Improving NOx Entitlement with Axial Staging

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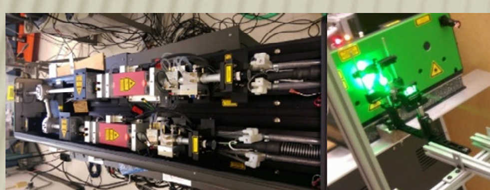
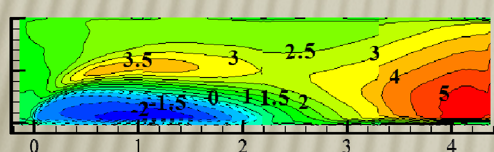
Background

- Gas Turbine OEM's are under pressure to increase efficiency without increasing emissions.
- Increasing turbine inlet temperature is one method to increase efficiency, but with a large NOx penalty.
- By injecting some of the fuel late in the combustor (axial staging)) it burns with a shorter residence time, reducing NOx.
- OEM's have tested full size axial staging designs at engine conditions, but are unable to obtain detailed measurements of the reacting jet-in-crossflow.

Experimental Measurements: PIV and Chemiluminescence

- High-speed PIV system (20kHz, 40kHz, 60kHz, 100kHz)
- High speed cameras 21,000-2,100,000 frames per second
- High-speed chemiluminescence CH*, OH* (40 kHz, 80kHz, 100kHz)
- Light-field focusing system for flow measurements and visualization
- LabVIEW control hardware and software
- Dynamic pressure transducers (PCB)
- Codes: DMD, POD, PIV, Turb, Physics-Based Models (Matlab/Fortran)





Jet-in-Crossflow Correlation

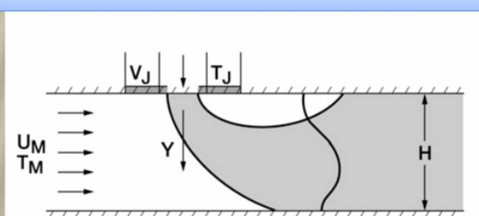


Figure 1.—Schematic of flow field for a confined jet in cross flow (shown for one-side injection of a single row of jets from the top duct wall).

- Excel based tool to predict non-reacting jet-in-crossflow (JiC).
- The data obtained in this project will be used to create a reacting JiC correlation.

CFD Validation

Validate the capabilities of our OpenFOAM based CFD code and a commercial code to predict reacting jet-in-crossflow.

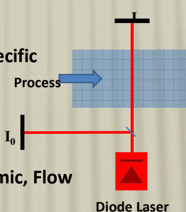
Motivation and Research Objectives

Explore novel configurations to implement axial staging with direct involvement of original equipment manufacturers (OEMs). Develop reacting Jet-in-Crossflow correlation and validate existing CFD capabilities.

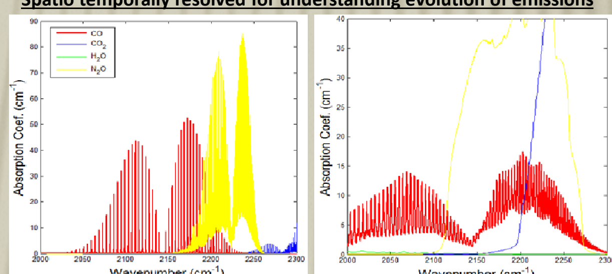
- **Conduct experiments using a high pressure combustion facility.**
- **Tune rig headend to give similar NOx curve as current engines.**
- **Axial stage testing with Fuel/Air and Fuel/Diluent axial mixtures with various levels of premixing.**
- **Axial Stage Modeling : Jet-in-crossflow correlation and CFD validation.**

Tunable Diode Laser Absorption Spectroscopy (TDLAS): NOx, CO

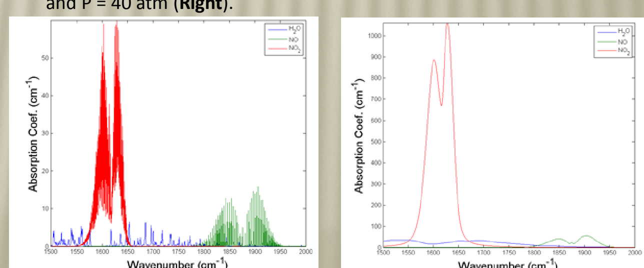
- **TDLAS Overview**
  - **Measure Process Transmittance (I/I_0) at Specific Wavelength(s)**
    - Diode Laser + 2 Photodetectors
  - **Apply Photon Conservation**
    - Beer-Lambert Law: $I/I_0 = f(X,T,P,V)$
  - **Infer Process Path-Integrated Thermodynamic, Flow Conditions**
    - Time-Resolved Composition, Temperature, Pressure, Speed
    - Axial profiles of species evolution will provide novel measurements needed for design and model validation



Spatio temporally resolved for understanding evolution of emissions



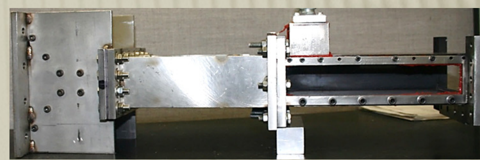
- Carbon Monoxide (target) and common interfering species (CO_2, H_2O, N_2O) absorption features at T = 296 K and P =1 atm (**Left**); and T = 1500 K and P = 40 atm (**Right**).

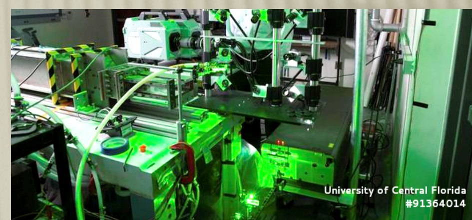


- NO, NO_2, and interfering water absorption features at $T = 296$ K and $P = 1$ atm (**Left**); and and $P = 40$atm (**Right**). Note the marked increase in absorption for NO and NO_2 at high pressures and the minimal water interference around 1600cm^{-1} and 1900cm^{-1}.
- UCF's Diagnostics will be validated using shock tube and high temperature cells before applying to the rig

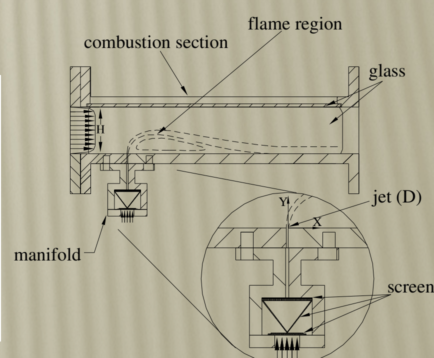
Experimental Rig - Headend

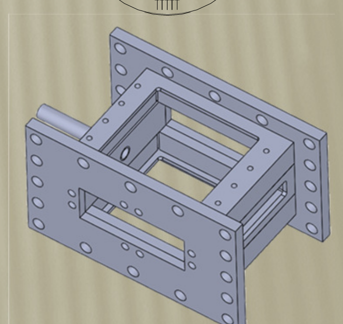
High speed and high temperature combustion chamber (vitiated with full optical test section): 2.5in x 3in x 6in, 100 m/s, 5 bar, 1kg/s (2 kg/s max).





Experimental Rig – Axial Stage





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