Experimental study of auto-Ignition phenomena in swirl-stabilized LPP flames in gas turbine model combustors using kHz framerate OH-PLIF and Stereo-PIV

I. Boxx1*, C. Carter2, M. Stöhr1, W. Meier1

1: Institute of Combustion Technology, German Aerospace Center, Stuttgart, Germany
2: Air Force Research Laboratory, Wright-Patterson AFB, OH, USA

* Correspondent author: Isaac.boxx@dlr.de

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The application of kHz framerate planar laser-induced fluorescence (PLIF) of the OH radical and stereo particle image velocimetry (PIV) to a series of lean, partially-premixed swirl flames in a pair of gas turbine model combustors revealed a phenomenon we refer to as flame-kernel events. A flame-kernel event is defined as the sudden appearance of a region of high OH-concentration fluid in the measurement plane of the OH-PLIF imaging system away from the contiguous flame front. Prior research suggests flame-kernel events may represent auto-ignition of hot, unburned fuel-air mixtures in the combustor. If confirmed, this would represent a new and potentially important mechanism for flame stabilization and control in swirled LPP flames. As flame-kernel events are spatiotemporally unpredictable, they are identifiable only in time-resolved sequences of planar measurements such as kHz framerate OH-PLIF. Given the large (several thousand frames per imaging run) datasets acquired in this study and the unpredictability of where flame-kernel events will occur, the use of automated feature recognition and statistical analysis tools was required. The objective of this study was to develop such tools and to use them to test the hypothesis that flame-kernel events represent auto-ignition through rigorous statistical analysis.

An image-processing routine was developed to autonomously identify and statistically characterize the flame-kernel events. Phase sorting of the kernel centroids with respect to the dominant fluid-dynamic structure of the combustors (a helical precessing vortex core) indicates through-plane transport of reacting fluid best explains their sudden appearance in the PLIF images. The concentration of flame-kernel events around the periphery of the mean location of the precessing vortex core (PVC) indicates they are likely the result of wrinkling and break-up of the primary flame sheet associated with the passage of the PVC as it circumscribes the burner centerline. The prevailing through-plane velocity of the swirling flow-field transports these fragments into the imaging plane of the OH-PLIF system. The lack of flame-kernel events near the center of the PVC, (where there is lower strain and longer fluid dynamic residence times), indicates auto-ignition is not a likely explanation for these flame kernels in a majority of cases. The lack of flame-kernel centroid variation in the case of the TM-Burner ‘quiet flame’ (which has no PVC) further supports this explanation.