Project 027(A) National Jet Fuels Combustion Program – Area #3: Advanced Combustion Tests

Georgia Institute of Technology, Oregon State University, University of Illinois at Urbana-Champaign

Project Lead Investigator

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University Participants

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- P.I.(s): Tonghun Lee, Associate Professor
- FAA Award Number: 113-C-AJFE-UI-005
- Period of Performance: 12/1/2014 to 11/30/2015
- Task(s):
    1. Optimize and apply laser diagnostics for application in the advanced combustion tests at GATech.

Project Funding Level

Funding Level: $40K
Cost Share: In-kind academic time of the PI, student support for at 25% for one semester, $3,050 in materials and supplies.

Investigation Team

Eric Mayhew is a graduate student at the University of Illinois at Urbana-Champaign and works with the execution of laser and optical diagnostics at GATech.

Rajavasanth Rajasegar is a graduate student at the University of Illinois at Urbana-Champaign and works with the optimization of laser diagnostics strategy.

Stephen Hammack is a graduate student at the University of Illinois at Urbana-Champaign and works with the execution of laser and optical diagnostics at GATech.

Project Overview

The objective of this proposal is to support the advanced laser and optical diagnostics in area #3 (Advanced Combustion Tests) of the FAA COE ASCENT's combustion program. The diagnostics effort will strive to meet two critical targets. The first is to optimize diagnostics that has enough fidelity to discern the combustion characteristics of candidate jet fuels in their respective testing conditions (support fuel screening). The second goal is to organize and analyze the data in a structured way that allows partners in the combustion program to refine and validate their numerical models. The success of this program will substantially accelerate the efforts of the FAA and the OEMs to certify alternative, fit for purpose fuels.

Task 1 – Optimize and apply laser and optical diagnostics for application in the advanced combustion tests at Georgia Institute of Technology

University of Illinois at Urbana-Champaign

Objective(s)

The objectives in this proposal are to work with Georgia Tech in their advanced combustor experiments and achieve the following four goals:

- Evaluate the experimental combustor set up and operating conditions for laser diagnostics
- Design laser and optical diagnostics set up and oversee data acquisition process
- Participate in fuel screening process for optimizing experimental design
- Analyze data and pass on structured information to modeling groups in combustion program

Research Approach

Diagnostics Optimization and Set up

The main goal here is the development of multi-phase 2D diagnostics using Planar Laser Induced Fluorescence (PLIF) and Particle Imaging Velocimetry (PIV) to understand the blow off development at the boundaries and flame dynamics in the GATech high shear and high pressure combustor. The goal will be to apply two simultaneous measurements from high speed PLIF, PIV, and chemiluminescence. In both PLIF and PIV, we will look to obtain quantitative and spatially resolved data. We will configure and set up the laser and optical diagnostics equipment around the high shear combustor at GATech with remote access and control, possibly with beam relay from an adjoining room due to vibration and thermal loading issues. For the high speed PLIF measurements, we plan to pump a high speed dye laser (Credo, Sirah) with a high speed diode pumped Nd:YAG (Edgewave) for generation of the UV light. We anticipate that the frame rate will be in the 5 to 10 kHz range. Energy per laser pulse at these conditions maybe small (20 μJ/pulse) and light collection from the PLIF will be enhanced using a f/1.8 UV lens. For the PIV measurements, we will use a stereo PIV system to ensure that we can collect velocity information in all three spatial coordinates.

Quantification of the LIF Signal

To ensure that the signal is fully quantified, we set out to build and calibrate a small scale flat flame burner for use in the GATech test rig. The combustor will be fully calibrated at Illinois using a combination of laser absorption and multi-line nitric oxide LIF thermometry. By calibrating the intensity of the setup with the flat flame combustor, we can assess first order values for concentration of radical concentrations in the flame. We were also required to address the issue of fuel PLIF as a significant interference source in our measurements. In order to account for the fuel PLIF, a two camera PLIF system with a multi-filter setup was used to selectively control the level of both the OH LIF signal and fuel LIF. The two images then can be used to isolate the OH LIF signal.

Milestones

These are the milestones according to each time period.

Proposed (3 Month): At the 3 month mark, we will conclude the analysis of the experimental setup and should be close to finishing the design of the laser and diagnostics setup.
Achieved: Design of the laser setup complete and fabrication of calibration torch started.

Proposed (6 Month): At the 6 month mark, we should be finalizing the experimental setup and getting ready to actually deploy measurements in Task 1 of the proposal. Fuel screening will be conducted during this phase.
Achieved: Most of experimental setup complete. Calibration torch completed and initial quantification of radicals complete.

Proposed (9 Month): At the 9 month mark, we should be almost complete with the initial shakedown of the tests in Task 1 and making changes to optimize the experimental setup. Send preliminary test guidelines and results of the fuel screening studies (sensitivity to fuel characteristics) to the modeling groups.
Achieved: First test run at GATech for simultaneous PLIF and PIV successfully complete and results analyzed. Laser and optical setup successfully implemented and tested. Identified key problems such as fuel PLIF. Main measurement campaign set for last quarter.

Proposed (12 Month): At the 12 month mark, we should have completed an initial set of data for tasks outline in the proposal. We should be planning for additional measurements in the next phase of the combustion program.
Achieved: Major three week campaign completed at GATech for two of the test fuels. Experiments included two camera PLIF and stereo PLIF over a wide range of test conditions. Data analysis started. Fuel PLIF isolated using two camera PLIF setup with differing detection bandwidth.

Major Accomplishments

The main accomplishment of year one in this project was that we were able to assemble the laser system around the test rig at GATech and accomplish the task of simultaneous stereo PIV and two camera PLIF. The schematic of the experimental setup is shown in Figure 1.

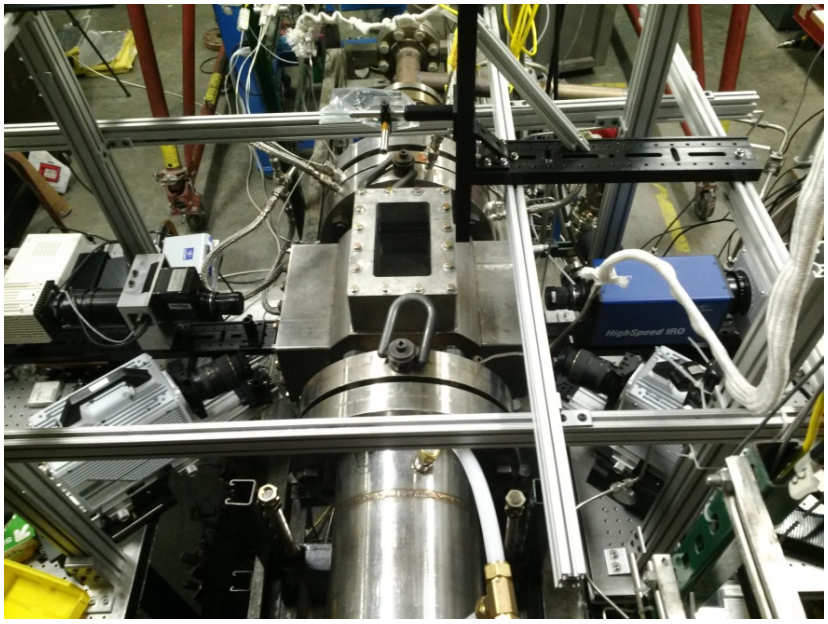

Figure 1 Diagnostics Setup at GATech with Stereo PIV and 2 Camera PLIF (4 high speed cameras + 2 lasers)

Figure one shows the experimental setup of the main combustor with the four high speed cameras positioned around it. The laser system, which is composed of a high speed Nd:YAG pumping a tunable high speed dye laser is situated in the adjacent room and the beam is routed to the experimental setup. Prior to reaching the test rig, the beam is expanded into a sheet using a custom set of optics and is routed into the test rig from the top. The beam is about 4 inches in width and about 100μm in thickness. The combustor itself is fully accessible through the top port and two side windows on either side. Prior to the measurements, the Illinois calibration burner is inserted into the chamber and imaging is done with the exact same setup to ensure wavelength position of the laser as well as the intensity of the OH LIF signal, which can later be fully quantified using a spectroscopic model. The laser is tuned to the A-X (1,0) transition of OH at 283nm. For the shakedown of the rig, an air pressure atomizer was used while for the actual tests in August, an air blast atomizer was mainly utilized.

The two cameras on either side at the top are the PLIF detection cameras, which are both intensified. The bottom two cameras at a slight angle are the PIF cameras which are mounted in a scheimpflug set up so as to ensure clear focus across the entire imaging plane. The entire system is synchronized at 5 kHz, which is an adequate repetition rate considering the turbulent intensity of the required flow conditions. The setup was installed and tested during May of 2015 and then the actual full scale measurements of A2, C5 fuels were conducted in August.

In addition to the quantification issue of the LIF signal, it became obvious during the May campaign that fuel PLIF was a major interference source in our measurements. In order to resolve this issue and to isolate the OH PLIF signal, a two camera PLIF setup was utilized with two differing spectral bandpass filters. The difference in the optical bandpass allows

the ratio of OH and fuel PLIF to be varied and the strategy is to use one set of images to correct for the fuel PLIF in the other image. An example of this is shown in Figure 2.

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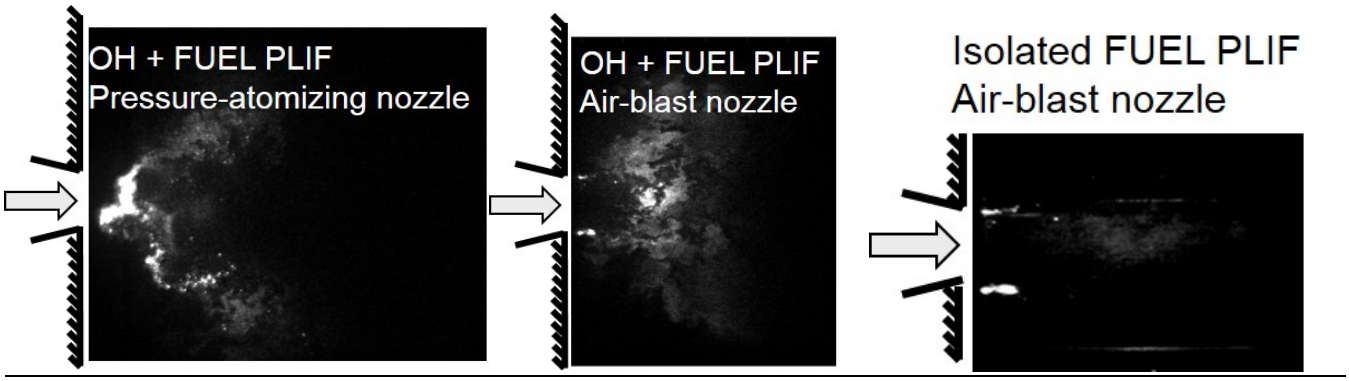

Figure 2 Two camera OH PLIF setup for isolation of fuel PLIF from the images. The image on the very right shows the isolation of the fuel PLIF using the added camera with a wide band-pass filter and suppression of OH PLIF.

Publications
None

Outreach Efforts
None

Awards
None

Student Involvement
Three graduate students (listed above) have participated in this project on a rotational basis to address various aspects of the project. Rajavasanth designed and fabricated the calibration burner used at GATech, and conducted experiments to determine the actual concentration of radical concentrations in the flame. Two other students (Stephen Hammack and Eric Mayhew) made trips to GATech to make test measurements in the high shear combustor. This included assisting in the setup of the laser and optics as well as participating in the actual measurements. The calibration torch as well as other optical and imaging equipment was taken down to GATech for testing.

Plans for Next Period
In year II of the NJFCP, an effort will be made to expand the scope of participation in the GATech combustion tests. This will include measurements over a wider region of test conditions as well as inclusion of more test fuels from the selection made by the PIs. We also anticipate that the measurements will include possibly new diagnostics strategies such as the CH C-X transition to monitor progression of flame front during ignition in the GATech program. Additionally, we will include improvements to the two camera detection method for isolation of fuel PLIF, which would result in enhanced abilities to obtain quantified OH concentrations.