the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Structure and Dynamics of Fuel Jets Injected into a High-Temperature Subsonic Crossflow: High-Data-Rate Laser Diagnostic Investigation—Purdue University

Background

High quality benchmark data on fuel flows in combustion turbines is useful in designing turbine engines fueled with coal-derived synthesis gas (syngas). In this project, Purdue University will use advanced laser diagnostics to provide comprehensive measurements of fuel flow conditions representative in modern gas turbine engines.

This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers. Both are managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high hydrogen content fuels derived from coal that is clean, efficient, and cost-effective, minimizes carbon dioxide (CO_2) emissions, and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

This project is a detailed investigation of the structure and dynamics of fuel jets injected into a subsonic oxidizing crossflow in order to enhance the fundamental level of understanding of these important flows and to provide a validation database for comparison with detailed numerical models of the reacting jets in crossflow (RJIC). Advanced laser diagnostics, including high-speed particle imaging velocimetry (PIV), high-speed planar laser-induced fluorescence (PLIF), and coherent anti-Stokes Raman scattering (CARS) will be used to probe the flow fields in a high-pressure gas turbine combustion facility. PIV and planar laser induced fluorescence of OH radicals (OH PLIF) will be used to visualize fuel/air mixing and combustion at data rates of 5-10 kilohertz (kHz). One kHz CARS will be employed for temperature measurements using femtosecond lasers. The combustion facility will utilize three different fuels: a natural gas (NG) baseline and two high-hydrogen-content (HHC) fuels. Accurate high-resolution spatialand temporal measurements of the resulting turbulent flame structures will provide improved understanding of the complex processes

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PARTNERS

None

PROJECT DURATION

Start Date	End Date
10/01/2011	09/30/2014

COST

Total Project Value
$586,271

DOE/Non-DOE Share
$468,995/$117,276

AWARD NUMBER

FE0007099

U.S. DEPARTMENT OF ENERGY

of fuel/air mixing and turbulence-chemistry interaction with attendant impact on operability when using HHC fuels. Additionally, the representative crossflow will be forced into stationary and oscillatory conditions to simulate an unstable condition. The enhanced mixing and combustion of the fuel jet will be measured to quantify the relationship between the unsteady combustion field and the forced oscillatory field. The benchmark quality data sets resulting from these experiments will include comprehensive measurements of mean and fluctuating components of velocity, temperature, and species at high pressure and with crossflow conditions representative of modern gas turbine engines with practical applications within the turbine industry.

Goals and Objectives

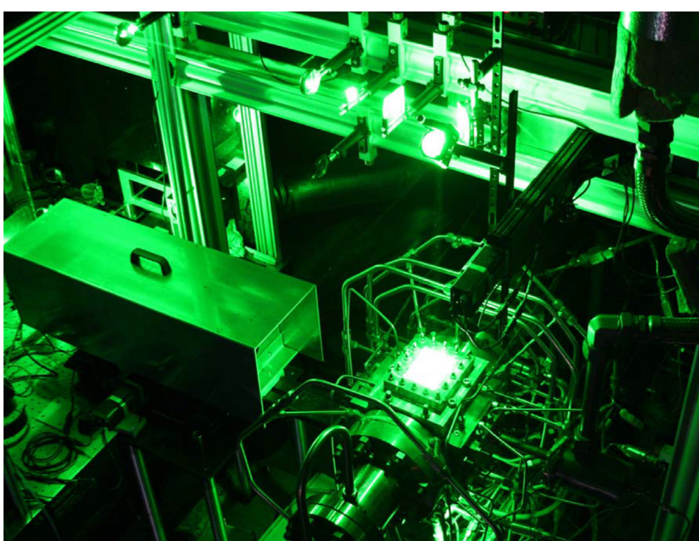
The primary goal of the project is to investigate the structure and dynamics of the reacting flow field for jets injected into a subsonic crossflow. The RJIC study has practical applications while also serving as an important test case for the development of numerical methods for turbulent reacting flow fields typical of gas turbine combustors. Secondary injection of the fuel, also referred to as distributed combustion, is being studied as a means for reducing NO_x emissions while increasing the power output of the gas turbine systems. By utilizing high-speed diagnostics techniques, the enhanced mixing and combustion of the fuel jet will be measured in order to determine the quantitative relationship between the unsteady combustion field and the forced oscillatory field.

Accomplishments

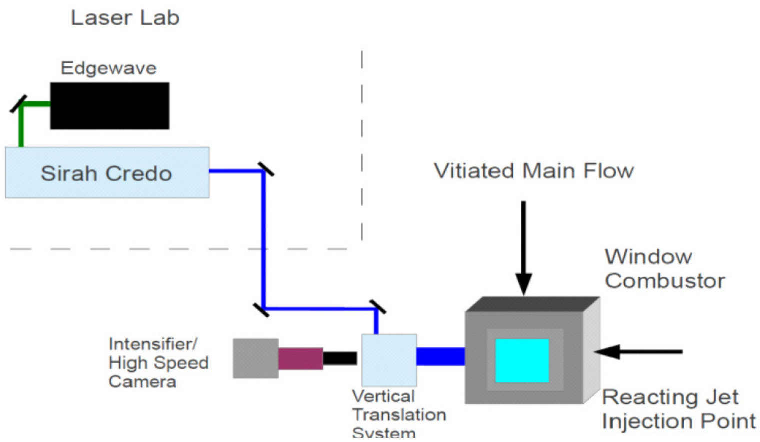
- Designed and fabricated the necessary components for the modification of the test rig for RJIC studies. The major difference between the old and new test rig configurations is that the window dimensions are considerably larger: 98 mm wide x 73 mm high in the new test rig as compared to 63.5 mm wide x 38.1 mm high in the old test rig.
- Performed a series of tests in the new test rig to compare performance and results from the new test rig with the old test rig. These measurements were performed using transverse jet injection nozzles designed in collaboration with Siemens Power Systems.
- Designed and fabricated a particle seeder for high-speed, high-pressure PIV.
- Completed dual pump (H_2/N_2) CARS experiment for 3 RJIC conditions. Data analysis is on-going and soon to be completed. For each test conditions the CARS probe volume was transverse through 140 spatial locations in a grid like pattern, and at each spatial location 300 H_2/N_2 spectra were collected, so in total for each condition 140X300 spectra were collected.
- Completed high-speed OH-PLIF measurements (@ 5kHz) of the RJIC for 4 different test conditions for NG jet injection. HHC gas jet injection will be completed in the near future. Orthogonal decomposition techniques were used to obtain qualitative and quantitative analysis of the PLIF images.
- Made rig modifications for the high speed PIV measurements.
- Completed high-speed PIV measurements at a repetition rate of 5kHz for the same test conditions as OH PLIF. Data analysis is on-going.

Benefits

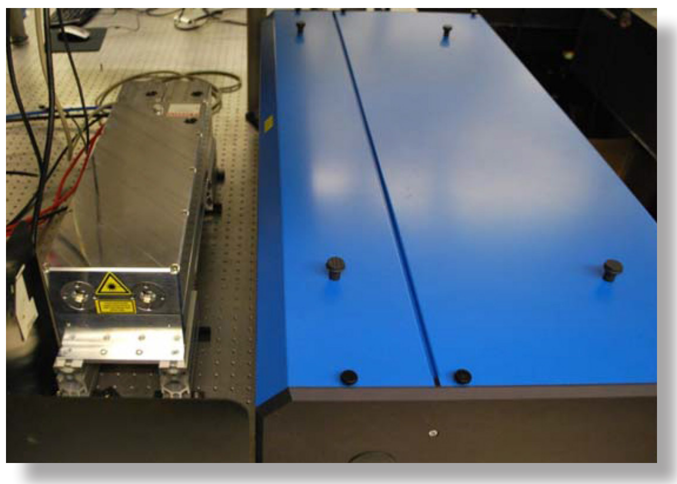
This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. The importance of this project is to further advance the understanding needed to develop practical guidelines for realistic composition limits and operating characteristics for HHC fuels.



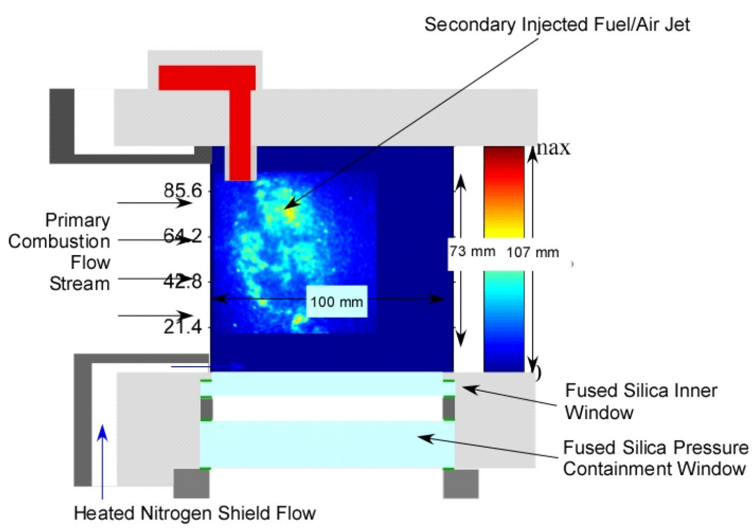
High-pressure reacting jet in vitiated crossflow test rig in operation with the new window assembly in place.



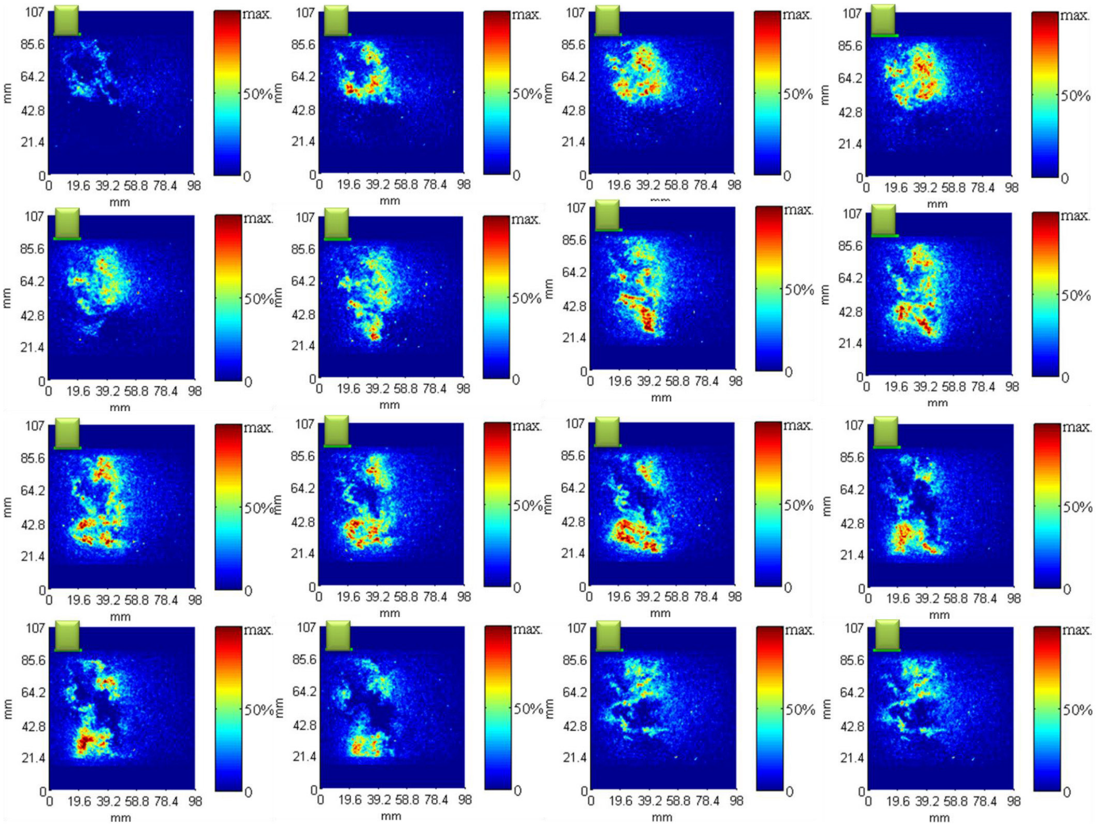
Schematic diagram of the high repetition rate OH-PLIF system with the intensified camera and combustor.



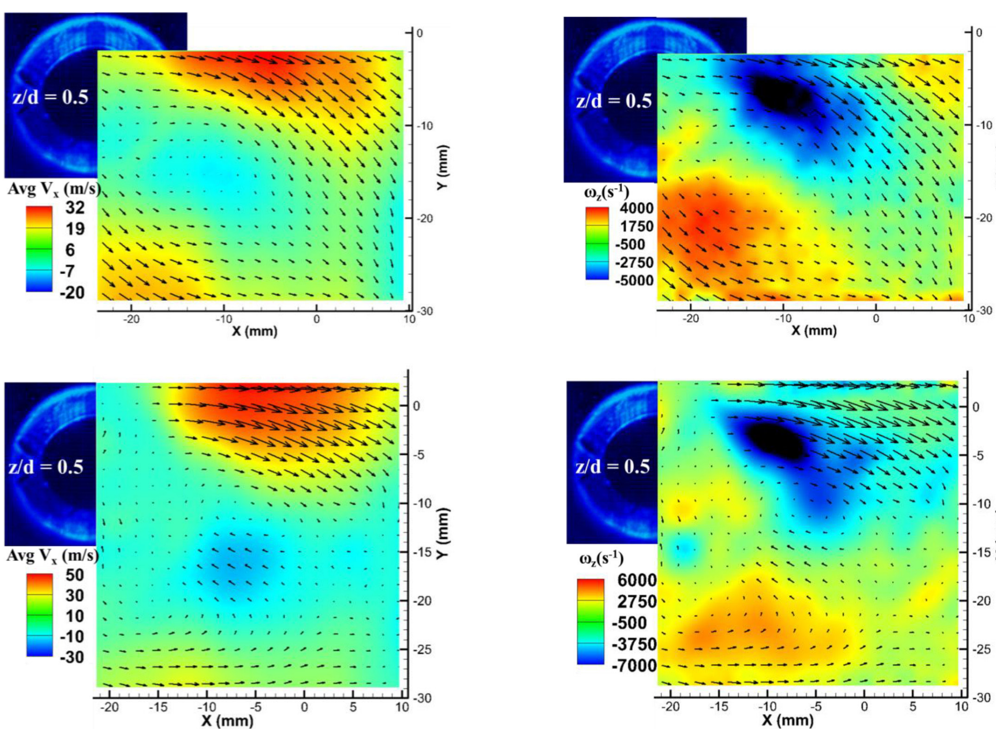
Photograph of the 5-10 kHz laser system for OH PLIF and PIV. The Edgewave diode-pumped, dual-head Nd:YAG laser is on the left. The Sirah Credo high-repetition-rate tunable dye laser in on the right.



Schematic diagram of the reacting jet in the vitiated swirling corssflow and the two window configuration.



A sequence of false colored PLIF images of J = 3 and φ = 3 case. This sequence of image is specifically chosen to show the complex flame structure and flame flapping phenomena. If the image at the top left corner represents time t = 0 sec, the last image shows time, t = 2.4 msec and all the images are taken at a Δt = 0.2 msec.



Plots showing the velocity vectors measured at the plane z/d = 0.5 from the nozzle exit plane for two test conditions, i) J = 3 and Φ_{jet}=3.0 (top) and ii) J = 8 and Φ_{jet}=3.0 (bottom). Contour on left column shows average axial velocity field and contour on right column shows average out of plane vorticity field.