Water Mist-Based Fire Suppression Modelling of an Office Space Scenario

Hai Jiang, Vaidya Sankaran, Med Colket, May Corn
United Technologies Research Center

Kati Laakkonen
Marioff Corporation

14th International Water Mist Conference, Istanbul, Turkey
October 22-23, 2014

BACKGROUND

Motivation: Develop modeling methodology that provides physical understanding into water mist fire suppression→ enable efficient test planning and execution

Previous large scale simulations: Ro-Ro Deck Fire with Cooling Mist

Wood pallets, 35 GJ fire size

Water mist sprinklers discharged: 12

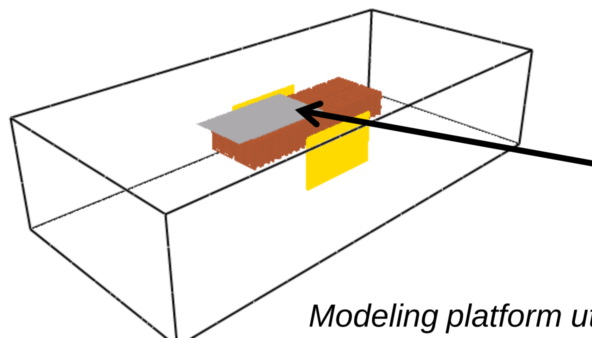
Simulation approach

Water mist injection

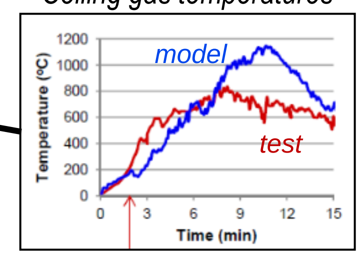
Fire growth

- *prescribed heat release rate*
- *pyrolysis*

Fire suppression



Ceiling gas temperatures



Modeling platform utilized with pyrolysis models: FDS 5 (svn 10095)

Reference: SupDet 2013, "Modeling water-mist based suppression of 34 GJ car-deck fires using FDS"

Can we apply the same methodology to simulate other fire test scenarios?

OBJECTIVE

Demonstrate a modeling approach that simulates a water mist-based fire suppression of the European Ordinary Hazard I office space scenario.

Fire load includes:

Wood
Paper
Plastics
Foam

Water mist injection:

Marioff HI-FOG® 2000 sprinkler

OVERALL MODELING APPROACH

Water mist injection

- ❑ Droplet injection
- ❑ Air entrainment
- ❑ Droplet transport

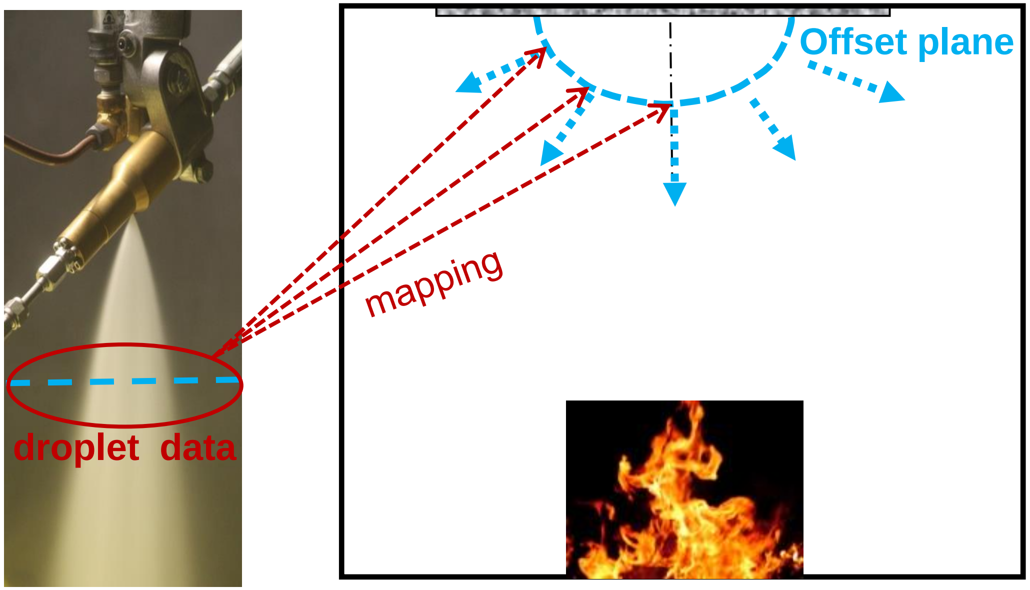
Fire growth

Water mist-based fire suppression

Modeling platform utilized in office space simulation: FDS 6 (svn 17743)

WATER MIST SPRAY INJECTION

Approach



1) Measure experimental data from single spray jet near the exit

2) Scale measured droplet number densities and velocities to conserve mass and momentum

3) Inject spray distribution with prescribed drop size and velocities at the offset plane

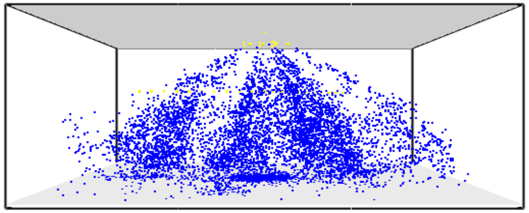
4) Use gas velocities from spray data to represent entrained gas motion

Reference: SupDet 2011 presentation, "A novel approach for simulating droplet transport for watermist applications"

WATER MIST SPRAY INJECTION

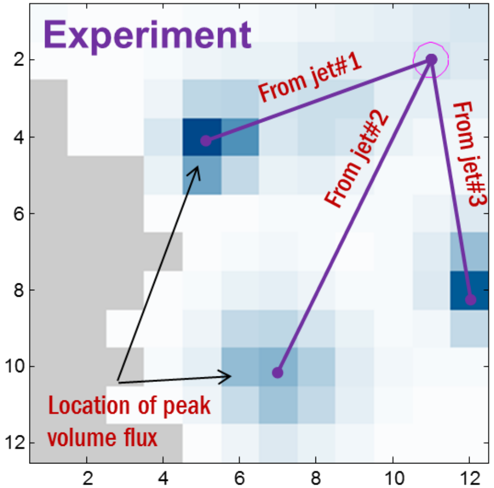
Cold spray simulation of the HI-FOG 2000 sprinkler verified with spray data

Droplet dispersion from Marioff HI-FOG 2000 sprinkler

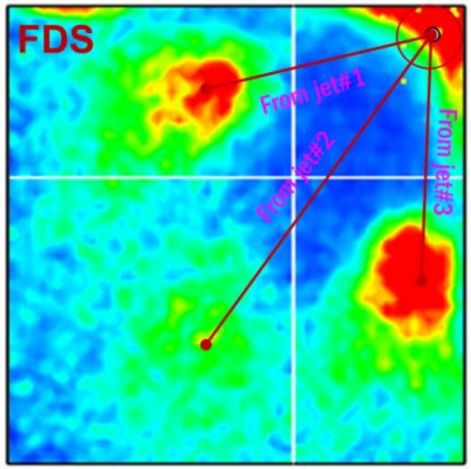


Mesh number	Mesh resolution (cm)	# cores	Simulated test period (sec)	Wall clock time (hrs.)
720,000	**5**	**9**	**10**	**1.4**

Water flux distribution

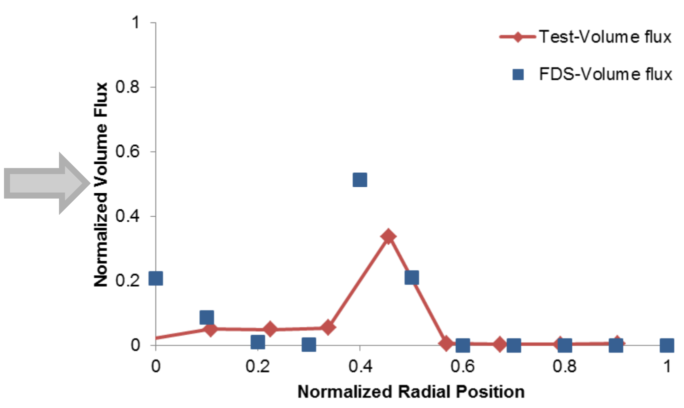


Patternation measurement (top view)



Accumulated Mass Per Unit Area (AMPUA) from simulation (top view)

Volume flux profile through jet#1



OVERALL MODELING APPROACH

Water mist injection

Fire growth

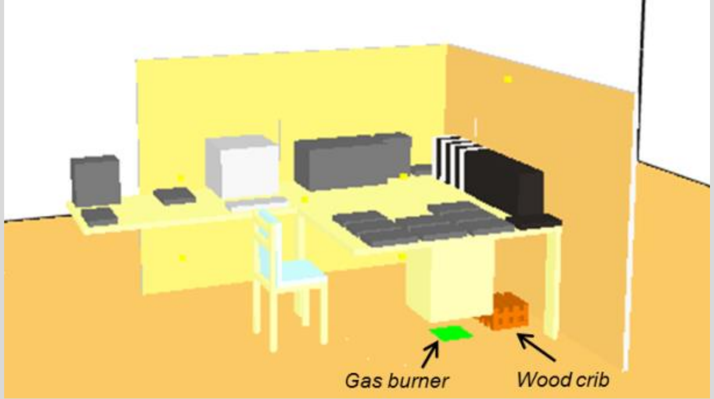
- ❑ Fire ignition
- ❑ Fire growth

Water mist-based fire suppression

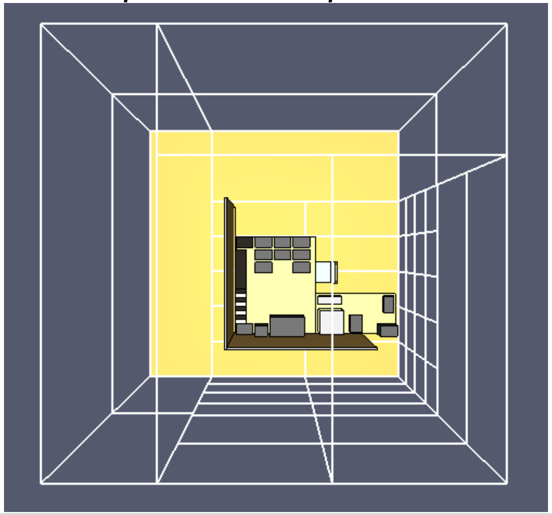
OFFICE SPACE: FIRE GROWTH

Realistic fuel package set up in a large domain with a non-uniform grid

Geometry visualization in Smokeview



Mesh partition – top view



Computational domain (L x W x H): 5.12 m x 5.04 m x 4.96 m

Non-uniform grid:

- 4 cm hexahedral mesh surrounding fuel package
- 8 cm mesh away from the table

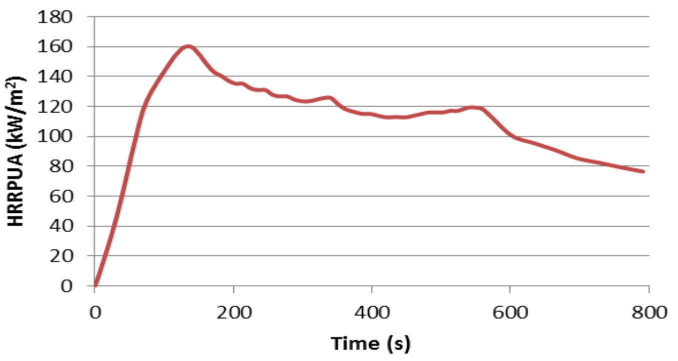
Parallel simulation on 48 computing processors

OFFICE SPACE: FIRE GROWTH

Approach: prescribe a heat release curve and ignition temperature for each material

Tune HRRPUA magnitude and ignition temperature for each material until fire growth is matched qualitatively.

*Example of input HRRPUA for wood**



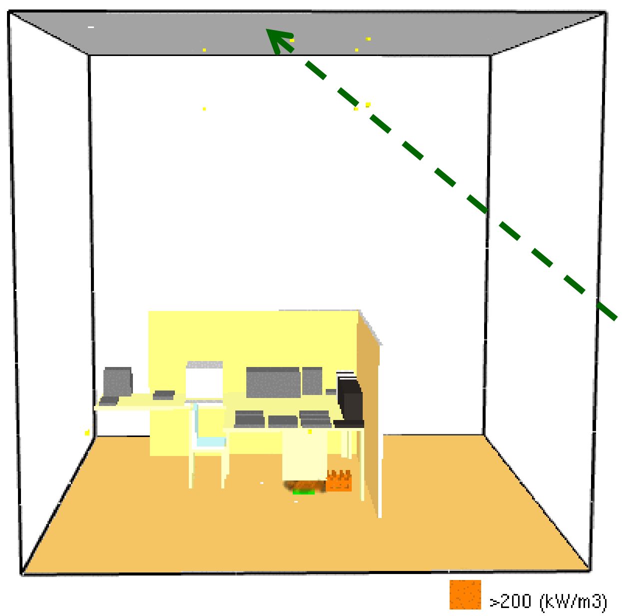
*Based on scaled U.MD wood crib test data
Reference: "Suppression Effectiveness of Water Sprays on Accelerated Wood Crib Fires", Bryson Jacobs, University of Maryland, 2011

Case	Mesh number	# Cores	Simulated test period (Sec)	Wall clock time (Hrs.)
Fire growth simulation	734,000	48	800	32

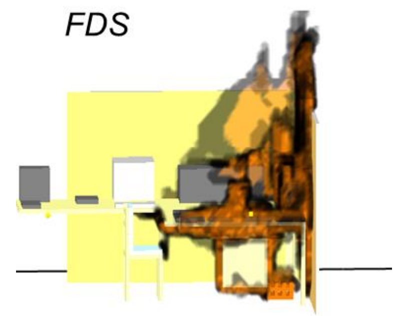
OFFICE SPACE: FIRE GROWTH

Simulation verified with fire size image, ceiling gas temperatures from free burn case

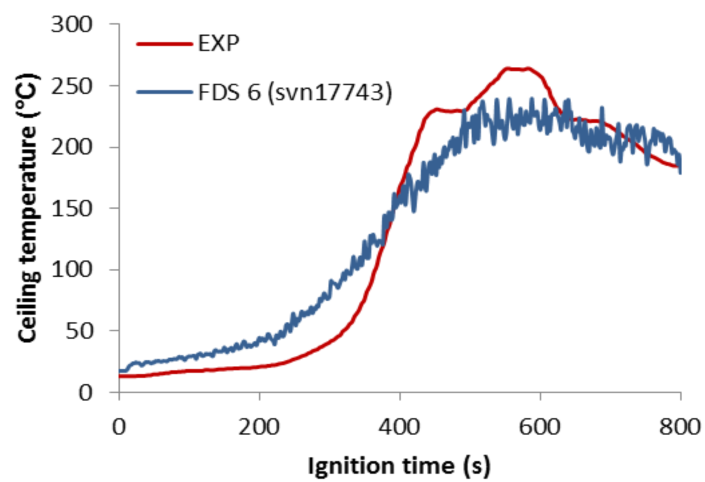
Fire growth—free burn



Verification: fire size at 435s after ignition



Evolution of ceiling gas temperature



OVERALL MODELING APPROACH

Water mist injection

Fire growth

Water mist-based fire suppression

Primary suppression mechanisms

- ❑ Gas phase extinction
- ❑ Reduction of burning rate via wetting

OFFICE SPACE: FIRE SUPPRESSION

Set-Up: Under 1 sprinkler simulation

For each material, prescribe

- Heat release rate per unit area (HRRPUA)
- Ignition temperature

Computational domain (L x W x H): 8 m x 8 m x 3.52 m

Non-uniform grid:

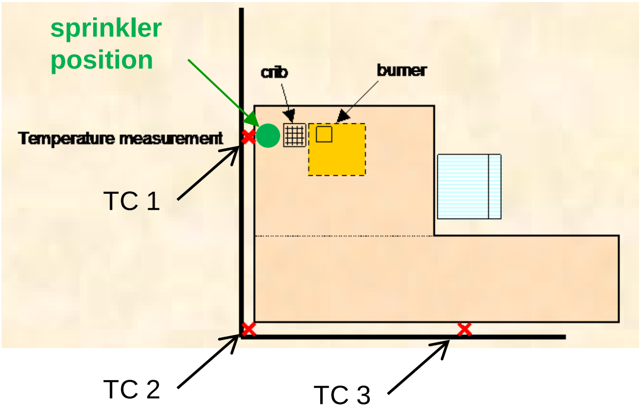
- 4 cm hexahedron mesh surrounding fuel package
- 8 cm mesh away from the table

Parallel simulation on 36 computing processors

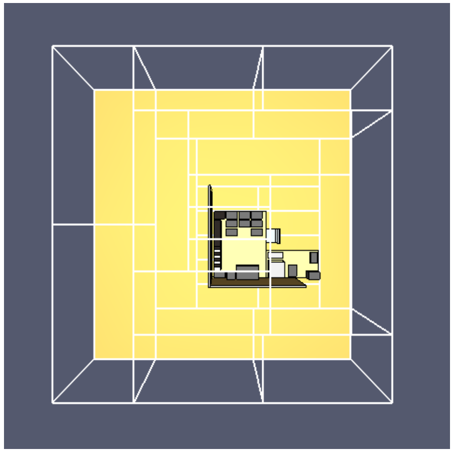
sprinkler activation: set at 159s after ignition

Case	Mesh number	# Cores	Simulated test period (sec)	Wall clock time (hrs.)
Fire suppression simulation	978,000	36	800	160

Under 1 sprinkler configuration with temperature measurement locations



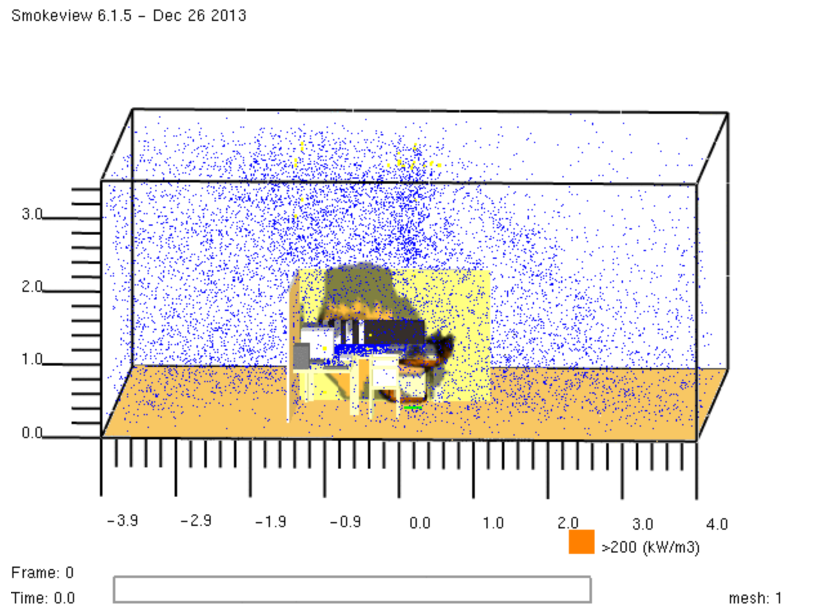
Mesh partition – top view



OFFICE SPACE: FIRE SUPPRESSION

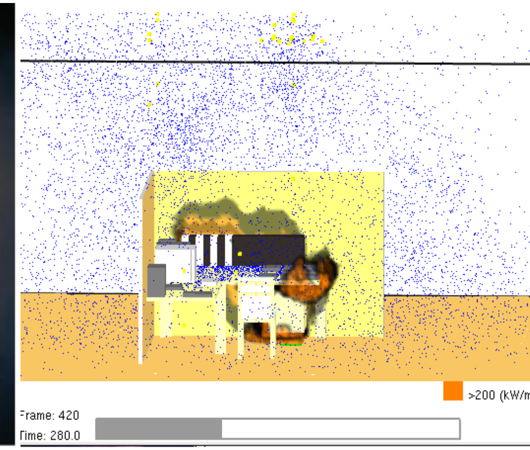
Under 1 sprinkler suppression case demonstrated; suppressed fire size trend captured

Modeled fire growth and spray suppression



Flame shape at 280s after ignition

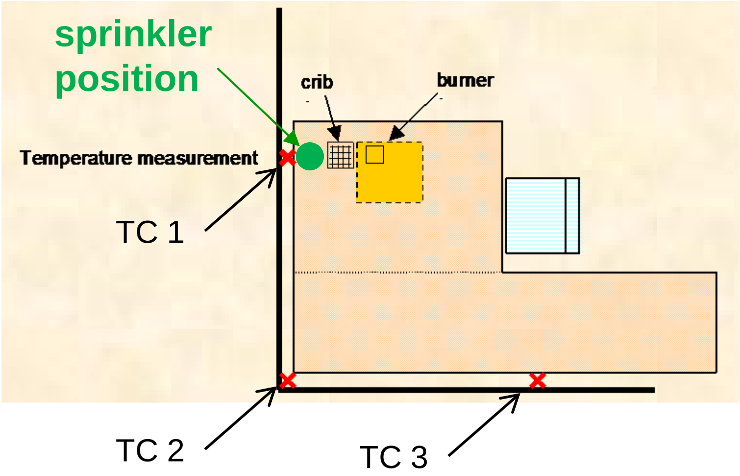
Test image

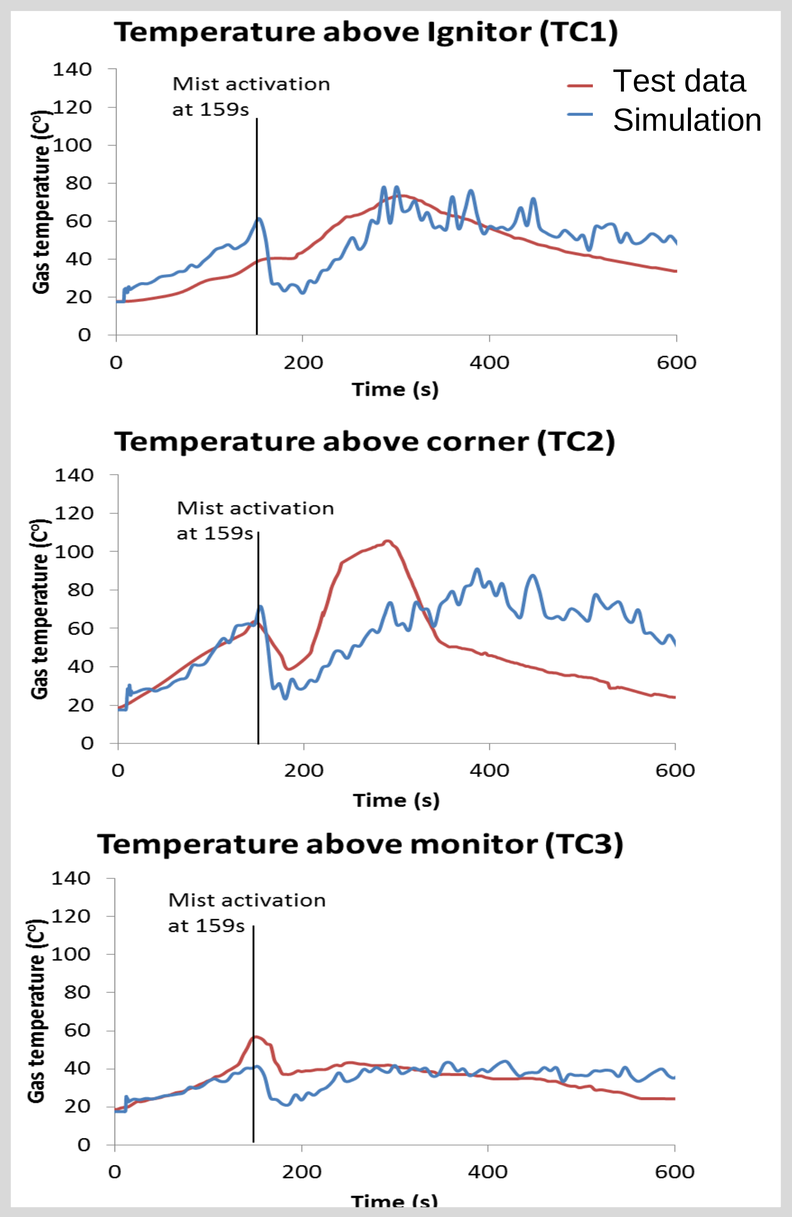


FDS result

OFFICE SPACE: FIRE SUPPRESSION

Ceiling gas temperature trends captured by simulations





Summary

- A simulation of the European Ordinary Hazard Group 1 Office Space was successfully demonstrated and verified with limited fire test data

- Modeling methodology used FDS 6 as a platform and included the following:
  - Defining the spray with experimentally-derived measurements of drop size, velocity, and entrained gas
  - Defining the fire growth of different fuel load types (wood, paper, plastics, foam) with unique heat release rates and ignition temperatures
  - Applying the extinction model and wetting

Thank you!

Questions?

Modeling & Numerical Considerations

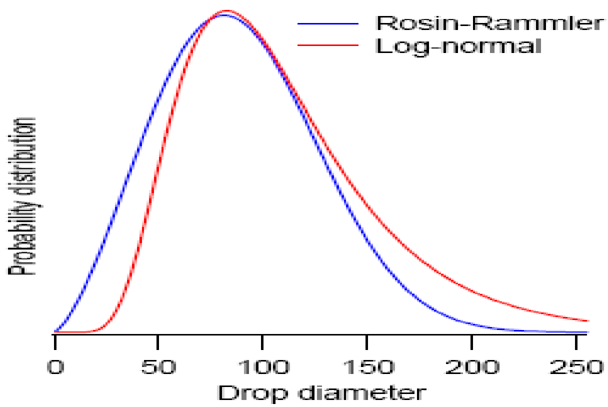
Fire Dynamics Simulator (NIST)

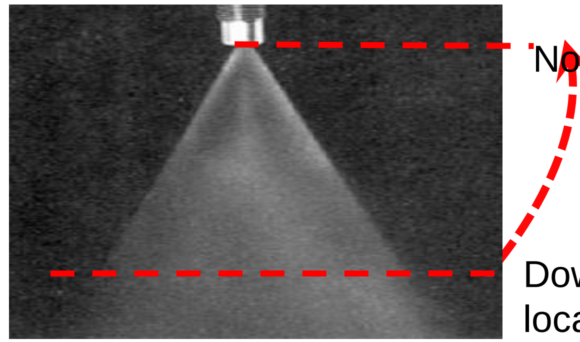
- Eulerian-Lagrangian approach for multi-phase physics
- Dynamic (or constant) Smagorinsky large eddy solver
- Finite rate reaction, a mixing controlled reaction, or a mixed-mode reaction
- Low Mach number assumption
- Low oxygen-limit flame extinction model
- Radiation solver – gray gas, wide band model, Mie theory for scattering/absorption

Water – Mist modeling

Traditional approaches:

- Apply downstream droplet distribution at **nozzle exit**





- Set droplet velocity based on flow-rate
- “Iterate” to match downstream profile

Disadvantages:

- Require non-trivial tuning for different nozzles & conditions
- Near nozzle simulation expensive and poses substantial numerical challenges
- Can violate conservation laws