Plasma Assisted Dynamics Control

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The primary purpose of the current research is to demonstrate the effectiveness of implementing a plasma discharge to improve combustor dynamics and flame stability. Specifically, a nanosecond pulsed, low temperature (<1000 K) and low power (~10 W) plasma discharge (NSPD) is employed to mitigate dynamic combustion instabilities with a minimal penalty of NOX production, thus eventually enabling ultra-compact, low emission combustion without adverse dynamics.

Initially a ~ 10 kW combustor that generates a realistic self-excited pressure oscillation of O(1000) Pa with an acoustic frequency between 150-200 Hz was successfully developed.. Using this combustor, more than a 10X reduction of sound pressure level (>20 dB) is observed when using the NSPD. High speed imaging indicates that the NSPD relocates and fixes the flame stabilization point from the vortex-shedding-affected outer recirculation zone to the vortex-shedding-free center zone. This relocation essentially decouples the burning from disruptive unsteady fluid mechanics and increases the robustness of the process. Due to the highly non-equilibrium temperature characteristic of the NSPD, the incremental increase of emissions in the presence of the discharge is minimal typically less than 0.5 EINOX, while the augmentation of combustion efficiency can be significant and on the order of ~10%. A new control algorithm that measures pressure oscillation amplitude, and actuates with plasma power is developed. This algorithm does not require a knowledge/measurement of pressure oscillation phase, as in traditional feedback control. One can control, therefore, the incoherent combustor dynamics while avoiding the challenges associated with convective and actuator phase delays. The impact of NPSD on swirl-stabilized flames was also investigated using a custom, variable swirl number (0-0.4) vortex valve. It is shown that the relative effect of plasma for dynamics reduction decreases with increasing swirl due to the inherent decrease in nascent flame dynamics. All observations in the current work suggest that the flame shape plays a central role to determine the degree of plasma effectiveness and that any noisy, outer recirculation zone stabilized flames will be significantly improved by the presence of NSPD.

Moving forward, the results shown in the current exploratory study have significant potential for i) staging and size reduction of a combustor due to wider operability and higher efficiency, ii) flame stabilization with no aerodynamic requirement for new combustor design paradigm such as no-swirler combustor, and iii) intrinsic mitigation capability for other flame dynamics problems such as lean limit enhancement and oscillation mitigation. Our next steps s aim to extend the current work to more realistic combustor conditions. Milestones include i) higher flow (~100 m/s) at ambient temperature and pressure with methane fuel, ii) High T test (~ 1150 F) at ambient P with propane fuel, iii) High T/P test (~1150 F/250 psia) with propane fuel, iv) Vaporized Jet A with the high T/P, and possibly v) more realistic swirler geometry with liquid Jet A. We believe that each milestone will seamlessly bridge the current exploratory efforts to future higher TRL development.