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Analysis of local ignition delay in DNS of a simplified gas turbine premixer with multi-stage autoignition

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With the increasing need for fuel flexibility, mitigation of auto-ignition inside gas turbine (GT) premixers has become crucial. They must be designed to ensure sufficient fuel-air mixing while minimizing the likelihood of auto-ignition. Direct numerical simulations (DNS) of a simplified version of the GT premixer studied by Jella *et al.* [1] are presented. The configuration consists of an array of hot air jets injected in a crossflow of methane and dimethyl ether (DME) (J = 20, Re_j = 4000) at high pressure. This fuel blend features a multi-stage ignition with low- (LTC) and high-temperature chemistry (HTC), with their own characteristic flame. Two DNS with the same geometry were performed, one focusing on LTC and the other on HTC.
Vabre *et al.* [2] used a combination of ignition kernel tracking and chemical explosive mode analysis (CEMA) on the HTC simulation to describe the dynamic ignition process and the following flame stabilization. In the present work, we investigate the ignition and stabilization dynamics of both LTC and HTC flames using metrics based on local ignition delay.
A local ignition delay τ_ign has been introduced theoritically by Zeldovich [3] as a metric to directly measure how close an autoignitive mixture is to its next ignition event. The local ignition speed is derived from this quantity as $S_\mathrm{ign} = 1/|\nabla\tau_\mathrm{ign}|$ and can be compared to the laminar flame speed to determine locally the relative participation of autoignition and diffusion on the propagation of a flame front. Here, τ_ign and S_ign are computed directly using a homogeneous reactor simulation from the local statevector in a subset of representative slices. It allows to follow dynamically the evolution of the ignition process and the transition from one ignition stage to the next. Conditioning on scalar dissipation rate (SDR) reveals that the first ignition events initiate in locally well-mixed regions before propagating to higher SDR regions. For all ignition stages, flame propagation modes inferred from S_ign show a progressive transition from autoignition to a more diffusion-assisted mode as the flames move upstream and stabilize behind the jets.
Finally, local ignition delay analysis is compared with CEMA in terms of timescales and flame propagation mode. The timescale of the most explosive mode is a good proxy for τ_ign in the pre-heat zone of the HTC ignition stages, but is less effective for the LTC ignition stage.

References

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