UK EXPLOSION LIAISON GROUP

UKELG 35th Anniversary Meeting
10-12 October 2017
DNV-GL, Spadeadam, UK

Investigation of non-uniform Hydrogen / Air mixture flame acceleration and transition to detonation

Reza Khodadadi Azadboni[a], Ali Heidari[a], and Jennifer X. Wen[b,*]

[a]Fire, Explosion and Fluid Dynamics Research Team, School of Mechanical & Automotive Engineering, Kingston University London, SW15 3DW, UK

[b]Warwick FIRE, School of Engineering, University of Warwick, Coventry, CV4 7AL, UK

***Jennifer.Wen@Warwick.ac.uk**

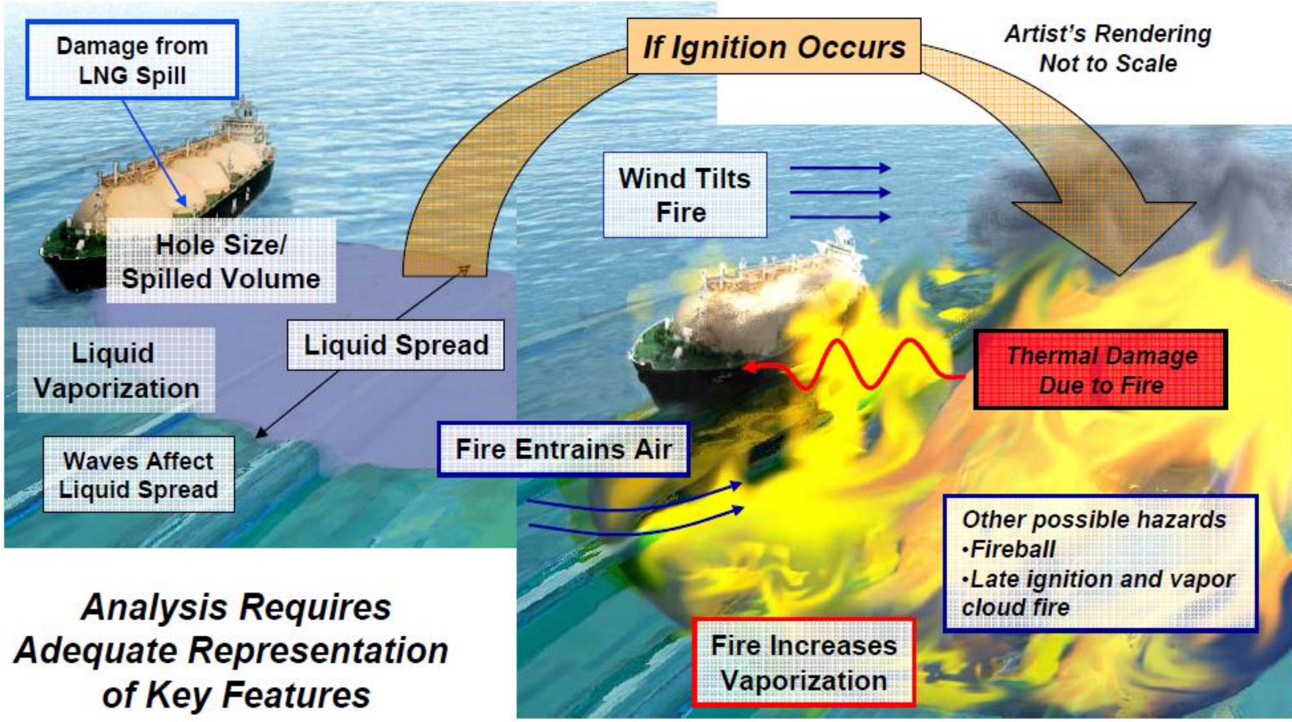
Contents

- Introduction
- Problem description
- CFD approach
- Results
- Conclusion

Problem Description

SafeLNG:>
Hazards of Liquid Fuel shipping

- ❑ Rollover
- ❑ Fuel cascade
- ❑ Spill and dispersion
- ❑ Flashing fuel jet fires
- ❑ pool fires



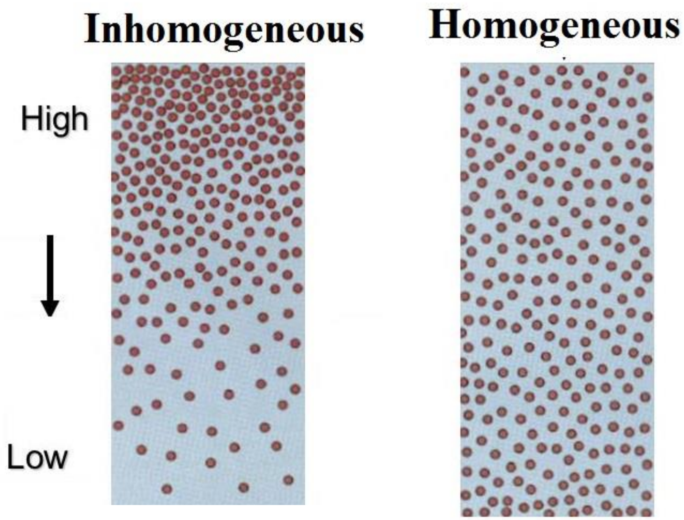
- ❑ Large scale **vapour cloud explosions**

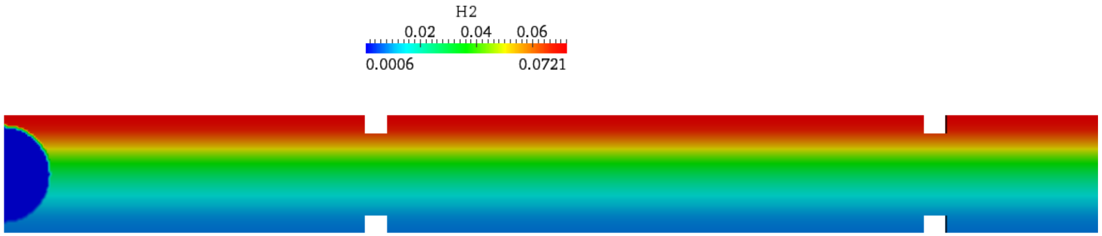
→ **Flame acceleration and interaction to obstacles and transition to detonation**

DDT experiment by Gexcon

Introduction

Concentration Gradient



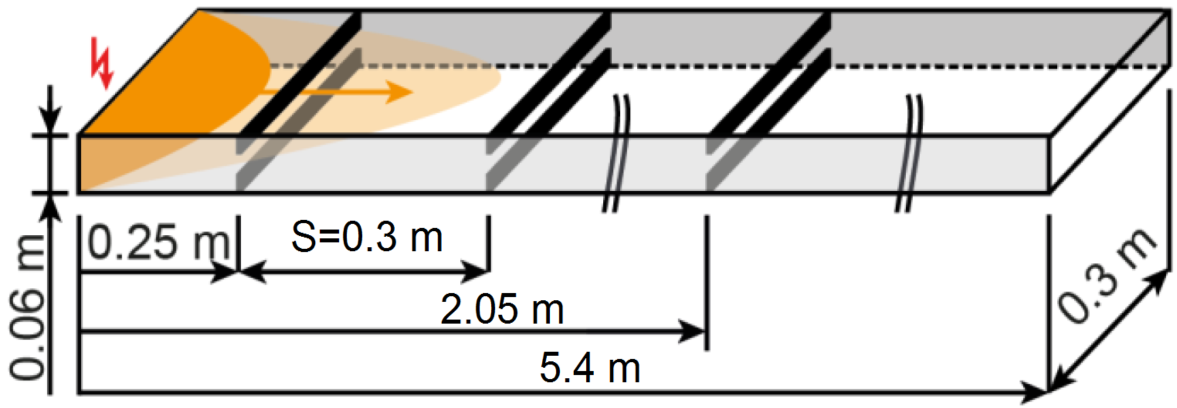


- ❑Effect of Concentration gradient in DDT
- ❑Effects of Blockage ratio in DDT

CFD Approach

- The density-based code developed under OpenFOAM solves the unsteady, compressible Navier-Stokes equation with single step Arrhenius chemistry.
- Cantera for the thermodynamic properties
- Harten–Lax–van Leer–Contact (HLLC) for accurate shock detonation capturing
- High capability of shock and detonation cell capturing
- Implemented Richtmyer Meshkov instabilities and Baroclinic vorticites effects in the solver
- Adaptive Refinement Mesh (AMR) method

The computational model



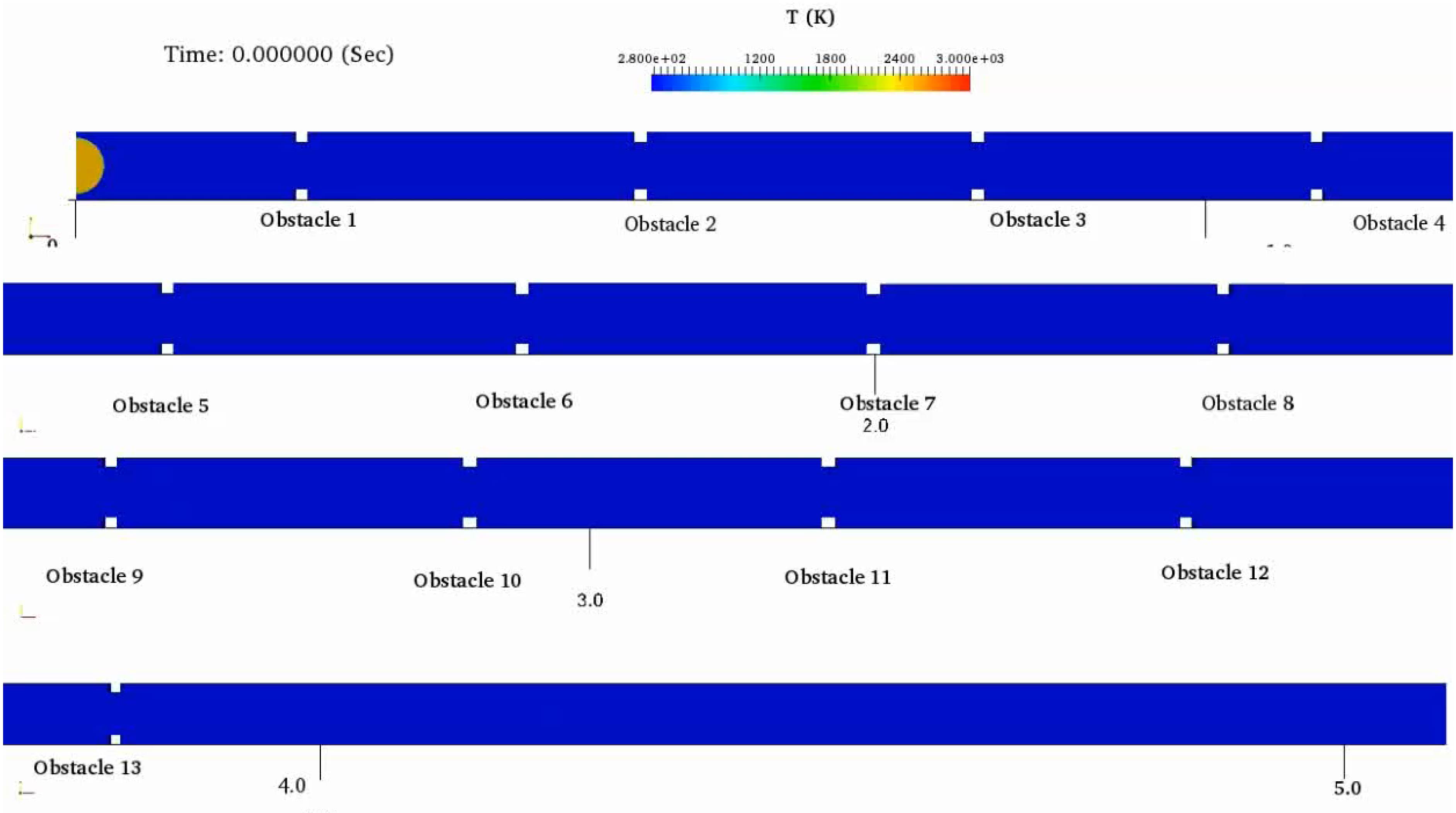
2-D calculations
Closed channel of 0.3 (W) 5.4 (L) 0.06 (H) (m)

Ignition:
Patch cells within a radius of 10 mm around the point of ignition (x=0, y=0.03m) to the burnt state (isobaric, adiabatic burnt mixture).

Boeck LR, Katzy P, Hasslberger J, Kink A & Sattelmayer T. (online 03/2016). The "GraVent DDT Database". Shock Waves, doi:10.1007/s00193-016-0629-0

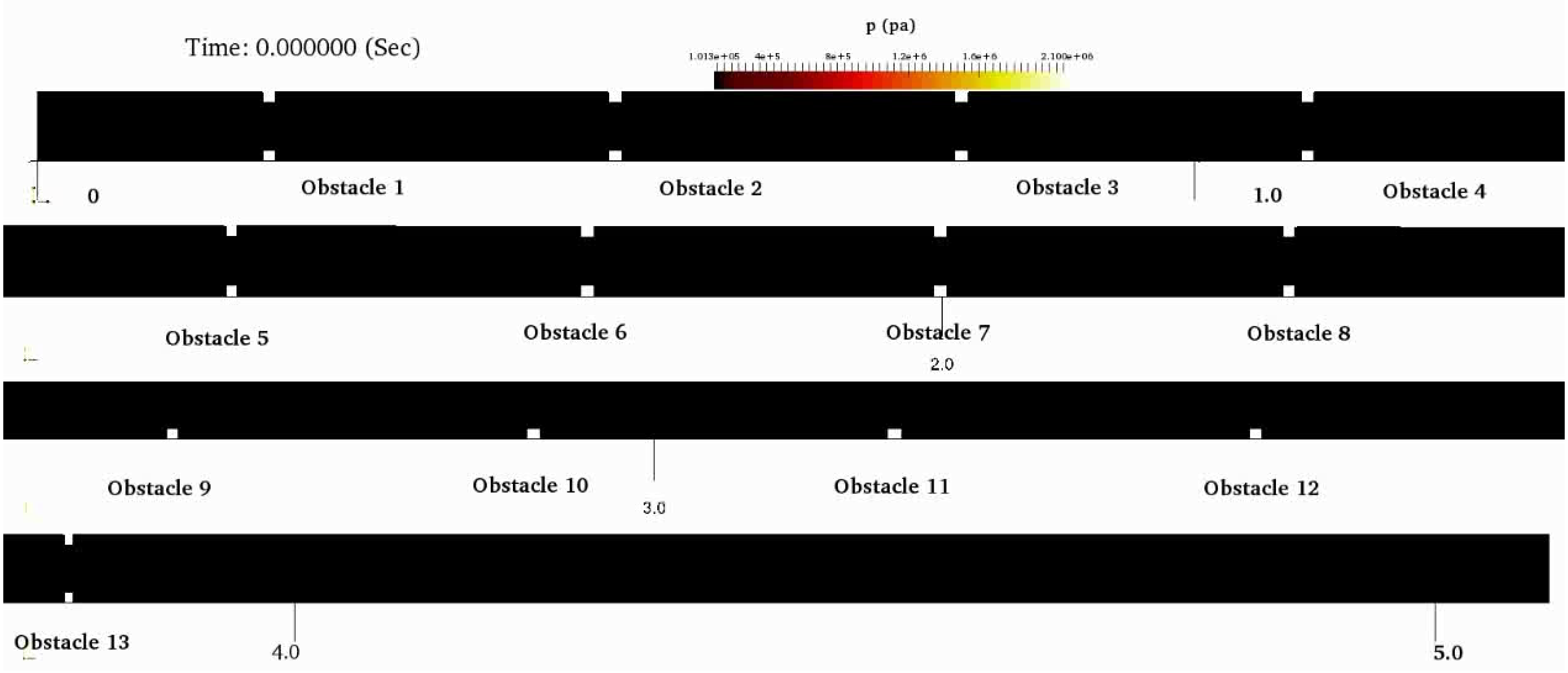
Inhomogeneous 30% H2/Air mixture BR60

Temperature Fields



Inhomogeneous 30% H2/Air mixture BR30

Pressure Fields



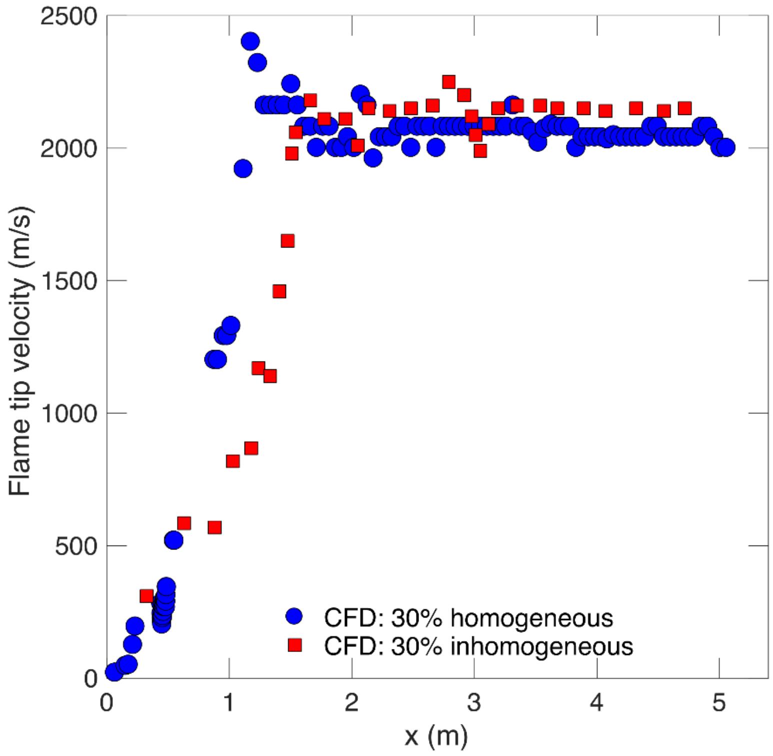
Effects of Concentration gradient

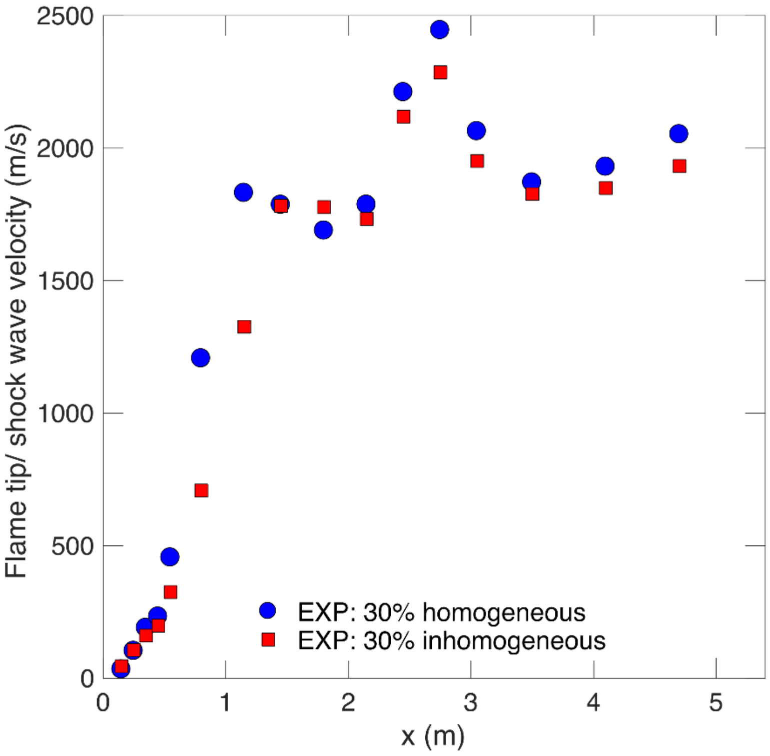
60 % Blockage ratio

- 30 % H2
  - Homogenous
  - Inhomogeneous
- 20 % H2
  - Homogenous
  - Inhomogeneous

30% H2/Air mixture BR60%

- Comparison between homogenous and inhomogeneous cases

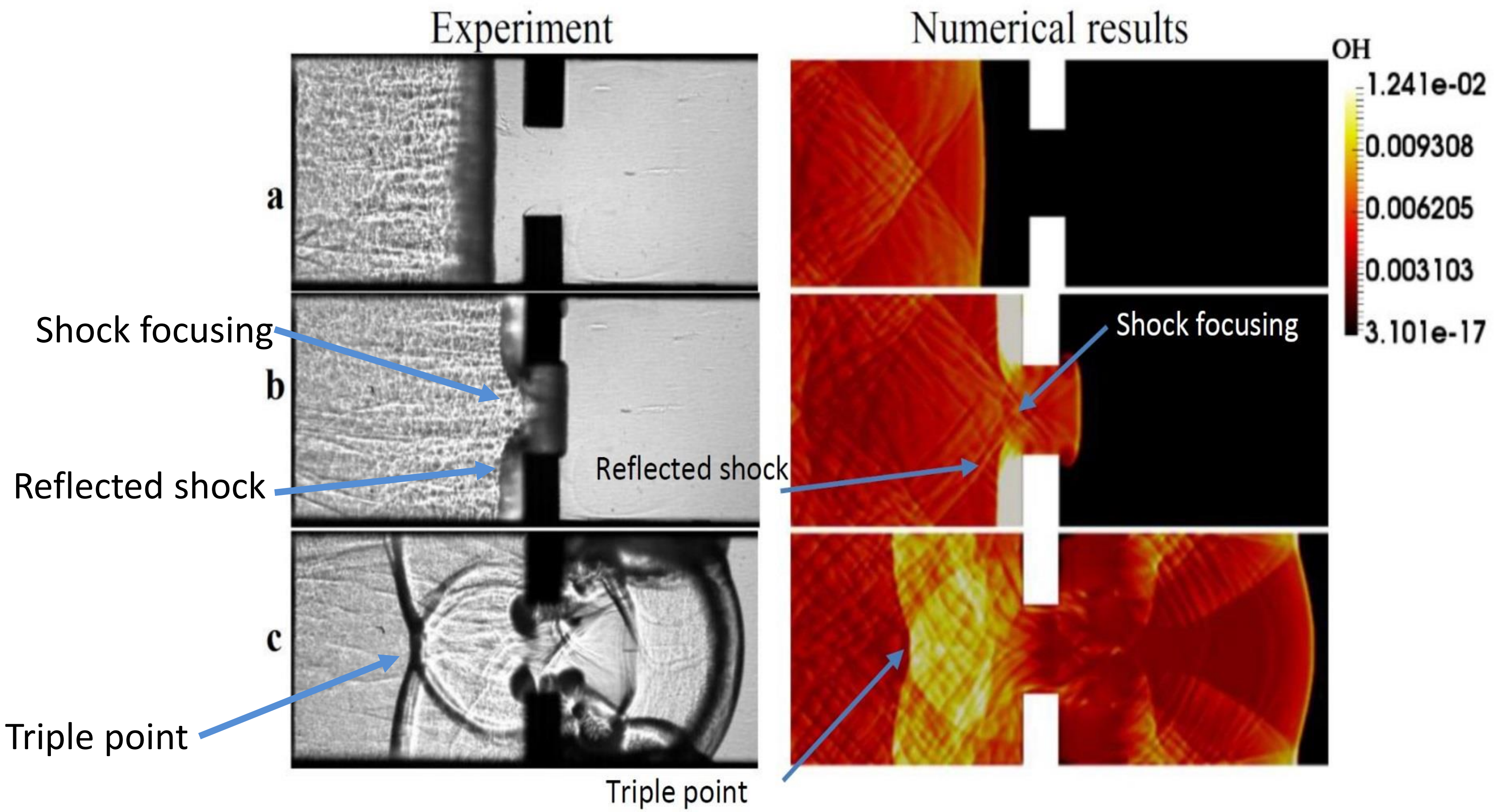




Homogenous mixture	**DDT happened at x=1.09**
Inhomogeneous mixture	DDT happened at x=1.45 m

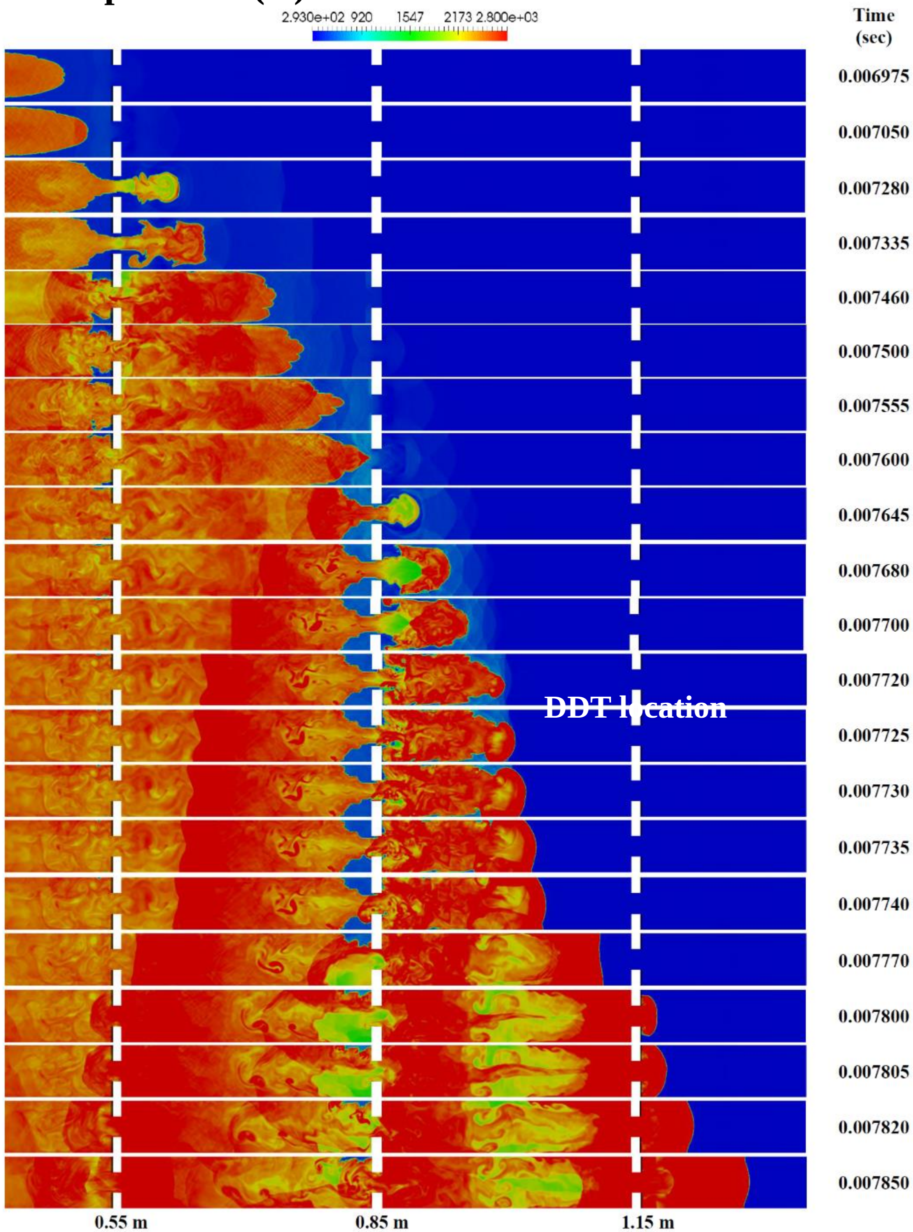
Homogenous 30% H2/Air mixture BR60%

Qualitative comparison between CFD and Experiment

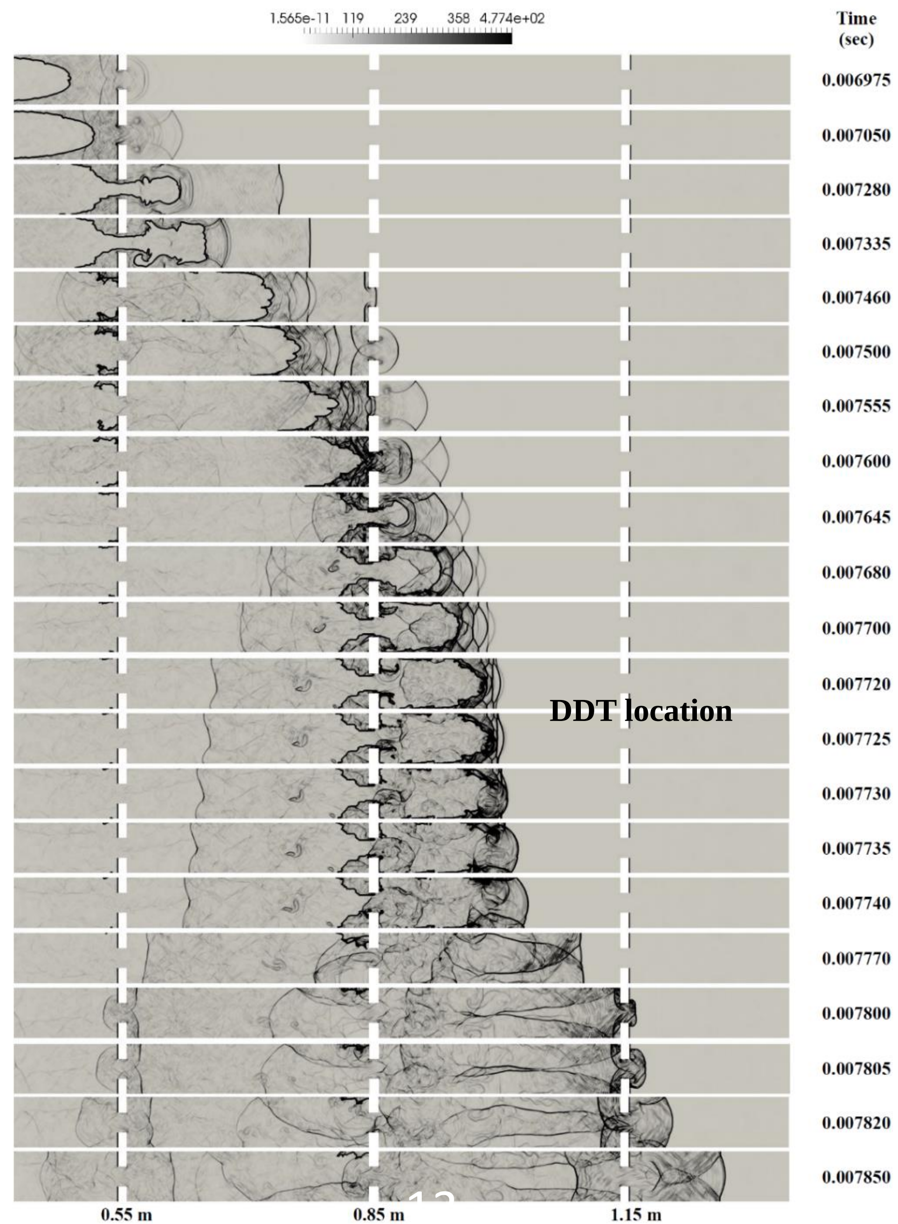


Homogeneous 30% H2/Air mixture BR60

Temperature (K)



Numerical Schlieren

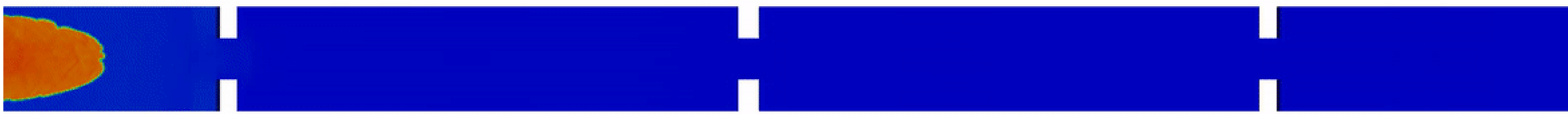


Homogeneous 30% H2/Air mixture BR60

Numerical Schlieren

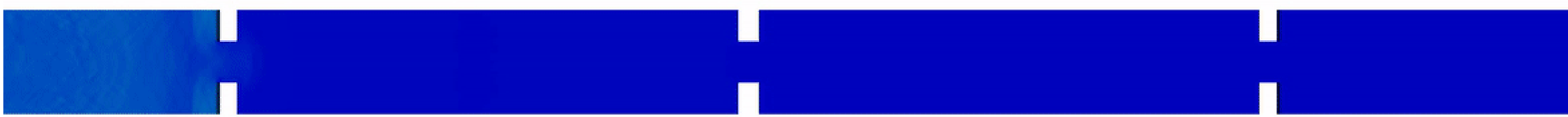
Time: 0.006950 sec

Temperature (K)



Time: 0.006950 sec

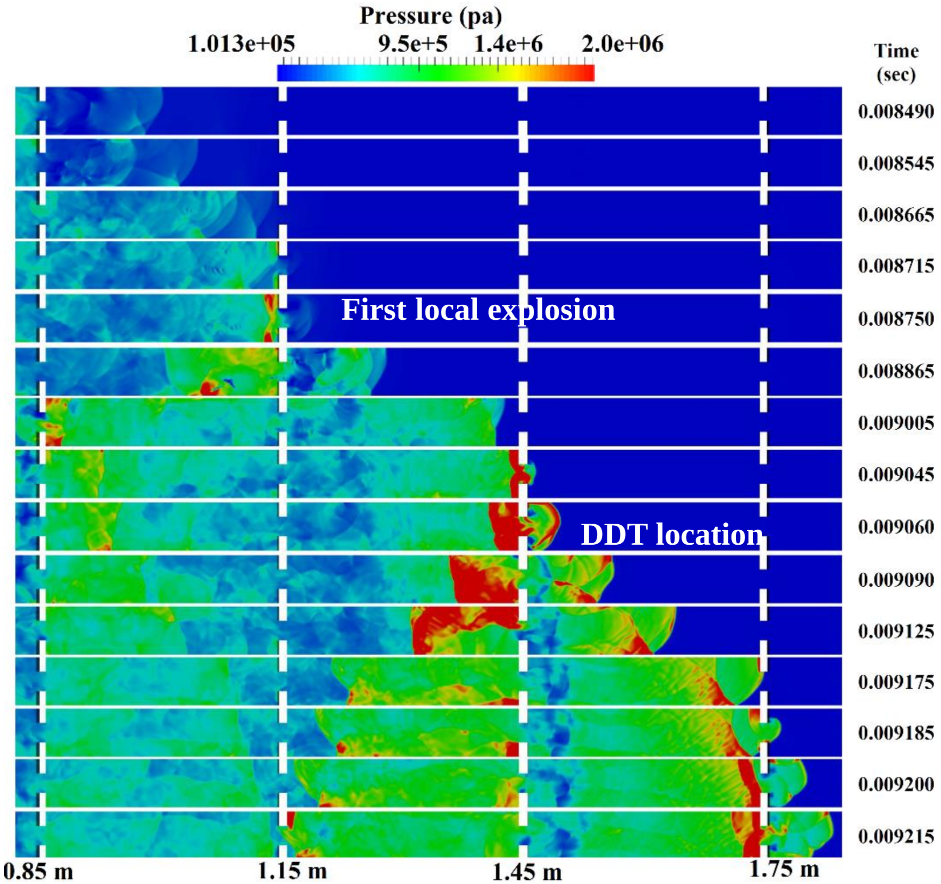
Pressure (pa)

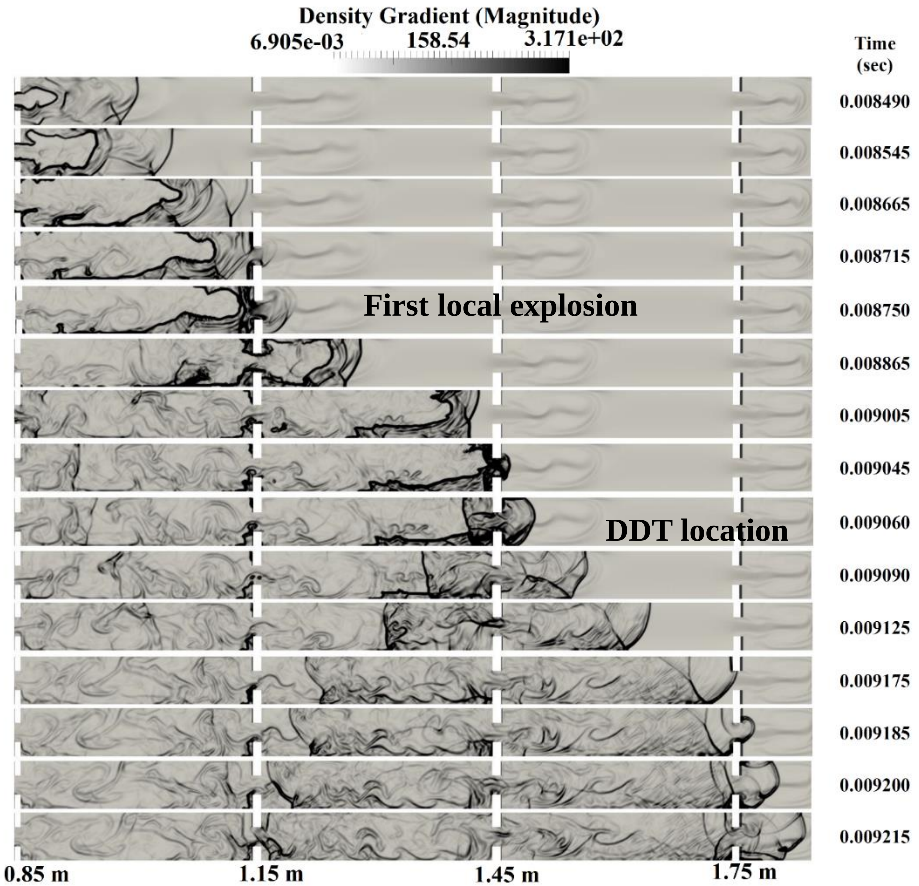


Time: 0.006950 sec

X=0.55m **X=0.85m** **X=1.15m**

Inhomogeneous 30% H2/Air mixture BR60



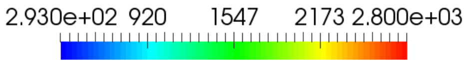


Inhomogeneous 30% H_2/Air mixture BR60

Numerical Schlieren

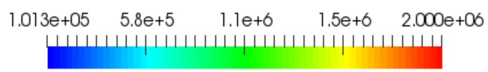
Time: 0.008475 sec

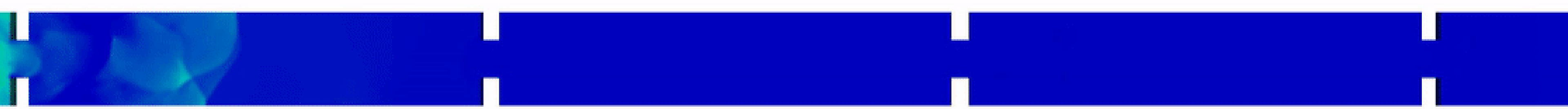
Temperature (K)



Time: 0.008475 sec

Pressure (pa)

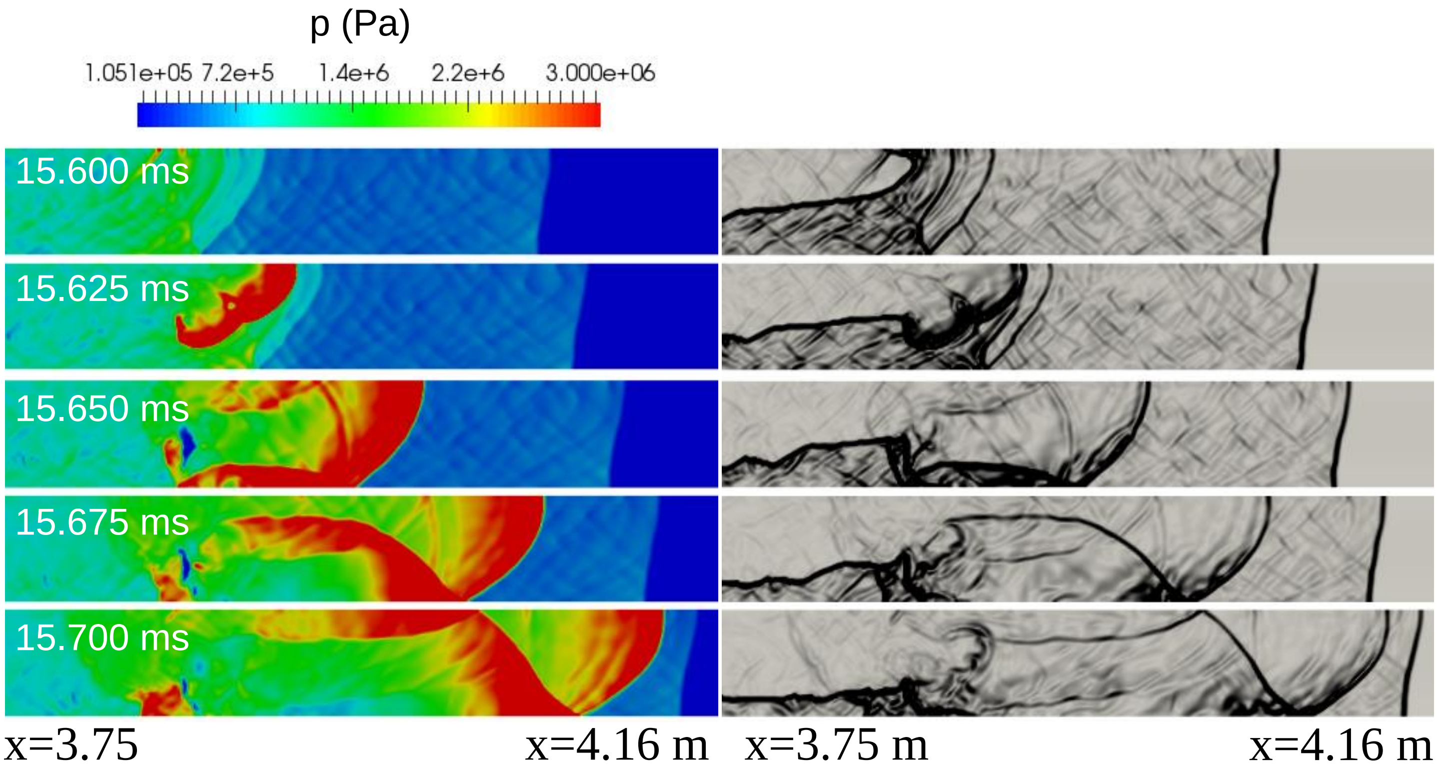




Time: 0.008475 sec

Inhomogeneous 20 % H_2/Air mixture BR60

Transition to detonation



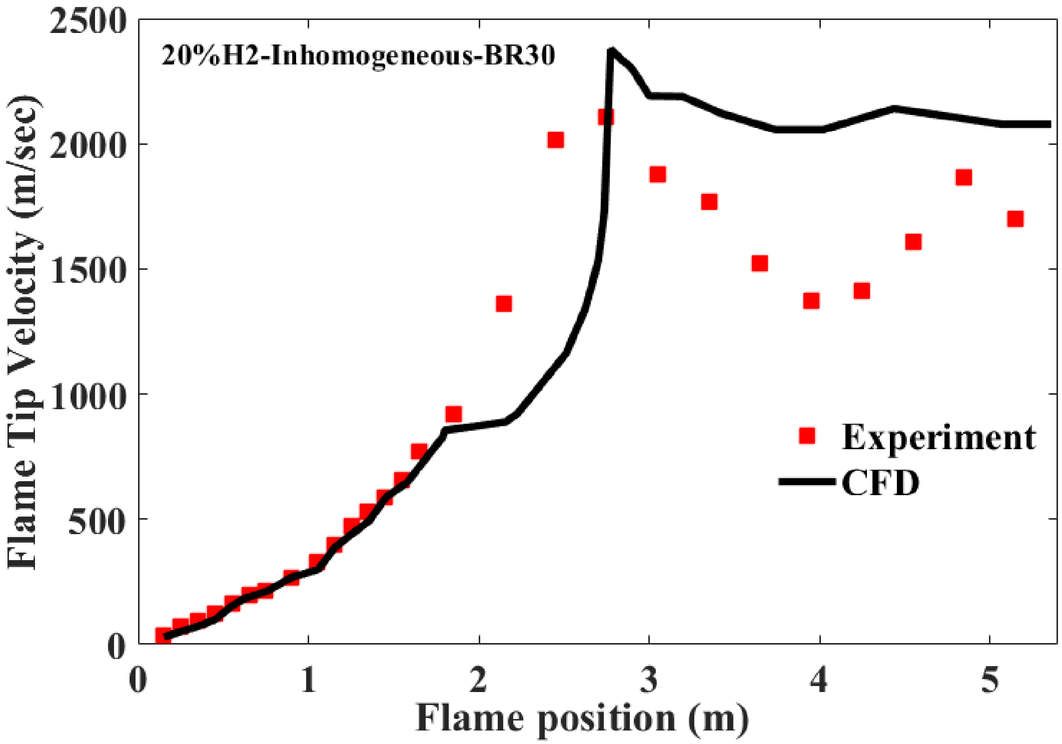
Homogenous mixture	DDT did not happen
Inhomogeneous mixture	DDT happened at x=3.95 m

30 % Blockage ratio

- 20 % Inhomogeneous H_2/Air
- 30 % Inhomogeneous H_2/Air
- 35 % Inhomogeneous H_2/Air

20% H2/Air mixture BR30%

- Comparison between CFD and Experiment



DDT happened at x=2.89 m

20% H2/Air mixture BR30%

Numerical Schlieren


Time: 0.016540 sec

Pressure

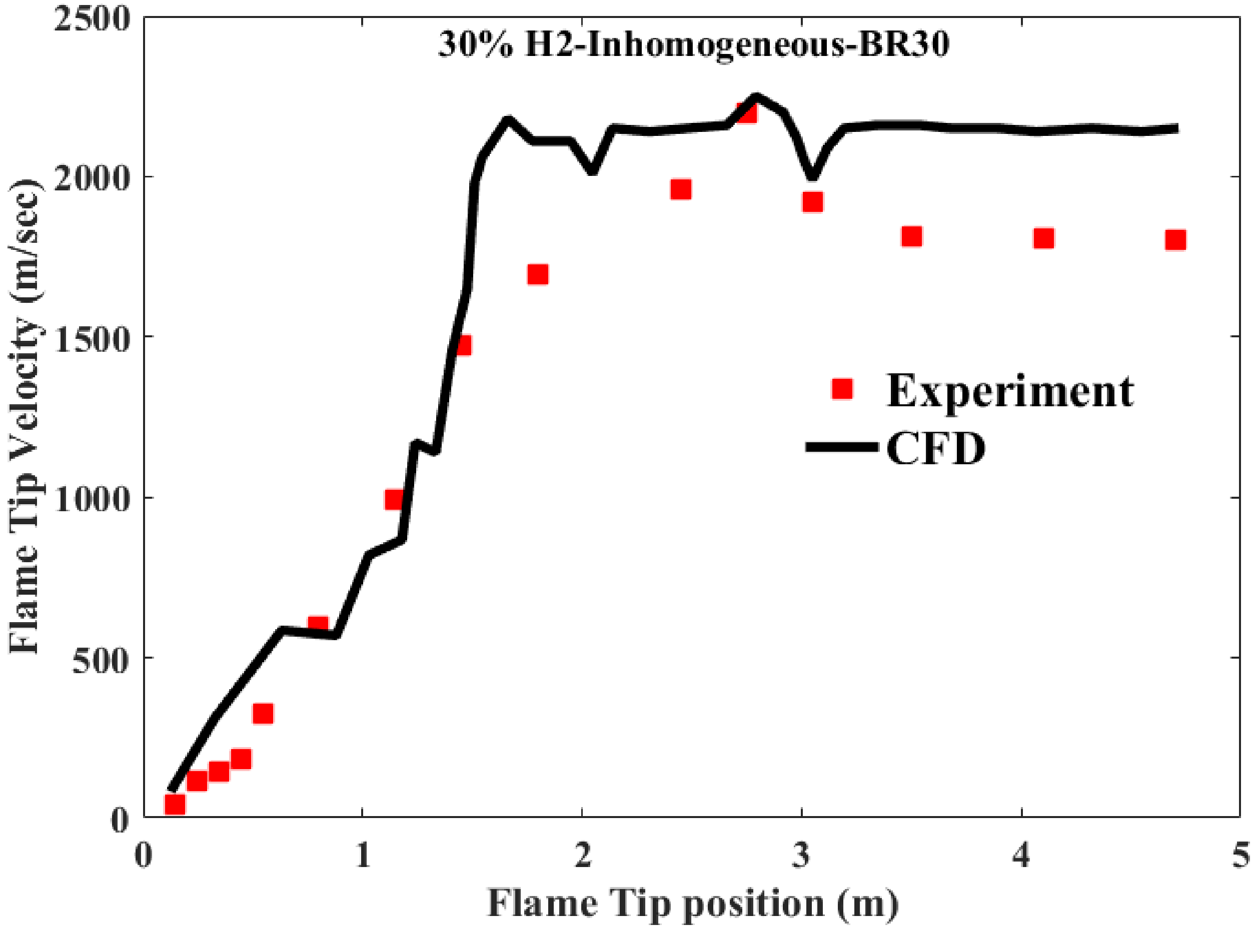

Time: 0.016540 sec

Temperature


Time: 0.016540 sec

30% H2/Air mixture BR30%

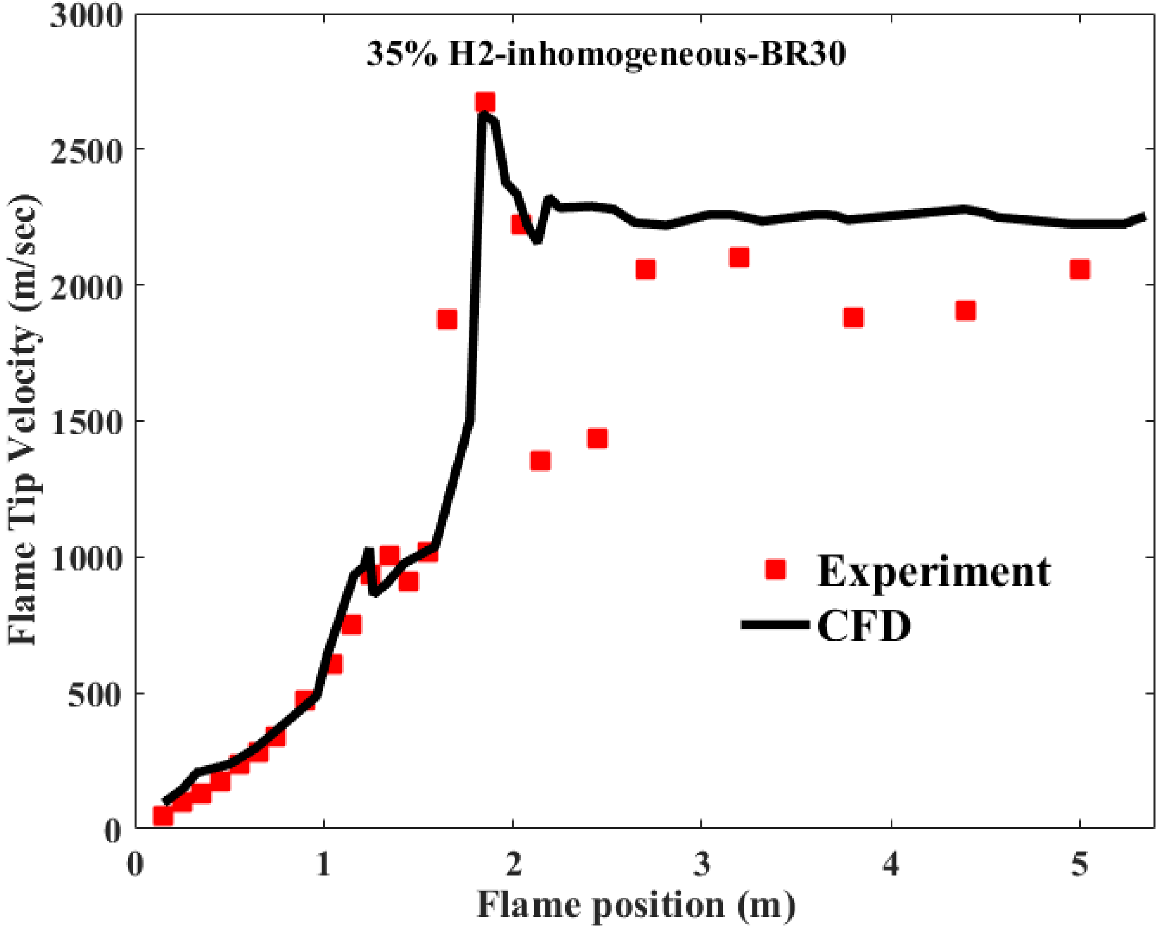
comparison between CFD and Experiment



DDT happened at x=2.05 m

35% H2/Air mixture BR30%

comparison between CFD and Experiment



DDT happened at x=1.8 m

35% H2/Air mixture BR30%

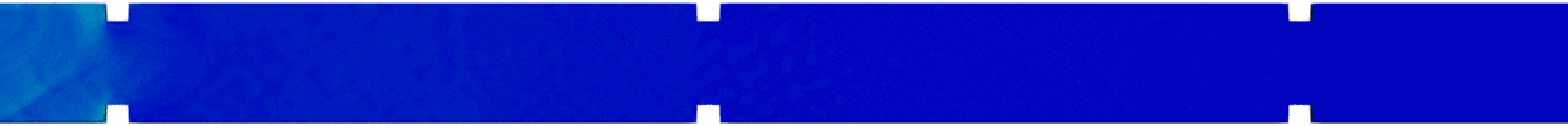
Numerical Schlieren

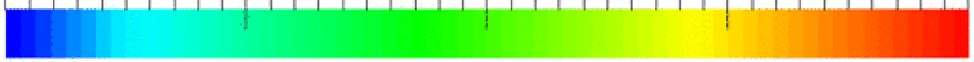
Time: 0.011810 sec

Pressure

Time: 0.011810 sec

Temperature





Higher resolution results

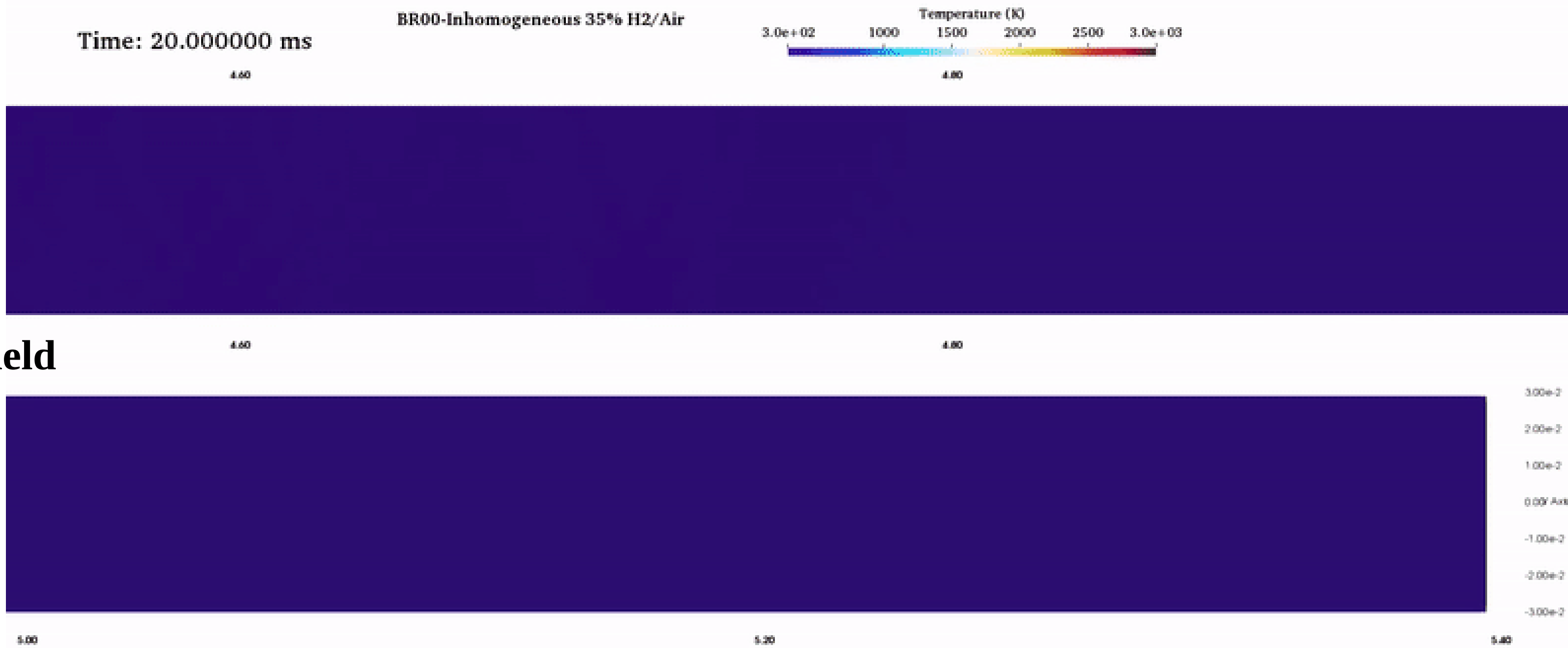
- Max Courant number: 0.3
- Time step = 3.28084e-08
- **Minimum cell size 10 µm (30 grid points per HRL)**
- Running duration: 60 days, with using 128 cores in cluster

Unobstructed channel

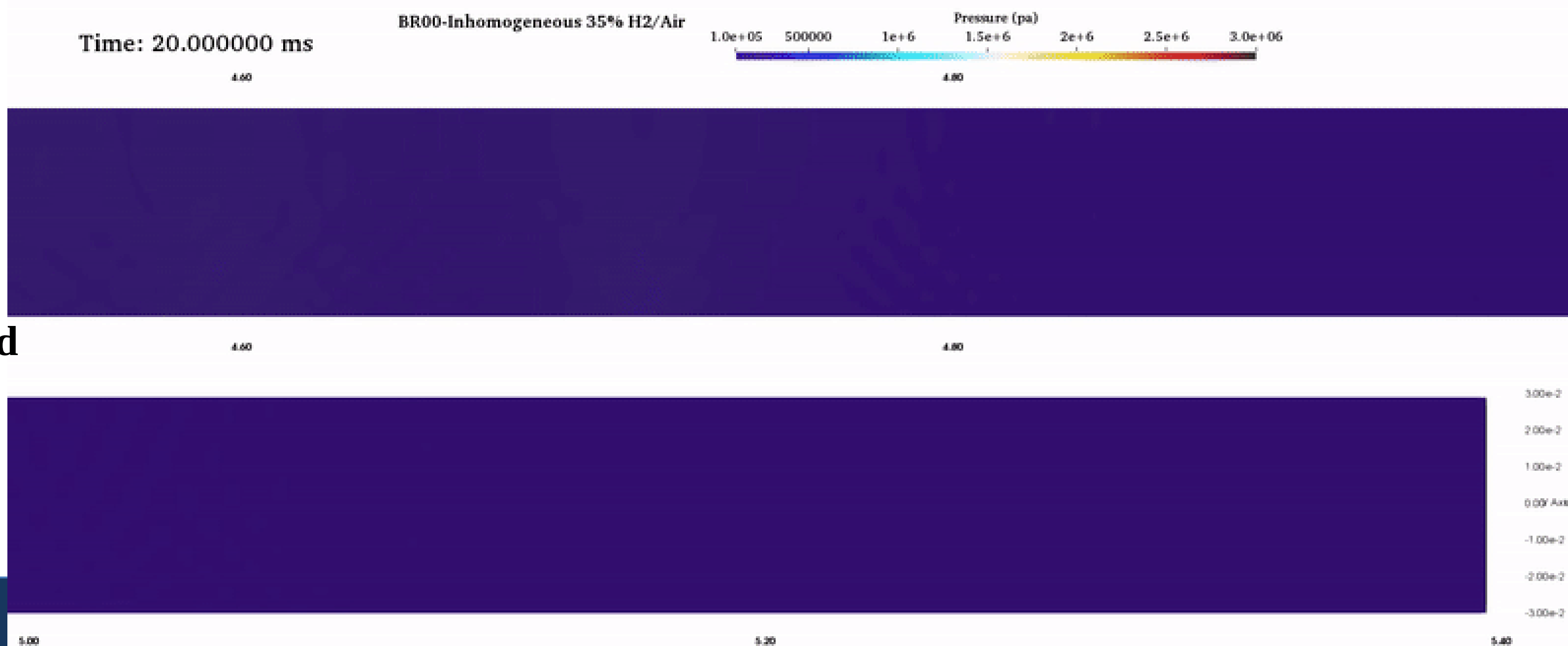
Transition to detonation		
Concentration	**Homogeneous**	**Inhomogeneous**
20 % H2/Air	No DDT (maximum flame speed = 45 m/sec)	No DDT (maximum flame speed = 200 m/sec)
25 % H2/Air	No DDT (maximum flame speed = 150 m/sec)	**DDT** at x=4.55 m
30 % H2/Air	No DDT (maximum flame speed = 1000 m/sec)	**DDT** at x=4.6 m
35 % H2/Air	DDT at x=4.9 m	**DDT** at x=4.78 m

Inhomogeneous H2/Air mixture, BR00 35%H2, BR00

Temperature field



Pressure filed



Kingston University London

Conclusion

- The flame position and flame tip speed are in reasonably good agreement with the experimental measurements.
- For both homogeneous and inhomogeneous 30% hydrogen cases, onset of detonation occurs within the obstructed channel section. The homogeneous mixtures shows slightly faster flame acceleration and earlier DDT.
- For the 20% case, transition to detonation is observed only for the inhomogeneous mixture, where the concentration gradient enables stronger flame acceleration, especially in the unobstructed channel section, compared to the homogeneous mixture.
- Increase in the fuel concentration was found to increase the FA and faster transition to detonation.
- High resolution study captured the keystone feature as well as hydrodynamic instabilities, such as Kelvin Helmholtz and Richtmyer-Meshkov instabilities.

Acknowledgement

Numerical characterization and simulation of the complex physics underpinning the Safe handling of Liquefied Natural Gas (**SafeLNG**) (2014-2017) is an Innovative Doctoral Programme (IDP) funded by the **Marie Curie Action** of the 7th Framework Programme of the **European Union**.

Thanks for your attention!

Any questions?