ASCENT Project 74

Low Emission Premixed Combustion Technology for Civil Supersonic Transport (CST)

Georgia Institute of Technology & GE

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Cost Share Partner: GE

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Objective:

Support development of low-emissions combustion technologies for p_3, T_3, FAR in CST engines

1) Characterize and understand the emissions and operability of lean premixed combustor for CST
2) Develop methods for computational design/analysis
3) Provide input to engine and environmental impact modeling

Project Benefits:

1) Advance novel LPP combustion technology for environmentally compatible CST
2) Reduce development time/cost through validated tools

Research Approach:

1) Experimental studies at realistic operating conditions using laser measurement techniques
   - High-speed spray imaging, chemiluminescence
   - Fuel PLIF (mixing), TiRe-LII (nvPM)
   - Exhaust emissions, noise
2) Large Eddy Simulations
   - Research-scale first-principles LES
   - Industrial-scale LES
   - Accuracy/cost trade-offs
3) Combustion dynamics modeling

Major Accomplishments (to date):

1) Design, fabrication, installation, operation of novel LPP combustor for CST conditions
2) Design, setup, operation of laser diagnostics and emissions measurements
3) Industrial standard practice LES of LPP combustor
4) Methodology for time/space-dependent BCs on high-fidelity LES

Future Work:

1) Data analysis from Campaign 1
2) Completion of high-fidelity LES
3) Campaign 2, LES 2, thermoacoustics modeling

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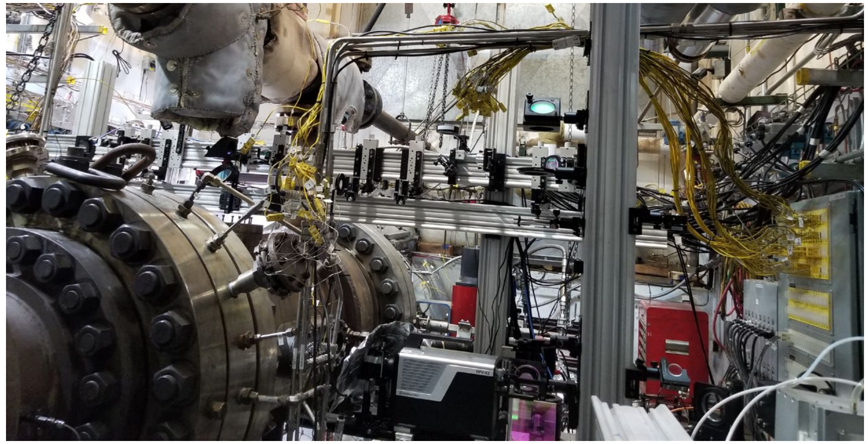
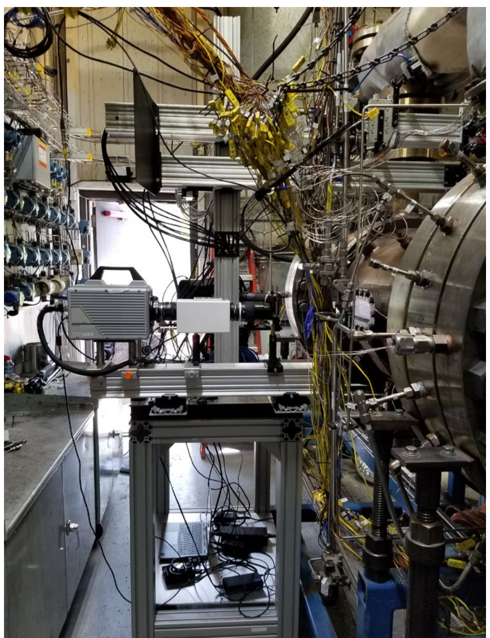
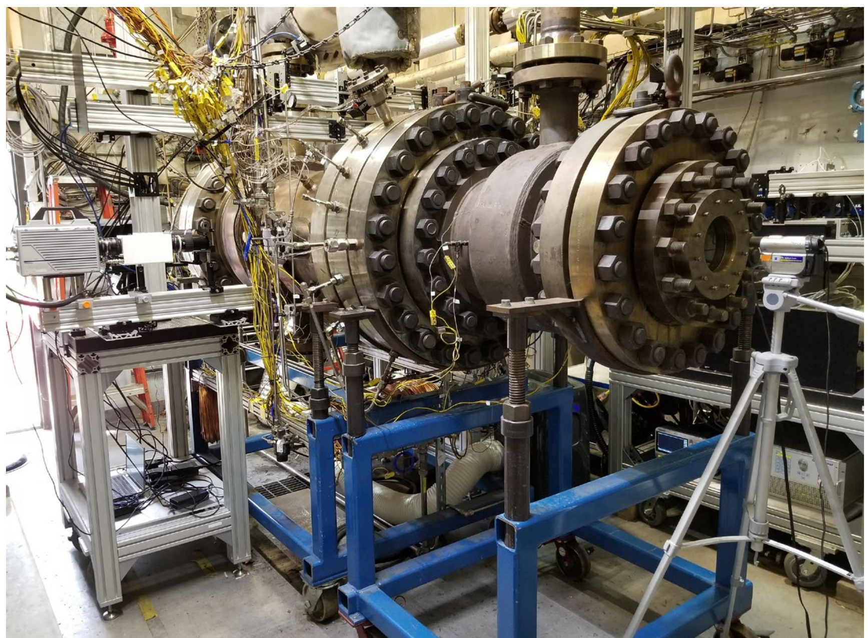
Experimental Campaign #1

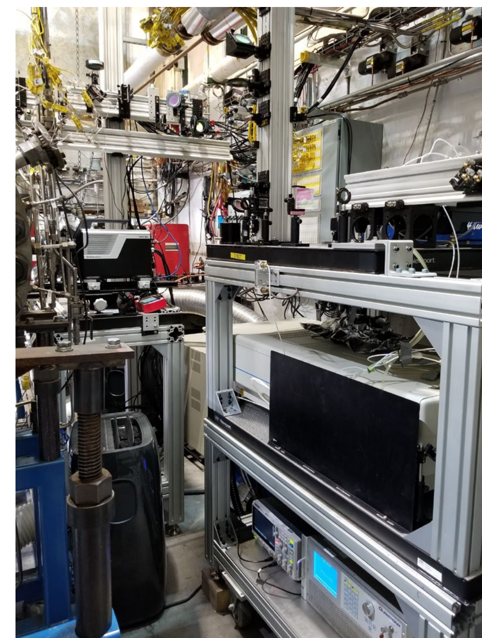
High-speed OH* CL
Mie scattering
Fuel PLIF
TiRe-LII
Emissions
- NO_x, CO, UHC



Quanta Ray Pro
Quantronix Hawk
2x Phantom v2640
Shimazu HPV-X2
Andor iStar







Test Rig Details

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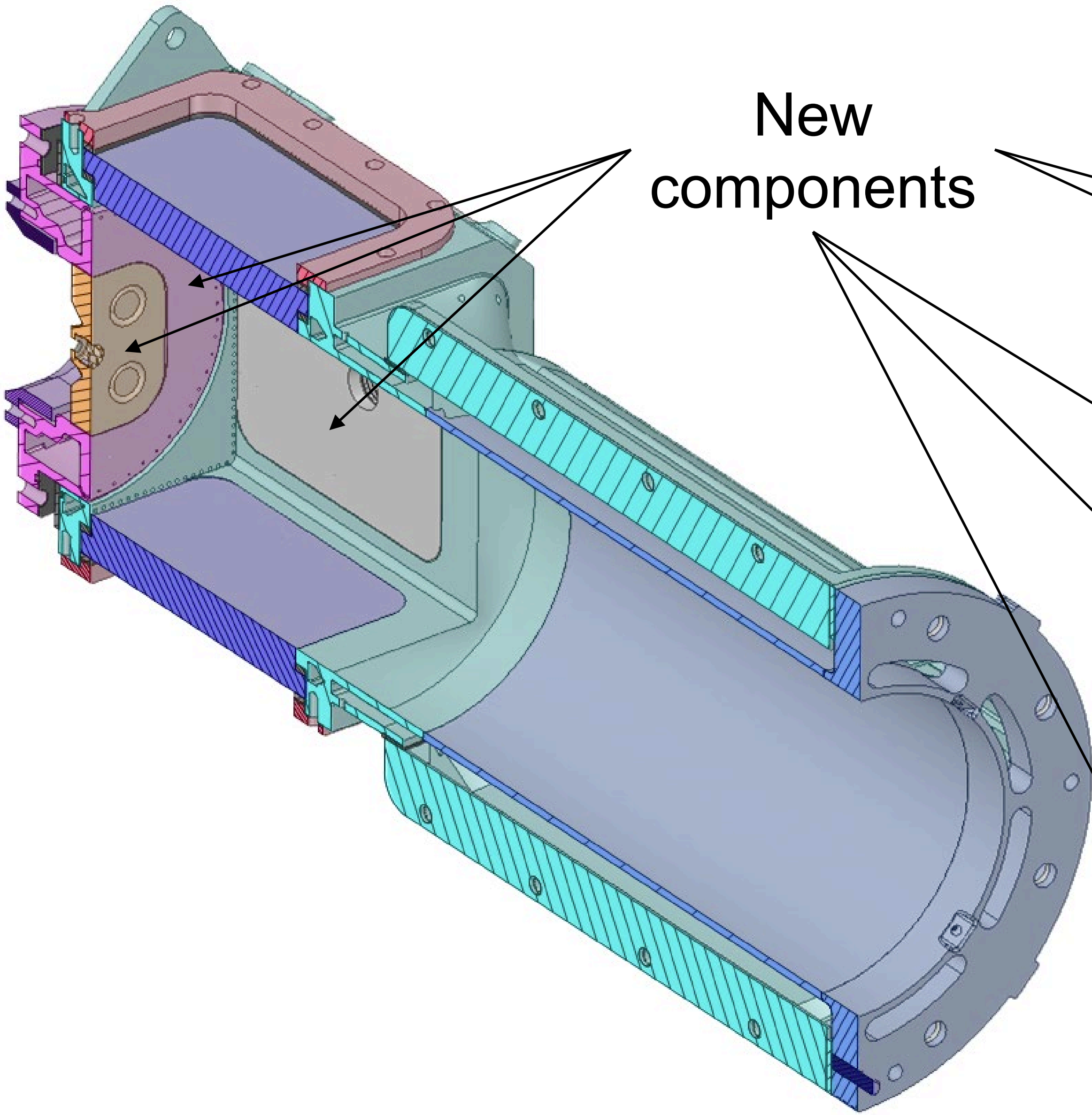
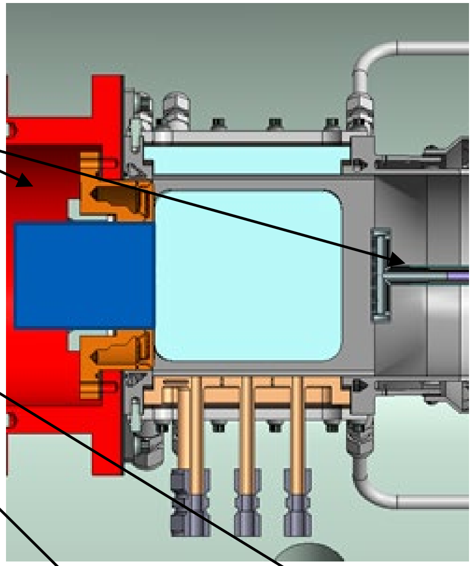
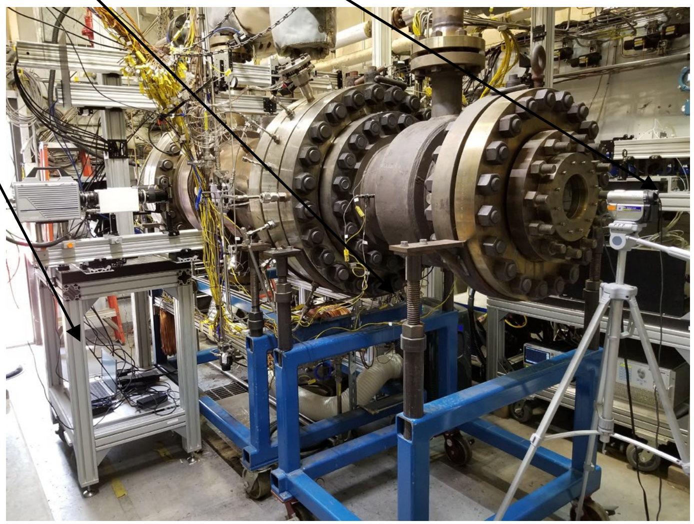


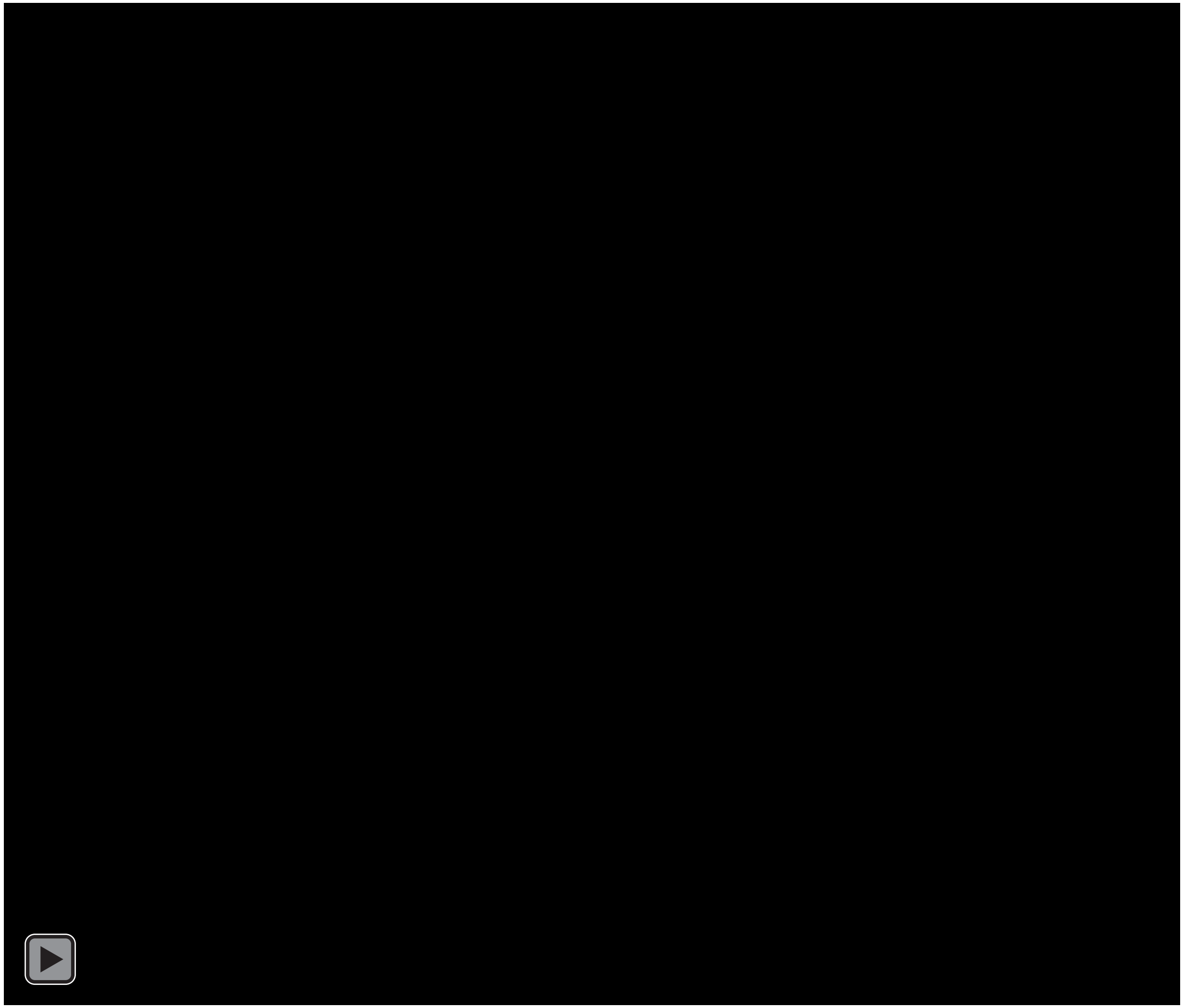
New components





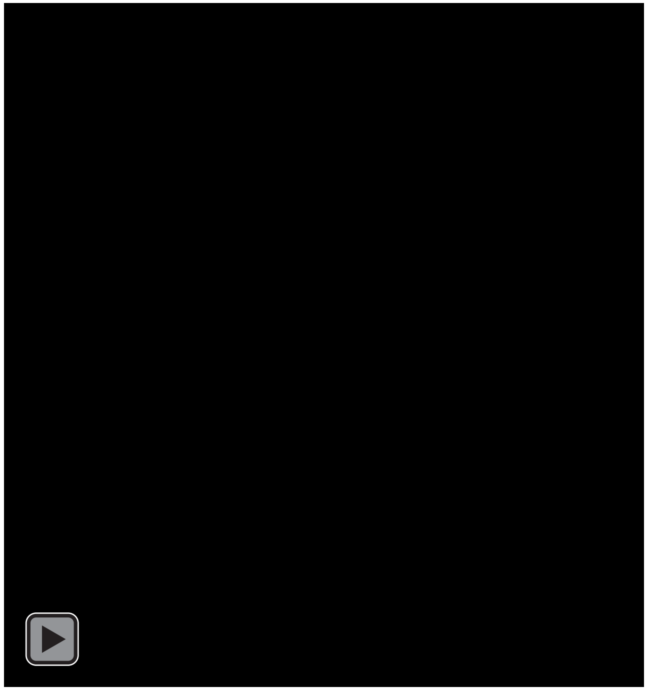
Typical Flame Video

$p_3 \approx 1.3 \times$ nominal cruise, $T_3 \approx 720$ K, $FAR_{\mathrm{mix}} \approx 0.045$



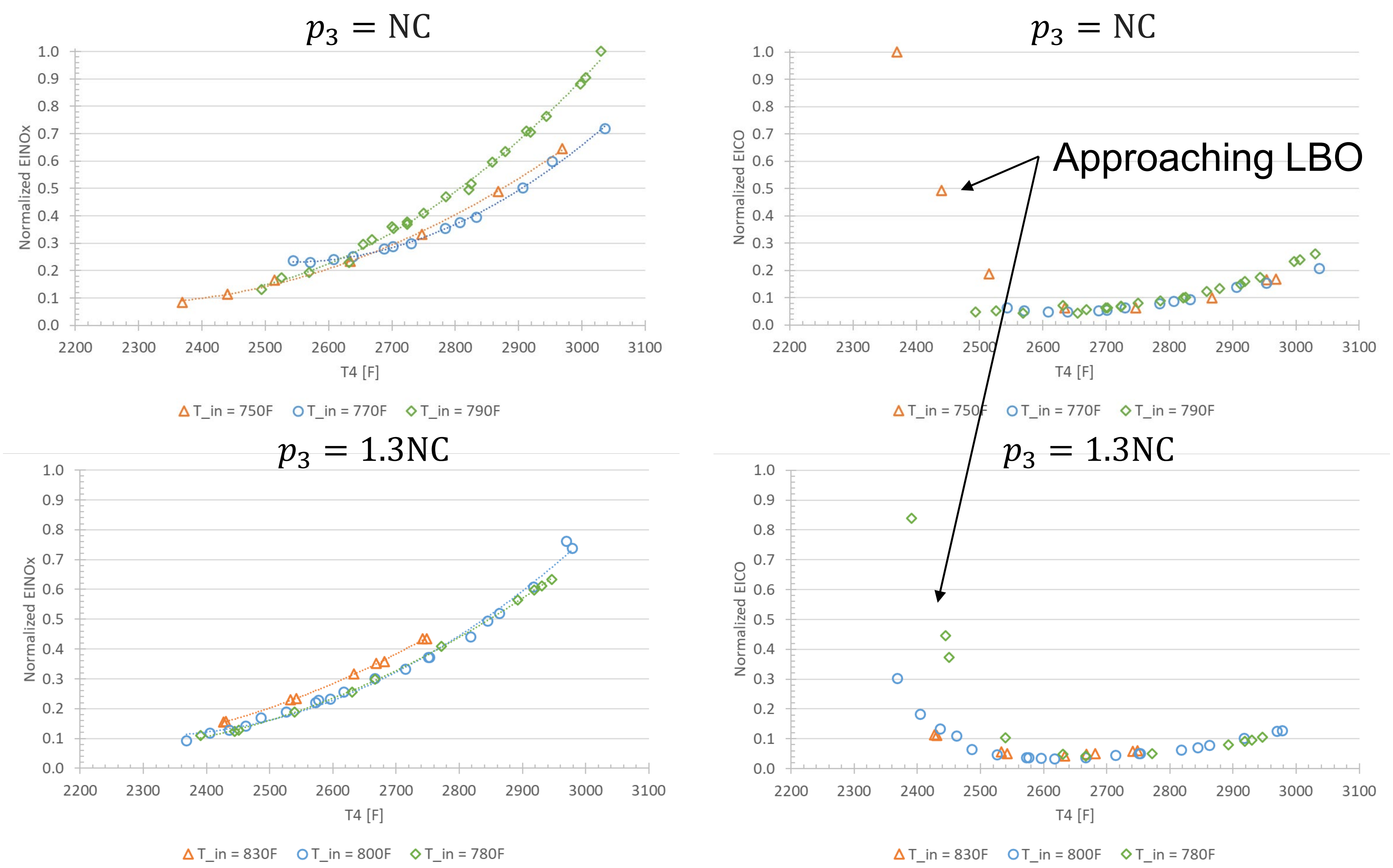
Flame video

$p_3 \approx 1 \times$ NC, $T_3 \approx 700$ K, $FAR_{\mathrm{mix}} \approx 0.055$

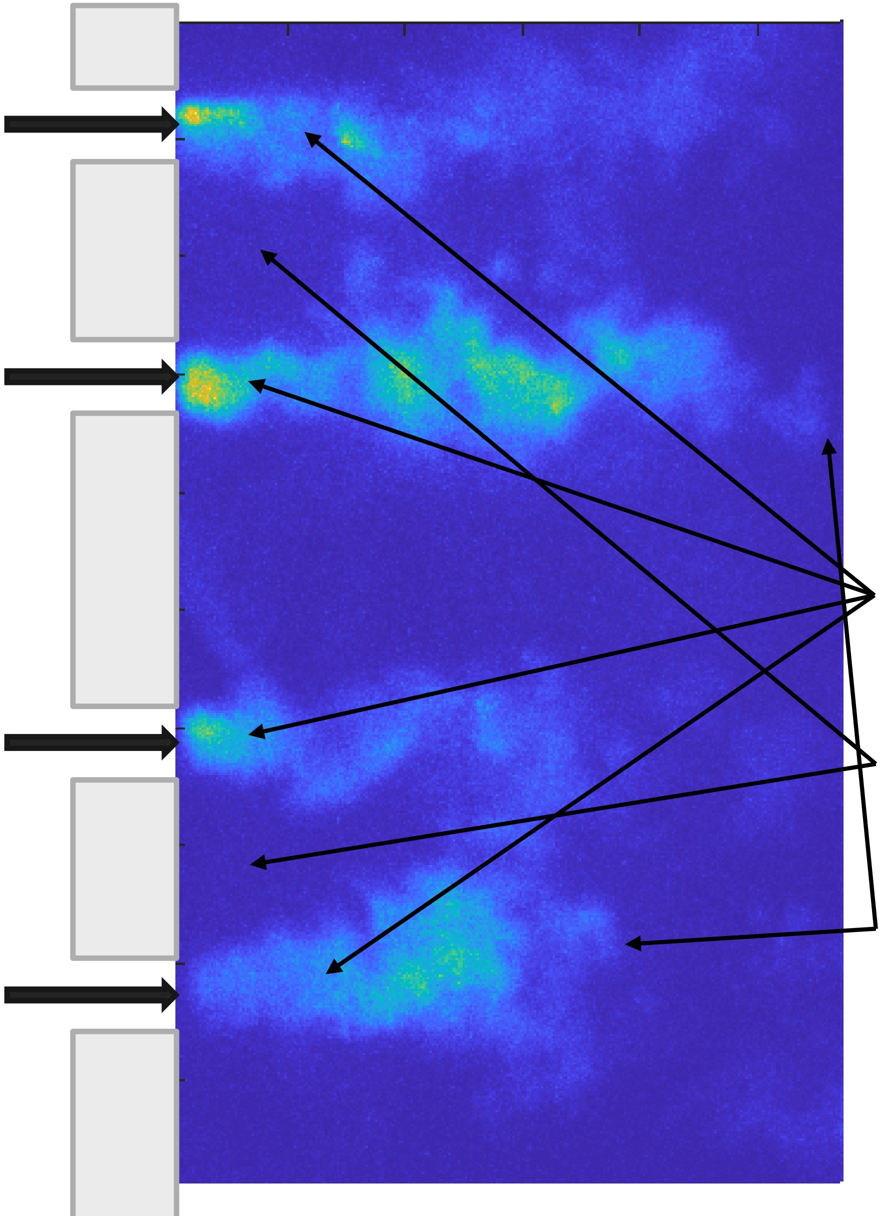


Droplet Mie scattering

Normalized Emissions Data



Typical Fuel PLIF



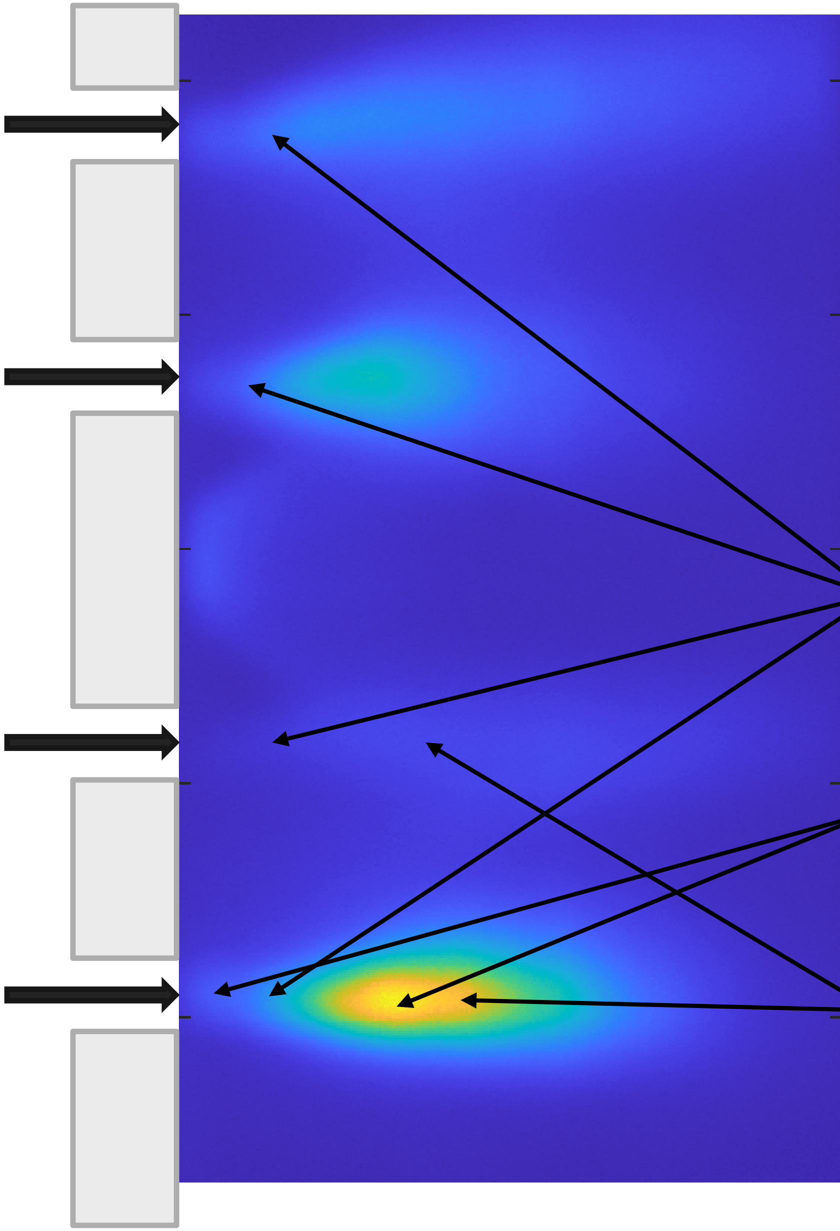
Darkfield correction
Background correction
Whitefield correction
Sheet correction
Absorption correction (TBD)

Partially premixed fuel/air

Burnt products in recirculation zone

Instantaneous flame length

Typical Mean Fuel PLIF

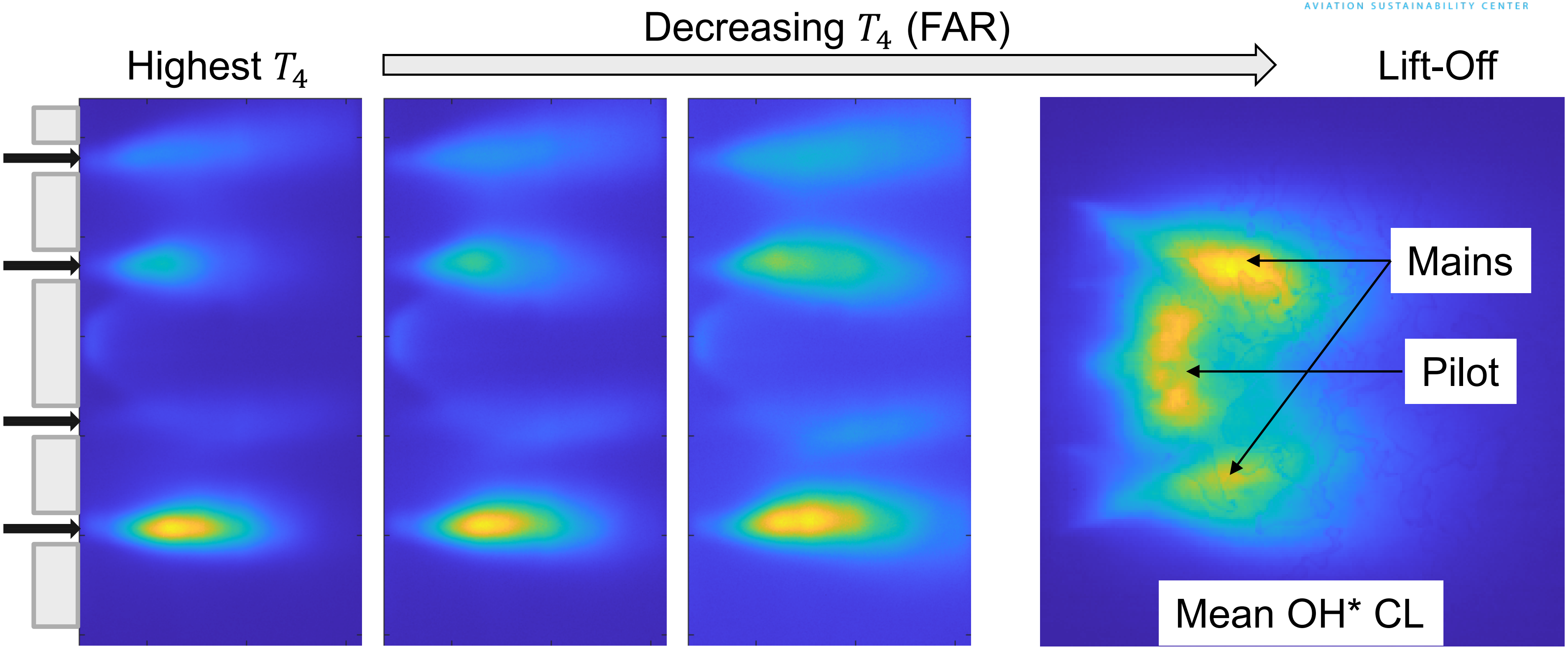


Non-uniform fuel distribution (as expected)

Effects of fuel injector clocking

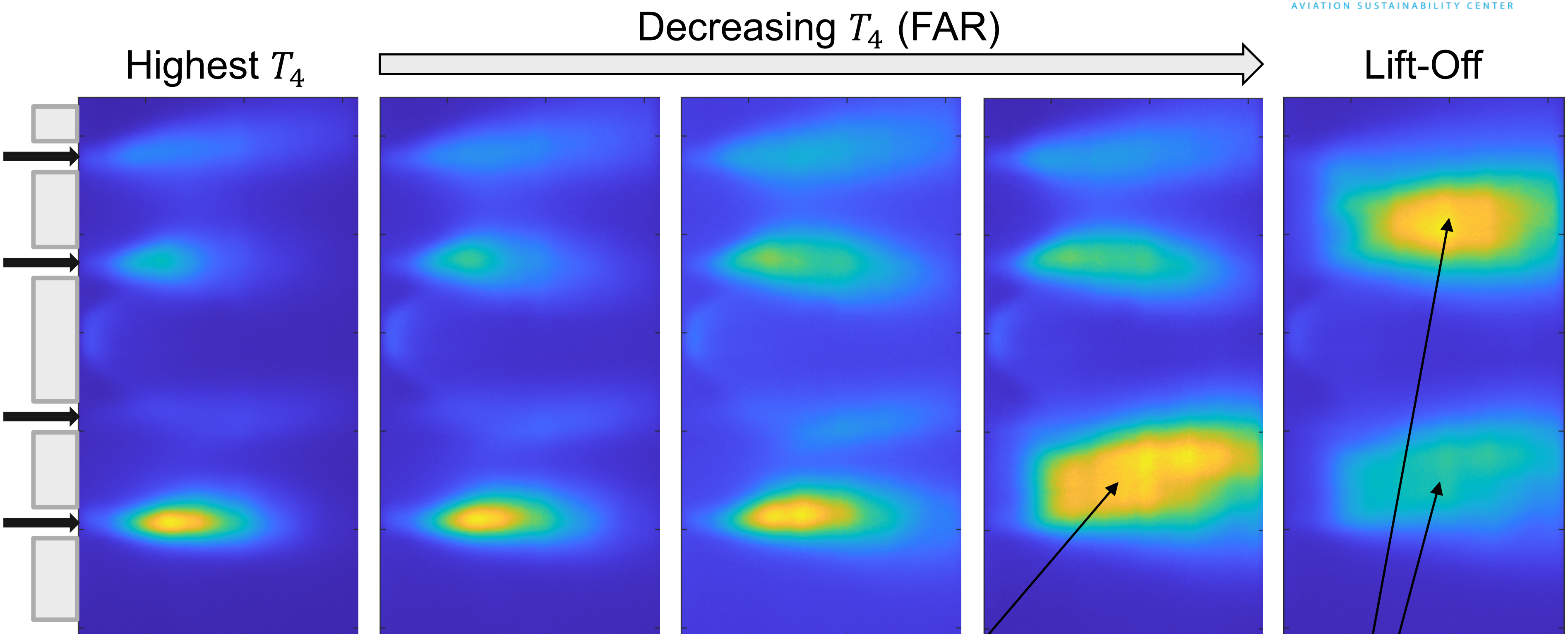
Significant asymmetry, potentially beyond clocking

Fuel/Air Mixing vs. FAR



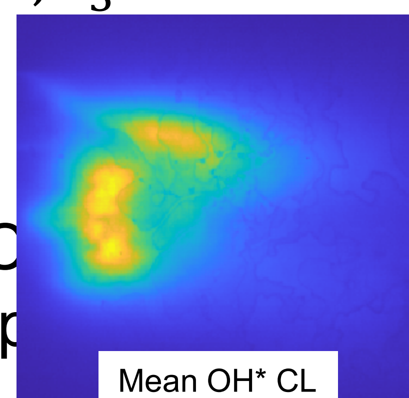
Mean PLIF fields $p_3 = \mathrm{NC}, T_3 = 800\ \mathrm{F}$

Fuel/Air Mixing vs. FAR



Mean PLIF fields $p_3 = \mathrm{NC}, T_3 = 800\ \mathrm{F}$

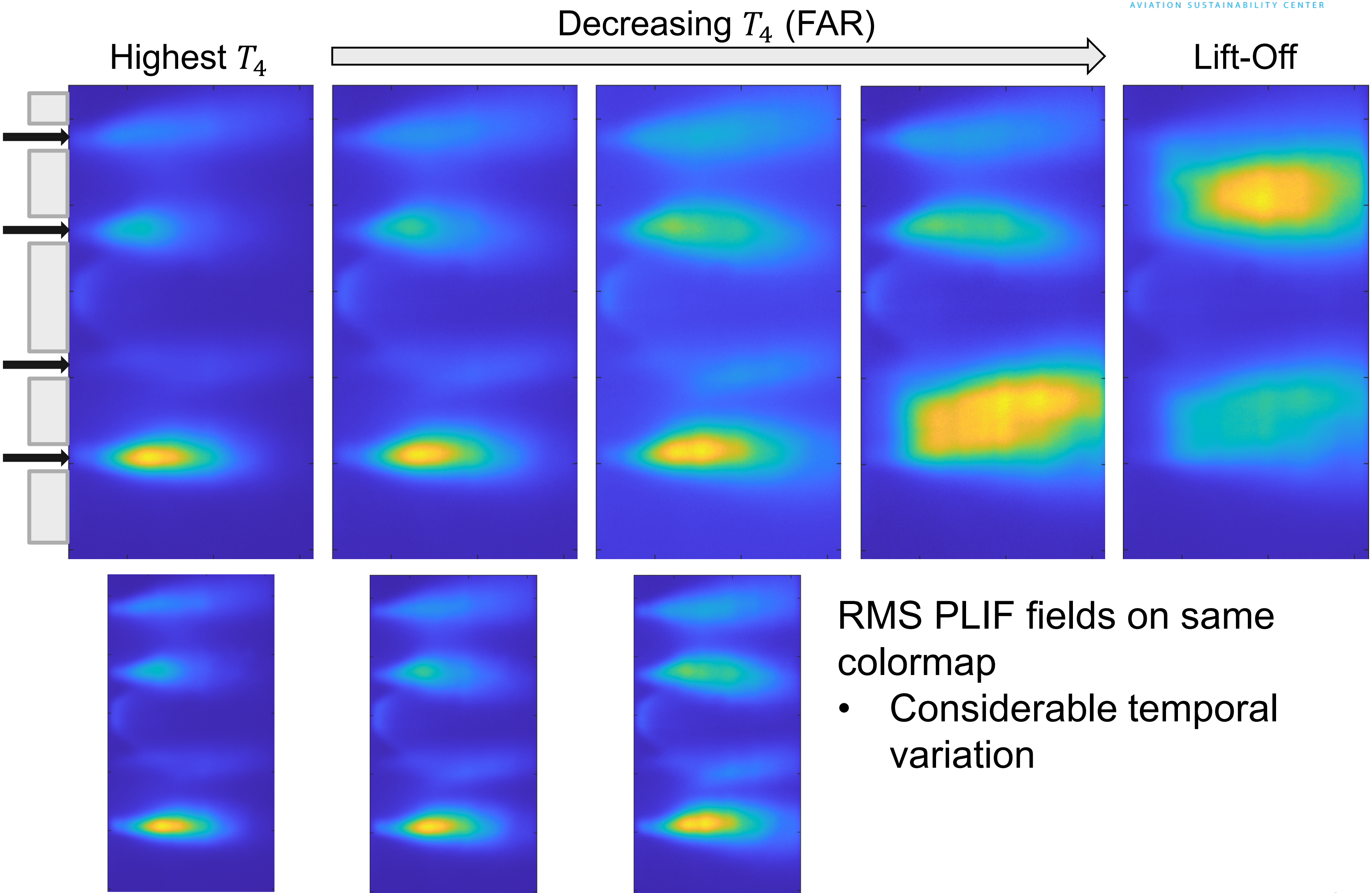
In all data sets, lower flame lifts first (at higher FAR)



O f

(effects of absorp)

Fuel/Air Mixing vs. FAR



RMS PLIF fields on same colormap

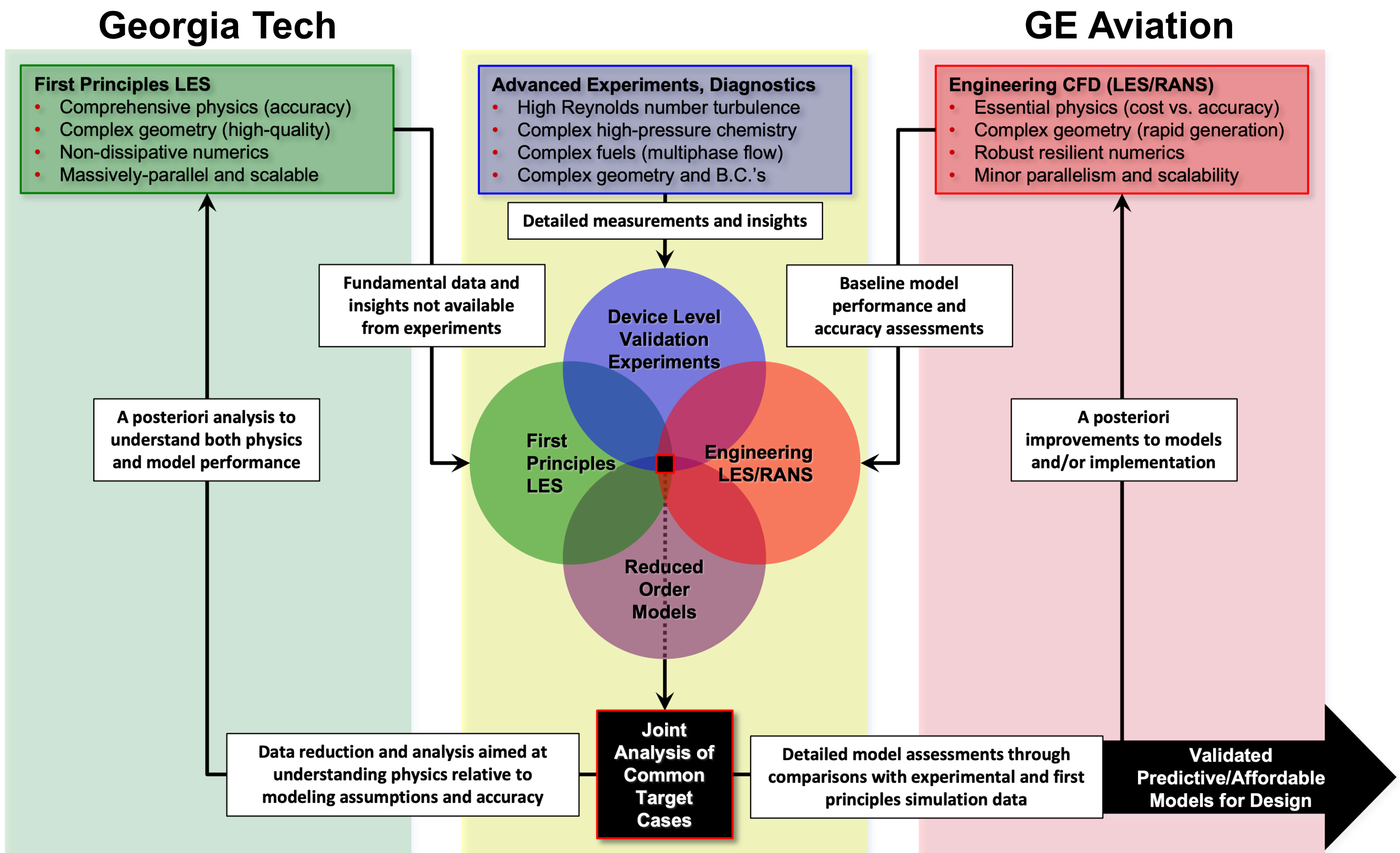
- Considerable temporal variation

Other Experiments Observations

- Mie scatting fields show good vaporization
- PLIF and Mie show potential to improve fuel uniformity
  - Potential of lower emissions and improved stability through more uniform mixing
- LII shows very little nvPM
  - Had to “hunt” for nvPM
  - Very little found (highly intermittent) in downstream region of mains
  - Primary particle size was below the detection limit
    - To be improved for next campaign

LES Overview

It currently is unclear how well industrial standard combustion LES practice, developed for other combustor architectures, works for LPP



Specialized Research Code, Expert User/Developer
Maximum accuracy/fidelity, unique use of high-performance computing

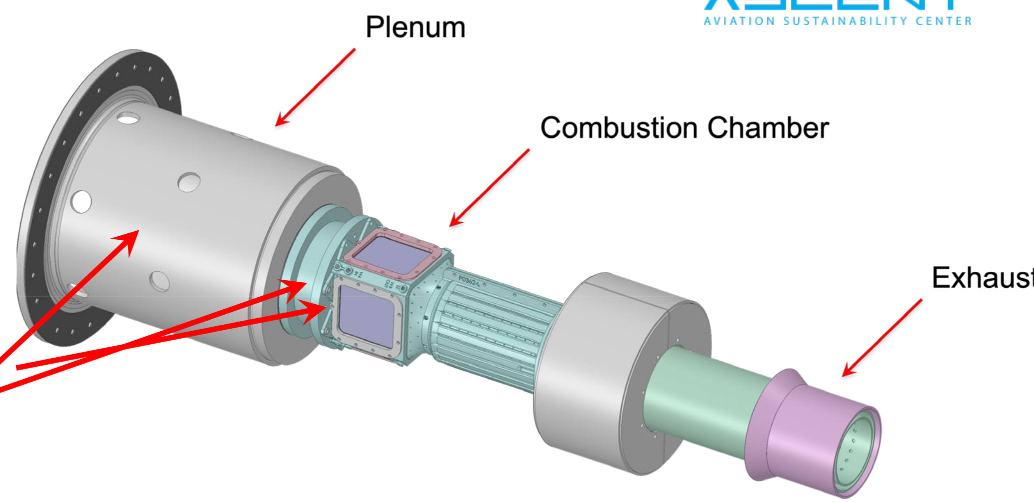
Collaborative Research Interface Links Basic Research to Engineering
Accelerated transfer of knowledge, models, model refinements

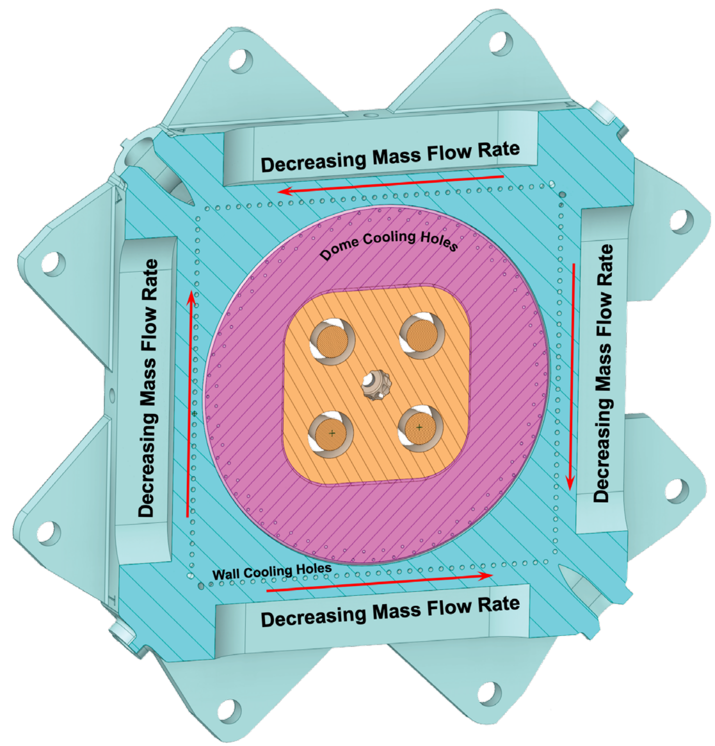
Professionally Supported Design Tool, Broad User Population
Fast solution turn-around, optimal balance between cost and accuracy

Simulation Design and Setup

- Common computational domain used by both GE and GT
  - Include all geometric features of pilot, burner nozzles, wall cooling holes, enclosure walls
  - GE Fluent calculations include both plenum and combustion chamber
  - GT RAPTOR calculations begin at burner inlet (i.e., burner nozzle inlets, etc.)

- Boundary conditions extracted from GE calculations and adapted for GT calculations; i.e., unsteady inflow velocities, temperature, mixture state, liquid fuel spray distribution, etc.



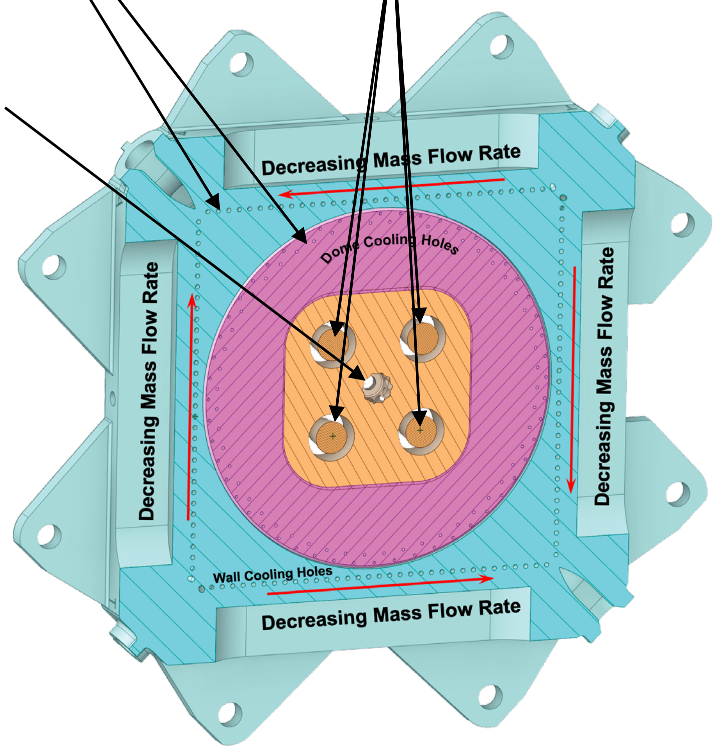


Simulation Design and Setup

Significant airflow through cooling holes that is spatially non-uniform

Partially premixed gas laden with liquid droplets
- Non-uniform within a premixer, between premixers, and in time

Radially swirling air into central liquid fuel jet



- Boundary conditions extracted from GE calculations and adapted for GT calculations; i.e., unsteady inflow velocities, temperature, mixture state, liquid fuel spray distribution, etc.

Treatment of BCs

Nonuniform mean profiles, Reynolds-stresses, and integral-scale distributions extracted

↓

Nonuniform drop-size, temperature, and velocity distributions extracted
(processed to eliminate parcel approximation)

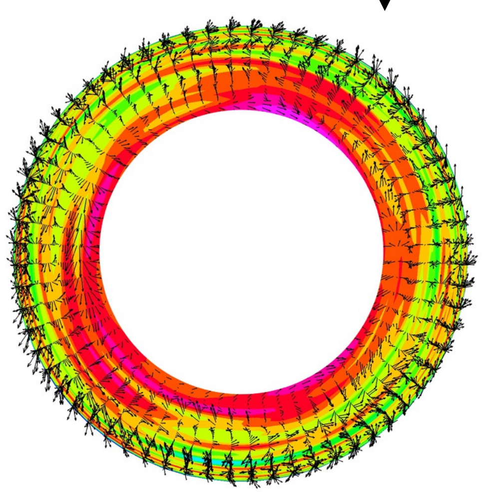
↓

Data parameterized as a function of radial and azimuthal locations across inlet planes

↓

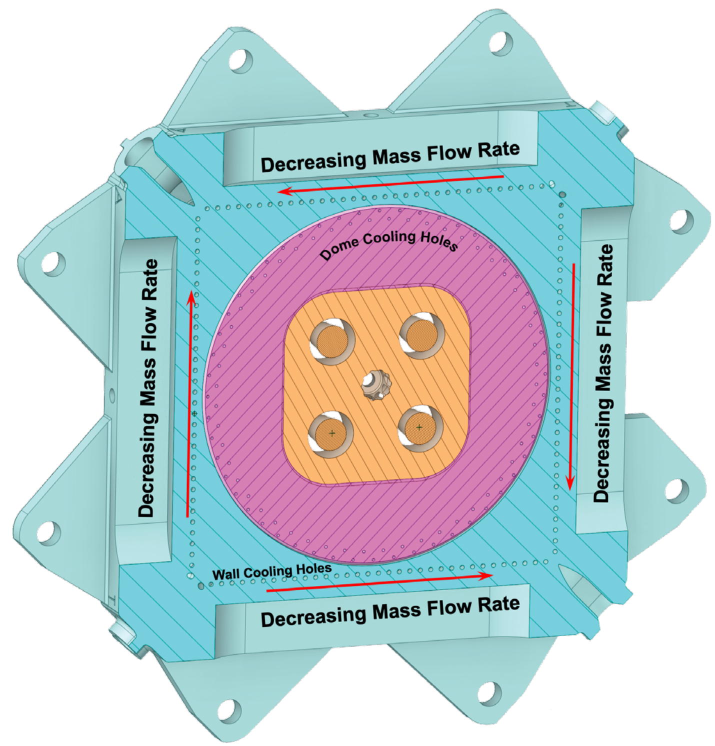
Combined input used to generate correlated time dependent boundary conditions via SEM

↓



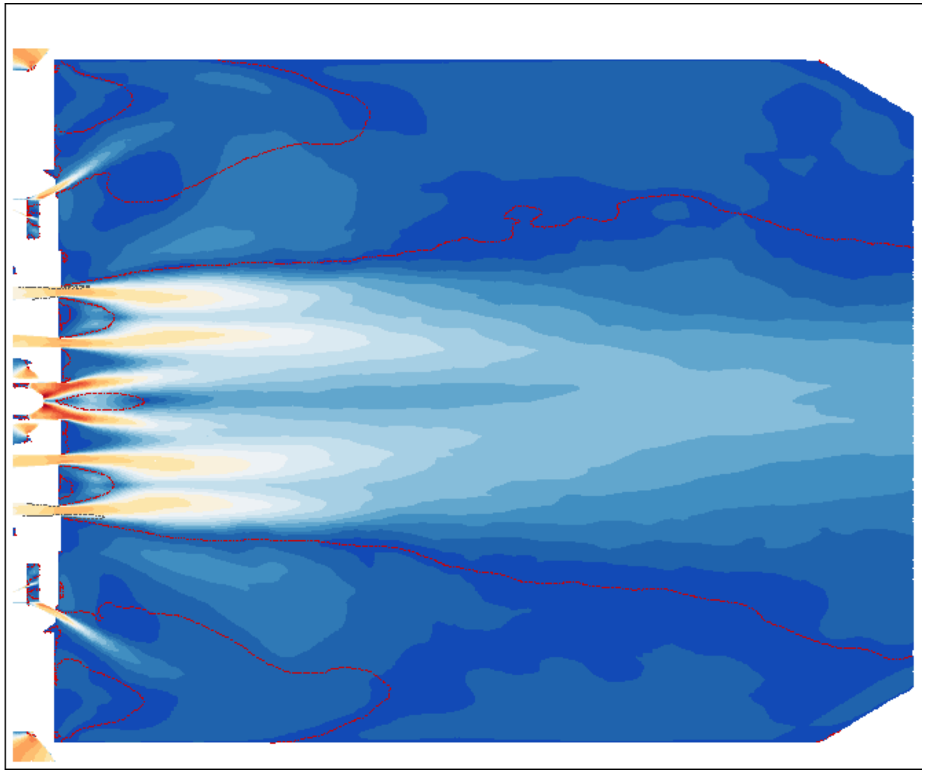
Correlated, fully-coupled, time-evolving, multiphase inflow condition with identical statistics

- Time-evolving turbulent flow dynamics reconstructed using Synthetic Eddy Method (Jarrin et al., 2008)
  - Modified to incorporate compressibility effects
  - Provides time-evolving turbulent inflow conditions that account for nonuniformities in the premixers

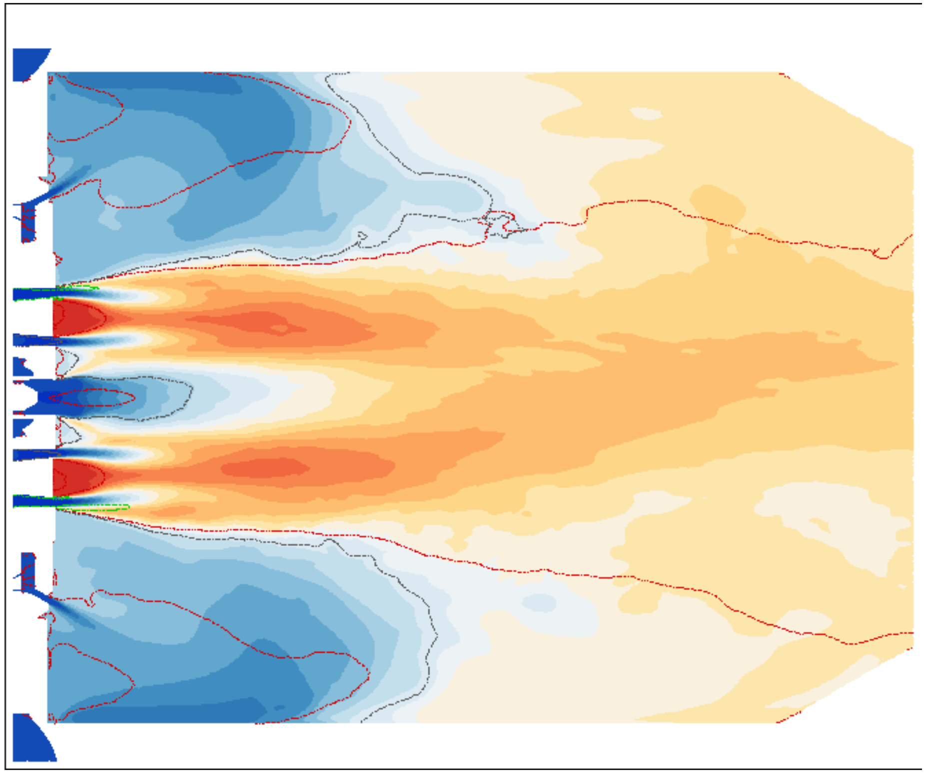


Progression of Model Predictions ...

Velocity



Temperature



- Analysis of sub-model accuracy and performance in a complex geometric environment
  - Turbulent velocity and scalar mixing
  - Turbulent mixed-mode combustion
  - Finite-rate chemical kinetics and combustion instabilities
  - Emissions and soot generation
  - Heat transfer and needs related to wall interactions
  - Best practices for model implementation

Conclusions and Future Work

- Novel CST LPP combustor designed, fabricated, deployed, operated, and measured
- Very encouraging emissions and stability
  - In line with forward-looking objectives
- Optical data helping understand limiting phenomena and guide refinements
- LES workflow complete and simulations running
- Year 2 focuses
  - Understand combustion dynamics
    - Flame transfer functions
    - Thermoacoustic modeling
  - Improved measurements, e.g. reduce LII detection limit
  - Systematic analysis of industrial and first-principles LES