CFD fire simulations

UNIVERSITY OF CHEMISTRY AND TECHNOLOGY PRAGUE

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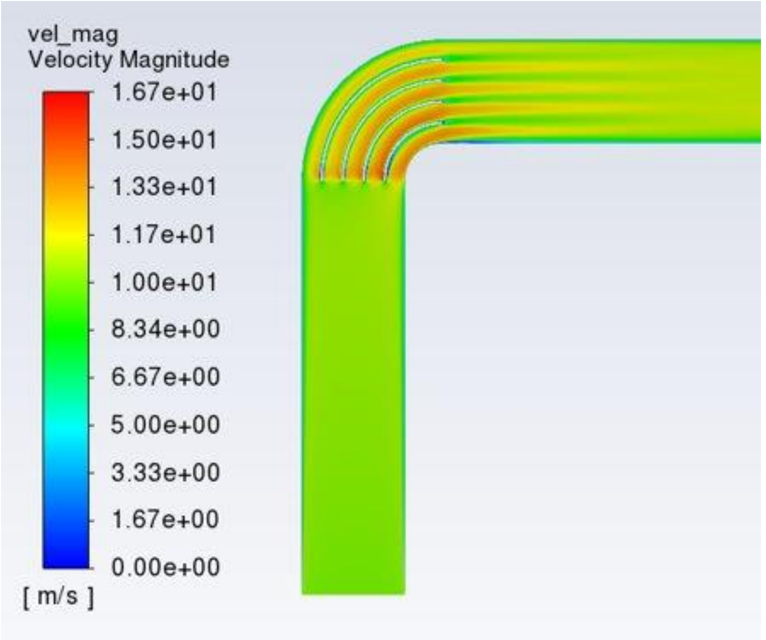
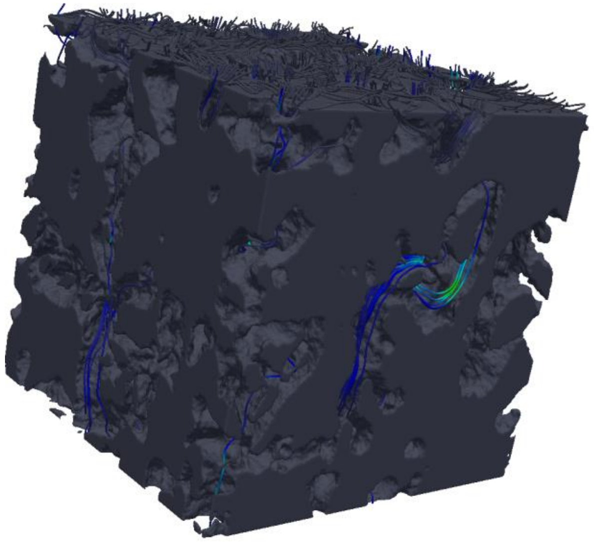
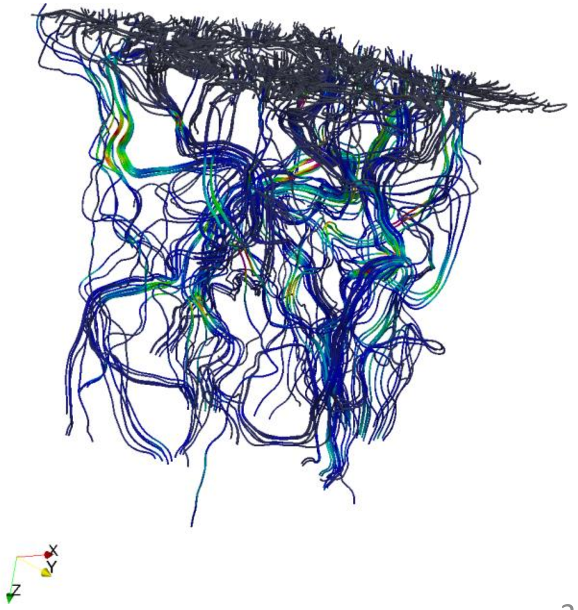
What is Computational Fluid Dynamics?

- Enhanced method for solving fluid flow problems
- Numerical solution of Navier-Stokes equations
- Other models for heat transfer, turbulence, reactions and more

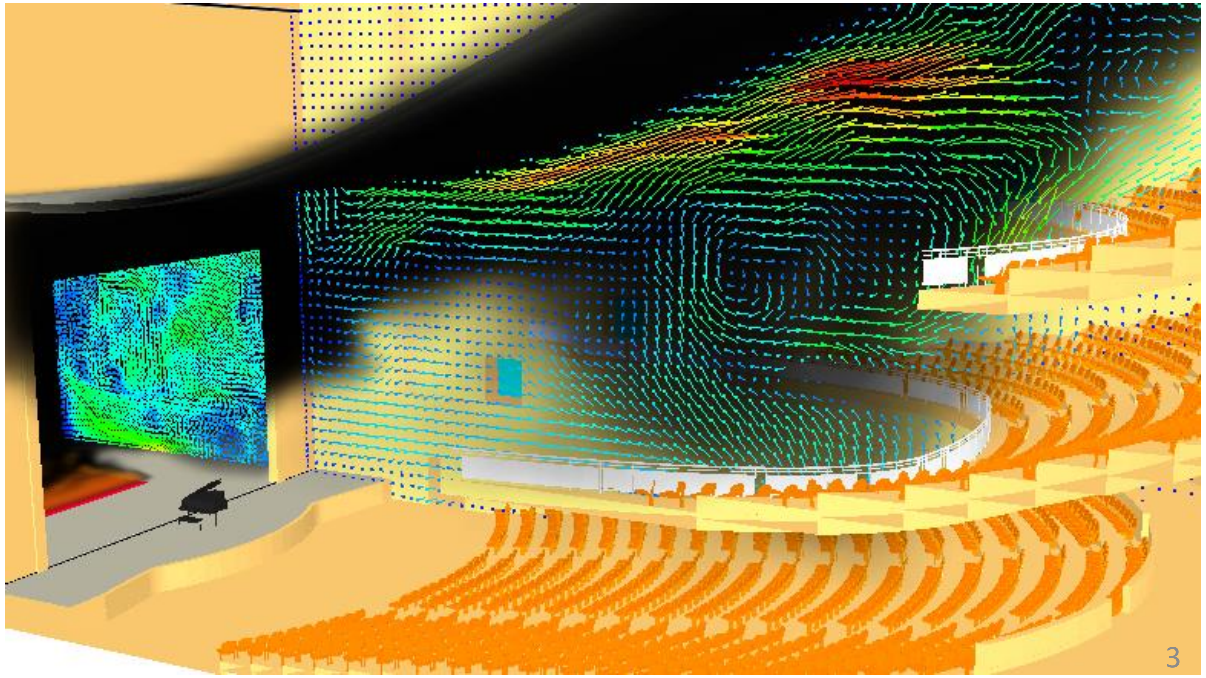






CFD in fire engineering - *extension of fire tests*

- Provides information about whole domain
- Different configurations of fire scenarios
- Non-destructive method



https://ignis.solutions/services/cfd-fire-smoke-modelling/

Performance based design

- Requirements on constructions and fire protection systems

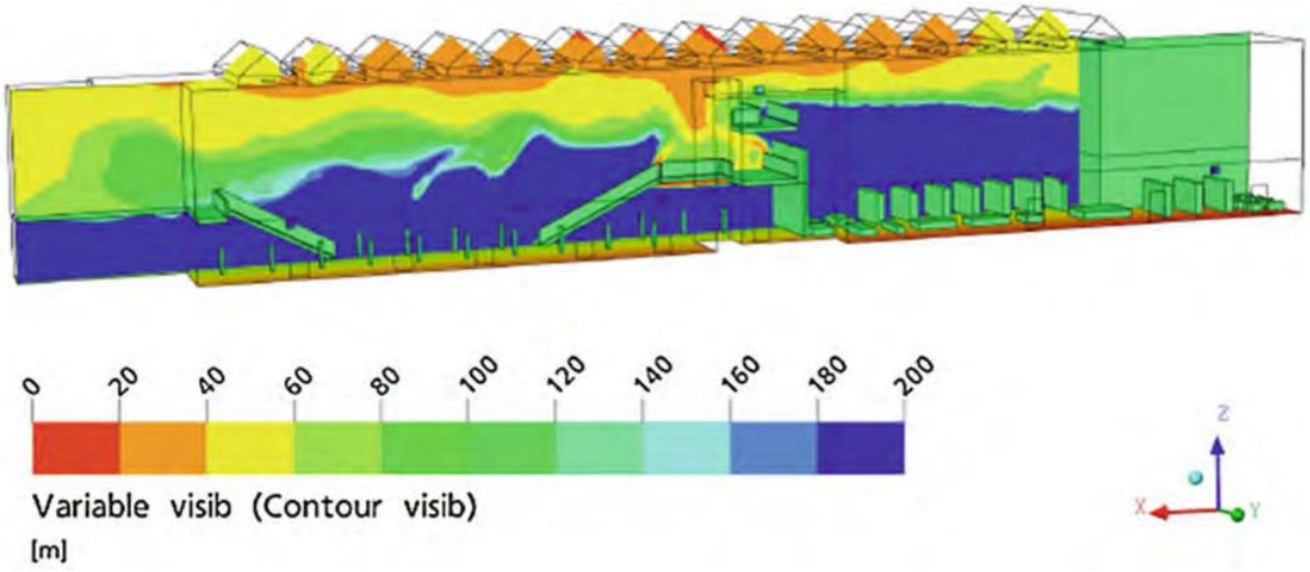


Fig. 32.5 Map of visibility in a vertical plane at time = 3 min for a fire in a library building (Figure courtesy: ANSYS Europe Ltd)

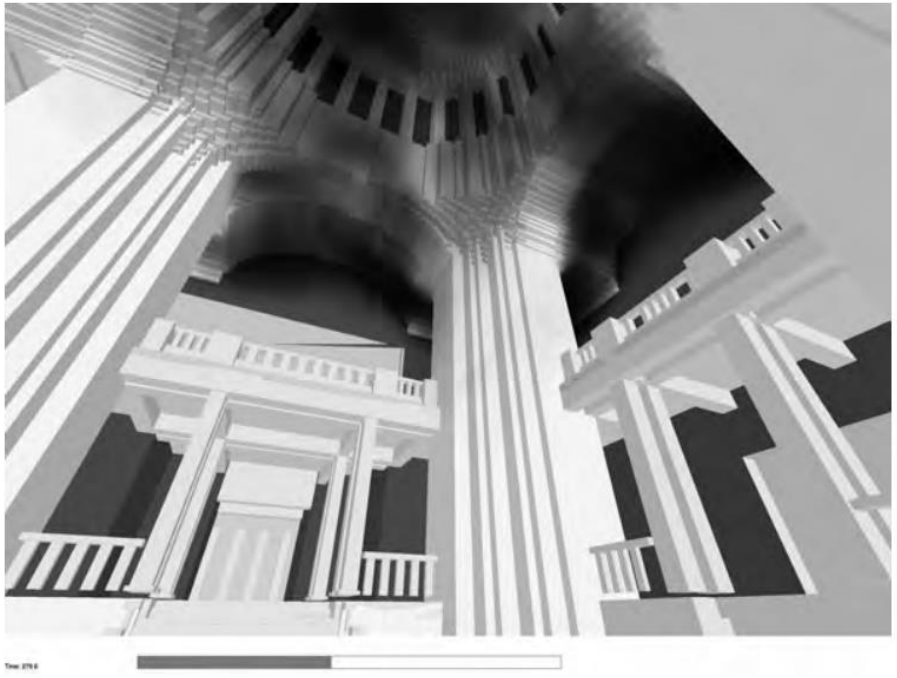


Fig. 32.6 Smoke filling analysis of the Rhode island State capitol (Figure courtesy: Hughes Associates)

Images from SFPE Hanbook [1]

Fire investigation

- WTC – NIST investigation report [2]

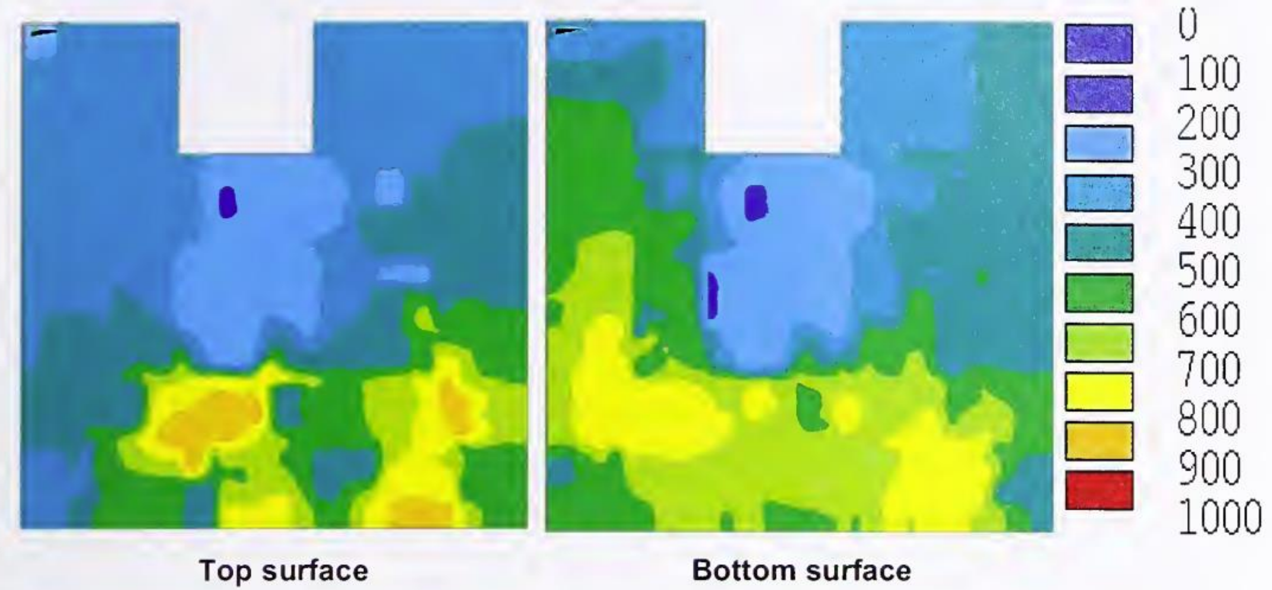


Figure 2–11. Temperature contours (°C) on the top and bottom faces of the concrete slab (96th floor, WTC 1) at 100 min after impact. A portion of the concrete slab on the north face (top) was damaged by the impact of the aircraft.

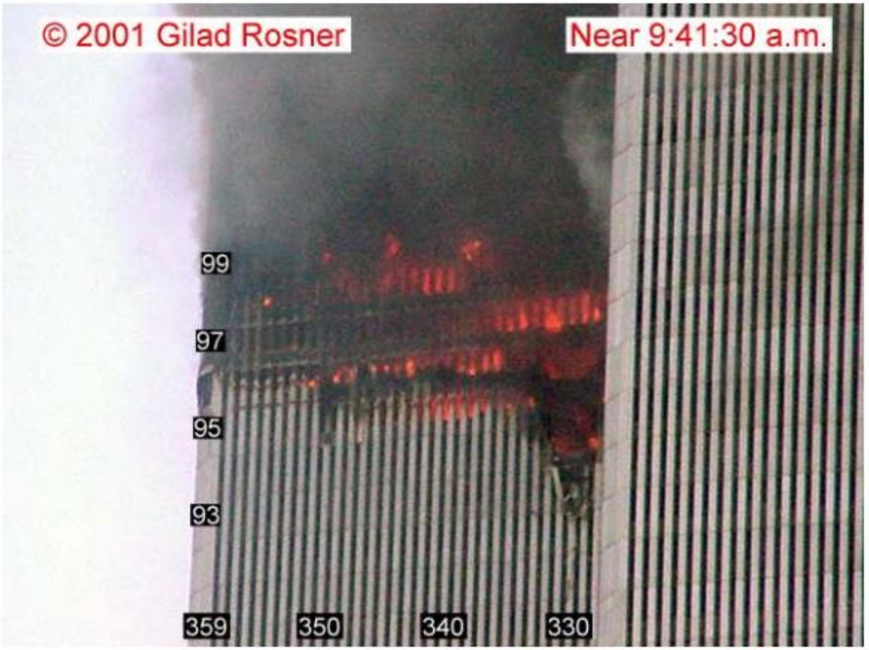


Figure 3–15. Photograph of the south face of WTC 1 taken at approximately 9:41:30 a.m. on September 11, 2001. Column and floor numbers were added to the original photograph.

Fire modelling - *a complex problem*

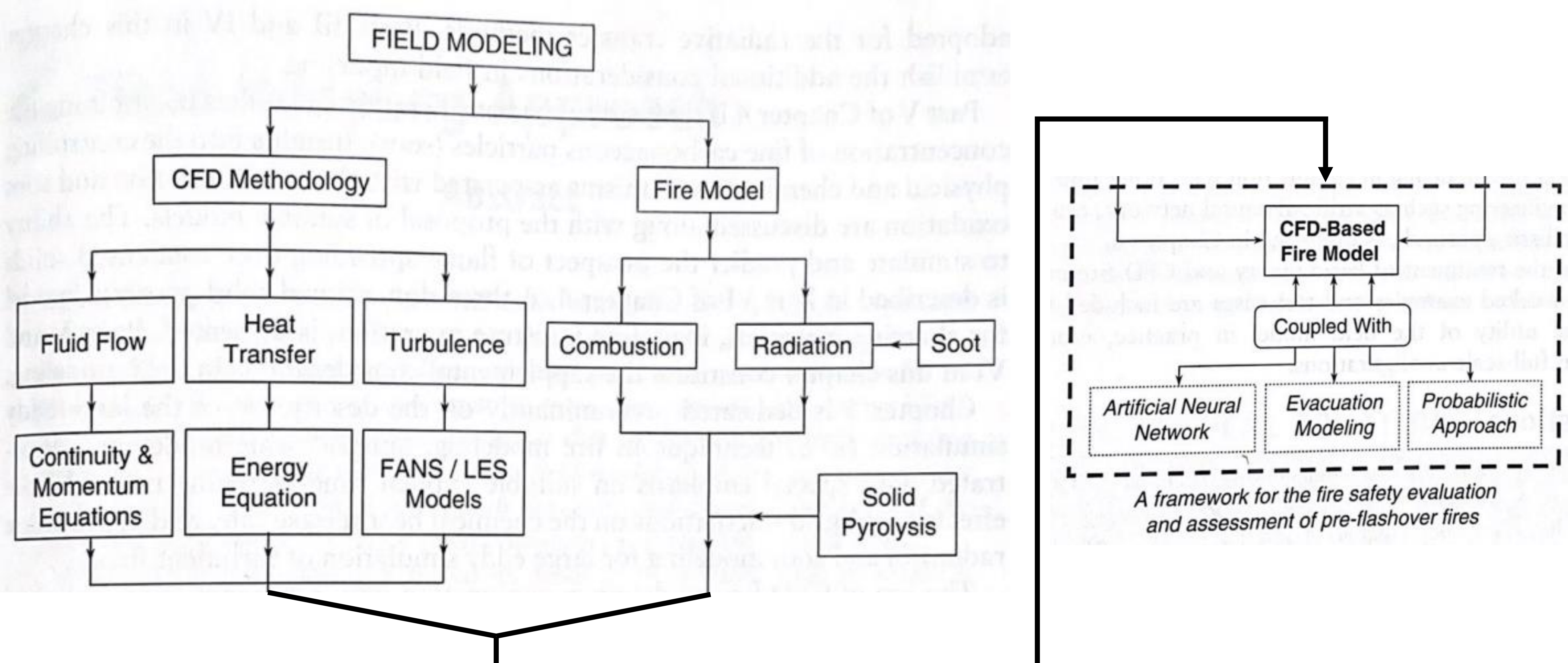


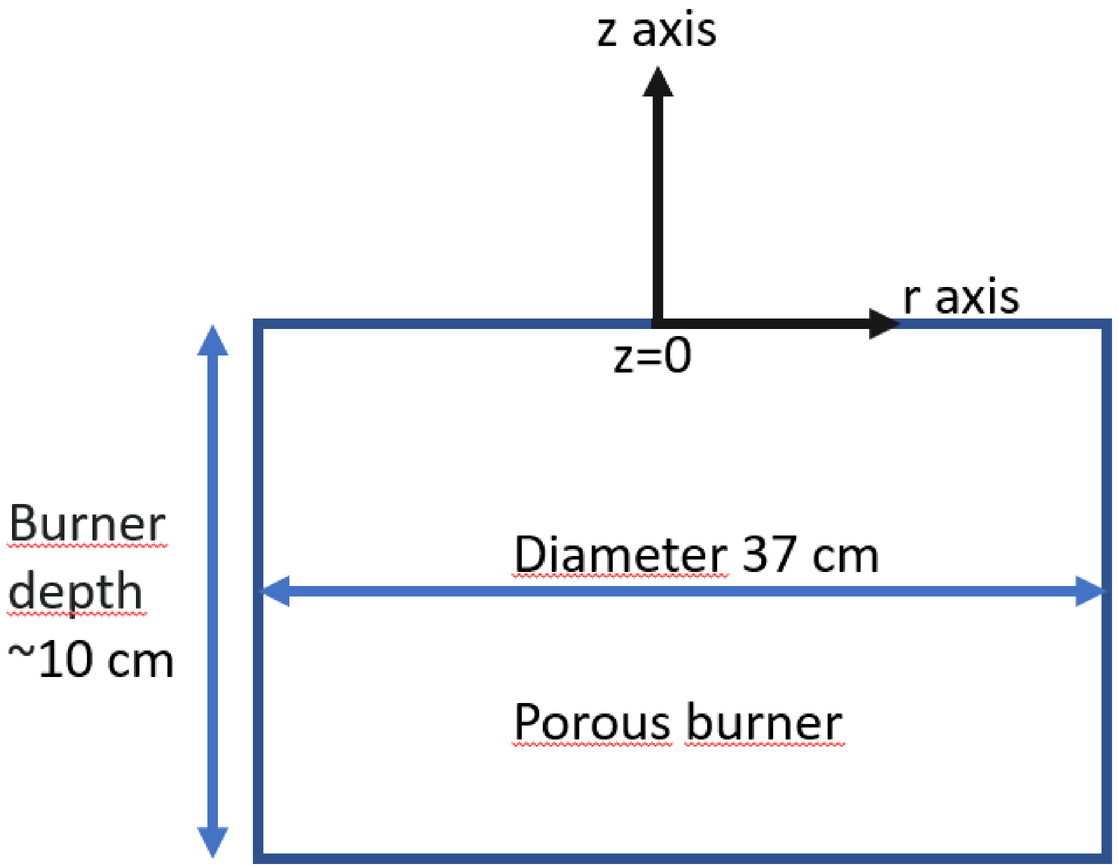
Image from [3]

MaCFP working group

- Fire research community initiative under International Association for Fire Safety Science (IAFSS)
- Effort to make systematic progress in fire modelling
- Based on well described experiments
- Categories: Gaseous pool fires, Liquid pool fires, Buoyant plumes, Wall fires, Extinction
- Participants: NIST, FM Global, universities and others
- Softwares: FDS, OpenFOAM or in-house codes

NIST experiment

- Gaseous pool fire
- Methane burner
- Defined flowrate
- Measured along z:
  - Temperature
  - Velocity
  - Species concentration



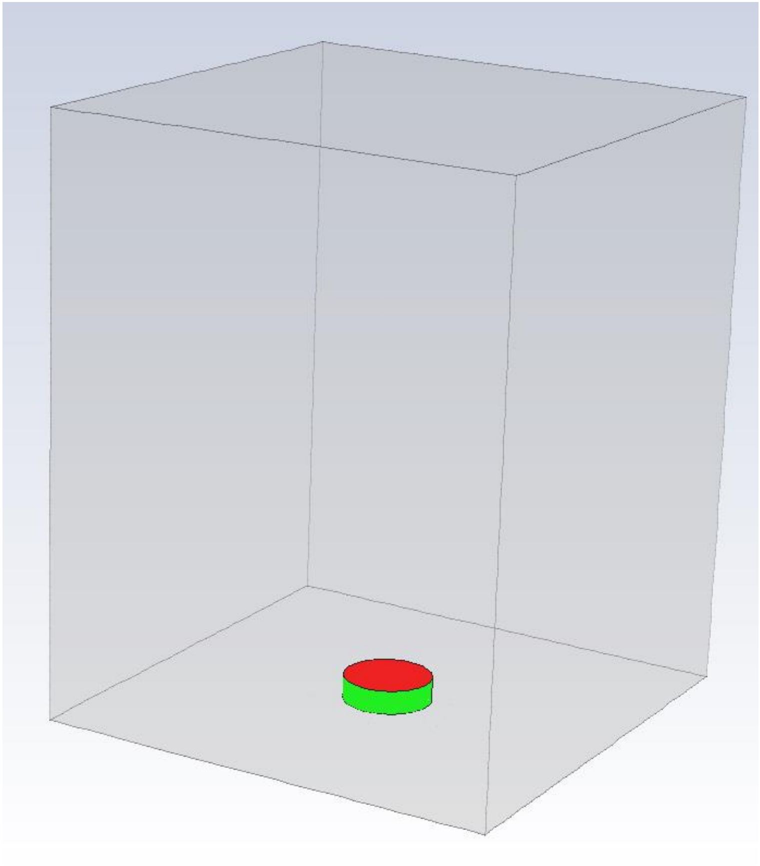
CFD model – Ansys Fluent

- Commercial software
- No solution in MaCFP group
- Universal – not primarily for fire engineering problems
    - <u>Great variety of models</u>

- My goal: recognize appropriate models and setting for fire engineering purposes

Domain

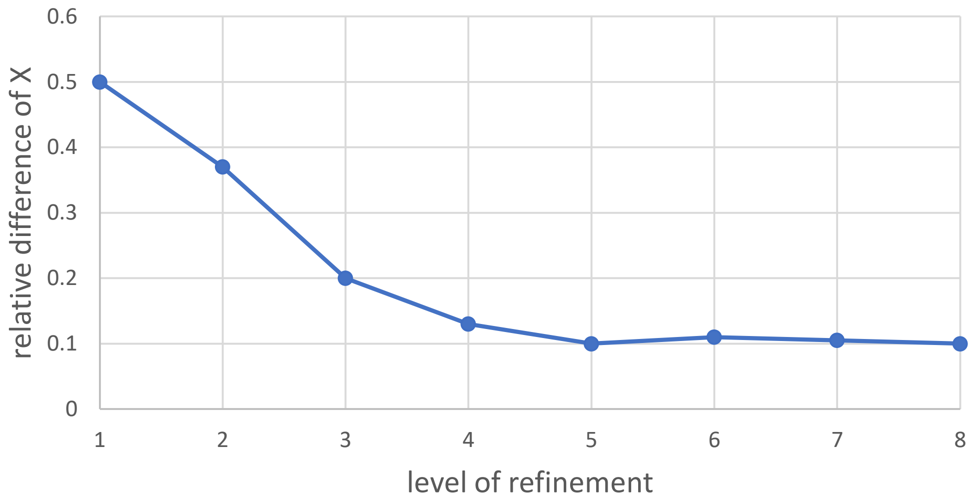
- Inlet (red)
- Wall (green)
- Pressure outlet (grey)



- What are the perfect dimensions of the domain?

Mesh size

- For the FVM
- Balance between accuracy and computation time



- Refining crutial regions of domain
  - How many cells should be at the fuel inlet?
  - How much do we refine the mesh around the flame?

Turbulence model

RANS

- Averaged fluctuations
- Used in industry
- Computationally cheap

LES

- Large eddies directly computed
- Used in fire engineering
- Computationally expensive
- Detailed

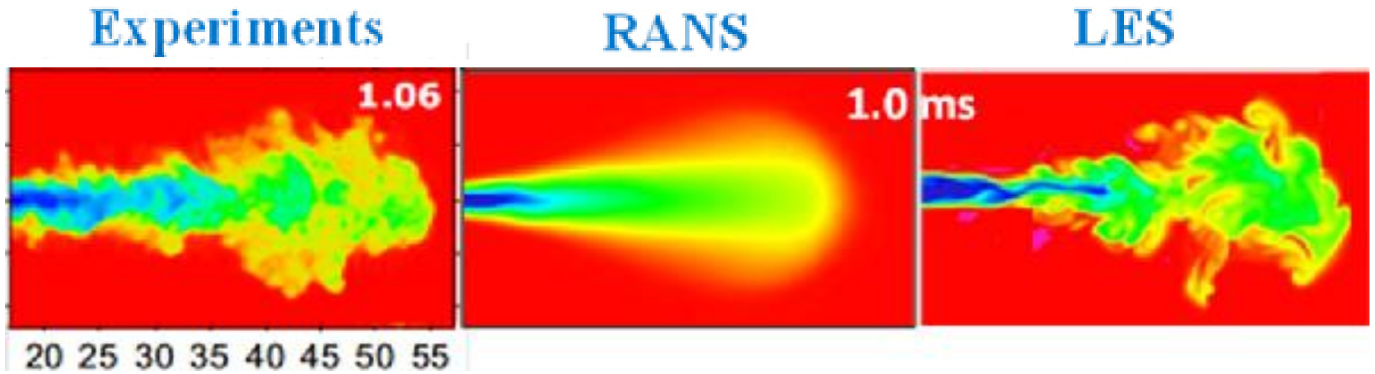


Image from [4]

Steady state or transient simulation?

$$\underbrace{\frac{\partial(\rho\phi)}{\partial t}}_{\text{time derivative}} + \underbrace{\nabla\cdot(\rho\boldsymbol{u}\phi)}_{\text{convection term}} = \underbrace{\nabla\cdot(\Gamma\nabla\phi)}_{\text{diffusion term}} + \underbrace{S_\phi}_{\text{source term}},$$

Steady state

- Simplification
- Cheap to compute
- Only for specific problems

Transient

- Process modeled in time
- Expensive (small time steps)
- It can reach the steady state

Can we consider the fire engineering problems to be steady state?

Combustion model

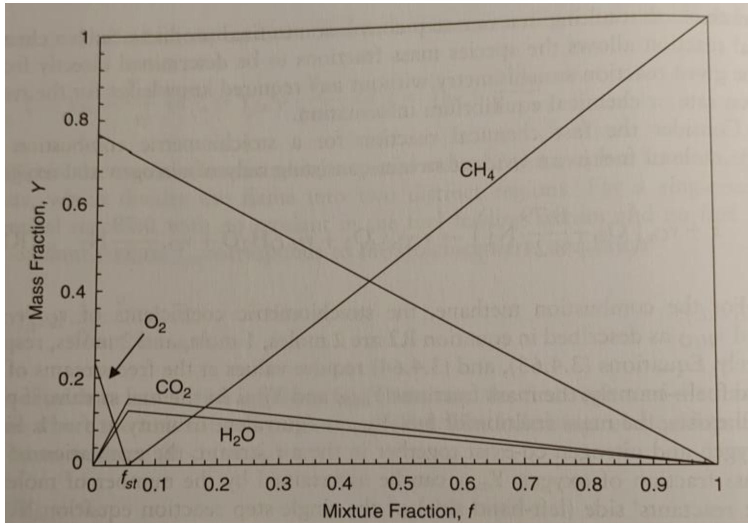
- Great variety in Fluent
- <u>Finite rate model</u>
  - Detailed mechanism, Arrhenius equation, expensive

$$\hat{R}_{i,r}=\Gamma\left(\nu''_{i,r}-\nu'_{i,r}\right)\left(k_{f,r}\prod_{j=1}^{N}\left[C_{j,r}\right]^{\eta'_{j,r}}-k_{b,r}\prod_{j=1}^{N}\left[C_{j,r}\right]^{\eta''_{j,r}}\right)$$

- <u>Eddy dissipation model</u>
  - Reaction rate based on mixing, two step reaction at max.

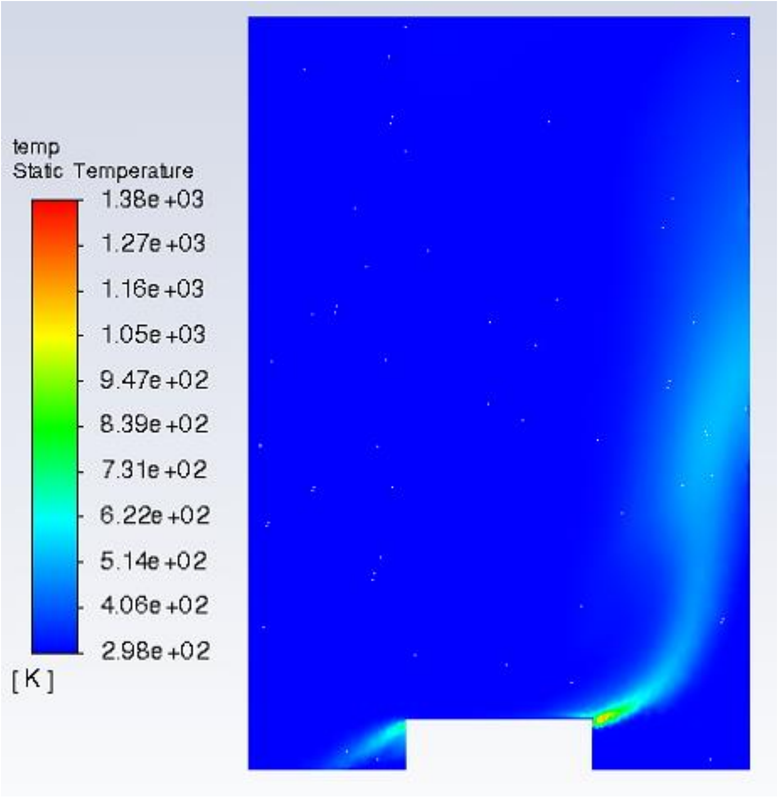
$$\overline{R}_{fu}=C_R\overline{\rho}\,\frac{\varepsilon}{k}\left(\widetilde{Y''^2_{fu}}\right)^{1/2}$$

- <u>Conserved scalar model</u>
  - Species represented by mixture fraction
  - immediate reaction
  - fluctuations handled via probabilistic approach (PDF tables)



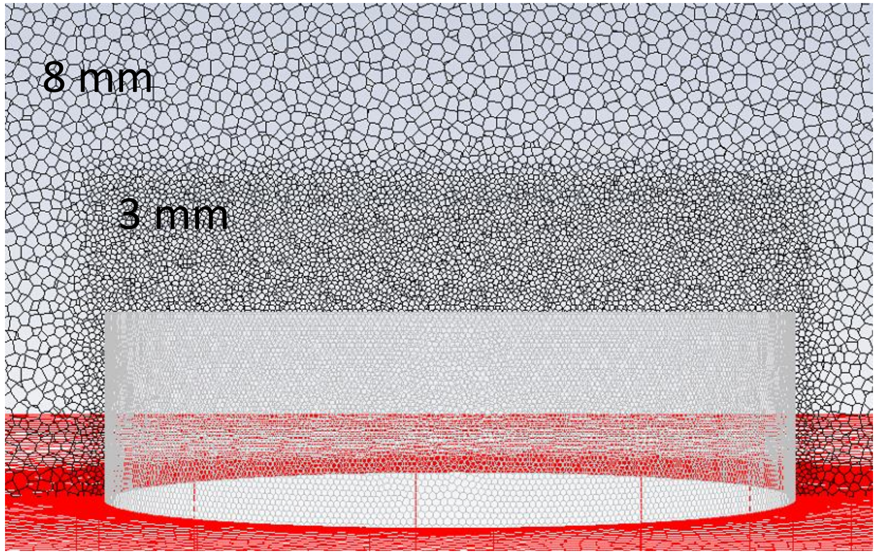
Results – First Attempts

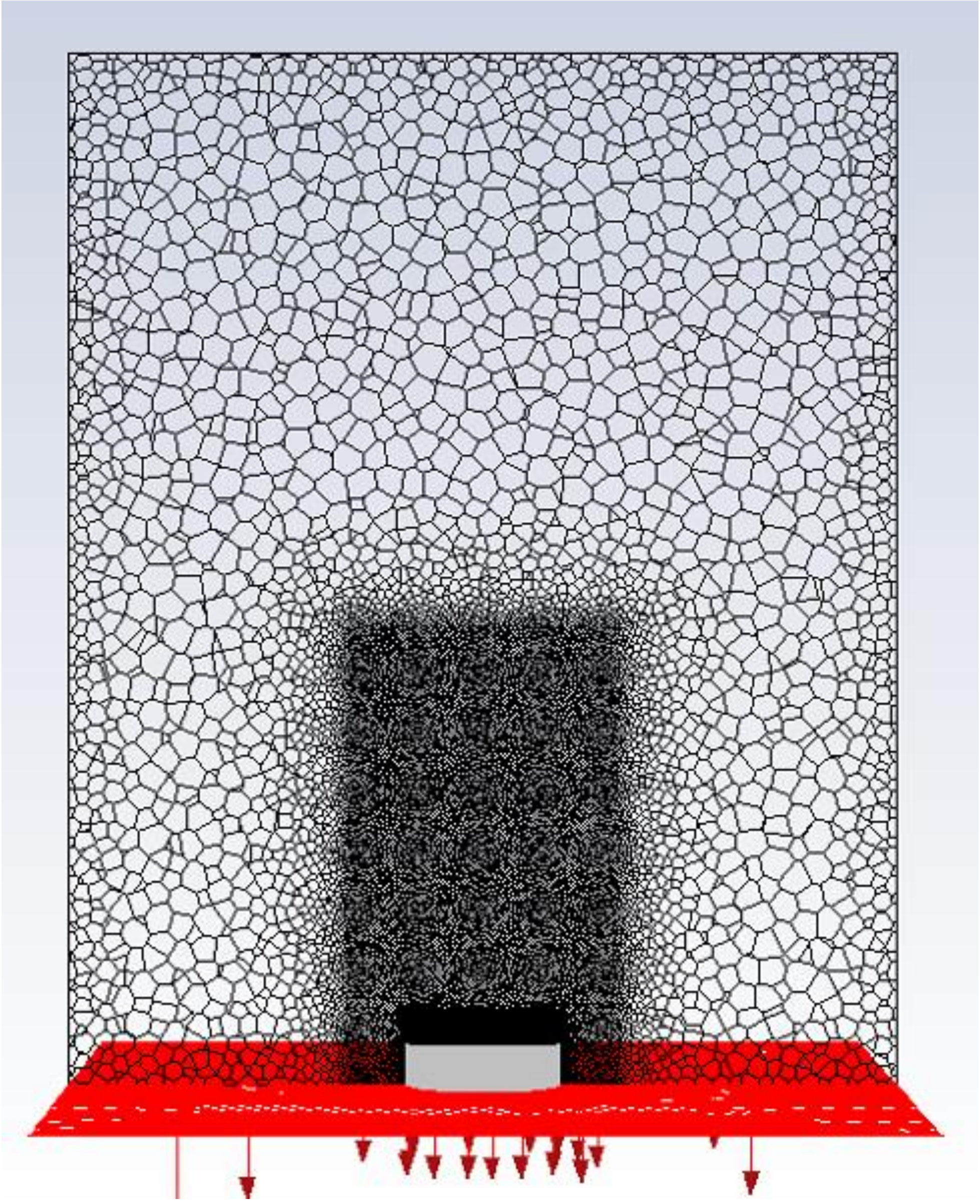
- Smaller domain (1 x 1 x 1.5 m)
- Basic EDM
- Not converged for steady and transient
- Issues at the pressure outlets
- Need of a larger domain



Results –Bigger domain

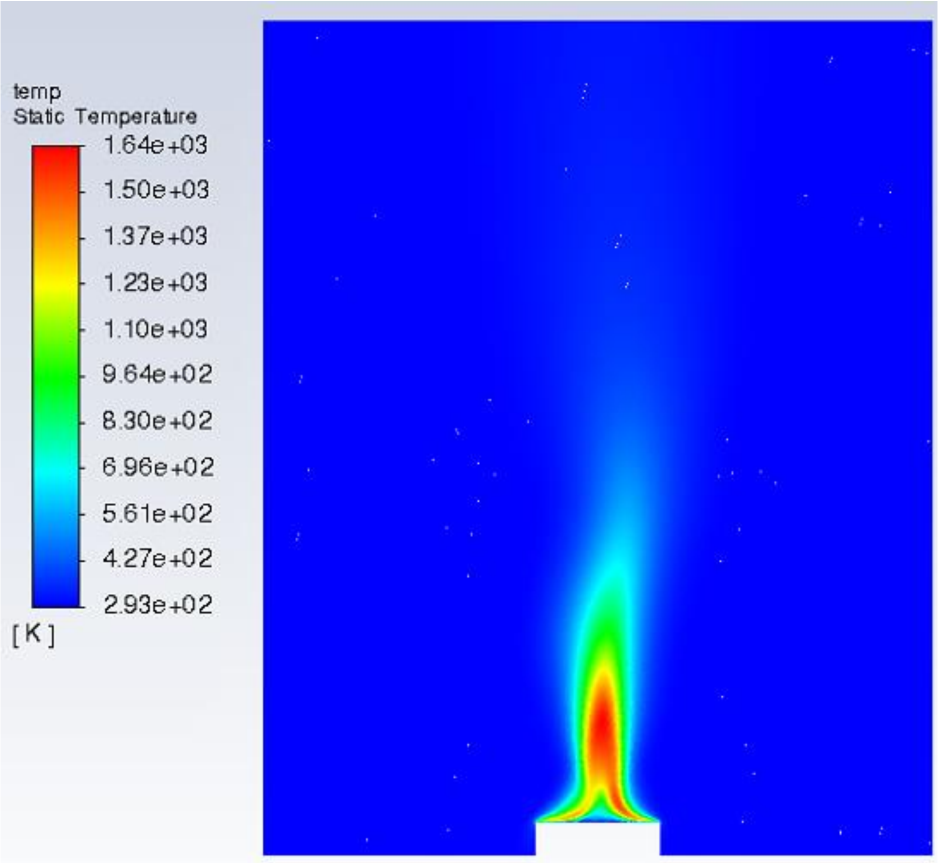
- Domian (2 x 2 x 2.5 m)
- Refined mesh around the flame area and inlet – 2 mil. cells



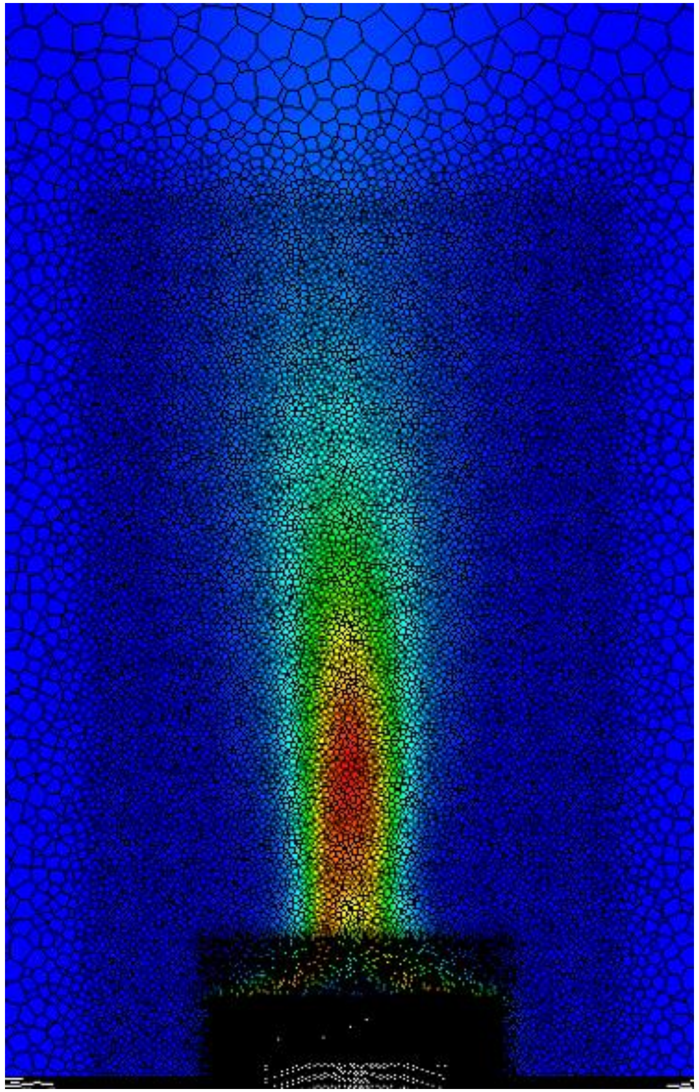


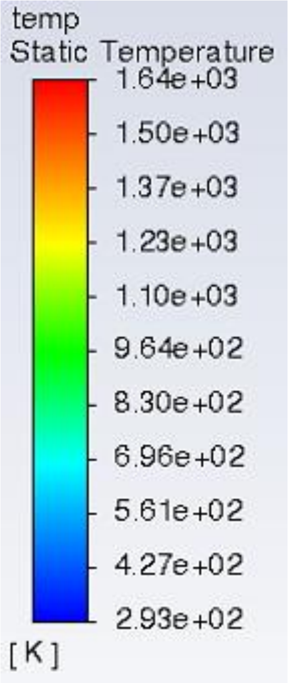
Results –Bigger domain

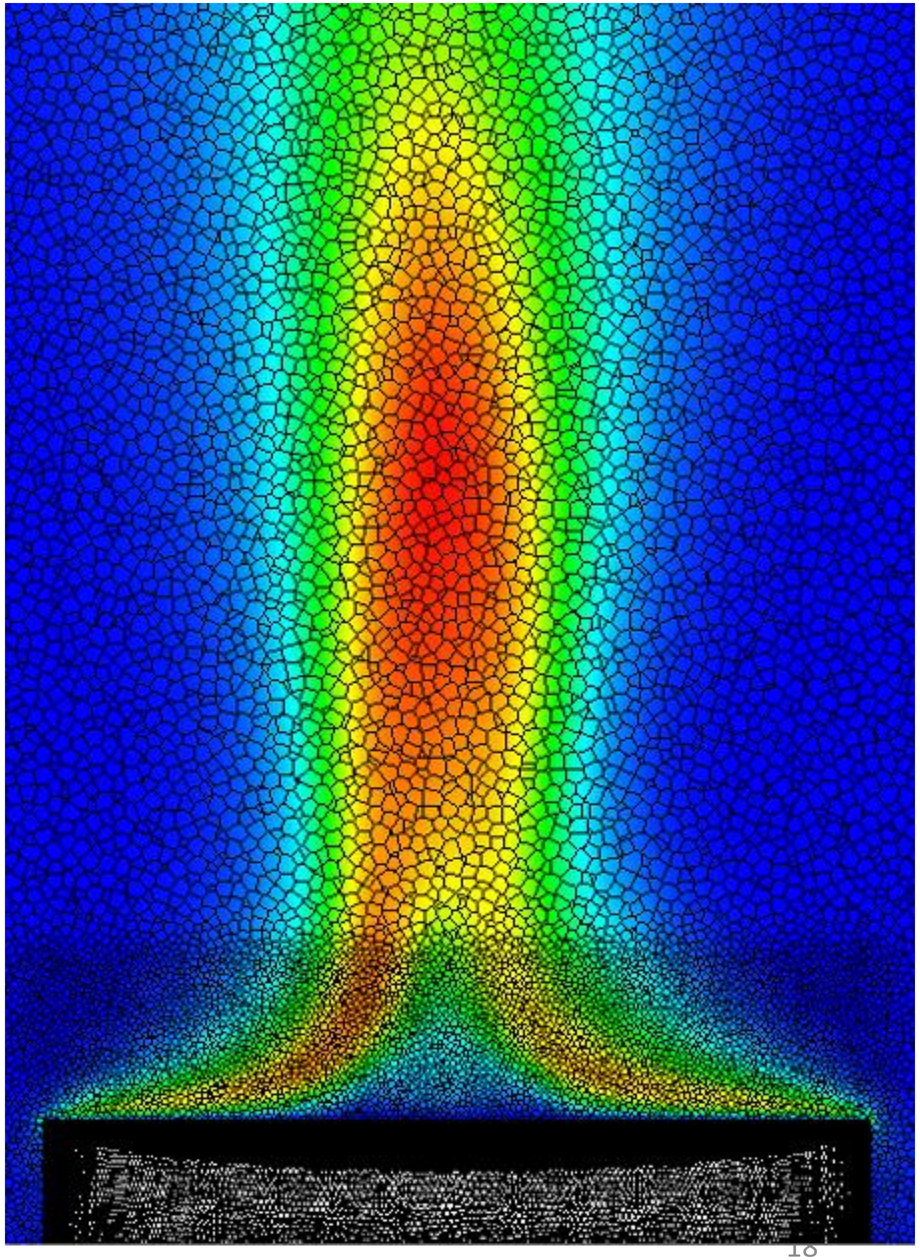
- EDM for combustion, steady state, RANS
- Not completely steady
- Boundary conditions are correct
- Stepping stone to complicated simulations



Results –Bigger domain

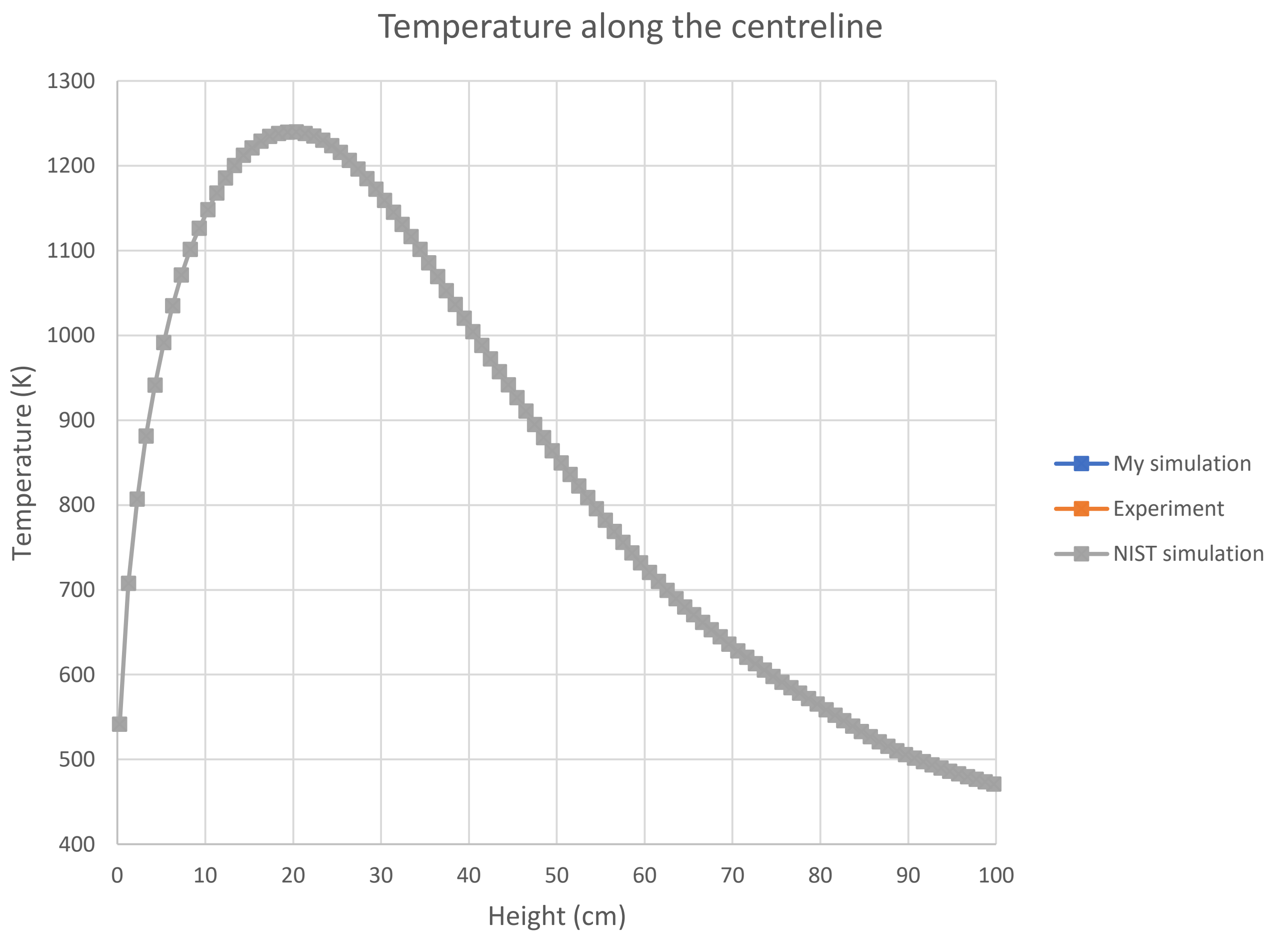






Comparison with experimental data

- Simple simulation – good result
- Overpredicted temperature
  - Complete combustion
- Developing this simulation can lead to good results



What to do next?

- Transient simulations with RANS and LES
- Adding creation of CO
- Use of Conserved scalar combustion model
- Creating a mesh size independence study

- Guidelines for using Fluent in fire engineering problems
- Comparing available models

Bibliography

[1]: Hurley, Morgan J., et al., eds. *SFPE handbook of fire protection engineering*. Springer, 2015.

[2]: Hamins, A. , Maranghides, A. , McGrattan, K. , Ohlemiller, T. and Anleitner, R. (2005), Experiments and Modeling of Multiple Workstations Burning in a Compartment. Federal Building and Fire Safety Investigation of the World Trade Center Disaster (NIST NCSTAR 1-5E), National Construction Safety Team Act Reports (NIST NCSTAR), National Institute of Standards and Technology, Gaithersburg, MD, [online], https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=101033 (Accessed November 21, 2021)

[3]: Yeoh, Guan Heng, and Kwok Kit Yuen. *Computational fluid dynamics in fire engineering: theory, modelling and practice*. Butterworth-Heinemann, 2009.

[4]: Som, S., P. Senecal and E. Pomraning. "Comparison of RANS and LES Turbulence Models against Constant Volume Diesel Experiments." (2012).

Thank you!

Any comments, questions, advices, tips?

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