An attempt to visualize spray inside the premixing duct of a coaxial-staging lean burner at simulated full power conditions of modern/future high pressure ratio aero engines

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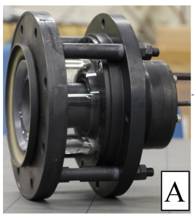
Abstract

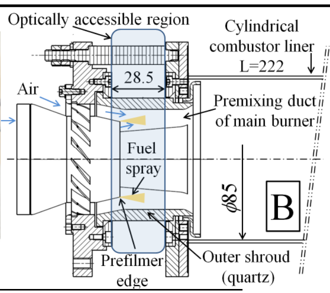
In order to reduce the fuel burn and the environmental impact by CO_2, the pressure ratio of modern aero engines tends to increase for better thermal efficiency. It is getting close to fifty even now and possibly higher in the future. This results in an increase of NOx emissions due to high combustor inlet pressure (p_{in}) and temperature (T_{in}). A solution for this problem is a coaxial-staging lean burner: It typically consists of a non-premixed-mode pilot burner at the center for flame stability and a lean-premixed-mode main burner surrounding the pilot for drastic NOx reductions. As the degree of fuel/air mixing in the main burner plays a key role in the NOx reductions, it is important to evaluate the spray and fuel vapor behavior inside the premixing duct of the main burner. Further, the evaluation should be carried out in realistic conditions, as the spray physics is strongly influenced by those of the ambient airflow. However, because of difficulty of experiments at such high pressures and temperatures and limited availability of huge facilities, the published data based on optical techniques on the phenomena inside the premixed duct in a realistic injector configuration are hardly available.

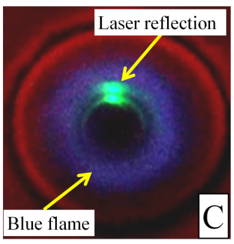
In this poster paper, our recent research activity on visualization of spray inside the premixing duct of a research-purpose coaxial-staging lean burner in such conditions is reported. The final targets of the test conditions will be up to p_{in} =4.7MPa and T_{in} =1000K. This can be realized by the JAXA high temperature and high pressure combustion test facility equipped with a 2MW electric heater with reliable temperature control for long-period continuous operations. The photograph and schematic drawing of the burner is presented in Figs. A and B. Its outer shroud is made of quartz and has an optical access of 28.5mm in length, including the position of the prefilmer edge of the main burner. A ceramic-coated cylindrical combustor with effusion cooling, 85mm inner diameter and 222mm length, was utilized. The flame was monitored by a periscope-like imaging system from the rear side, as shown in Fig. C. So far, for the visualization inside the premixed duct, the shadowgraphy and the laser sheet imaging (Mie scattering from the fuel spray) have been attempted. In addition, the kerosene LIF visualization is ongoing though it is qualitative at this stage.

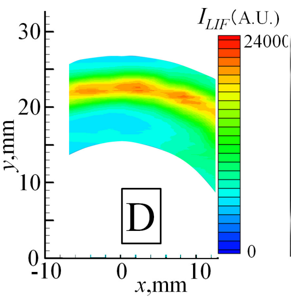
Some typical results are presented in Figs. D and E. They were obtained at p_{in}=4MPa and T_{in} =900K, simulating typical takeoff conditions (almost full power) of modern civil aero engines. No pilot fuel was supplied for these cases. The main burner local air to fuel ratio (AFR_m) was kept at modest values since currently this research-purpose burner had not been optimized and combustion oscillations took place in the lower AFR_m range. For the stable combustion case at AFR_m=40, an example of time-averaged kerosene LIF results is presented in Fig. D, showing circumferential variation of fuel distribution in the premixing duct (6mm downstream from the prefilmer edge). For the oscillating combustion case at AFR_m=32.5, the two spray pictures close to the filmer edge taken at different times (Fig. E) show its temporal variation caused by the strong pressure oscillations.

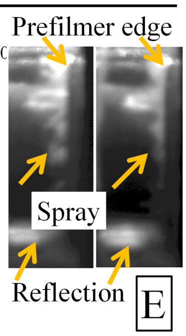
Some technical issues on conducting experiments at such conditions are also discussed in our paper. This includes 'schlieren' effects or in other words 'beam steering' due to large density gradients along the optical paths, and contamination of the optical outer shroud by a green substance presumed as chromium oxide, which is probably originated from heating wires of the electric heater.











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