SAND2011-1557C

COMPUTATIONAL TEST DESIGN FOR HIGH-SPEED LIQUID IMPACT AND DISPERSAL

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Fire Science & Technology

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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Primary Goal:

In preparation for some testing to validate a unique impact to fireball computational capability, we are first simulating the environment to understand how best to instrument the test.

Methods:

- **Water dispersal from the braking of a rocket sled will be used to evaluate code capability.**
- ***Sierra/StructuralDynamics* Presto code for structural dynamics**
- ***Sierra/FluidMechanics* Fuego code for predicting reacting flows**
- **It is hoped that this capability will address aircraft impact simulation needs for scenarios like that of September 11, 2001**

Outline

- Introduction and Demonstration of Past Work
  - Novel Methods Introduction
  - Water Slug Impact Validation
  - Heptane Cube Impact
- Methods
  - Description of Rocket Test
  - Description of Simulation Matrix
- Simulation Results (First Round)
- Subsequent Simulation Findings
- Summary

Code Details

- **Presto SPH used for highly deforming structure and water**
  - **Using constants to approximate liquid behavior**
  - **Typical runs on ~100 CPUs for a few days**
- **Fuego CFD Lagrangian/Eulerian Drop Models used:**
  - **Reactions modeled with Eddy Dissipation Concept (EDC) reactions and Temporal Filtering of the Navier-Stokes Equations (TFNS) turbulence model**
  - **Multiple levels of mesh refinement**
  - **Drop breakup with a modified Taylor Analogy Break-up (TAB) model**
  - **Typically run on ~200 CPUs for around 8 days**

Simulation Codes

- **Coupling methods are significant, and have required study and development to best model these scenarios**
- **Dimensionless drop separation distance used to define transfer time appropriate for individual drops:**

$$B = \frac{CharacteristicSeparationDistance}{CharacteristicDropLength}$$

- **Presto products initialized as spheres in Fuego**
- **Aluminum (casing) ignored in Fuego**
- **Impacting drops all stick in Fuego**

Illustrating the Physics Challenge

Presto	Phenomena	Fuego
✓	Gravity Force	✓
✓	Structural Deformation	
✓	Mass Conservation	✓
✓	Momentum	✓
~	Energy Conservation	~
✓	Structural Material Interactions	
~	Sensible Energy	✓
	Surface Tension Forces	~
~	Liquid Phase Viscous Forces	~
~	Gas Phase Transport	✓
~	Multiphase Interactions	~
	Chemically Reacting Flows	✓
~	Wind	✓
	Turbulence	✓
~	Thermal Response of Materials	✓

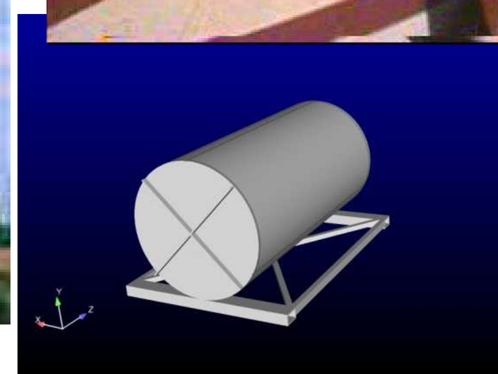
Scenarios

Two previous cases are presented here as introduction:

- Validation to a large-scale water tank impacting a concrete barricade
  - Brown A.L., Wagner, G.J., "Fluid Spread Model Validation for Emerging Liquid Tank Impact Predictive Methods," Accepted to the ASME IHTC Conference, ASME IHTC-2010, August 8-13, 2010, Washington DC, USA, IHTC14-23067.
- A notional impact of a 0.3 m square tank of heptane
  - Brown A.L., "Impact and Fire Modeling Considerations Employing SPH Coupling to a Dilute Spray Fire Code," Proceedings of the ASME 2009 Summer Heat Transfer Conference, ASME SHTC-2009, July 19-23, 2009, San Francisco, CA, USA, HT2009-88493.
  - Brown A.L., "Impact and Fire Modeling for Complex Environment Simulation," The 2010 Western States Meeting of the Combustion Institute, Paper # 10S-12, March 21-23, 2010, Boulder, CO, USA.

Impact Validation

- Tests performed in 2002 provided data for validating liquid spread dynamics for an aluminum tank impacting a concrete slab
- Liquid deposition, particle sizing, and video data



Simulation Matrix

- **Wind was not reported, so it was treated as a free parameter**
- **Geometry fidelity was examined, including undercarriage and cross-member for high fidelity**
- **Various temporal staging assumptions were analyzed**

Fluid Test Matrix

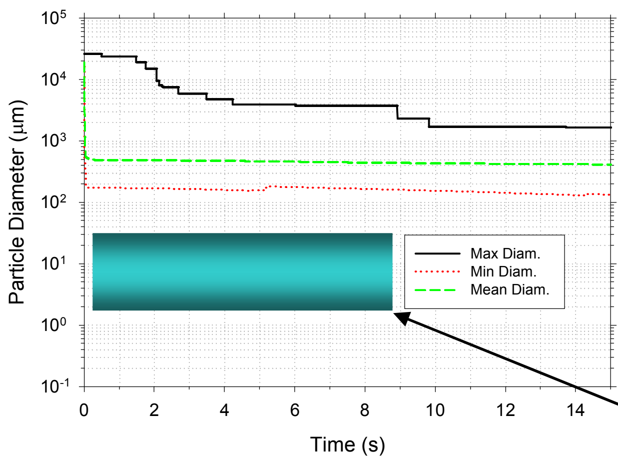
Case	Geometry Fidelity	Wind	Temporal Staging
1	Low	No	No
2	Low	No	5 times*
3	High	No	6 times**
4	Low	2 m/s	No
5	Low	1 m/s	No
6	High	No	11 times**
7	High	1 m/s	11 times**

* Dimensionless Staging Distance: 1.7
** Dimensionless Staging Distance: 1.5

Drop size and Spread Distance Results

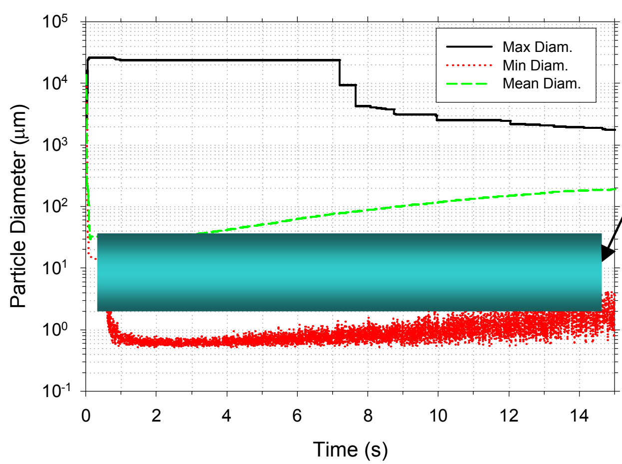
- **Simulation matrix evaluated transfer coupling, geometry fidelity, and wind assumptions**

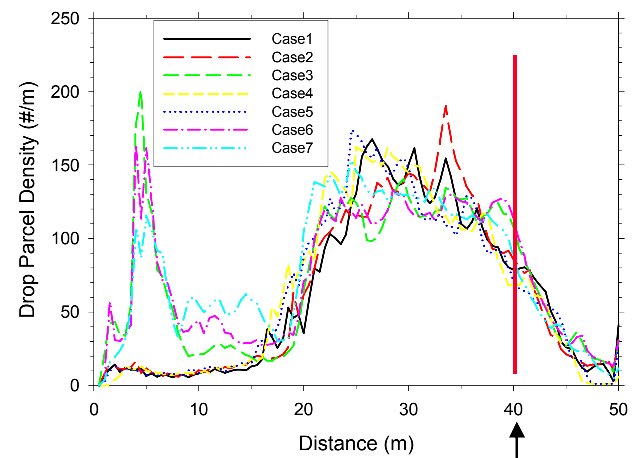
Low Geo. Fidelity



Data

High Geo. Fidelity

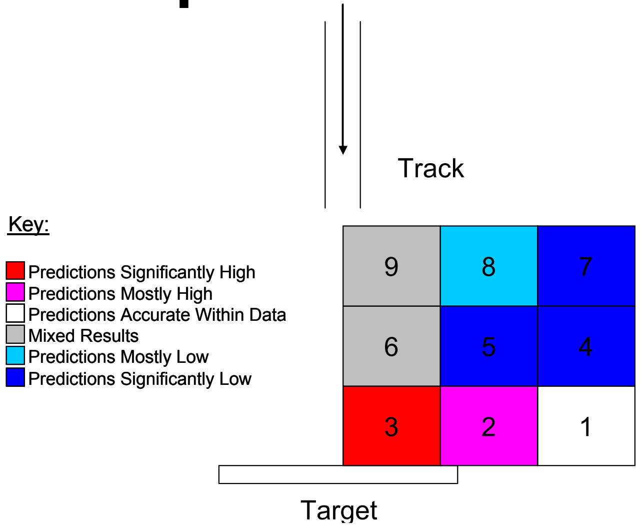


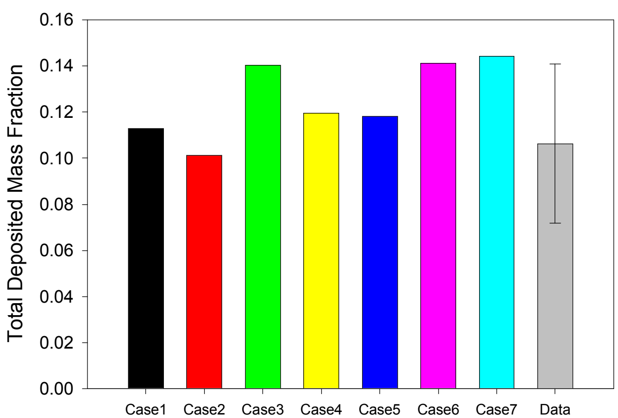


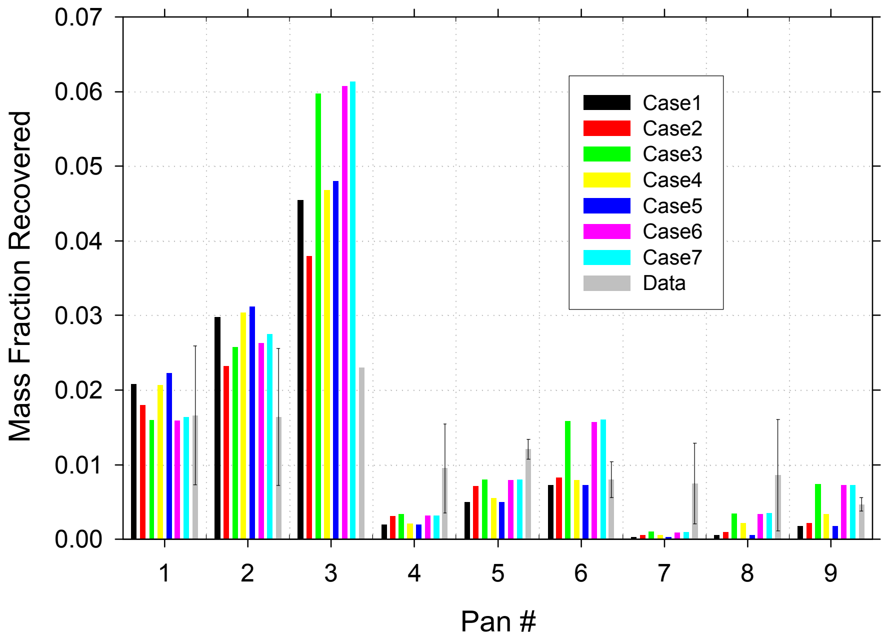
Data Peak

Liquid Deposition Results

- **Geometry fidelity was found to be most significant, and coupling methodology was also important**







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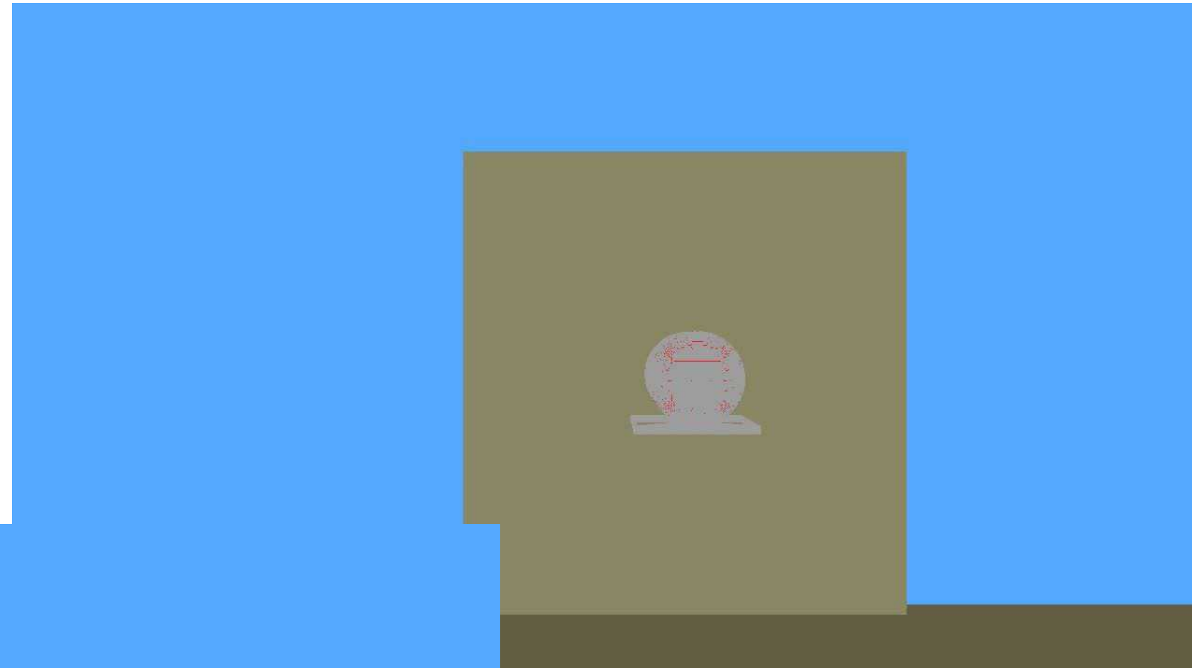
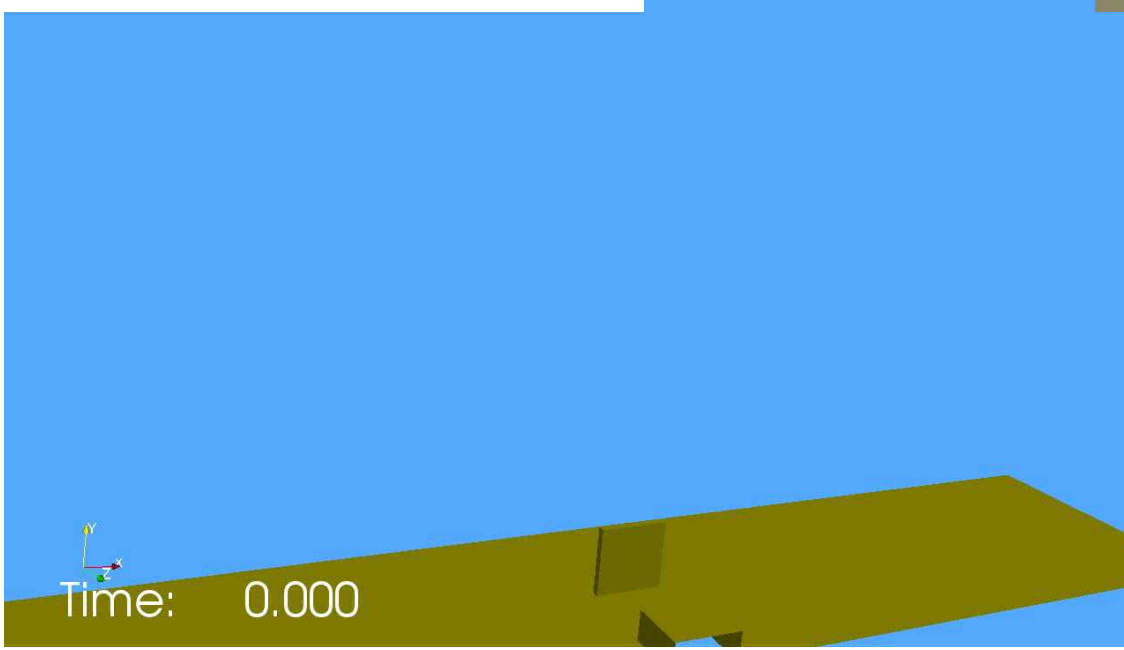
Simulation Videos

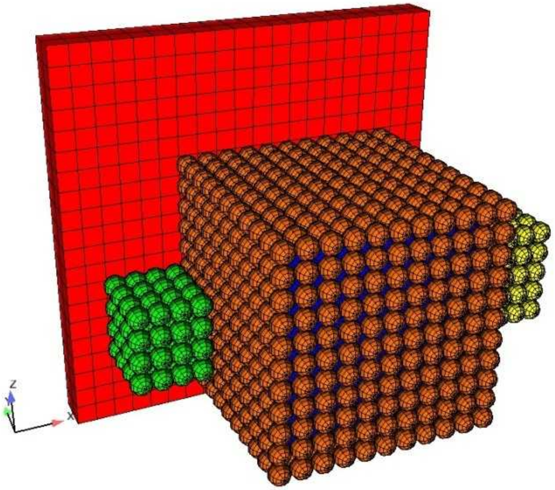




The Scenario

Designed to help understand discretization sensitivities

- **23 cm cube of liquid in a 2.54 cm thick aluminum tank with two adjacent cubes**
  - **Impact an immobile target at 182 m/s**
  - **Presto modeled with SPH and 4 levels of refinement**
- **Open air environment with ground located 6.35 m below impact point**
  - **Two levels of fluid mesh refinement**



Simulation Matrix

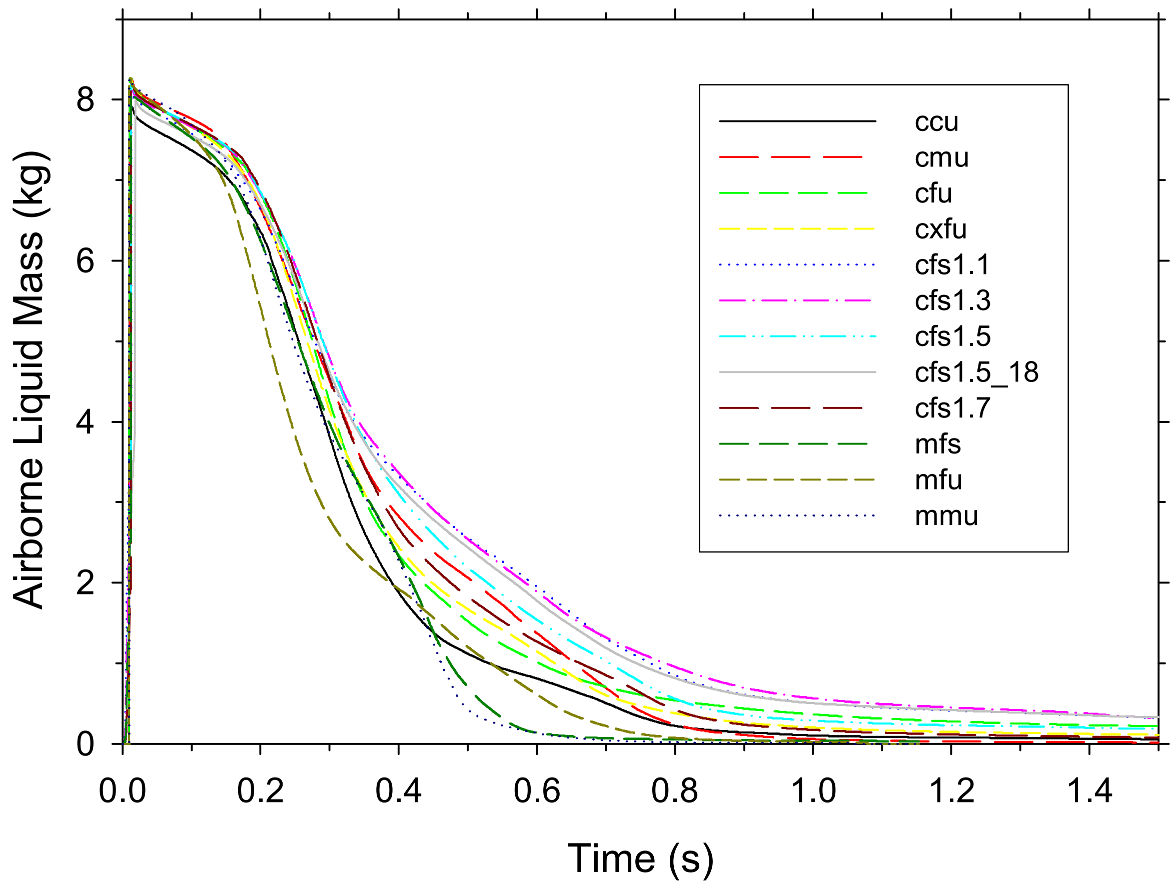
- Cases are named to indicate meshes used and staging assumptions
- Differences between cases reflect accuracies with discretization and staging

Case	Fuego Mesh	Presto Mesh	Temporal Staging	Dimensionless Spacing
ccu	coarse	coarse	No	
cmu	coarse	medium	No	
cfu	coarse	fine	No	
cxfu	coarse	xfine	No	
cfs1.1	coarse	fine	Yes	1.1
cfs1.3	coarse	fine	Yes	1.3
cfs1.5	coarse	fine	Yes	1.5
cfs1.5_18	coarse	fine	Yes*	1.5
cfs1.7	coarse	fine	Yes	1.7
mfs	medium	fine	Yes	1.5
mfu	medium	fine	No	
mmu	medium	medium	No	

*All staged cases use 1 ms steps out to 12 ms except this one, which uses 1 ms steps out to 18 ms.

Mass Results (1/2)

- **Results are relatively similar, with subtle differences not well illustrated by line plots.**

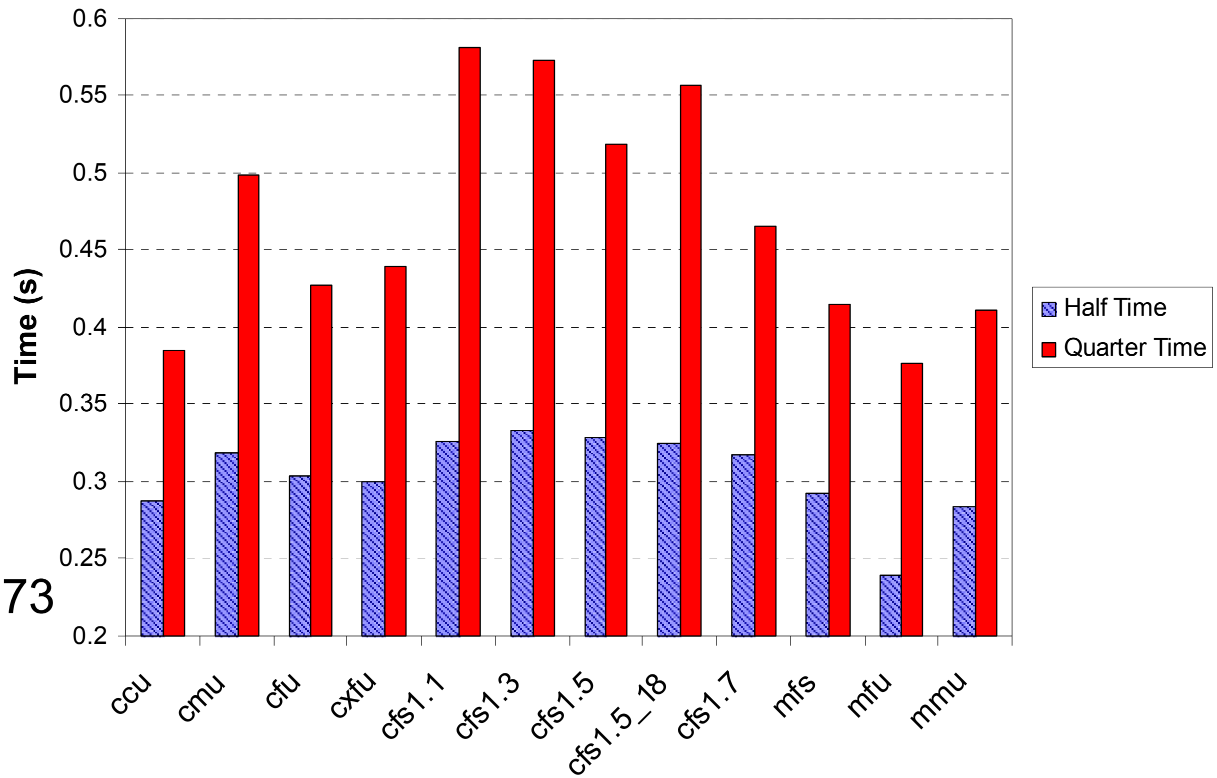


Mass Results (2/2)

- Mass loss is slower for staged predictions
- Mass loss is faster for medium Fuego mesh
- Moderate trend depending on dimensionless spacing magnitude assumed

half avg. = 0.305
half st.dev. = 0.026

quarter avg. = 0.471
quarter st.dev. = 0.073

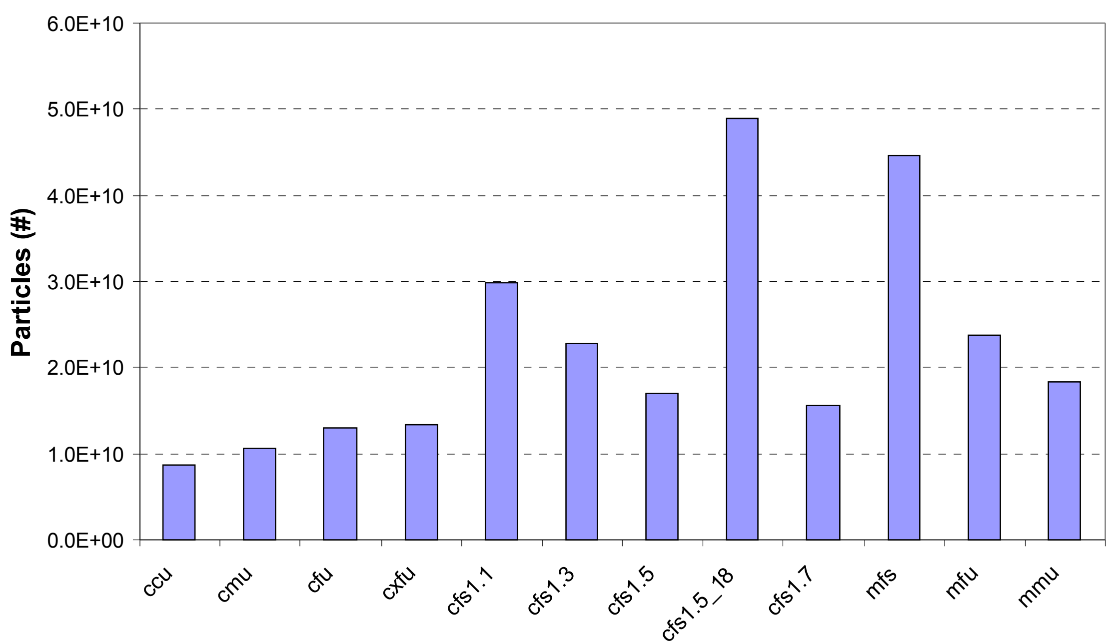


Maximum Predicted Particles Results

- Staging appears to increase break-up
- Finer Fuego mesh yields more particles
- Dimensionless spacing significant to result
- Small to moderate effect of Presto resolution
- 18 ms case results in substantially more particles

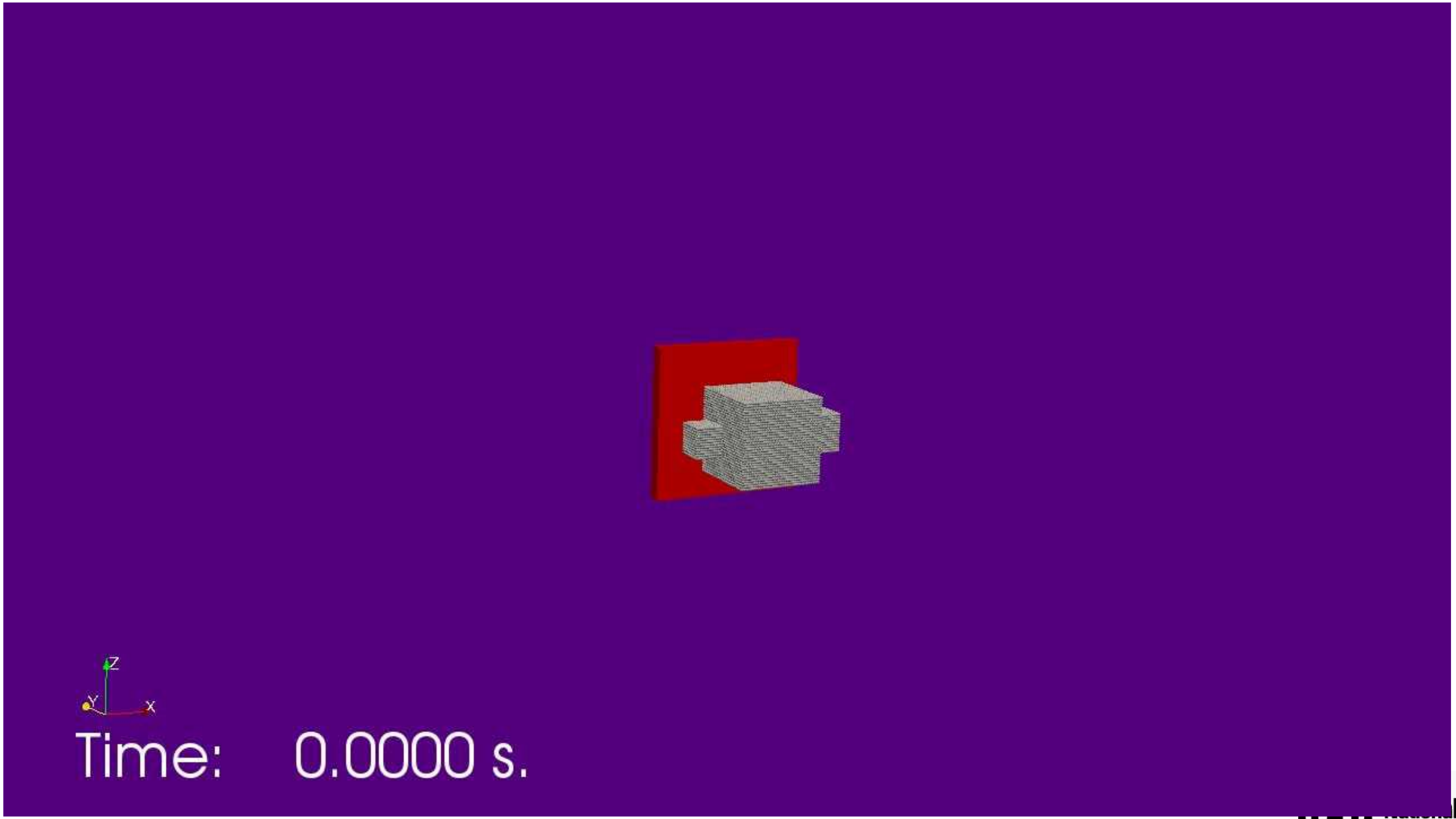
avg. = 2.2e10
st.dev. = 1.29e10

log avg. = 10.29
log st.dev. = 0.23



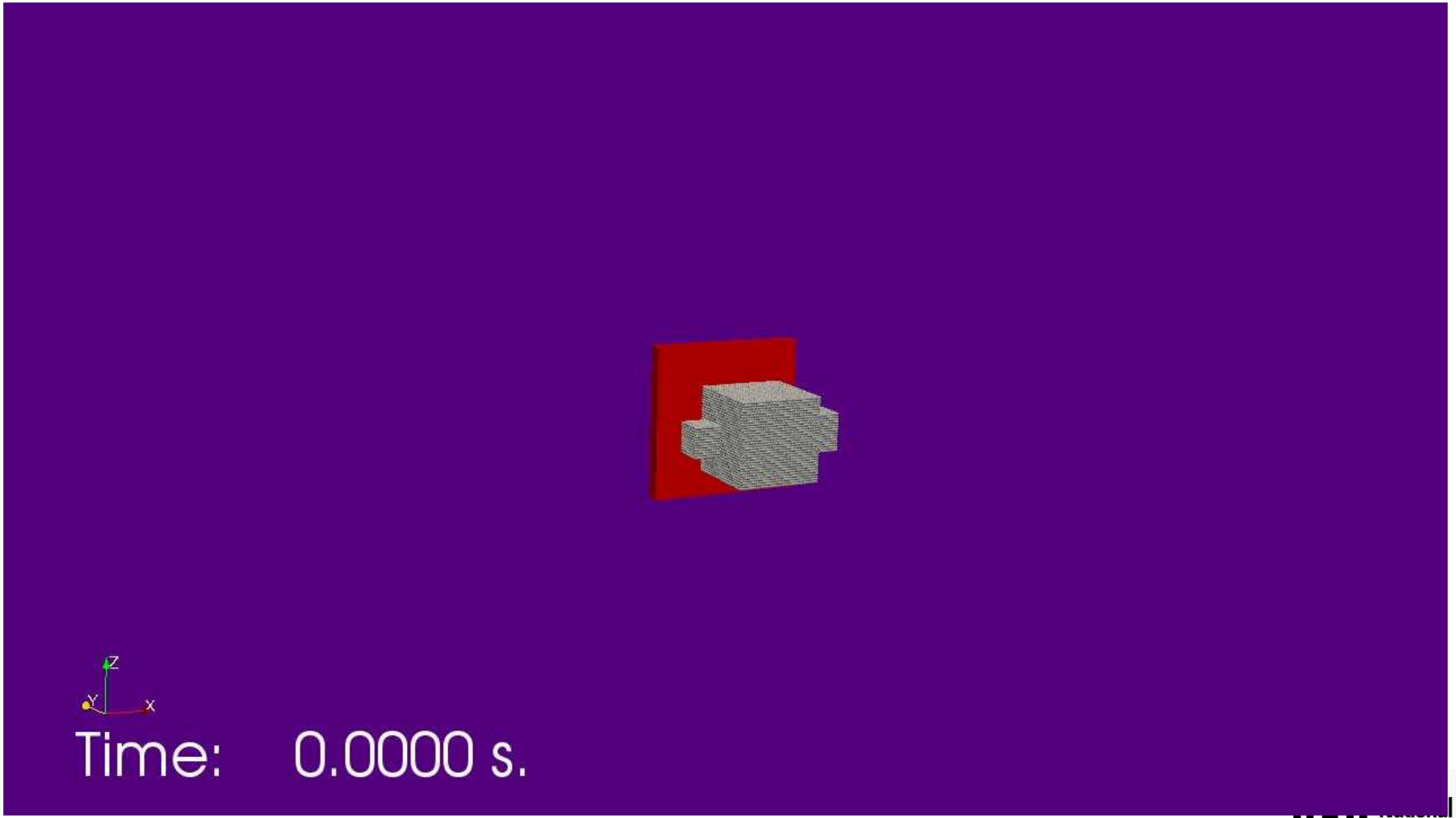
Coarse Video

- **Case cfs1.5**



Medium Video

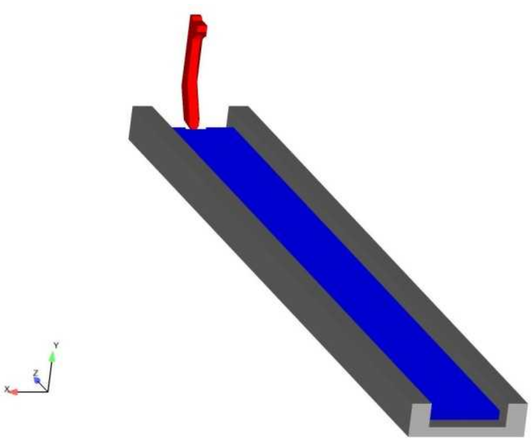
- Case mfs
- Substantial increase in resolution of the fireball



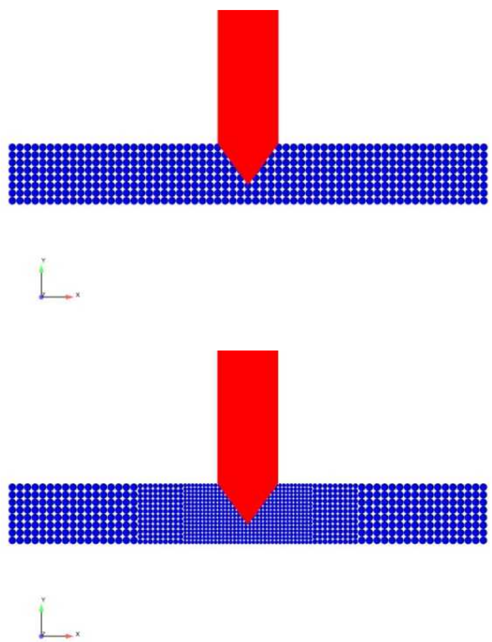
Sled Track Simulation Details

These simulations are pre-test design calculations to locate instruments for validation data:

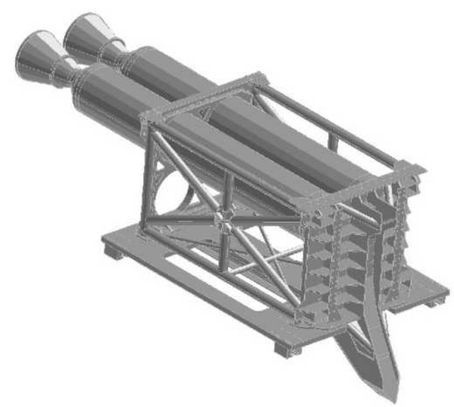
- liquid dispersal velocity (photometrics)
- local droplet size distributions and velocities (Malvern Spraytec and phase Doppler particle analyzer)
- ground level liquid deposition (catch pans)
- droplet evaporation and vapor transport (RH sensors)



Initial Presto Geometry



Two Mesh Densities Used



Designed Geometry

Simulation Matrix

The simulation matrix involved three Presto calculations and four Fuego calculations.

Structural Test Matrix

Simulation	Water Element Size (cm)	Water Draw (cm)	Initial Scoop Velocity (m/s)
S1	1.9	10.2	146
S2	1.9	15.9	91.4
S3	0.95-1.9	10.2	146

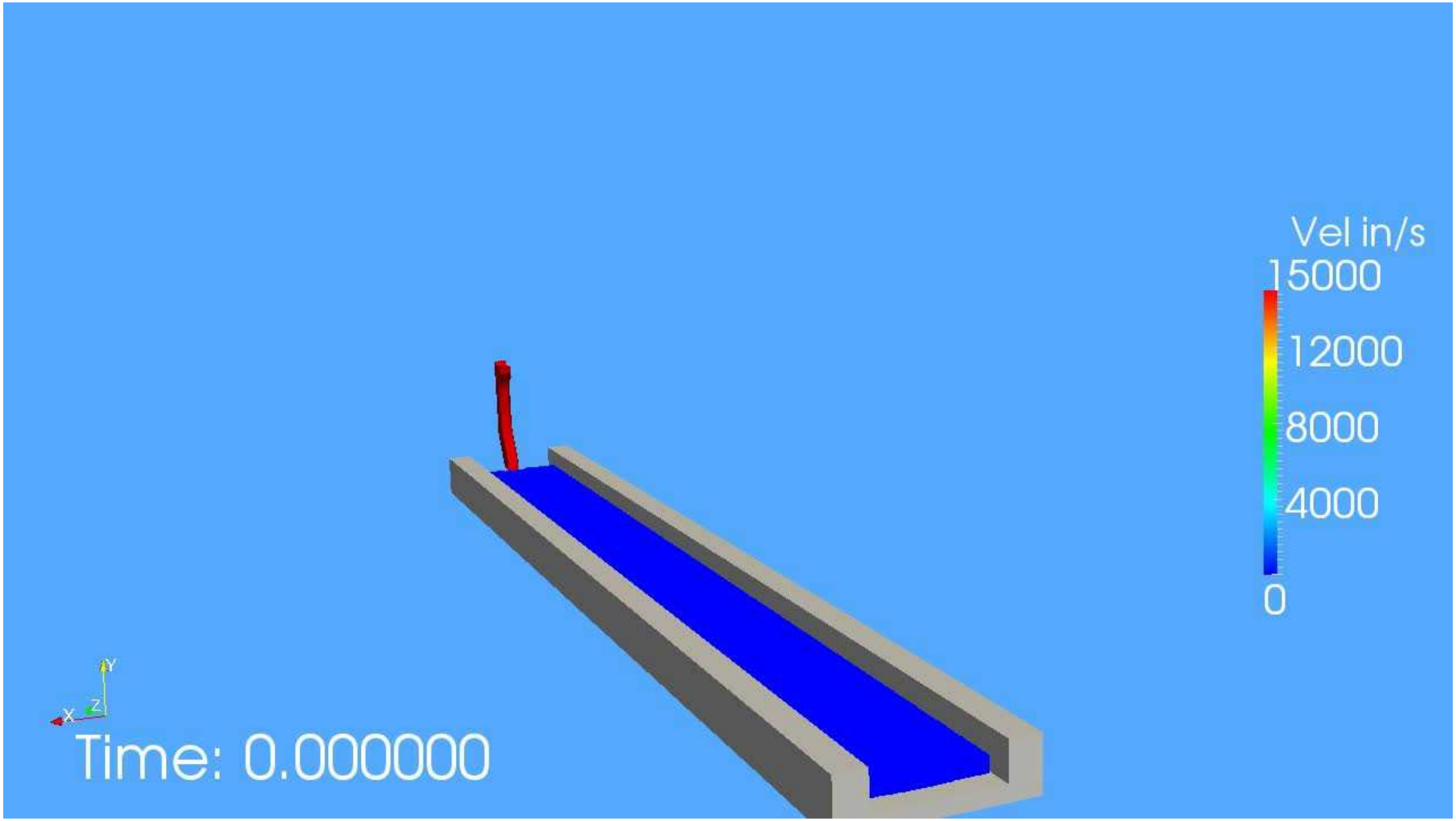
Fluid Test Matrix

Fuego Simulation	Presto Sim.	Simulation Transfer Time (s)	Number of Transfers	Fuego Mesh Elements (Thousands)
F1	S1	0.01-0.10	10	700
F2	S2	0.02-0.24	11	700
F3	S3	0.01-0.11	11	700
F4	S1	0.01-0.10	10	2,000

B=1.3

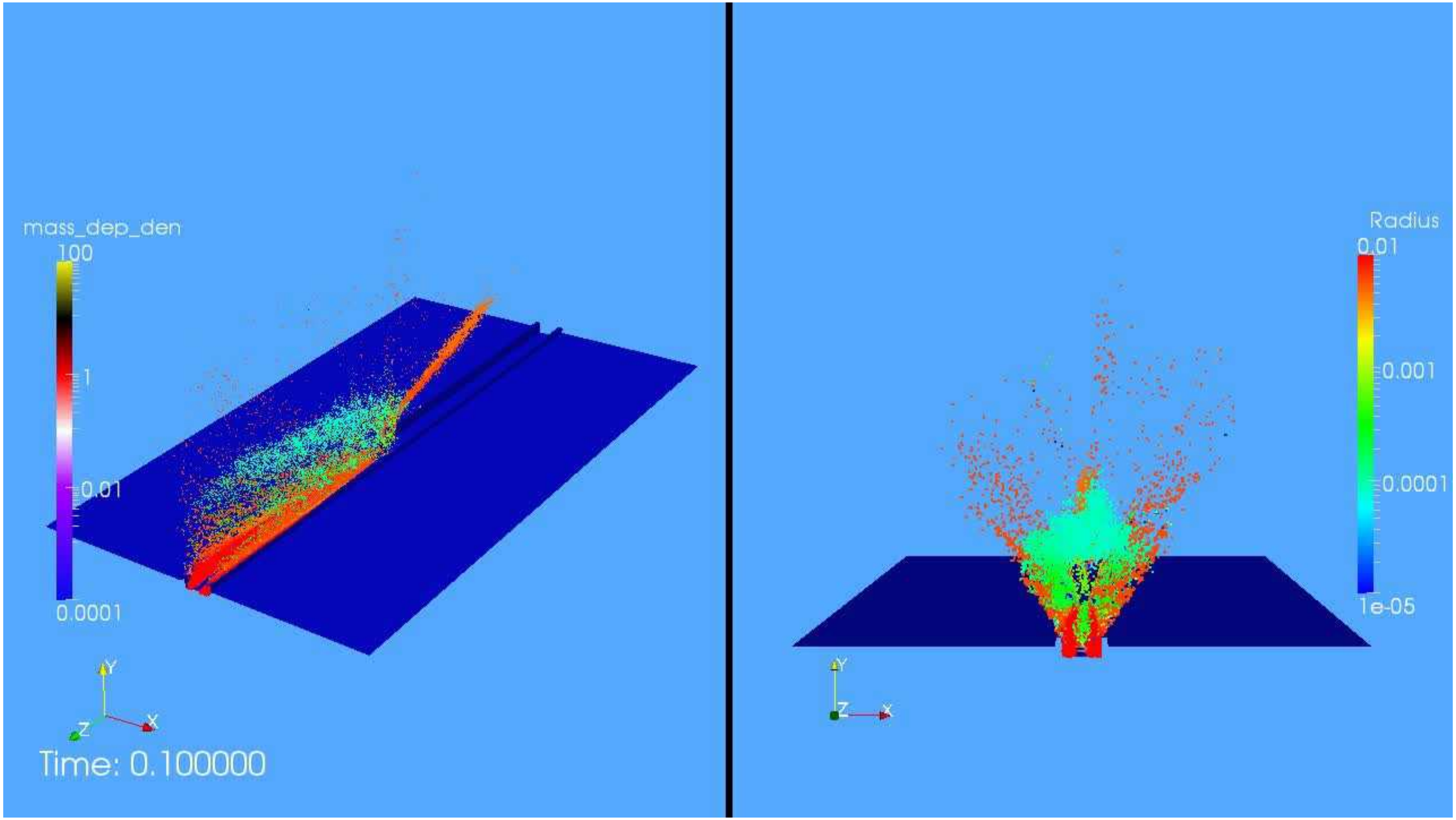
Sled Track Presto Video

Case S3



Sled Track Fuego Video

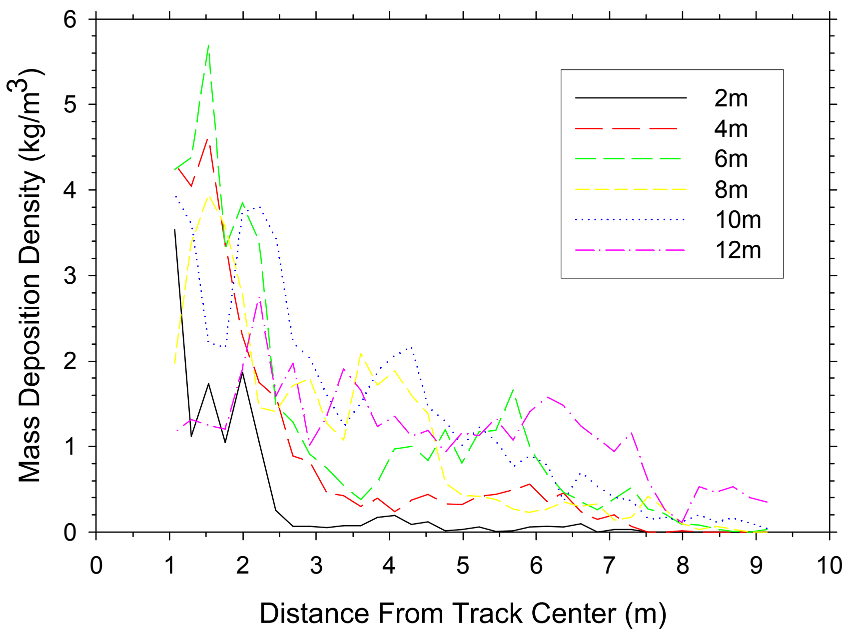
Case F1



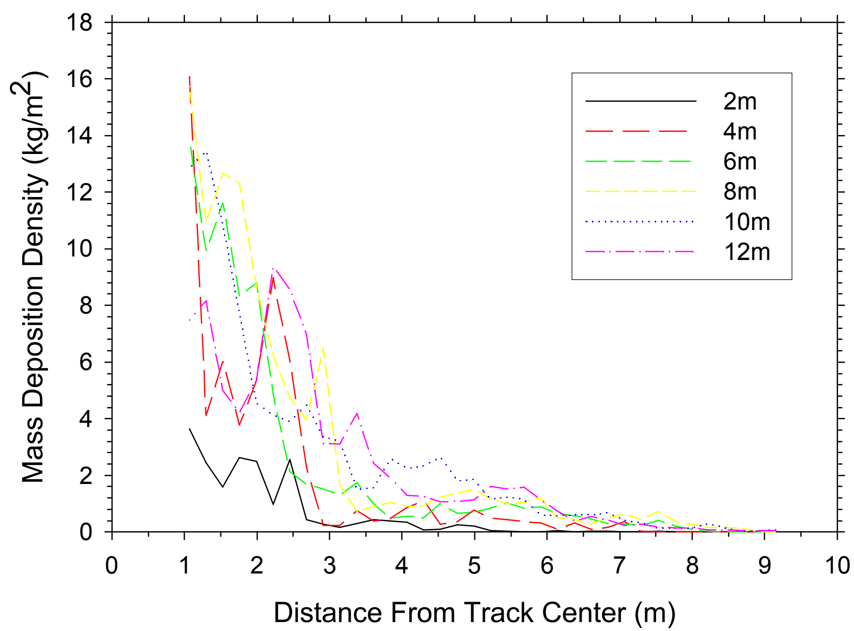
Predicted Environment

Ground deposition and air water vapor concentration predictions help locate instrumentation

Lesson: Catch pans need to be close to the track



Case F1 Deposition at Various Distances



Case F2 Deposition at Various Distances

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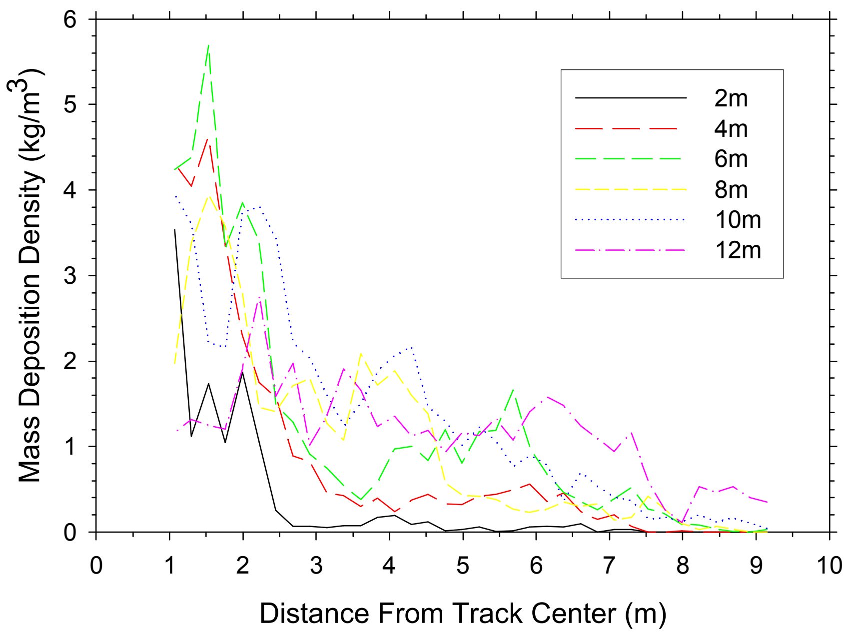
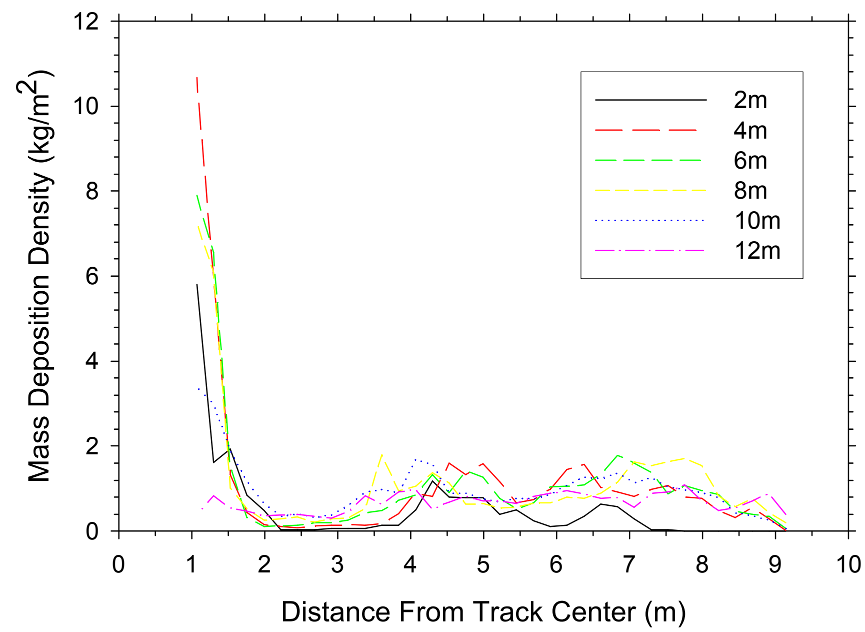
Structural Resolution Differences

- Two otherwise identical cases with varying SPH resolution gave significantly different results (below)
- The explanation did not make the conference paper



Case F1 Deposition at Various Distances



Case F3 Deposition at Various Distances

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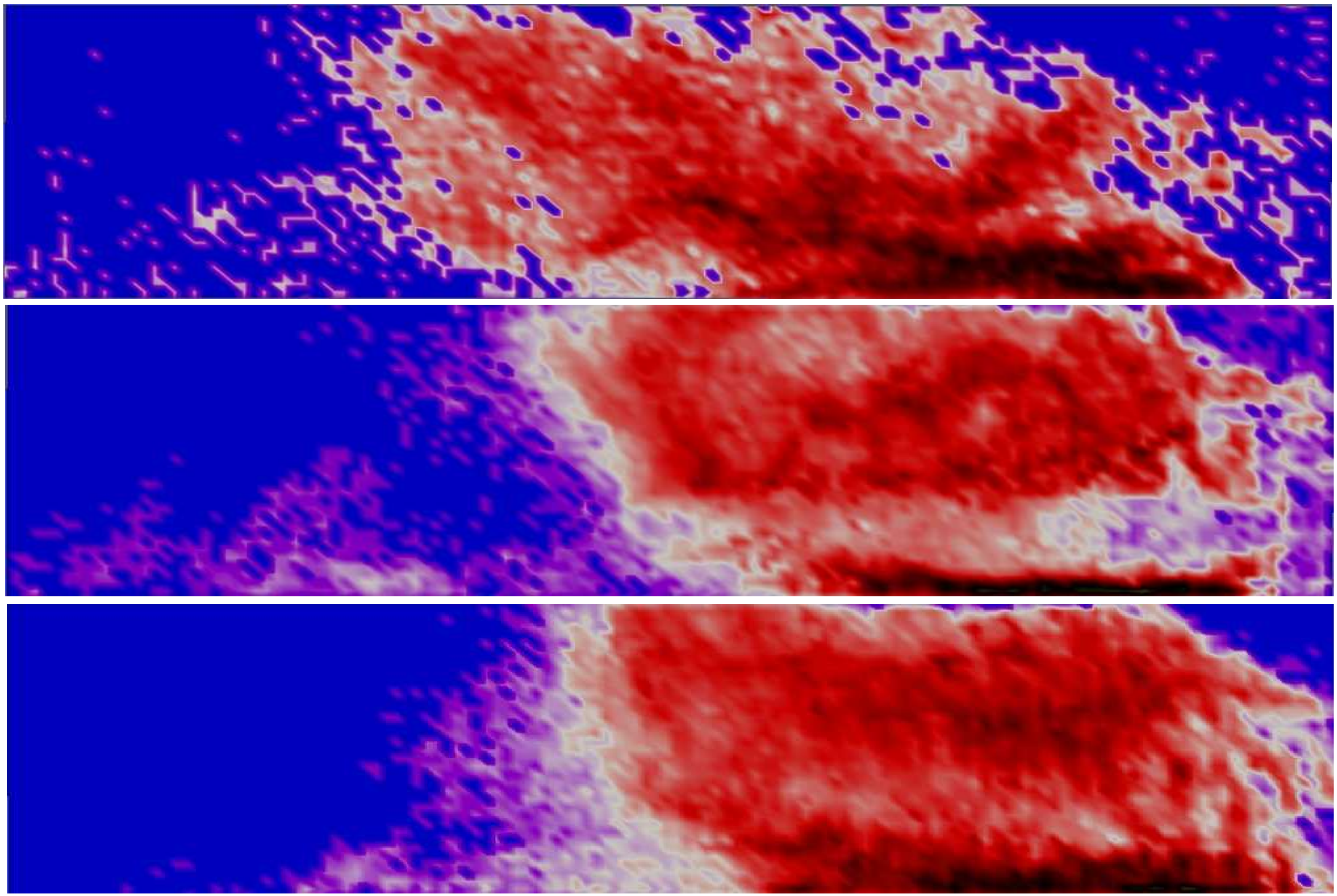
Deposition for SPH Resolution Increases

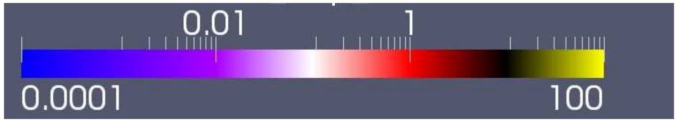
F1

F3

Further refinement



Mass Deposition Density [kg/m^2]



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Issue Resolution

- A subsequent (additional) SPH refinement case was performed.
- Dip in deposition and recovery results were similar to the intermediate refinement case (S3/F3).
- Results were more similar in general.
- This demonstrates a length scale refinement sensitivity for this calculation methodology
  - Not clear yet if it is only expressed in the fluid code, or the structural code as well
  - More work needs to be done to fully understand mesh sensitivity

Summary

- A new capability exists to predict fires from impact scenarios involving code coupling.
- Model validation work is ongoing, with existing validation suggesting the accuracy of the capability.
- Modeling resolution assumptions including discretization and coupling transfer method have been analyzed, and are shown to be important to the predictive results.
- Predictions help locate instrumentation for the test.
- The validation work provides confidence in being able to employ these capabilities for other similar scenarios.
- Future work includes additional validation and scenarios more closely related to the application space.

Acknowledgements

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

This work was made possible by support from the Sandia C6, LDRD, and ASC programs.

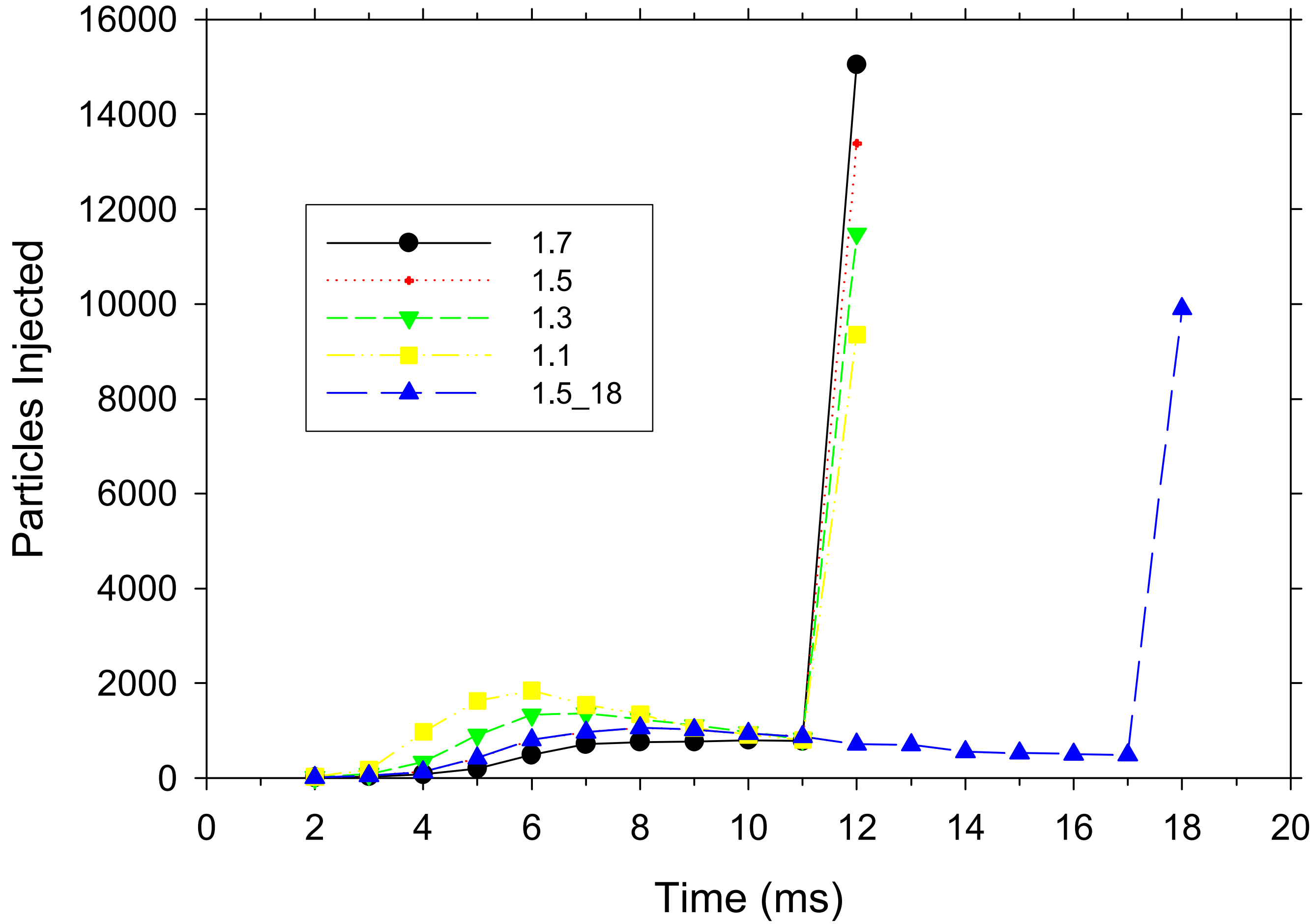
Significant contributions from Greg Wagner and Kurt Metzinger aided in the development of this capability.

Extra Viewgraphs

Properties

Property	Units	Value
Heat of Vaporization	kJ/kg	310
Boiling Temperature	K	371.58
Critical Temperature	K	540.3
Density	kg/m^3	692
Thermal Conductivity	W/m/K	0.15
Specific Heat	J/kg/K	2100
Viscosity	kg/m/s	0.000542
Absorptivity	--	0.05
Surface Tension	Nm	0.0216

Coupling Details

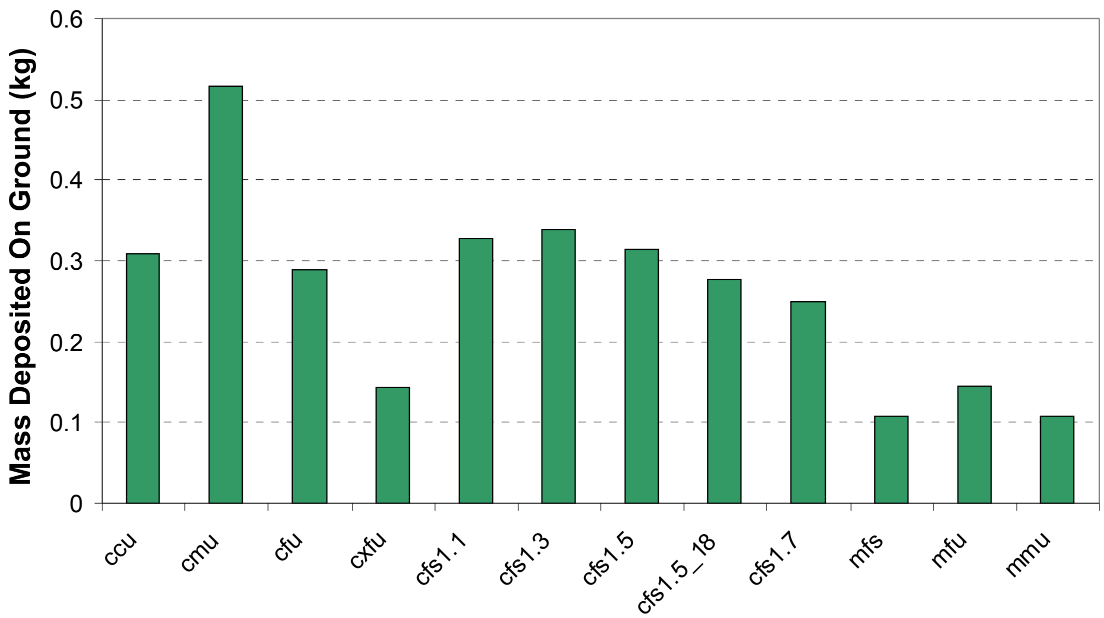


Ground Deposit at 1.0 s

Deposit mass almost identical from 0.4 to 1.25 seconds: early versus late deposit

- **Any refinement mostly lowers deposit**
- **Dimensionless spacing has minor effect**

avg. = 0.261
st.dev. = 0.119



Sauter Mean Diameter

- No particular trends evident
- Uniformly, larger average drops predicted at later times

half avg. = 222.5
half st.dev. = 60.5

quarter avg. = 439.6
quarter st.dev. = 119.7