Investigation on the Acoustic Behavior of a Turbulent Swirl-Stabilized Combustor Fed with Liquid Fuel

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Keywords: PIV, High-speed Diagnostics, Combustion Instability, Precessing Vortex Core (PVC)

Burners operating in lean premixed prevaporized (LPP) regimes are considered as a good candidate to reduce the pollutant emissions from gas turbines. Lean combustion regimes provide a uniform lean mixture of fuel and air that burns at lower temperature than non-premixed flames, mainly reducing thermal NOx emissions. However, combustion in this regime often faces stability issues. In particular, the coupling of heat release and pressure oscillations in the combustor can produce self-excited oscillations. In addition, the flame that is stabilized by swirling flow motion in gas turbine combustor is strongly affected by energetic large-scale coherent flow structure known as Precessing Vortex Core (PVC).

In the present work a swirl-stabilized combustor fed with liquid fuel (dodecane) is used for the investigation of combustion instability, structure of PVC and their relative strength. The droplet and velocity field distributions are characterized using High Speed Particle Imaging Velocimetry. The acoustic pressure fluctuations are measured close to the injection device and on the combustion chamber axis. CH* chemiluminescence is also measured as an indicator of the reaction rate in the flame. Details of the burner and measurement system can be found in Providakis et al., (2013). To investigate the effect of equivalence ratio on the instability, the measurements are conducted by changing equivalence ratio in the φ = 0.4 to 0.7 range. For one data set, the amount of fuel is kept constant while the equivalence ratio is varied from 0.4 to 0.7 (PCα = PCβ), keeping the power produced by the burner constant. The other is that the global air flow rate are constant (FCα = FCβ) and the amount of fuel is varied with the constant global air flow field. The frequency and amplitude of the acoustic and aero-dynamical instability are investigated varying the global equivalence ratio. In order to give detailed insight into the flow dynamics, dynamic mode decomposition (DMD) is used. Performing Multi-variable DMD (Richecoeur et al, 2012) on Mie scattering intensity signal, velocity distribution and acoustic pressure signal, the two dominant structures are captured at each frequency associated with acoustic instability and PVC. Figure 1 show amplitude spectra of the DMD for two operating conditions. In the higher equivalence ratio condition (PCa), the spectrum reveals high amplitude relatively wide peak at 288 and 320 Hz which as expected by the Rayleigh criterion in the case of thermo-acoustic instabilities. The amplitude of the acoustic peak decreases with decreasing equivalence ratio. The spectrum in the lowest equivalence ratio case (PCb) shows narrow strong peak centered at f=2040, which represents aerodynamic instability corresponding to the helical structure known as PVC. Using amplitude spectrum of DMD, its relative strength can be calculated. It is revealed that the strength of PVC tends to be high in the low equivalence ratio conditions while it seems to drop in φ > 0.55. Instead, the strength of the acoustics mode shows constant increase with the equivalence ratio. It likely indicates that the strong fluctuating cycle associated to acoustic mode may interfere with the coherent structure of PVC in high equivalence ratio cases.

Figure 2 (a) and (b) show reconstructed DMD mode associated to the frequency of PVC (PCa (a)) and acoustic oscillation (PCa, (b)) for the first phase and 90° for two operating conditions. Contours of 25% Mie scattering intensity (black line) are added. Correlation coefficient of reconstructed DMD mode at PVC frequency in each run is calculated to determine the coherence of the spatial distribution of modes associated to the frequency of PVC in each mode. They show high value at low equivalence ratio conditions and the values decrease with equivalence ratio increase. It explains that the acoustic pressure oscillation interferes with the coherent structure of PVC and its effect becomes stronger with equivalence ratio increase.