Project 030(B) National Jet Fuels Combustion Program, Area #6: Referee Swirl-Stabilized Combustor Evaluation/Support

University of Dayton Research Institute, University of Illinois

*this report covers portion of University of Illinois

Project Lead Investigator

Tonghun Lee
Associate Professor
Mechanical Science & Engineering
University of Illinois at Urbana-Champaign
1206 W. Green St.
Urbana IL 61801
517-290-8005
tonghun@illinois.edu

University Participants

University of Illinois at Urbana-Champaign

- P.I.(s): Tonghun Lee, Associate Professor
- FAA Award Number: 13-C-AJFE-UI-004
- Period of Performance: 10/1/2015 to 11/30/2015 (Report for period of 2016 only)
- Task(s):
    1. Optimize and apply laser diagnostics for application in the Referee Combustor.

Project Funding Level

Funding Level: $140K (entire period of 12/1/2014 to 11/30/2015)
Cost Share: In-kind academic time of the PI, Lab Renovation Cost by Department for Diagnostics Work

Investigation Team

- Eric Mayhew (Graduate Student, University of Illinois at Urbana-Champaign): Execution of laser and optical diagnostics at GATech.
- Rajavasanth Rajasegar (Graduate Student, University of Illinois at Urbana-Champaign): Optimization of laser diagnostics strategy.
- Stephen Hammack (Graduate Student, University of Illinois at Urbana-Champaign): Execution of laser and optical diagnostics at GATech.

Project Overview

The goal of this study is to develop, conduct, and analyze advanced laser and optical measurements in the referee combustor (WPAFB, Bldg. 490, RC 152) selected by the ASCENT National Fuel Combustion Program. We will conduct advanced spatially resolved high-speed Planar imaging as well as other advanced diagnostic measurements which can provide insight into the physicochemical response of the combustion process for various alternative fuels. Moreover, the results will provide data for development of new predictive combustion models in ASCENT. Once fully characterized, the standard referee combustor rig can streamline and simplify fuel certification procedures outlined in the ASTM D4054 (Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives) through minimization of full-scale engine testing.

Task 1 – Analysis of laser and optical diagnostics measurements in the Referee Combustor

University of Illinois at Urbana-Champaign

Objective(s)

The main objectives of the work in this proposal are to work with UDRI and AFRL in carrying out diagnostics measurements for the referee combustor. The following tasks will guide this collaboration:

- Identify the operating conditions and key parameters for detection in the referee combustor
- Design laser and optical diagnostics for chemiluminescence imaging of radicals
- Analyze data and pass on data to modeling groups in combustion program

Research Approach

Diagnostics Optimization and Schlieren Imaging

During October 2017, Schlieren imaging was conducted on the swirl-stabilized referee combustor. We used a standard Z-configuration with a narrowband LED (~440 nm center wavelength, ~20 nm FWHM) focused through an aperture. This wavelength region is chosen to avoid the major chemiluminescence peaks (OH* at ~310 nm, CH* at ~430 nm, and C_2* at ~516.5 nm) and the broadband emission (particularly of A-2). Two 6-inch diameter mirrors collimated and then focused the light onto a knife-edge and then into a Photron SA-Z. Figure 1 shows a picture of the experimental setup with the light source on the near side and the camera on the far side. Imaging of the non-combusting flow was conducted at 2 kHz, and the combusting flow was imaged at 10kHz. The non-combusting imaging is conducted at 3 different swirler pressure drops: 2, 3, and 4.5 percent. The combusting imaging is conducted, where possible (due to lean blowout restrictions) at global equivalence ratios: 0.096 (A-2 and C-1), 0.092 (A-2 and C-1), and 0.086 (A-2 only), all with swirler pressure drop and combustor pressure held constant.

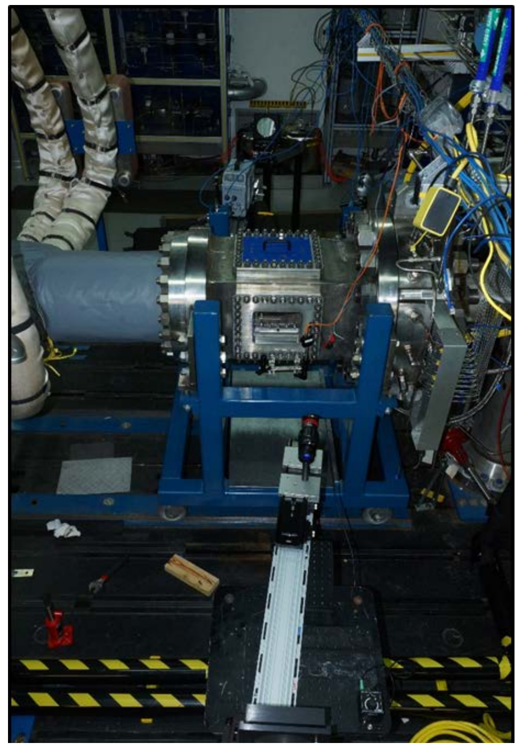

Figure 1: Picture of the Schlieren imaging setup spanning the swirl-stabilized referee combustor at AFRL.

Milestone(s)

Milestones from Each Period

Analysis Period (Final 2 Month): For the final 2 months, we will begin preliminary analysis of the imaging conducted in October.

Achieved: We completed preliminary analysis with averaged images and calculations of the measured dilution jet angles shown below.

Major Accomplishments

In the last, two months we have completed a preliminary analysis of the Schlieren imaging conducted in October. The primary interest of this first analysis was the issue of 1) whether the primary dilution jets bent, 2) by how much, and 3) whether there was significant dilution jet flapping. Schlieren begins to answer these questions as the imaging marks density gradients in the test section; some of the strongest density gradients are due to the relatively cold dilution jets impinging on the main flow. To help answer the first two questions, 3,000 images at each condition are averaged (more than 35,000 images were taken for combusting cases). In the averaged image, the peak count intensity along the dilution jet stream is used to mark the center of the jet at each point moving from the outside of the combustor to the inside of the combustor. A liner regression fit on the points is conducted to obtain the average angle.

As seen in Figure 1 (left), even the non-combusting case shows an average dilution jet bending of about 14° on the top half of the combustor and 10° on the bottom half of the combustor for a swirler pressure drop of 3 percent. The combusting cases all demonstrated greater dilution jet bending than the non-combusting cases as seen in Figures 2 and 3.

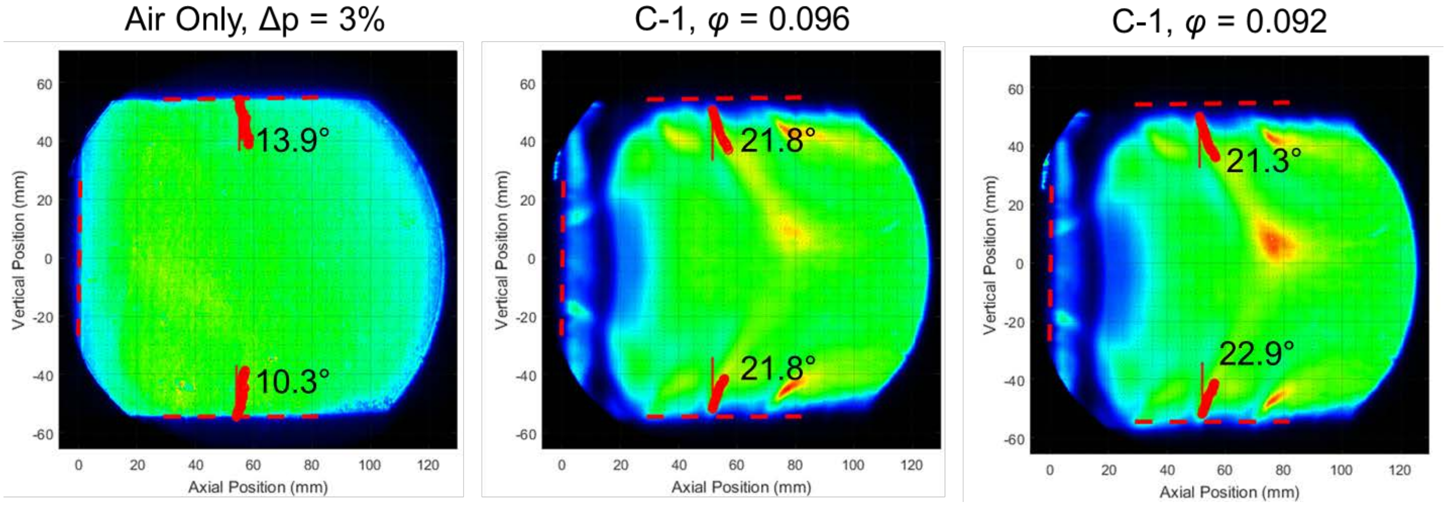

Figure 2: Average of 3,000 instantaneous Schlieren images with the measured dilution angles for air only (left) with a swirler pressure drop of 3 percent, C-1 at a global equivalence ratio of 0.096 (center), and C-1 at a global equivalence ratio of 0.092.

Figures 2 and 3 both show that there is very little variation in the dilution jet angles across equivalence ratios. The averaged images for A-2, shown in Figure 3), reveal that some of the asymmetry seen in OH* images may also be reflected in the dilution jet bending. The larger flame lobe in the lower half of the combustor, as seen in Figure 4, corresponds to greater bending in the lower half for A-2. This effect is the strongest in the φ=0.096 case with a lower bending angle of 24.5˚ and the weakest in the φ=0.086 case with a bending angle of 22˚. Analysis averaging more images to accurately pinpoint these trends is ongoing.

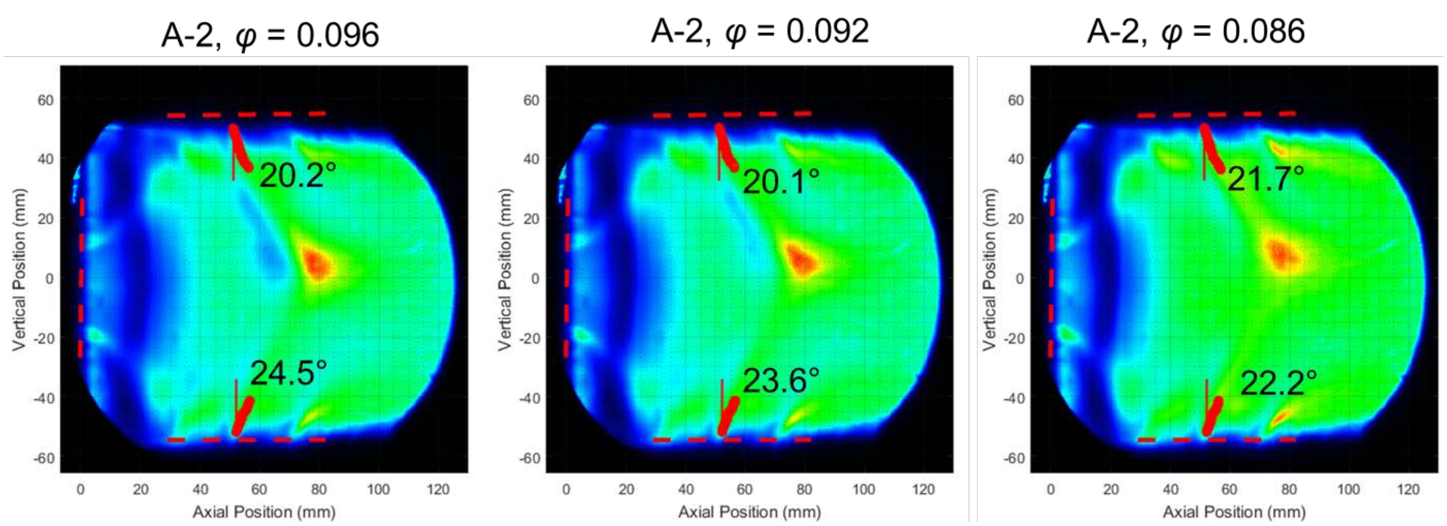

Figure 3: Average of 3,000 instantaneous Schlieren images with the measured dilution angles A-2 at a global equivalence ratio of 0.096 (left), A-2 at a global equivalence ratio of 0.092 (center), and C-1 at a global equivalence ratio of 0.086.

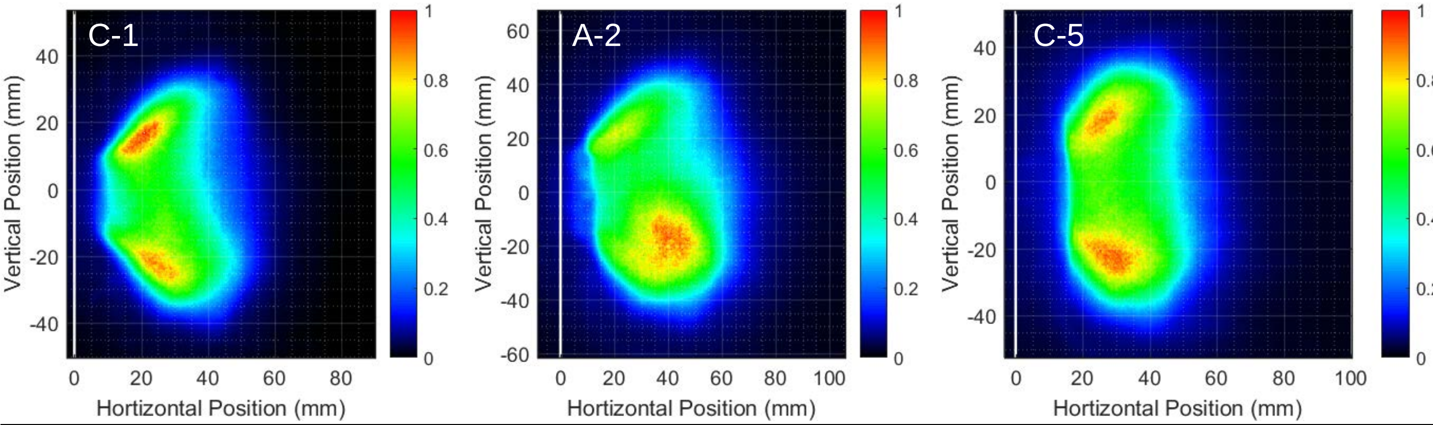

Figure 4: Averaged OH* images of the three down-selected NJFCP fuels at an equivalence ratio of 0.096

The third question of whether the dilutions jets flap has not been analyzed quantitatively, though the 10 kHz Schlieren imaging shows no visual evidence that the jets wave more than 10 degrees. Sample imaging, including the averaged images with calculated dilution jet angles, has been passed along to the modeling teams for comparison with their simulations.

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 to be used in the referee combustor, and conducted experiments to determine the actual concentration of radical concentrations in the flame. Two other students (Stephen Hammack and Eric Mayhew) made multiple trips to AFRL 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.

Plans for Next Period
In year II of the NJFCP, an effort will be made to fully integrate a PDPA system in the referee combustor. We also expect to continue assisting in their effort to take images in the referee combustor and analyze the data. The PDPA systems are already at AFRL and will be ready for deployment when we can find a window of run time in the referee combustor. Finally, we will assist with quantification of the referee combustor using the calibration torch built for this project at the University of Illinois.