Project 28a

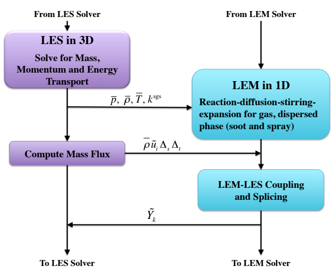
Spray-Turbulence-Chemistry Closure in LES to Account for Fuel Sensitivity

Motivation and Objectives

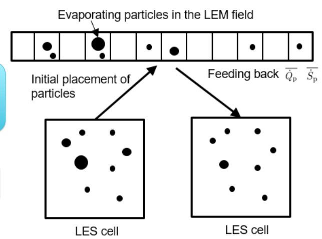
High pressure and lean operating conditions required for higher efficiencies and lower emissions, however, they lead to undesirable combustion dynamics

1. Establish a new multi-scale **subgrid model** for three-phase reacting flows (gas, liquid droplets, soot)
2. Demonstrate ability to predict **fuel sensitivity** on for **stable and LBO conditions** under NJFCP
3. Demonstrate predictive capability for cold restart and altitude relight, and validate against NJFCP data

Two Phase Subgrid Model Development

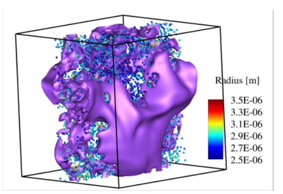


LEMLES Flowchart

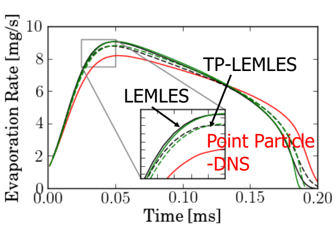


Two Phase (TP) LEMLES

- Evaporation and mixing of droplets directly interact with the gas phase subgrid reaction and mixing
- Modifications to the established LEMLES including a new UDF based subgrid model for use in other codes.



Autoignition of heptane spray in decaying isotropic turbulence



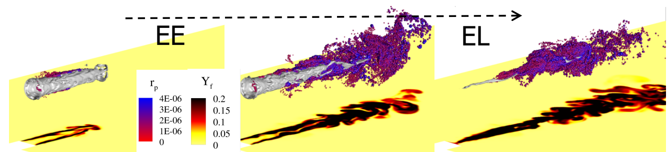
Summary

Final objective: Establish predictive capabilities to evaluate fuel sensitivities at relevant operating conditions focusing on LBO, cold restart, and altitude relight. Develop a subgrid closure for such predictions

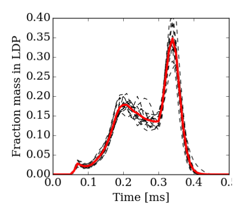
Challenges: multi-scale, multi-mode burning, multi-phase physics, finite-rate detailed/reduced kinetics, break-up and dense-dilute transition, computational cost

Hybrid EE-EL for Dense-to-Dilute transition

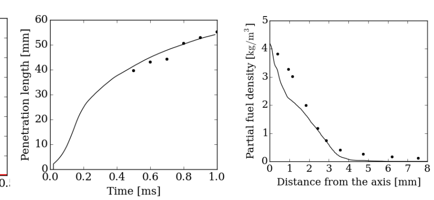
- Dynamic transition strategy between Eulerian-Eulerian (EE) and Eulerian-Lagrangian (EL) for spray combustion
- EE saves computational cost in the dense, EL more accurate in dilute. Hybrid approach more physical.
- Extension towards interface resolved EE simulations in the dense regimes to be addressed in future



Iso-surfaces of volume fraction shown in gray and EL droplets represented as spheres colored by their radii



Fractional EL mass



Comparison with Experiments

- Validation against experimental evaporating spray jet
- Extent of EE to EL transition can be modified by changing the transition volume fraction

Lead investigator: S. Menon, Georgia Tech
Research Team: A. Panchal, R. Ranjan, P. Milan
Project managers: Aniel Jardines, FAA; Jeff Moder, NASA

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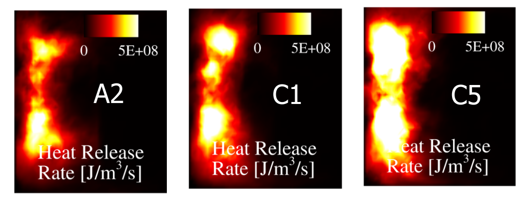
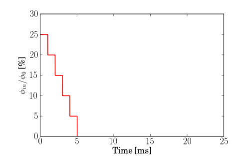
NJFCP rig: LES of Stable and LBO comb.

- **LESLIE**: Multi-block finite volume compressible multi-species and multiphase flow solver
- Finite rate kinetics: A2 (29 species, 185 steps), C1 (27 species, 185 steps), C5 (29 species, 210 steps)

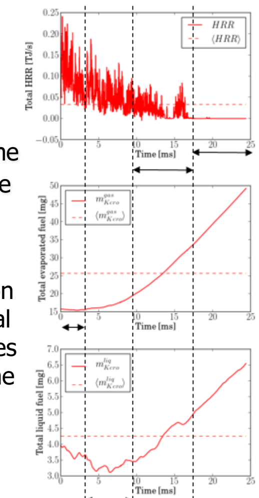


Four stages for Numerical LBO

- (0-3 ms) Quasi-stable regime
- (3-9 ms) Reduced burning regime
- (9-17 ms) Unstable flame regime
- (> 17 ms) Completion of LBO



Stepwise reduction in the fuel flow rate



Evolution of global quantities with time

Conclusions

- Detailed analysis of hybrid EE-EL for evaporating sprays
- Initial studies for two phase Subgrid LEM closure
- LES of NJFCP rig at stable and LBO conditions

Next Steps

- Continuation of two-phase subgrid model development
- Comparison of NJFCP LES predictions with experiments
- Application of the two phase subgrid model to test rigs

[1]A. Panchall et al., AIAA-2016-4694.
[2]R. Ranjan et al., AIAA-2016-4895.
[3]A. Panchal et al., 10th U.S. National Combustion Meeting, 2017.

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