Perspectives on R&D Needs for Gas Turbine Power Generation in a Carbon Constrained World

Adel Mansour, PhD, MBA
Gas Turbine Fuel Systems Division

Parker Hannifin
Mentor, OH

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Outline

- Market and Technology Drivers for Next Generation Fuel Nozzles/Injectors/Premixers
- Examples of Gaps in Science and Technology
- Research Recommendations

Nozzle/ Injector/ Premixer Centric View

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Market and Technology Drivers for Next Generation Fuel Nozzles/Injectors/Premixers

- More Efficient Engines
- Low Emissions
- Fuel Flexibility
- Reduced Development Costs
- Reduced Life Cycle Costs

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Market and Technology Driver
More Efficient Engines

More Efficient Engines

Needed Technologies

New High Temperature Materials

Joining, Fatigue Properties, CMC, TBC, Lifing

Thermal Management

Reduce Wetted Wall Temperature

Coking and Thermal Stability of Fuels

Smart, Adaptively Controlled Nozzles

Flow Tolerance Improvements/ Robust Flow Control

More control Knobs to Taylor Performance

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Market and Technology Driver
Low Emissions Engines

Low Emission Engines

Needed Technologies

New Lean Premix (LP) and Lean Direct Injection (LDI) Concepts

Improve LBO Margin (Operate Leaner)

- Improve Turn Down Ratio of Fuel Nozzles
- Improve Atomization-Enhance Vaporization

Control of Combustion Dynamics

- Feed back loop between combustor and fuel flow metering
- Flame detection
- Emissions detection (NOx, CO sensors)
- High bandwidth flow control valves
- Develop Control Algorithms

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Market and Technology Driver
Fuel Flexibility

	Fuel Flexibility for Power Gen Applications
Needed Technologies	

Multi-Fuel Nozzle
Hydrogen Syngas Combustion
Synthetic Gas, Naphtha, Bio Gas, LBTU Gas
Need to study reaction kinetics-- Flame speed, etc…
Study flashback and autoignition
Study flame holding and effects of higher injection speeds

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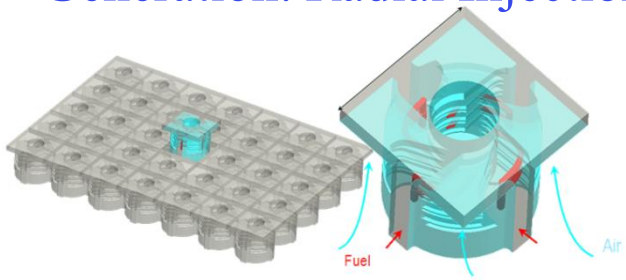
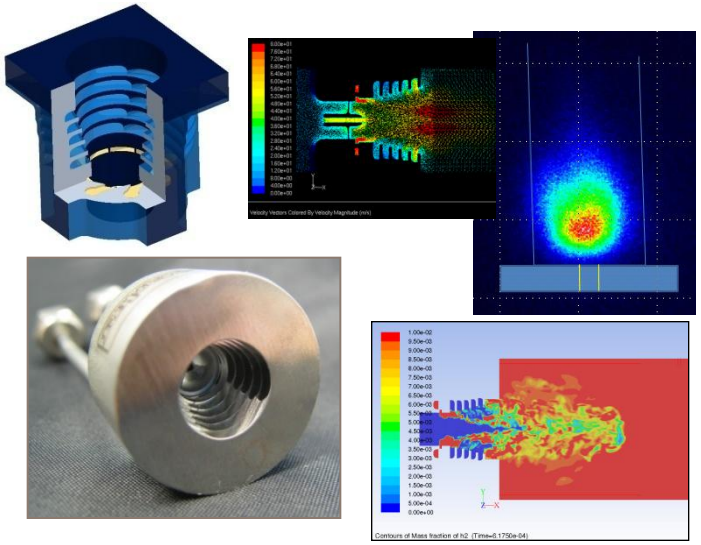
Micro-Mixing Lean Premix System for Ultra-Low NOx Emission Hydrogen/Syngas Combustion

Single Cup Module

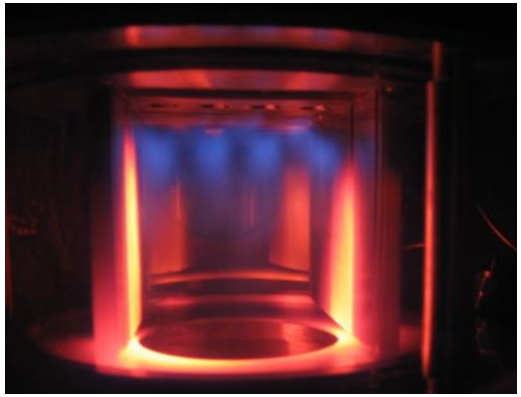
1st Generation: Radial Injection



2nd Generation Radial/Axial Injection



Multi-cup Module



1.3 MWth Full Scale Injector

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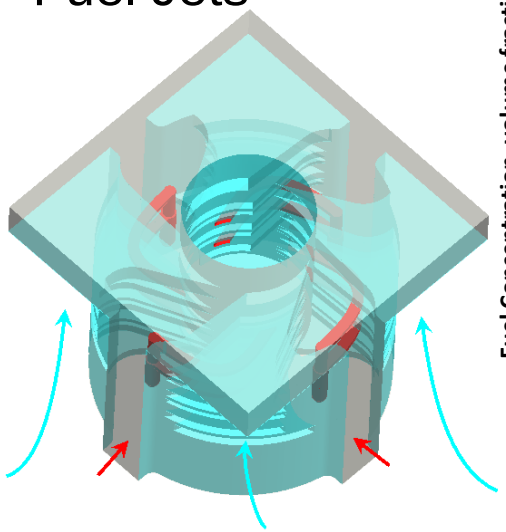
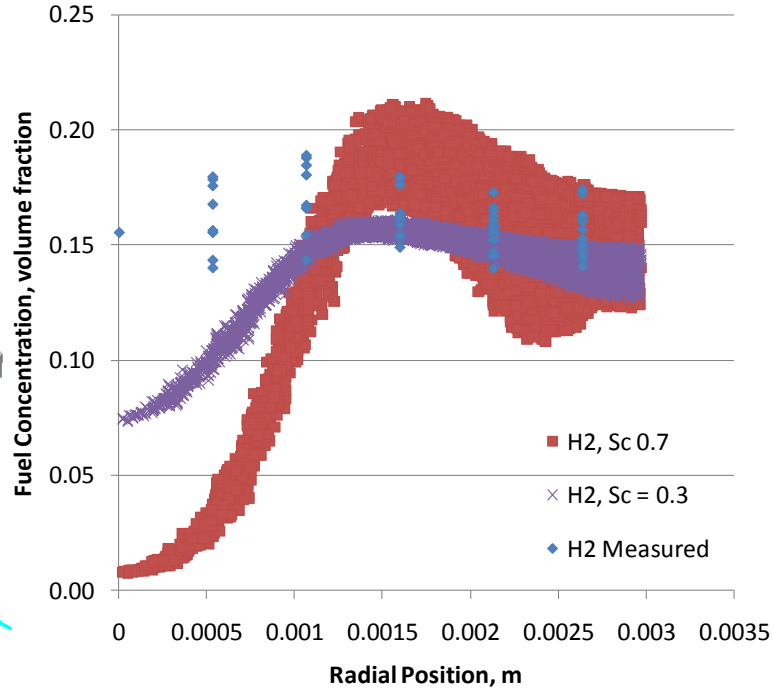
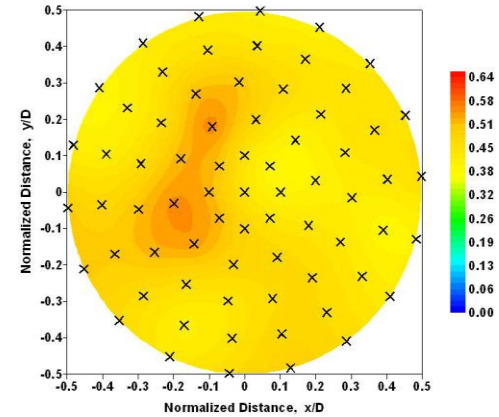
Examples of Gaps in Science and Technology:
CFD Modeling-Mixing

Angled Swirling Fuel Jets

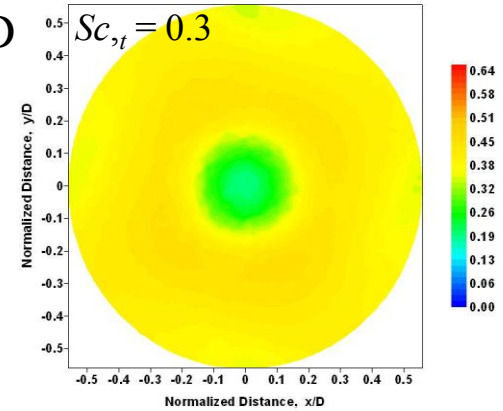




Exp.



CFD



- Demonstrated that RANS is unable to accurately predict fuel-air mixing in micro-mixing cups.

Higher Fidelity Computations: Turbulence Modeling, Fuel Air Mixing, Better Anchoring of CFD code, LES.

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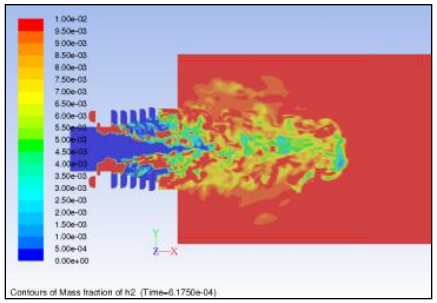
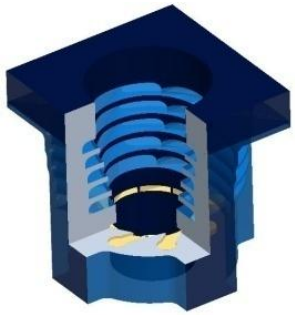
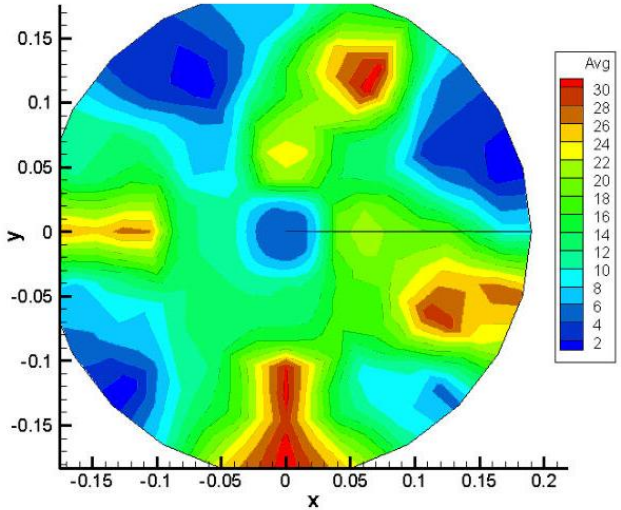
Examples of Gaps in Science and Technology:

CFD Modeling-Mixing

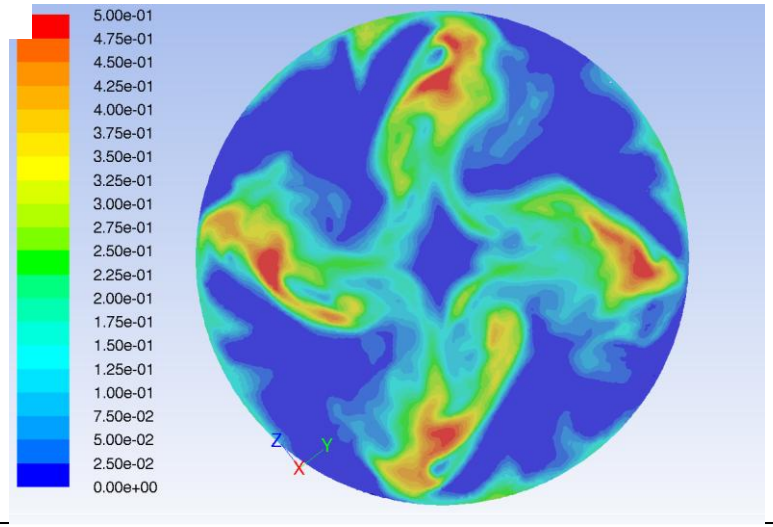


Measurements at atmospheric conditions (time-averaged volume fraction)





Time-averaged LES results



- LES Grid: 14.6 Million hexahedral and polyhedral cells, 2 weeks on 60 processors
- LES captures more details of the flow/mixing structures

- What level of details is needed to capture all relevant flow physics? And at what cost?

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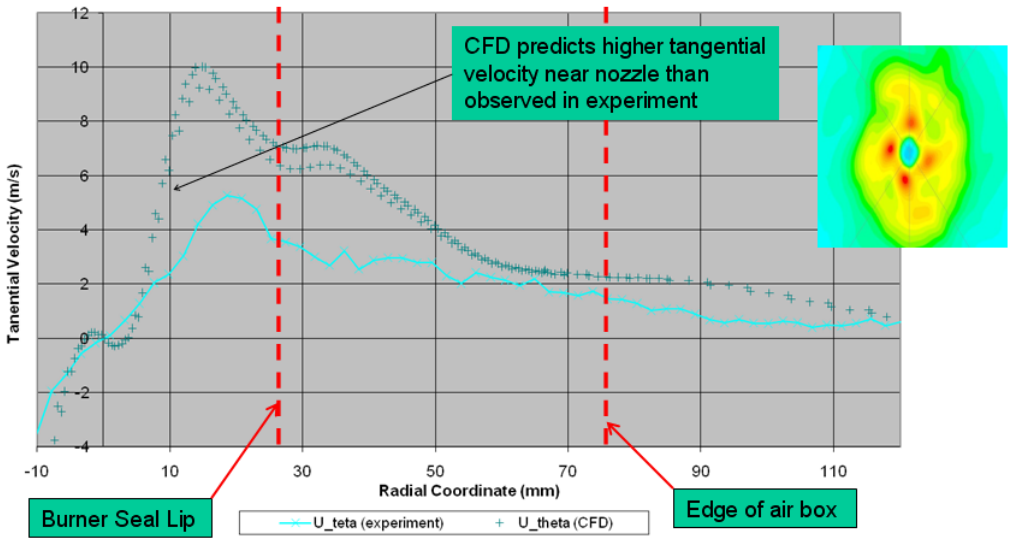
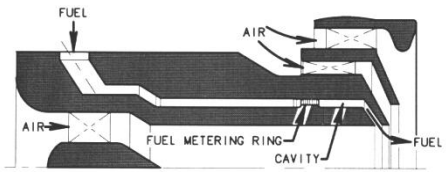
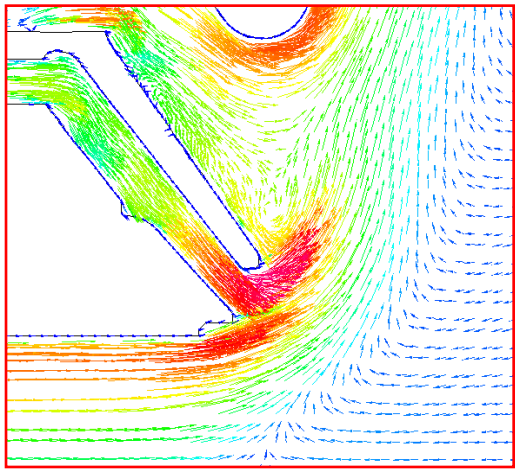
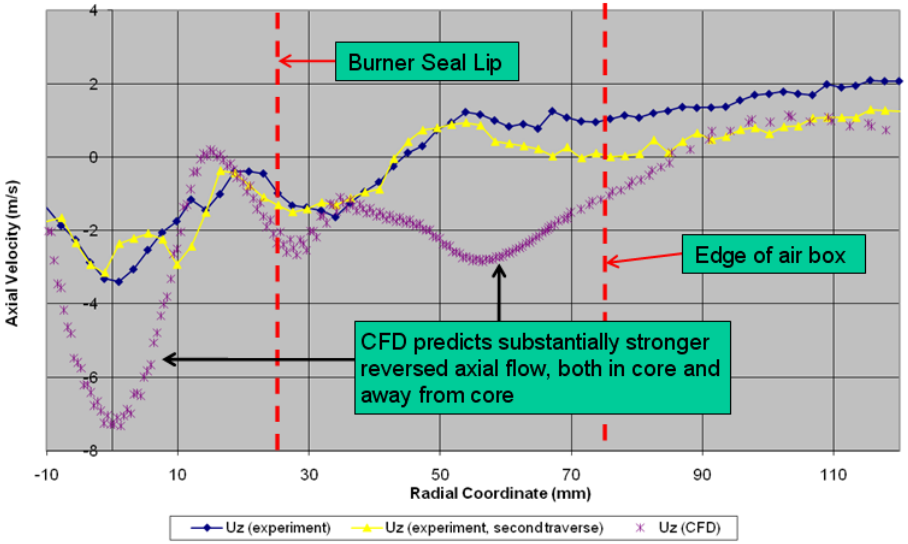
Examples of Gaps in Science and Technology:

CFD Modeling-Aerodynamics- URANS









- URANS results fail to match experimental results.
  - URANS results show higher tangential velocity near the exit of the fuel nozzle than is observed in experiment.
- <u>Adequate predictive capability for aerodynamics is a prerequisite before spray dispersion can be predicted reliably.</u>

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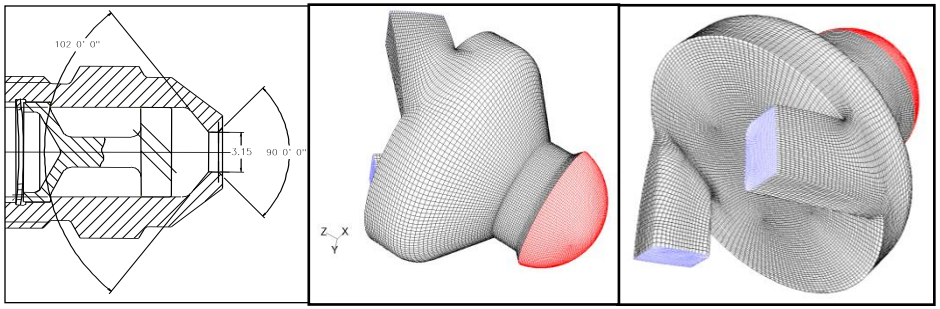
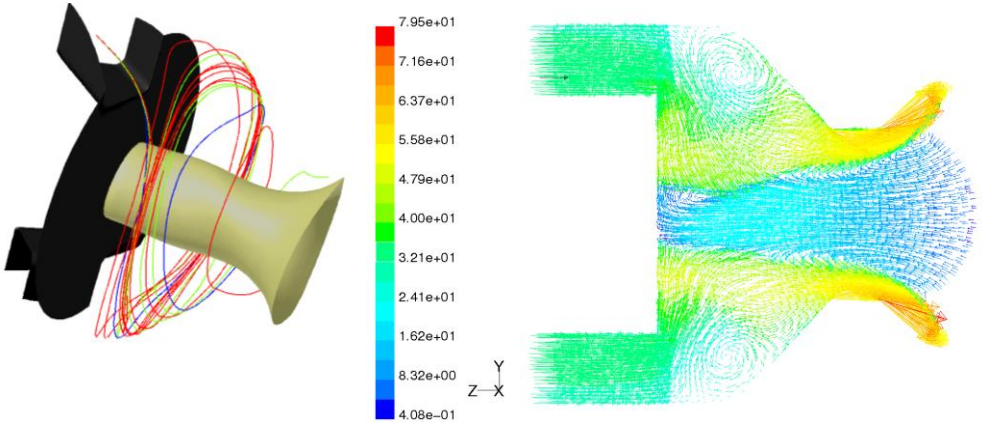
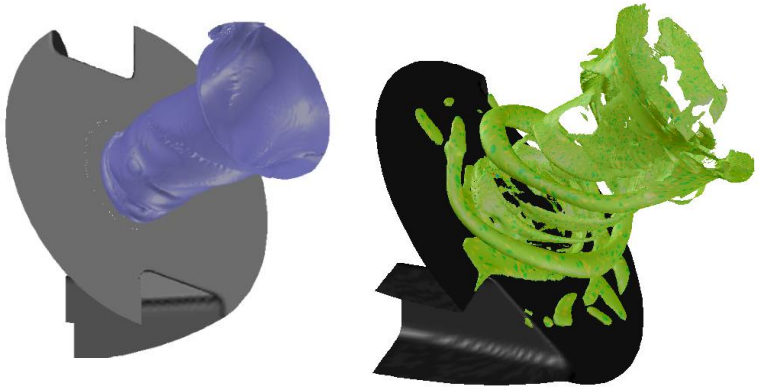
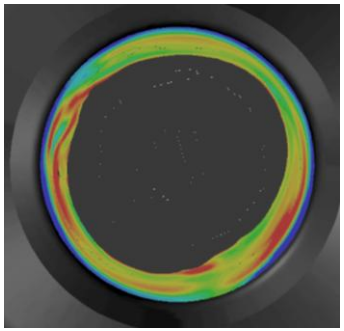
Examples of Gaps in Science and Technology:
CFD for Simplex Atomizers Flows





Steady State RANS simulations
(air core and velocity field)





Simulations of pre-filming (air core)

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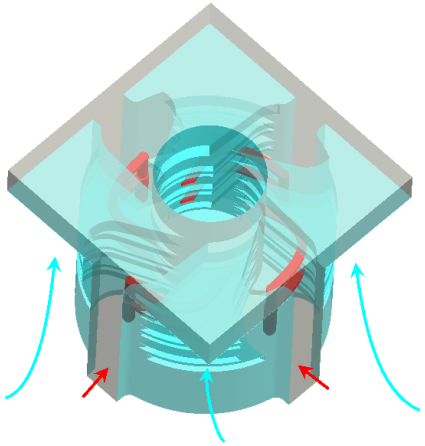
Examples of Gaps in Science and Technology:
Flashback Prediction

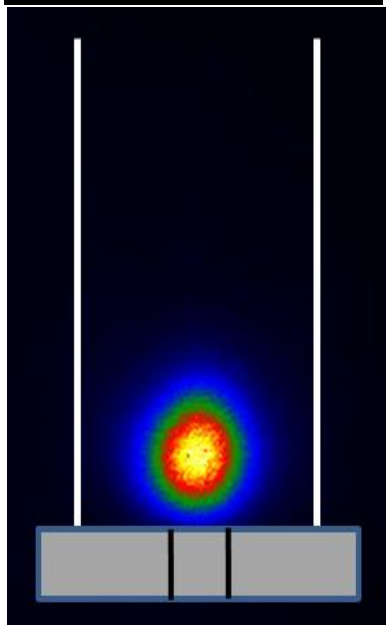
- 1st Generation Micro-Mixing Cup: Reaction Structure: OH Visualization for 100% H_2 - Flashback

At P > 5 atm, flame ingress observed for AFTs of interest



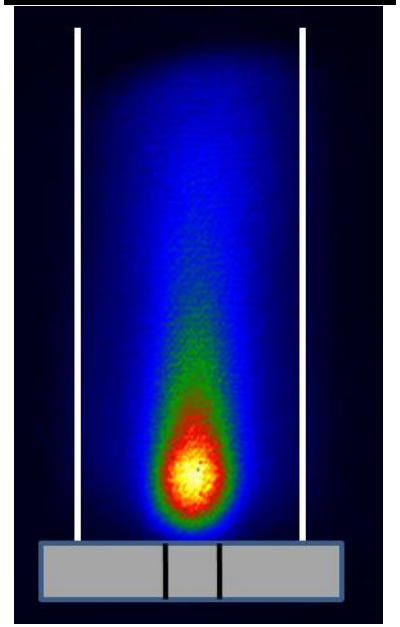
Flashback occurs through the BL

1-5 ppm NOx



S1F3, 2 atm, 1750 deg-K
5% ΔP/P

10-20 ppm NOx



S1F3, 4 atm, 1675 deg-K
5% ΔP/P

Better understanding of flashback (reaction kinetics, flame ingress mechanics, boundary layer vs. bulk flame ingress).

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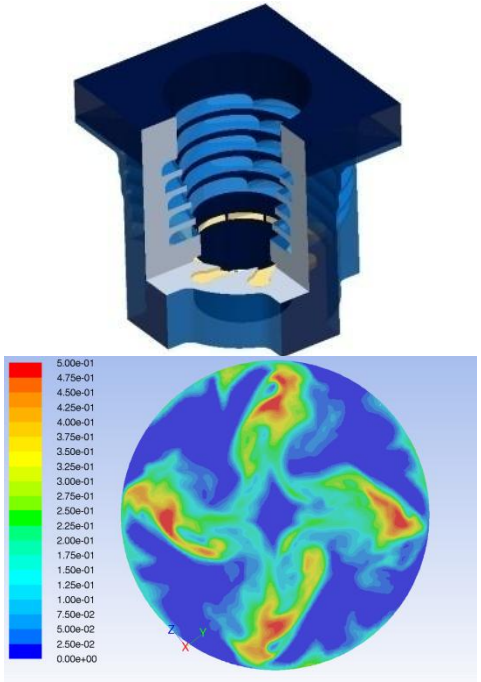
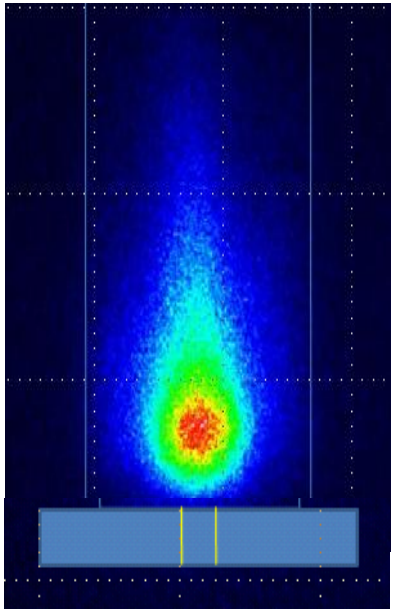
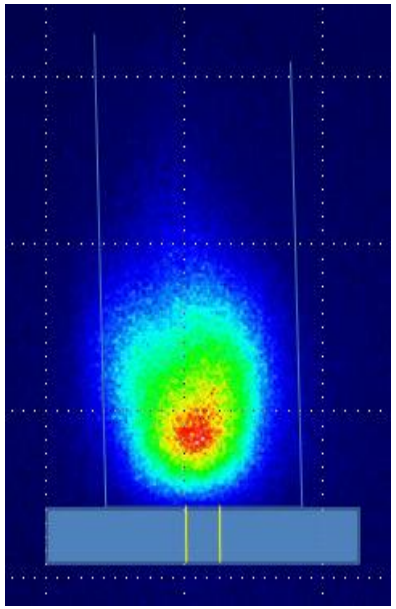
Examples of Gaps in Science and Technology:
Flashback Prediction

- 2nd Generation Micro-Mixing Cup: Reaction Structure: OH Visualization for 100% H_2: No Flashback





3atm



8atm

- **NO Flashback at Flame Temperatures as high as 2000 K**
- **Leaning the BL eliminates flashback**

Develop fuel injection concepts that are robust to flashback

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Research Recommendations

- Enhanced single phase and dual-phase/spray modeling
- Enhanced understanding of physical and chemical processes in combustion
- Flame stability enhancement research, ignition and lean blowout prediction
- Fuel flexibility
  - Flexible/robust designs operating on wide range of fuels
  - Flame kinetics, high pressure chemistry, mechanism development
- Flashback predictive tools to facilitate flashback resistant injectors
  - Improved understanding of flashback, effects of tailoring of velocity and fuel concentration profiles, effects of turbulence and bulk coherent structures
- Understand potential tradeoffs between emissions reduction and nozzle, combustor and hot section life

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