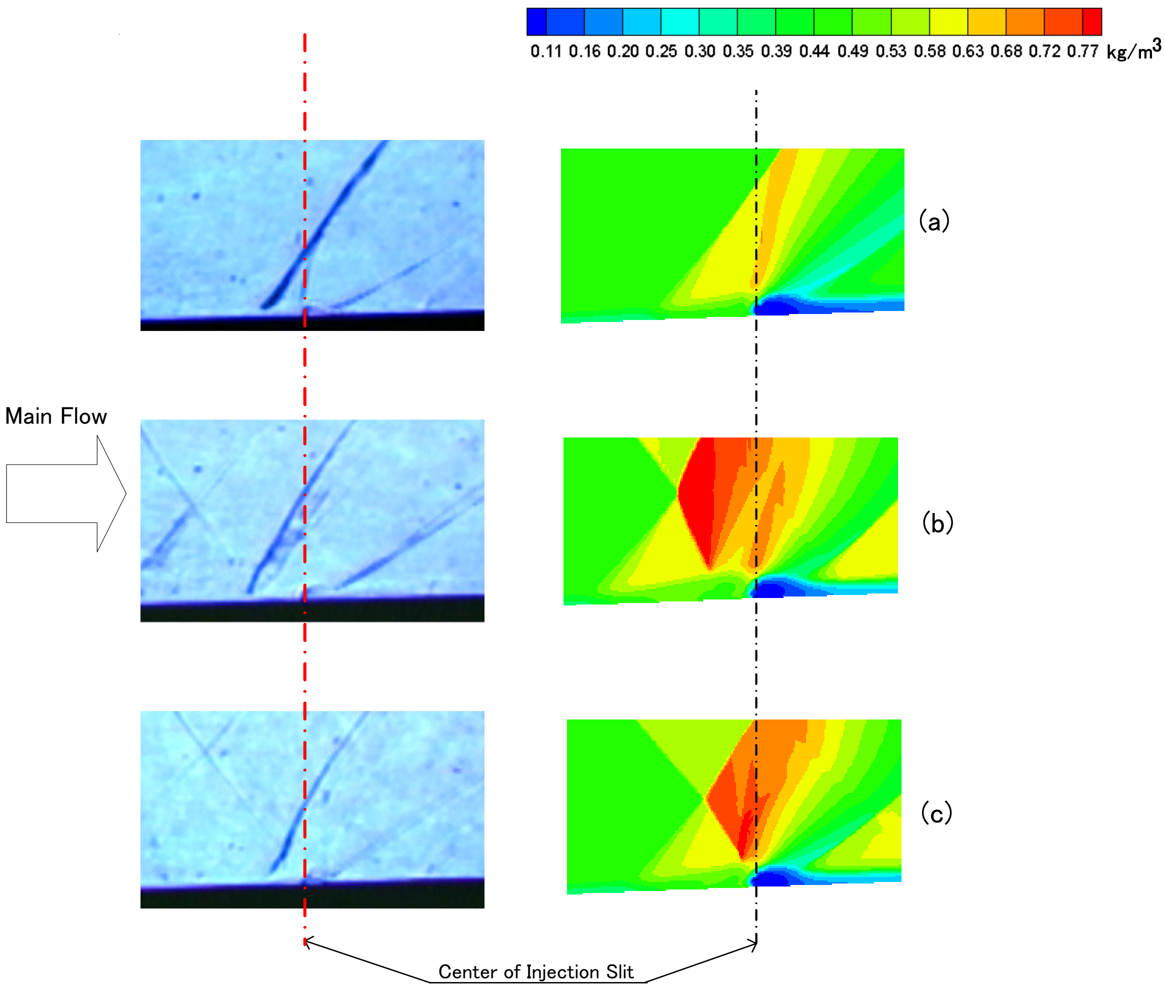

Fig.5 Comparison with schlieren images and the calculated density distributions
(a) without shock generator
(b) incident shock wave on the upstream side of the injection slit
(c) incident shock wave on the downstream side of the injection slit