Modeling and Simulation of Magazine Pressurization During M1 Combustion Event

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Motivation

- Deflagrating HD1.3 propellant pressurizes storage magazines to extreme limits
- Potential hazards due to pressurization need to be considered for safety siting
- Better understanding of HD1.3 deflagration is needed to understand potential risks
- Use small-scale experiments to develop med/large-scale model

*A. Farmer, K.P. Ford, J. Covino, T.L. Boggs, and A. Atwood, "Combustion of hazard division 1.3 M1 gun…," Technical Report, TM8742, NAWCWD (2015).

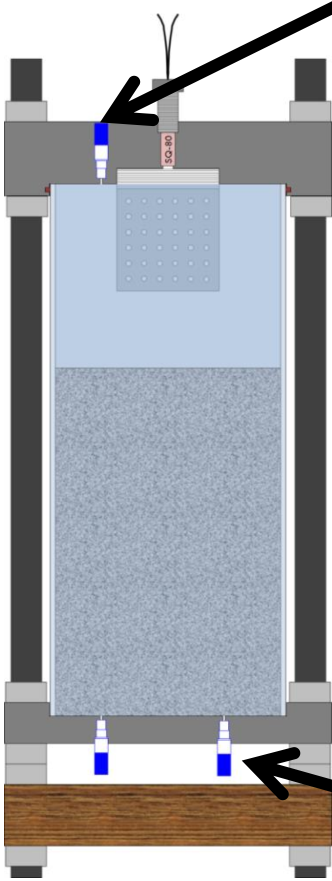
Outline

- Model development of burn rate vs. pressure
- Small scale 2D simulations of current experiments
- Large scale 3D simulations of highly loaded magazine
- Conclusions and Future Work

Burn Rate vs. Pressure

M1, 7P Gun Propellant

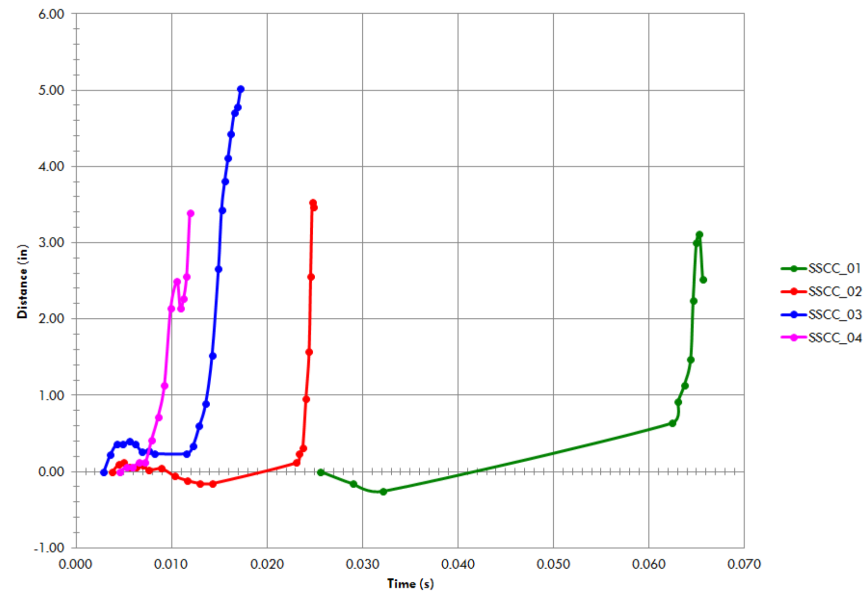
Test Chamber

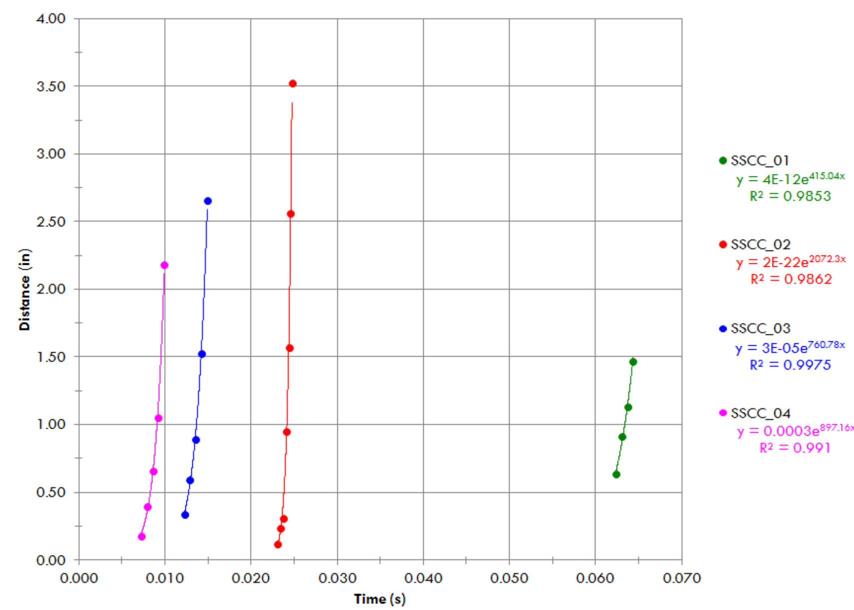


Pressure tap

Pressure tap

Use fits of exp. burn rates





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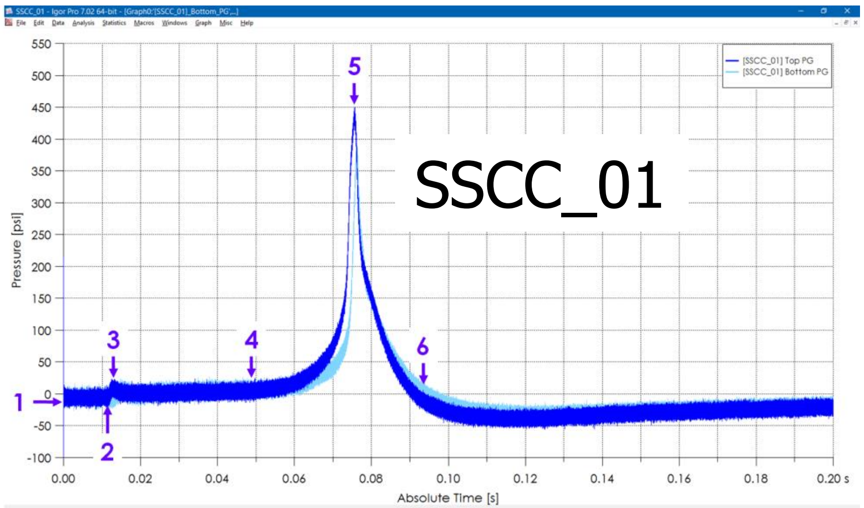
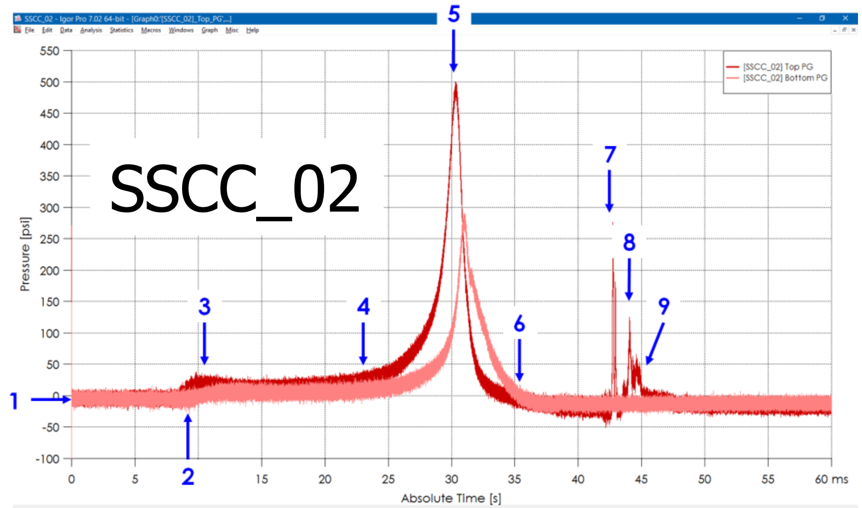
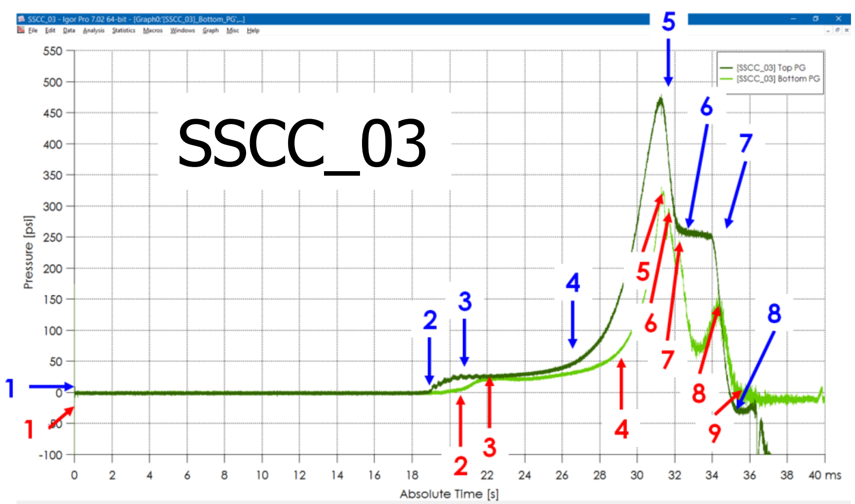
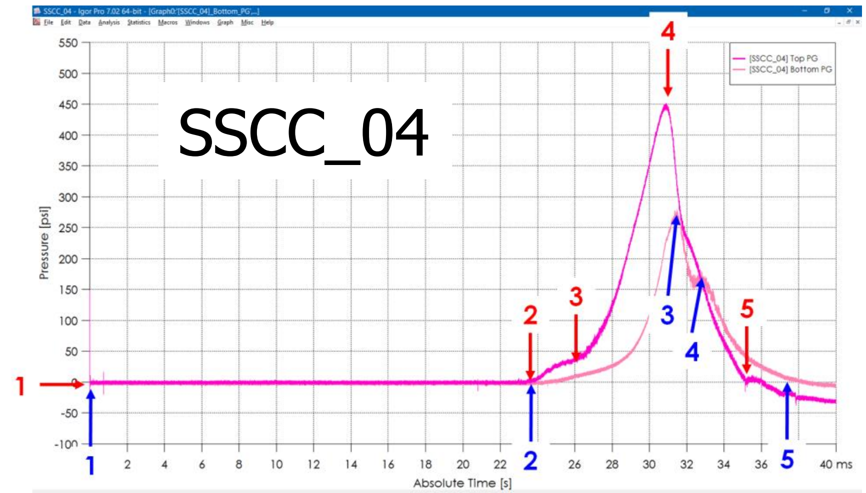
Burn Rate vs. Pressure

- Assume ignition has occurred
- Fit pressure at top gauge gain btwn points 4-5 (3-4 SSCC_04)



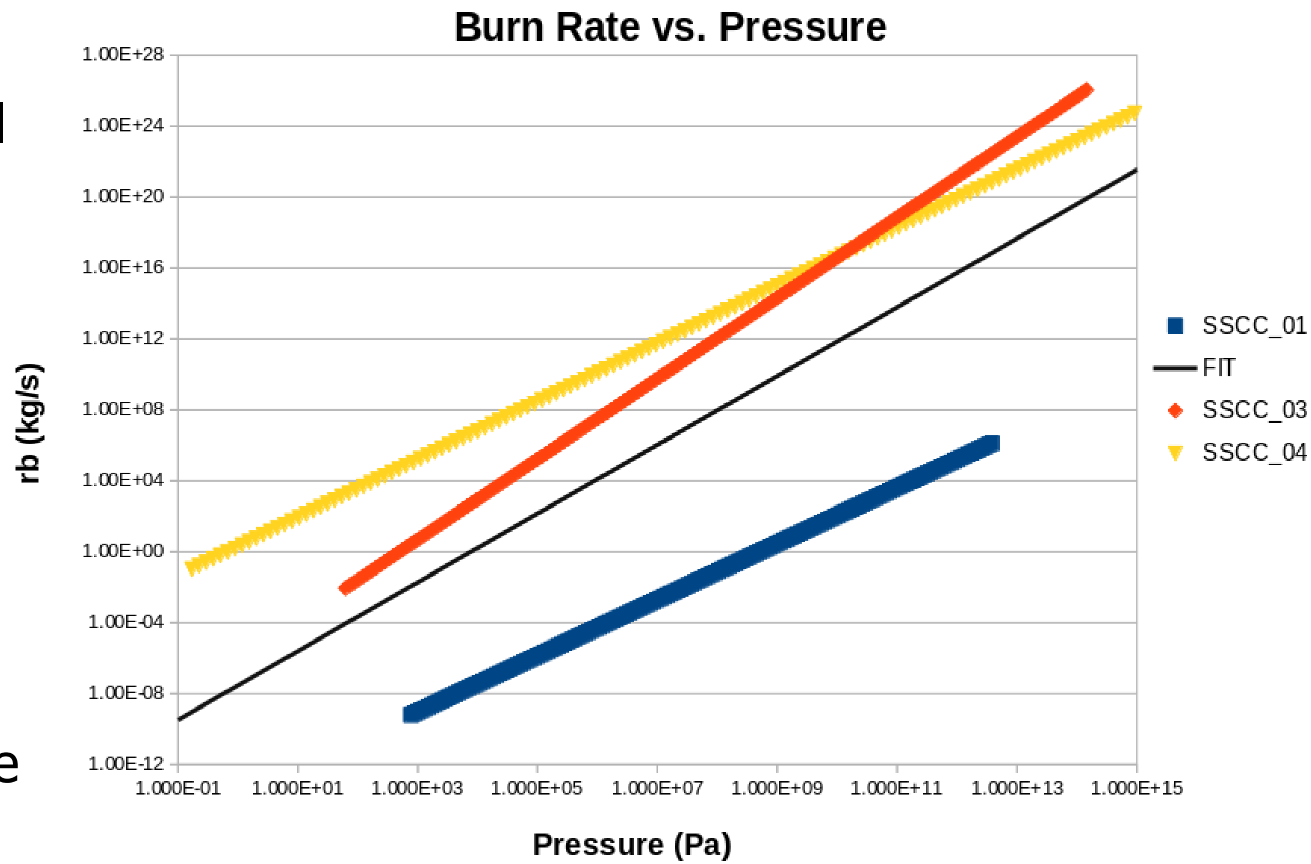






Burn Rate vs. Pressure

- Use burn rate curve fits from experimental data with reported packing densities to obtain $r_b(kg/s)$
- Fit the pressure gain in the chamber using the data from the top pressure gauge
- Need to determine the combustion temperature



$$r_b = b * P^n$$
$$b = 1.4309e^{-4}$$
$$n = 1.5935$$

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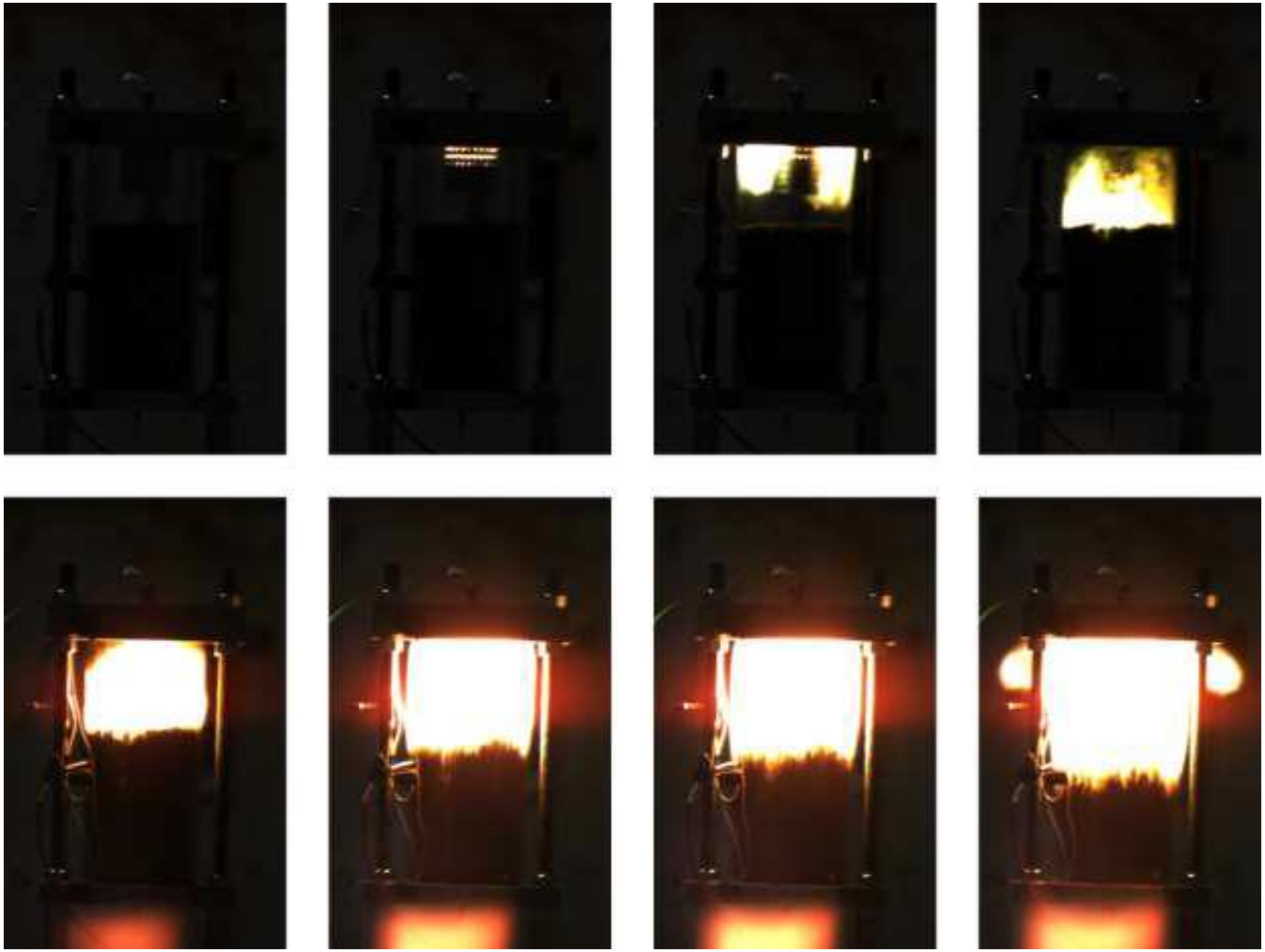
Experimental Images

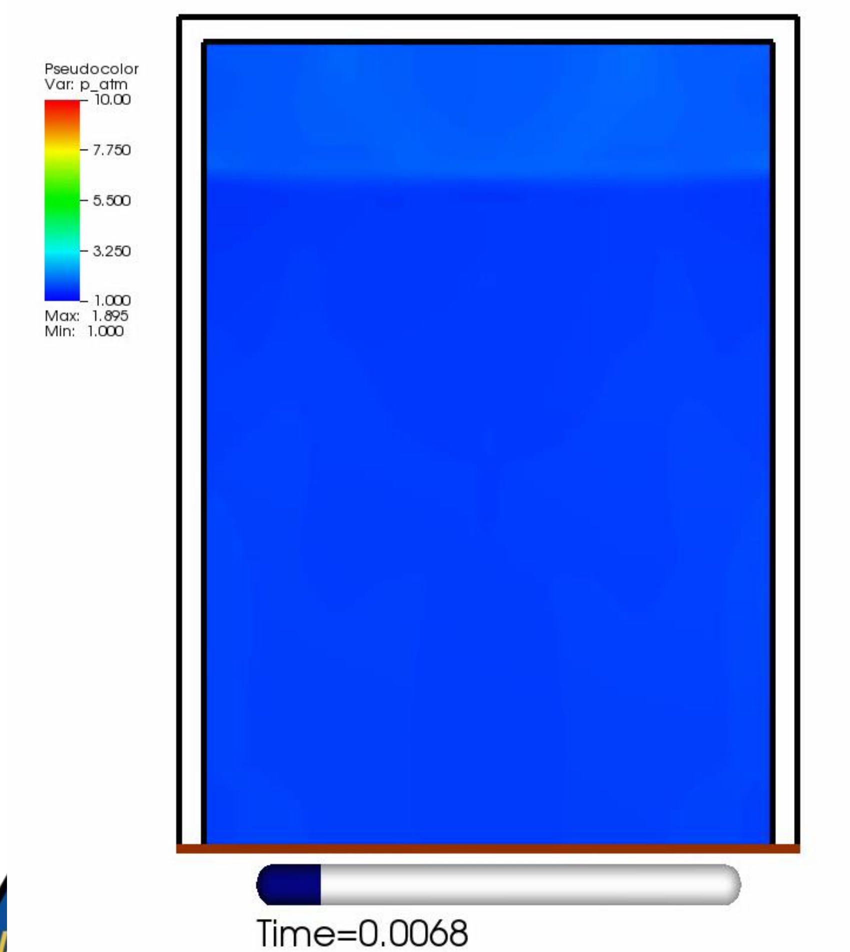
SSCC_03



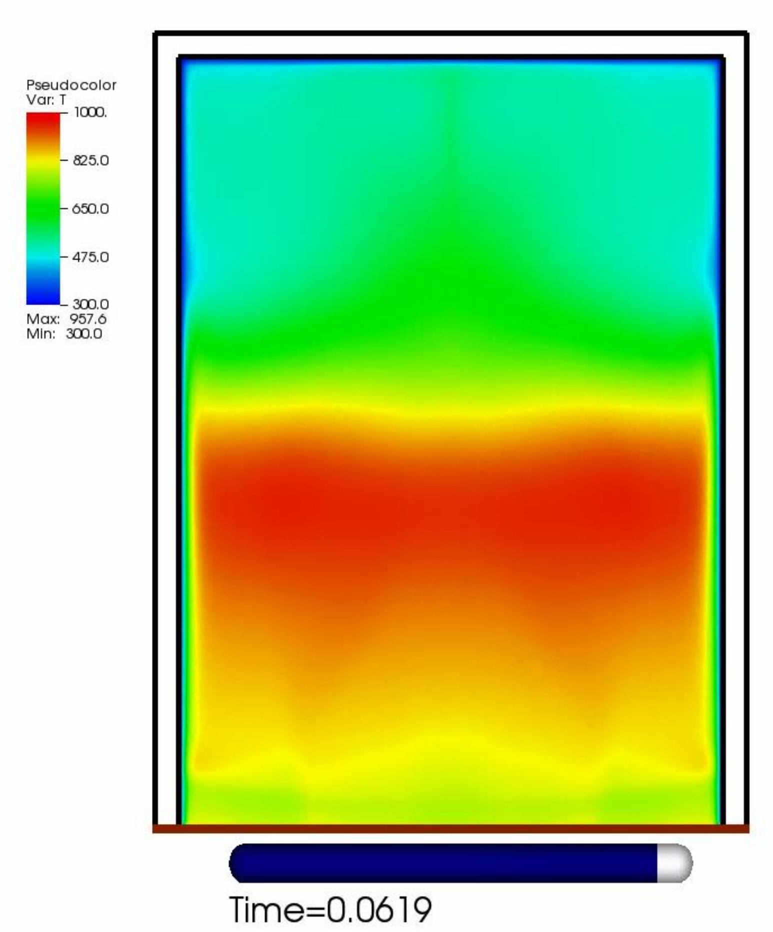
Small Scale Simulations

$T_{comb} = 800K$

Pressure Gain



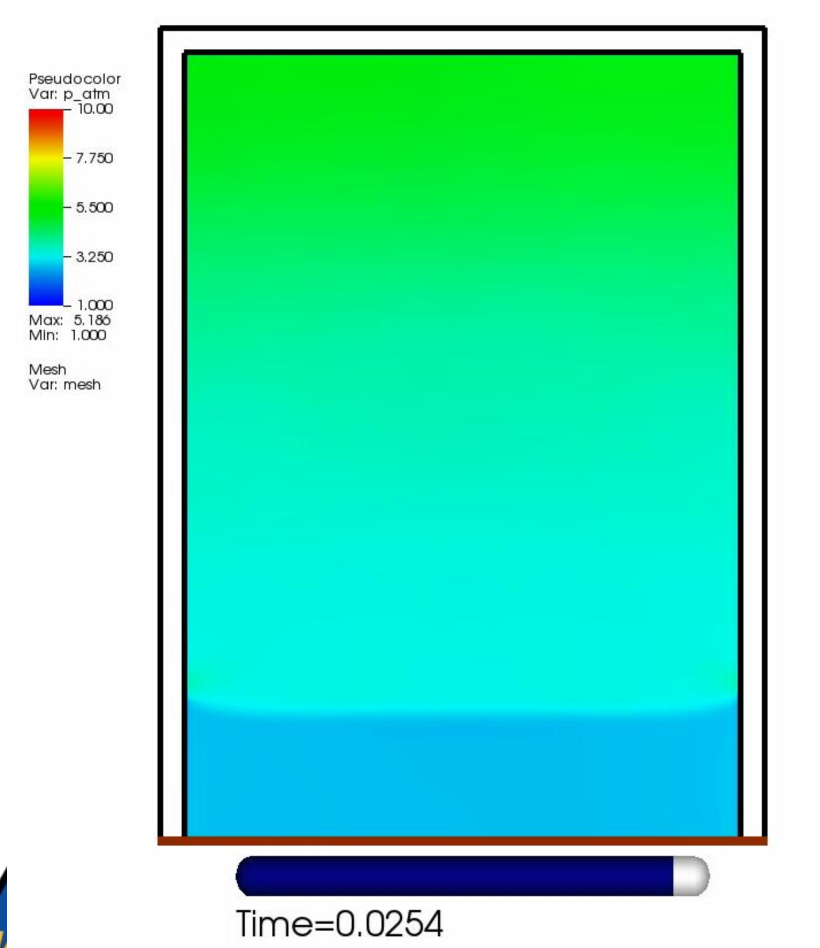
Temperature Gain



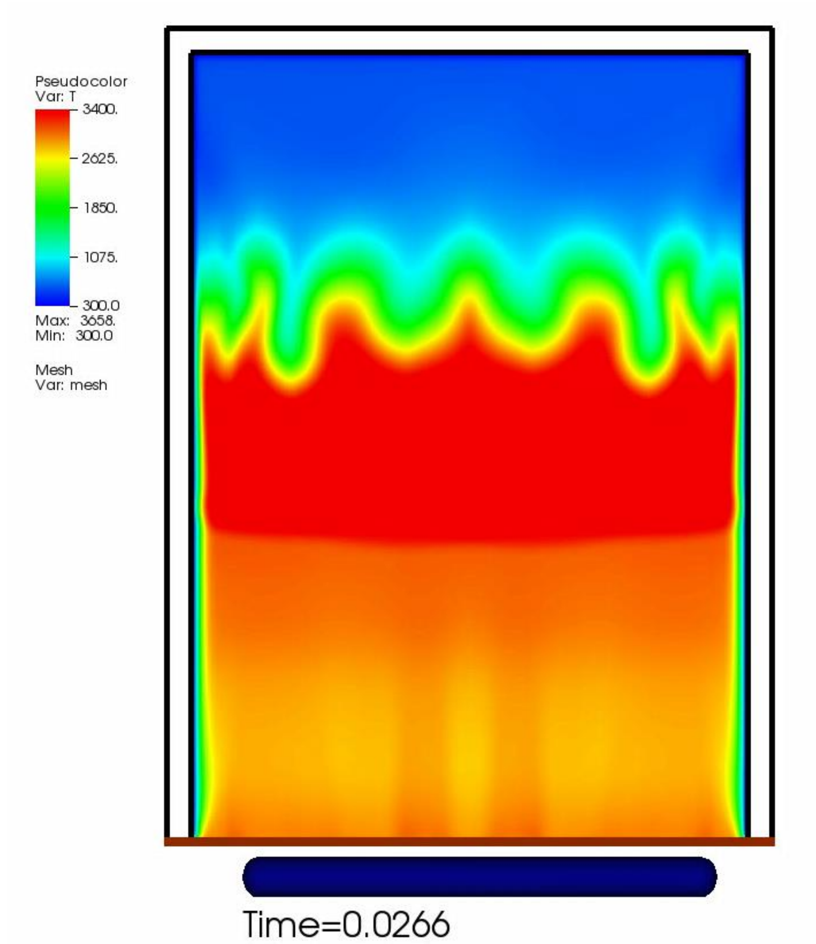
Small Scale Simulations

T_{comb}= 3000K

Pressure Gain



Temperature Gain



Small Scale Simulations

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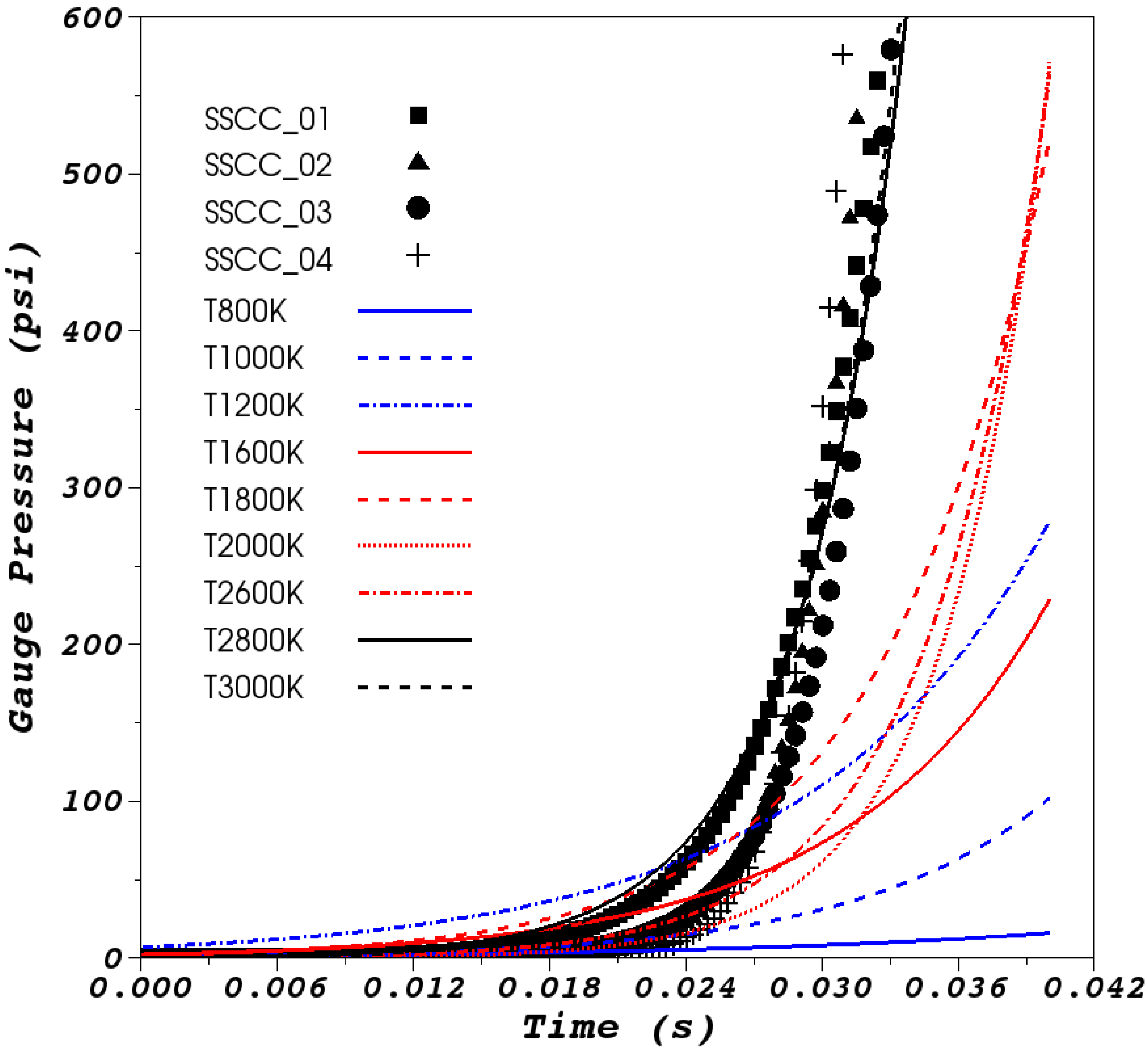
- Fully-compressible N-S equations in 2D
- Time is explicitly resolved
- Burning rate vs. pressure at bottom boundary
- Simulated adiabatic boundaries for walls
- Track pressure rise vs. time
- Conducted sim. for 9 comb. temperatures



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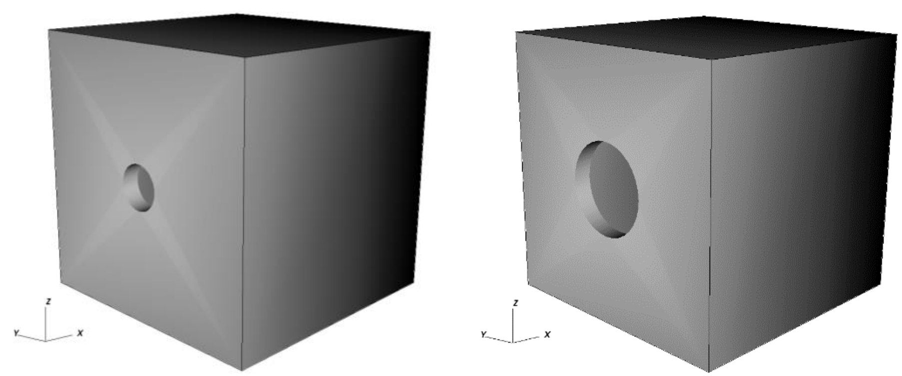
Large Scale Simulations

- Use small-scale experimental and simulation results to estimate large-scale response
- Read solid models into Finite Volume CFD solver to simulate structure boundaries
- Solve fully compressible Navier-Stokes with large eddy simulations (LES) to account for turbulence

Mass: $$\frac{\partial(\bar{\rho})}{\partial t} + \nabla \cdot (\bar{\rho}\tilde{\boldsymbol{u}}) = 0$$

Momentum: $$\frac{\partial(\bar{\rho}\tilde{\boldsymbol{u}})}{\partial t} + \nabla \cdot (\bar{\rho}\tilde{\boldsymbol{u}}\tilde{\boldsymbol{u}}) = \nabla \cdot \left[-\bar{p}\tilde{\boldsymbol{I}} + \tilde{\bar{\boldsymbol{\tau}}} + \tilde{\boldsymbol{T}}_{\boldsymbol{uu}}\right] + \bar{\rho}\tilde{\boldsymbol{g}}$$

Energy: $$\frac{\partial(\bar{\rho}\tilde{e}_t)}{\partial t} + \nabla \cdot \left(\bar{\rho}\tilde{\boldsymbol{u}}\tilde{h}_t\right) = \nabla \cdot \left[\tilde{\mathbf{T}}_{\boldsymbol{u}h} + \tilde{\mathbf{T}}_{\boldsymbol{uu \cdot u}} + \overline{\mathbf{u} \cdot \tilde{\boldsymbol{\tau}}} - \bar{\boldsymbol{q}}\right] + \bar{\rho}\tilde{\boldsymbol{u}} \cdot \tilde{\boldsymbol{g}}$$



Large Scale Simulations

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Simulation Test Cases

Test	Drums	Loading Density $\left(\frac{kg}{m^3}\right)$	Vent Diameter (cm)	Vent-Area-Ratio
1	3	15	9	0.00159
2	3	15	29	0.01651
3	3	15	39	0.02987
4	3	15	59	0.068349
5	3	15	69	0.09348
6	3	15	79	0.12254
7	3	15	99	0.19244
8	8	63	9	0.00159
9	8	63	29	0.01651
10	8	63	39	0.02987
11	8	63	59	0.068349
12	8	63	69	0.09348
13	8	63	79	0.12254
14	8	63	99	0.19244

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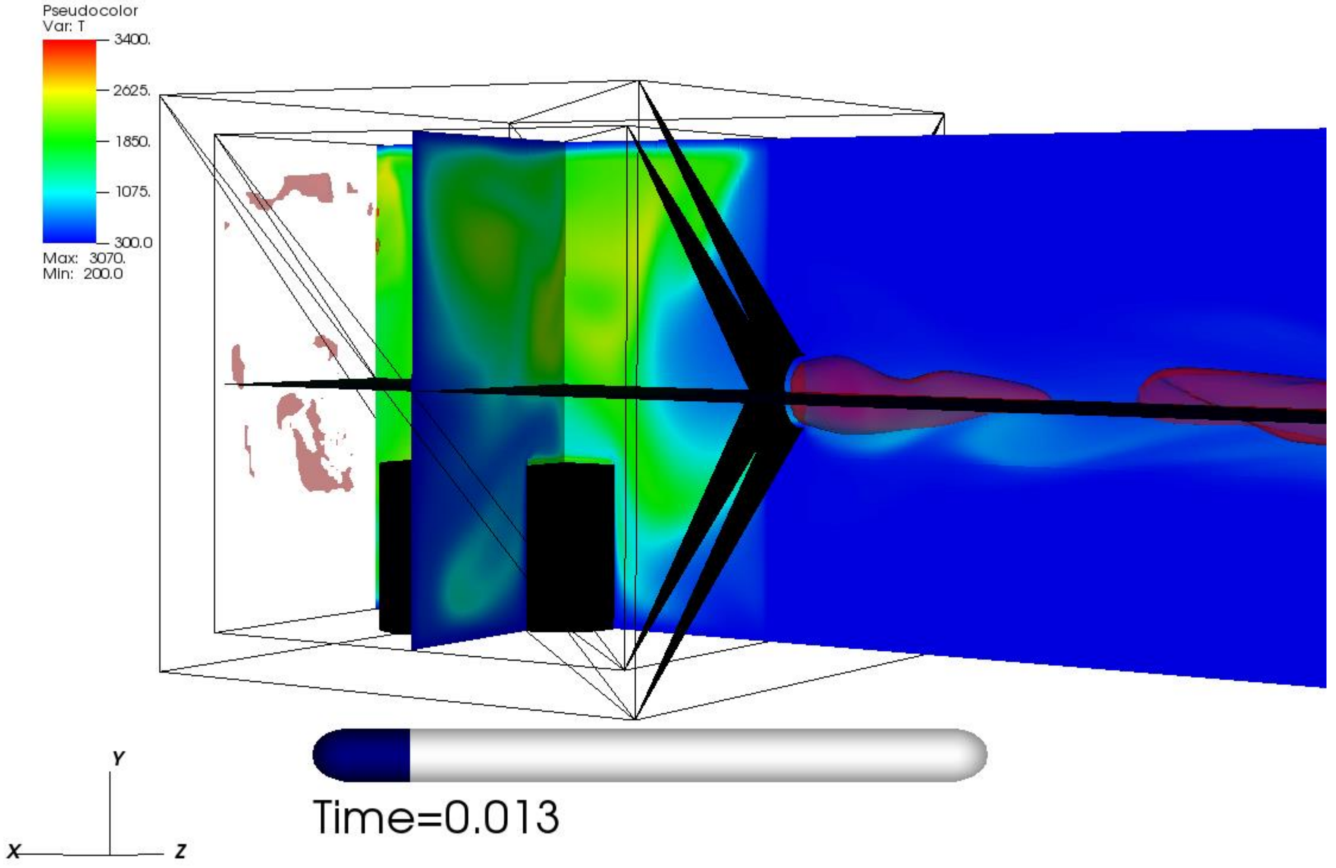
$$* \; VAR = \frac{\pi\left(\frac{D}{2}\right)^2}{V^{\frac{2}{3}}}$$

Large Scale Simulations

- Case 2
- 3 drum
- 15 kg/m^3
- D = 29 cm
- VAR = 0.01651

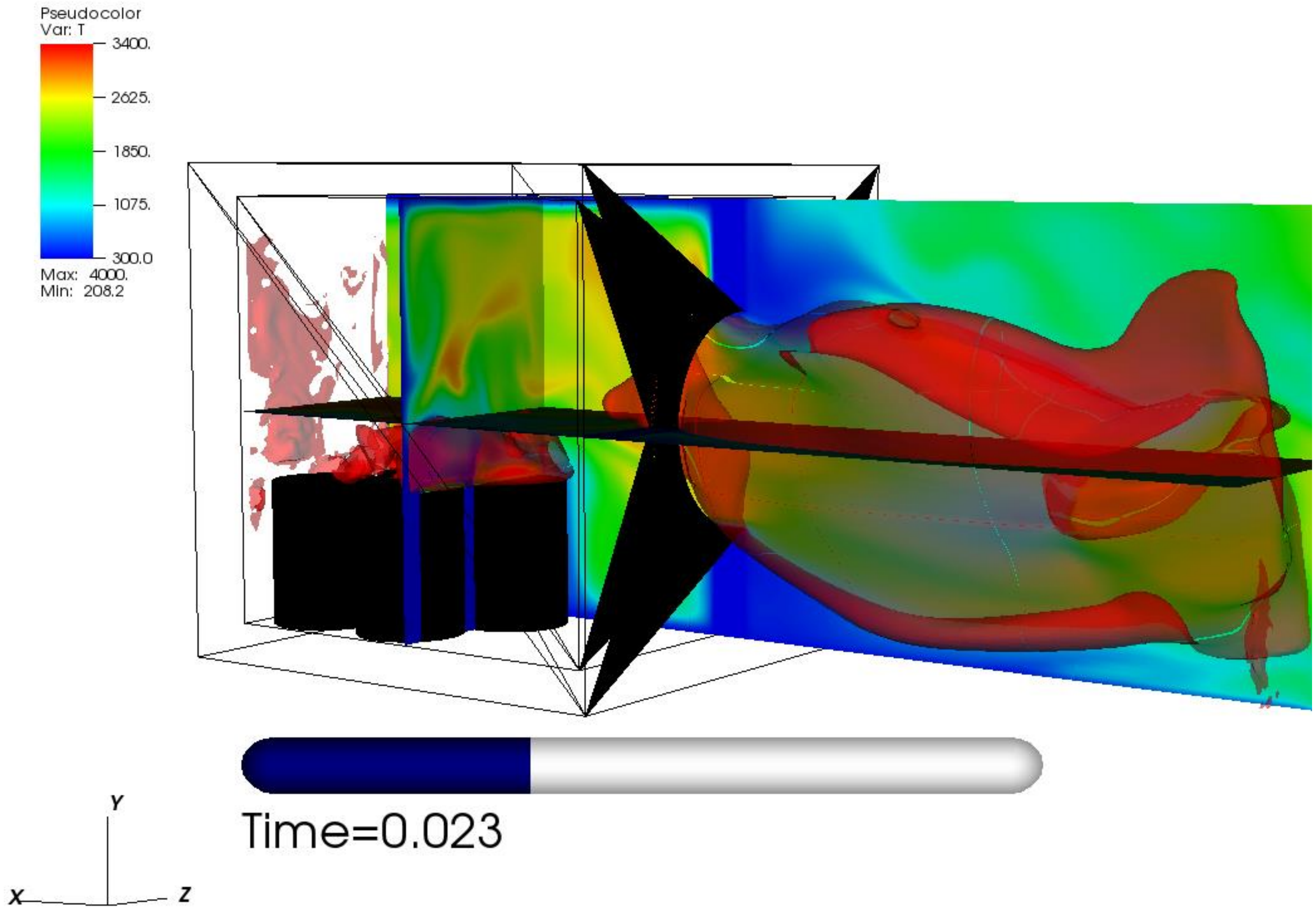
- Temperature in 3 slices
- Contour is Mach number of 1



Large Scale Simulations

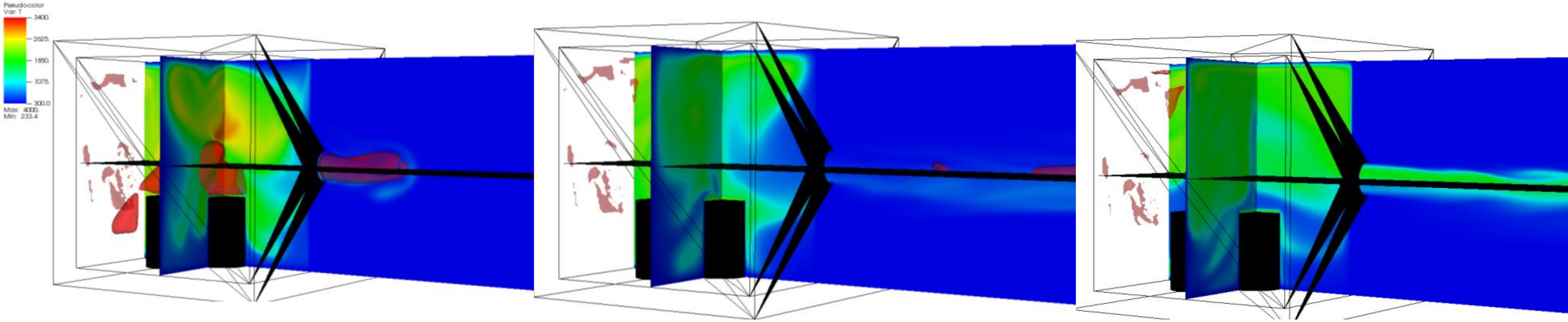
- Case 14
- 8 drum
- 63 kg/m^3
- D = 99 cm
- VAR = 0.19244

- Temperature in 3 slices
- Contour is Mach number of 1

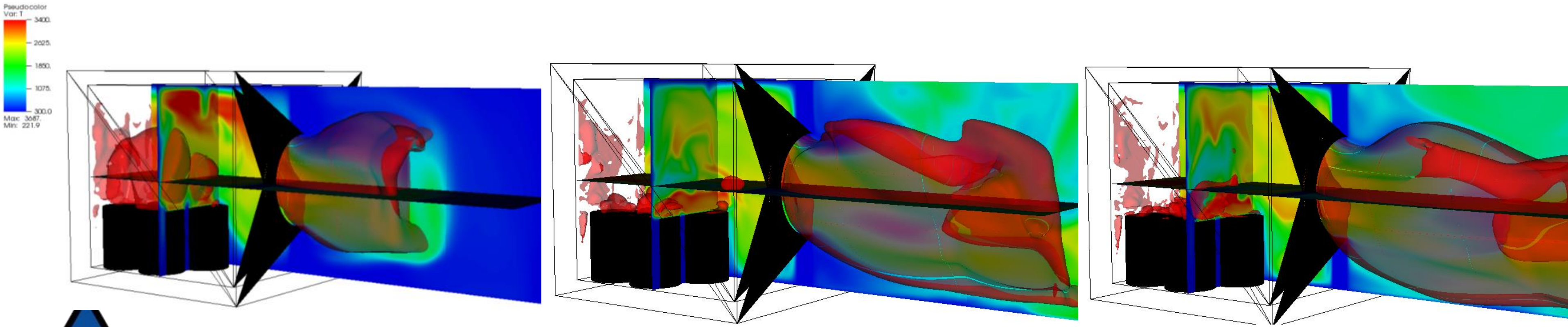


Large Scale Simulations

3 Drum D = 29 cm



8 Drum D = 99 cm



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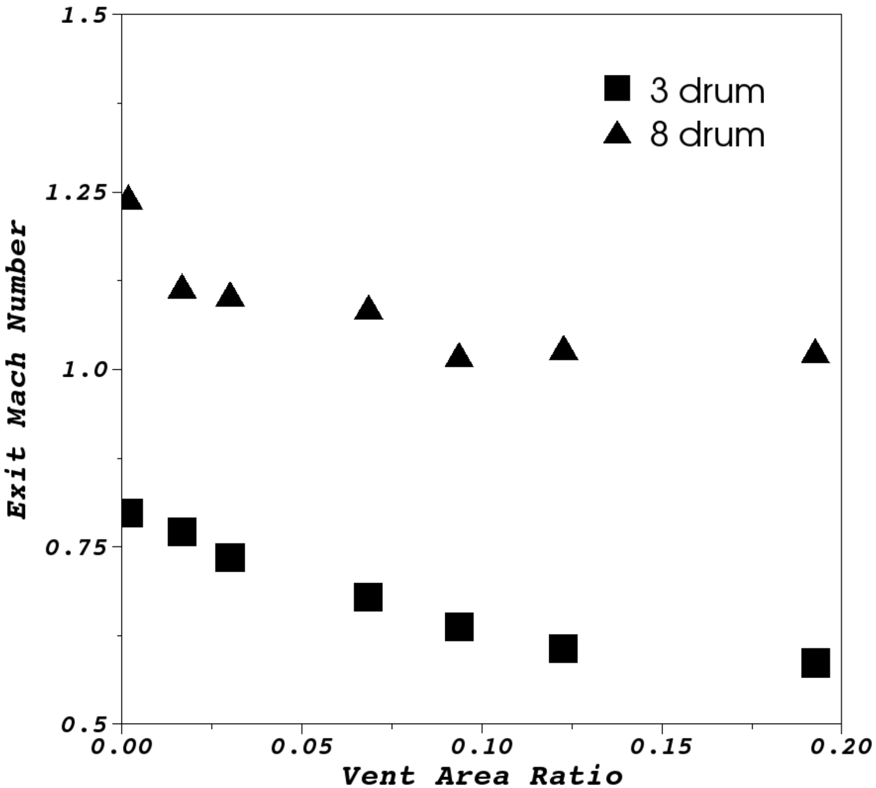
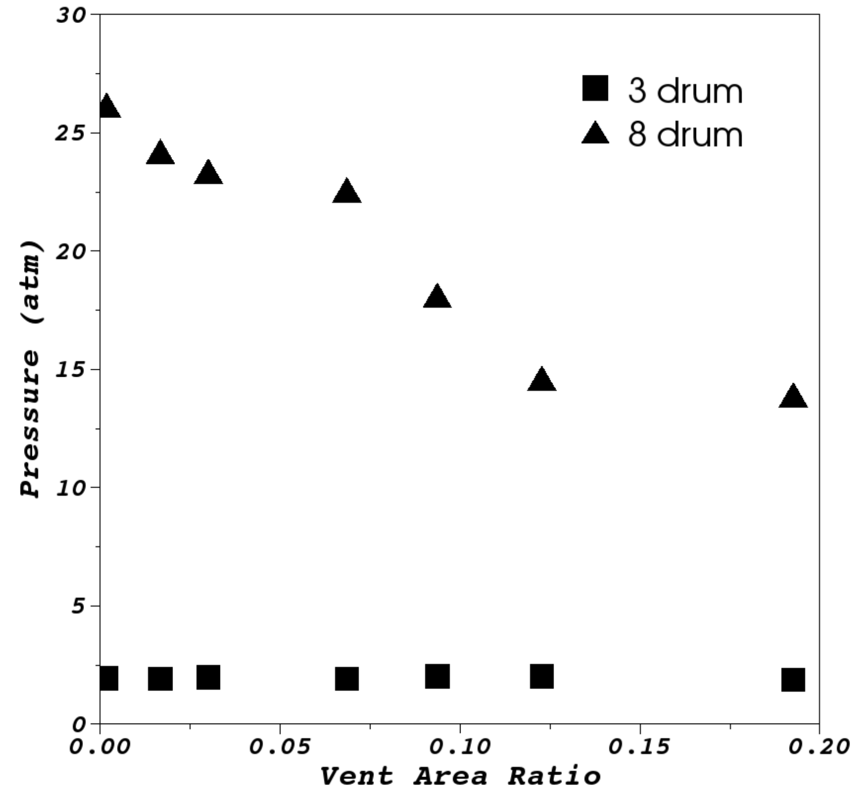
Large Scale Simulations

- Exit Ma number vs. VAR for 3 and 8 drum case
  - 3 drum: never choked. 8 drum: always choked
- Max gauge pressure vs. VAR
  - Const. P for 3 drum, significant inc. in max P for 8 drum case

Ma Vs. VAR



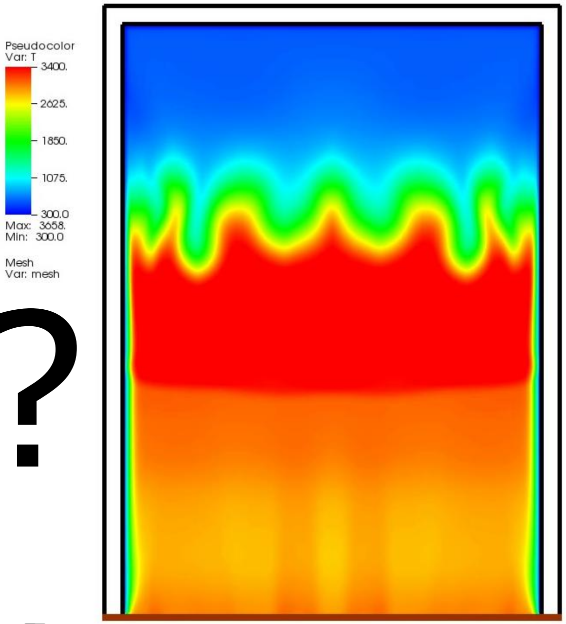
Max P_g Vs. VAR



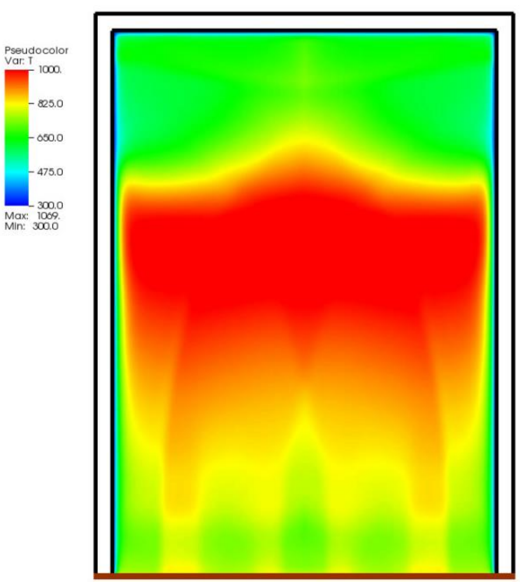
Conclusions

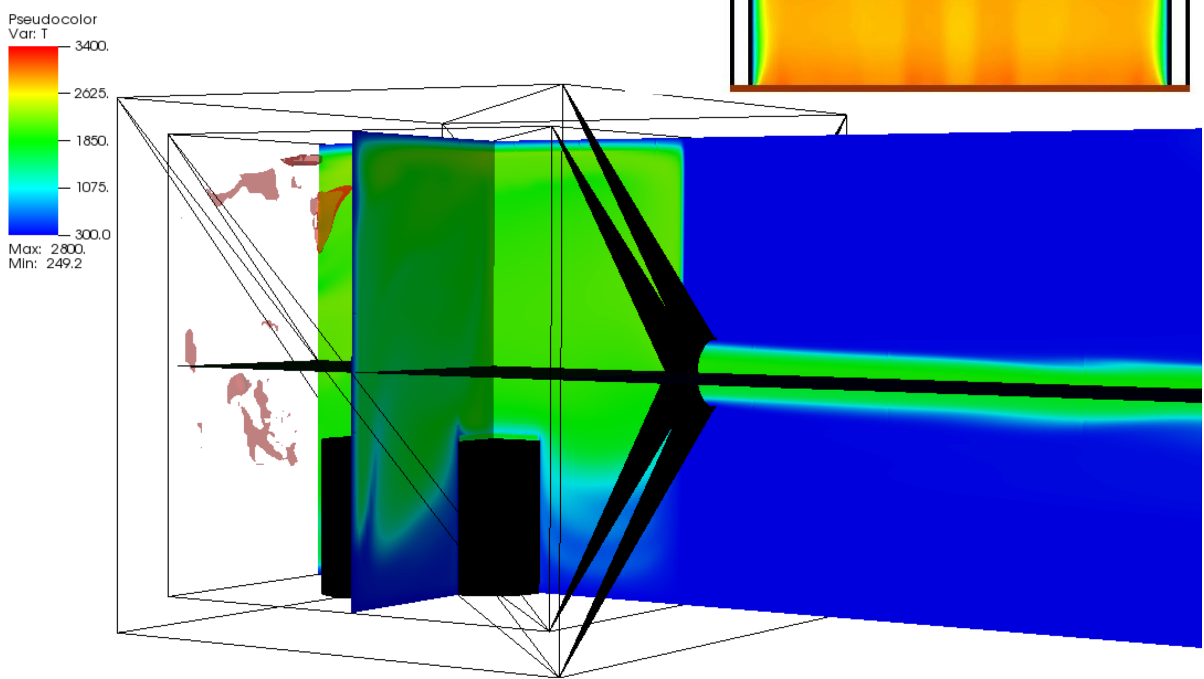
- Developed a burn rate model based on experimental results of small-scale convection combustion tests
- Used detailed 2D simulations to determine the combustion temperature that best matched the pressure rise of small-scale tests
- Conducted large scale 3D simulations using the developed model to study effects of loading density and vent-are-ratio
- Pressurization and choked flow is highly dependent on loading density
  - Pressurization is extreme only under choked flow conditions
- Next step investigate different loading densities and observe changes in ejection Ma number and pressurization

Thank You!



Questions?

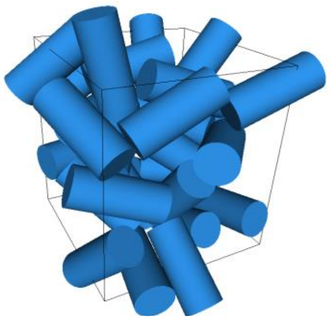




Supporting Slides

Supporting Experimentalists

Pack32



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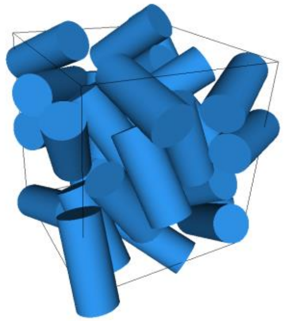

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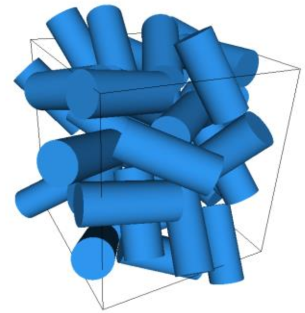

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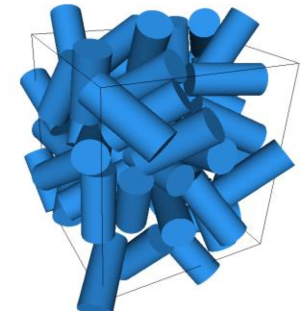

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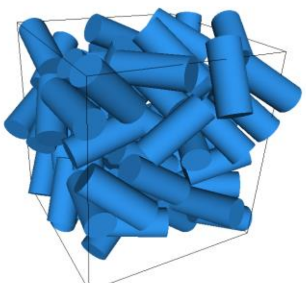
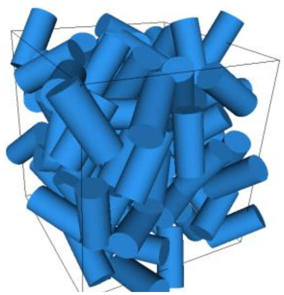
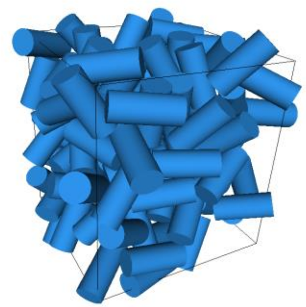


Pack100



Pack120



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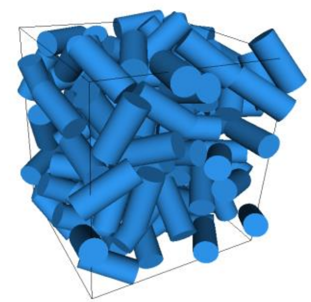

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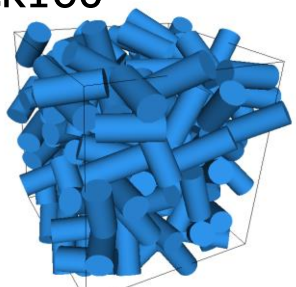

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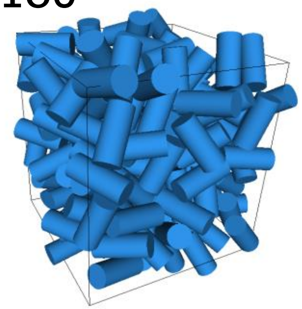

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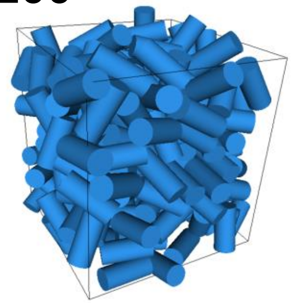
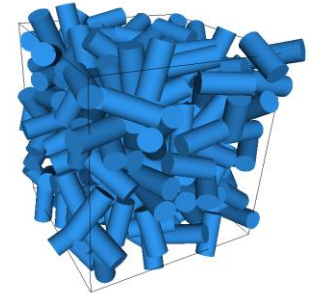


Pack250



Supporting Experimentalists

Pack #	scaling	L (in)	r (eff)	D (in)	pac. frac.
32	0.985474	0.87335359	0.492737	0.985474	0.512347
33	0.995635	0.88235854	0.4978175	0.995635	0.506632
40	1.06157	0.94079192	0.530785	1.06157	0.5072
60	1.215194	1.07693764	0.607597	1.215194	0.50657
80	1.337494	1.1853232	0.668747	1.337494	0.506488
100	1.440772	1.27685094	0.720386	1.440772	0.50688
120	1.531049	1.35685685	0.7655245	1.531049	0.506829
140	1.611776	1.42839929	0.805888	1.611776	0.506911
160	1.685137	1.49341378	0.8425685	1.685137	0.507552
180	1.752613	1.55321283	0.8763065	1.752613	0.507355
200	1.815259	1.6087314	0.9076295	1.815259	0.507118
250	1.955428	1.73295294	0.977714	1.955428	0.506839
300	2.077952	1.84153701	1.038976	2.077952	0.506033
400	2.287082	2.02687365	1.143541	2.287082	0.506488

- Take slices of the packing configurations to determine distribution of void within the pack