Turbulence in fire simulation and the modelling of turbulence in the Fire Dynamic Simulator

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Turbulence is a challenge

- Entrainment in fire plume
- Ceiling jets
- Interface between hot layer and cold layer
- Detection
  - Heat transfer
- Sprays

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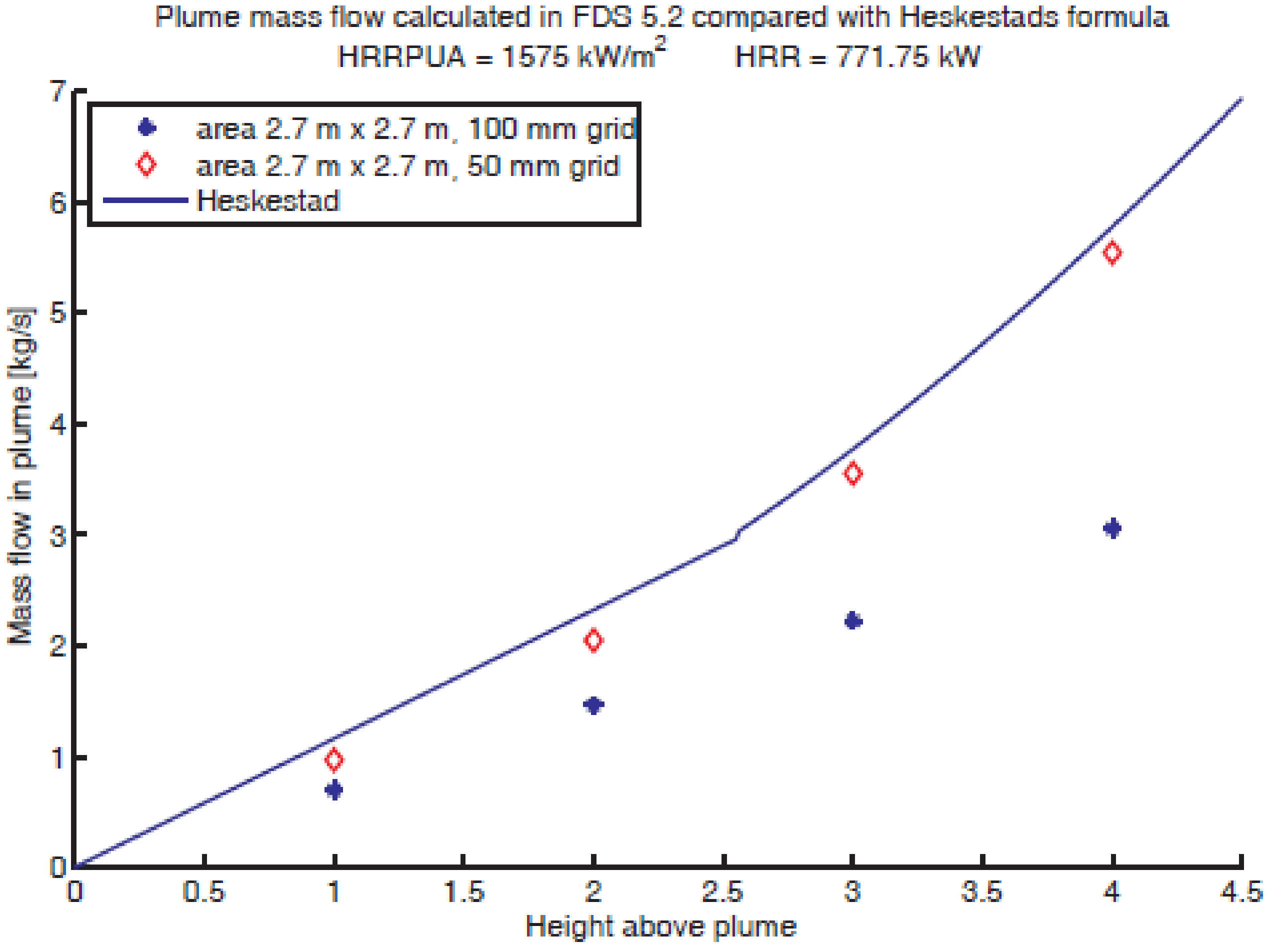
Plume mass flow



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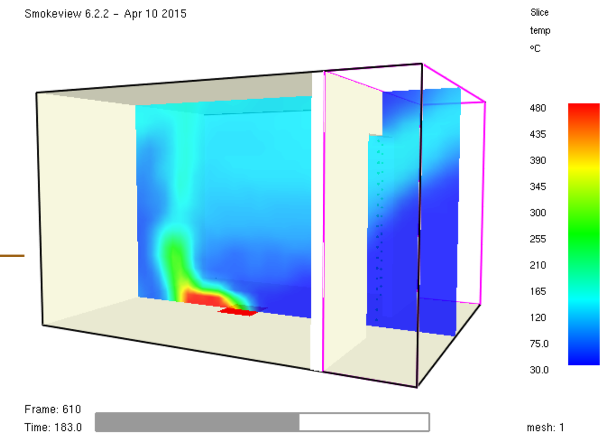
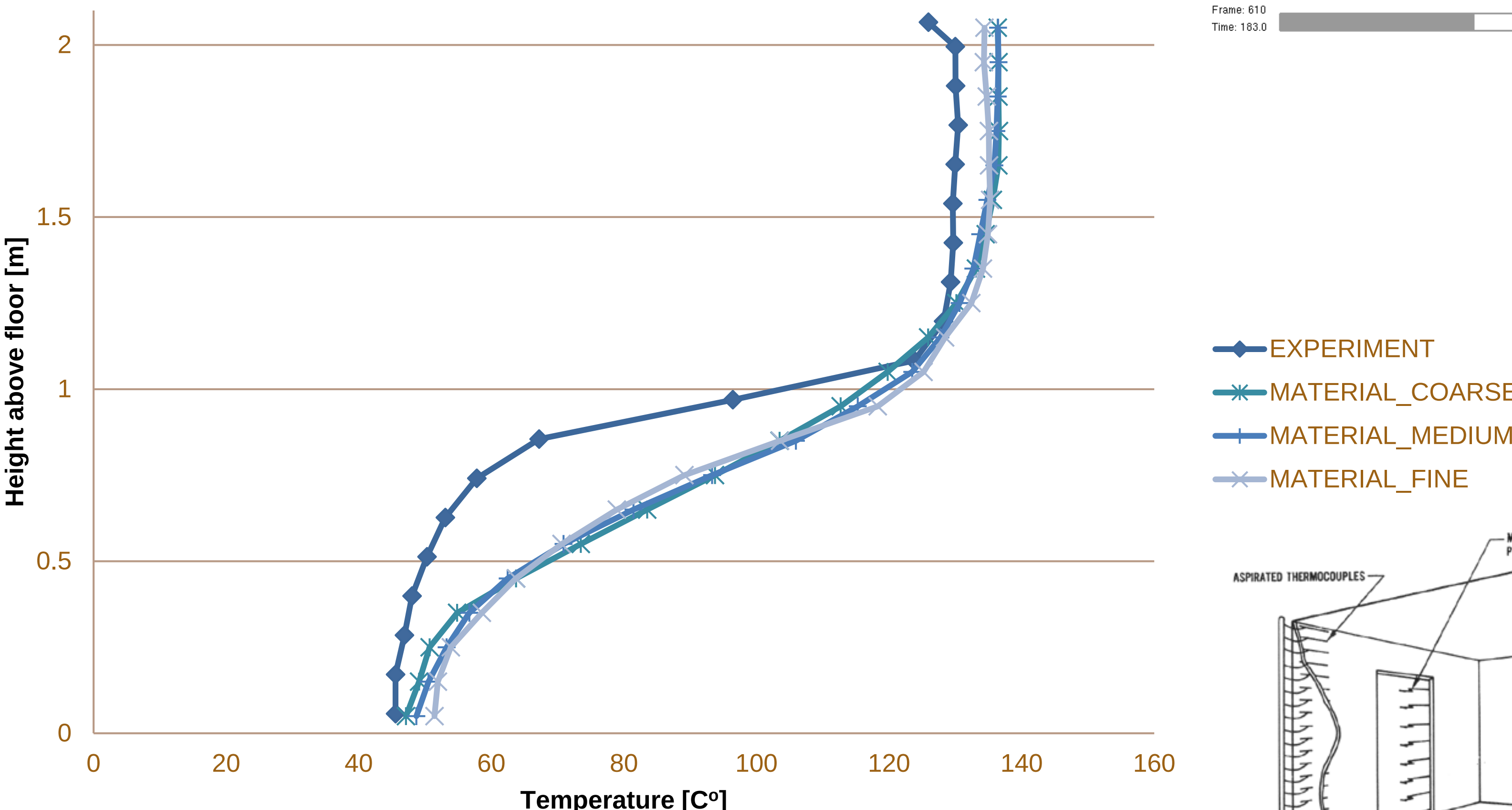
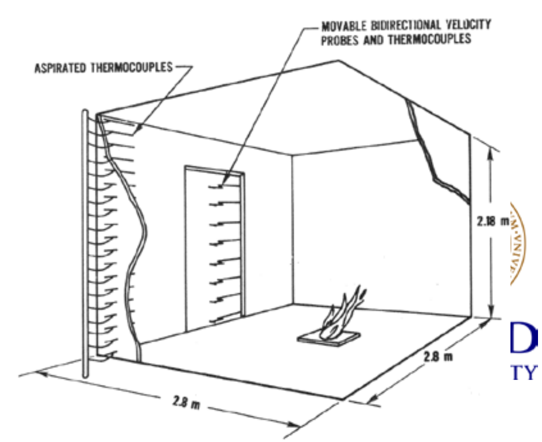
Steckler room (example)



Temperature corner grid



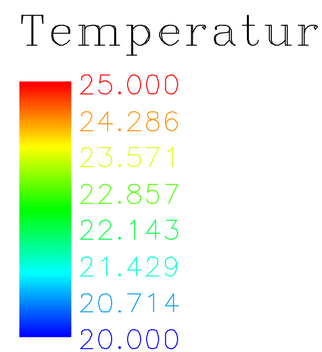


RANS versus LES

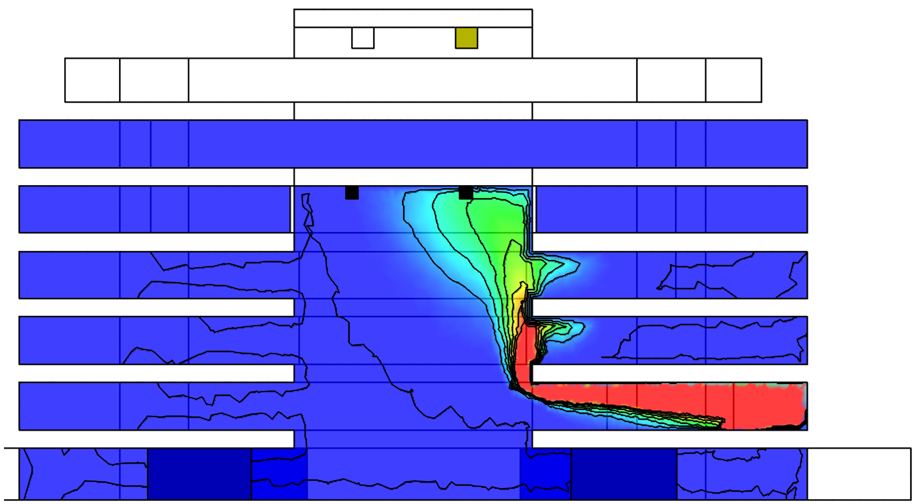
Kontorhus med atrium

1 MW fast brand – mekanisk udsugning

90 sekunder

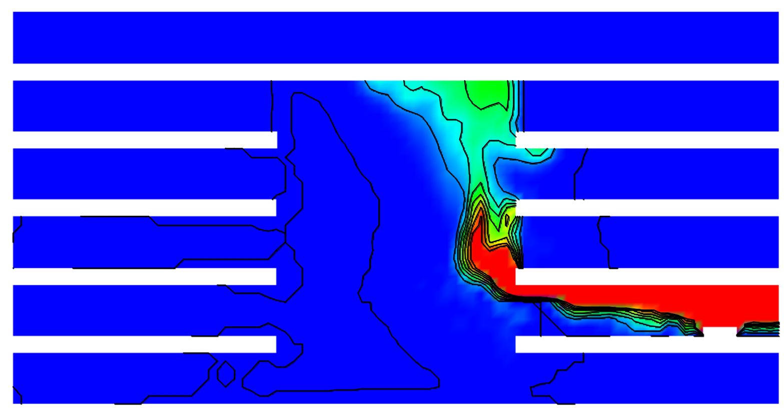


RANS model



CFX 5.7

LES model



FDS 4.03

DBI 2004

Grid resolution in FDS

- How do I ensure that my grid is fine enough ?

- Several methods exists, some examples

  - Use D* (Characteristic fire diameter)
  - Look at figure, which you want to evaluate
  - Calculate resolved turbulent energy

Using D* to determine grid size (Characteristic fire diameter)

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}} \right)^{\frac{2}{5}}$$

FDS Users Guide

4 < D*/dx <16

Danish best practice:

D*/dx >10

Ref:

Anwendung von CFD-Programmen für brandtechnische Berechnungen. / Carlsson, Jörgen; Husted, Bjarne; Göransson, Ulf; Dederichs, Anne. vfdb-Zeitschrift, Vol. 3, 2006, p. 127-131.

Calculation of D*

- For a fire of 2.1 MW

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}}$$

$$D^* = \left(\frac{2 \qquad 1}{1.2 \cdot 1.0 \cdot 0\,2 \quad .1 \cdot 9\sqrt{9.8\,1\,5}}\right)^{0}_{3} = 1.2^{\;0}_{\;1} \approx 1.2\; m$$

Or this website: http://www.koverholt.com/fds-mesh-size-calc/

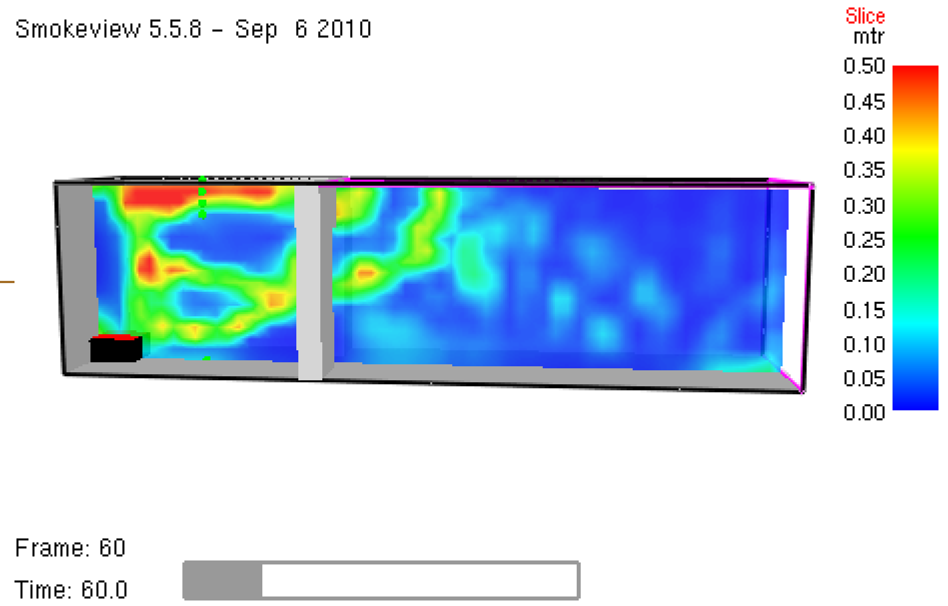
Grid size

D*/dx (D*=1.29m)	Grid size
4	32 cm
8	16 cm
16	8 cm

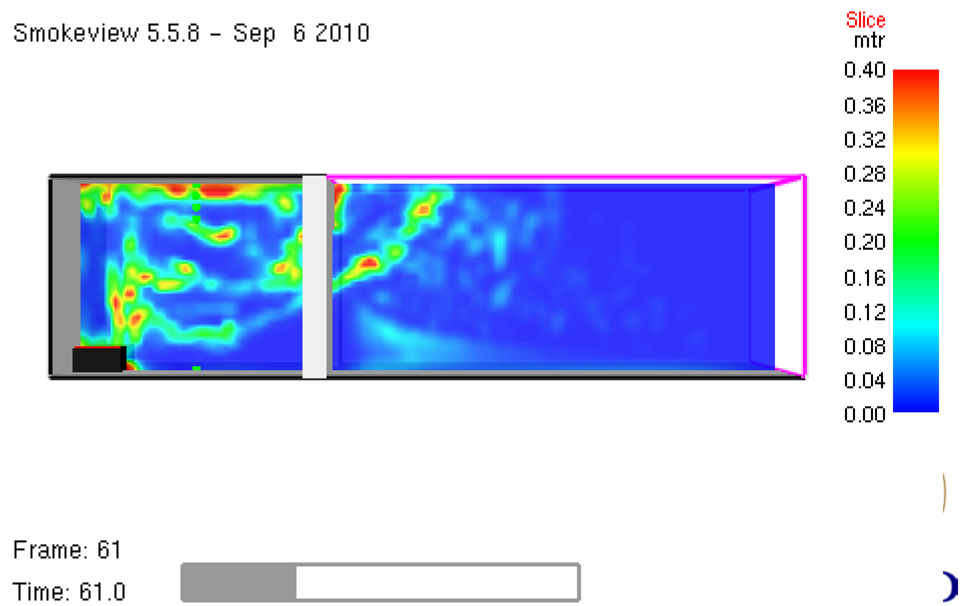
Each time you double the number of grid nodes, calculation time goes up by about a factor 16.
2^3 more cells and half the time step.

Example two different grid size in room corner

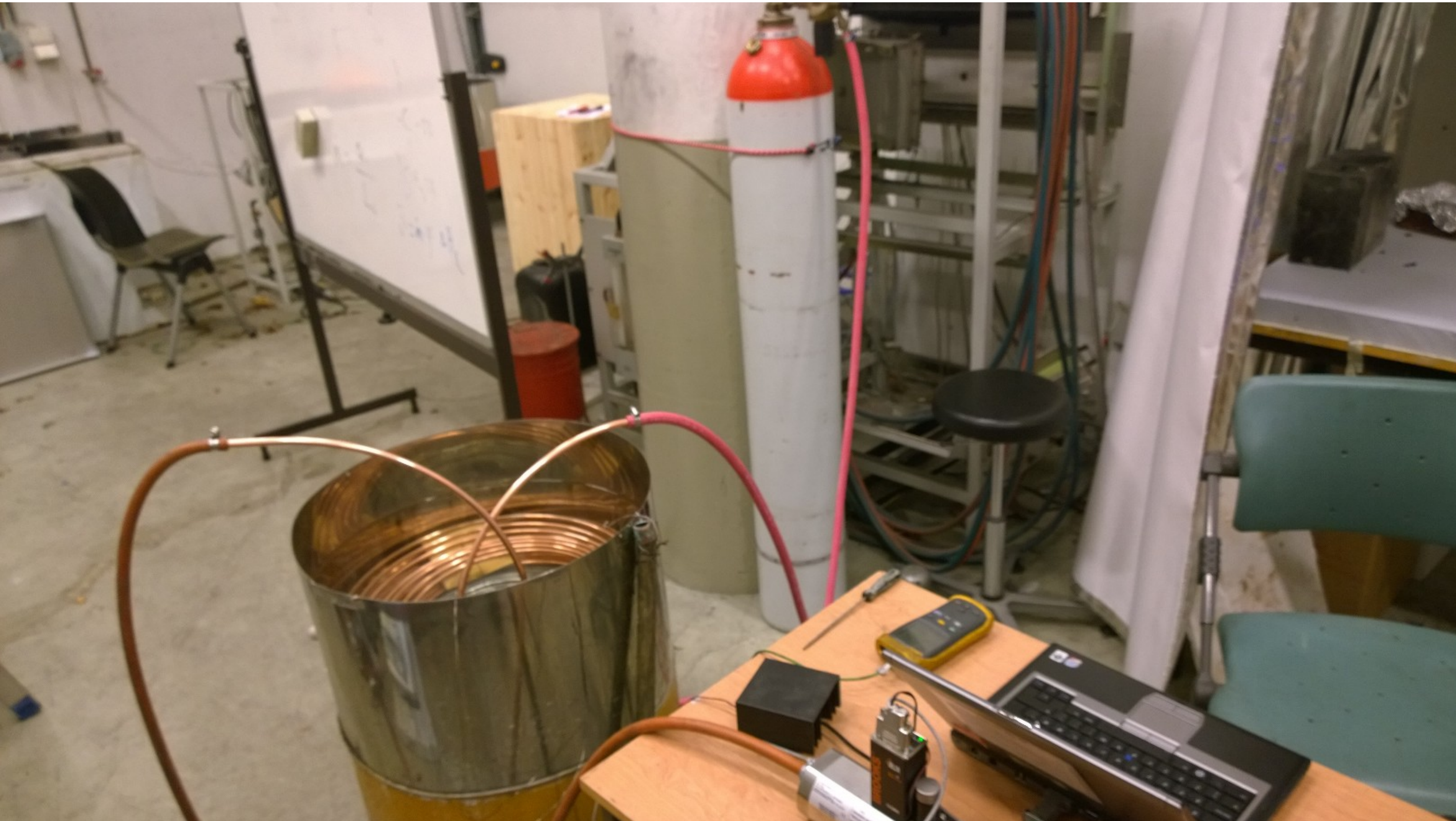
50 mm grid



25 mm grid



Pulsation of a flame



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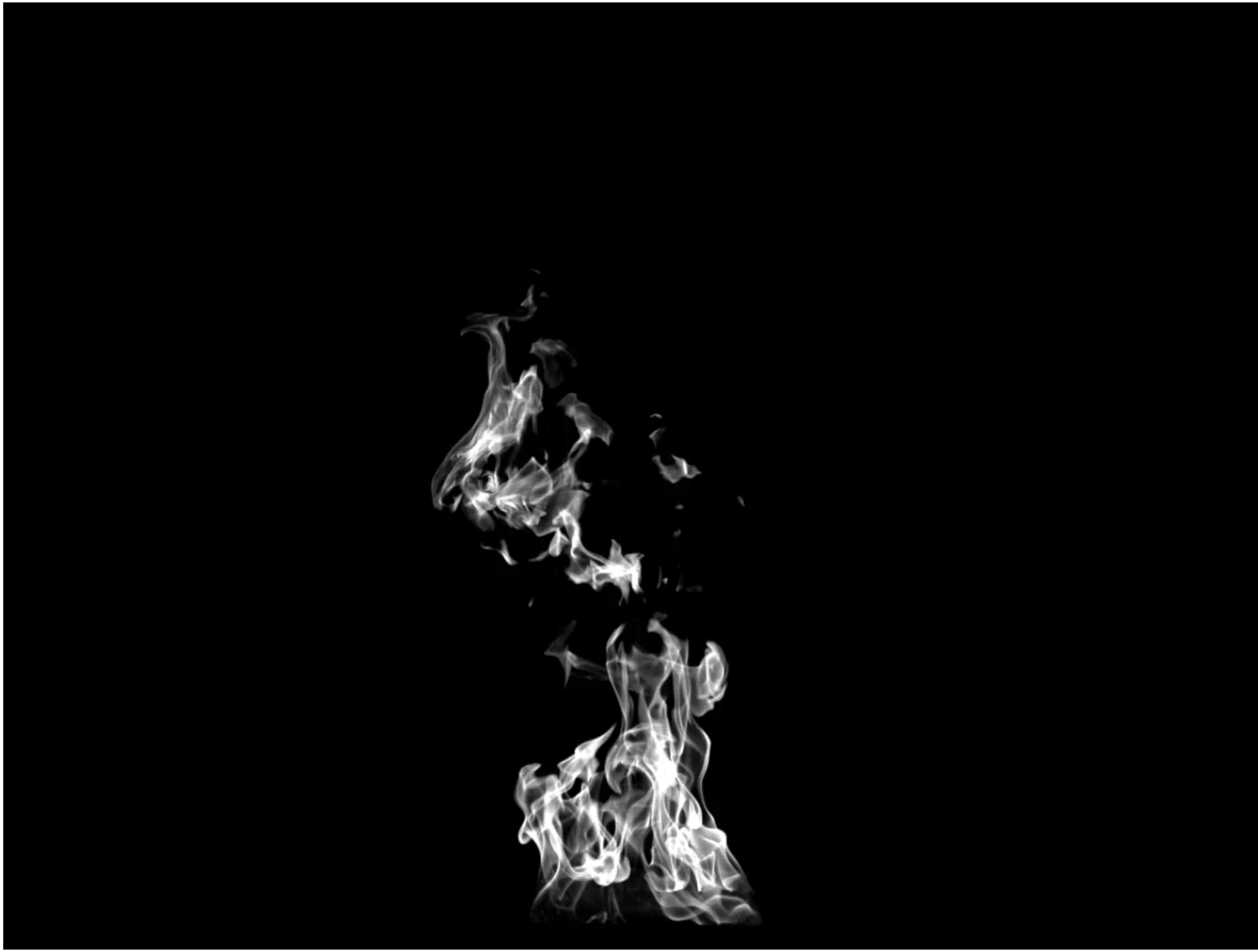
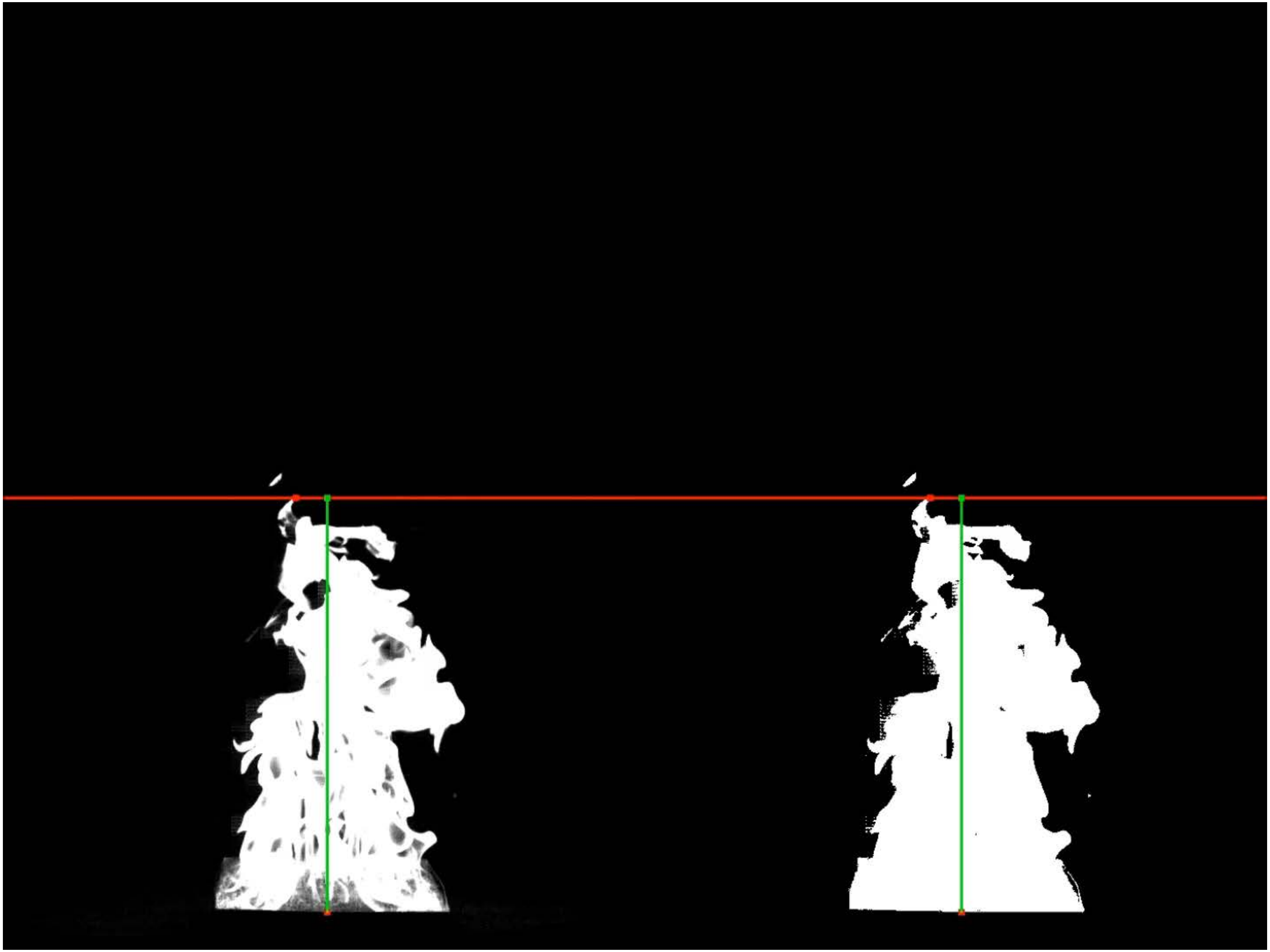
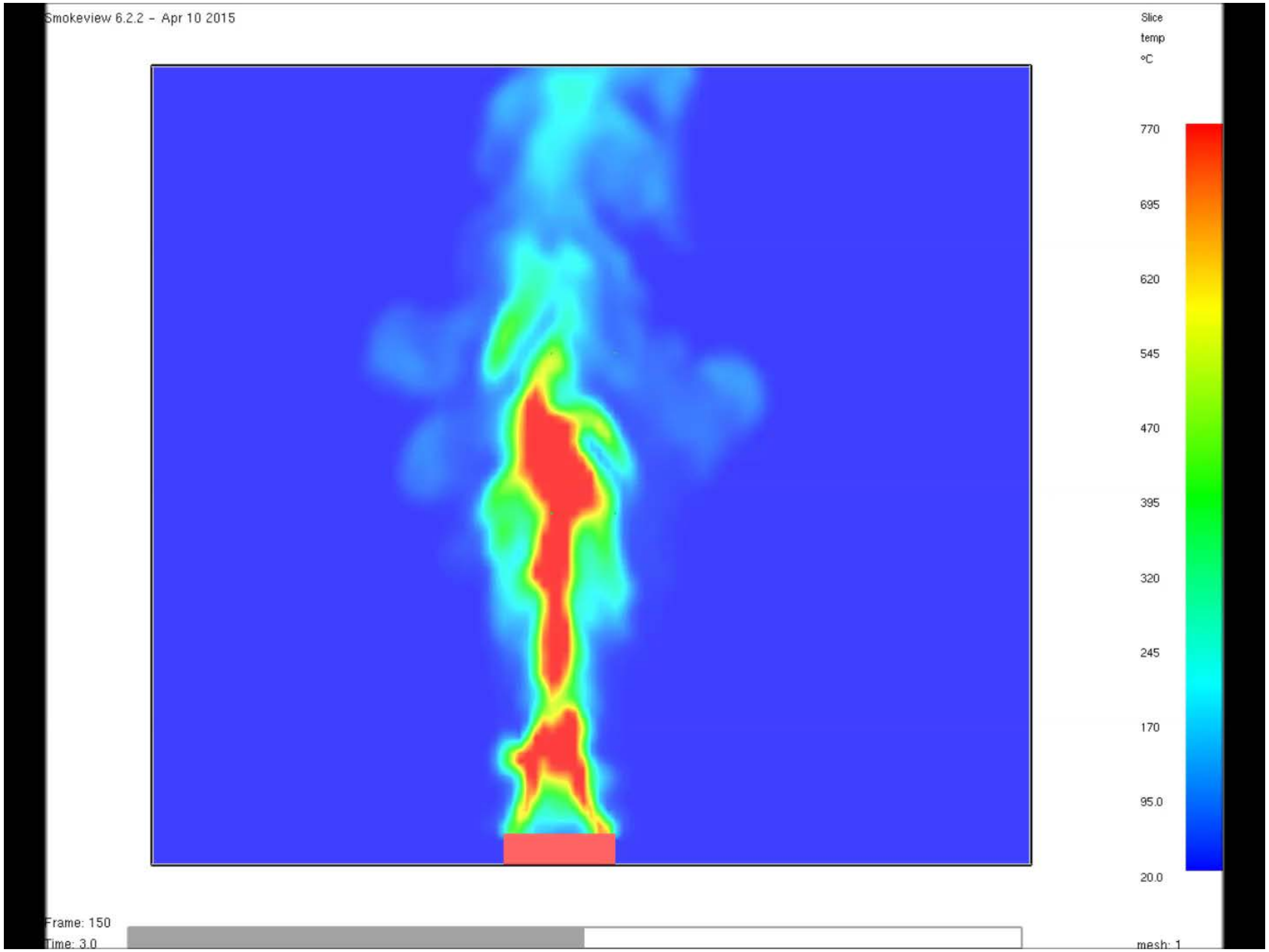
High speed image of methane flame (1000 Hz)



Flame height



Energy spectrum of frequencies using FFT in Matlab



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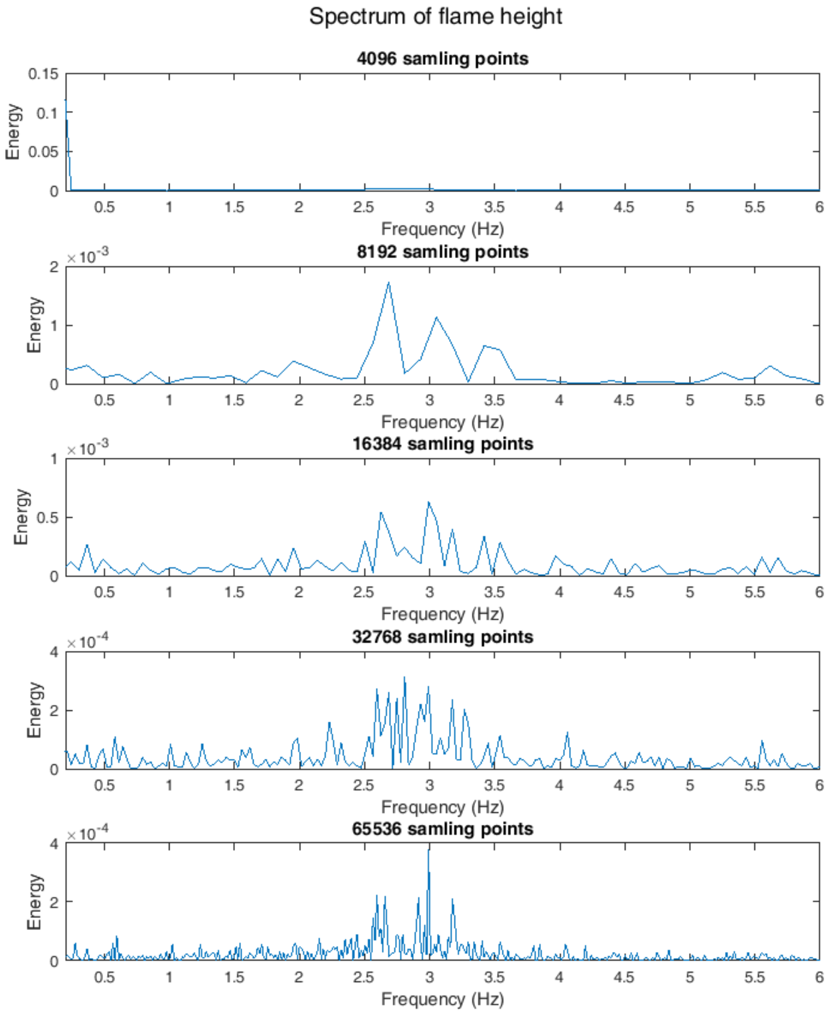
Energy spectrum of frequencies using FFT in Matlab on simulations in FDS



Simple correlation from
SFPE Handbook, 3. ed. Page 2-15
Gunnar Heskestad
Fire Plumes, Flame height and air entrainment

$$f(Hz) = 1.5 \cdot \frac{1}{\sqrt{D(m)}}$$

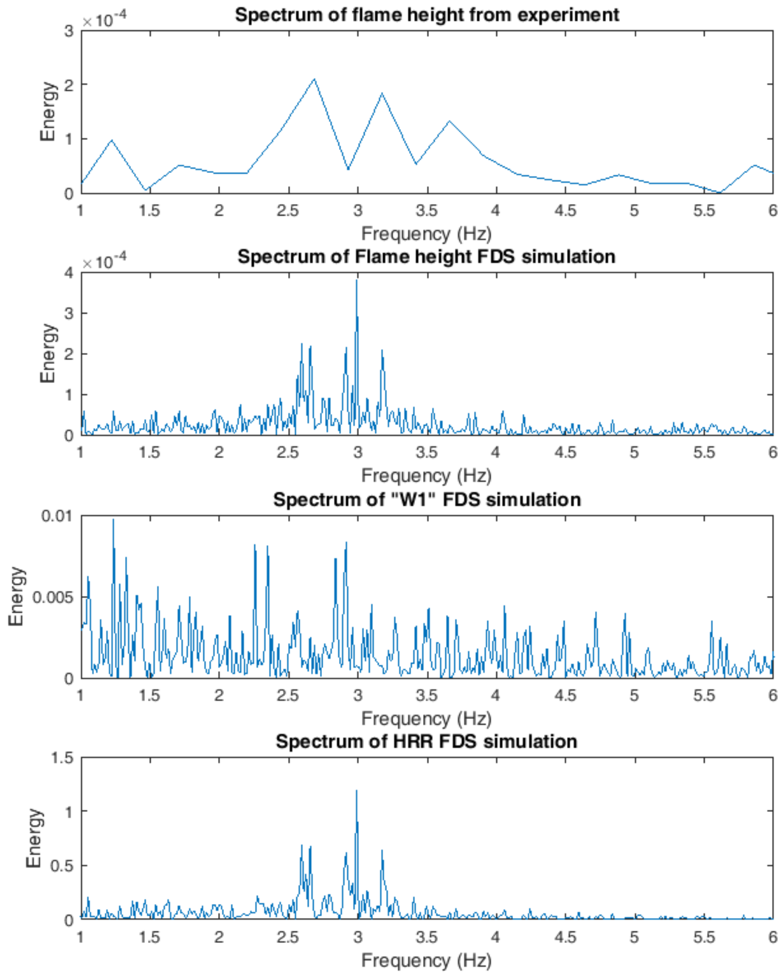
Example:

Square fire $0.3m x 0.3m$

$$D_h = \frac{4 \cdot A}{Perimeter} = \frac{4 \cdot 0.3 \cdot 0.3}{4 \cdot 0.3} = 0.3m$$

$$f(Hz) = 1.5 \cdot \frac{1}{\sqrt{D(m)}} = 1.5 \cdot \frac{1}{\sqrt{0.3}} = 2.7\ Hz$$

Energy spectrum of frequencies using FFT in Matlab on simulations in FDS



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Example:

Square fire 0.3*mx*0.3*m*

$$D_h = \frac{4 \cdot A}{Perimeter} = \frac{4 \cdot 0.3 \cdot 0.3}{4 \cdot 0.3} = 0.3m$$

$$f(Hz) = 1.5 \cdot \frac{1}{\sqrt{D(m)}} = 1.5 \cdot \frac{1}{\sqrt{0.3}} = 2.7\ Hz$$

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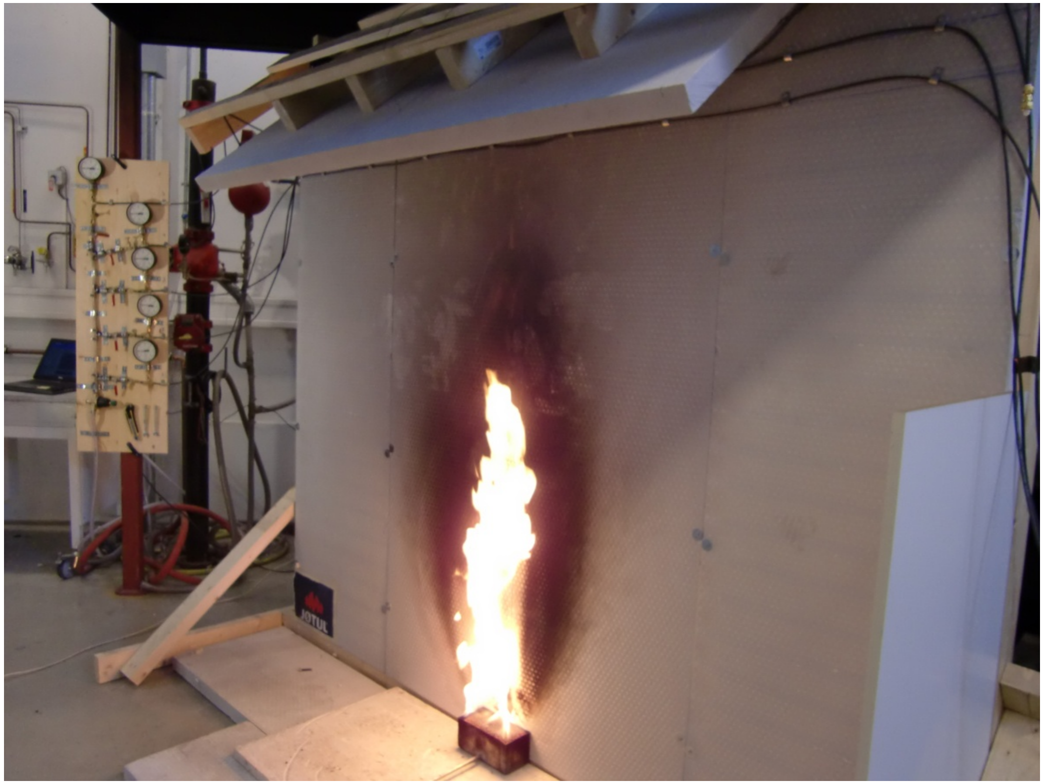
Detection on a wall: Y^+ (yplus)

- Y^+ is a nondimensional variable for the distance from wall to the first cell.
- The is important when using a log-law or similar model to model the velocities close to the wall
- Recommended value: $30 < Y^+ < 100$ (FDS user guide)
- Example:
  - Following slides

Example for boundary conditions (Wall and Y+)
Simulation of the activation of pressure line detectors placed under roof eaves and comparison with experimental data



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Acknowledgement

- Most of the experimental work has been done by one a my students at Stord/Haugesund University College

  Vivi Rygnestad Helgesen

  Utvendig deteksjon ved verneverdige bygninger. B.Sc. Thesis. June 2013, Haugesund

  This project has been done together with the Heritage authority in Norway.

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RIKSANTIKVAREN

Detection of fire along building facades

Line detection

-Cost effective, hard to see

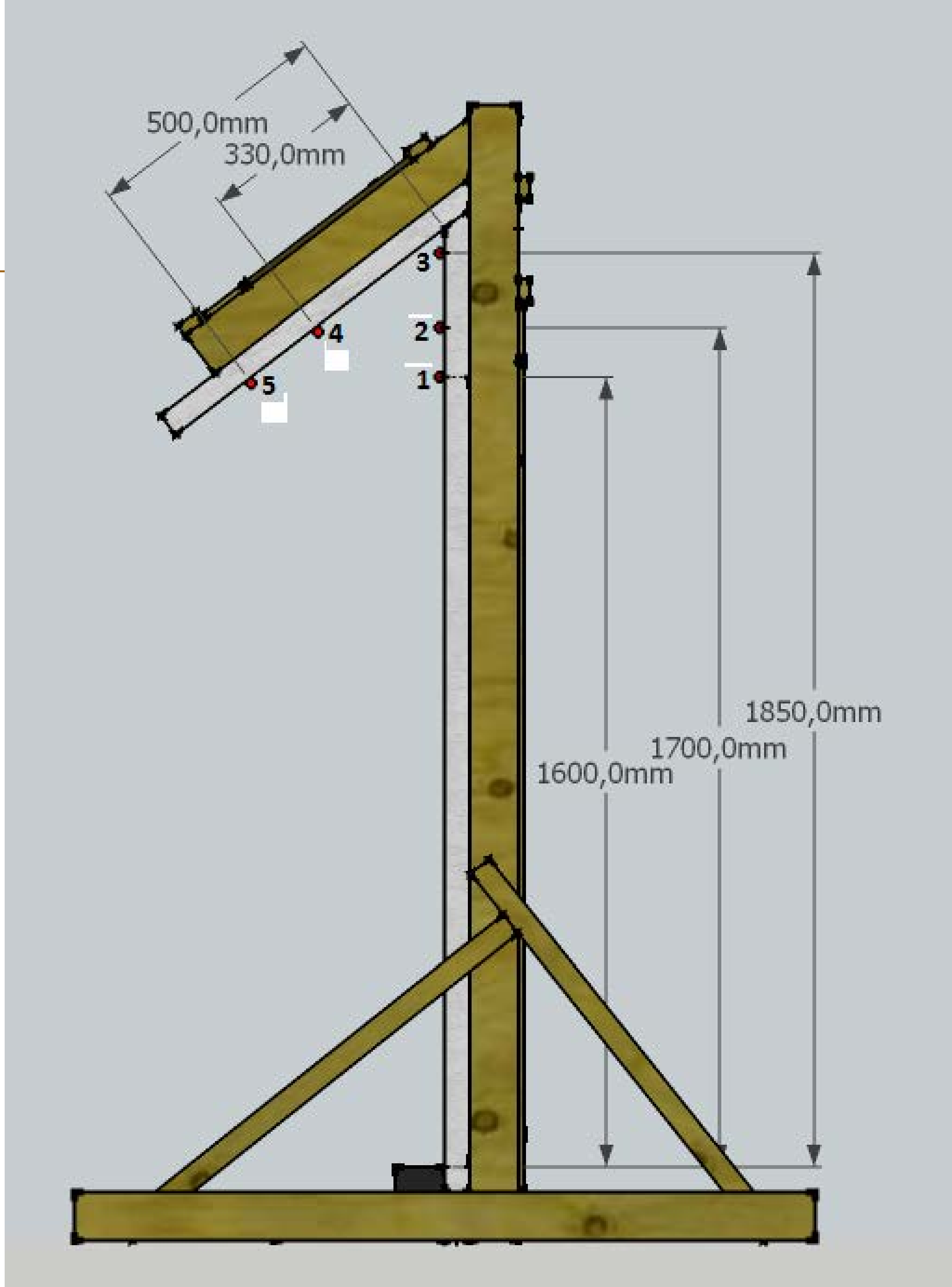
Pressure line detectors (PLD)

- Used at Stave Churches
- Pressurises with air or nitrogen
- Can be made fully mechanical (no electrical power needed)

Test setup with 5 tubes and 5 (10) thermo-couples at centre line.

Later experiments two different thickness of thermocouples

1. sec. sampling



Video

- Experiment #16, 2-5-2013

http://youtu.be/VzyELLUlFug

Tabell 10: Utløsningstid for ny deteksjonslinje. *)Under forsøk 15 ble ikke utløsningstid for linje 1 registrert.

Tid til utløsning for ny slange [s]					
	1	**2**	**3**	**4**	**5**
Forsøk 11	121	114	139	121	215
Forsøk 12	90	97	87	91	235
Forsøk 13	86	87	85	94	180
Forsøk 14	35	72	65	72	82
Forsøk 15	*	63	60	51	95
Forsøk 16	29	72	49	53	88
Forsøk 17	39	74	47	52	105

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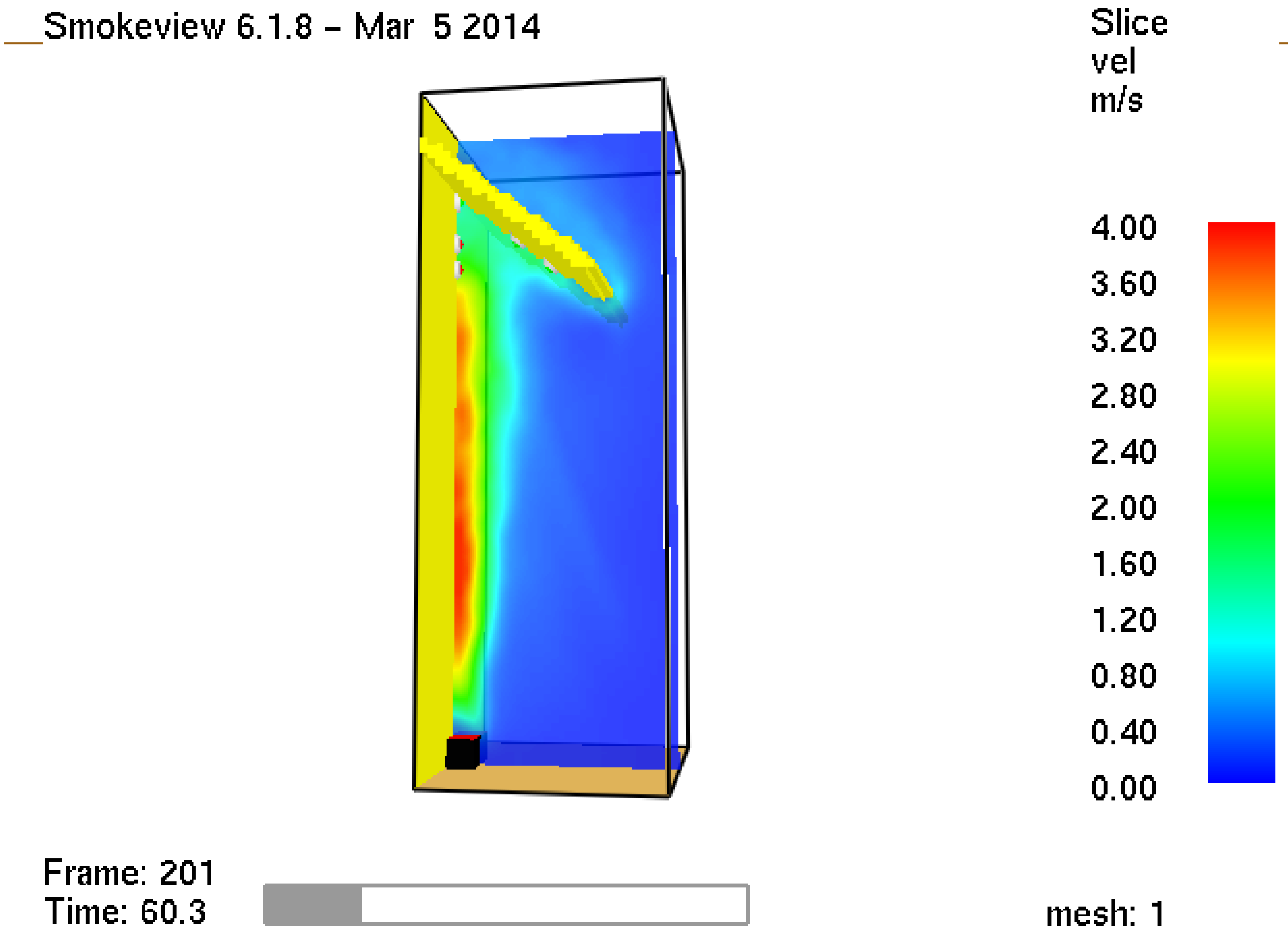
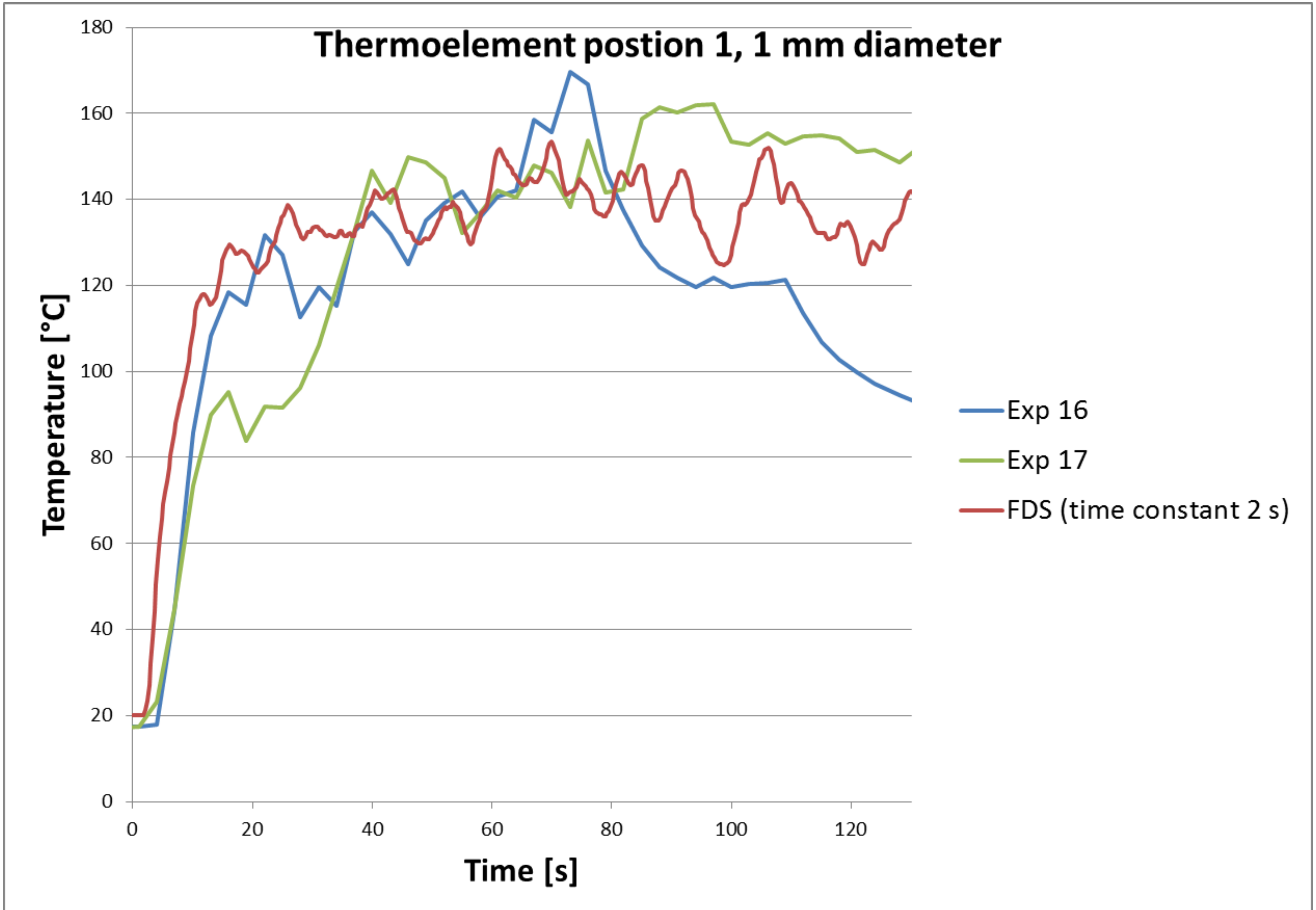
Modelling in FDS 6.0.1 (Build 17534)





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Simulation vs. experiments

	Measurements (95% confidence interval)	50 mm	25 mm	12.5 mm	6.25 mm
D*/dx (D*=265 mm)		5.3	10.6	23.0	40.8
Detector 1	31.6 - 60.6	39.6	44.7	56.7	
Detector 2	65.6 - 88.7	47.4	55.2	89.7	
Detector 3	57.8 - 70.7	54	67.5	86.1	
Detector 4	53.4 - 72.2	79.8	78.9	73.5	
Detector 5	99.1 - 133.6	184.2	144.6	108.3	

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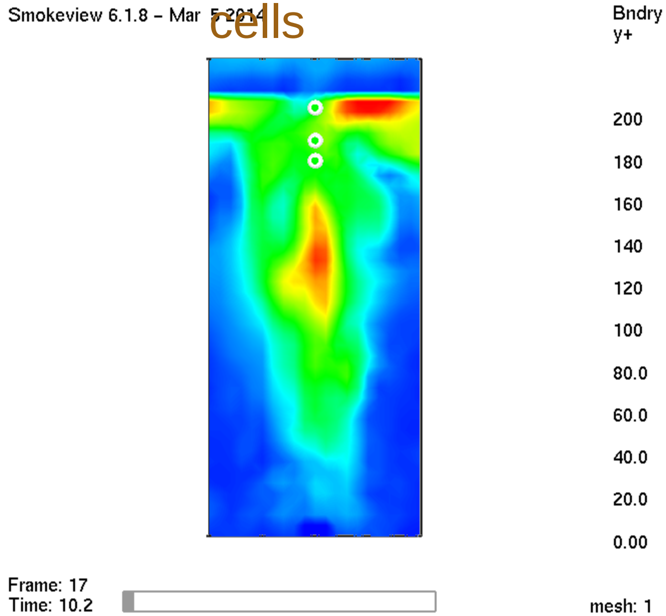
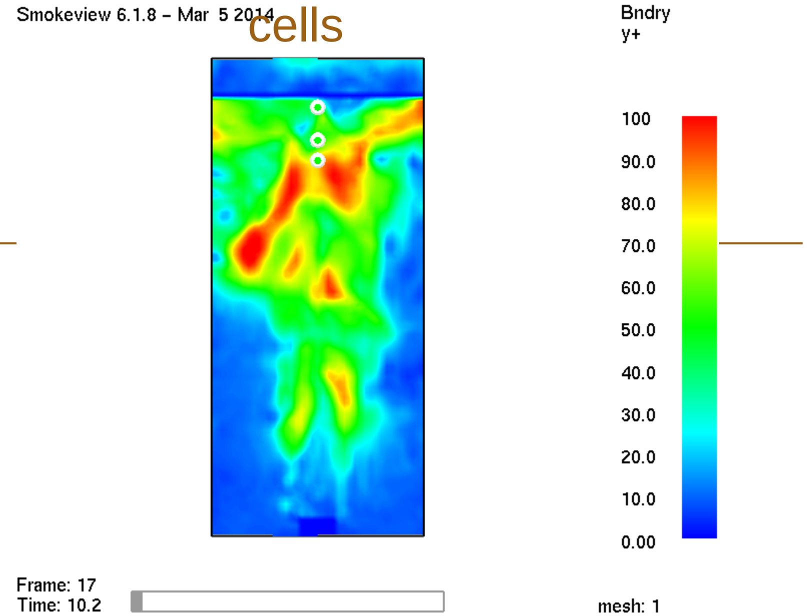
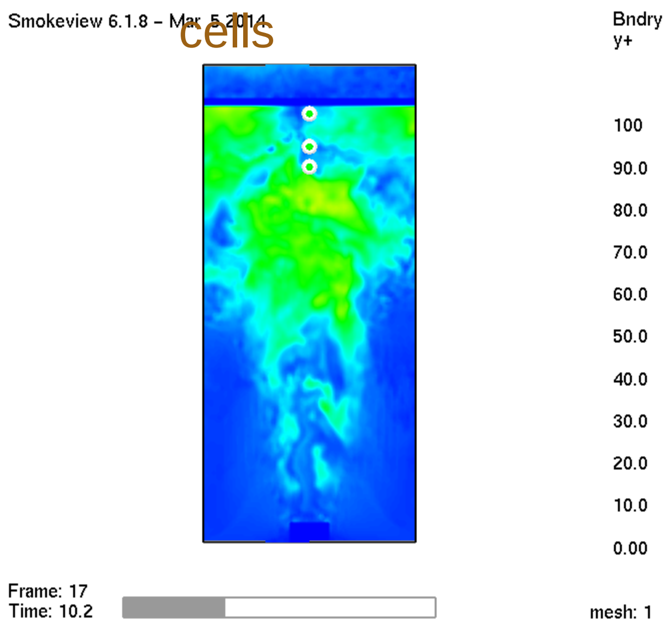
50 mm cells



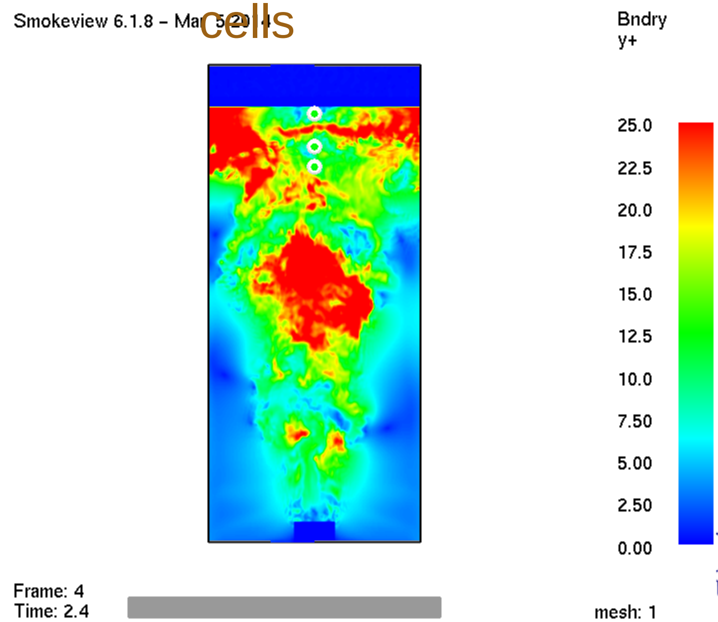
25 mm cells



12.5 mm cells



6.25 mm cells



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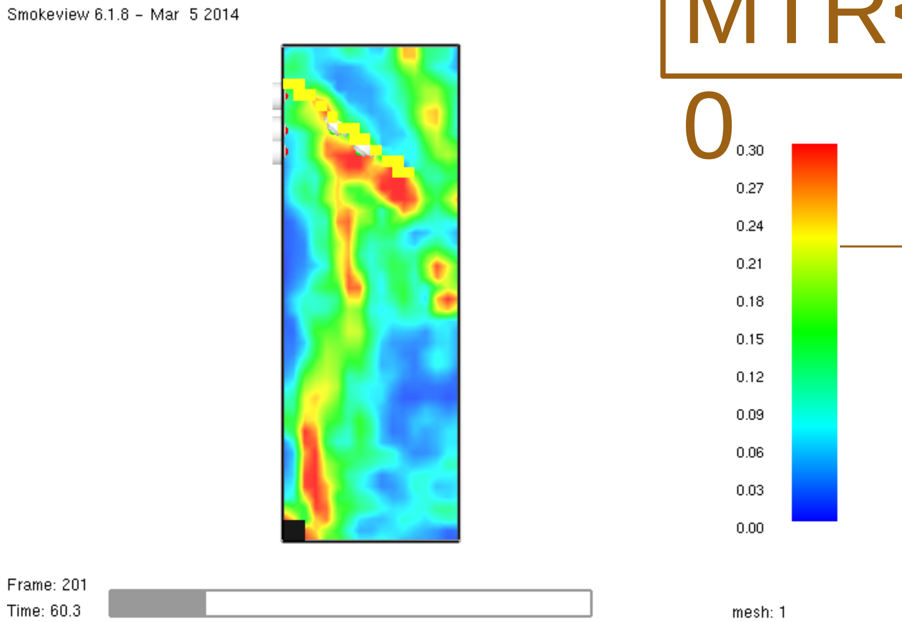
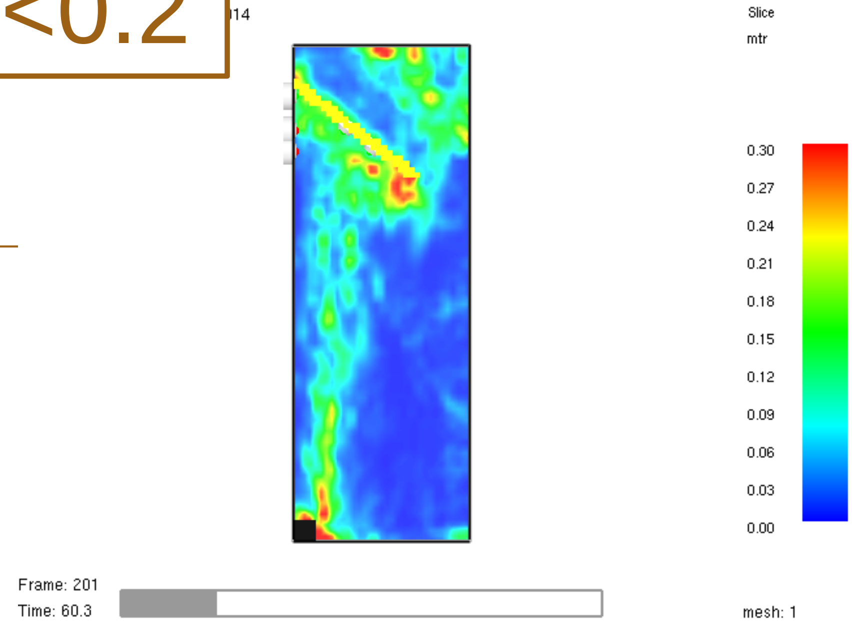
MTR<0.2
0

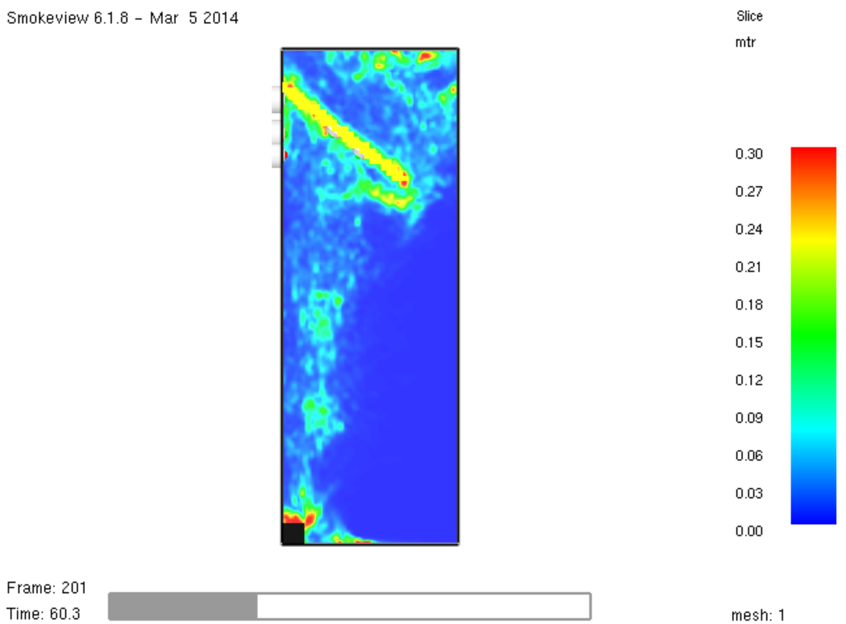
50 mm



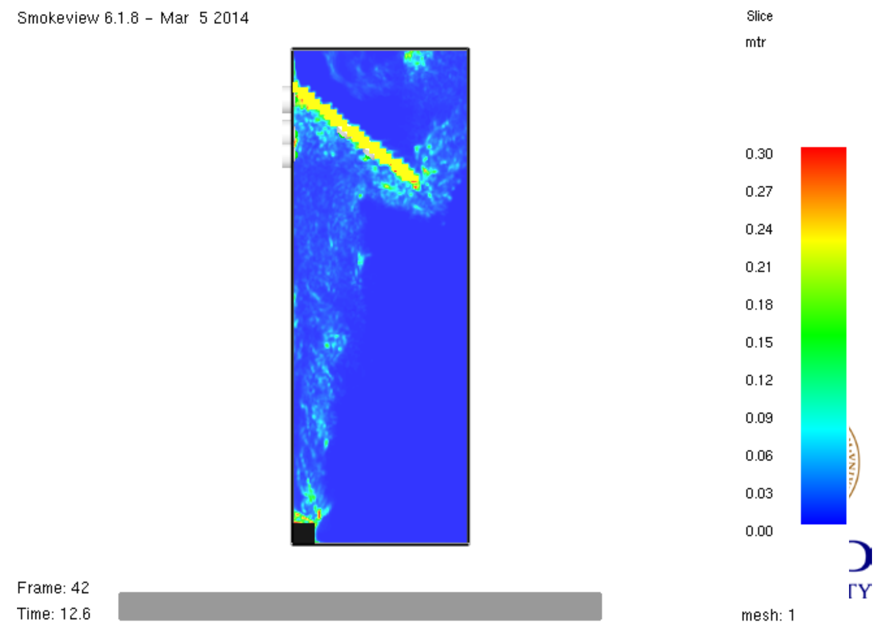
25 mm



12.5 mm



6.25 mm



Comparison of detection time (no wind)

- FDS predicts similar detection time than the experimental results for position 1 for all grid sizes
- For position 2, 3 and 4 all 3 grid sizes gives similar results
- For position 5, the two finer grid (25 mm and 12.5 mm) performs much better than the coarse grid (50 mm)

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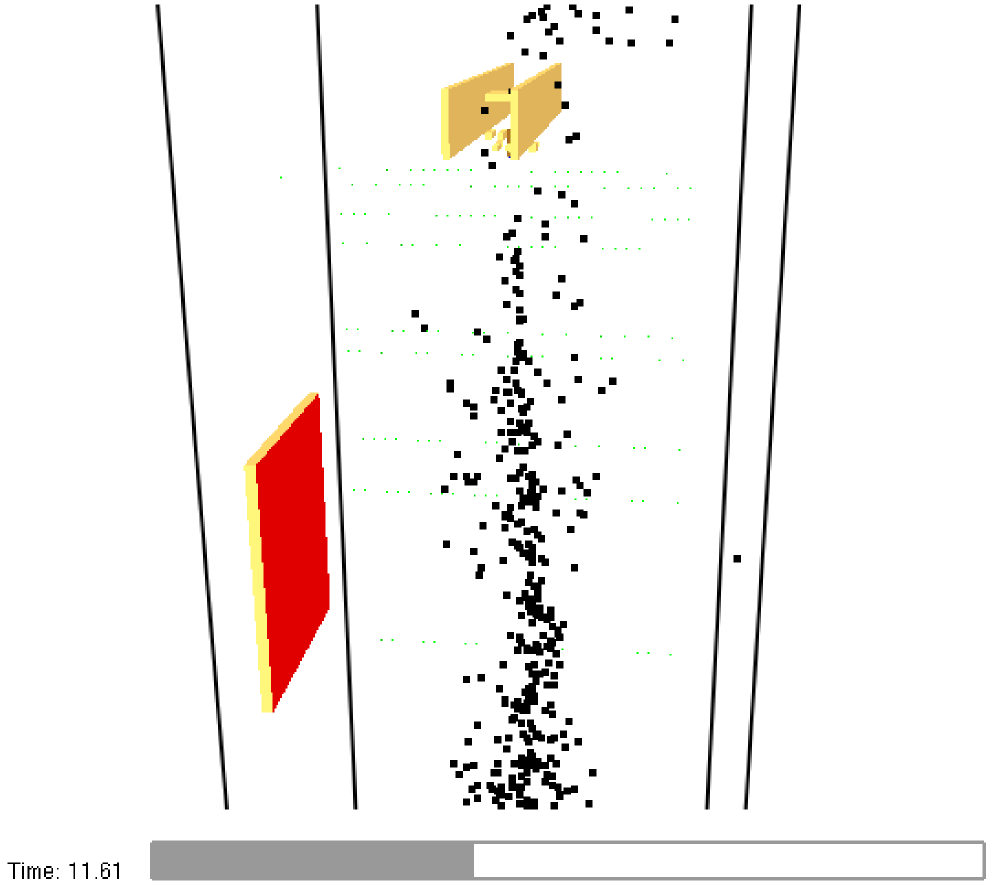
Simulation setup (FDS 6.2 and 6.3)



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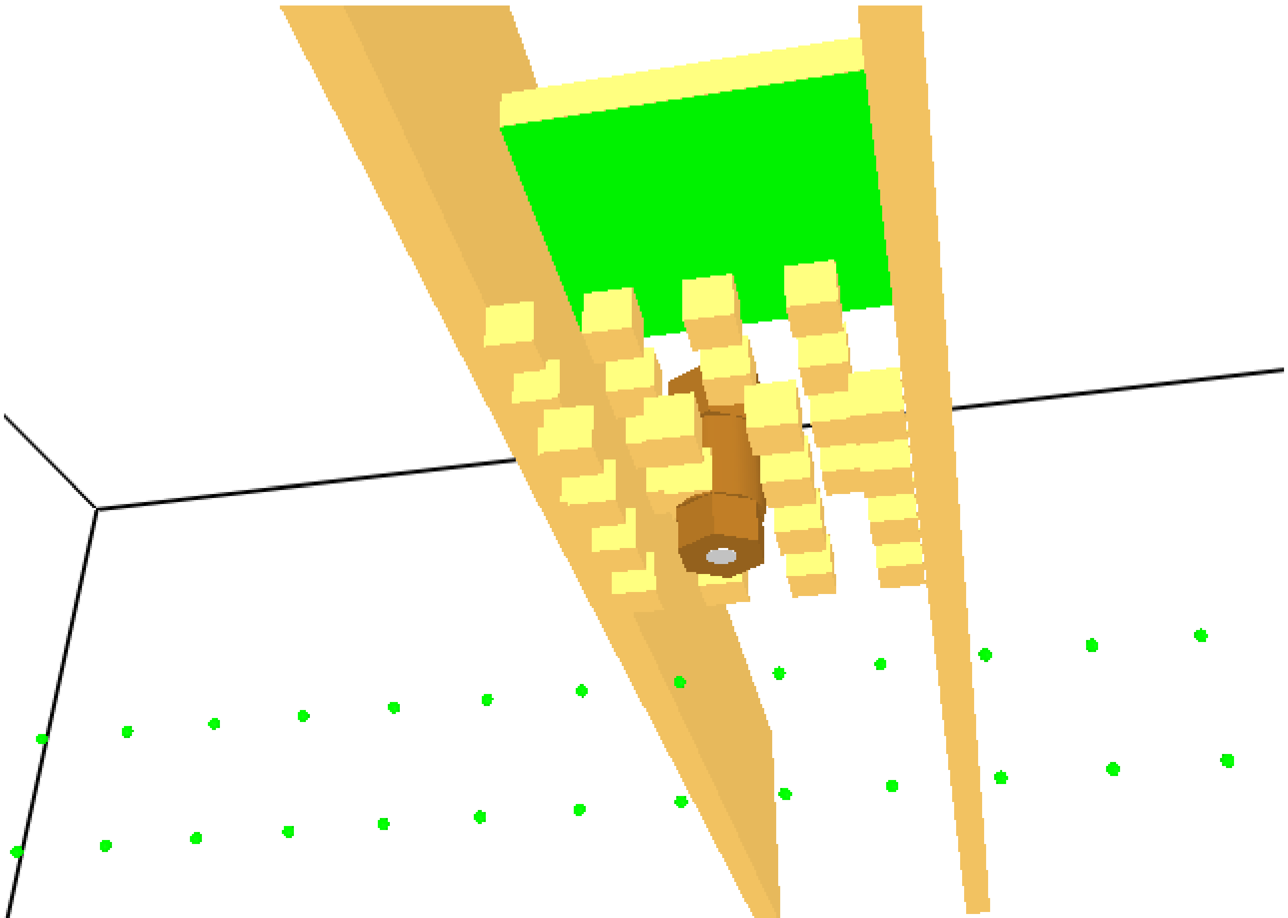
Modelling of spray



Velocity profile