ASCENT Project 67

Impact of Fuel Heating on Combustion and Emissions

Purdue University

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Objective:

This project will characterize the global and local impact of hot fuel injection on the performance of aviation gas turbine combustion systems in high-OPR aircraft engines using extractive exhaust sampling and advanced optical and laser-based diagnostics. Conditions where the fuel temperature is above the critical temperature are of great interest.

Project Benefits:

The benefit of this project will be advancement of low emissions gas turbines to the next level of cycle efficiency by providing key insights needed to design combustion devices for operation with hot fuels.

Research Approach:

Purdue's COMRAD facility houses a high-pressure, liquid-fueled, swirl injector (GE TAPS) in an optically-accessible chamber that closely replicates engine conditions. An 81 kW fuel heater heats liquid fuel to temperatures up to 800F. To detect changes in combustion behavior, optical diagnostics and exhaust gas sampling are performed. Advanced laser diagnostics to be applied are planar laser-induced (PLIF) OH fluorescence for reaction zone imaging, particle imaging velocimetry, PLIF and Mie scattering for fuel vapor and liquid imaging, and coherent anti-Stokes Raman scattering (CARS) for temperature measurements.

Major Accomplishments (to date):

- Designed and built fuel heating system.
- Began initial emissions sampling to down-select conditions of interest from test matrix, operated with fuel at 200F.
- Acquired high-speed chemiluminescence images.

Future Work / Schedule:

- Perform survey emission sampling measurements with fuel temperatures of 400F and 600F (April-July 2021).
- Down-select conditions for detailed laser diagnostic measurements (Aug 2021)
- Detailed laser diagnostic measurements (Aug 2021-June 2022).

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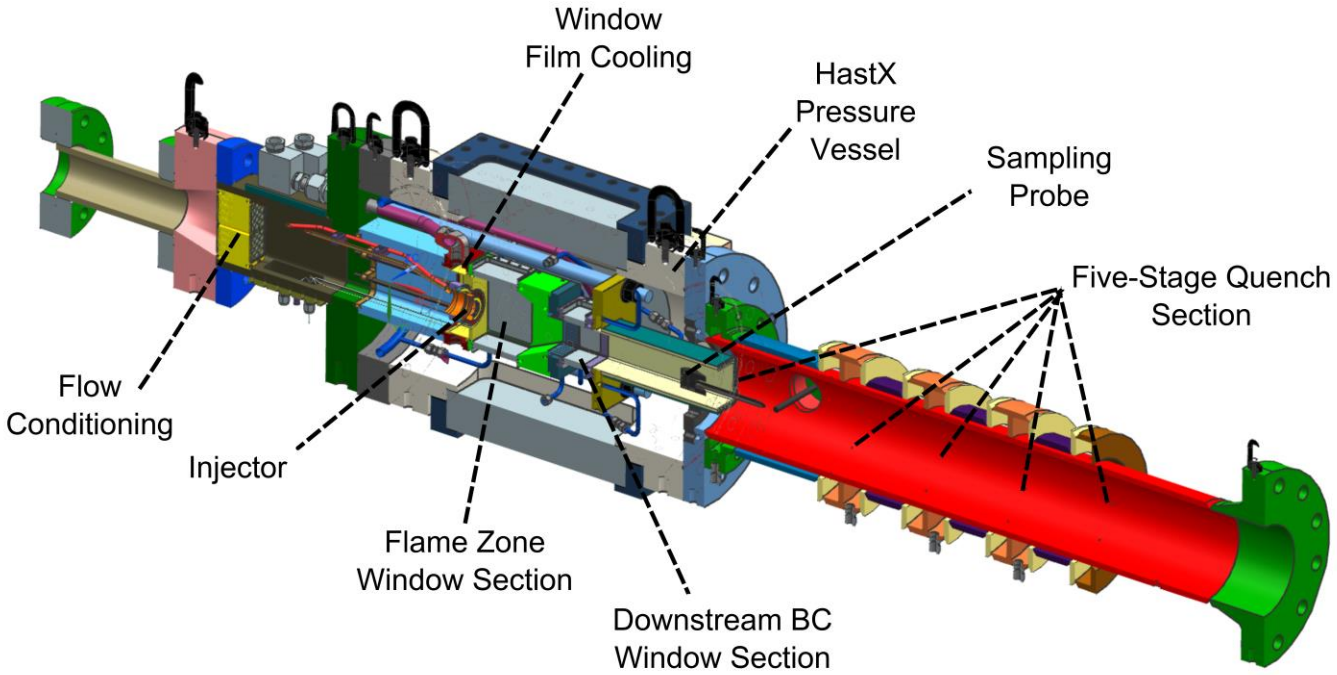
Experimental Systems

- Experiments are performed in the Combustion Rig for Advanced Diagnostics (COMRAD) located at Zucrow Laboratories at Purdue University
- Facility capability to simulate engine-cycle conditions
  - Up to 8 MW steady-state thermal power
  - Up to 600 psi P_3
  - Up to 1400°F T_3
- Extensive optical access to the flow, including flame zone and downstream region
- Sampling probe installed in exhaust section for emissions measurements
- Capable of using Jet-A, Fischer-Tropsch synthetic paraffinic kerosene (FT-SPK), and other alternative fuels



Experimental Systems

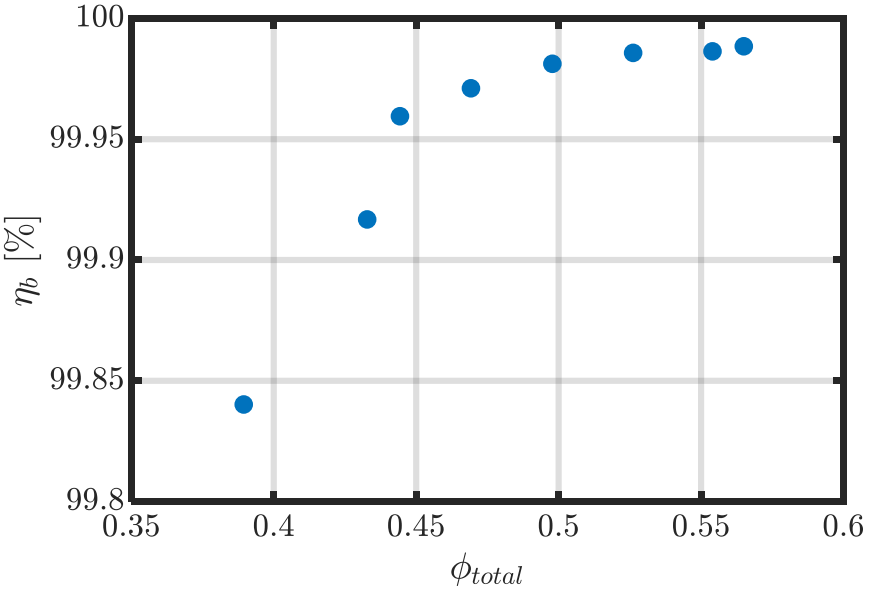
- Designed and fabricated a fuel heating system that is capable of heating jet fuel up to 800°F at pressures up to 600 psi
- Independent heater zones enable separate control of primary pilot, secondary pilot, and main fuel supply temperatures
- Cartridge heaters with PID controllers allow precise control of fuel temperature at heater exit
- Emissions measurements are being performed at fuel temperatures of 200, 400, and 600°F to down-select conditions of interest for high-repetition rate laser diagnostics

Operating Conditions for Parametric Survey

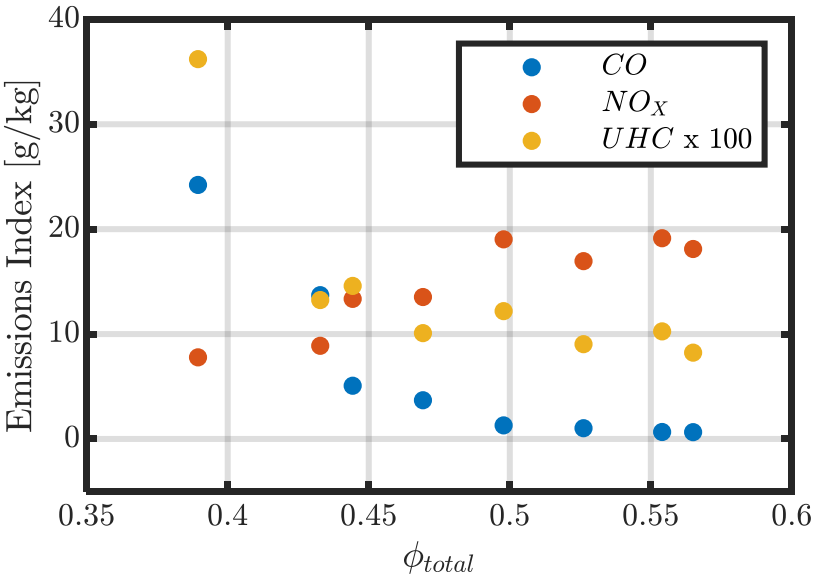
T_{fuel} [F]	T_3 [F]	P_3 [psi]	$\dot{m}_{air}$ [lb/s]	ϕ [-]	$\dot{m}_{f,pilot}/\dot{m}_f$ [%]
200	900	150	1.29	0.55→0.37	30
400					
600					
200		300	2.58	0.55→0.37	
400					
600					

Experimental Results: Emissions

- Completed initial emissions sampling over a range of equivalence ratios for T_{fuel} = 200 °F and P_3 = 150 psi
- Measurements show that lean roll-off (<99.9% combustion efficiency) occurs around ϕ = 0.43
- Minor species show the expected trends: NO_X increases with equivalence ratio and CO and unburnt hydrocarbons (UHC) decrease
- Currently performing similar sweeps for T_{fuel} of 400 and 600°F with P_3 of 150 and 300 psi
- Results will enable comparisons of combustion performance as fuel temperature is increased to near supercritical conditions



Combustion efficiency for T_{fuel} = 200 ˚F



Minor species for T_{fuel} = 200 ˚F

Experimental Results: OH* CL Imaging

- 50 kHz OH* chemiluminescence imaging is being performed along with the emissions measurements
- Mean flame images show high levels of heat release in regions where the pilot and main flames interact, with a more axially extended flame at higher equivalence ratios
- Both the high-speed imaging and a high-frequency pressure measurement indicate stable combustion at all conditions tested so far with heated fuels