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LES OF A PREMIXED TURBULENT COUNTER-FLOW FLAME AND A PREMIXED HYDROGEN ENRICHED FLAME

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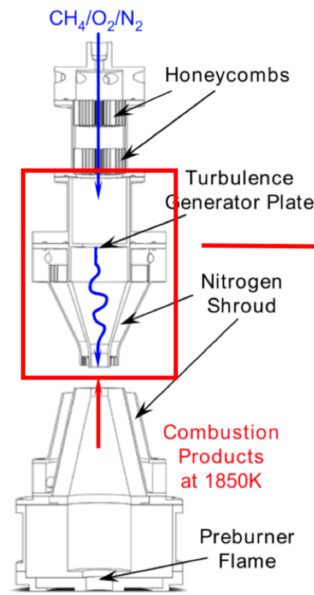
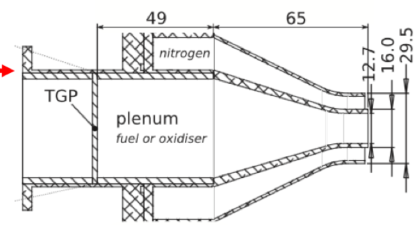
TCF: Introduction

Turbulent Counter-flow Flame (TCF) Configuration

- Compact reaction domain
- Flame region not attached to the burner
- Simple flame shape and flow field





Target flame Configuration (Coriton, 2013).

Specific Ojectives

- Selected flame: premixed opposed jet flames by Yale (Coriton, 2013), Re_t ~ 1000
- Code: BOFFIN-LES (LES-pdf) Jones et al. 2010

Operating conditions

- TGP: $Re_t = 1050$
- Reactant Mixture: Equivalence ratio from 0.5 to 1.2
- Burnt Gas: Vary O/N ratio to change temperature

Re_t	1050	ϕ_b	1.0
$K_{bulk}(s^{-1})$	1400	Cp_u	$CH_4/O_2/N_2$
$T_u(K)$	295	Cp_b	Product
$T_b(K)$	1850	onr_u	30/70
ϕ_u	0.85	onr_b	26/74

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TCF: Simulation Numerics

Chemical Kinetics

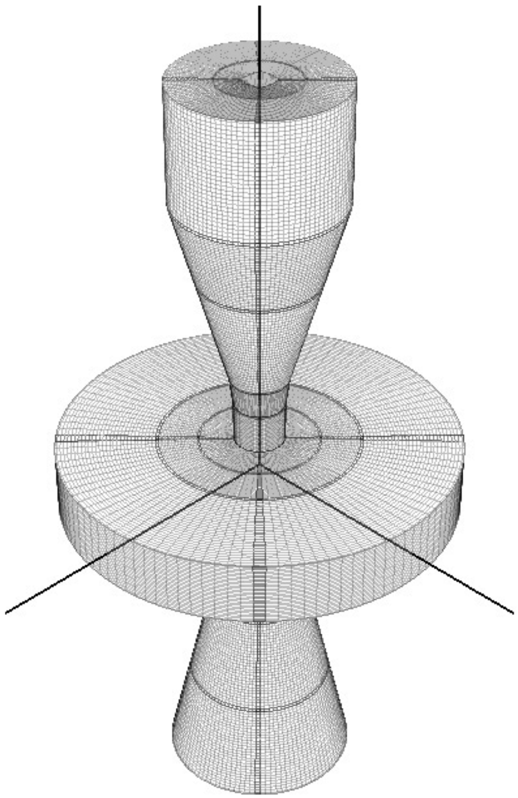
- 15-step reduced mechanism based on ARM2 (Sung, 2001)

Computational Mesh (Mesh 1)

- From the TGP to the product nozzle inlet
- Structured mesh: about 2.8 million cells
- Minimum spacing is 0.14mm in the axial direction and to 0.1mm in the radial plane

Artificial Turbulence

- A synthetic turbulence inflow generator based on the use of digital filters (Klein, 2003)



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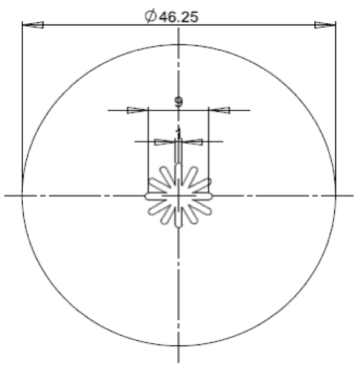
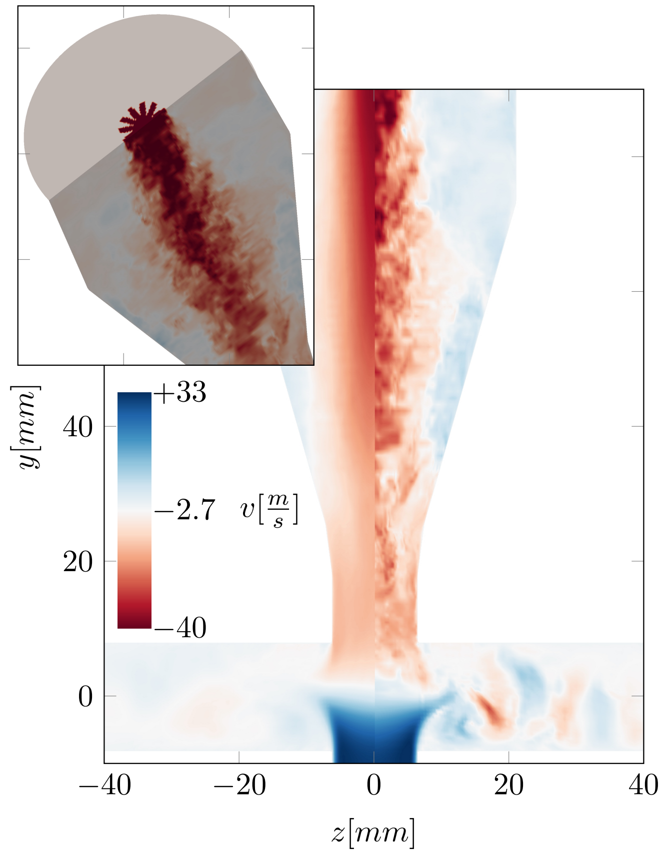
TCF: Flow through the Turbulence Generator Plate

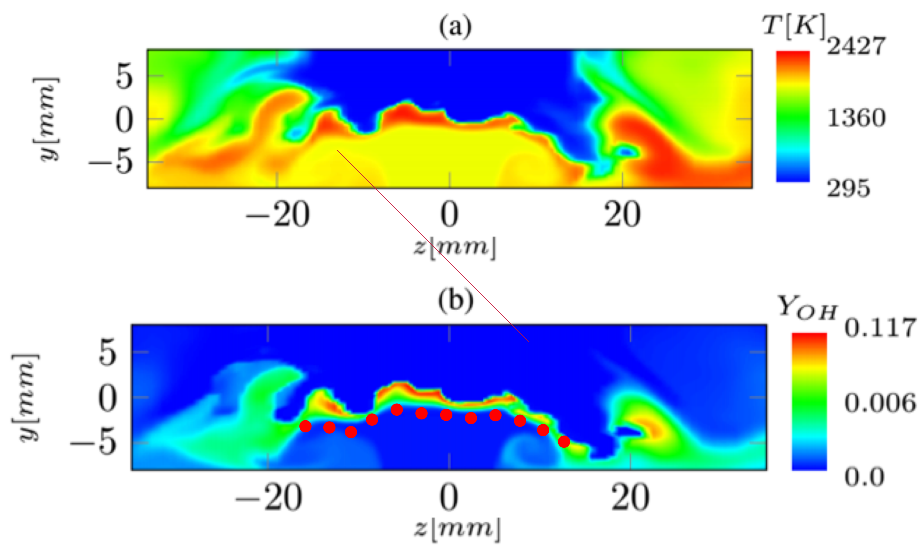




- Instantaneous (right) and mean (left) axial velocity contour plot
- The turbulence generation scheme is effectively modelled

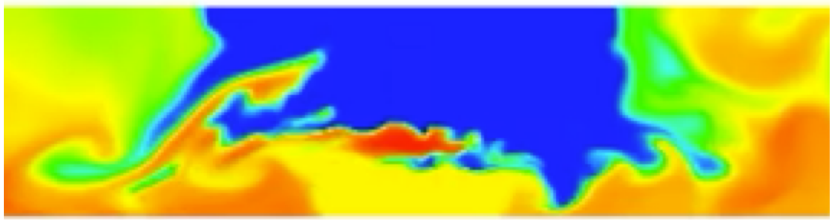
TCF: Instantaneous visualisation of Temperature, OH

- Different regions of the flow field.
- Definition of flame region, flame front.
- Gas mixing layer interface (GMLI), separates the two opposed streams



Instantaneous contour plots of (a) temperature, (b) Y_{OH} on a plane intersecting the solution domain along the centreline.

- Highly turbulent features
- Formation of extinction regions, ignition kernels
- Re-ignition: flame propagation and convection
- Large scale motions of the GMLI



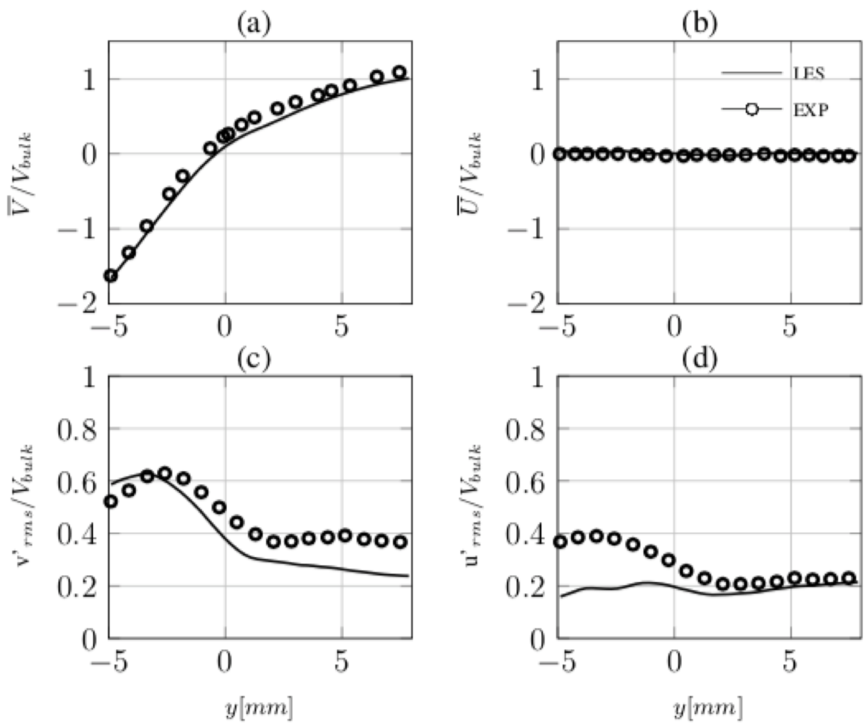
Visualisation of the temperature field.

TCF: Centre line Velocity Profiles

- The velocities are normalised by the bulk velocity of the upper stream, 11.2m/s.

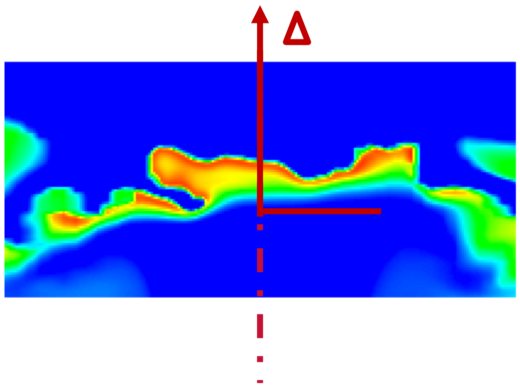
- Mean velocities profiles are in good agreement with the exp data.

- Rms velocities are under predicted, which is likely due to insufficient resolution of the flow through the turbulence generator.

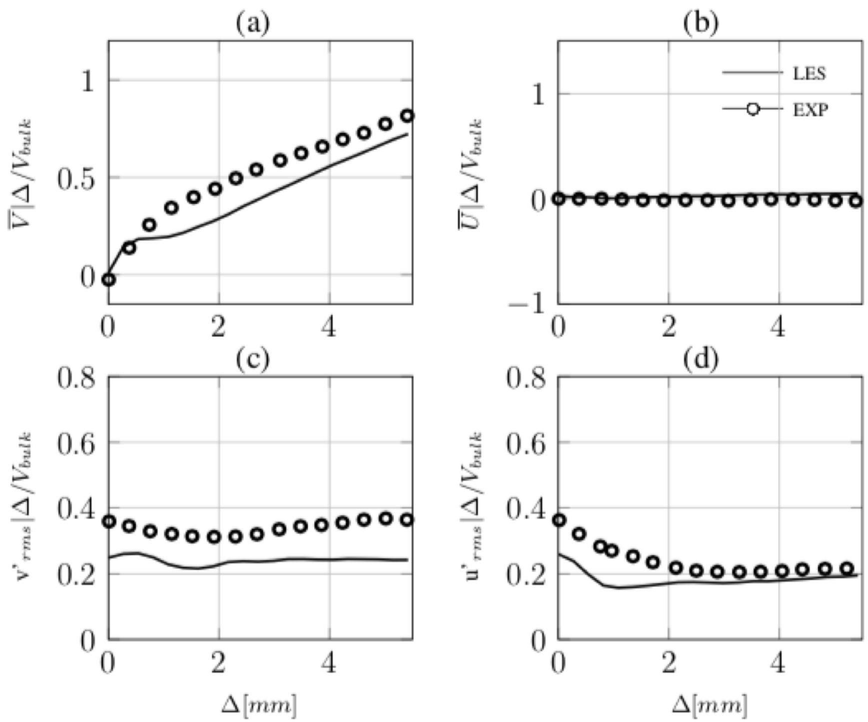


The normalised centre-line profiles of the mean and RMS axial and radial velocities compared with experimental data.

TCF: Centre line Velocity Profiles



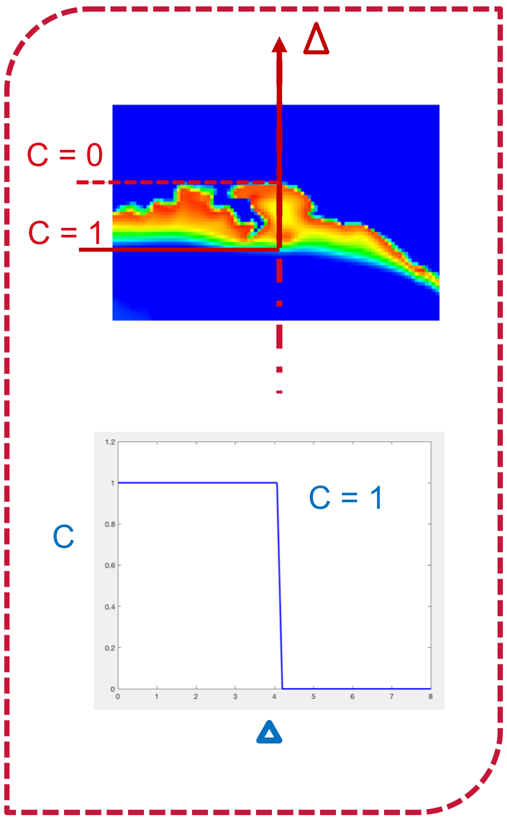
- The velocities are presented in the relative frame of the GMLI
- Velocities are predicted reasonably well by the simulation
- The observed large scale motions of the GMLI locations are well predicted in the simulations

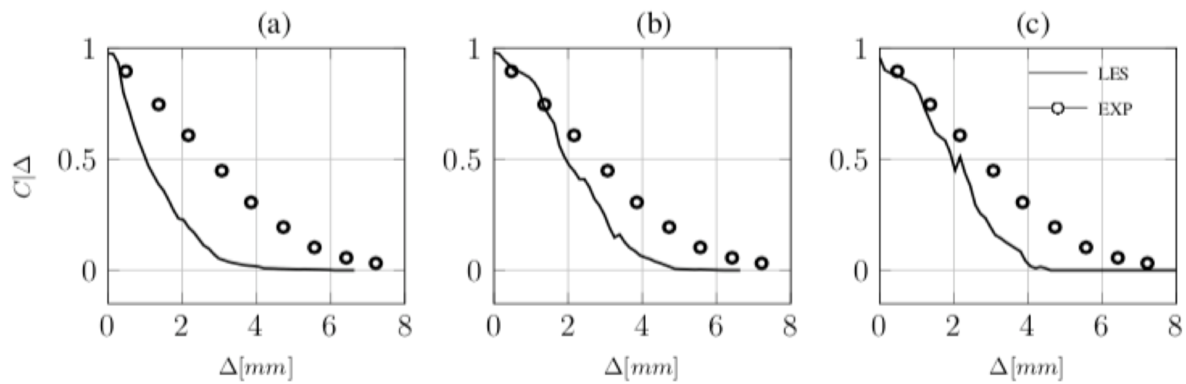


The normalised centre-line profiles of the conditional mean and RMS axial and radial velocities compared with experimental data. coordinate represents the distance from the gas mixing layer interface (GMLI) and increases in the direction of the upper nozzle.

TCF: Conditional Reaction Progress Variable

- To quantify the probability of finding the fresh combustion product, a binary progress variable is defined: unity in the flame region and zero everywhere else

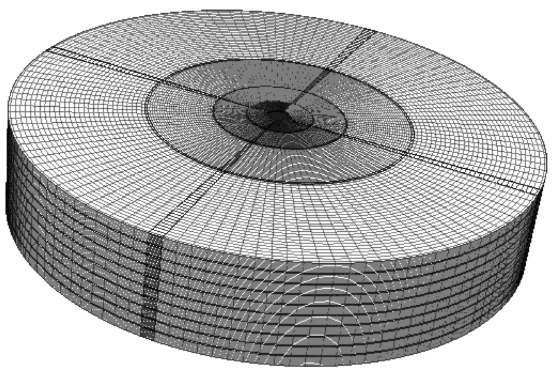




The conditional mean progress variable along the centre line for (a)1-field, (b)8-field and (c)16-field simulations compared with experimental measurements.

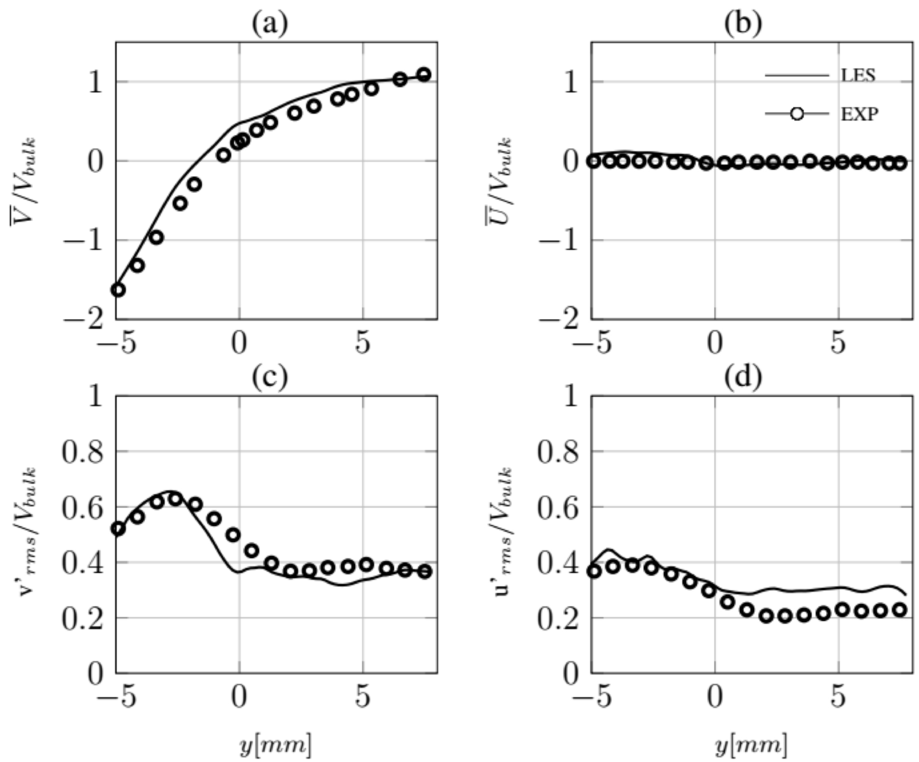
- 8 stochastic fields are sufficient to represent SGS chemistry effects for the case considered, consistant with the findings by Mustata (2006)

TCF: Smaller computational domain



Cylinder domain (Mesh 2)

- Better control of turbulence
- lower computational cost



The normalised centre-line profiles of the mean and RMS axial and radial velocities achieved with mesh 2.

TCF: Conclusions

- The mean flow fields are reasonably reproduced, while the discrepancies in the RMS velocity fields are likely attributable to insufficient resolution in the vicinity of the turbulence generator for simulations with mesh 1.
- The fluctuating feature of GMLI obtained numerically is consistent with the experimental observations.
- New simulations are ongoing with a small cylindrical computational domain. The predicted velocity components are in good agreement with experiment data.
- Future work will focus on the effect of reactant equivalence ratio/strain rate on the flame stability in terms of probability of extinction with use of mesh 2.

LES of Hydrogen Enriched Flames

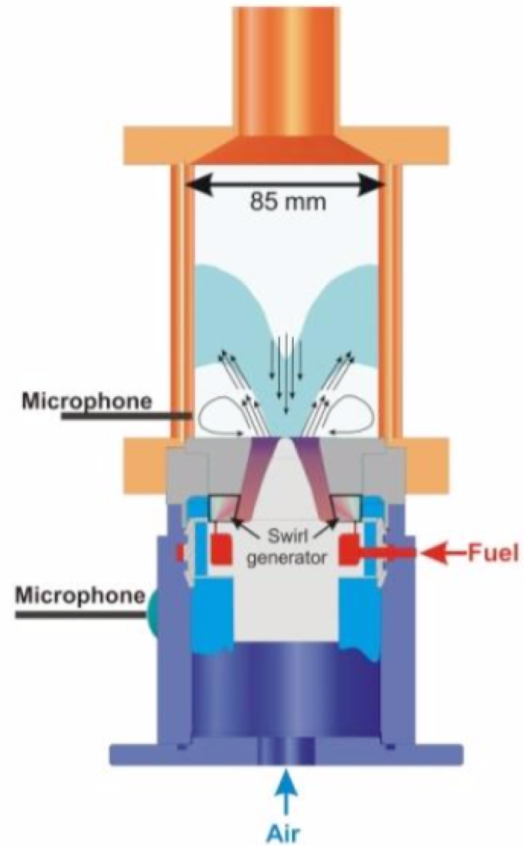
Backgrounds

- Lean premixed combustion often exhibits thermoacoustic and hydrodynamic instability
- H_2 combustion exhibits higher laminar flame speed, higher flame temperature and lower lean flammability.

Target Flames

- Hydrogen enriched flames based on PRECCINSTA burner studied experimentally in DLR (Chterev, 2019).
- Technically premixed, swirl stabilized.
- Selected Operating conditions

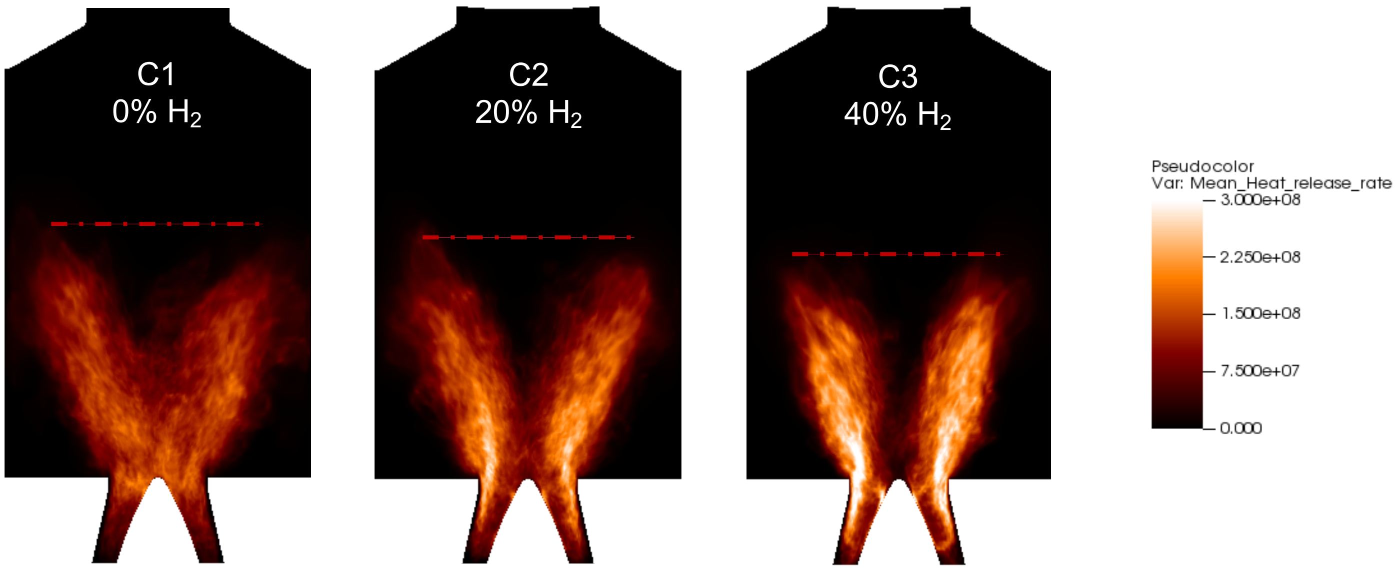
Equivalence ratio	0.85
Thermal Power	20 kw
%Vol.H2	0%, 20%, 40%



PRECCINSTA premixed swirl burner (Meier, 2007). The shape of the flame zone is indicated in the combustion chamber and the overall flow field is sketched (Chterev, 2019).

LES of Hydrogen Enriched Flames: Preliminary results

Time averaged flame images on average



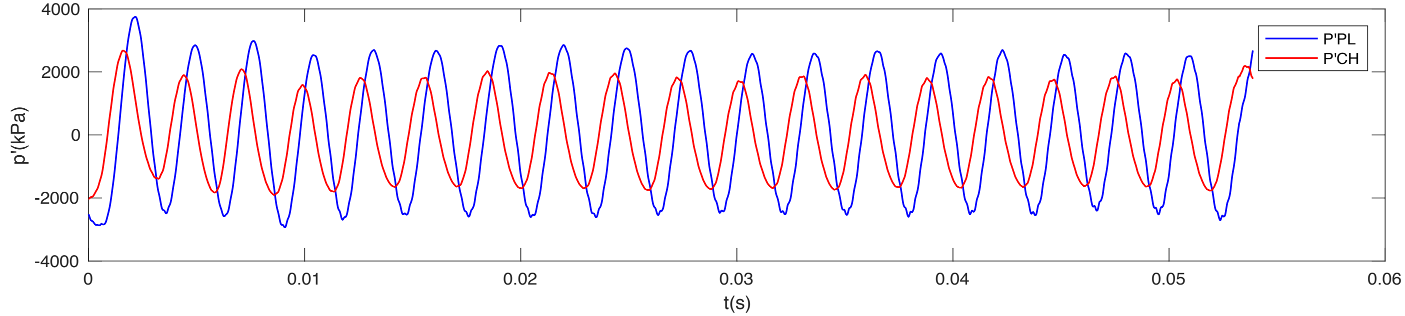
Mean Heat release rate in 3 cases investigated

Hydrogen addition results in

- Higher heat release rate on average
- Shorter flame, closer to the combustor inlet
- More flash back, less lift off

LES of Hydrogen Enriched Flames: Preliminary results

Pressure signals

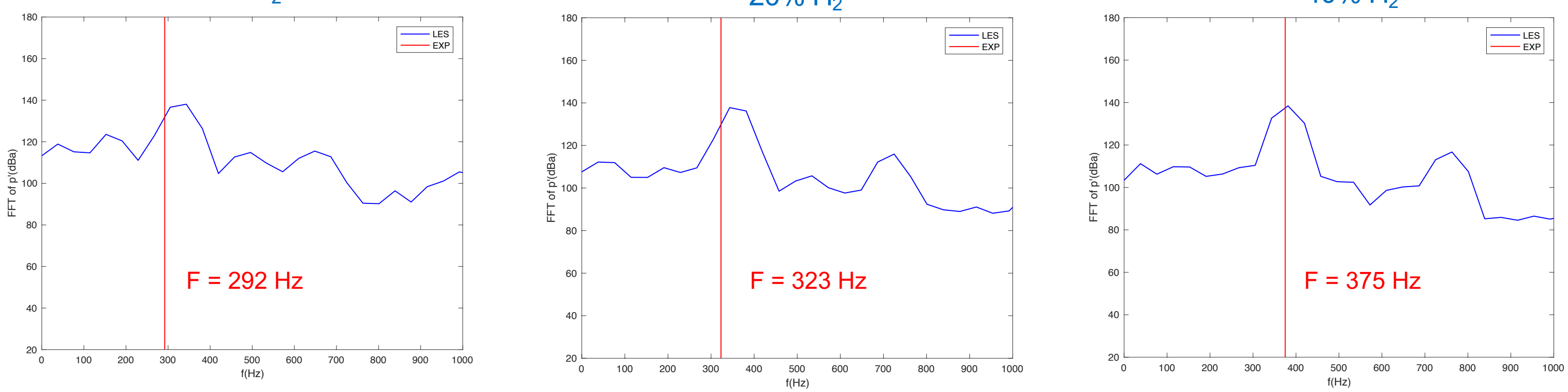


Pressure signals in air plenum (P-pl) and combustion chamber (P-ch) for Case 2

C1
0% H_2

C2
20% H_2

C3
40% H_2



FFT of pressure signals in combustion chamber compared with measurements

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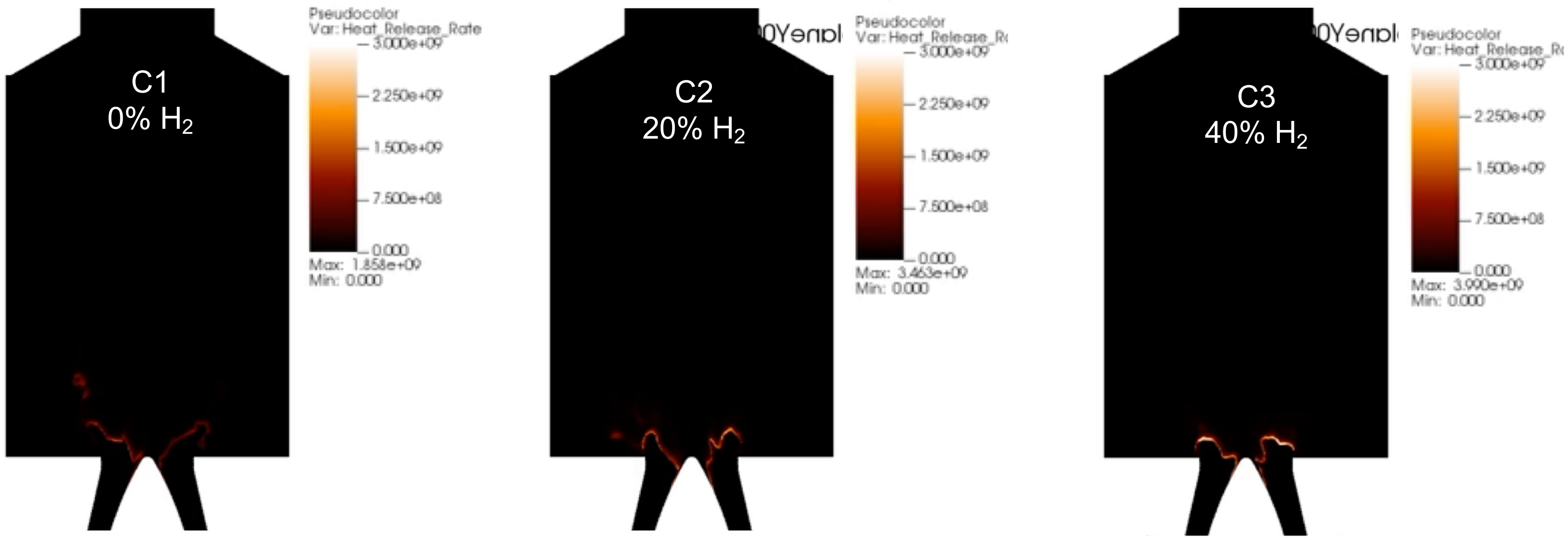
LES of Hydrogen Enriched Flames: Preliminary results

Instantaneous flame features



Instantaneous Heat release rate in 3 cases

- Limit cycle oscillations are observed in all 3 cases
- Hydrogen addition raises the oscillation frequency, changes the flame shape

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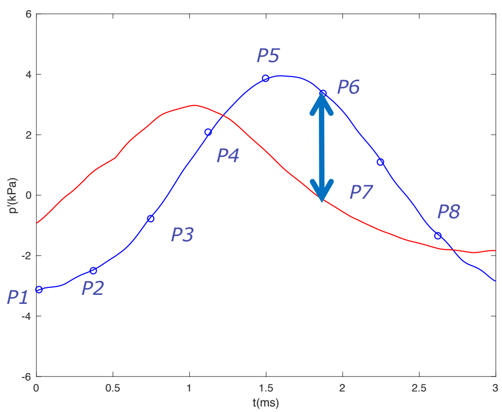
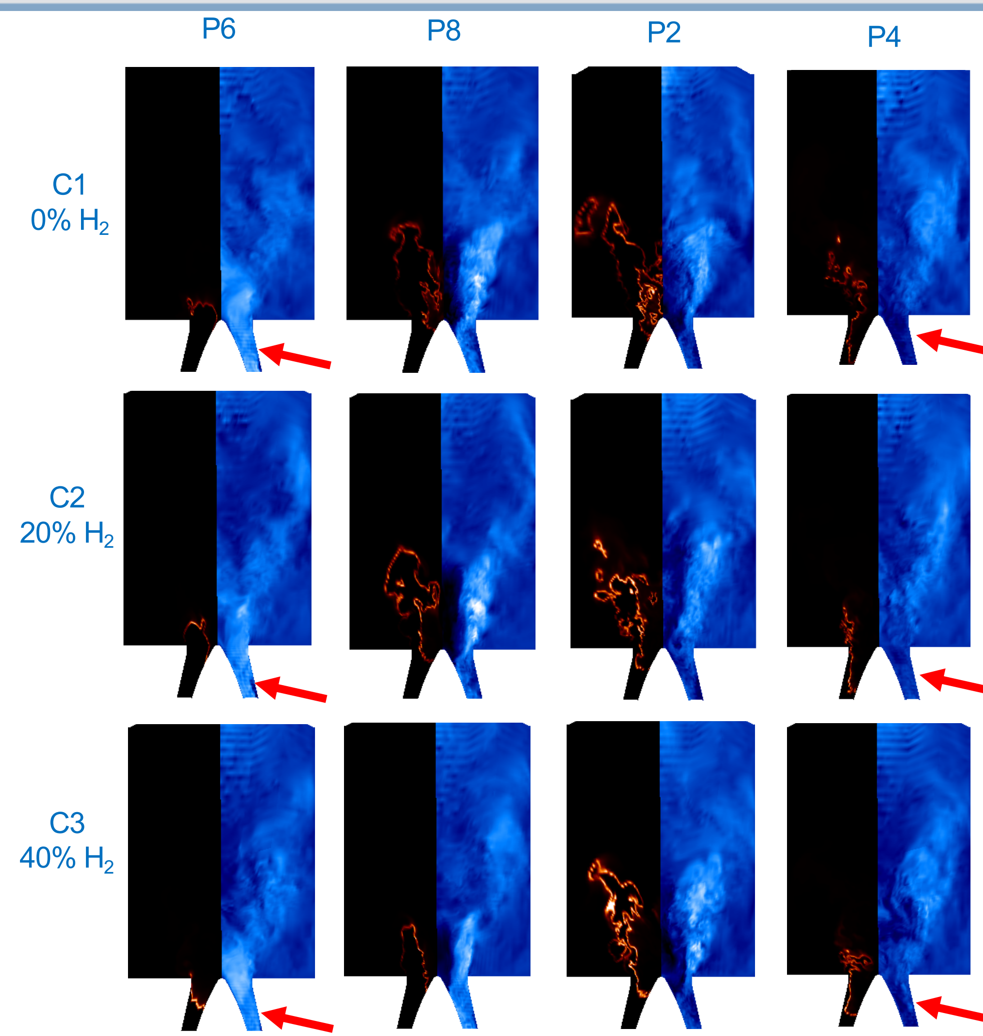
LES of Hydrogen Enriched Flames: Preliminary results

Oscillations of heat release rate and velocity



Temporal variation of P-pl and P-ch

- 8 phases are defined based on the angles in one period.
- Pressure oscillations lead to an oscillation of axial velocity in the nozzle
- Hydrogen addition: change of flame shape, less lift off, more conpact flame.



Heat release rate (left) and axial velocity (right) in phase

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LES of Hydrogen Enriched Flames: Summary

- The LES successfully predicts the limit-cycle oscillations which are consistent with experimental observations.
- The effect of adding hydrogen to the combustion in terms of flame shape, thermal acoustic flame features are well reproduced in the simulations.
- The dominant frequencies of all the three cases are in good agreement with measurements.
- Future work includes the study of velocity field, phase averaged properties and hydrodynamic features of these hydrogen enriched flames.

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