the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Large Eddy Simulation Modeling of Flashback and Flame Stabilization in Hydrogen-Rich Gas Turbines using a Hierarchical Validation Approach—University of Texas at Austin

Background

The focus of this project is the development of advanced large eddy simulation (LES)-based combustion modeling tools that can be used to design low emissions combustors burning high hydrogen content fuels. The University of Texas at Austin (UT) will develop models for two key topics: (1) flame stabilization, lift-off, and blowout when fuel-containing jets are introduced into a crossflow at high pressure, and (2) flashback dynamics of lean premixed flames with detailed description of flame propagation in turbulent core and near-wall flows. The jet-in-crossflow (JICF) configuration is widely used for rapid mixing of reactants in both the premixing chamber and in axially staged configurations. The high reactivity of hydrogen strongly impacts the flame stabilization mechanism in JICF by altering the structure of the reaction zone. This, in turn, changes the blow-off and emission characteristics. Lean premixed combustors are also sensitive to combustion instabilities, leading to flashback where the flame stabilizes in the premixing zone. Since hydrogen is highly flammable and has a higher laminar flame speed compared to conventional fuels, the propensity for flashback is increased. The availability of high-fidelity predictive computational models will provide a significant boost to the design of next generation gas turbines.

The LES modeling work and laboratory experiments will be performed by UT. Sandia National Laboratories has agreed to provide direct numerical simulation (DNS) modeling as validation for LES combustion simulations, host and co-mentor graduate students from UT, and provide feedback on UT's planned DNS experiments. General Electric (GE) and Siemens have agreed to assist UT in developing relevant combustor configurations and flow conditions that will be most beneficial to next generation gas turbine designs. Additionally, GE and Siemens will help UT design computational experiments aimed at deriving empirical relationships between flow conditions and combustion phenomena. The computational models developed here will be directly implemented in the OpenFOAM open source computational platform and shared with the industrial partners.

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PARTNERS

General Electric
Sandia National Laboratories
Siemens

PROJECT DURATION

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

COST

Total Project Value
$635,726

DOE/Non-DOE Share
$497,638/$138,088

AWARD NUMBER

FE0007107

U.S. DEPARTMENT OF ENERGY

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 (HHC) 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

The proposed work aims to develop LES models for simulating HHC gas turbine combustion, with specific focus on premixing and flashback dynamics. The project is divided into three components: (1) LES model development using DNS andcanonical experimental data, (2) targeted experimental studies to produce high quality mixing and flashback dynamics under engine relevant conditions, and (3) validation of LES models using a validation pyramid approach and transfer of models to industry using an open source platform.

Goals and Objectives

The overall goal of the project is to develop predictive computational tools for simulating gas turbines burning HHC fuels. A rigorously validated combustion model for LES-based description of flashback dynamics and flame stabilization in jet-in-crossflow (JICF) configuration will be developed. Simultaneously, validation-specific experiments of flame stabilization in JICF configuration and flashback dynamics in high-pressure systems will be conducted. The models developed will be transferred to industry using an open sourceinfrastructure. Specific objectives are:

- Formulate LES-based hybrid probability density function (PDF)/ flamelet approach for multi-regime combustion in gas turbines.
- Develop a comprehensive set of experiments for flame stabilization in JICF and flashback dynamics.
- Use a validation pyramid approach to demonstrate model accuracy in practical operating conditions and transfer models to industrial collaborators.

Accomplishments

- Designed a new premixed swirl flame burner to study flashback in collaboration with industry experts.
- Evaluated a new technique for comparing LES results and experimental data using particle image velocimetry (PIV) data acquired in JICF. This technique reveals the inadequacy of models for turbulent, intermittent quantities.
- Developed a direct quadrature method of moments (DQMOM) approach for complex geometries and implemented it in a highly parallel open source code. Preliminary simulations of canonical flow configurations show that the methodology is capable of accurately capturing flame evolution in turbulent flows. In particular, the methodology predicts the change in flame length and location as the hydrogen content in the fuel changes.
- Based on discussions with GE and Siemens, an open source platform called OpenFOAM is being used for transferring the models. The first version of the DQMOM model has been shipped to Siemens under this framework.
- Completed Kilohertz-rate PIV study of swirl burner with premixed and non-premixed fuel injection.
- Completed LES study of swirl burner with inflow conditions obtained from experiments.
- Completed simulation of flashback in turbulent channels and comparison to high-resolution direct numerical simulation study.
- Developed a flamelet-based model for premixed and partially-premixed combustion.

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.

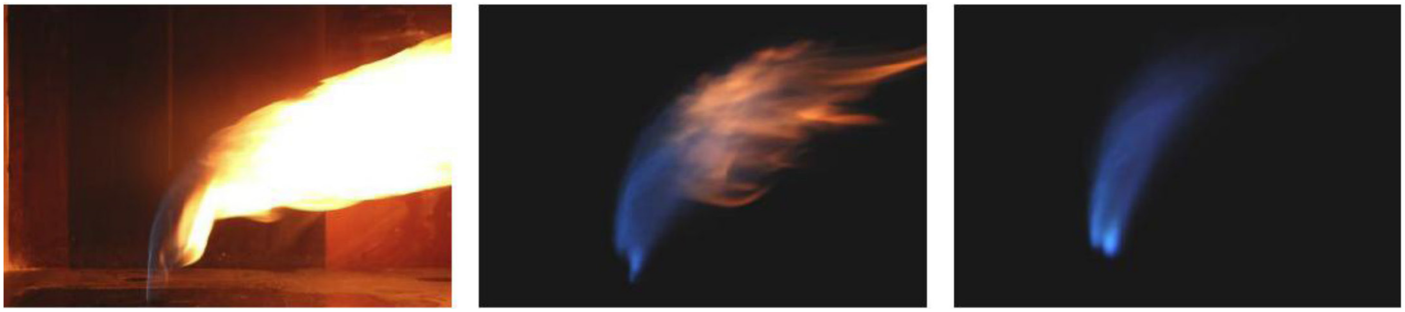

Figure 1. Jet flames in crossflow with different levels of premixing. The fuel is 70% CH_4 +30% H_2. From left to right: non-premixed, jet fluid diluted by 25% (volume basis) with air, and jet fluid diluted by 50% with air.

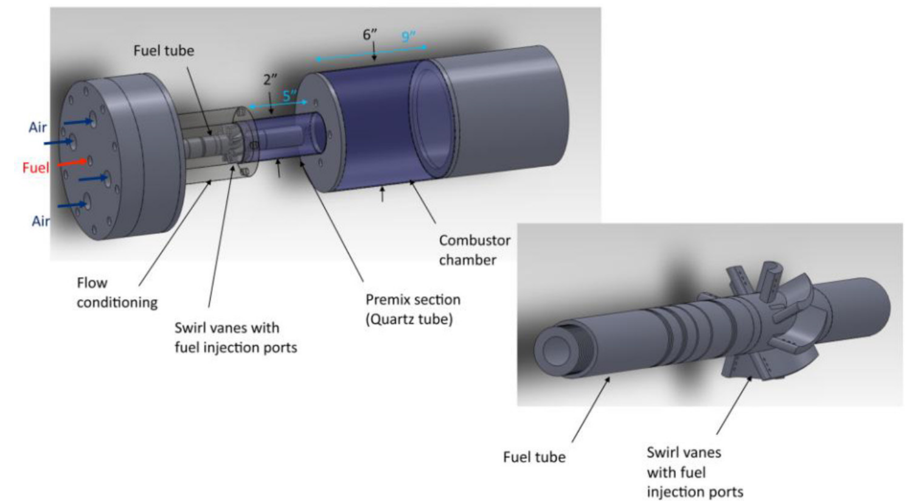

Figure 2. UT high pressure combustor.

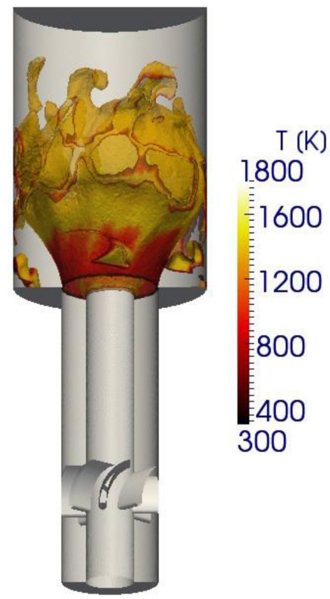

Figure 3. Instantaneous contour of mixture fraction = 0.2, colored by temperature.

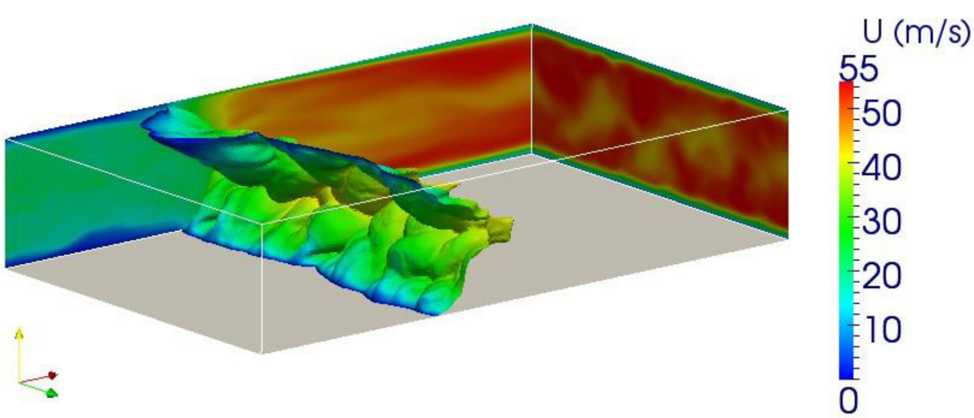

Figure 4. Instantaneous contour of T = 1400 K, colored by velocity.

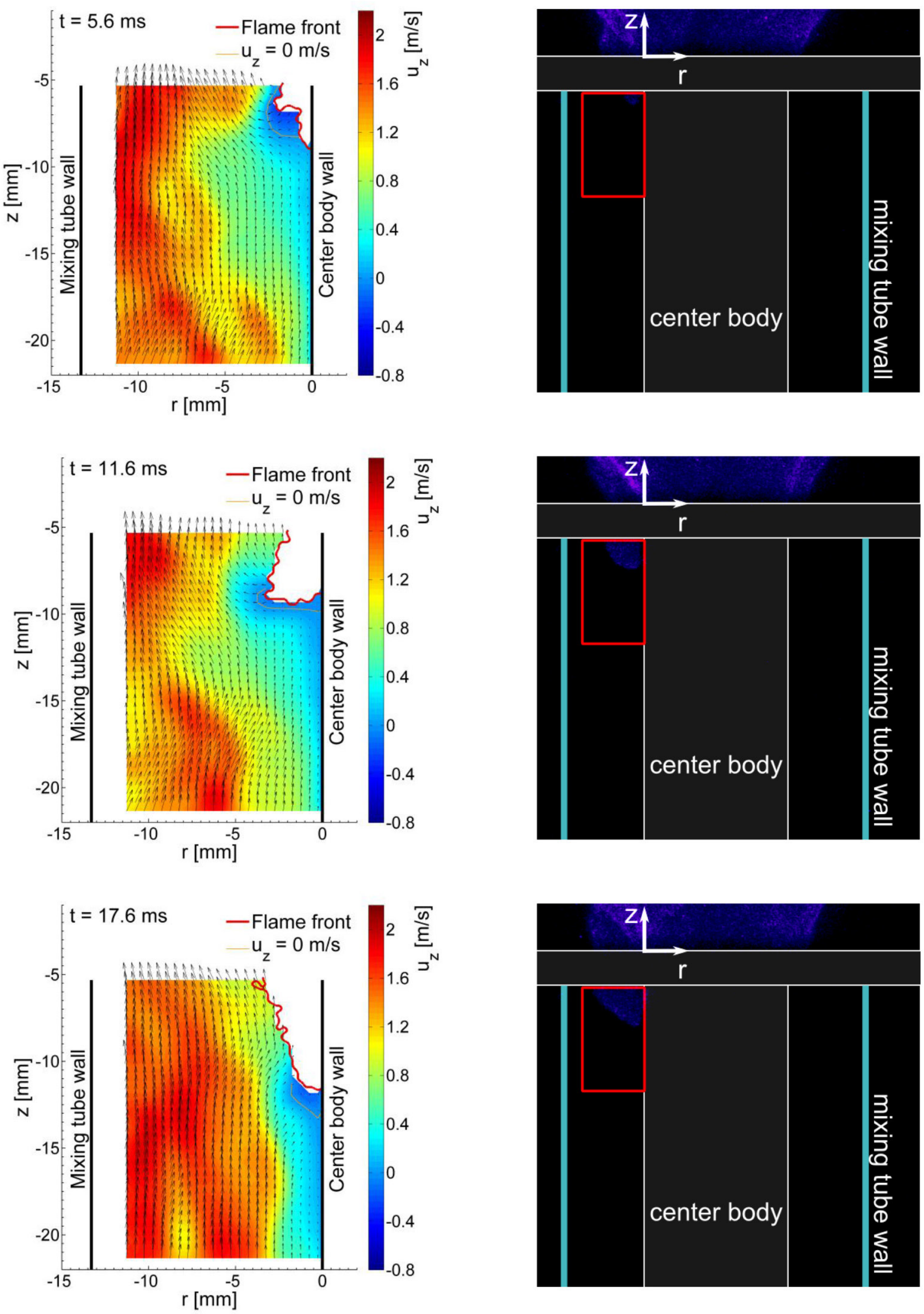

Figure 5. Time-sequenced images of simultaneous two-component PIV velocity fields and chemiluminescence of a CH_4/H_2-flame during flashback. The PIV is at left and the luminosity is at right. (a) time=5.6 ms, (b) time=11.6 ms and (c) time=17.6 ms. The edge of the flame, as marked by the evaporation of oil droplets, is shown by the red line in the PIV images. The reactants flow upward and the flame (red line in PIV image at left) propagates downward.