Experimental and Numerical investigation of hot-jet ignition with shock effects in a constant-volume combustor

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A wave rotor, an array of channels arranged around the axis of a cylindrical drum, can be used as a combustor in gas turbine engines in order to reduce the consumption of the fuel by increasing the fuel efficiency. Since the wave rotor combustor consumes fuel in constant volume channels, the engine system derives benefit from not only high temperature of the combusted gas, but also high pressure by containing the hot gas in the channels. Combustion of gas mixture in one of channels ignited by hot jet penetration under the necessity of rapid ignition accompanies complex non-steady phenomena, such as shock wave propagation, shock-flame interaction, and vortex generation in the channel. Especially, when a shock wave passes through the flame surface, the heat release rate and fuel consumption rate can be suddenly increased by a deformation of the flame surface, which are closely related with the combustion time of the fuel mixture. This research aims to investigate the ignition process, and the shock-flame interaction in a constant volume combustor experimentally and numerically to extract useful information for future wave rotor combustor design. Various mixtures of CH_4 and H_2 with equivalence ratio 1.0 were set as fuel for the main chamber, providing variation in chemical kinetic timescale. The hot gas jet consists of combusted gas mixture of a fuel composed of 50% CH_4+ 50% H_2 (by volume), burned in the pre-chamber with air at equivalence ratio 1.1. For experimental research, three dynamic pressure transducers were installed on the main chamber to measure the pressure changes caused by shock waves and flame propagation in the main chamber. Time-dependent flame and shock wave images up to 20,000 fps were obtained by a high speed camera, and a Z-type schlieren system. The schlieren technique, an optimum system to capture shock waves in the channel, utilizes light deviation due to flow density gradient, visualizing flows which are invisible to the human eye. In numerical research, adaptive mesh refinement for velocity and temperature, and multi-zone reaction modeling to speed up the kinetics were used to analyze turbulent combustion with minimum computational cost. Advanced post-processing techniques were used to calculate flame surface area, heat release rate, and vorticity deposited on flame surface to understand the flame wrinkling and surface increase. Finally, pressure data in main chamber, flame propagation speed, and the large scale of vortices under different initial conditions obtained from the experimental study were compared to the numerical results under the same conditions in order to suggest reference data for designing future wave rotors.