Impact of Fuel Heating on Combustion Performance and Lean Combustion Characterization Project 67

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ASCENT

Project 67

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Purdue University

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PM: Theodore Johnson

Cost Share Partner(s): Purdue University

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 overall pressure ratio aircraft engines using extractive exhaust sampling and advanced optical and laser-based diagnostics.

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 800 F. Optical diagnostics and exhaust gas sampling are performed. Some of the advanced laser diagnostics preformed in this combustor include OH planar laser-induced fluorescence (PLIF) for reaction zone imaging, 3-component particle image velocimetry, Mie scattering for droplet imaging, and laser induced incandescence (LII) for soot measurements.

Major Accomplishments (to date):

- Characterized effect of fuel temperature (370-580 K) and chamber pressure (1-2 MPa) on emissions with Jet A and Shell GTL GS190.
- Investigated effect of fuel temperature on flame structure and dynamics with 10 kHz stereo-PIV, Mie scattering, and chemiluminescence measurements.
- Characterized soot formed with LII measurements for Jet-A and HEFA fuels across a range of thermal power density.
- Characterized effects of Jet-A temperature on soot formation.

Future Work / Schedule:

- Emissions characterization of HEFA SPK with distinct addition of aromatics (SAK) at a range of fuel temperatures and thermal power densities.
- NO PLIF measurements in the reaction zone.

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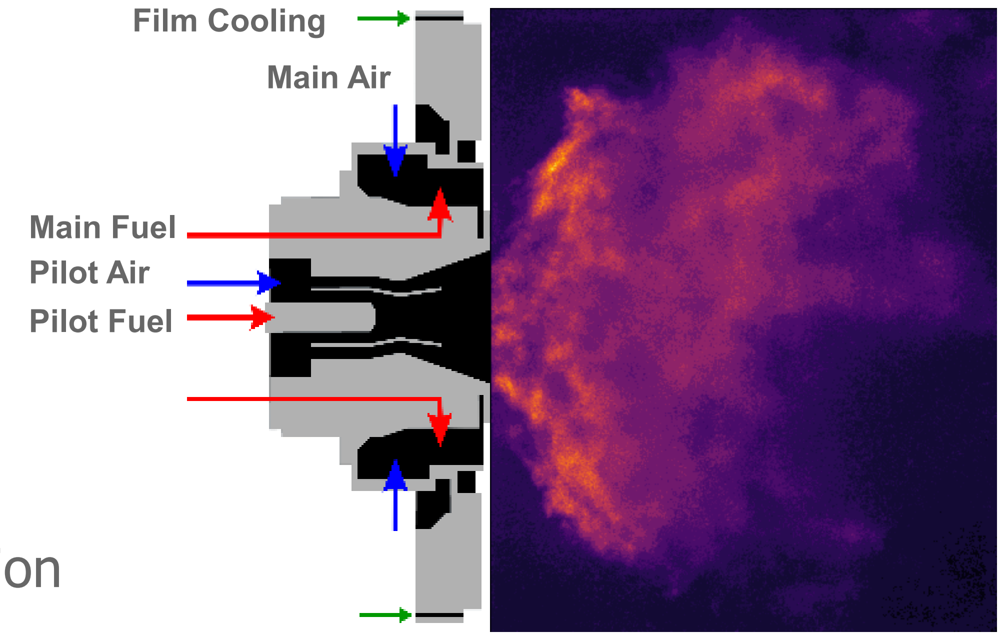
Introduction

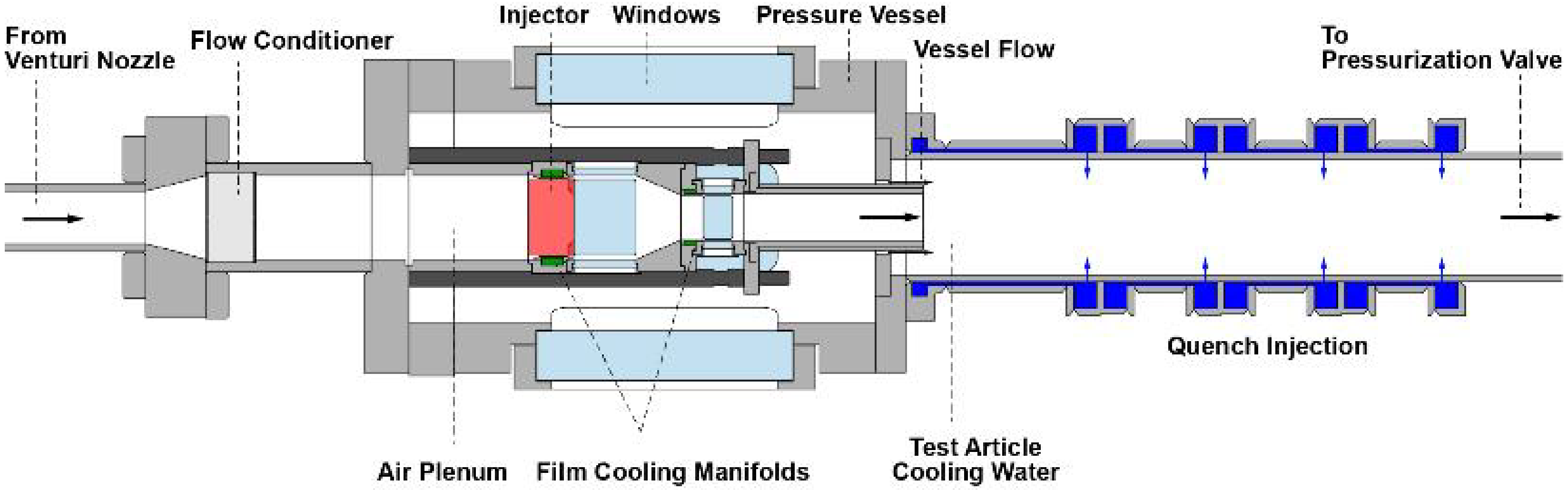
Characterize the effect of fuel temperature on the flame structure, dynamics, and emissions of a high-pressure lean-burn piloted swirl flame

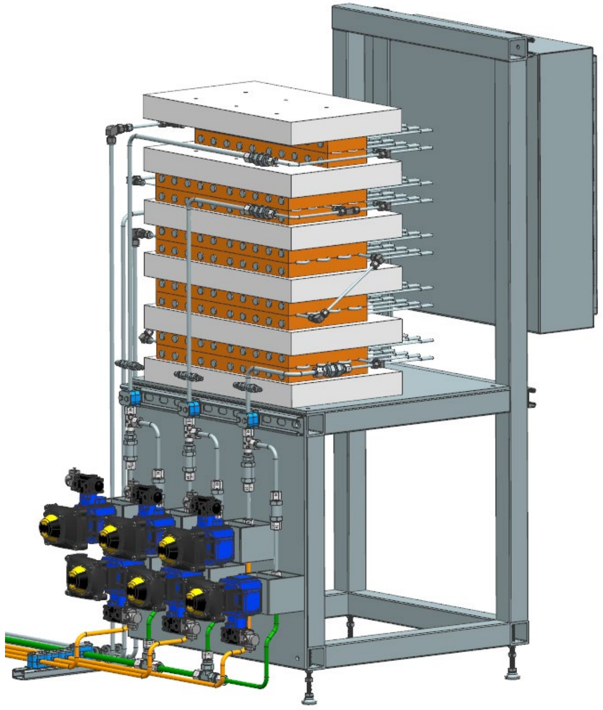
- Potential to increase the performance of aviation engines with heated fuels
- This project will characterize the impact of fuel heating on combustion and emissions in a lean-burn, high-pressure ratio aviation combustor
- Accomplishments of the past year:
  - Performed LII measurements in a high-pressure swirl-stabilized lean-burn combustor
  - Compared soot volume fraction formed in the combustion region as a function of fuel inlet temperature
  - Procured significant quantities of SAK for use in this combustor to study effects of aromatics on soot formation



Experimental Configuration

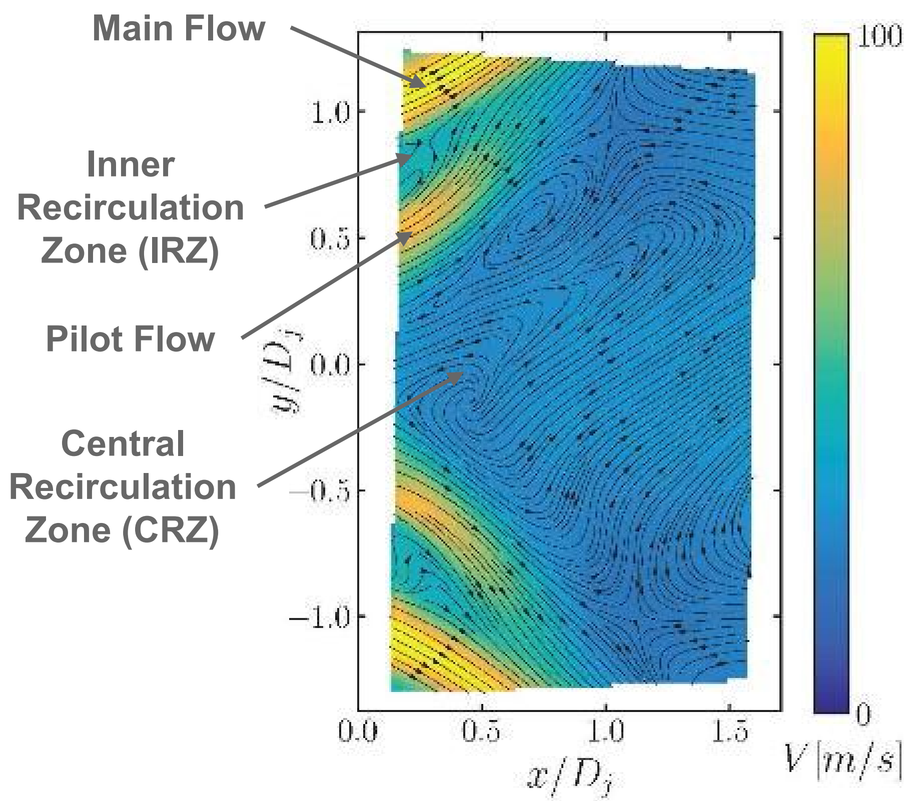
- Experiments performed in the Combustion Rig for Advanced Diagnostics (COMRAD) located at Purdue University's Zucrow Laboratories
- Optically accessible facility capable of simulating gas-turbine combustion conditions
- 81 kW fuel heater supplies liquid fuel up to 800 F

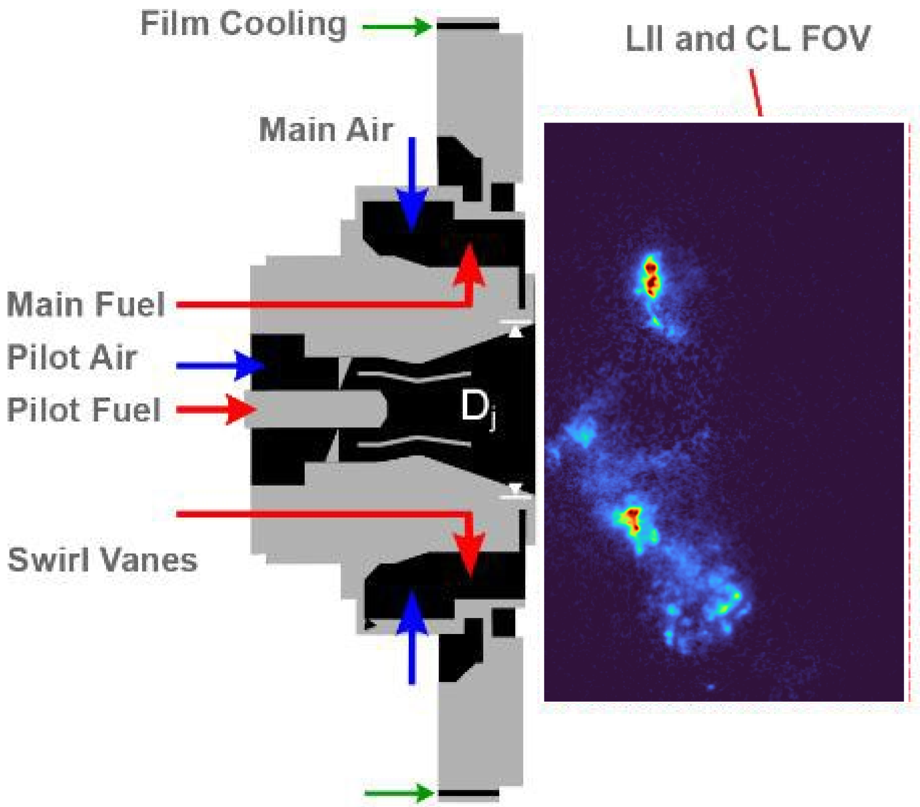




Experimental Configuration

- COMRAD is equipped with a lean-burn, piloted, partially premixed, liquid-fueled, swirl injector

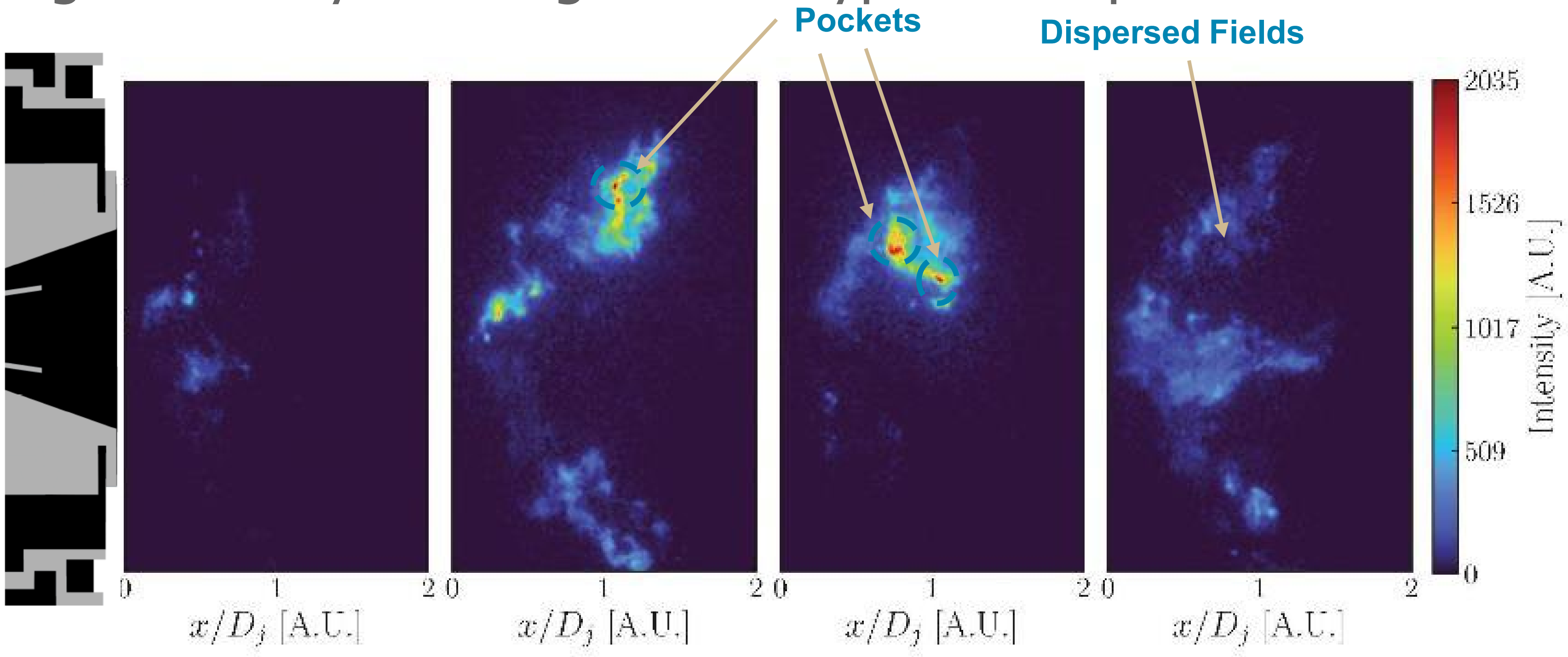




Single-Shot Jet-A LII Images

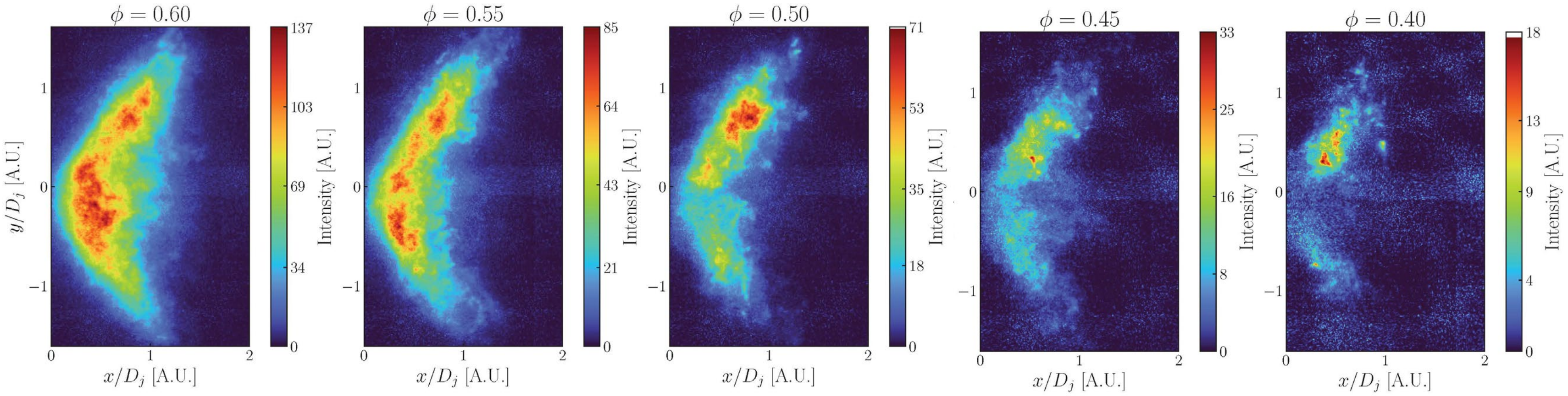
- LII signal is proportional to soot volume fraction
- Measurement rate is significantly slower than kinetic and transport timescales
- Localized, high-intensity soot regions are typical in liquid-fueled turbulent flames

$\phi = 0.60$
T_{fuel} = 300 K



Jet-A LII Measurements

- Ambient fuel temperature, variation in equivalence ratio
- Full range of color scale utilized for each image, intensity is proportional to soot volume fraction
- Pilot rich-to-lean transition results in soot structure shift

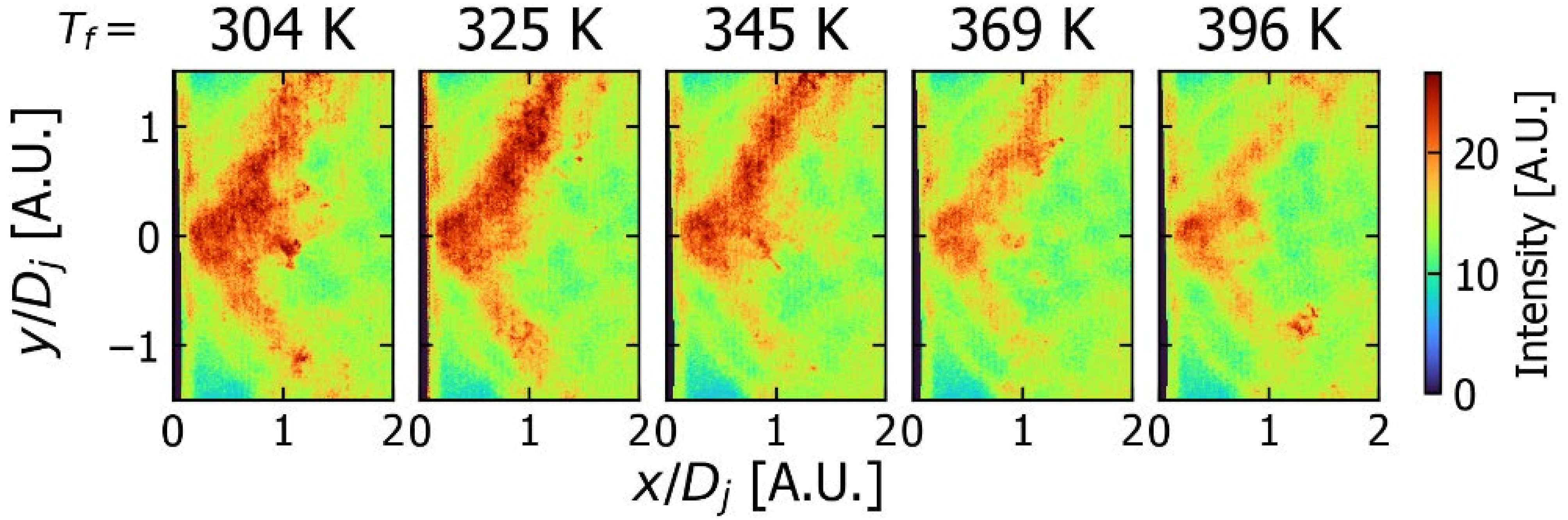


Independent flow equivalence ratio

Global ϕ [-]	Pilot ϕ [-]
0.60	1.30-1.33
0.55	1.19-1.23
0.50	1.10-1.14
0.45	0.97-1.00
0.40	0.85-0.87

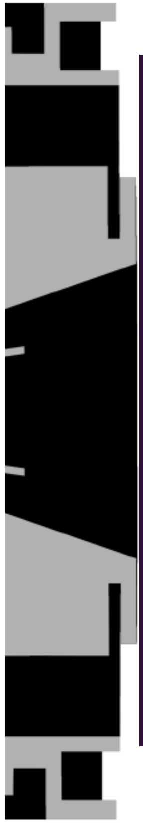
Jet-A LII Measurements

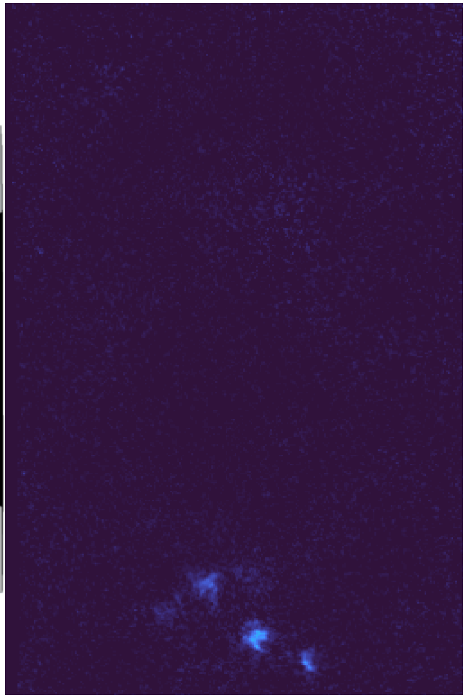
- Single equivalence ratio condition selected (ϕ = 0.50), varying inlet fuel temperature
  - Soot structure shifts from CRZ to upper half of combustion region
  - Slight decrease in signal intensity, suggesting decrease in soot volume fraction



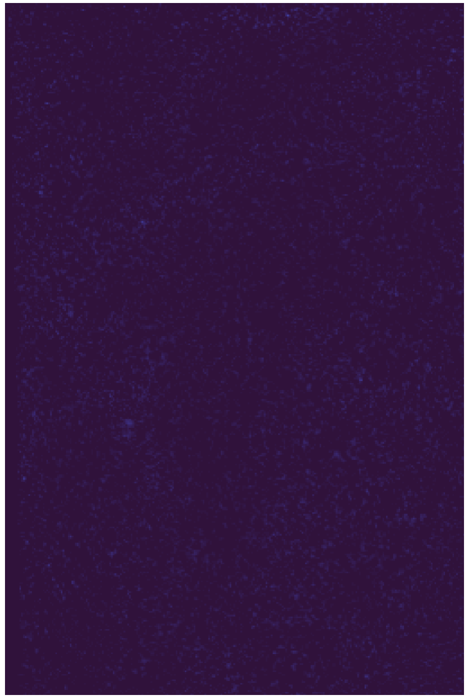
Single-Shot Comparison: Fuel Temperature

- Elevated fuel temperatures reduce probability of high intensity soot pockets
- Remaining dispersed fields shrink in scale and intensity

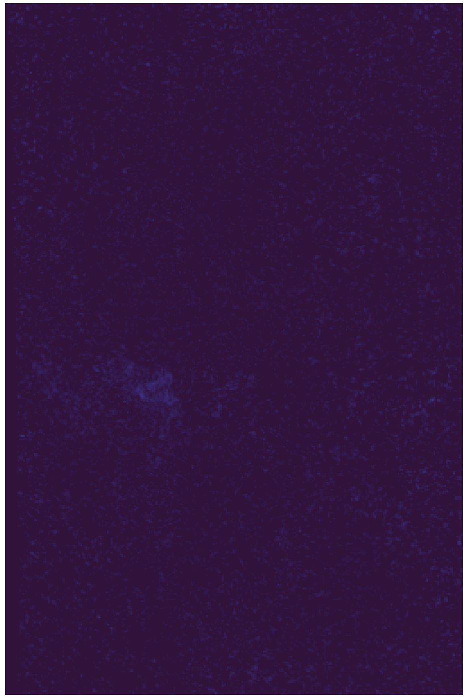




$\phi = 0.5$, T_{fuel} = 304 K



$\phi = 0.5$, T_{fuel} = 345 K



$\phi = 0.5$, T_{fuel} = 396 K

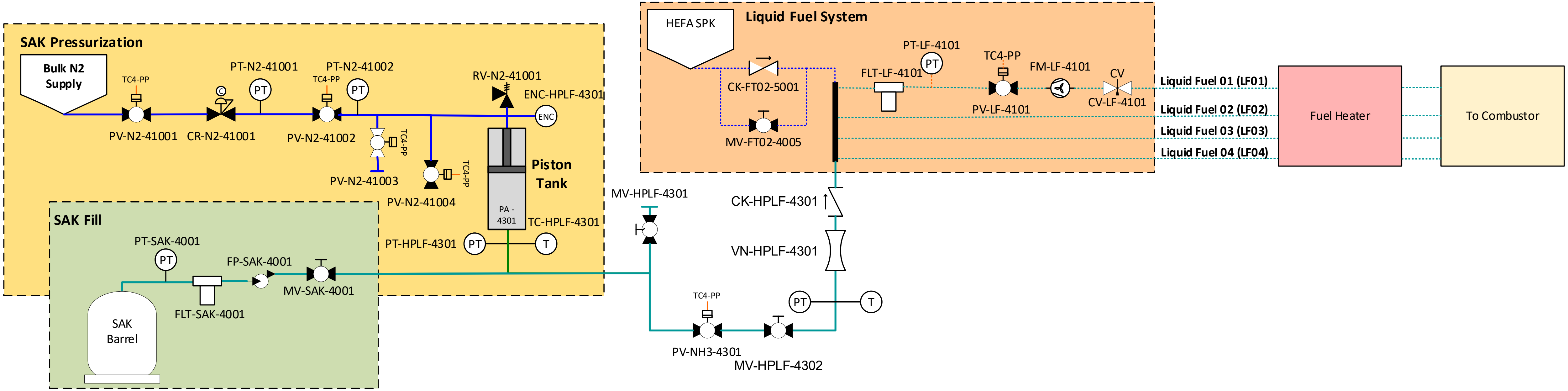
Fuel Blending Update

- PAHs are an immediate precursor to soot
  - SPKs with limited aromatic content produce significantly less soot
- 13 gallons of SAK procured
- Sufficient SAK for limited steady-state aromatic content testing
- Development of an in-situ fuel blending system expands testing to full allowable range
  - 8-25%v/v aromatics required per ASTM D7566

SAK [gal]	SAK Fuel Fraction [%]	HEFA Used [gal]	Total Fuel [gal]
2.4	4	57	60
4.8	8	55	60
7.1	12	52	60

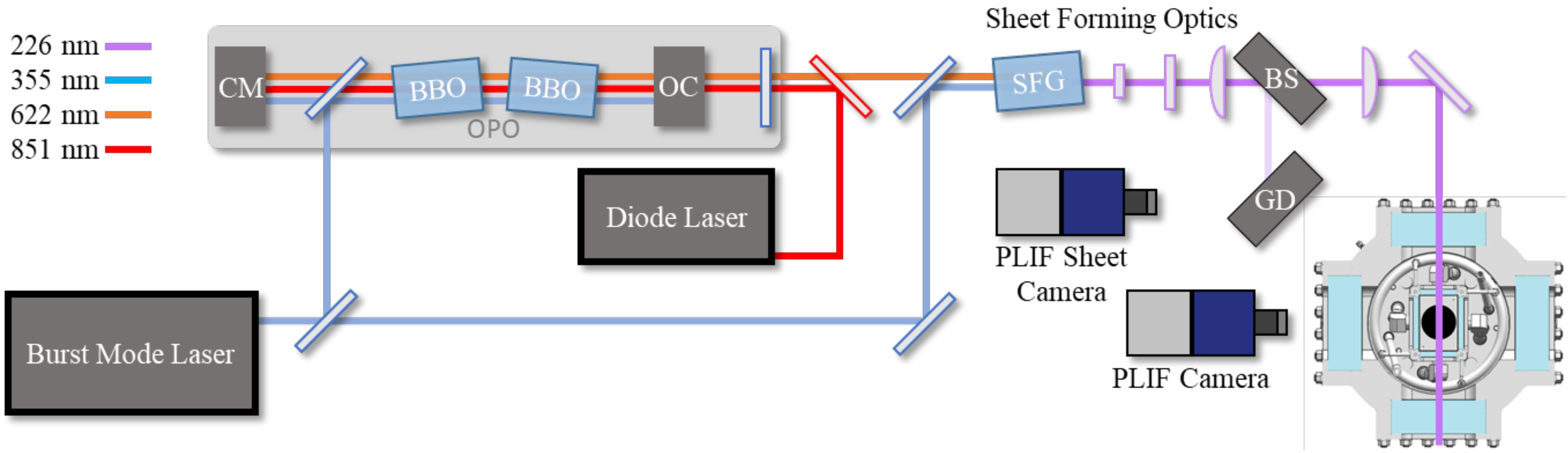
Fuel Blending Update

- SPK delivered from bulk storage utilizing mechanical pump
- SAK delivered from piston tank to liquid fuel system only when measurements are being performed, will drastically reduce SAK consumption rate
  - Linear encoder provides position feedback from piston
- SAK flowrate metered using cavitating Venturi nozzle



NO PLIF Measurement Update

- Excitation of P1(23.5) line in A-X(0,0) band of NO at ~226 nm
  - Good signal-to-noise ratio at high pressure conditions
- Burst mode laser with optical parametric oscillator (OPO) provides 100 kHz pulse bursts
- Heated high-pressure gas cell measurements verified excitation wavelength, necessary pulse energy, and detection limits (~100 ppm)
- Fused silica windows required to transmit excitation laser and image NO fluorescence



Summary

- Characterized soot produced in a high-pressure swirl-stabilized flame
  - Compared ambient temperature fuel injection versus elevated fuel temperatures
- Developed high-speed NO-PLIF diagnostic system, demonstrated imaging capabilities at elevated pressures and temperatures
- Designed an SAK mixing system to vary aromatic mix-in percentages during combustor operation and conserve limited quantities of SAK
- Next Steps:
  - Perform LII measurements with elevated temperature HEFA fuel
  - Assemble and implement SAK mixing system to investigate effects of aromatics on soot production
    - Single-ring aromatics will be mixed with HEFA-SPK (World Energy) in discrete incremental concentrations (0, 4, 8, 12, 16, and 20%)
    - Characterization engine with other SAFs with increased availability
  - Deploy NO-PLIF diagnostic system in the gas-turbine facility

Acknowledgements

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