

Western States Section of the Combustion Institute (WSSI) Fall Meeting

10/02/2017, Laramie, WY

Model Sensitivities in LES Predictions of Buoyant Methane Fire Plumes

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Challenges in the Fire Modeling

- .. as discussed in MaCFP Workshop (Measurement and Computation of Fire Phenomena), 2017
- Slow, buoyancy driven flow
- Flame extinction / re-ignition
- Complex solid fuel sources
- Soot
- Radiation-turbulence interactions
- etc.

Fire Plume / Pool Fire

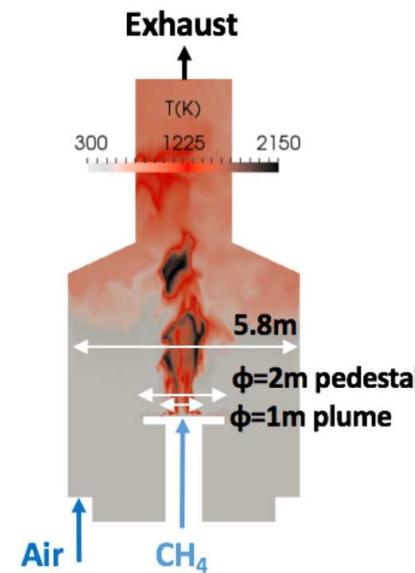
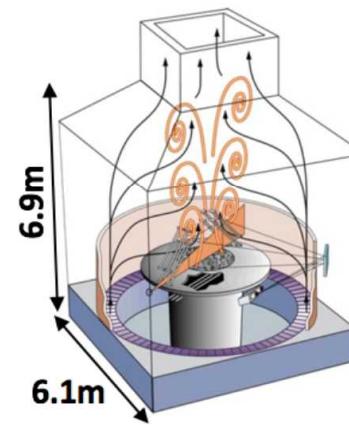
- A representative fire scenario
 - Natural fires, industrial accident, leaked fuel, etc.
 - Huge environmental impact; a great danger
 - Addresses some of the major modeling challenges
 - Currently being heavily studied



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FLAME Experimental Facility

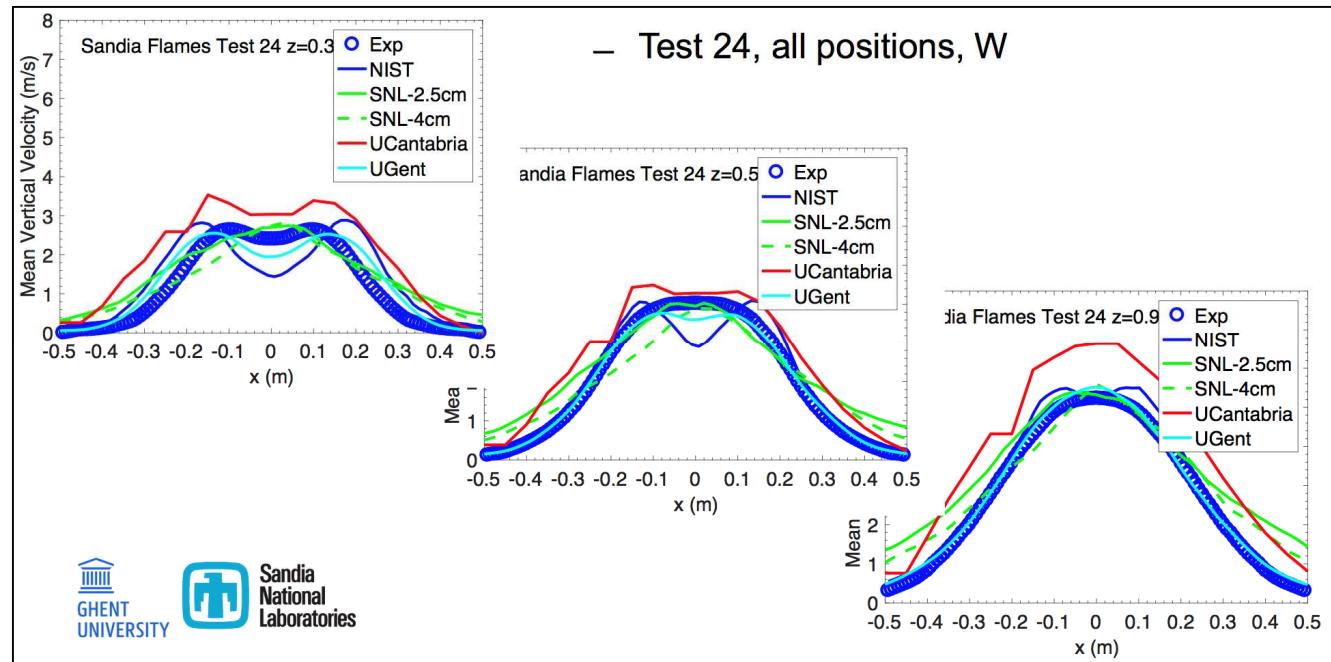
- FLAME (the Fire Laboratory for Accreditation of Models by Experimentation)
 - High-fidelity, large-scale, controlled, indoor facility for pool fire / fire plume
 - Various gaseous and liquid fuels were tested
 - Laser diagnostics (PIV, PLIF), heat flux gauges, CARS devices were added
- Current study focuses on CH_4 fire plume case
 - PIV data is available



Model Uncertainties

- The configuration has been studied well
 - It was one of the target experiments in the MaCFP workshop
 - Some results match well to the experiment
- However, prediction is largely affected by several modeling choices

Results from several research groups were presented at MaCFP 2017 workshop:



Objectives

- Understand model sensitivities of the methane fire plume
- List of model choices
 - Geometry details
 - LES sub-filter and turbulent-combustion model
 - Mesh resolution

Numerical Tools

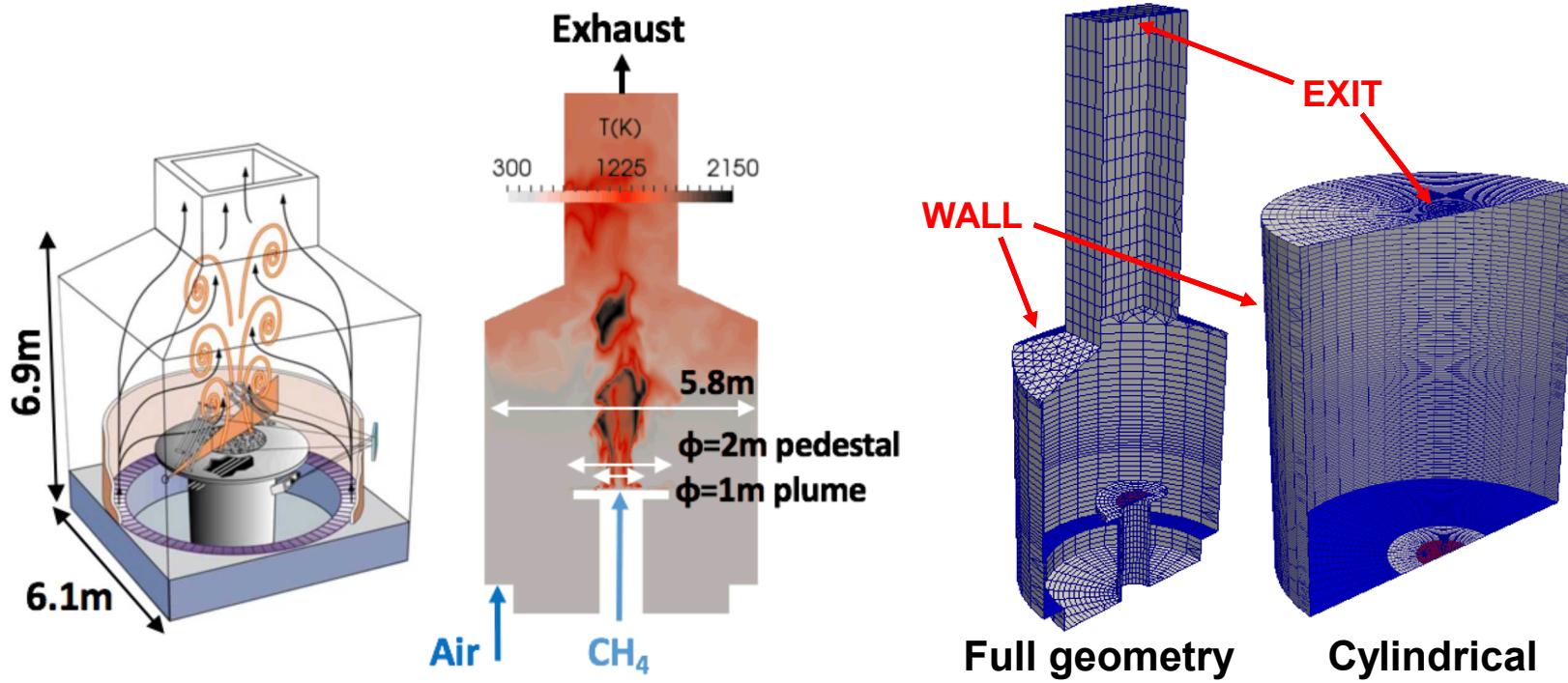
- SIERRA: Sandia's engineering mechanics simulation code suite
 - Fuego: low-Ma reacting turbulent flow solver
- LES subfilter models
 - Smagorinsky $\mu_t = \rho (C_s \Delta)^2 |\tilde{S}|$
 - One-equation $\mu_t = \rho C_\mu \Delta k^{sgs \frac{1}{2}}$
- Closure for chemical source
 - EDC with fast chemistry
 - Radiation heat flux added through radiation transport equation
 - Steady Flamelet

Domain Sensitivity

- To verify the effect of omitting geometry details

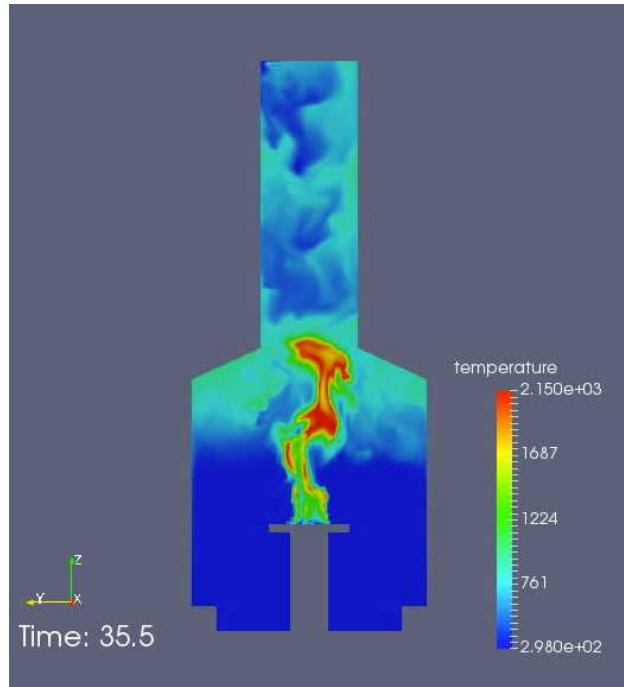
Domain shape	Total elements	Mesh size near plume	Air velocity	Fuel velocity
Full geometry	1.7M	2.5cm	0.33	0.097
Cylindrical	0.23M	4cm	0.14	0.097
Cylindrical	1.6M	2cm	0.14	0.097
Cylindrical	7.0M	1cm	0.14	0.097

(Equivalence ratio: 0.25)

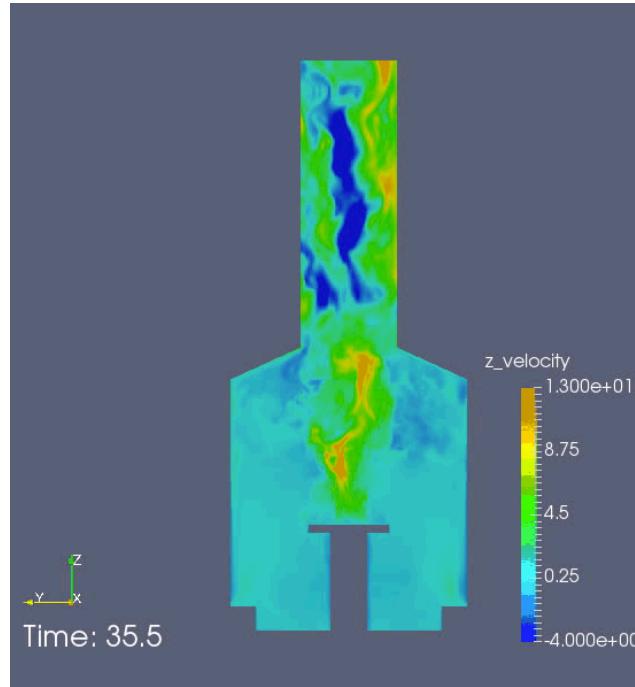


Domain Sensitivity

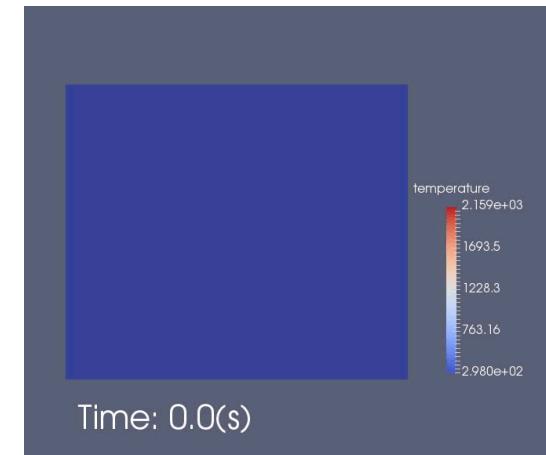
- Plume of the full geometry case shows strong interaction with surrounding walls



Temperature



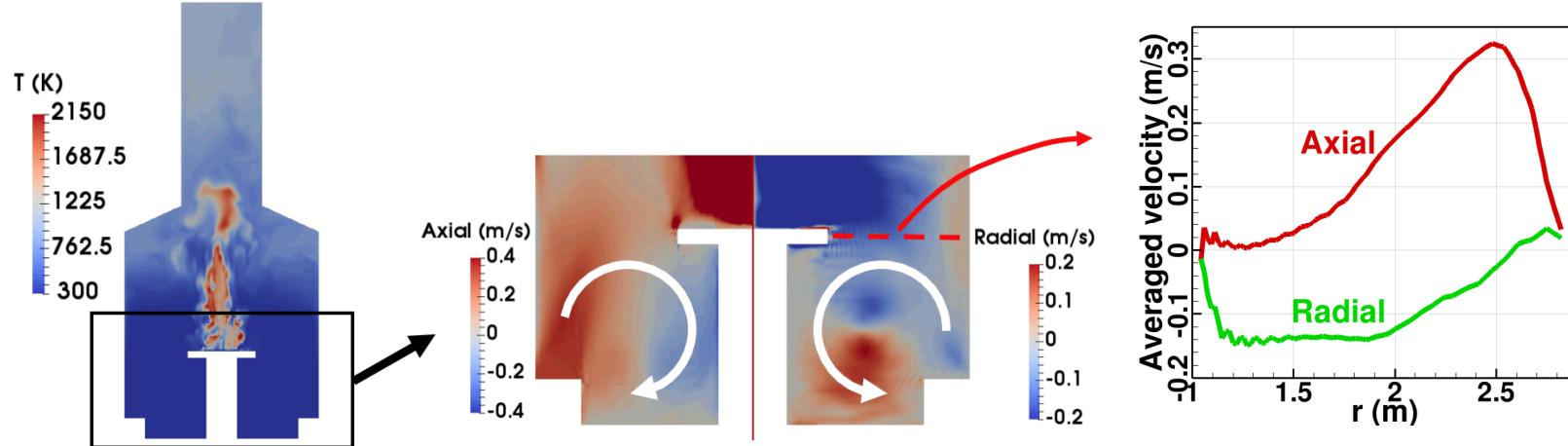
Axial velocity



Temperature

Domain Sensitivity

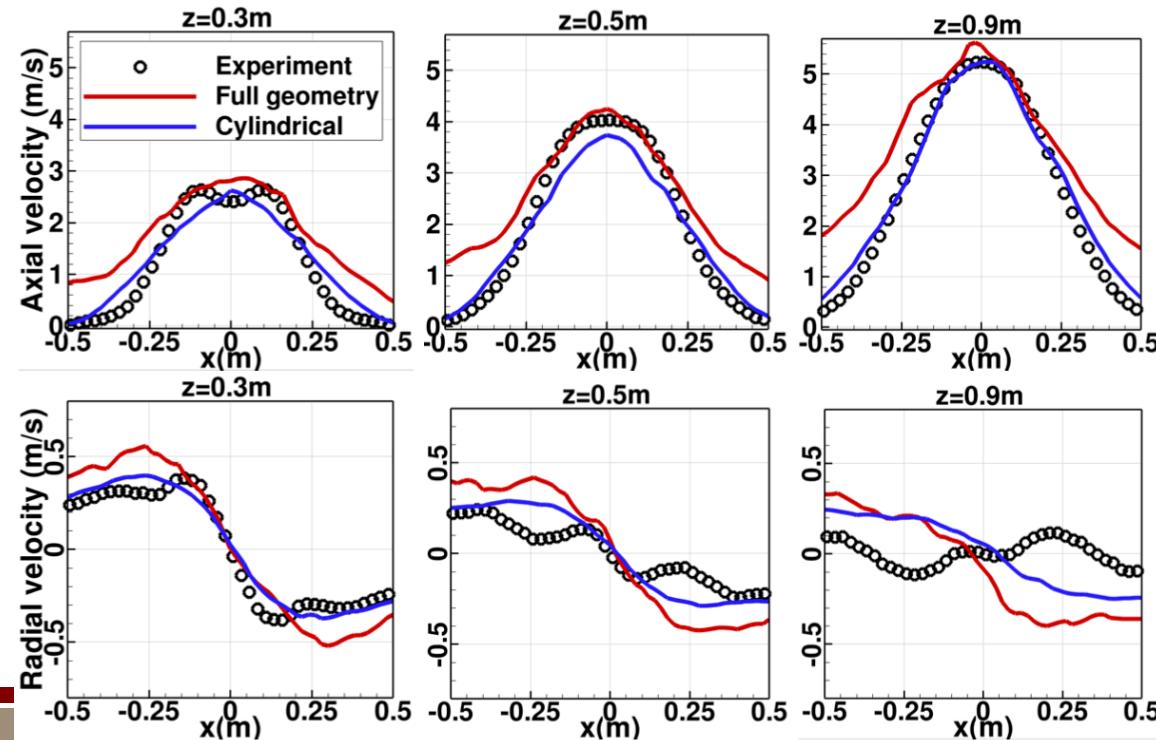
- Plume of the full geometry case shows strong interaction with surrounding walls
- Recirculation develops below the pool



Domain Sensitivity

- Plume of the full geometry case shows strong interaction with surrounding walls
- Recirculation develops below the pool
- Full geometry shows stronger external turbulent fluctuations and entrainment

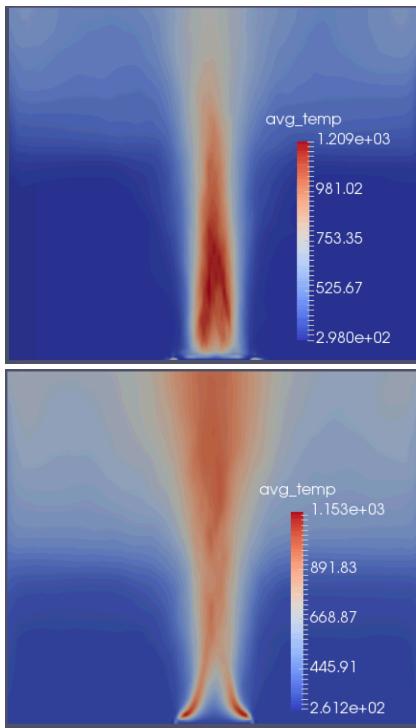
Axial and radial velocity between full geometry (1.7M) and cylindrical (0.23M) meshes



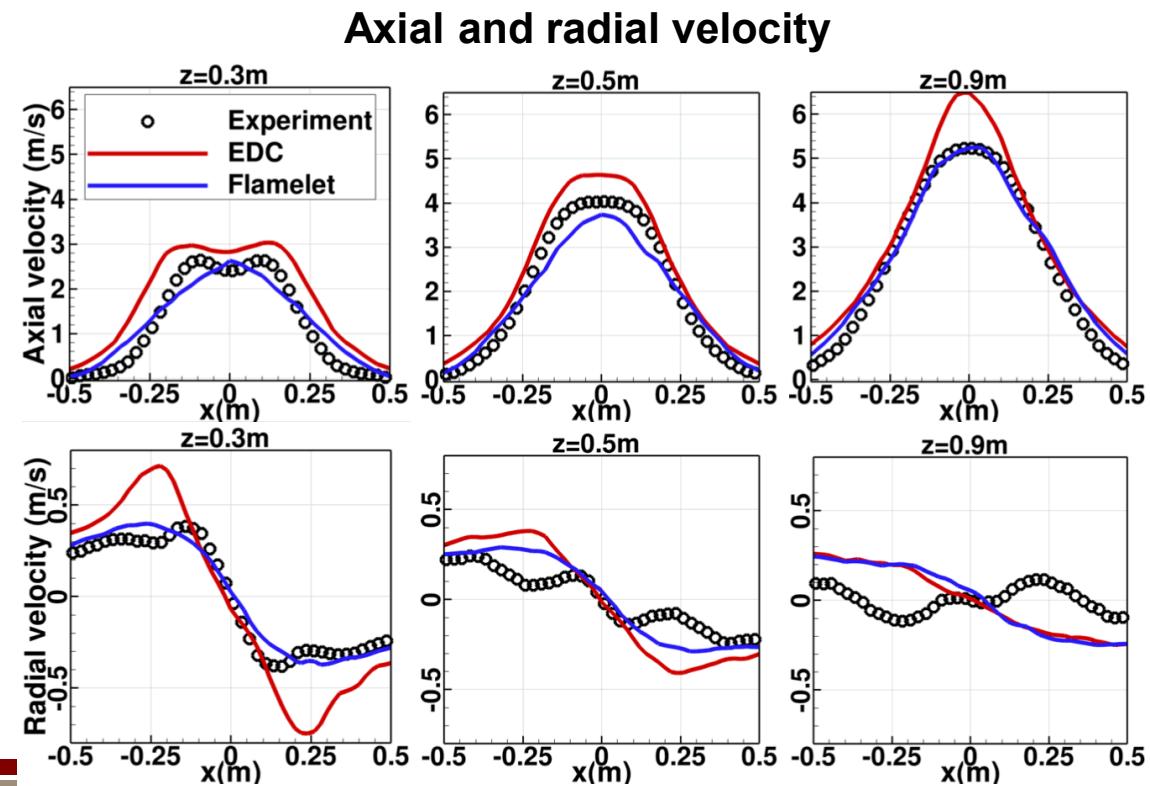
Combustion Model

- Steady flamelet vs. EDC with fast chemistry
 - Adequate models for mixing-limited flames
- EDC narrows jet; leads to greater buoyant forcing
 - EDC predicts continuous reaction zone from the plume edge

$\langle T \rangle$
Flamelet
(0.23M)



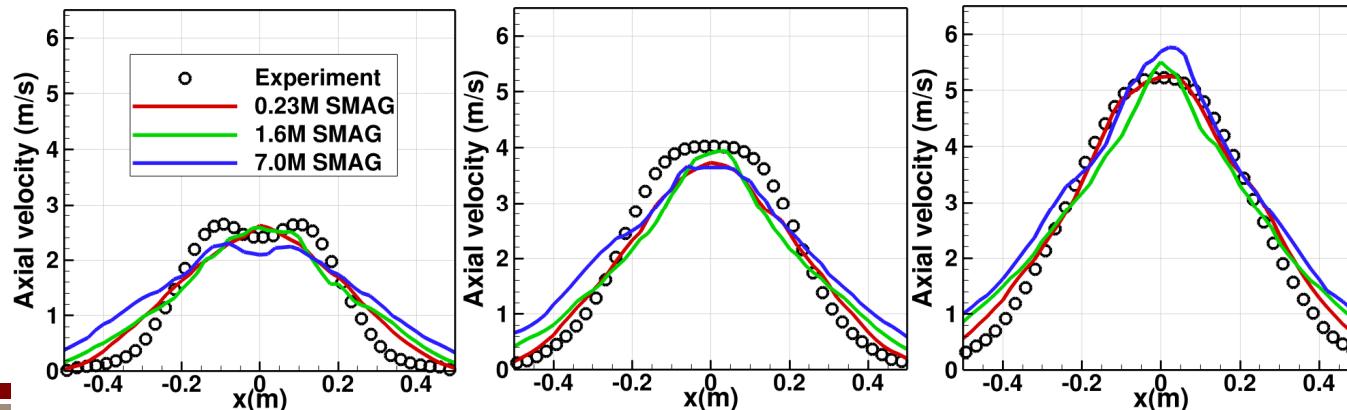
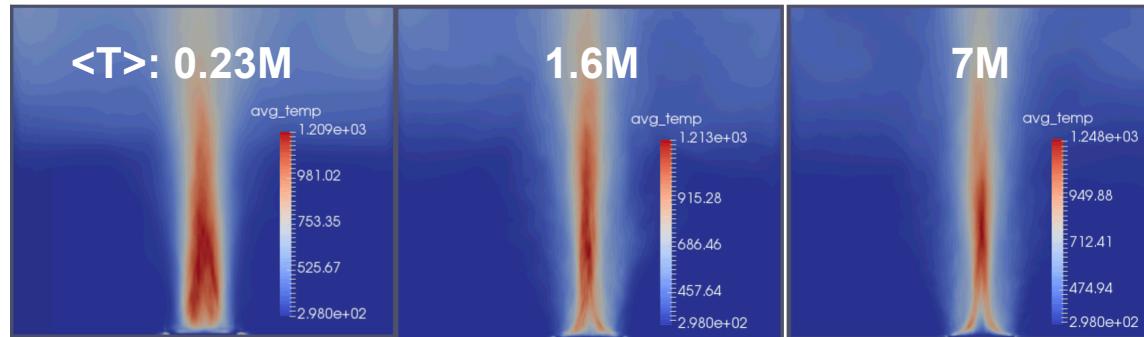
EDC
(0.23M)



Mesh Resolution Study

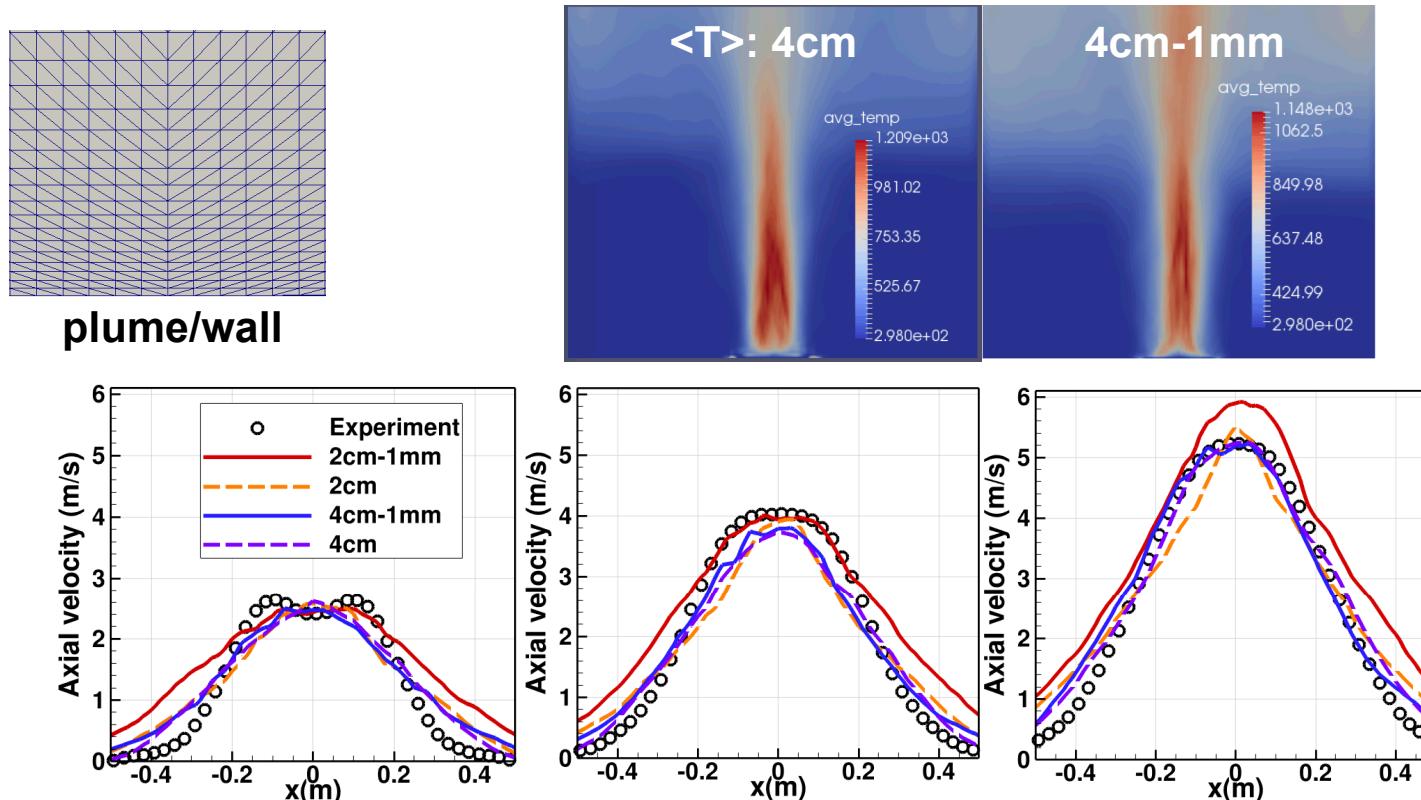
- 1. Control cell size in all directions (4, 2, or 1cm)
 - Mesh refinement does not improve statistics

Domain shape	Total elements	Mesh size near plume	Air velocity	Fuel velocity
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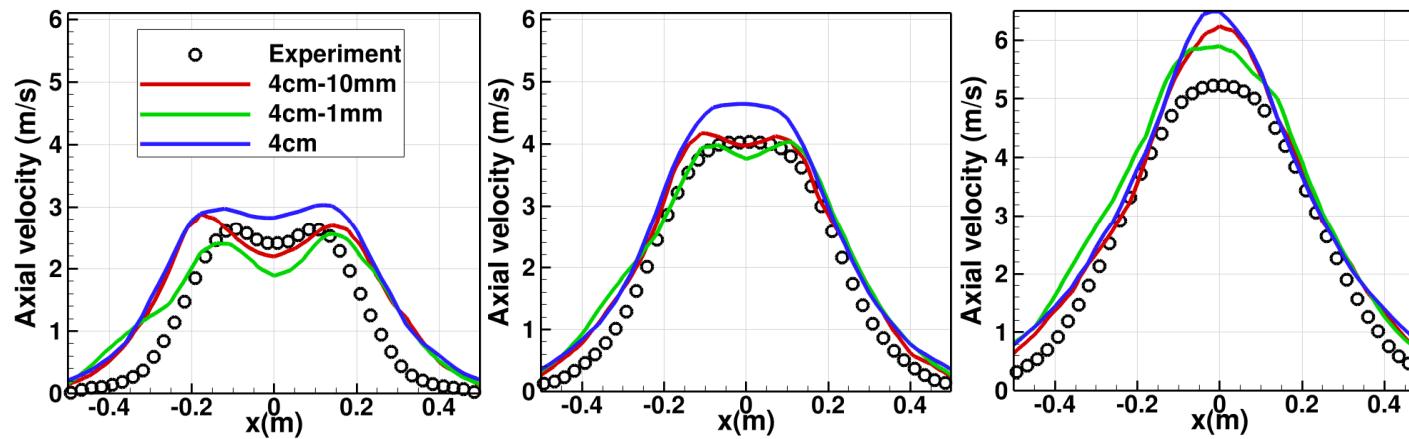
Mesh Resolution Study

- 2. Resolve wall
 - Mesh clustered toward wall, with the smallest mesh size of 1mm or 1cm
 - Smagorinsky-Flamelet: 2cm vs 2cm-1mm, 4cm vs 4cm-1mm
 - Catches continuous reaction zone once directionally resolved (4cm-1mm)

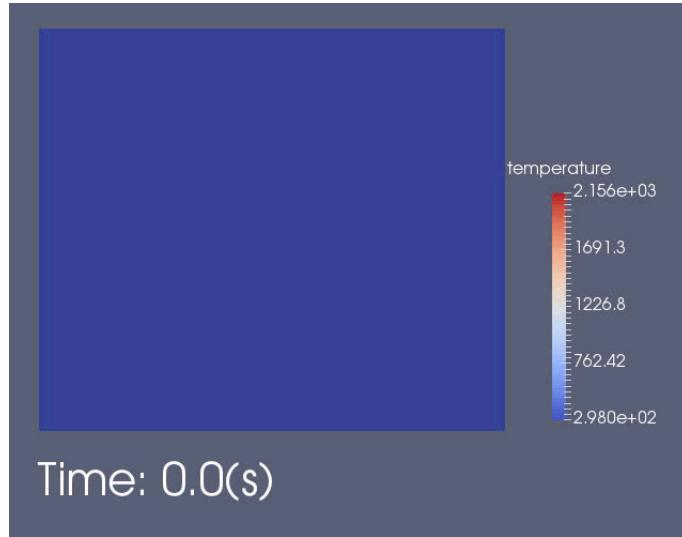


Mesh Resolution Study

- 2. Resolve wall
 - EDC result improves with refined mesh



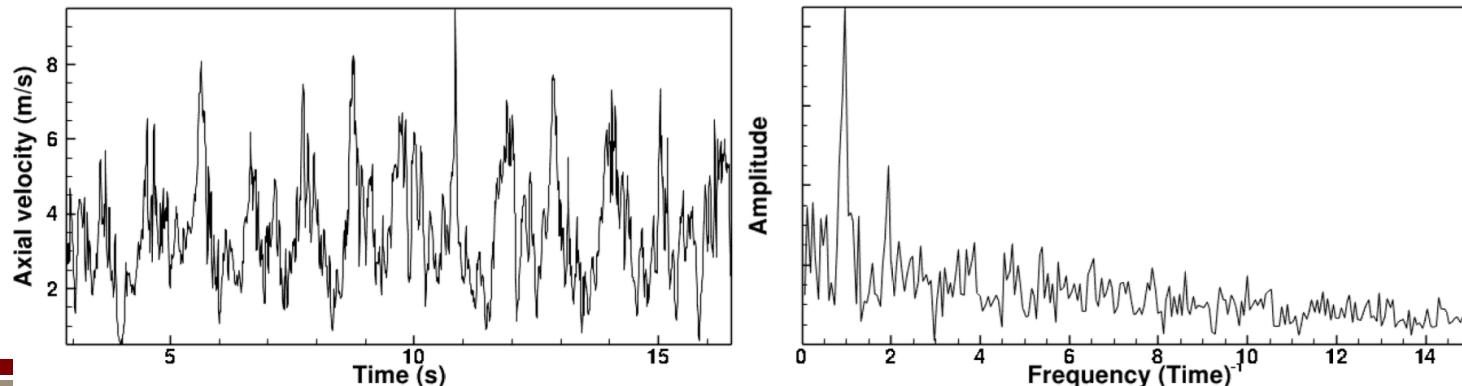
Puffing Frequency



- Resolved mesh better predicts puffing frequency (theoretical value ~ 1.5 Hz)

	Puffing frequency (Hz)
4cm flamelet	0.6 (not resolved), 0.8 (wall resolved)
2cm flamelet	0.9 (not resolved), 1.0 (wall resolved)
1cm flamelet	1.1
4cm EDC	1.5 (not resolved), 0.8 (wall resolved)

Velocity at $z=0.5\text{m}$ location along the centerline, with FFT of the data



Conclusion

- Various LES were performed to understand model sensitivity of buoyant methane fire plume
- While coflow velocity profile may vary, geometry details are not critical
 - Excessive flow entrainment and turbulent strength were predicted with when full geometry details were included
- EDC predicts continuous reaction zones from the plume edge with lower resolution
 - However, after certain height, flamelet predicts better statistics
- Higher mesh resolution does not guarantee better results
 - Stronger flow entrainment is predicted as mesh resolution increases
 - In general, plume puffing frequency improves with better mesh
- Further assessment of uncertainties is required

LES Subfilter Model

