CFD analysis of delayed ignition hydrogen releases from a train inside a tunnel

Tolias I.C.[1], Rattigan W.[2], Lyons K.[2], Koumroglou V.C. [3], Venetsanos A.G.[1]

[1]*Environmental Research Laboratory, **National Centre for Scientific Research Demokritos**, Agia Paraskevi, Athens, 15341, Greece*

[2]**HSE Science and Research Centre**, Buxton, United Kingdom

[3]Core department, **National and Kapodistrian University of Athens**, Euripus Campus, Greece

tolias@ipta.demokritos.gr

Introduction

- Hydrogen
  - Significant reductions in greenhouse gas emissions
  - Significant improvements in energy efficiency
- Accidental release in confined space ⟶ catastrophic consequences in the case of an explosion

- Computational Fluid Dynamics (CFD)
  - Attractive methodology for risk assessment: Accurate modelling of the geometry and the flow

- HyTunnel project[1]
  - The aim was perform pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces

[1] https://hytunnel.net/

Introduction

- Delayed ignition experiments that were recently performed by HSE in a model of a tunnel were simulated using CFD
  - Hydrogen release and dispersion
  - Delayed ignition (deflagration)

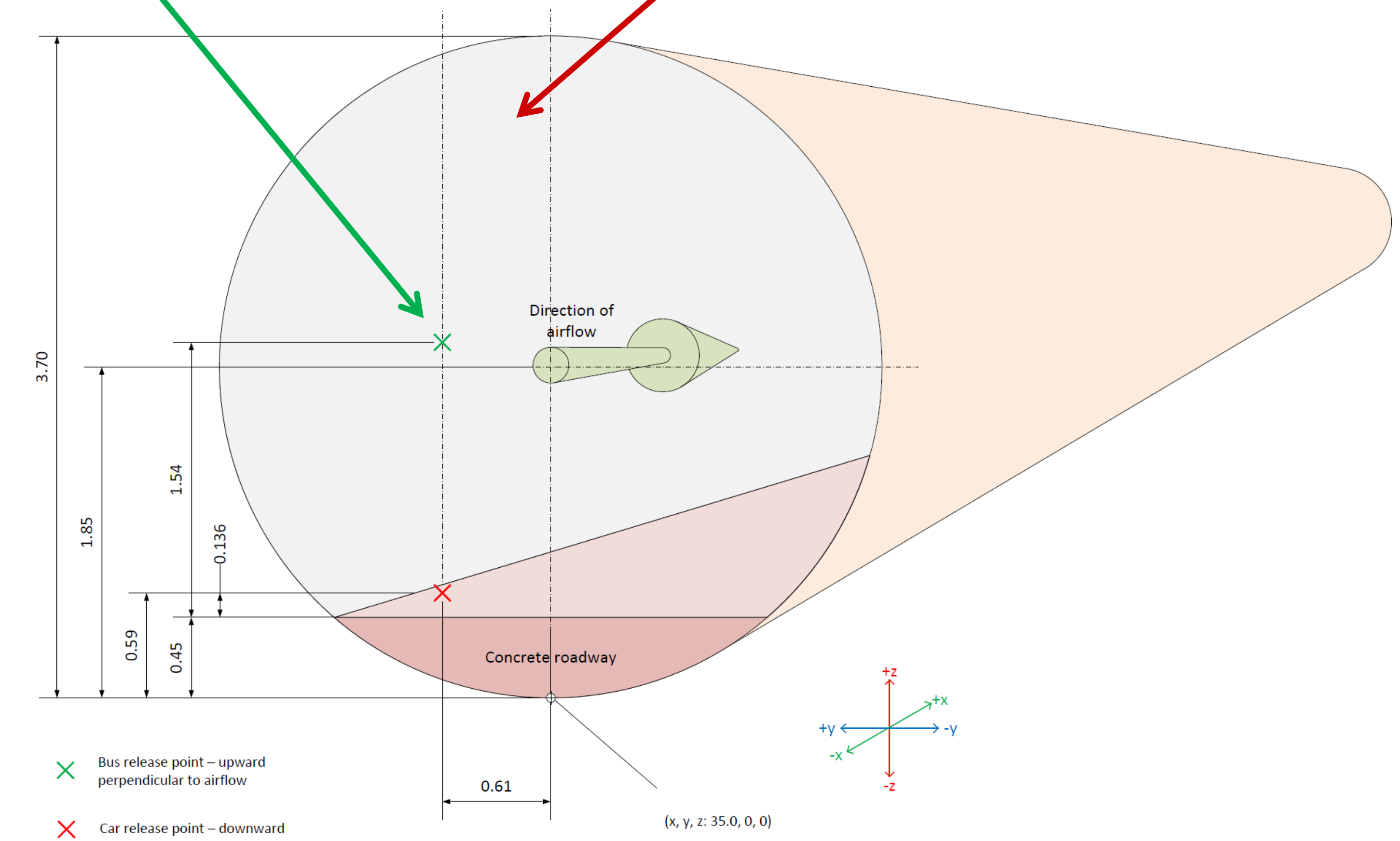
- The **aims of the work** are:
  - analyze the experiments using CFD models to gain a deeper understanding of the phenomena
  - investigate the impact of certain parameters, such as wind and ignition delay, on the results.
  - to verify the accuracy of our CFD model

Experiments

- Geometry:
  - Tunnel length: 70 m
  - Maximum height: 3.25 m
  - Horseshoe cross section
  - Case without congestion
- Forced or natural ventilation

Experiments

- **Release**: x=35, y=0.6, z=1.54 m (Direction: Upwards)
  Ignition: x=38, y=0.6, z=2.95 m (3m downwind the release)



Experiments

- **Basic examined cases in this work**
  - Test 6: Only hydrogen concentrations are measured
  - Test 25: Ignited case, overpressure measurements

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
6	No	–	No	Forced ventilation	0.8 – 1.5
25	Yes	8.5 s	No	Forced ventilation	1.0 – 1.6

- Secondary cases
  - Tests 55-57: Ignition delay effect

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
55	Yes	0.0 s	No	**Natural** ventilation	1.5 – 1.9*
56	Yes	1.8 s	No	**Natural** ventilation	1.5 – 1.9*
57	Yes	6.5 s	No	**Natural** ventilation	1.5 – 1.9*

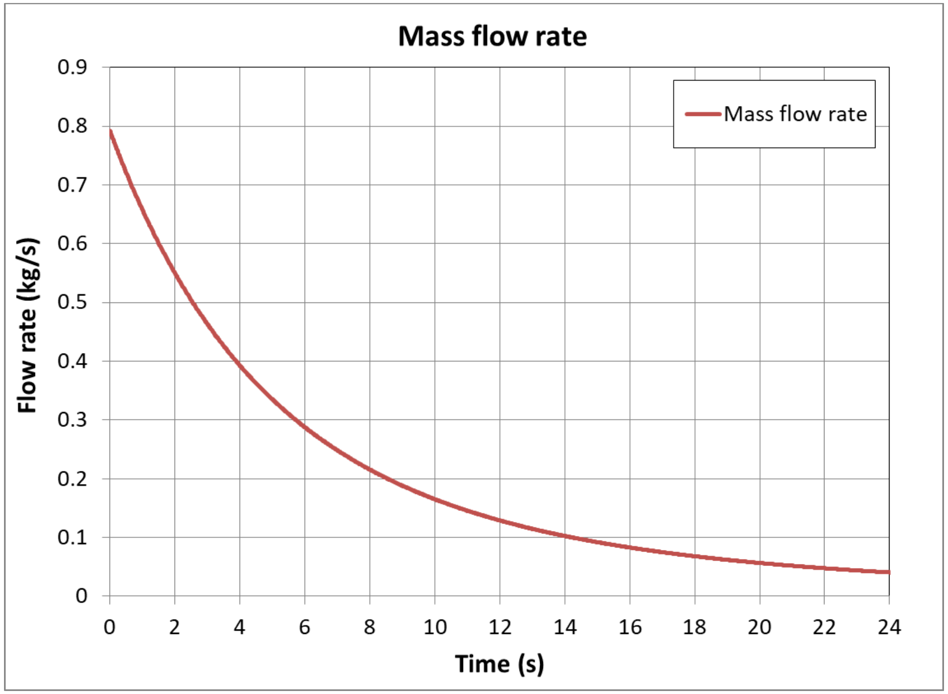
*Great uncertainty of the wind speed

Hydrogen

- Train release case
- Storage mass: 5.55 kg
- Storage pressure: 580 bars

Release

- Pressure inside the tank was used to estimate mass flow rate



CFD modelling

- ADREA-HF code
- Continuity, Navier-Stokes, Energy, Species mass fraction equations
- Turbulence: k-ε model (Kato, Launder 1993 modification)

Deflagration model:

- Turbulent burning velocity model[1]

$$S_T = \Xi_k \cdot \Xi_{lp} \cdot \left[S_L + u' \left(1 + Da^{-2} \right)^{-1/4} \right]$$

Ξ_k: Turbulence that is generated by the flame front itself

Ξ_{lp}: non-equidiffusive effects

$S_L + u'(1+Da^{-2})^{-1/4}$: Turbulence that exists in front of the flame front (Schmid's relation)

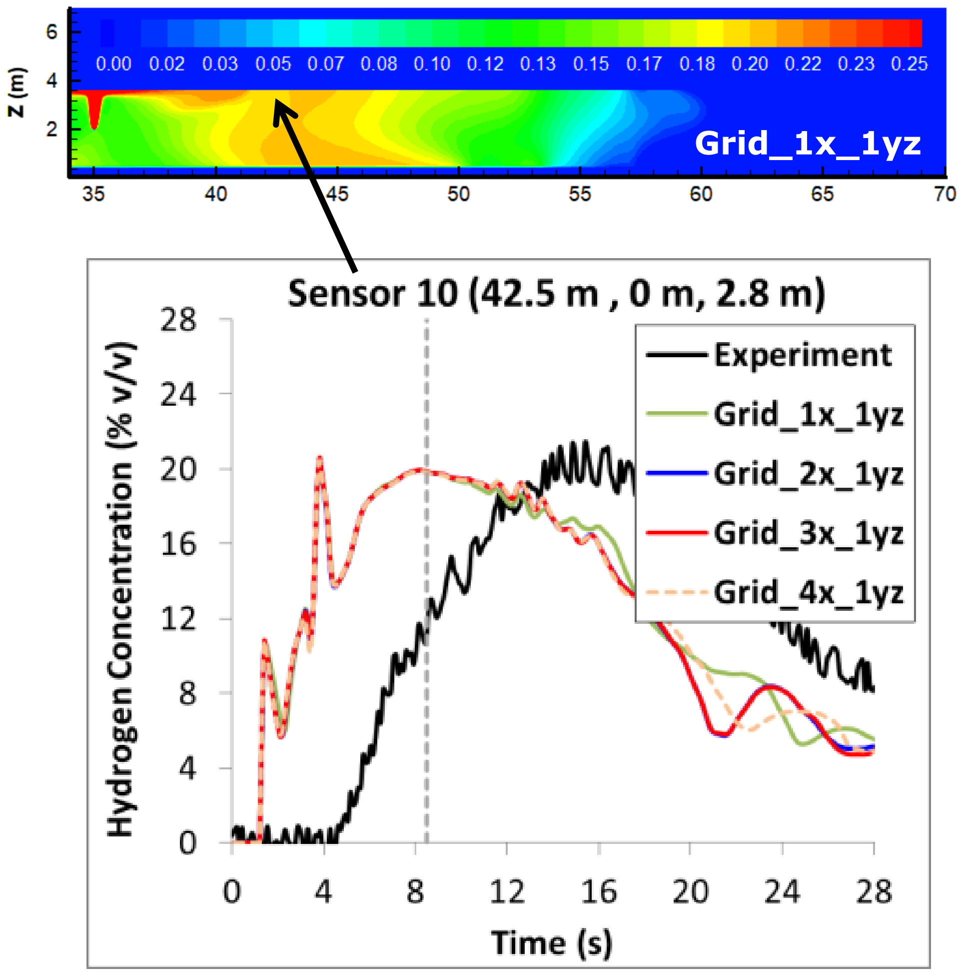
[1] Tolias I.C., Venetsanos A.G., 2018, An improved CFD model for vented deflagration simulations – Analysis of a medium-scale hydrogen experiment, IJHE, 43 (52), 23568-84

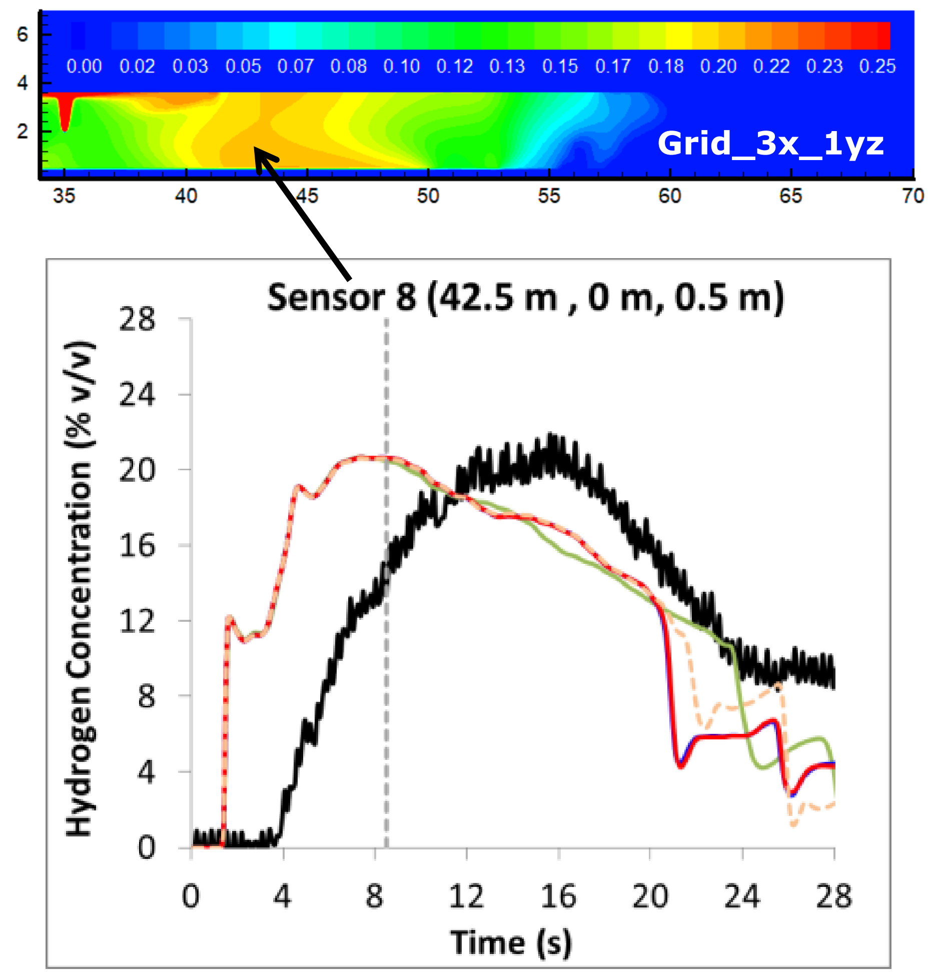
CFD results - Grid sensitivity

- **Grid sensitivity study**
  - First the grid sensitivity study in the x direction was examined
  - Four different grids were used
  - Wind speed equal to 1.3 m/s is used (average of the experimental measurements)

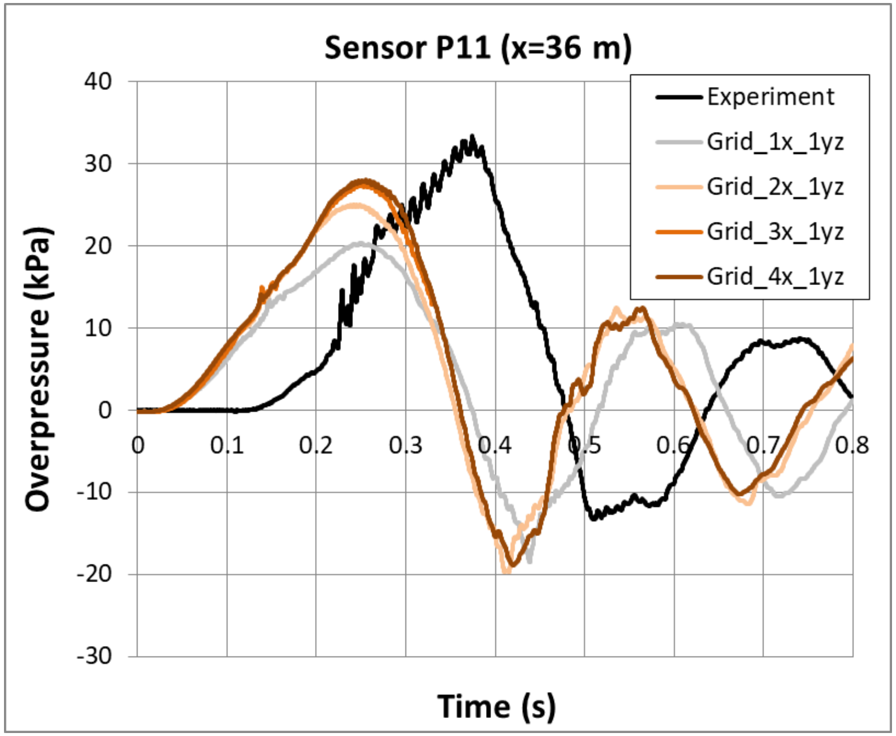
Grid cases						
ID	Name	Number of cells in x direction	Number of cells in y direction	Number of cells in z direction	Total number of active cells	Number of cells in source
1	Grid_1x_1yz	**288**	117	94	1,242,886	4
2	Grid_2x_1yz	**490**	117	94	1,821,909	4
3	Grid_3x_1yz	**646**	117	94	2,268,849	4
4	Grid_4x_1yz	**788**	117	94	2,679,705	4

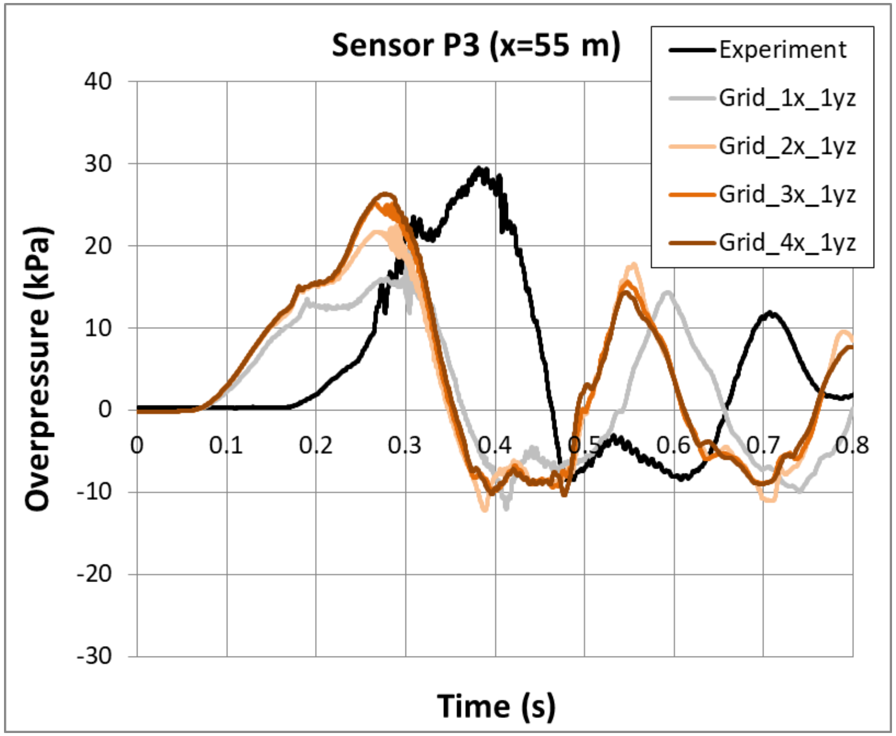
- **Grid sensitivity study:** x direction
  - Hydrogen concentrations at ignition time (8.5 s)





- **Grid sensitivity study:** x direction
  - Overpressures (ignition at x=38 m)





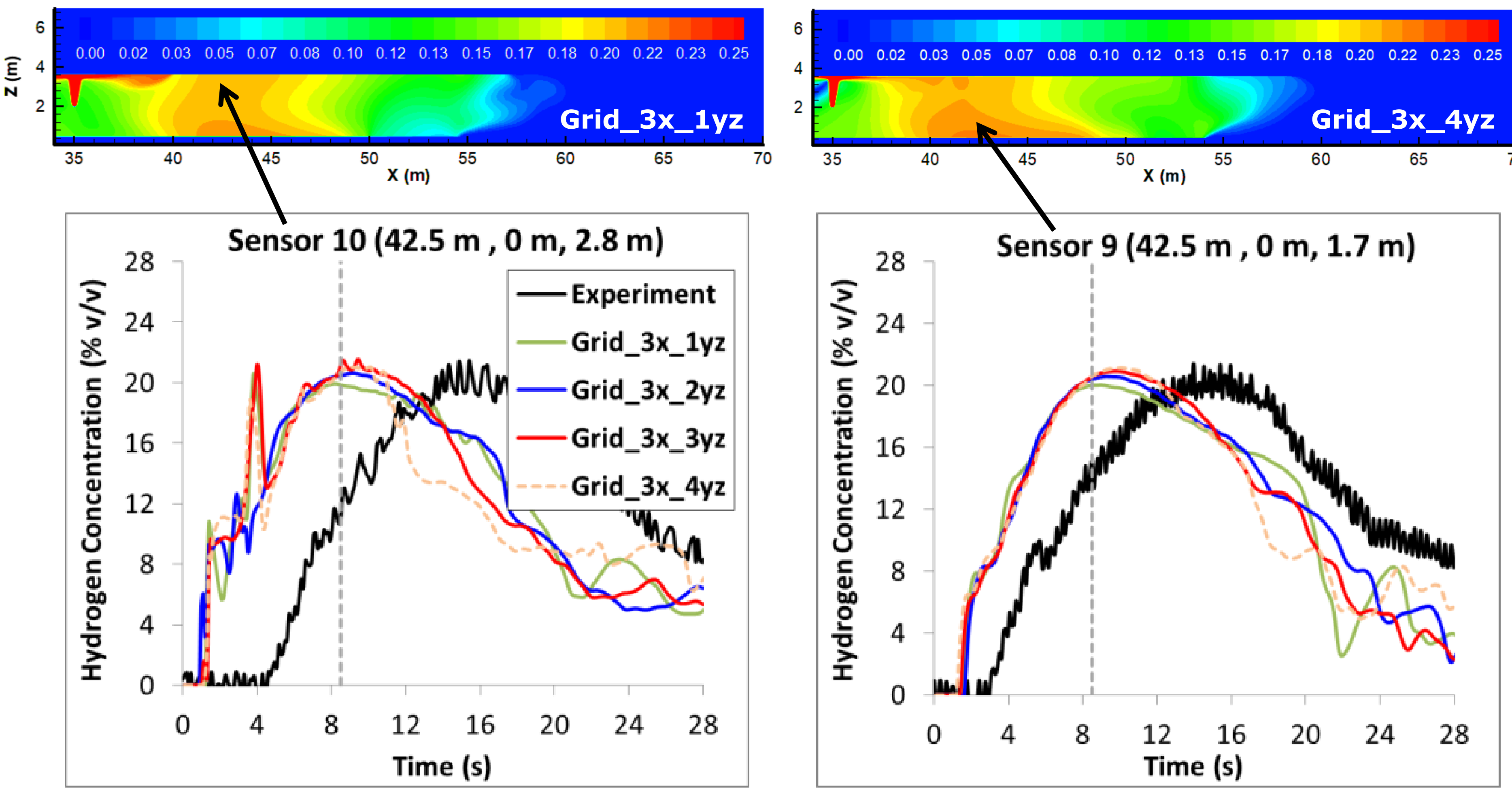
  - Grid independency is achieved in 3rd grid

CFD results - Grid sensitivity

- **Grid sensitivity study**
  - y and z direction was examined
  - Four different grids were used

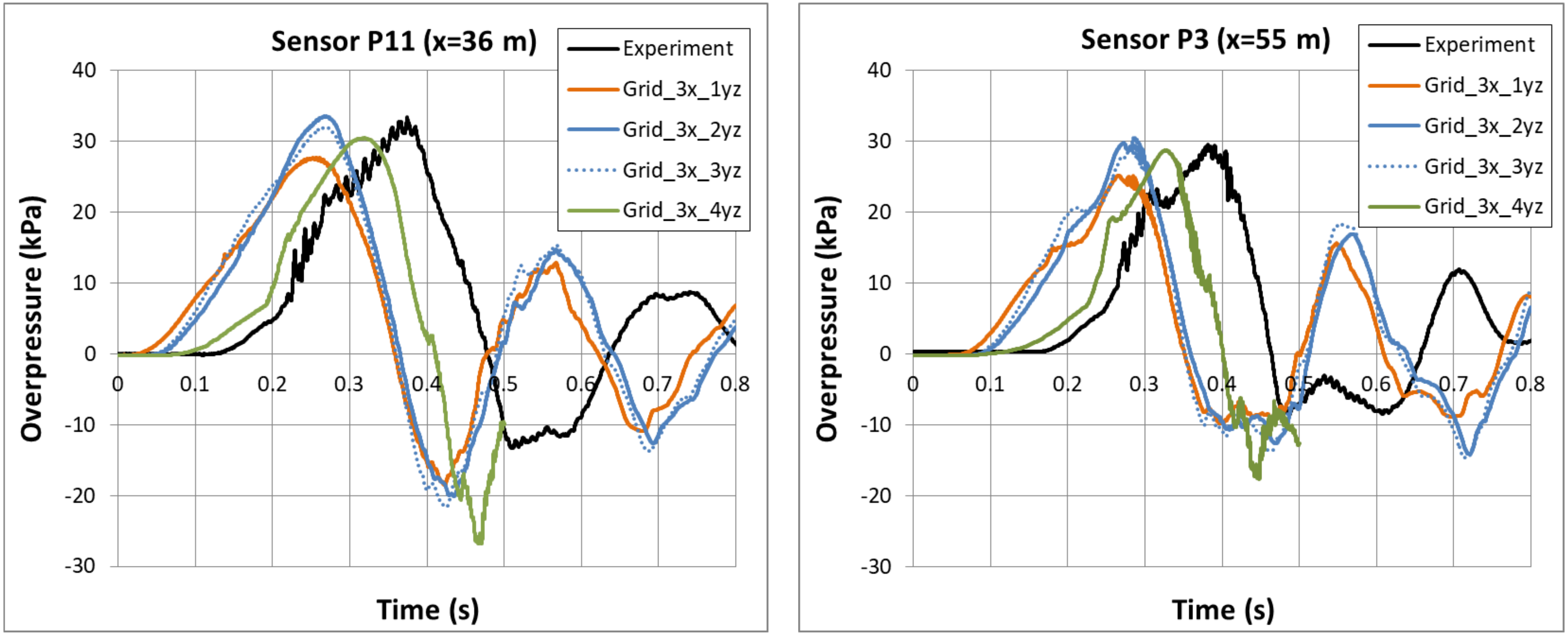
Grid cases						
ID	Name	Number of cells in x direction	Number of cells in y direction	Number of cells in z direction	Total number of active cells	Number of cells in source
3	Grid_3x_1yz	646	117	94	2,268,849	4
5	Grid_3x_2yz	646	**144**	**114**	3,804,269	4
6	Grid_3x_3yz	646	**152**	**124**	4,470,576	4
7	Grid_3x_4yz	**658**	**171**	**142**	6,384,087	**9**

- **Grid sensitivity study:** y, z direction
  - Hydrogen concentrations at ignition time (8.5 s)



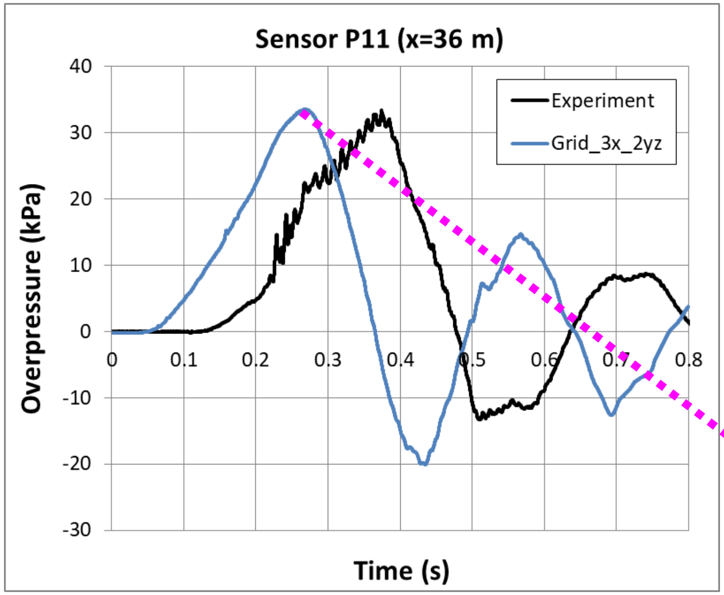
CFD results - Grid sensitivity

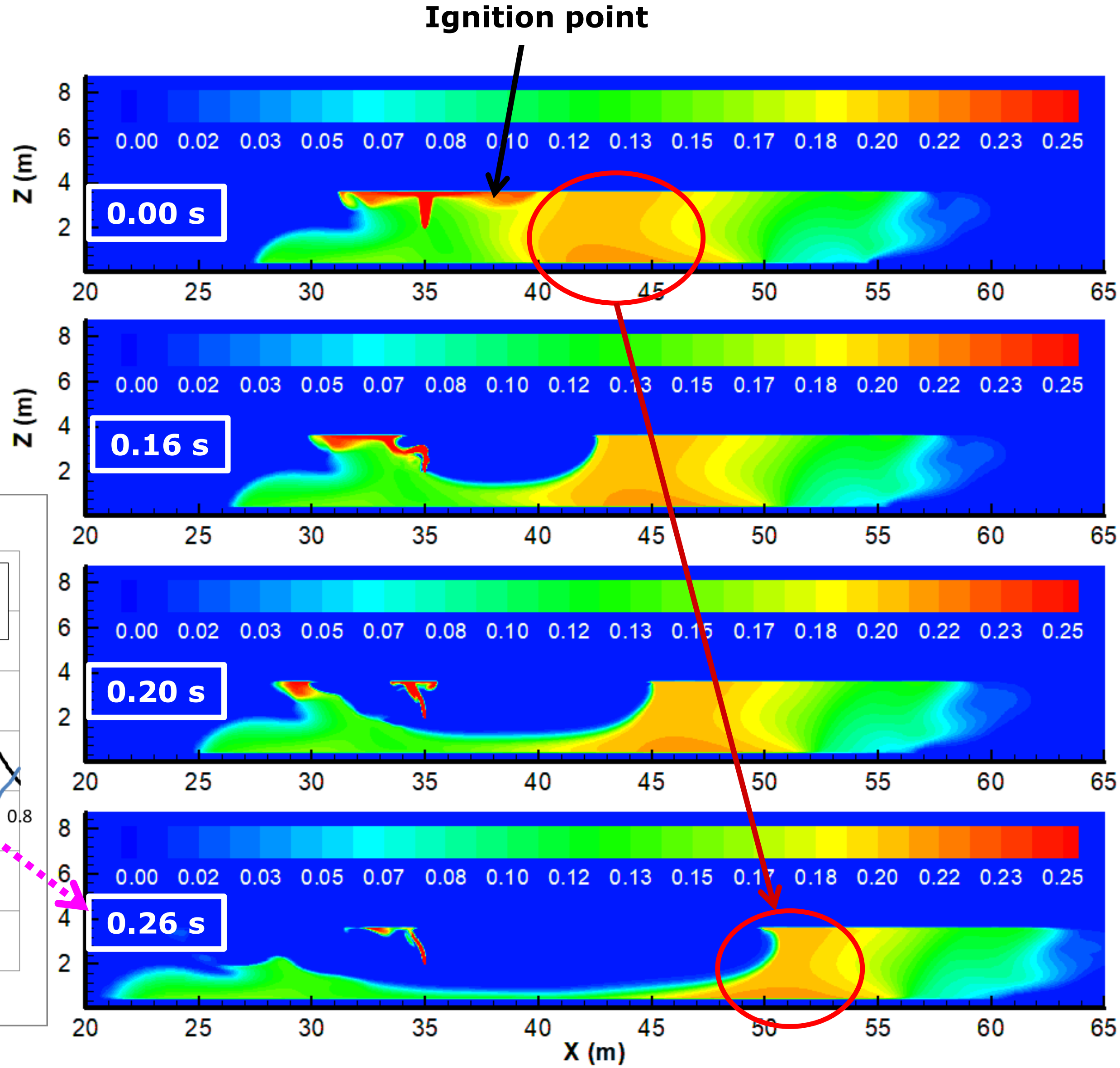
- **Grid sensitivity study:** y, z direction
  - Overpressures (ignition at x=38 m)



  - The second grid (blue line) is used in the rest of the study

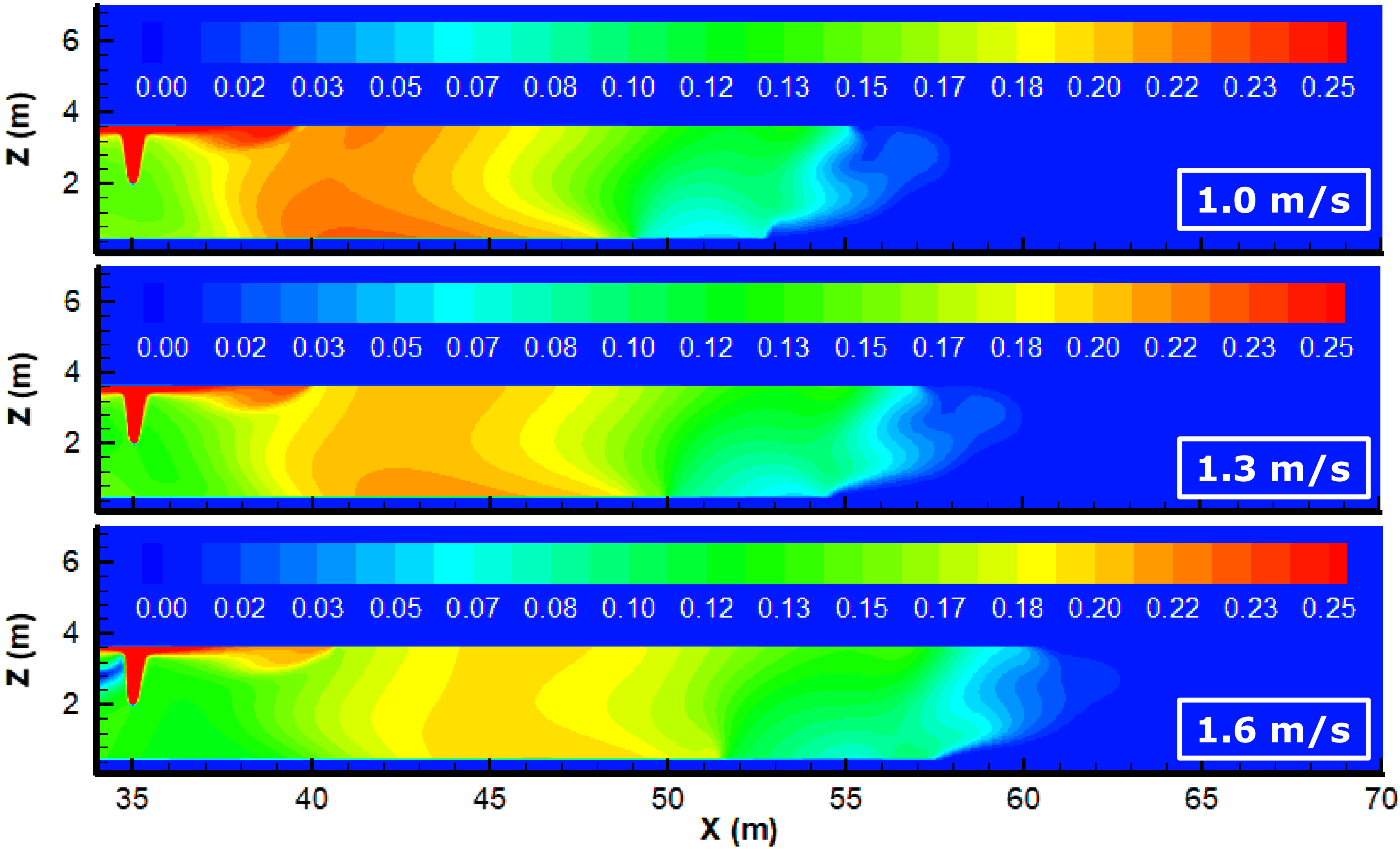
- **Flame propagation**



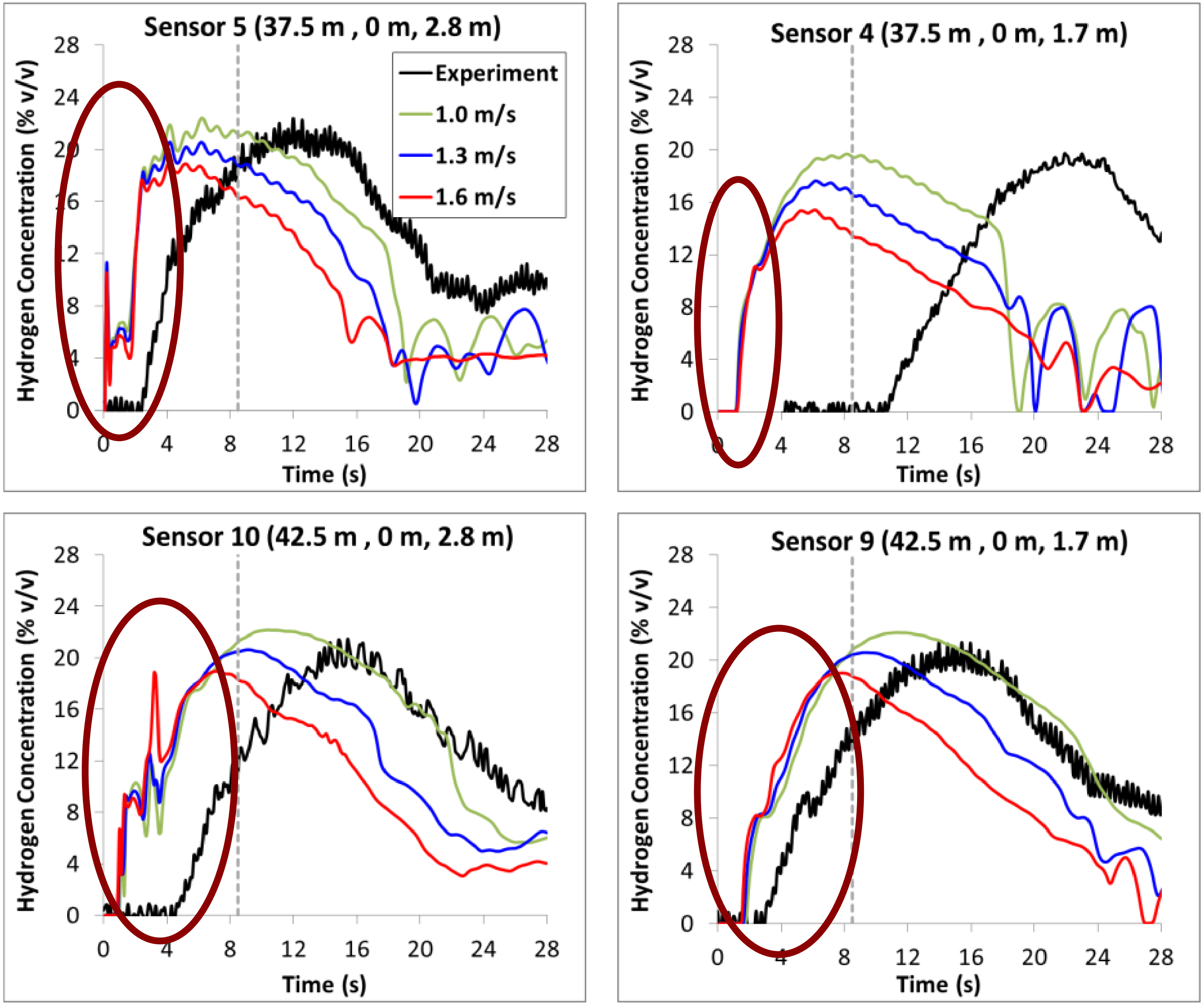


CFD results – Wind effect

- **Three wind velocities were examined**

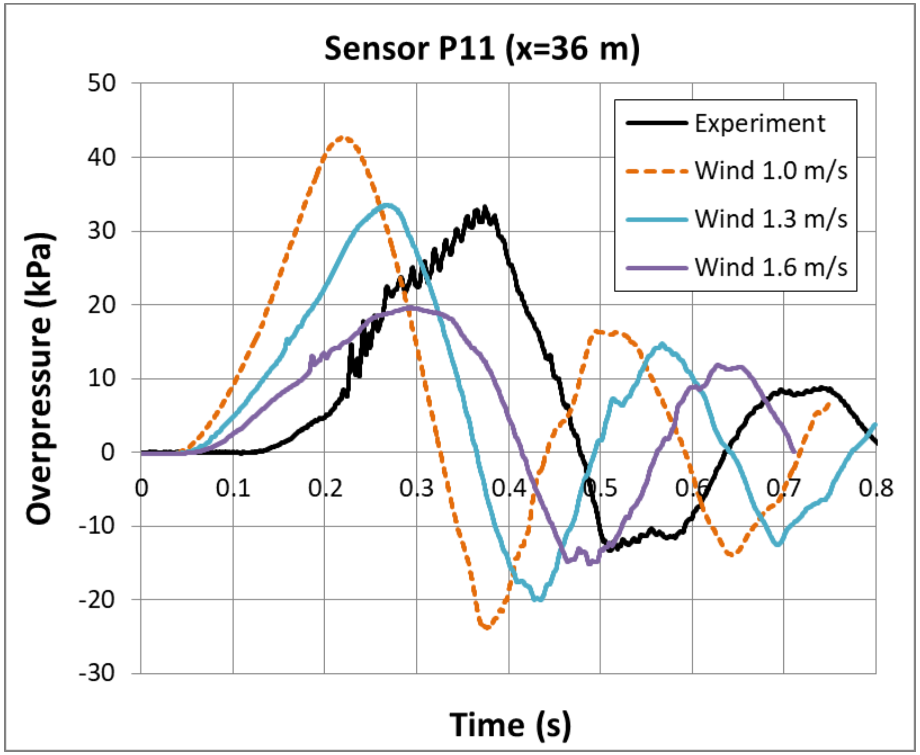


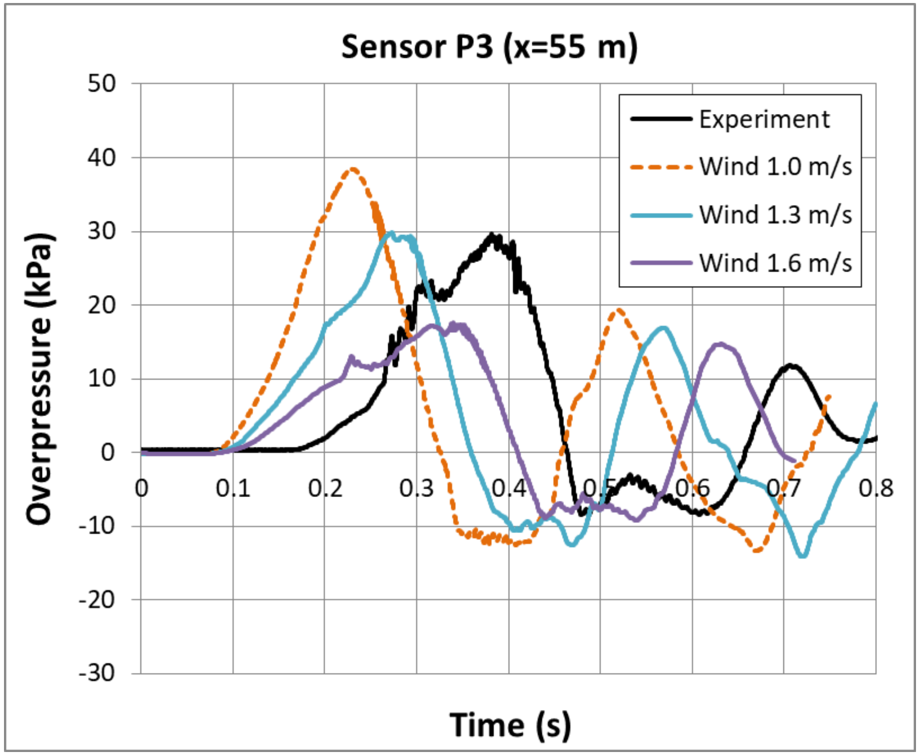
CFD results – Wind effect



CFD results – Wind effect

- Overpressures



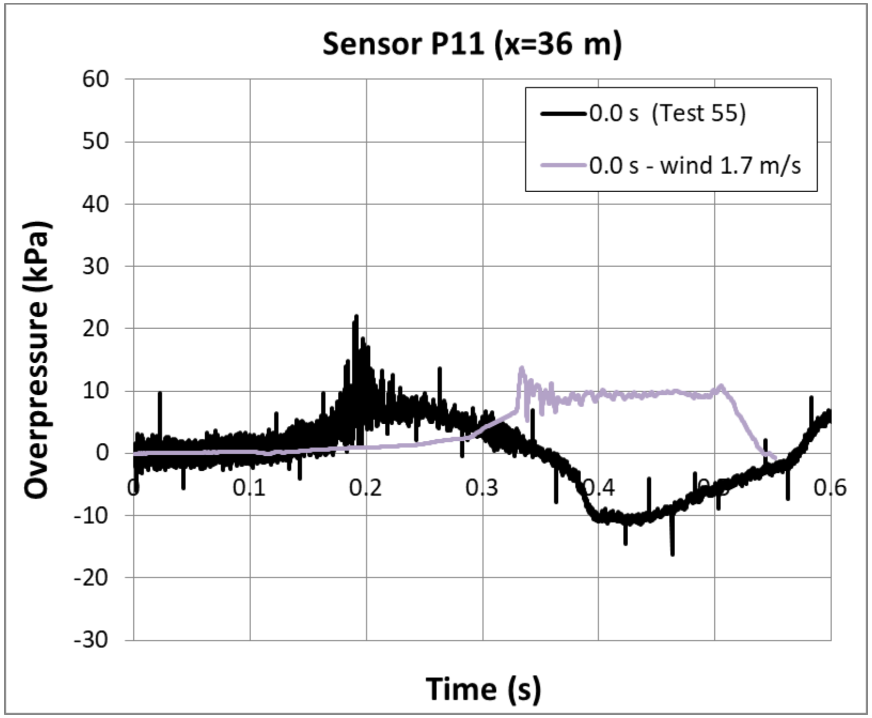


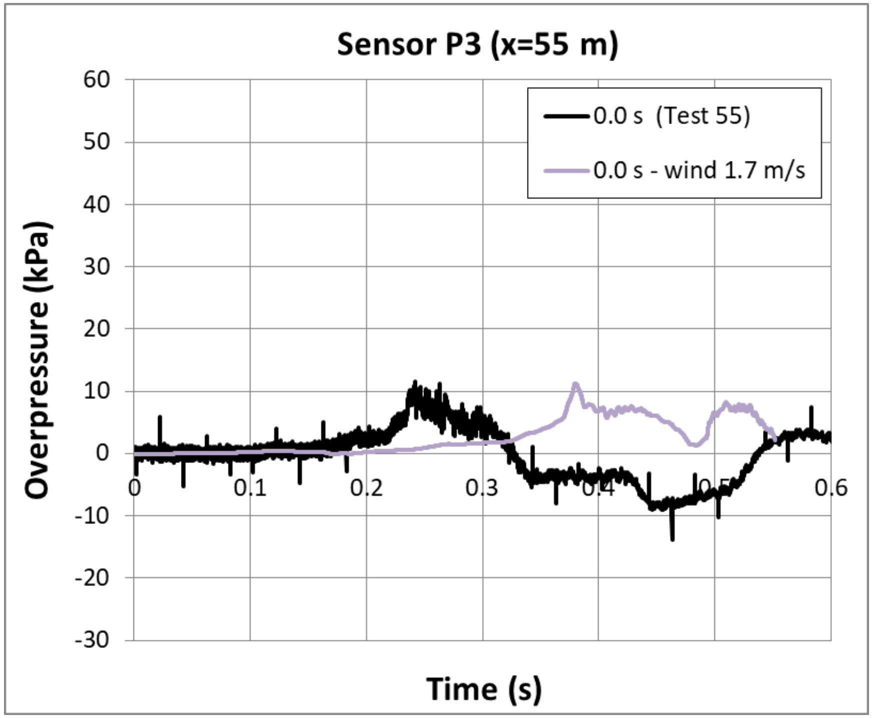
- 1.3 m/s to 1.6 m/s: 23% increase of wind results in 65% decrease in overpressure

- Simulations of other tests: Ignition delay
  - Tests 55-57: Ignition delay effect

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
55	Yes	0.0 s	No	**Natural** ventilation	1.5 – 1.9*
56	Yes	1.8 s	No	**Natural** ventilation	1.5 – 1.9*
57	Yes	6.5 s	No	**Natural** ventilation	1.5 – 1.9*

*Great uncertainty of the wind speed



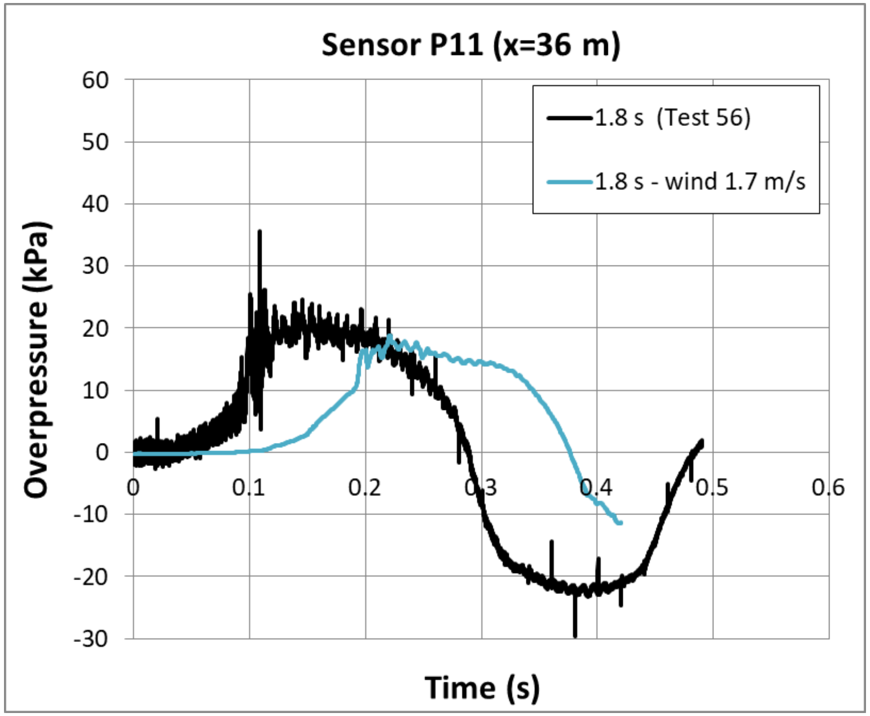


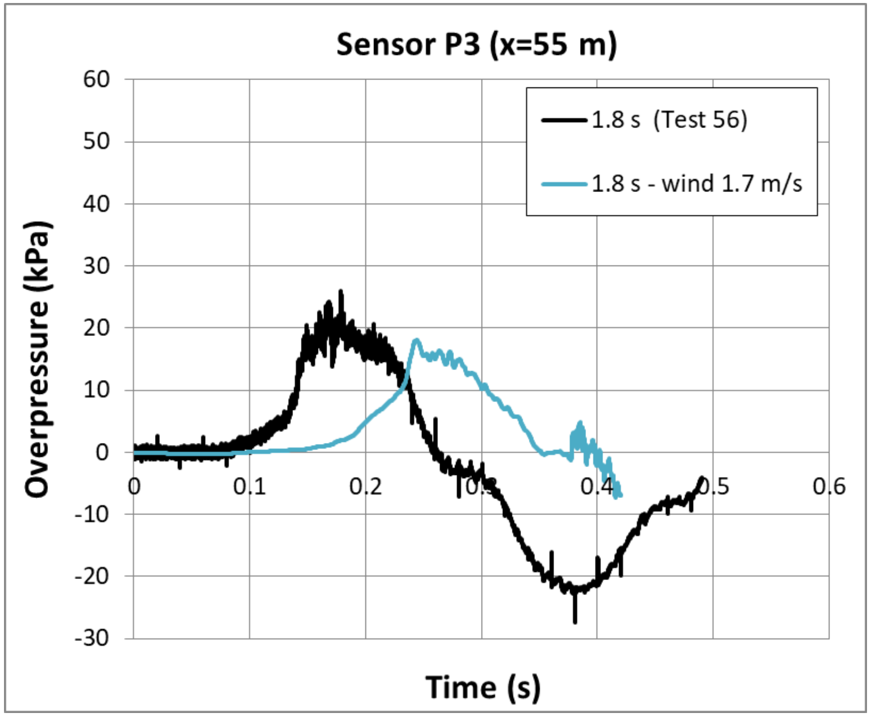
CFD results – Ignition delay

- Simulations of other tests: Ignition delay
  - Tests 55-57: Ignition delay effect

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
55	Yes	0.0 s	No	**Natural** ventilation	1.5 – 1.9*
56	Yes	1.8 s	No	**Natural** ventilation	1.5 – 1.9*
57	Yes	6.5 s	No	**Natural** ventilation	1.5 – 1.9*

*Great uncertainty of the wind speed



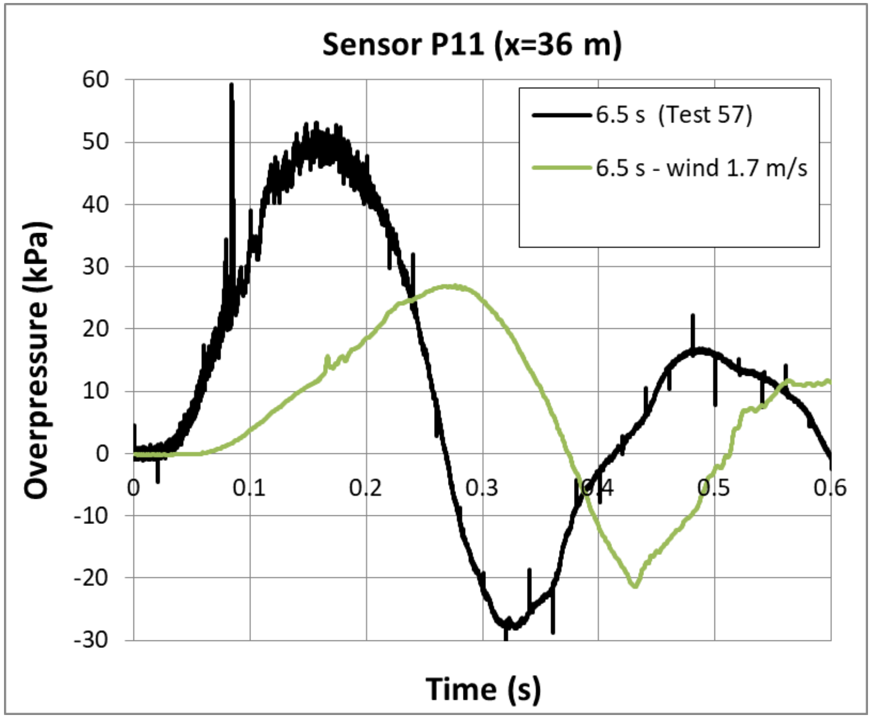


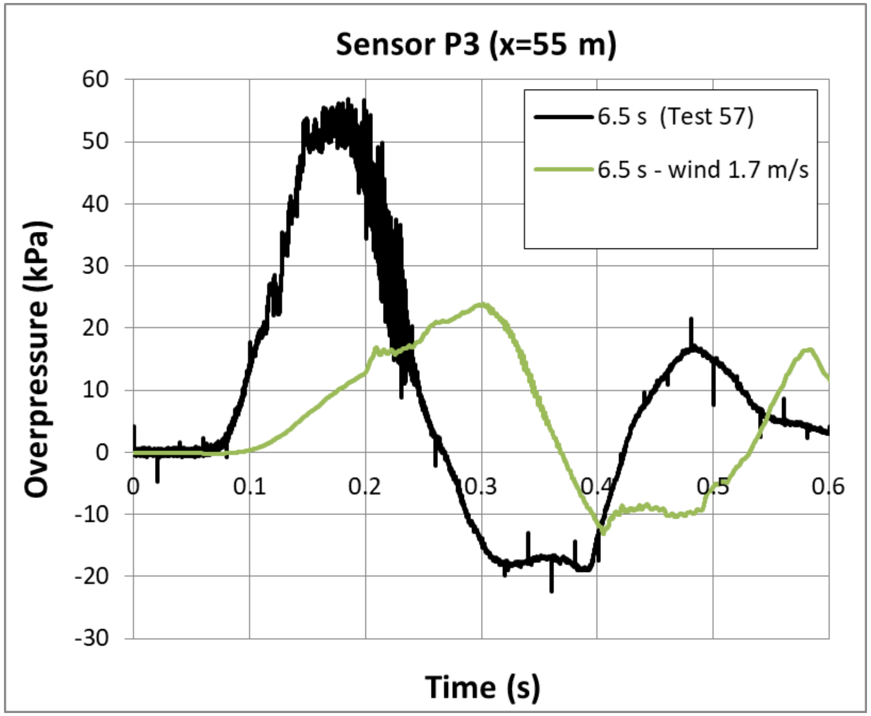
CFD results – Ignition delay

- Simulations of other tests: Ignition delay
  - Tests 55-57: Ignition delay effect

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
55	Yes	0.0 s	No	**Natural** ventilation	1.5 – 1.9*
56	Yes	1.8 s	No	**Natural** ventilation	1.5 – 1.9*
57	Yes	6.5 s	No	**Natural** ventilation	1.5 – 1.9*

*Great uncertainty of the wind speed



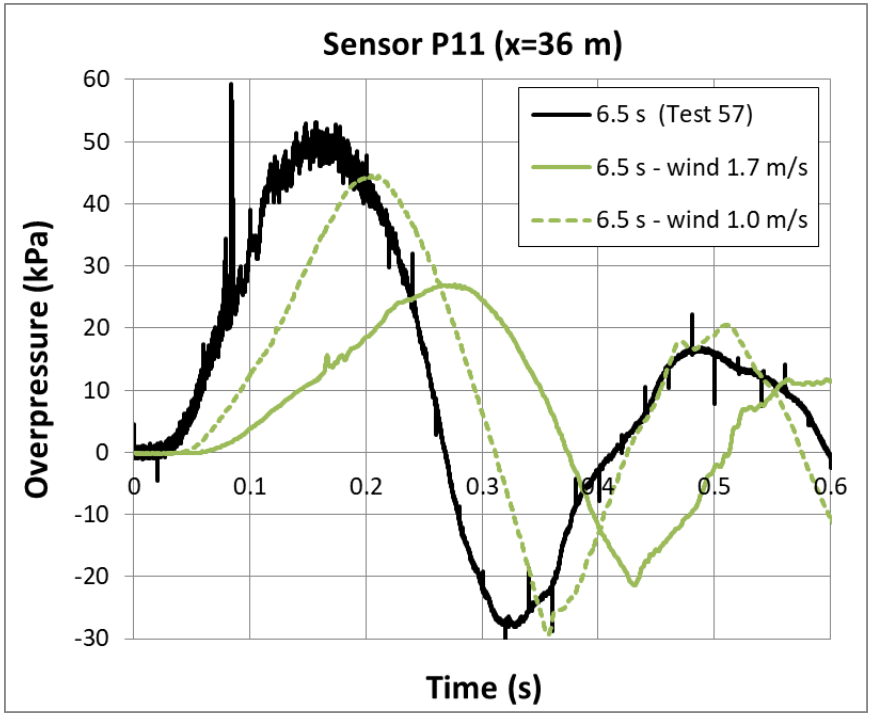


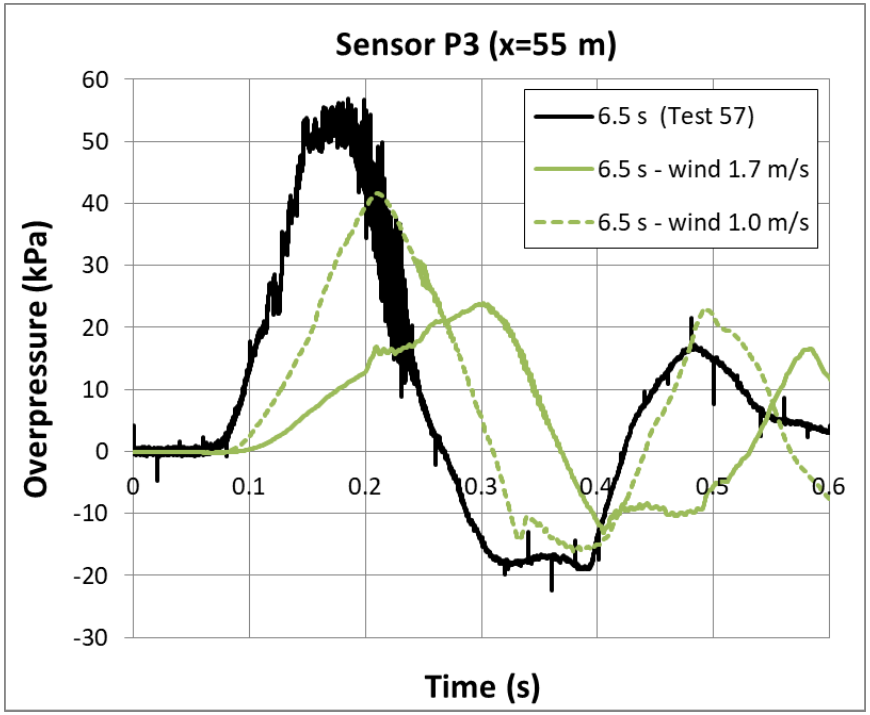
CFD results – Ignition delay

- Simulations of other tests: Ignition delay
  - Tests 55-57: Ignition delay effect

Test Number	Ignited	Ignition delay	Congestion	Wind type	Wind range
55	Yes	0.0 s	No	**Natural** ventilation	1.5 – 1.9*
56	Yes	1.8 s	No	**Natural** ventilation	1.5 – 1.9*
57	Yes	6.5 s	No	**Natural** ventilation	1.5 – 1.9*

*Great uncertainty of the wind speed

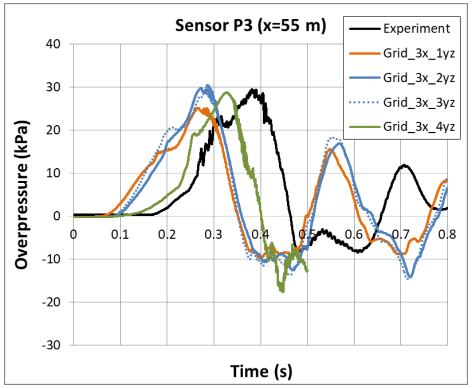


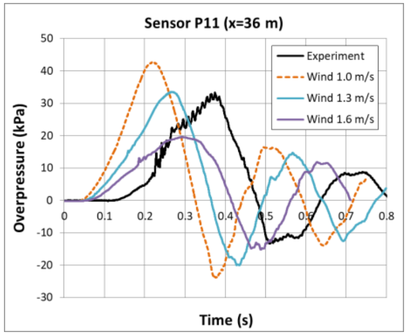


Conclusions

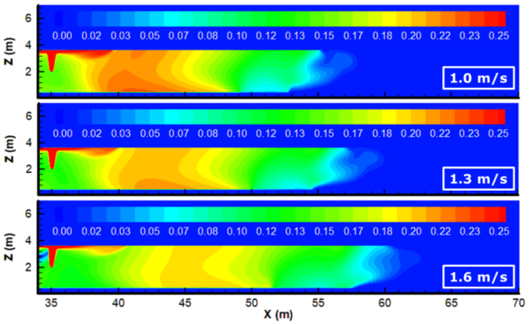
- Detailed grid independency study was conducted revealing that deflagrations results are particular sensitive to grid changes.
  - 3.8 million cells to achieve satisfactory grid independency
- The agreement between simulation results and measurements was very good in the forced ventilation case.
- Simulation results reveal that only the hydrogen that exists in 5 m radius (1.5 times the tunnel height) from the ignition point contributes to maximum overpressure.
- Small changes in wind speed can have significant changes in overpressure. The higher the wind is the lower the overpressure is.
- About the experiments with different ignition delay, good agreement is achieved in the 0.0 s and 1.8 s cases. In the 6.5 s case the overpressure is predicted better when using wind speed equal to 1.0 m/s.

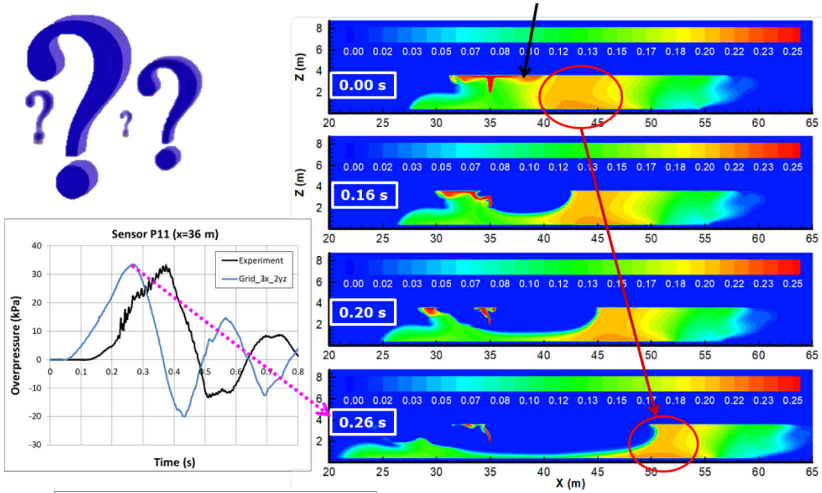
Ευχαριστώ! (Thank you)

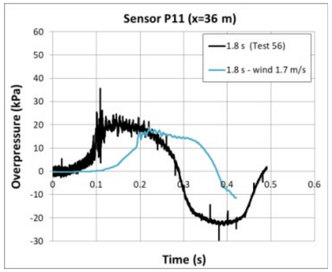


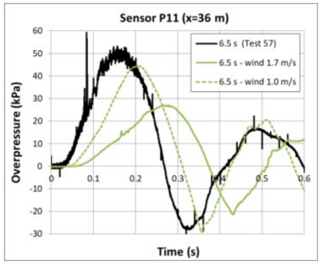


Questions









Acknowledgements: The research leading to these results was financially supported by the **HyTunnel-CS** which has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 826193

The authors would like also to acknowledge the Greek Research & Technology Network (GRNET) for the computational time granted us in the Greek National HPC facility ARIS (http://hpc.grnet.gr) under project H2TUN (pr014025)

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

European Commission | Horizon 2020 European Union funding for Research & Innovation