2. 30.09
3. 18.10

BERGISCHE
UNIVERSITÄT
WUPPERTAL

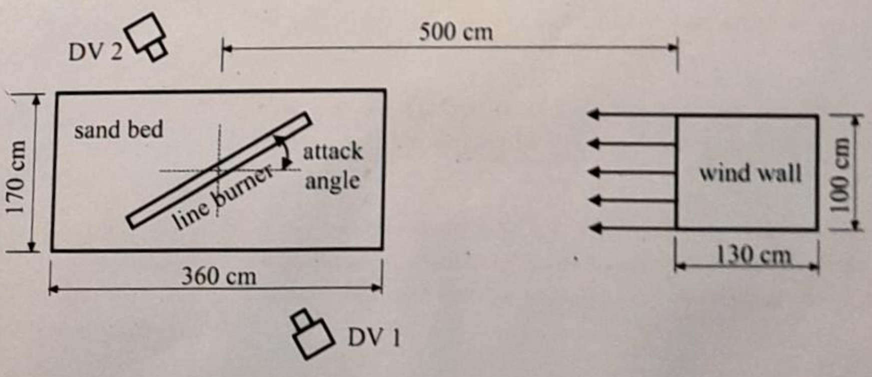
Project Task: Flame whirling characteristics

Topic

Zhou e.t al conducted experimental investigations on the occurrence of fire whirls caused by vortex effects on a burning flame [1]. Based on parameter studies, they have examined several critical conditions and mechanisms for the initial formation of concentrated vortex in a line fire exposed to wind. Those were a reasonable attack angle between the line fire and the cross wind and a wind speed within a critical range. Subject of the investigation primarily were n-heptane fires in linear burners with different lengths. Another varying parameter was the elevation of the burner above the ground surface. A top view on the experimental setup is shown in Figure 1. In further studies [2] they deduced a correlation for the critical wind speed U_c at an attack angle θ of the wind to the dimensionless heat release rate

$$U_c sin\theta\sqrt{gw} \sim \dot{Q}_t^{1/3}/(\rho_\infty c_{p,\infty} T_\infty g^{0.5} w^{1.5})^{1/3} \tag{1}$$

where $\dot{Q}_t$ is the heat release rate per unit length, ρ_∞, $c_{p,\infty}$, T_∞ are the density, specific heat and temperature of ambient air, g is the gravitational constant and w is the line burner width. Also within their investigations they applied empirical correlations for the estimation of the flame height of fire whirls under critical wind speed.



*-fan

Figure 1: Top view on experimental setup [1]

Task

Design an appropriate model that maps the presented experimental setup and is capable of reproducing the described phenomena in terms of the formation of fire whirls. Consider relevant parameters and boundary conditions described in the referenced scientific publications. Subsequently, examine whether the simulation results are consistent with the experimental outcomes and whether the encountered phenomena can be adequately described by the empirical relationships described in [2].
In particular consider the following sub-tasks:

1. For the theory part, familiarise yourself with the primary articles and the concept of fire whirls.
2. Create a FDS model that considers the geometric and physical boundary conditions of the experimental setup in a sufficiently high level of detail. First, limit the scope of the analysis to the following parameters:
   - $\theta = 20°$ (Attack angle of wind)
   - $w = 5\ cm$ (width of line burner)
   - $l = 200\ cm$ (length of line burner)
   - $\dot{Q} = 40\ kW/m$ (Heat release rate per unit length)

   For the given parameters calculate the critical wind speed U_c and use it as input parameter for the simulations.
3. Perform a grid sensitivity analysis and determine an appropriate cell size for the model. If necessary, make a suitable division of the computational domain into different meshes.
4. Try to reproduce the described phenomenon of fire whirls with the FDS simulation based on the given boundary conditions. Provide a reasonable analysis of the results and evaluate whether and how well the experimental observations can be reproduced.
5. Vary several parameters of the experiment, e.g. wind speed, and evaluate the influence on the phenomenon.
6. Evaluate which boundary conditions are necessary for the formation of fire whirls. Discuss to what extent these can be adequately represented by FDS and, if necessary, investigate them in corresponding submodels.

Remarks

- Consider processing the task using Jupyter Notebooks and the fdsreader Python module, see lecture notes.
- Break up the computational domain into multiple meshes and assign them to individual MPI processes to reduce computation times. Consider also to speed up the processing of individual meshes by assigning multiple cores using OpenMP.
- Focus not solely on the presented article. Look into the literature to solve problems and questions you may encounter.
- With the WebPlotDigitizer you can extract plot data from images.
- If you get stuck, feel free to reach out to us.

General Info

The time to work on this topic is about four weeks. After about two weeks there will be an intermediate meeting. Each group is supposed to give a brief overview on the status of their work. This meeting is supposed to provide a forum for the participants to show aspects were they are stuck and discuss strategies to solve these issues with the others. This intermediate meeting is NOT part of the grading process.
Familiarise yourselves with the theory part of the setup. Starting from the documents discussed above conduct also a brief literature review. The theory part is supposed to be discussed during the final presentation.
Note: More important than the exact reproduction of experimental results is a conceptual approach to the problem as well as a comprehensive and reasonable modelling.

Grading:
At the final meeting each group is to deliver a presentation. It is divided into three parts of about 8 minutes each. Be mindful of this time with respect to the other students.

- Part 1: Theory
- Part 2: FDS setup
- Part 3: Results and comparison with the literature

Not the goal, how to go to the goal

Theory

FDS

After the presentation each group is asked questions about their project. The presentation and the questions are part of the grade. Each member of the group should give one of the presentations. The grading for each member is split, with the first part being based on the group performance and a second part based on the individuals performance during the presentation and answering the questions.

References

[1] Kuibin Zhou, Naian Liu, Panpan Yin, Xieshang Yuan, and Juncheng Jiang. "Fire Whirl due to Interaction between Line Fire and Cross Wind". In: *Fire Safety Science* 11 (Jan. 2014), pp. 1420–1429. DOI: 10.3801/IAFSS.FSS.11-1420.

[2] Kuibin Zhou, Naian Liu, and Xieshang Yuan. "Effect of Wind on Fire Whirl Over a Line Fire". In: *Fire Technology* 52 (June 2015). DOI: 10.1007/s10694-015-0507-9.

1. 22.09 → Review the literature & task
→ 1 & 2 task

2. 1.10 → semi presentation