the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Combustion Dynamics in Multi-Nozzle Combustors Operating on High-Hydrogen Fuels—Pennsylvania State University

Background

Combustion dynamics is a major technical challenge to the development of efficient, low emission gas turbines. Current information is limited to single-nozzle combustors operating on natural gas and neglects combustors with configurations expected to meet operability requirements using a range of gaseous fuels such as coal derived synthesis gas (syngas). In this project, Pennsylvania State University (Penn State) in collaboration with Georgia Institute of Technology (Georgia Tech) will use multiple-nozzle research facilities to recreate flow conditions in an actual gas turbine to study complicated interactions between flames that can aggravate the combustion dynamics in syngas-fueled multi-nozzle can or annular combustion turbines.

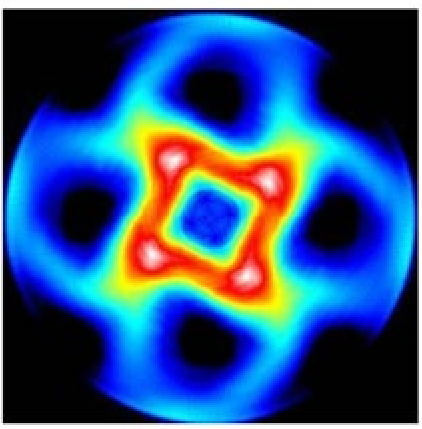

Figure 1. Two-dimensional cross-section of three-dimensional flame in multi-nozzle combustor showing complex flame structure resulting from the flame and flow field interaction.

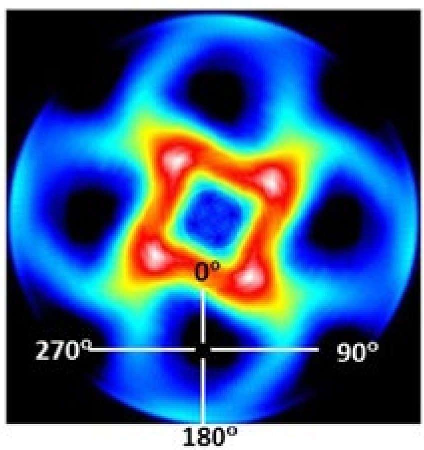

Figure 2. Positioning of two-dimensional vertical slices around outer nozzle.

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

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PARTNERS

Georgia Institute of Technology

PROJECT DURATION

Start Date	**End Date**
10/01/2008	09/30/2013

COST

Total Project Value
$1,062,500

DOE/Non-DOE Share
$700,000/$362,500

AWARD NUMBER

NT0005054

U.S. DEPARTMENT OF ENERGY

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

Gas turbine combustors capable of meeting future emissions regulations must not compromise overall system operability. Furthermore, they must be capable of operating on a wide range of gaseous fuels, such as syngas and high hydrogen content fuels. One of the most significant challenges to achieving these goals is the problem of combustion dynamics, a phenomenon that arises from acoustic resonances in the combustion chamber. This research develops an understanding of the coupling between acoustics and flame behavior in multi-nozzle combustor configurations in order to better design the fuel-flexible clean combustion systems of the future. This includes both transverse acoustic excitation in multi-nozzle annular combustors and longitudinal acoustic excitation in multi-nozzle can combustors. In the first phase of the study, single nozzle flame response to both longitudinal and transverse acoustic excitation is studied in order to understand the scope of the multi-nozzle problem. In the second phase, experiments are conducted in two multi-nozzle combustor test facilities to simulate transverse acoustic forcing in an annular configuration and longitudinal acoustic forcing in a can combustor configuration. Based on the design of industrial gas turbines, these facilities allow for the investigation of the underlying physics of flame-flame interactions, including the measurement of the longitudinal and transverse flame response functions (e.g., how heat release fluctuations are influenced by fuel or velocity fluctuations) that can aid in the development of new multi-nozzle flame response models.

Goals and Objectives

The goal of this study is to understand the coupling between acoustics and flame behavior in multi-nozzle combustor configurations. The expected results fall into three categories: acoustic behavior, fluid mechanics behavior, and flame behavior in a synergistic research approach. For example, the new flame response models will be incorporated into thermo-acoustic models for predicting instability frequencies and amplitudes in multi-nozzle combustors, which are essential tools for preventing or minimizing the incidence of detrimental combustion instabilities in future gas turbines. To achieve these goals, very comprehensive sets of both experimental and modeling work will be conducted.

Accomplishments

- Characterization of velocity disturbance field of a transversely forced, single and triple-nozzle swirl-stabilized flame using high-speed particle image velocimetry (PIV).
- Developed description of the flame transfer function for transversely forced flame response.
- Measured flame transfer function using global chemiluminescence, PIV, and two-microphone techniques.
- Developed flame response model of transversely forced flame.
- Measured the velocity-forced flame transfer function in the multi-nozzle can combustor over a range of operating conditions.
- Demonstrated that multi-nozzle flame transfer function gain results scaled with Strouhal number.
- Compared the flame transfer function in single- and multi-nozzle can combustors showing qualitative similarities in the gain and phase.
- Developed a new flame imaging technique for characterizing the three-dimensional structure of multi-nozzle flames.
- Illustrated the comparison between flame transfer function for transversely forced flames and longitudinally forced flames, to show relative importance in disturbance pathway. Identified Strouhal number of importance.
- Developed a model for premixed flames excited by helical flow disturbances. Illustrated the differences in helical mode effects on local flame response and global flame response, showing only symmetric modes contributed to flame transfer function.

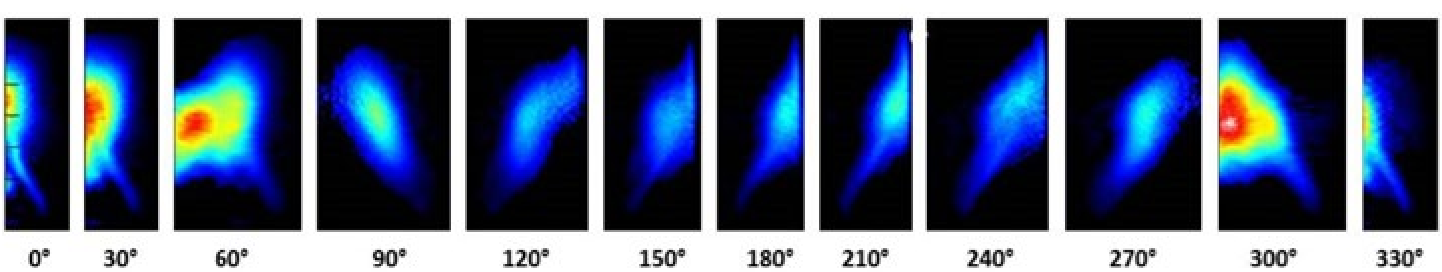

Figure 3. Two-dimensional vertical slices around outer flame showing significant variations in the degree and nature of flame confinement from flame-flame interaction at 0, no confinement at 90, flame-wall interaction at 180, and no confinement again at 270.

- Analyzed the space-time dynamics and heat release analysis for non-premixed flames excited by bulk axial velocity fluctuations. Compared results to those for premixed flames to highlight key differences in physics.
- Determined time-varying consumption speed definition for harmonically forced turbulent premixed flames.
- Obtained the first three-dimensional flame structure measurements in a multi-nozzle can combustor under steady and velocity-forced conditions, revealing the complex flame structure produced by flame and flow field interactions.
- Used three-dimensional flame structure measurements to determine the local flame response and local flame transfer function in the multi-nozzle can combustor.
- Showed that flame confinement plays an important role in relating the local flame response in the multi-nozzle combustor to the overall flame response of a single-nozzle combustor.
- Demonstrated and validated the use of a reconstruction technique for measuring heat release rate fluctuations in technically premixed flames.
- Performed the first flame transfer function measurements in the multi-nozzle can combustor under technically premixed conditions.

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. This project will aid in the design of fuel-flexible clean combustion turbine systems of the future.

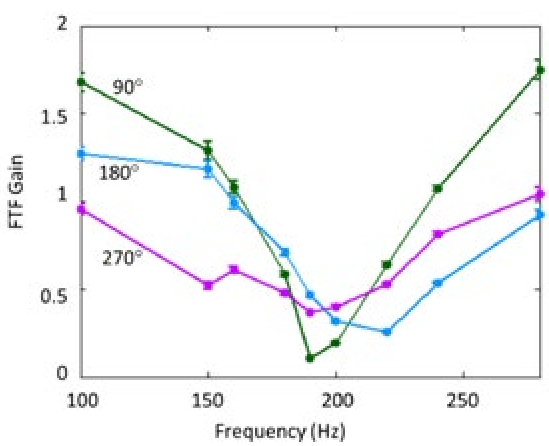

Figure 4. Flame transfer function gain versus forcing frequencies around outer nozzles at positions of 90, 180 and 270, showing a significant difference between the two unconfined cases of 90 and 270 which can be attributed to flame-swirl interactions.

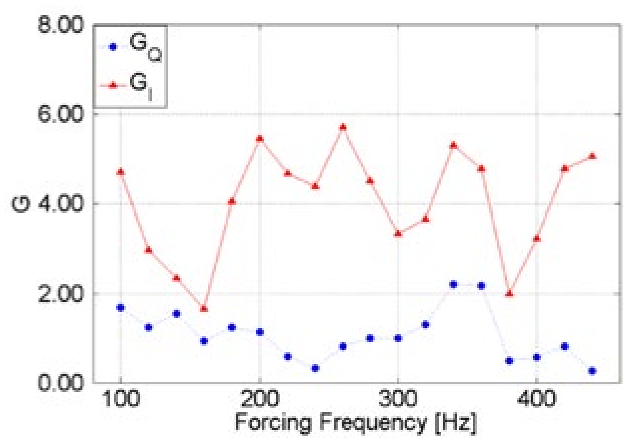

Figure 5. A comparison between the flame transfer function gain of a velocity-forced technically premixed flame using the chemiluminescence intensity as a measure of the heat release rate (GI) and using the reconstruction technique to determine the actual rate of heat release rate (GQ).

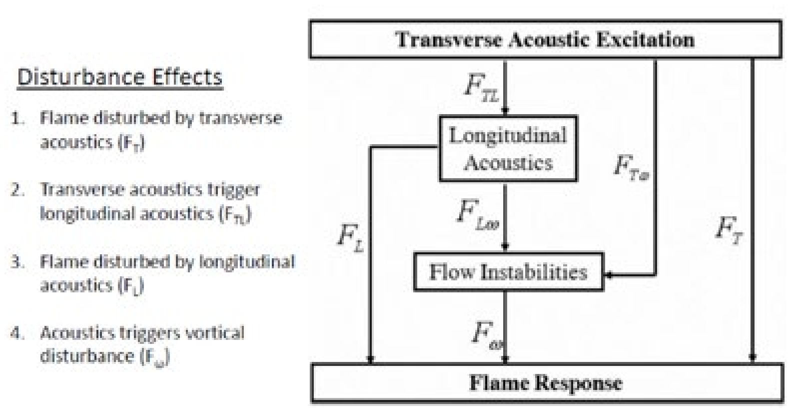

Figure 6. Velocity disturbance mechanisms present in a transversely forced flame.

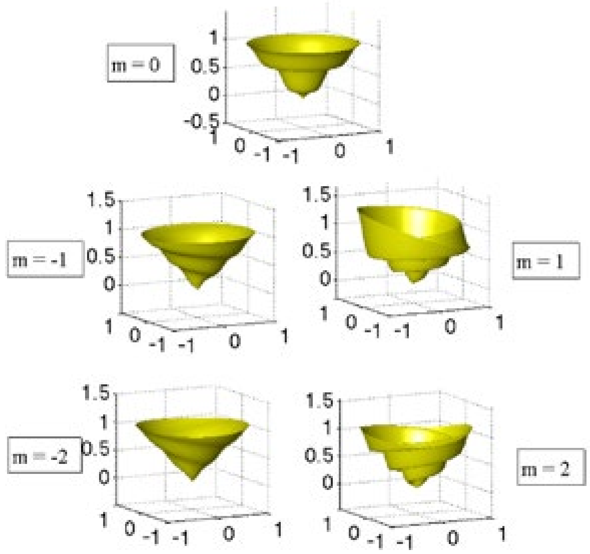

Figure 7. Flame surface plots showing response of flame to different helical modes.

Figure 8. Experimental setup for transversely excited, swirling lifted flame with a triple nozzle configuration.

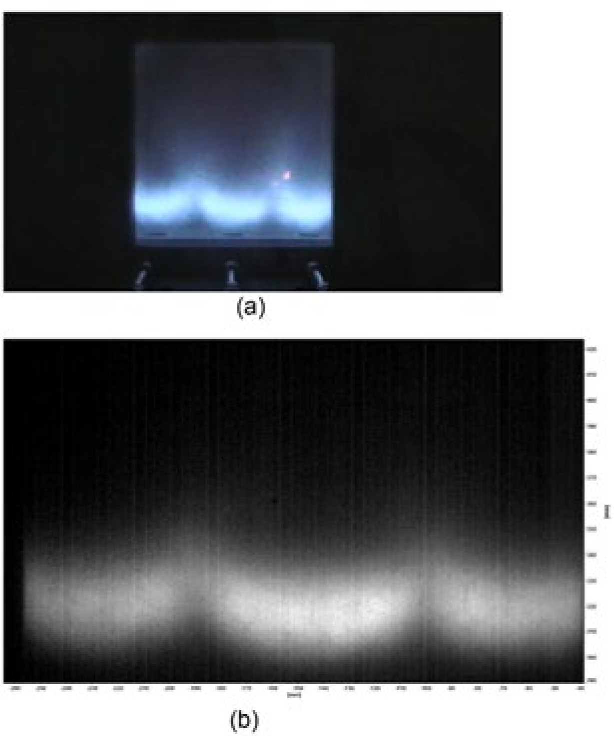

Figure 9. (a) Sample image showing triple nozzle flame, (b) Time-average chemiluminescence image.

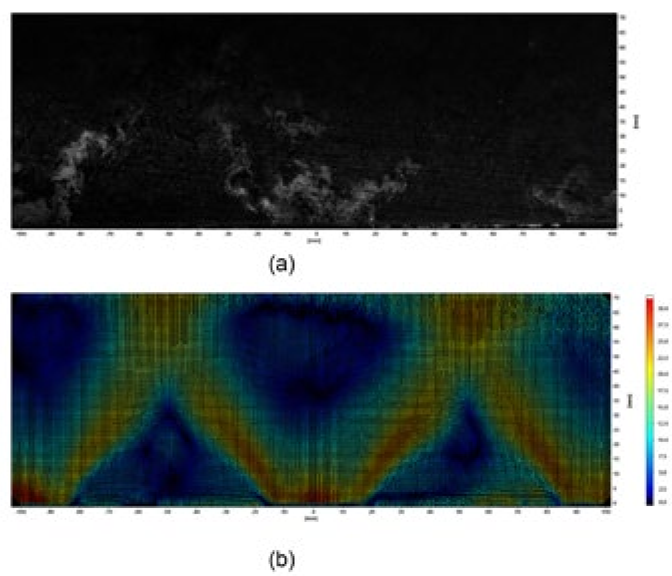

Figure 10. PIV in the axial plane showing (a) Instantaneous image of seeded flow and (b) Time-average vector field.