Fundamental Studies in Syngas Premixed Combustion Dynamics

FACT SHEET

I. PROJECT PARTICIPANTS

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II. PROJECT DESCRIPTION

A. Objectives

The objectives of this project are to develop a fundamental understanding of syngas combustion dynamics in cases when flames are stabilized by recirculating flows formed in the wake behind sudden expansions or in swirl stabilized flows. For this purpose, syngas with different hydrogen-carbon monoxide ratios, premixed with air at different equivalence ratios, and at different inlet combustor temperature and Reynolds numbers are used in two types of combustors, a planar combustor and an axisymmetric combustor. Stability maps, optical diagnostics of the time dependent flame shape and heat release profiles, and other mechanistic characteristics are recorded. The insight gained from these experiments will be used to suggest different variations on the flame stabilizations environments aimed at passively stabilizing the flames.

B. Background/Relevancy

Background

Combustion of reformed fuels; syngas being one of the most prominent, is getting more attention as dependence on clean coal technology for energy and fuel production is expected to expand to unprecedented levels. Syngas, produced by burning coal in pure oxygen and steam in high pressure gasifiers, has been proposed as the fuel of choice for modern high efficiency low emission combined cycles power plant, in which gas turbine engines are used as topping cycles that take advantage of high temperature combustion products to improve the overall efficiency of the power plant. Incorporating technologies to filter out turbine-corroding gases from the gasifier products and delivering clean syngas to the gas turbine combustor enables the use of syngas in gas turbines. Furthermore, efficient separation technologies can be used to produce hydrogen from the syngas, which can then be fed into fuel cells to further improve the energy conversion efficiency of the plant. The sequestration of carbon dioxide, following the production of steam for the bottoming cycle, makes this plant environmentally ideal.

Relevancy

This project will provide data and models necessary for the design of stable, efficient and clean combustors for gas turbine engines running on coal-derived syngas and insight into the mechanisms governing the stability limits and the ensuing dynamics, with the goal of proposing solutions that lead to efficient, clean and stable burning at high temperatures and high efficiency. Innovative solution for stabilizing ultra clean combustion at lean and ultra lean conditions will be demonstrated in the laboratory, as well as abstracted in design guidelines.

C. Period of Performance.

8/1/2005—8/1/2008

D. Project Summary

Under the University Turbine Research (UTSR) program, The Massachusetts Institute of Technology is studying the fundamentals of lean and ultra-lean premixed syngas combustion in combustor geometry similar to those used in gas turbine engines and with composition similar to those obtained in gas fired, humid coal gasification. The study is focused on the impact of the design and operating conditions on the combustion efficiency, emission and stability characteristics of syngas combustion. Data on flammability limits, stability characteristics, laminar and turbulent flame propagation, impact of the anchoring mechanism, burning conditions and syngas composition will be collected experimentally and synthesized into models. Diagnostics, corroborated with computational analysis will be used to determine the role of chemistry, transport and fluid mechanics in the mechanisms of combustion of syngas under the same conditions.

III. PROJECT COSTS

Year 1:	$162,716
Year 2:	$151,882
Year 3:	$141,233
Total cost:	$455,821

IV. MAJOR ACCOMPLISHMENTS SINCE BEGINNING OF PROJECT

- Rebuilt the planar combustor experiment to enable use of syngas as fuel, including the design of the upstream fuel preparation section for arbitrary mixture composition and temperature
- Acquired a new data acquisition system and upgraded a number of diagnostic sensors and probes.
- Conducted a range of syngas tests in the planar combustor, exploring the effects of equivalence ratio and fuel composition on combustor stability
- Completed the design and began fabrication of a new axisymmetric swirl stabilized combustor, with flexible modular construction, optically accessible test section and compatibility with the existing planar combustor.

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

- Develop complete stability maps for the backward facing step planar combustor by varying the inlet temperature and Reynolds number and measuring the pressure oscillations as we vary the fuel composition and mixture equivalence ratio
- Install and "shake-down" the new swirl stabilized combustor
- Develop the stability maps for the swirl stabilized combustor, using the same parameters as in the step combustor as well as the inlet swirl ratio
- Experiment with passive stabilization techniques in both the planar and swirl-stabilized environments

VI. MAJOR ACCOMPLISHMENTS PLANNED IN OUTYEARS (6-18 MONTHS)

- Define stability mechanism under lean blowout conditions, and compare with the sudden expansion case in which turbulent conditions are different.
- Use the collected data to construct reduced models for the response of lean premixed syngas combustion to external perturbation.
- Investigate flame stabilization mechanisms in lean syngas combustion using detailed measurements of the velocity field and the heat release rate.
- Obtain correlations between the flow field and the heat release rate field for a set of cases, defined by the configuration of the combustion stabilization zone and the mixture conditions, to define the impact of the fluid dynamics on flame stability.
- Repeat these measurements for different passive control strategies for flame stabilization in the axisymmetric geometry, as determined by techniques involving near field injection of air, or a fuel-air mixture with different stoichiometry.
- Define, on the basis of the measurements, a strategy for in-design passive control of syngas combustion.
- Perform numerical simulations of unsteady flame propagation and response to unsteady flow perturbations to determine the impact of pressure on the combustion process.
- Define scaling relations for the dependence of flame propagation and stability on pressure.

VII. ISSUES

None.

VIII. ATTACHMENTS

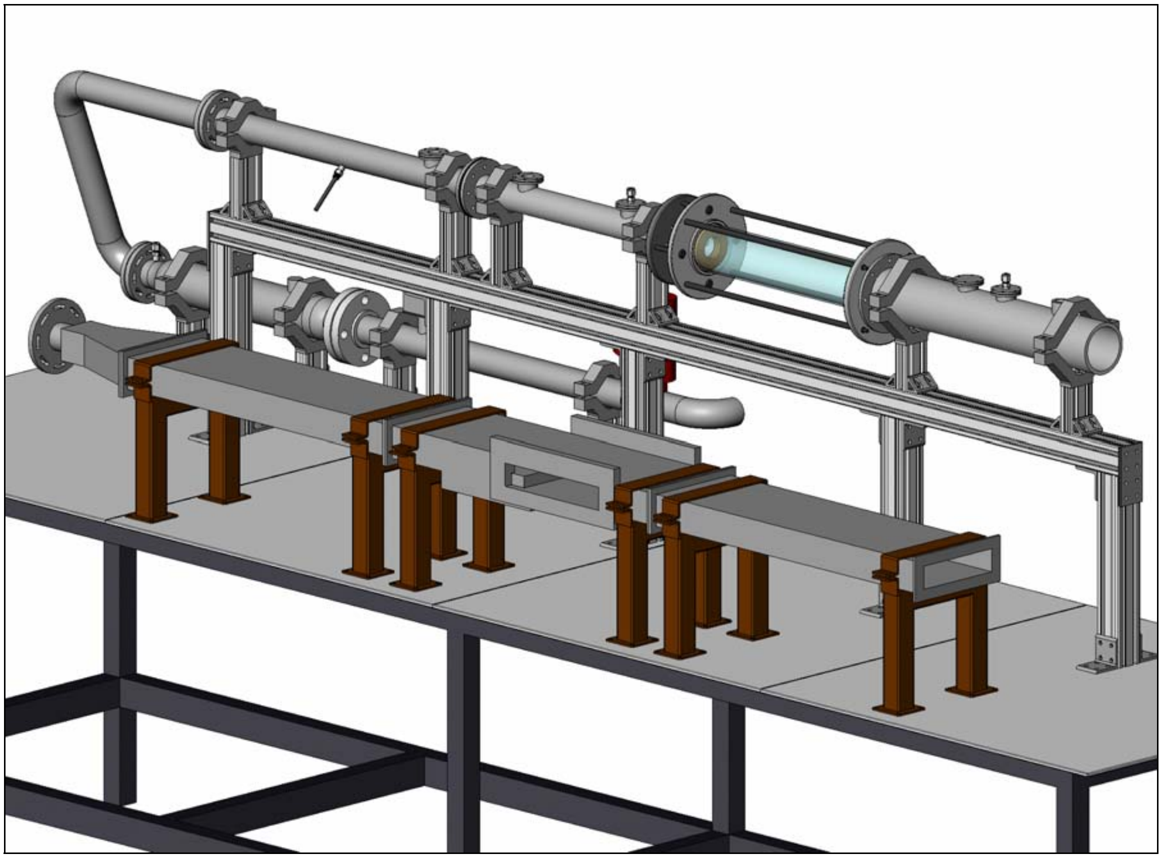

Figure 1: Combined lab setup with swirl stabilized and planar combustors.

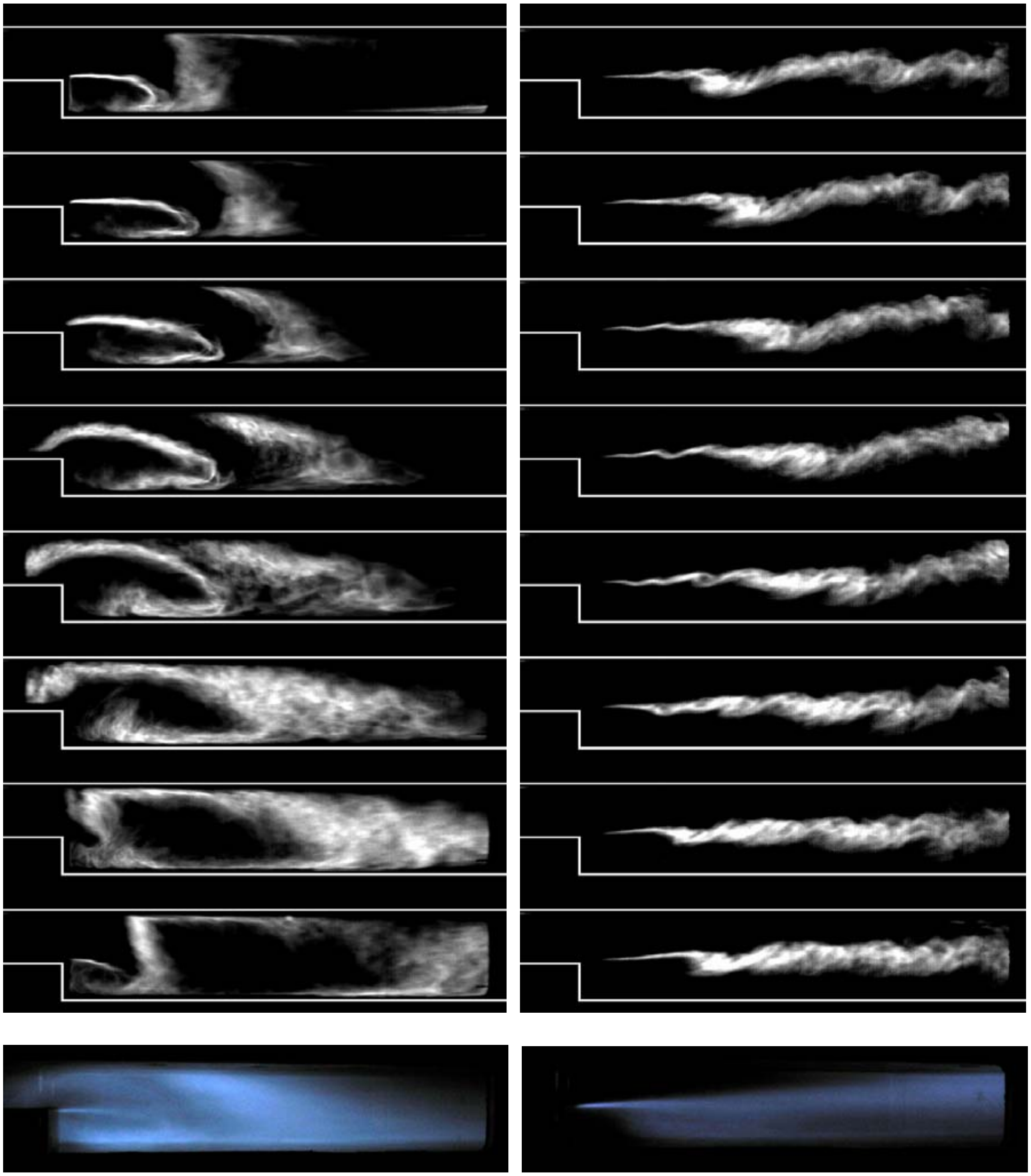

Figure 2: Image Sequence of unstable (left, Φ=0.42) and stable (right, Φ=0.38) flames with 80% CO fuel composition. The inter-frame timing is approximately 4.1 ms. The exposure time is 0.47 ms. The final frame in each is a 100 ms exposure showing the average flame structure.