Experimental study of combustion dynamics in a lean-premixed low swirl burner

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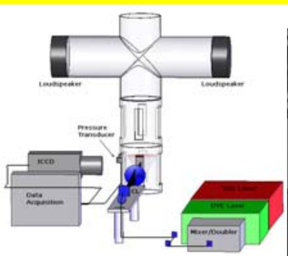
I. Introduction

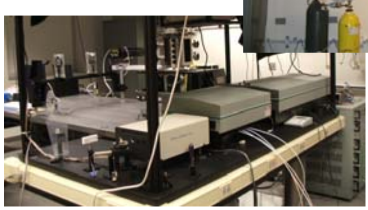
- Currently, there is no ability to a *priori* predict and control combustion instability in lean premixed combustors. This limits both the useful life and operating range of gas turbines.
- **Need**: tools and techniques to assess and refine new burner and combustor technology, including new low-swirl, low-pollutant (NOx, soot) designs without extensive full-scale testing
- **Need:** methods for tuning combustors to handle wide fuel-heating-value variations so as to enable use of alternative and biomass fuels (without inducing combustion instabilities)

II. Objectives

- Develop experimental techniques for reliably determining the dynamic response of a wide range of burners
- Construct a database of combustor response functions as a starting point for a structured approach for modeling and active control of combustion instability
- Examine combustion instability as the interplay of multiple, unstable physical phenomena so as to garner insights which can then be applied during the design process

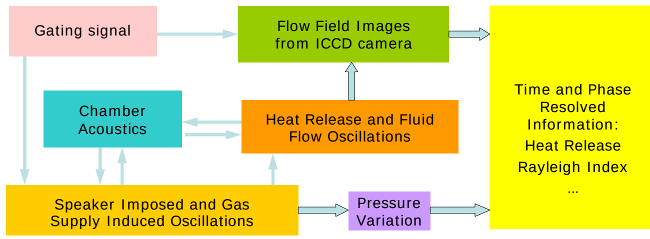
III. Approach





- Experimental setup
  - ✓ Chamber
  - ✓ Laser system
  - ✓ Intensified CCD camera
  - ✓ Adjustable premixer
  - ✓ Acoustic system (function generator, controller, amplifier)

- Experimental parameters for the low swirl burner
  - ✓ CH_4 + AIR
  - ✓ Equivalence ratio: 0.5 - 0.63
  - ✓ Acoustic frequency: 37 Hz – 125 Hz

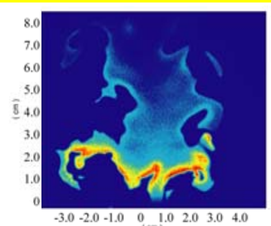


Physical Coupling and Data Flow

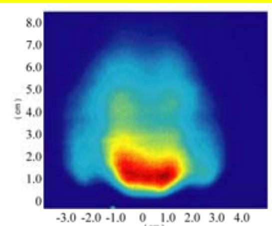
Experimental Goals:

- Simulate the acoustic environment of a flame experiencing pressure oscillations in a real combustor
- Examine how the imposed pressure fluctuations couple to flow and flame behavior
- Use OH PLIF (planar laser induced fluorescence of the hydroxyl radical) to measure the spatial heat release

IV. Data Analysis

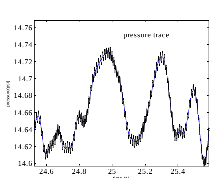


Single Shot OH PLIF Image

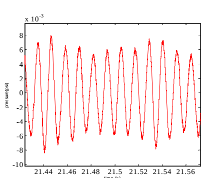


Averaged OH PLIF Image

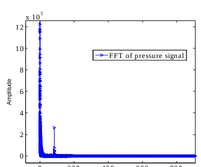
OH Distribution in the Flame Zone
(110 Hz driving frequency)



Chamber Pressure Oscillation



Pressure Oscillation Induced by Acoustic Driving



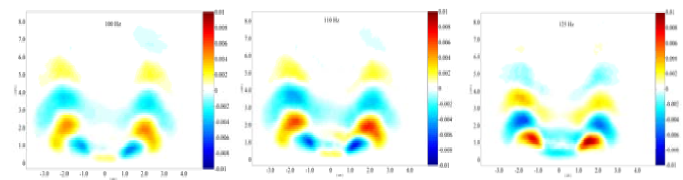
FFT of Pressure

- The measured pressure signal is filtered and employed to provide synchronization of the flow field with local pressure variation
- Comparison of both instantaneous and averaged fields allows calculation of more complex quantities and weak instabilities

- Rayleigh Index
  - The amount of energy transferred during one cycle of oscillation from heat addition to mechanical energy of acoustical motions

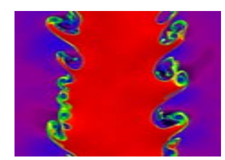
$$R_f = \int_0^1 \frac{p'q'}{p_{rms}\bar{q}} d\xi$$

- Negative R_f means that pressure oscillation and heat release are out of phase , hence more stable flame
- Rayleigh index changes with frequency (ramifications of this are still being analyzed)

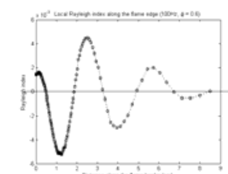


Local Rayleigh Index
(1 atmosphere mean pressure, equivalence ratio = 0.60)

- Kelvin-Helmholtz Instability
  - Waves or vortices that appear between two fluids flowing at different velocities but sharing a mutual boundary
- Nitrogen co-flow and flame products have different velocities and densities



Kelvin-Helmholtz Instability Simulation
from:http://www.astro.princeton.edu/~jstone/tests/kh/kh.html



Local Rayleigh Index Along the Flame Edge

V. Conclusions

- A new experimental system was constructed which enables examination of here-before unexplored physical interactions underlying the problem of combustion instability
- Dynamic characteristics of combustion were studied under different equivalence ratios, driving frequencies, and mean pressures
- Thermo-acoustic coupling in combustion was studied and (a rarely seen) Kelvin-Helmholtz instability was observed and quantified

VI. Future Work

- Gather data at chamber pressures of up to 5 atmospheres
- Use PIV to measure the velocity field during acoustic driving
- Record temperatures (via dual line OH PLIF)
- Construct response function for the system to enable active control and computational modeling of the combustion instability