# Project 067 Impact of Fuel Heating on Combustion Performance and Lean Combustion Characterization

## Purdue University

## Project Lead Investigators

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## University Participants

**Purdue University**

- P.I.s: Dr. Robert P. Lucht and Dr. Carson D. Slabaugh
- FAA Award Number: 13-C-AJFE-PU-038
- Period of Performance: October 1, 2020, to September 30, 2024
- Task:
  1. Investigate the effects of fuel heating on combustion performance and products for aviation gas turbines

## Project Funding Level

The ASCENT Project 067 was funded by the Federal Aviation Administration (FAA) at the level of $250,000 for the project period from June 5, 2020, to June 4, 2021; an additional $250,000 for the time period from June 5, 2021, to September 30, 2022; an additional $250,000 for the time period from October 1, 2022, to September 30, 2023; and an additional $200,000 was approved for the project period of October 1, 2023, to September 30, 2024. A no-cost extension of this funding period is now in place. The required cost-sharing 1:1 match of $950,000 was provided by Purdue University.

## Investigation Team

Prof. Robert P. Lucht (P.I.)
Prof. Carson D. Slabaugh, (co-P.I.)
Ben Murdock, Zander Hodge, Tristan Shahin, and Keaton Koenig (graduate students), Responsible for the design of system components, such as the fuel heating system, and will be responsible for executing test operations.
Dr. Rohan Gejji, Research Engineer, Help graduate students with their design projects and supervising test operations.
Dr. Theodore Johnson, Current Program Manager
Dr. Bahman Habibzadeh, Program Manager from October 1, 2023, to June 30, 2025
Dr. Prem Lobo, Program Manager from October 1, 2022, to September 30, 2023

## Project Overview

The goal of this project is to evaluate the effects of heating jet fuel before injection in an aviation gas turbine combustor on combustion efficiency, pollutant formation, and dynamics. In an aircraft engine, heat that would otherwise be wasted can be directed into the fuel to increase its sensible enthalpy before injection. Thermochemistry dictates that this increase in sensible enthalpy must lead to lower fuel consumption for a given combustor exit temperature. However, the effects of elevated fuel temperature on combustion performance characteristics (e.g., the fuel spray pattern, spatial distribution of reaction zones, pollutants, and combustion dynamics) are not yet well understood. The ASCENT Project 067 team will perform experiments with heated fuels by using a piloted, partially premixed fuel injector located in an optically accessible combustor. This process will allow us to apply advanced laser diagnostic techniques to compare the behavior of the combustor at different fuel temperatures over a wide range of operating conditions.

The platform for the planned experiments is the Combustion Rig for Advanced Diagnostics (COMRAD). The test rig (Figure 1) is designed to operate at steady-state conditions with thermal power as high as 8 MW, inlet air pressure ($P_3$) as high as 4.0 MPa, and inlet air temperature ($T_3$) as high as 1,000 K. To facilitate operation at these conditions, the test article is made of aviation-grade alloys and is thoroughly water cooled, and the inner windows are film cooled with heated nitrogen. Before this project, extensive testing with ambient-temperature fuels was performed in this test rig, with a focus on 5- and 10-kHz particle image velocimetry (PIV) measurements in the downstream boundary condition window section, and 50- and 100-kHz PIV measurements in the flame zone.

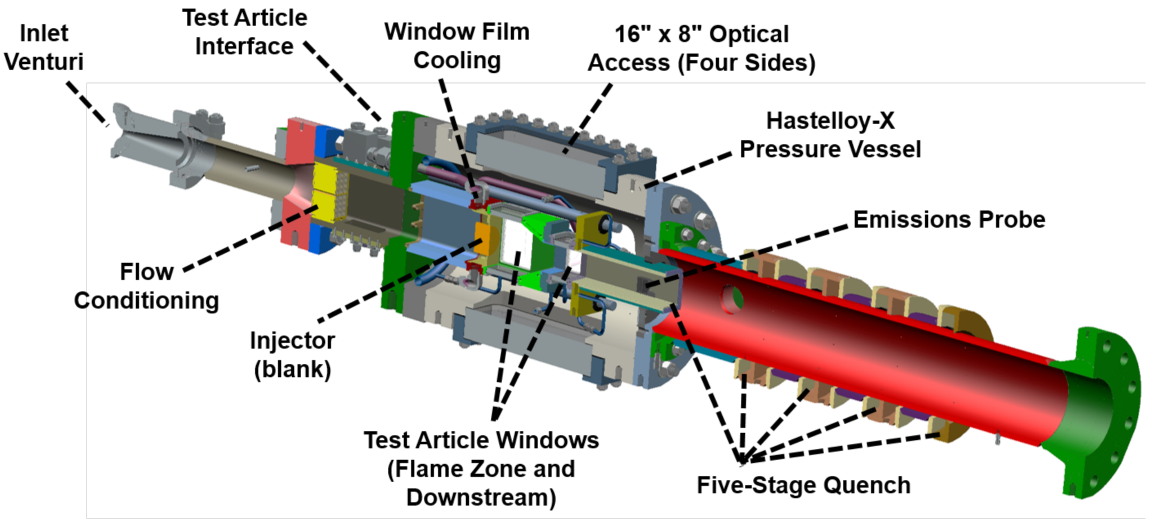

**Figure 1.** Schematic diagram of COMRAD.

## Task 1 - Investigate the Effects of Fuel Heating on Combustion Performance and Products for Aviation Gas Turbines

**Purdue University**

### Objective

The goal of this project is to determine the effects of fuel heating on the performance of aviation gas turbines. Fuel heating can potentially lead to higher efficiency but can also lead to changes in the fuel distribution pattern and in the locations of reaction zones in the combustor. These changes may also affect pollutant formation and combustion dynamics during engine operation. The ASCENT Project 067 team will perform experiments using heated fuels and measure the fuel distributions, reaction zone distributions, pollutants, and combustion dynamics at a range of fuel temperatures from near room temperature to above the supercritical temperatures for hydrocarbon fuels.

## Research Approach

Our team will perform experiments with heated fuels by using a piloted, partially premixed fuel injector located in an optically accessible combustor. This experimental system will allow us to apply advanced laser diagnostic techniques to compare the behavior of the combustor at different fuel temperatures over a wide range of operating conditions. These advanced diagnostic techniques include fuel planar laser-induced fluorescence (PLIF) imaging to monitor fuel distribution patterns, hydroxyl (OH) radical PLIF (OH PLIF) imaging to monitor reaction zones, PIV to measure the flow fields, and laser-induced incandescence (LII) imaging to monitor spatially resolved soot volume fractions. We will also measure combustion products with probe sampling and will use pressure transducers to measure combustion dynamics.

### Facility Overview

COMRAD is supplied by facility fluid systems including heated air, heated nitrogen, high-pressure water, and liquid jet fuel. Three types of liquid jet fuel were used separately for this work: (a) Jet A fuel, (b) Shell® gas-to-liquids (GTL) GS190, a Fischer-Tropsch synthetic paraffinic kerosene (FT-SPK), and (c) World Energy® hydroprocessed esters and fatty acids (HEFA). The rig features a piloted swirl injector (shown schematically in Figure 2) housed inside a duct within a large-windowed pressure vessel enabling optical access to the entire flame from four sides. Figure 3 shows a diagram of the test rig. Combustion air is supplied to the test article at 755 K and up to 20 bar. After it is metered, the air passes through a flow conditioner and into the air plenum, which supplies both the pilot and main sections of the injector.

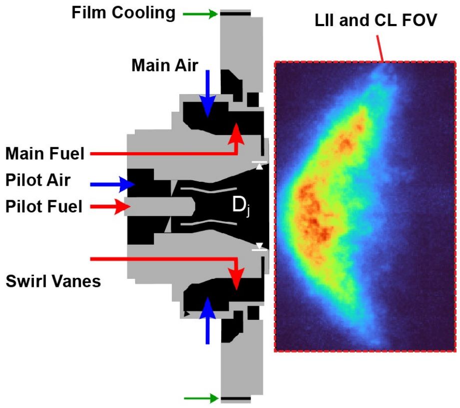

**Figure 2.** Schematic diagram of the injector indicating reactant flow routing. The laser-induced incandescence (LII) and OH* chemiluminescence (CL) fields of view (FOV) are also shown.

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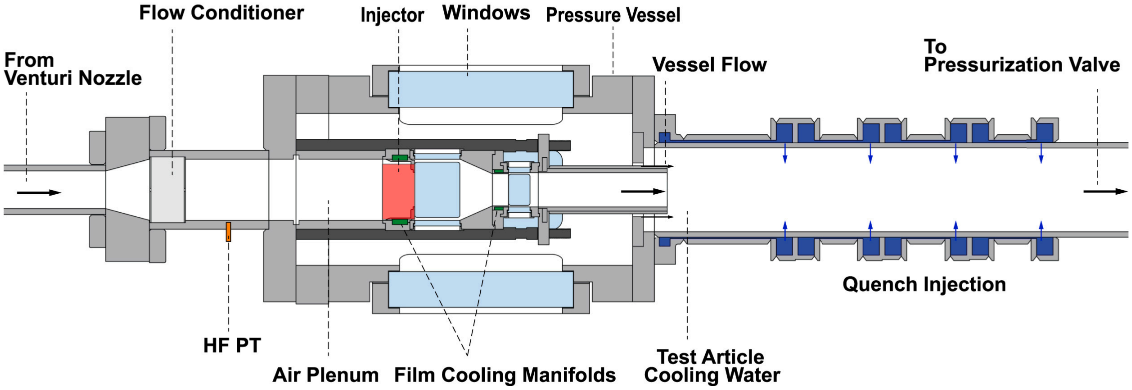

**Figure 3.** Schematic diagram of the combustor.

Liquid jet fuel is supplied to the injector at temperatures as high as 590 K by an 81-kW fuel heater. The fuel heater (Figure 4) comprises a stack of copper blocks with 20 cartridge heaters inserted into each block. Fuel flows in stainless steel tubes through three independent circuits, two pilot circuits, and one main circuit. The mass flow rates in each circuit are measured with Coriolis flow meters. In the fuel heater, the stainless-steel tubes are clamped between each pair of copper blocks before being delivered to the test rig. The temperature of the fuel is monitored both in the fuel heater (to ensure that no phase change is encountered) and immediately upstream of the injector. Fuel passes through approximately 50 cm of trace-heated tubing from the heater to the test rig. The tubing is air-jacketed within the test rig to inhibit heat transfer from the heated air before the injector is reached. To prevent coking in the fuel lines at high fuel temperatures, the fuel tank is sparged with nitrogen for 30 minutes before use to remove dissolved oxygen, and the tank ullage is purged with nitrogen during the experiment. A dissolved oxygen sensor (Mettler Toledo® Inpro 6850i) is used to ensure that the levels of dissolved oxygen remain below 0.2% of the fully saturated level during the experiment. An inert gas purge circuit is used to prevent the collection of stagnant fuel in the heater and the tubing to the experiment when fuel is not flowing to the experiment. This purge displaces the fuel to a collection tank through a bypass circuit and counter-flow heat exchanger that cools the fuel temperature to ambient temperature with water as the heat transfer medium.

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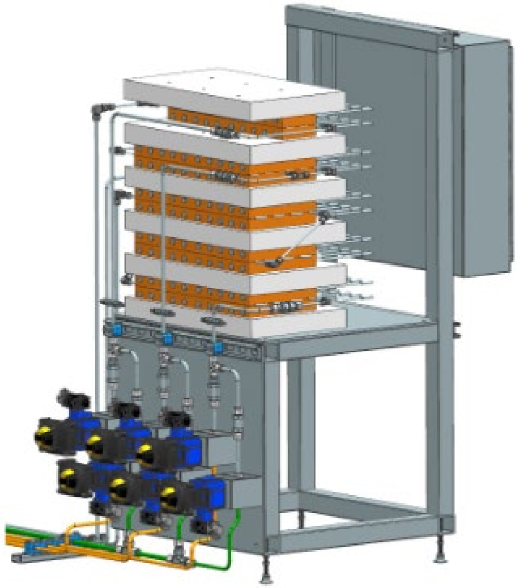

**Figure 4.** Fuel heater.

At the injector, fuel is injected into two co-swirling flows of air separated by a bluff body. The inner flow forms the pilot flame, and the outer flow forms the main flame, where most of the fuel is burned. The fuel flow rates to the pilot and main circuits are separate to enable independent control of the fuel/air ratio in each part of the flame. The pilot flame is operated at a higher fuel/air ratio than the main flame, allowing the main flame to stabilize as the pilot products mix with the main reactants. The main reactant stream is assumed to be partially premixed when it reaches the flame, but the pilot flame is mostly non-premixed.

The flame zone is contained by a rectangular duct with a height/width ratio of approximately 1.4. Fused quartz windows are installed on each side of the duct to enable imaging of the flame. These windows are film cooled with heated nitrogen at approximately 590 K to lessen the thermal load created by the flame. The film cooling flow rate is independently controlled but is set to a constant fraction of the combustion air flow rate. The duct then contracts vertically to a height/width ratio of approximately 0.75. Downstream of this contraction, another windowed section is present. A separate supply of heated air flows through the pressure vessel at the same pressure as the combustor, and this flow merges with the test article flow in a pipe, where water is radially injected into the flow to cool it. An electrically actuated butterfly valve is installed at the exit of the flow path to back-pressurize the combustor. The inner duct is coated with a thermal barrier coating and cooled by internal water channels. This cooling water is directed into the flow at the exit of the inner duct.

Heated air and nitrogen sources are metered with sonic Venturi nozzles, high-pressure water is metered with cavitating Venturi nozzles, and jet fuel is metered with Coriolis flow meters. The test rig is equipped with pressure transducers (GE® PMP50E6) and K-type thermocouples (Omega® GKMQSS-062G) for flow metering and in several different locations throughout the flow path. These instruments are sampled at 100 Hz to monitor the operating conditions, and a National Instruments® LabVIEW virtual instrument is used to display measured values and send commands to pneumatically and electrically actuated valves in the test cell. The relative uncertainties of calculated mass flow rates have been determined to

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be below 0.83% for gases and below 0.10% for liquid fuel according to the Kline–McClintock[1] method, with a 95% confidence interval. A high-frequency pressure transducer (Kulite® WCT312M-70BARA) is installed in the air plenum to monitor acoustic oscillations.

During testing operations in Spring 2024, a facility water softener failure resulted in damage to the water-cooled portions of the test article. The damage to the exhaust duct of the combustor was severe and the cost of the repair was more than $50,000. Because this failure was a facility issue, Purdue University insurance rather than the FAA project paid for the repair, but the exhaust duct had to be refabricated, and it took over 6 months to complete that fabrication. The experiment repair was completed in early Spring 2025, allowing testing to resume.

### Laser-Induced Incandescence Overview

LII is an in-situ method for determining soot levels in a combustion flow field. The diagnostic was first applied to a lab scale laminar diffusion flame (Yale burner) to validate the accuracy of the experimental setup and then used to investigate soot formation for both rich and lean dome operation in COMRAD. Comparison of soot levels between several different fuels has begun with noticeable decrease in signal for synthetic fuels lacking aromatics such as World Energy HEFA across all operating conditions. LII measurements provide valuable information of the spatial locations for particulate formation in the combustor flow field. GE Aerospace is very interested in the types and number of particulates that are in the combustor exhaust.

Two-dimensional LII measurements can be obtained in a flame by using a laser sheet that passes through a plane of interest and measuring the incandescence signal with a camera. Comparative soot volume fraction measurements can be determined by gating the detection device around the entire incandescence signal.

A Quanta-Ray® Pro-290 Nd:YAG laser is used to generate a 1064 nm beam at a frequency of 10 Hz. Using an excitation wavelength of 1064 nm reduces poly-aromatic hydrocarbon (PAH) laser-induced fluorescence (LIF) and excitation of diatomic carbon ($C_2$) molecules. The beam is attenuated to the desired power with a half-wave plate and a thin-film polarizer allowing for a max of 240mJ down to as low as 8.5mJ. A set of cylindrical lenses (f = -50, +300) is used to expand the beam in a vertical direction and collimate it. Two horizontal cylindrical focusing lenses (f = +150) are then used to focus the beam into a sheet with a variable focal length. The focal point of the laser sheet is aligned with the center line of the injector. For the experiments in the gas turbine combustor, the sheet is 48.49 mm wide and 0.53 mm thick at the focal point. The sheet is introduced to the experiment from above, perpendicular to the injector's face. The sheet is aligned with the center of the injector while ensuring vertical alignment using a reflected beam. A diagram of the setup used for the COMRAD testing is shown in Figure 5.

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[1] The Kline-McClintock Method is used to determine the uncertainty of a calculation given certain measurements and the tolerances on those measurements. The method defines the uncertainty as a range where the true value lies in.

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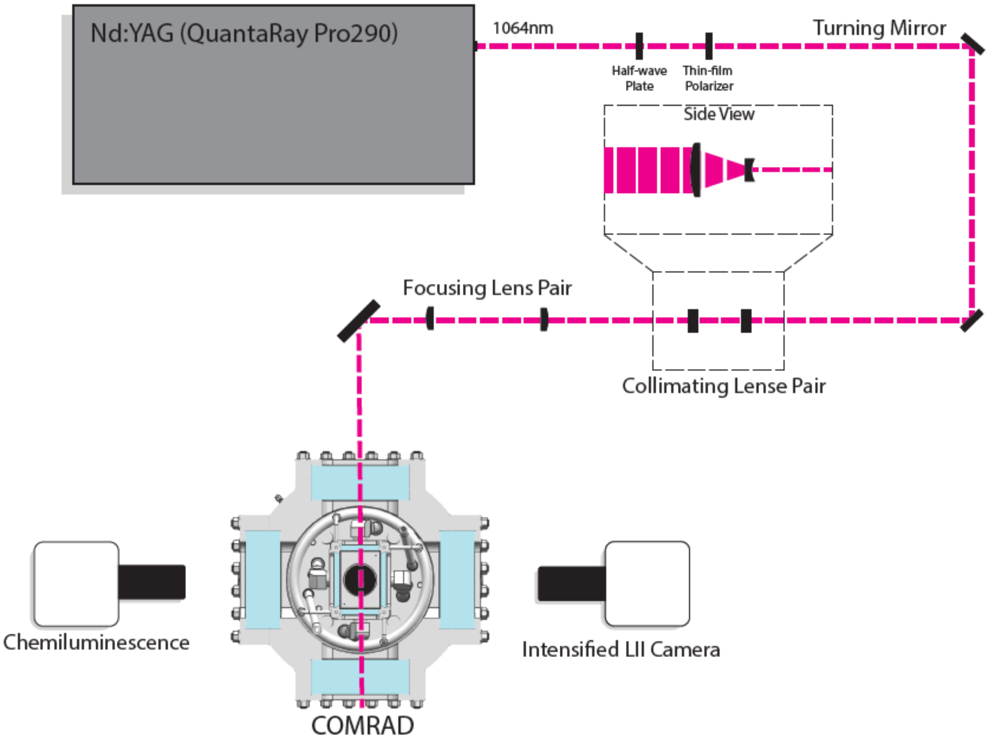

**Figure 5.** Schematic diagram of the LII diagnostic system for measurements in COMRAD.

An intensified ultrahigh-speed complementary metal-oxide-semiconductor (CMOS) camera (Phantom® TMX and Lambert™ High-speed Intensified Camera Attachment [HiCatt]) measures the LII signal emitted from soot within the flame. A gate time of 250 ns is used to capture the incandescence with the arrival of the laser occurring approximately 50 ns after the beginning of the gate. The camera was equipped with a 50 mm lens to achieve the desired spatial resolution. A bandpass filter centered at 450 nm with a 20 nm bandwidth isolates the LII signal at a wavelength with negligible interference from $C_2$ chemiluminescence. A shortpass filter with a cut-off wavelength of 900 nm is used to block any scattered 1064 nm laser light from reaching the camera.

### Time-Resolved LII Model

Prior to attempting LII measurements in the COMRAD test rig last year, our team performed LII experiments in a well-characterized sooting laminar diffusion flame. This allowed us to optimize experimental parameters such as the details of the time gate for the detection of the LII signal and also allowed us to develop data analysis methods. Another consideration for performing these measurements in the Yale burner is that we were using the infrared 1064-nm out of the Q-switched Nd:YAG laser, a beam that presents significant eye hazards. Our team wanted to gain experience with working this beam prior to attempting alignment in the test cell for the COMRAD experiments.

Measurements collected in the Yale burner included both time-integrated and time-resolved LII. Time-integrated measurements allow for the extraction of relative soot volume fraction and time-resolved measurements enable primary particle size measurements. We have previously performed time-integrated measurements in the gas turbine combustor. Time-resolved measurements require detection devices with sufficiently high repetition rates to resolve a single signals decay. The LII signal intensity is a function of three major variables, primary particle diameter, number of particles in an agglomeration, and temperature of the particles, as shown in Equation 1.

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**Equation 1.** LII signal intensity.

$$S_{LII} = f(d_p, N_p, T) = \frac{8\,\pi^3\,d_p^3\,N_p\,h\,c^2\,E(m)}{\lambda_c^6\left[exp\left(\frac{hc}{\lambda_c k_B T}\right)\ -\ 1\right]}$$

Temperature of the solid soot particles must be accurately modeled to predict LII signal, which is dependent on the heat transfer mechanisms removing heat following the rapid laser heating event. This includes conduction to adjacent particles and the gas environment, sublimation of solid particles to the gas phase, and thermal radiation to the background. The net change in internal energy is related to the particle temperature as shown in Equation 2.

**Equation 2**. Change in internal energy.

$$\frac{dU_{Internal}}{dt} = \frac{\pi}{6}d_p^3 N_P \rho_s c_s \frac{dT}{dt}$$

These fundamental equations are combined with chemical equilibrium calculations to develop a versatile representative molecular kinetic model. This model employs an ethylene-air reaction mechanism to compare to the work of Liu et al. (2006) and an n-Dodecane kinetic mechanism for Jet A fuel combustion. The n-Dodecane model uses an average chemical composition representative of the gas turbine rig bulk conditions. Figure 6 shows the resulting soot particle temperature and LII signal intensity as a function of time for each model. The primary particle size, number of particles in an agglomeration, and pressure are held constant at 30 nm, 200, and 1 MPa respectively. Each model reaches a peak soot particle temperature of just over 3000 K, with the resulting temperature decay occuring faster for the heavier hydrocarbon model. This results in a more rapid LII signal intensity decay as well, though the variation is subtle. The LII signal intensity decay time is much shorter at this elevated pressure condition (150 ns) compared to the previous work in the atmospheric diffusion flame (1500 ns). While single-point detection devices are capable of acquiring sufficient datapoints to reconstruct a decay of 150 ns, two-dimensional detector arrays that enable time-resolved (TiRe)-LII imaging are limited to a period of 100 ns between datapoints.

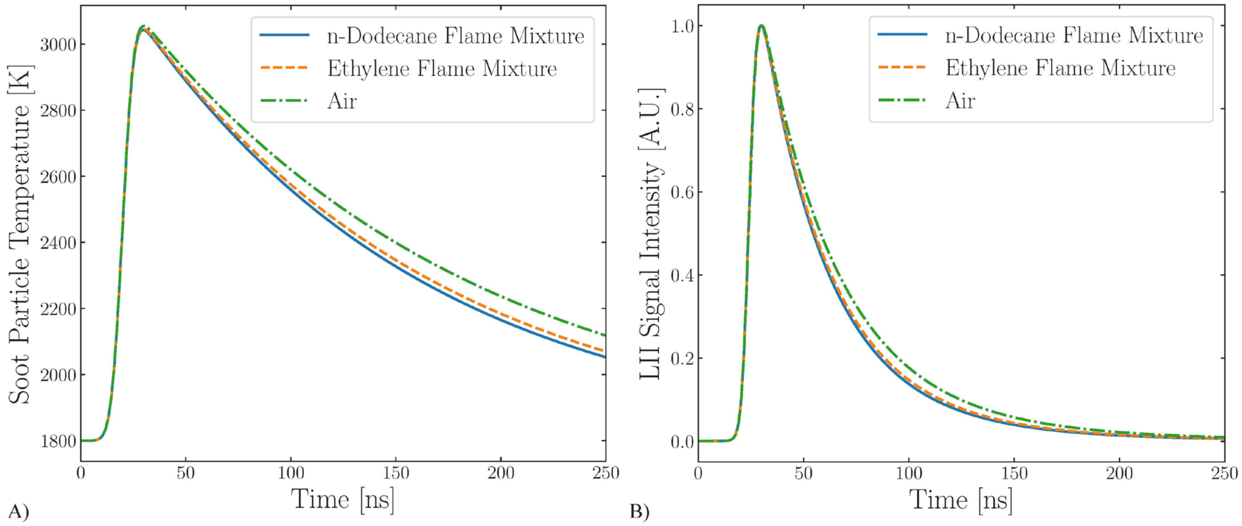

**Figure 6**. Two graphs showing (a) simulated particle temperature and (b) normalized LII signal.

**LII Measurements in COMRAD**

The filter stack does not completely isolate the LII signal, as shown in Figure 7(a). To account for this, the collection system is operating at 250 kHz, a much higher repetition rate than the 10 Hz excitation laser. This allows capture of a background frame 4 us prior to the laser introduction to the experiment (Figure 7[b]). At these conditions, this sufficiently freezes motion to perform a background subtraction. The resulting corrected image is shown in Figure 7(c).

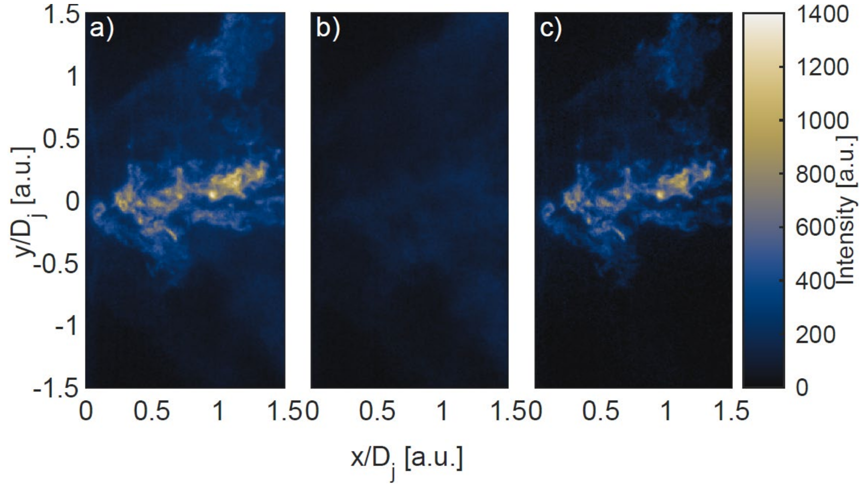

**Figure 7.** Three images illustrating LII signal processing: (a) LII signal image, (b) Background image taken 4 us prior, and (c) Resulting background subtracted LII signal.

**Pilot Only Operation**

Soot formation in pilot only operation of current generation combustors is of particular interest due to its use during landing approaches at airports. Studies by Mueller et al. (2025) determined non-volatile particulate matter (nvPM) concentrations surrounding airports can be primarily correlated with arrival aircraft. To investigate this in the optically-accessible combustor, conditions such as inlet air flowrate and temperature, equivalence ratio, and dome pressure drop are held constant. The primary variables investigated are supplied fuel temperature and fuel type (Jet A or World Energy HEFA fuels). Resulting average LII signals from pilot operation with Jet A fuel from 311 to 472 K fuel temperatures are shown in Figure 8. Throughout each fuel temperature, the majority of the LII signal is located along the vertical centerline of the combustor. The pilot element is centered at a y/D$_j$ of 0, which is locally rich for this pilot-only condition. As fuel temperature increases, the bulk intensity of soot volume fraction decreases. At the 472 K condition, the average signal is approximately half the value at the ambient fuel temperature condition. This may be a combination of two factors. Increasing fuel temperature decreases the evaporation timescale, which has been previously shown to dampen combustion instabilities. Reducing evaporation timescales allows for longer residence times for chemical kinetics processes. Soot particles may be consumed, which is supported by the shortening of the most intense regions of soot volume fraction. The increased sensible enthalpy of the fuel may also raise the flame temperature slightly, which results in an increase in the critical sooting equivalence ratio for most hydrocarbons. A higher flame temperature would reduce the quantity of carbon available for soot formation as it is instead converted to carbon dioxide ($CO_2$).

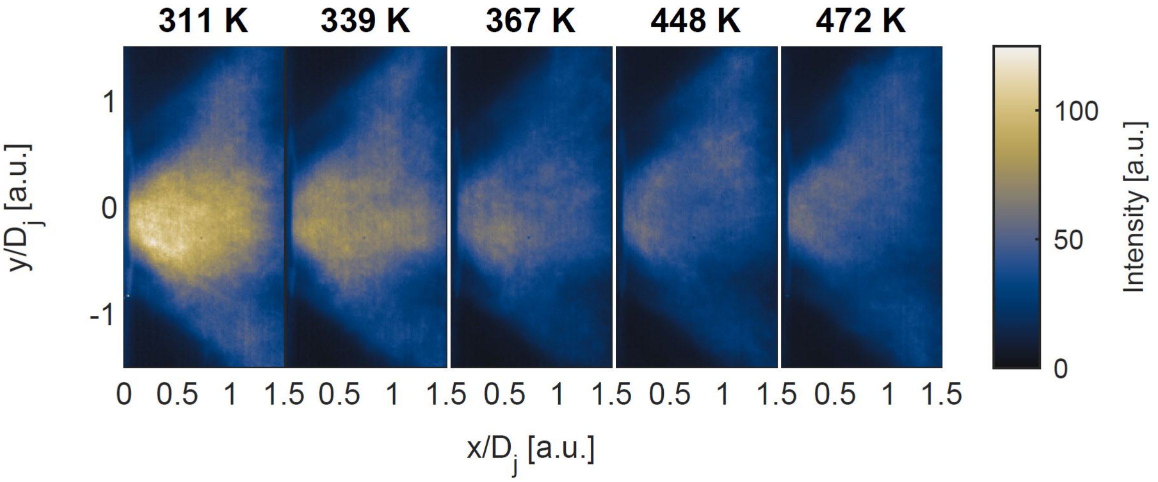

**Figure 8**. Results of time-averaged LII signals from Jet A fuel for pilot-only operation. The inlet fuel temperature is listed above each image.

Experiments were performed using the World Energy HEFA fuel at the same pilot operation conditions, shown in Figure 9. The color scale in this figure is approximately one-quarter of that in Figure 8, highlighting the distinct difference due to a lack of aromatics in this fuel. As fuel temperature is increased, there is not a significant variation in LII signal intensity. This suggests the mechanism responsible for the decrease in signal for the Jet A fuel measurements is related to the aromatic content. There is not a significant variation in soot formation structure as the HEFA fuel temperature is increased, along the centerline it remains relatively uniform. If soot is in fact being consumed as a function of flame temperature, this mechanism is not active for the neat HEFA fuel.

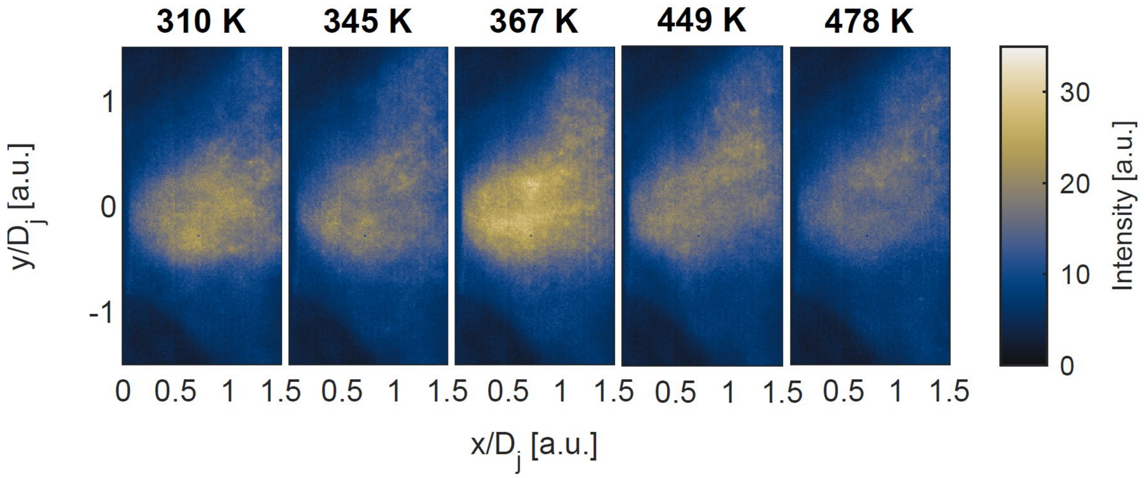

**Figure 9**. Results of time-averaged LII signals from HEFA fuel for pilot-only operation. The inlet fuel temperature is listed above each image.

**Development of Ultrahigh Speed Nitric Oxide Planar-Laser Induced Fluorescence**

Previous work done on this project utilized extractive gas sampling measurements to investigate combustion product variations as a function of fuel temperature. Nitric oxide (NO) was found to increase by a factor of two as fuel temperature was increased from 366 K to 589 K. To further investigate this NO increase, we have developed an ultrahigh speed NO planar-laser induced fluorescence (NO PLIF) diagnostic. The optical system is shown in Figure 10. A burst-mode laser operating at 100 kHz provides the necessary energy at 355 nm to pump an optical parametric oscillator (OPO), which converts the 355 nm light to a 622 nm signal. An idler diode laser operating at 851 nm spectrally narrows the signal leaving the OPO. A portion of the 355 nm beam is routed around the OPO to be used in a sum-frequency generation process with the 622 nm light. The resulting beam at 226 nm is tuned to excite the P1(23.5) line in the NO A-X(0,0) band.

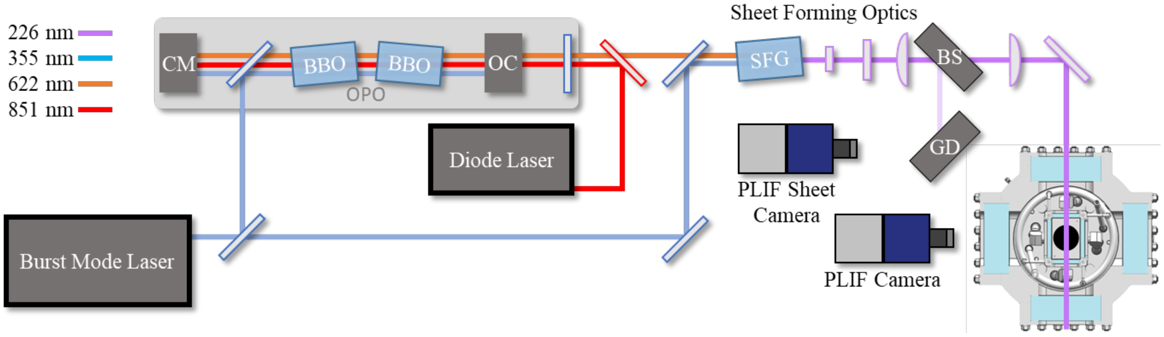

**Figure 10**. NO PLIF diagnostic system.

A heated, high-pressure gas cell was used to contain up to 8000 ppm of NO for verification of excitation wavelength, necessary pulse energy, and a detection limit of approximately 100 ppm. Signal was verified at up to 0.5 MPa and 670 K. Prior to implementation into the gas turbine combustor, new windows made of fused silica are necessary to transmit the excitation laser and image the NO fluorescence.

## Small-volume Fuel Delivery System

PAHs are known to be an immediate precursor to soot. In petroleum-based jet fuels, the aromatic content of approximately 17% significantly increases nvPM formation compared to neat synthetic paraffinic kerosene (SPK) fuels. To investigate the sensitivity of aromatic content on soot formation, we would like to blend either synthetic aromatic kerosene or petroleum-based aromatics into neat SPK. Current ASTM D7566 standards (ASTM, 2022) allow variations in aromatic content from 8-25%v/v for Jet A fuel, and up to 50% blending of HEFA SPK. Due to the extremely limited quantity of synthetic aromatic kerosene (SAK) and the large quantity of fuel necessary for testing in our gas turbine combustor, it is necessary to develop a small-volume fuel delivery system. This system would allow us to expand our testing matrix to investigate the bounds of ASTM D7566 for both aromatic addition and fuel blending, and influence of fuel temperature.

A schematic diagram of the small volume fuel delivery system is shown in Figure 11. The bulk fuel (shown as HEFA SPK) is delivered from the bulk storage tank utilizing a mechanical pump. This is the same system currently used for operations. The small volume fuel (shown as SAK) is delivered using a piston accumulator system. Tank level is monitored using a linear encoder to provide piston location feedback. This allows pressurization of the fuel using a volume of gas, and more importantly rapid flow control for the small volume fuel. This will drastically reduce small volume fuel consumption rate. This liquid flowrate is metered using a cavitating Venturi nozzle.

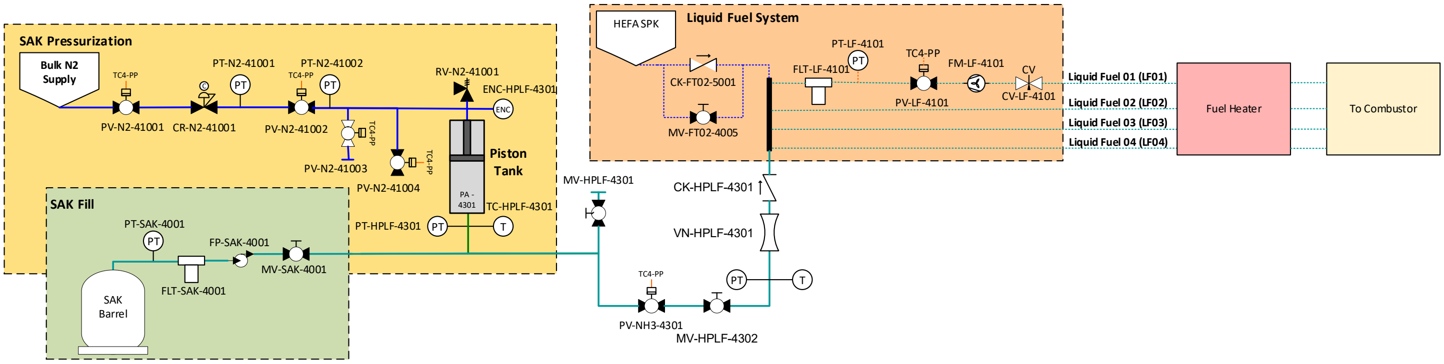

**Figure 11.** Schematic diagram of the small volume fuel delivery system.

## Milestones

- Completed the full-scale facility reconfiguration in the test cell housing this experiment allowing for the continued operation of the COMRAD test rig.
- Applied the previously developed LII system for the measurement of soot formation and oxidation processes in the combustion zone to COMRAD. Measurements were taken in the combustor utilizing Jet A fuel and synthetic aviation turbine fuel (SATF) (World Energy HEFA) at a variety of inlet fuel temperatures.
- Procured significant quantities of SAK for testing in COMRAD. This SAK will be mixed into SPK to match the aromatic content using a piston accumulator fuel delivery system.

## Major Accomplishments

- Continued our development of LII for determining soot levels in our combustion flow.
- Developed a time-resolved LII model for extracting primary particle size, which was applied to the lab-scale calibration flame and compared to potential high-pressure combustor operating conditions.
- Testing in COMRAD was performed with Jet A fuel and SATF (World Energy HEFA) for a range of fuel temperatures at a pressure of 1.0 MPa with LII measurements.
- Developed an ultrahigh speed NO-PLIF diagnostic capability, demonstrating imaging of NO in a heated gas cell at 100 kHz.

## Publications

### Peer-Reviewed Journal Publications

Hodge, A. J., Shahin, T. T., Gejji, R. M., Philo, J. J., Lucht, R. P., & Slabaugh, C. D. (2025). Fuel temperature effects on combustion stability of a high-pressure liquid-fueled swirl flame. *Journal of Propulsion and Power, 41*(1), 53-63. https://doi.org/10.2514/1.B39592

McDonald, C. T., Shahin, T. T., Philo, J. J., Gejji, R. M., Fish, D. D., Slabaugh, C. D., & Lucht, R. P. (2025). Combustion product measurements in a liquid-fueled aviation gas turbine combustor with heated fuels. *ASME Journal of Engineering for Gas Turbines and Power, to be submitted.*

Philo, J. J., Shahin, T. T., McDonald, C. T., Gejji, R. M., Lucht, R. P., & Slabaugh, C. D. (2023). Effect of fuel temperature on the structure of a high-pressure liquid-fueled swirl flame, *Fuel, 354*. 129142. https://doi.org/10.1016/j.fuel.2023.129142

### Published Conference Proceedings

McLean, T. N., Koenig, K. C., Murdock, B. K., Shahin, T. T., Hodge, A. J., Gejji, R. M., Slabaugh, C. D., & Lucht, R. P. (2025, January 6-10). *Laser-induced incandescence measurements in a high-pressure swirl-stabilized flame* [Conference presentation]. AIAA SciTech 2025 Forum, Orlando, Florida. https://doi.org/10.2514/6.2025-1580

Hodge, A., Shahin, T., McLean, T., Gejji, R., Lucht, R., & Slabaugh, C. (2024, January 8-12). *Fuel temperature effects on combustion stability of a high-pressure liquid-fueled swirl flame* [Conference presentation]. AIAA SciTech 2024 Forum, Orlando, Florida. https://doi.org/10.2514/6.2024-1241

McDonald, C. T., Philo, J. J., Shahin, T. T., Gejji, R., Slabaugh, C. D., & Lucht, R. P. (2021, August 9). *Effect of fuel temperature on emissions and structure of a swirl-stabilized flame* [Conference presentation]. AIAA Propulsion and Energy 2021 Forum, virtual. https://doi.org/10.2514/6.2021-3480

## Outreach Efforts

None.

## Awards

Professor Lucht was the recipient of the **2025 Propellants and Combustion Award** from the American Institute of Aeronautics and Astronautics. The citation reads “For numerous contributions to combustion, propulsion, and power generation through innovative development of advanced laser diagnostics and applying them to practical energy systems.”

## Student Involvement

Three PhD students (Tristan Shahin, Ben Murdock, and Zander Hodge) are currently working on the project. John Philo graduated in March 2022 with his PhD after working on the project and is currently employed at Blue Origin. Colin McDonald graduated in September 2022 with his MS degree and accepted a position with Astra (Merced, California), where he is responsible for setting up a new rocket engine test facility. Thomas McLean graduated in May 2024 with his MS degree after working on the project and is currently attending U.S. Air Force Flight School. Keaton Koenig graduated in May 2025 with his MS after working on the project. Tristan Shahin defended his PhD dissertation in October 2025 after working on the project.

The project provides outstanding research experiences for the graduate students, including the design of system components for, and the operation of, a sophisticated aviation gas turbine combustion test rig, as well as application of advanced laser diagnostic methods for measurements in this test rig. As noted above, the graduate students have been responsible for designing system components, such as the fuel heating system, and for executing test operations.

## Plans for Next Period

The focus for the next period of this project will be a detailed comparison of a selected SATF with a well-characterized petroleum-based fuel, Jet A or fuel A2 from the National Jet Fuel Combustion Program. The SATF will be a mixture of SPK and SAK, and the composition will be selected in consultation with other FAA ASCENT researchers and our collaborators at GE Aerospace. The nominal SATF composition is expected to be 92% SPK (World Energy HEFA) and 8% SAK (single-ring aromatic compounds from Virent®). SATFs with SAK contents as low as 4% and as high as 30% will also be investigated, depending on the availability of supplies from Virent. We may also explore petroleum-based single-ring aromatic compounds if we cannot obtain enough SAK from Virent.

We plan to expand our operational test matrix to include conditions of significant interest to GE Aerospace. Thus far in our test program, the relative equivalence ratios for the pilot and main have been fixed. GE Aerospace is interested in expanding the test matrix to investigate the effect of varying equivalence ratios in the main and pilot on hot fuel effects, especially as it relates to nitrogen oxides ($NO_x$) formation. Along these same lines, pilot-only operation is of significant interest. We will also explore the effects of fuel heating for rich dome operation, implemented by supplying sufficient fuel in the streams to create a globally rich mixture.

Additionally, LII will be used to further investigate soot formation measurements taken in lean dome operation. Additional funding will allow us to expand the operational test matrix to include conditions with higher pilot to main fuel, globally rich conditions, and further fuel composition blends. The LII measurements will provide valuable information of the spatial locations for particulate formation in the combustor flow field for engines using both conventional Jet A fuel and a variety of SATFs. We are also interested in both nonvolatile and volatile particulate formation. GE Aerospace has shown considerable interest in the types and number of particulates that are in the combustor exhaust. Further experimentation with differing laser sheet location and increased laser repetition rate are both of considerable interest to gain further special and temporal resolution. The effects of passing through the turbine on nvPM particulates are not well understood. In addition to LII, the NO PLIF diagnostic system will be applied with PIV to probe the flow field for selected operating conditions.

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