Numerical Investigation of Hydrogen-Air Shuttling Transverse Combustion

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Pressure gain combustor (PGC) has attracted serious attention for decades because of its potential in achieving higher thermal efficiency than conventional deflagration-based engines. There are different types of PGC and recently a novel concept of combustor was proposed by Nagoya University in which fast combustion waves shuttle repeatedly in a two-dimensional linear channel. The present paper will focus on this type of combustor, i.e. shuttling transverse combustor (STC), to investigate the wave dynamics through numerical simulations.

The present STC simulation is conducted in a two-dimensional rectangular computational domain of 280 mm x 100 mm as shown in Fig. 1. The premixed fuel/oxidizer mixture is injected through a series of nozzles at the bottom and the burned gas leaves the combustor through the upper end. The left and right boundaries of the domain are solid walls where wave reflections are expected to occur. For the injection nozzles, they are set at constant interval and each nozzle is 4 mm long for the baseline case. The total injection area ratio is 0.4. In the present simulation, the premixed stoichiometric hydrogen/air is injected through the nozzles with injection total pressure of 10 atm and total temperature of 300 K. The chemical kinetic model of hydrogen/air combustion used here is a detailed mechanism with 9 species which has been validated and applied to several detonation simulations. The flow field of STC is solved by discretizing two-dimensional unsteady Navier-Stokes equations and chemical species transport equations with minimum cell size of 0.05 mm to resolve the fine structure of the flame front.

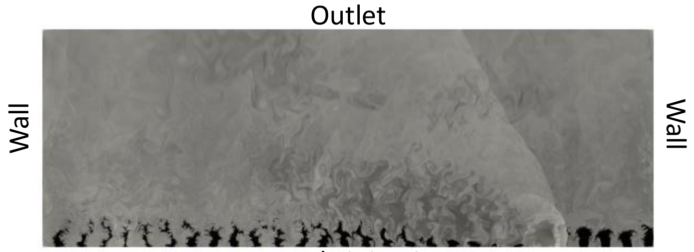

Fig. 1. Computational domain of STC chamber

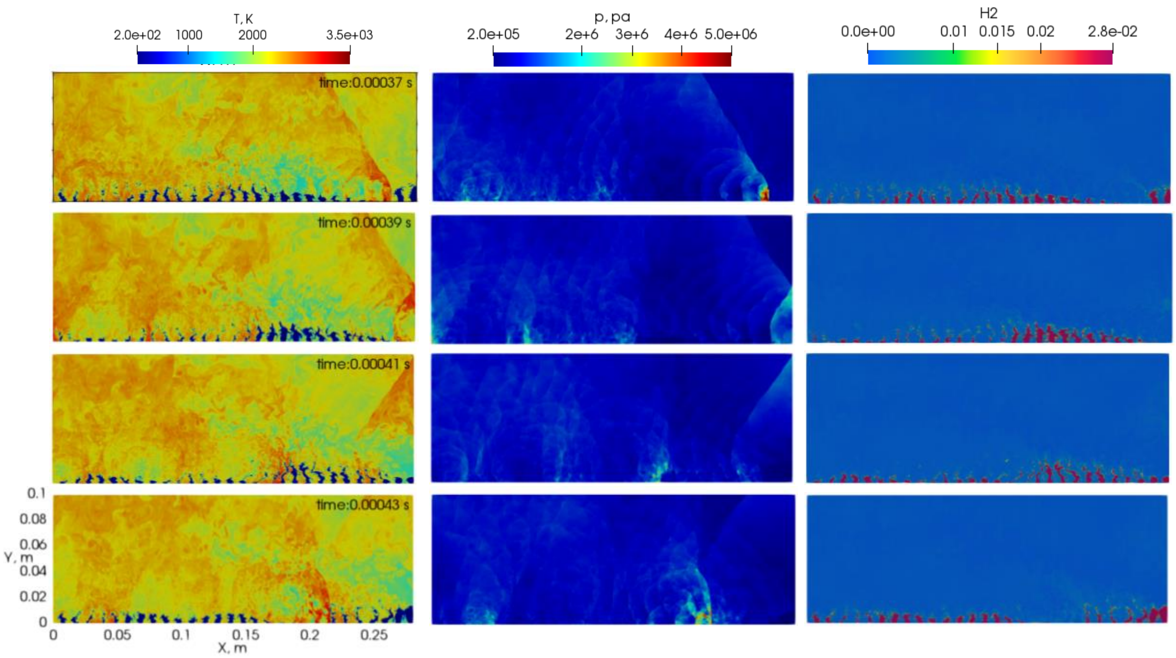

Fig. 2. Time sequence of distribution of temperature, pressure and mass fraction of hydrogen.

The simulation results show that the flow field of STC of hydrogen and air is complicated by frequent detonation wave reflection at side walls, extinction, re-ignition and collisions. The detonation wave is sustainable in STC mainly through highly frequent re-ignition close to the injection boundary. Figure 2 provides a typical case of detonation extinction and re-ignition which shows instantaneous distribution of temperature, pressure and the fuel H_2 mass fraction. It is seen in Fig. 2 that there is a detonation wave propagating to the right wall at a speed of around 2000 m/s at time 0.00037 s. It is soon reflected at the right wall and the detonation quenches due to insufficient reactant near the right wall region. At time 0.00041 s, there exists a hot zone close to the injection boundary at x=0.17 m which involves intense deflagration. The shock wave moving to the right couples with the hot zone which eventually generates a new detonation wave as shown at time 0.00043 s. The rich reactants with relatively high penetration height in front of the shock wave also facilitates the formation of the new detonation wave which can be seen in the distribution of H_2 at time 0.00041 s. Besides the new detonation wave mentioned above, there will form another detonation wave around x = 0.05 m which can be predicted by the strong deflagration and high pressure. The detonation waves in STC are mostly short-lived because of frequently experiencing reflection, collision or insufficient reactants which is of great difference from that of other types of PGC. The wave behaviours in STC are also affected with different parameters, e.g. injection nozzle size, area ratios, injection pressure and the chamber size etc. Besides, the wave mode identification and control of STC needs in-depth investigation for the real application for propulsion system.