ASCENT Project 74

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

Georgia Institute of Technology & 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, S-PIV
   - Fuel PLIF, 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) Two Experimental Campaigns completed to characterize emissions, lean operability, and thermoacoustic dynamics
   - NOx, CO, UHC
   - Velocity fields, FTFs, phase relationships, sprays
2) Industrial and 1st Principles LES
3) Establish methodology for code-to-code and experimental comparison

Future Work:

1) Complete data analysis, code-to-code comparisons, etc.
2) Execute Campaign 3 experiments and LES, focused on impact of SAF

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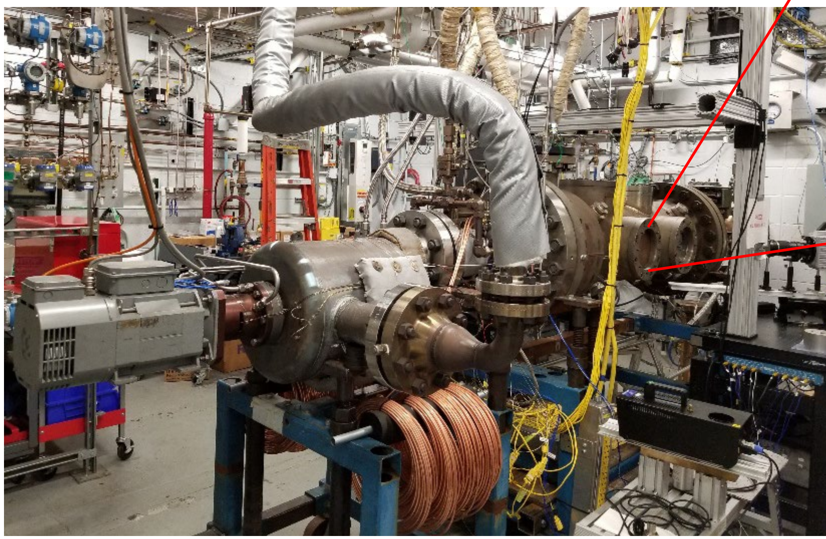
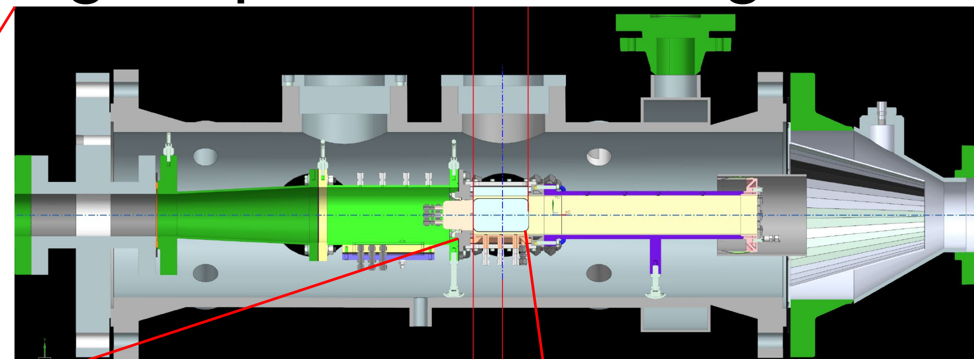
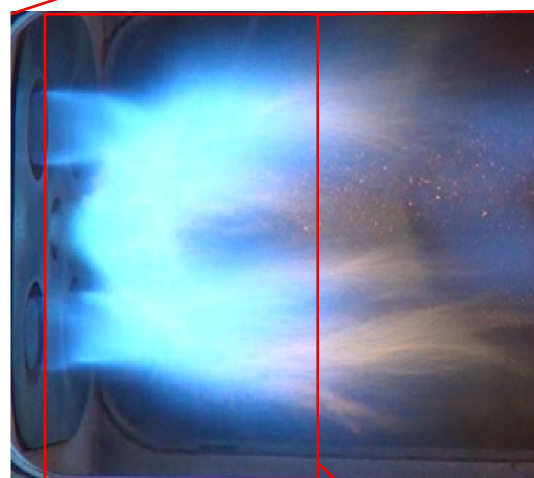
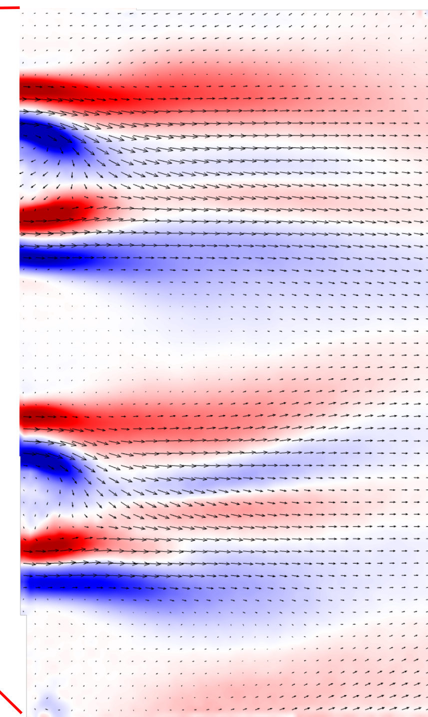
Thermoacoustic Dynamics in LPP Combustor

Physical mechanisms setting response to forcing → prediction and mitigation







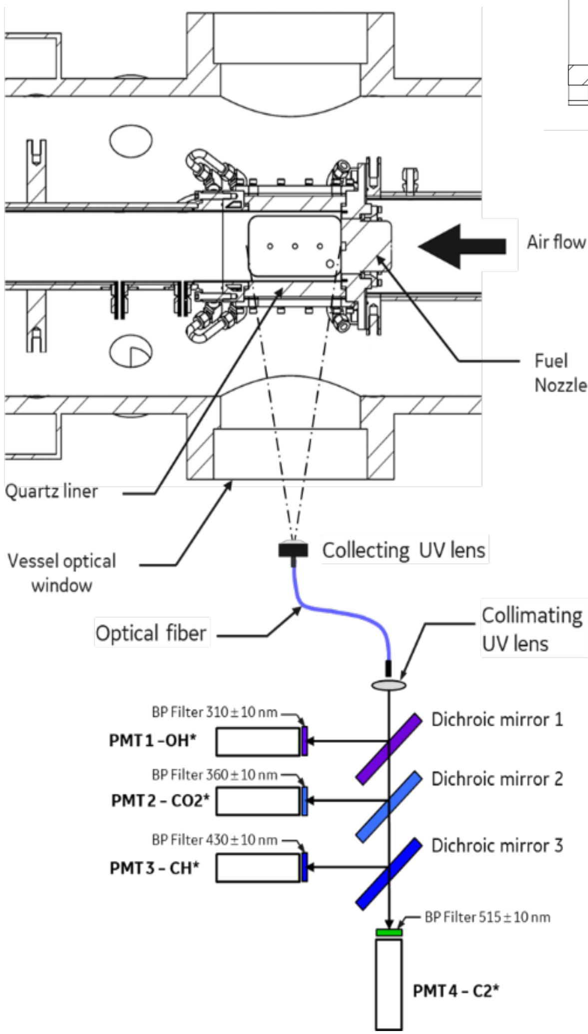


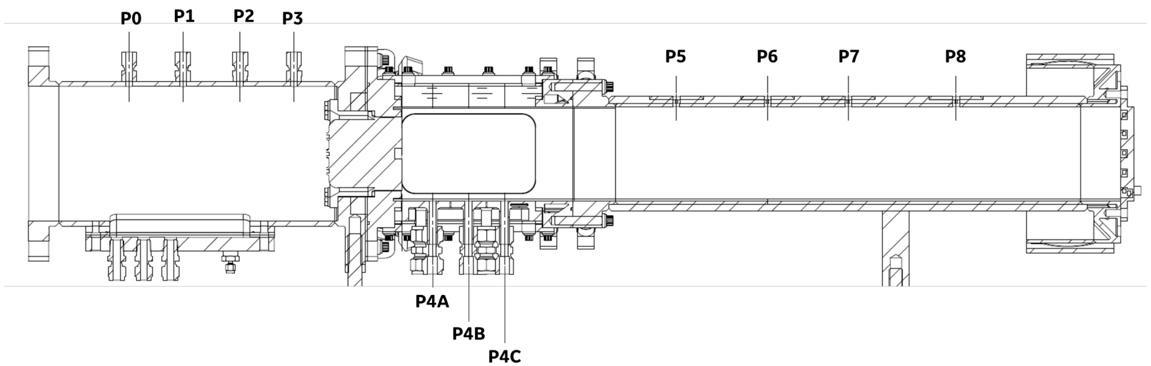
High-speed OH* chemiluminescence
High-speed stereoscopic PIV
High-speed fuel droplet Mie scattering
Fuel vapor PLIF

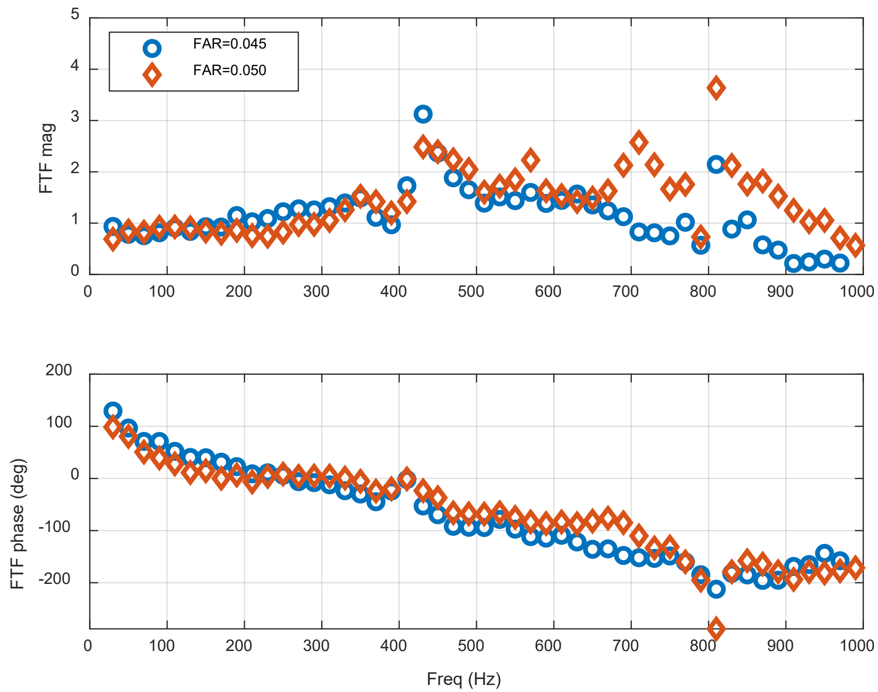
Mean velocity field with out-of-plane vorticity

Thermoacoustics & FTF

- $FTF = \frac{Q'/\bar{Q}}{u'/\bar{u}}$





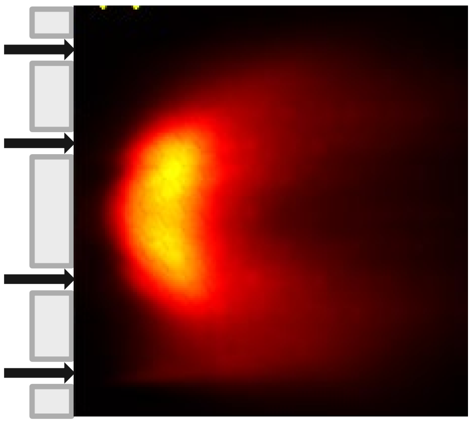


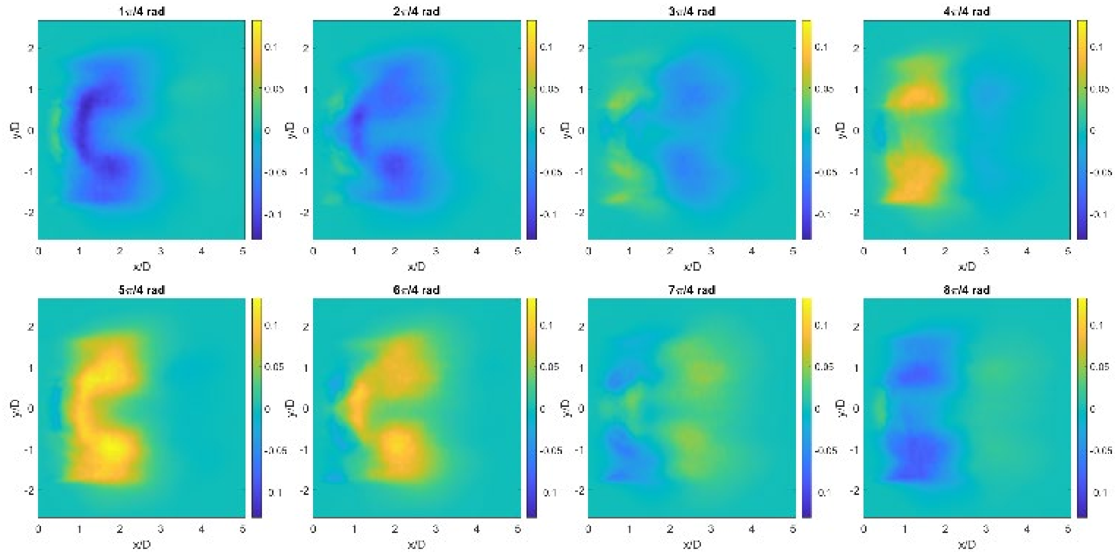
Acoustic method, $p_3 = 7.93$ bar, $T_3 = 560$ K

Flame Analysis (300 Hz Forcing)

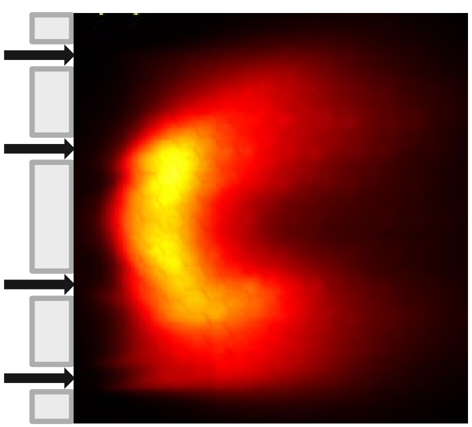
Phase-averaged OH* CL oscillation fields

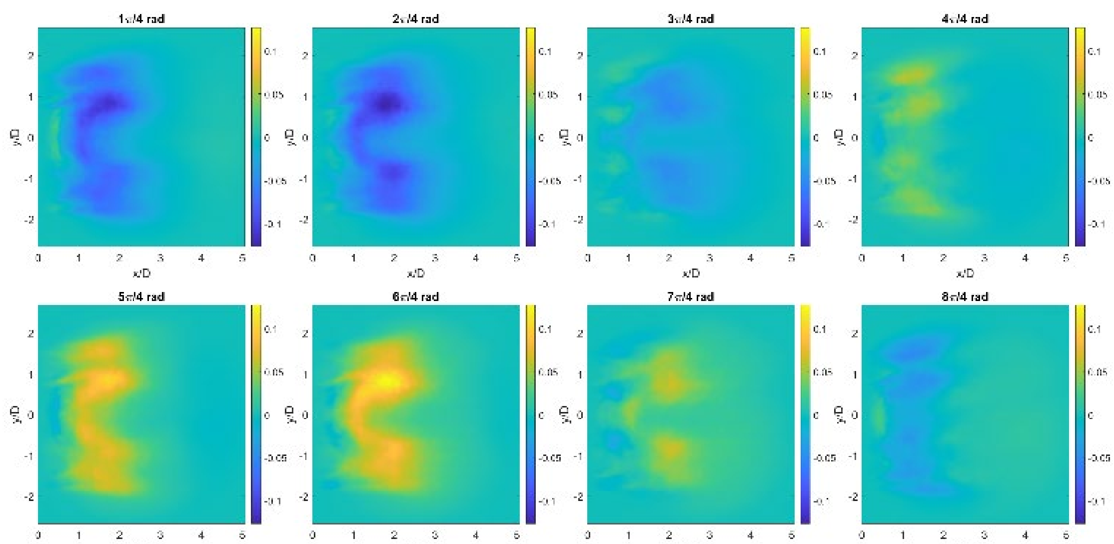
- FAR = 0.045





- FAR = 0.05



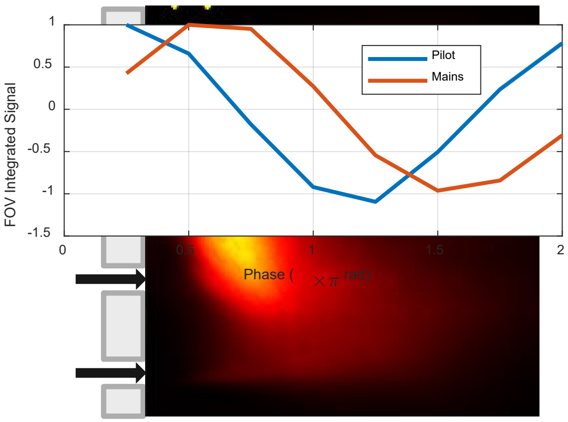


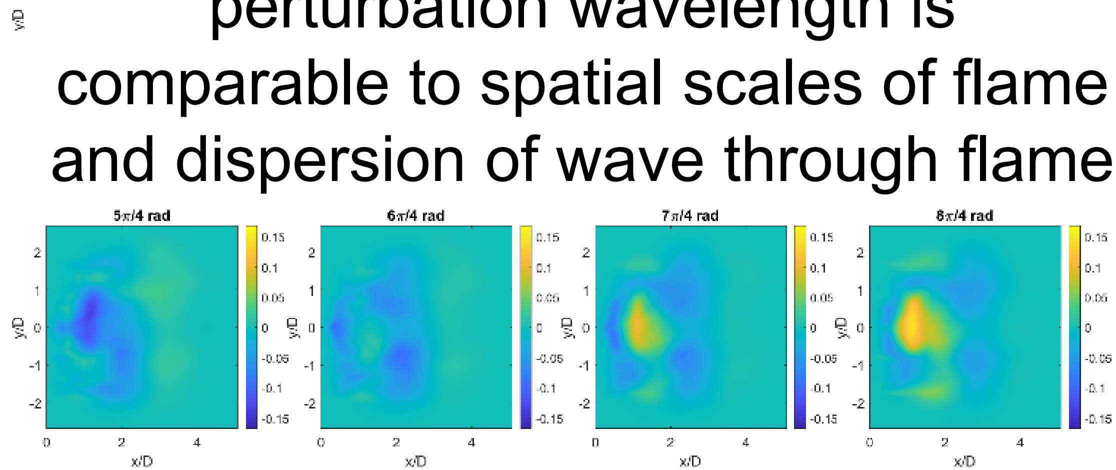
Flame Analysis (900 Hz Forcing)

Phase-averaged OH* CL oscillation fields

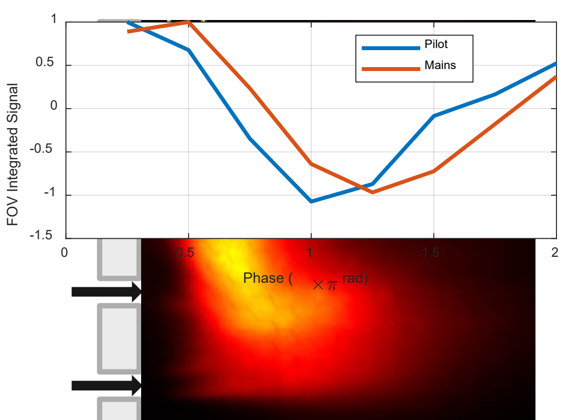
- FAR = 0.045

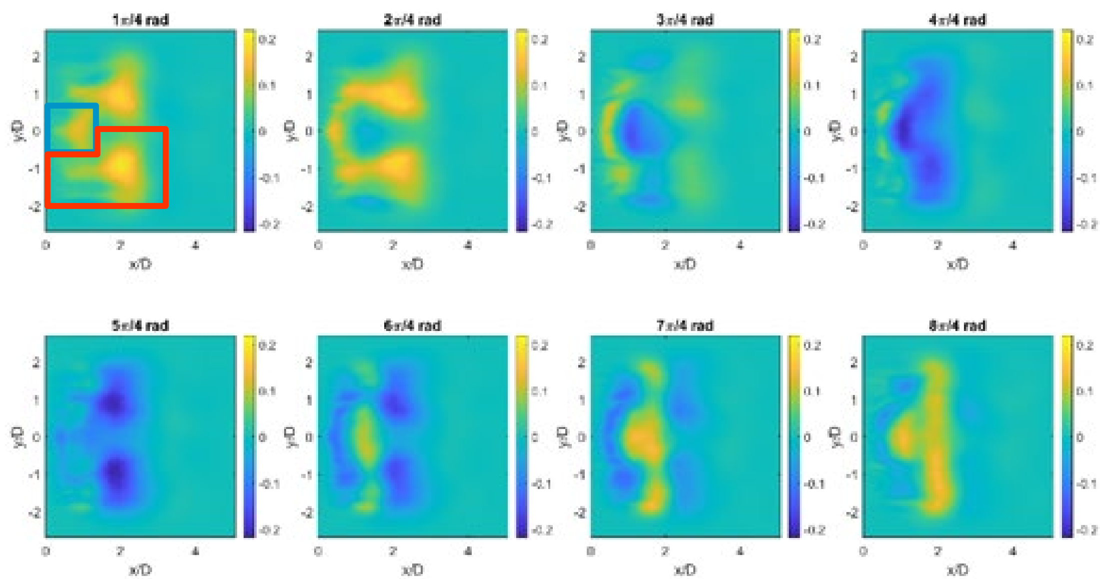
Different phase pattern because perturbation wavelength is comparable to spatial scales of flame and dispersion of wave through flame





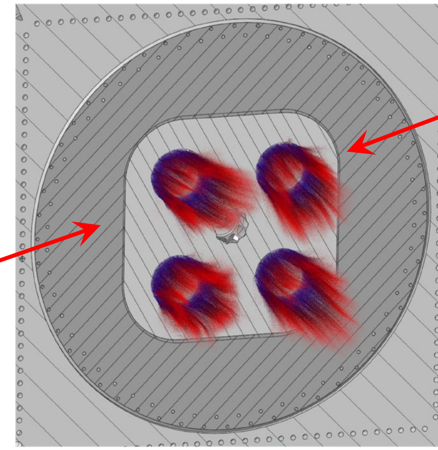
- FAR = 0.05





Questions regarding accuracy of spray models revealed

- Code-to-code comparisons performed with common BC's to assess accuracy of sub-models (e.g., liquid fuel spray dynamics, multiscalar mixing, combustion closure)
  - Parcel approximation (GE) versus tracking physical drops (GT)
  - FPV combustion model (GE) versus finite-rate chemistry (GT)
    - Both codes using HyChem A2NOx_skeletal mechanism (71 species, 1037 reactions)
    - GE via flamelet library, GT via full mechanism
    - GT has interfaced 71 species A2 mechanism with detailed evaluation of gas-liquid EOS, thermodynamics, and transport properties via in-house software capabilities (e.g., fully coupled time-accurate treatment of differential diffusion and gas-liquid interphase exchange processes)
  - Local flame structure, unsteady lift-off, emissions (e.g., Borghi diagram)

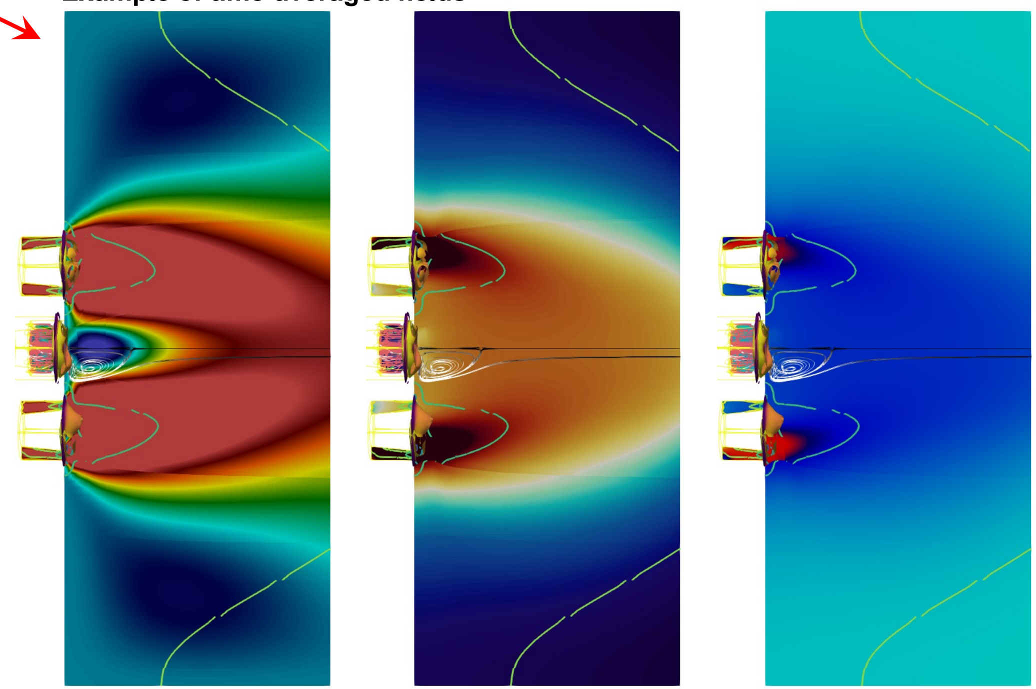


Example of spray distribution via tracking physical drops

Analysis of both mean and instantaneous fields provide systematic assessments regarding the validity of key modeling assumptions

Goal: Provide quantitative assessments required to reduce calculation cost while maintaining accuracy

Example of time-averaged fields



Current focus on liquid fuel spray dynamics

Goal is to understand discrepancies between GE CFD and experimental imaging
Challenges include accounting for secondary breakup and dilute spray dynamics

1. Primary atomization (sheet, filament and lattice formation)

2. Secondary breakup (including particle deformation, coalescence)

3. Dilute spray dynamics

a. Drop dispersion
b. Multicomponent drop vaporization
c. Two-way coupling between gas and dispersed liquid phase
  − Turbulence modulation (damping of turbulence due to particle drag effects)
  − Turbulence generation (production of turbulence due to particle wakes)

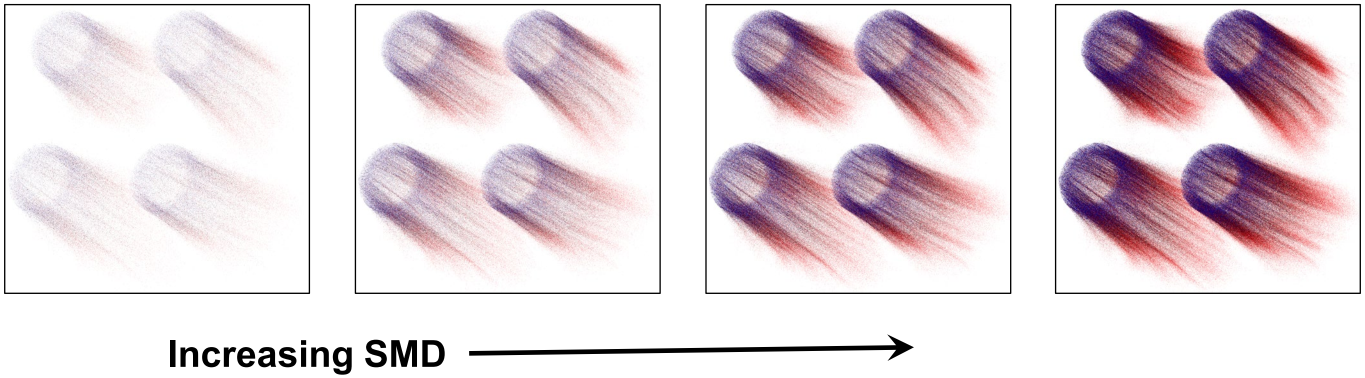
A new dense spray formulation based on space-time filtering has been implemented

Current focus is on advanced treatment of secondary breakup and dilute spray dynamics

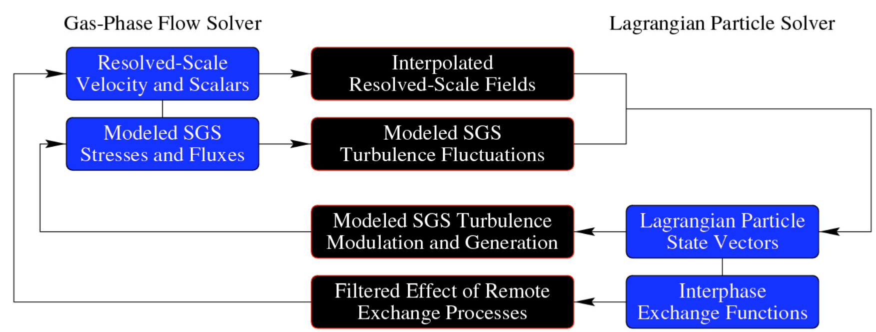
4. Turbulent mixed-mode combustion

a. Complex high-pressure hydrocarbon chemistry
b. Emissions and soot

First-principles spray model employed to evaluate accuracy of parcel method

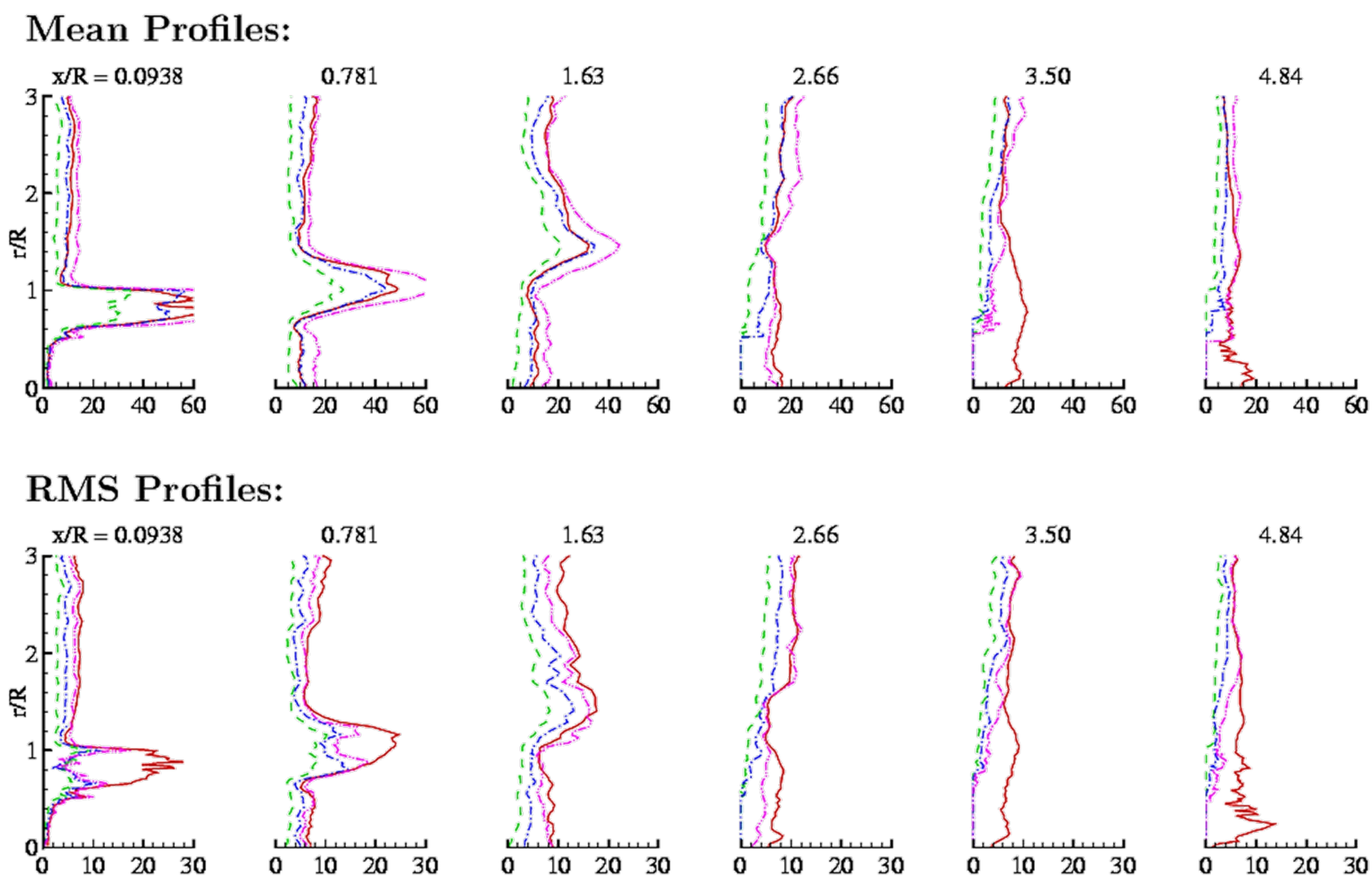


- **Instantaneous particle motion tracked in Lagrangian frame as succession of SGS eddies traversed**
  - Decompositions of the form $u_p(x,t) = U_p(x,t) + u_p''(x,t)$ reconstructed
  - Correlated fluctuations generated stochastically
  - Stochastic intervals coincident with particle-eddy interaction time
- **Particles interact with eddies for time taken as smaller of eddy lifetime or transit time**
- **Refined (high-fidelity) distribution (e.g., particle dispersion, vaporization, energy exchange) reduced to equivalent distribution of parcels, then compared to GE model predictions**



GT results used to assess and calibrate parcel method in GE code

e.g., Drop Reynolds Number distribution



[1] ○ All Classes; □ $d_p = 30 \pm 5\ \mu m$; ◇ $d_p = 45 \pm 5\ \mu m$; △ $d_p = 60 \pm 5\ \mu m$.

Conclusions

- Experimental Campaign #2 articulated dynamic response of combustor to acoustic forcing across a wide range of conditions
  - FTFs
  - Physical understanding setting response to acoustics
- Data are providing insights regarding in-combustor processes affecting flame responses
  - Potential to inform mitigation
- LES helping to establish good practice for affordable simulations, including spray modeling
- Experimental Campaign #3 and LES will demonstrate the influence of SAF on LPP emissions and operability