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Study of thermoacoustic instabilities in premixed hydrogen-enriched swirling flames using LES

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LES of Hydrogen Enriched Flames

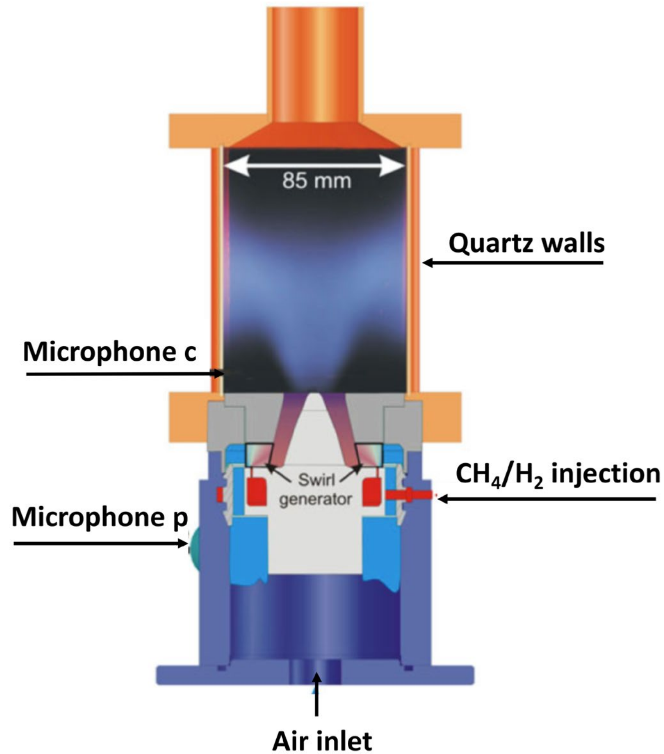
Backgrounds

- 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	23 kw
%Vol.H2	0%, 20%, 40%

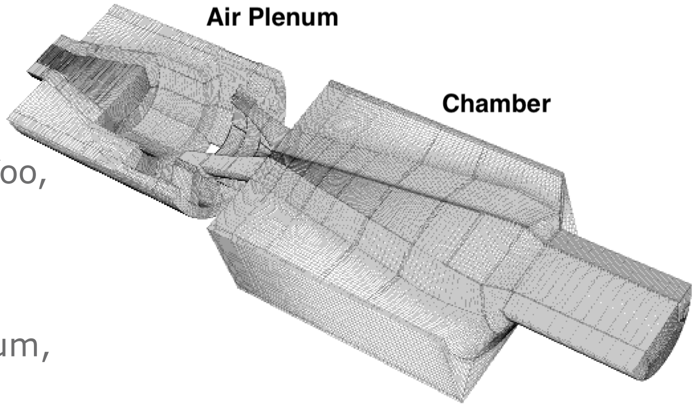


PRECCINSTA premixed swirl burner (Chterev, 2019).

Numerical Setups

Numerical setups

- In House compressible LES code: BOFFIN-LESc (Fredrich,2020)
- Non-reflective outflow boundary conditions at chamber outlet (Yoo, 2005)
- Isothermal wall boundary condition
- Multiblock structured mesh ~2.7 million cells, including air plenum, swirler and combustion chamber
- Mesh independent study done in the same geometry in previous work (Fredrich,2020)



A view of the computational mesh.

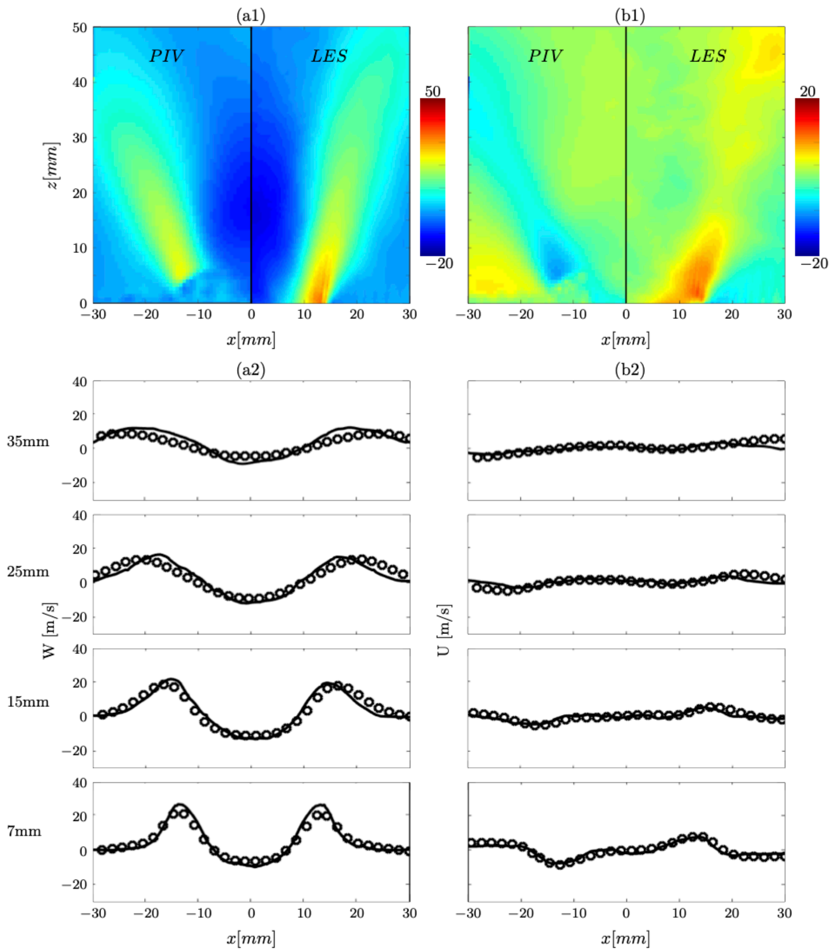
Chemical Kinetics

- 15-step reduced mechanism based on GRI-Mech 3.0 (Lu, 2008)

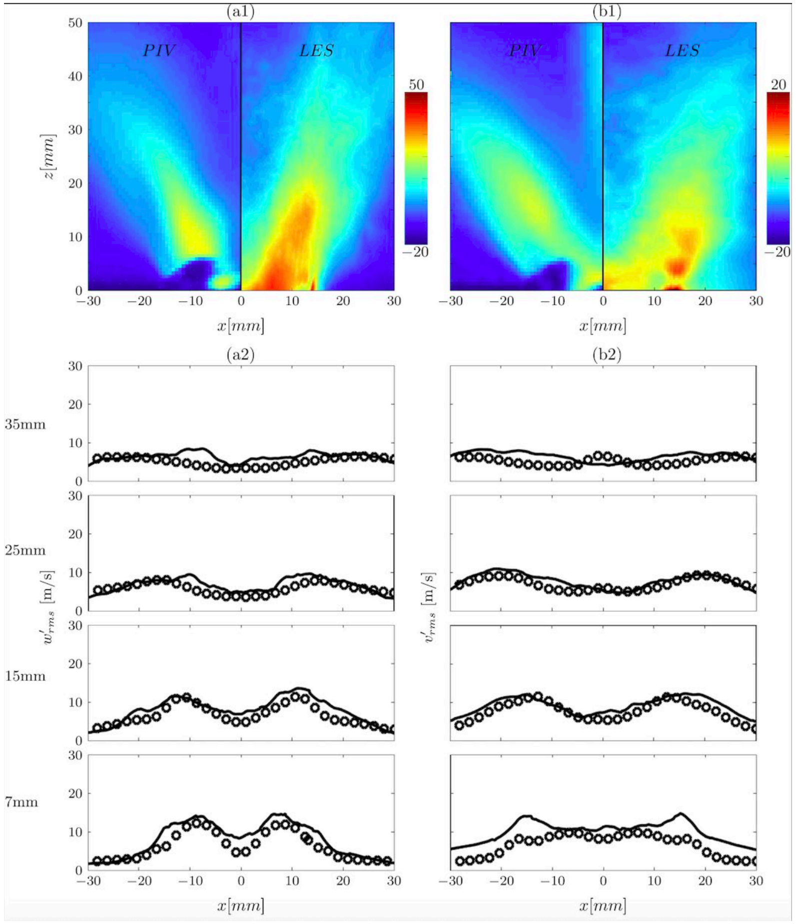
Numerical details

- Initialised for 6 flow-through times is enough for a statistically stationary flow to develop
- Statistic time-averaged over 6 flow-through times

Iso-thermal flow field



Mean velocity fields and profiles at 4 downstream positions:
(a) axial mean velocity (b) radial mean velocity.



RMS velocity fields and profiles at 4 downstream positions:
(a) axial RMS velocity (b) radial RMS velocity.

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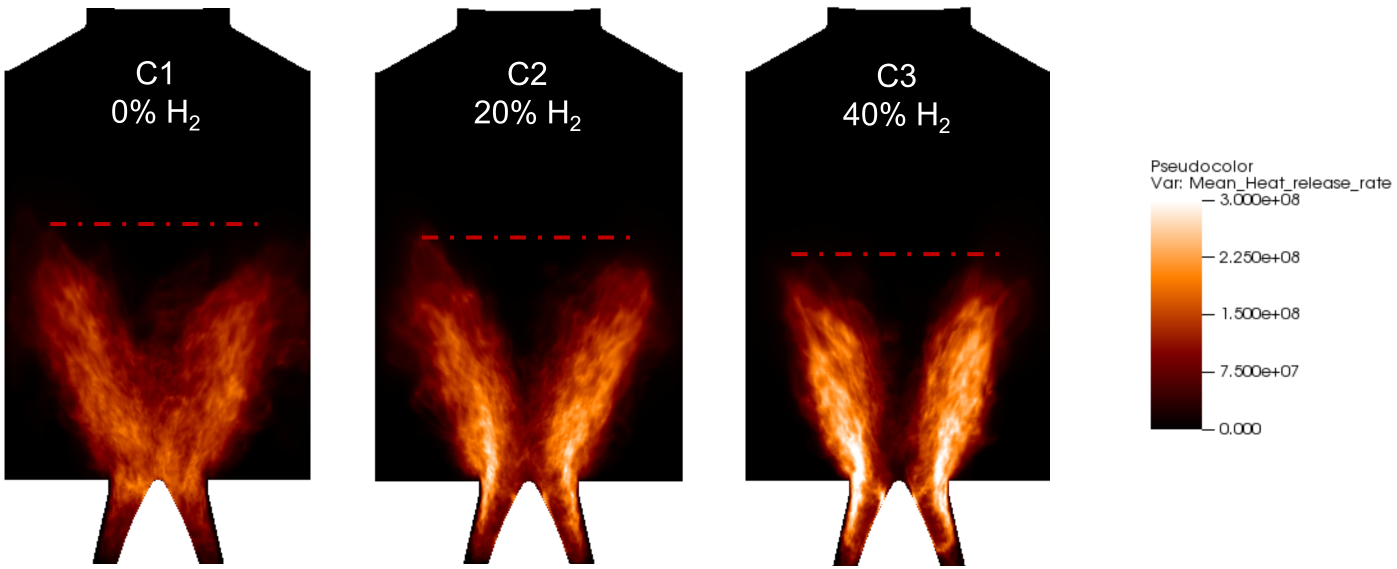
Flame topology

Time averaged Heat release rate (HRR), line of sight integration



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

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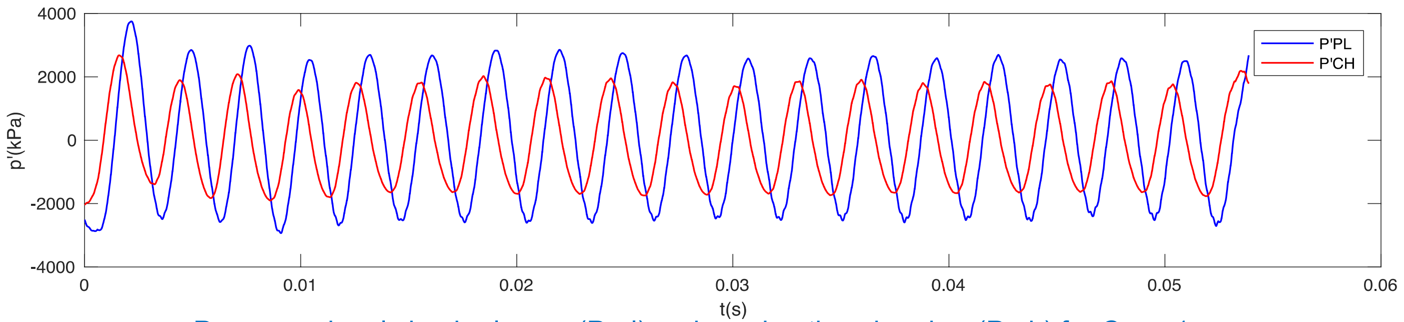
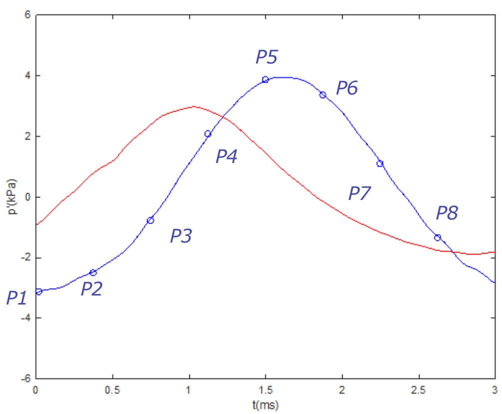
Acoustic fluctuations

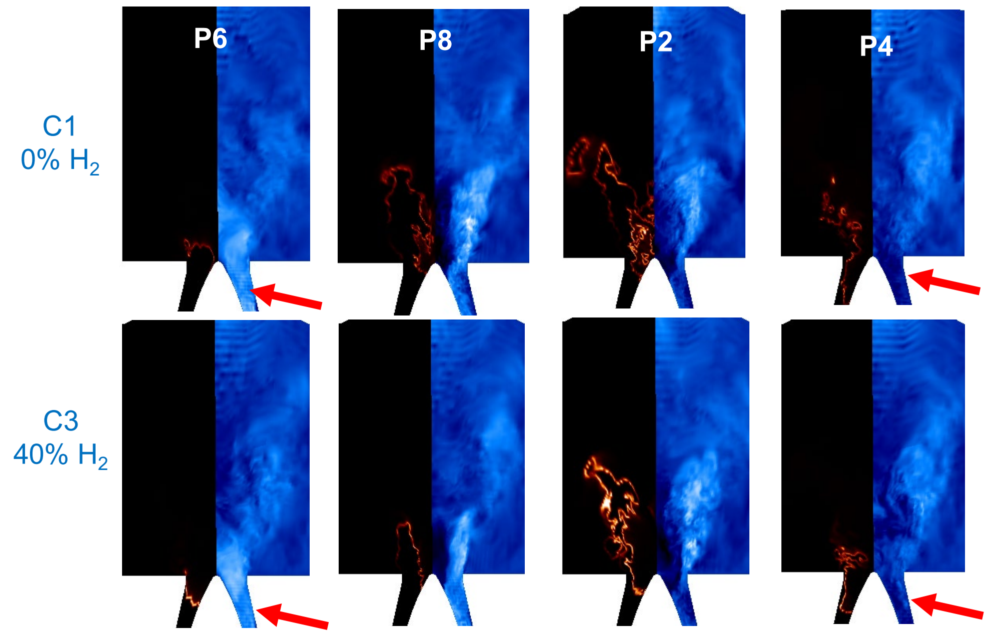
Self-sustained limit cycle oscillations



Pressure signals in air plenum (P-pl) and combustion chamber (P-ch) for Case 1

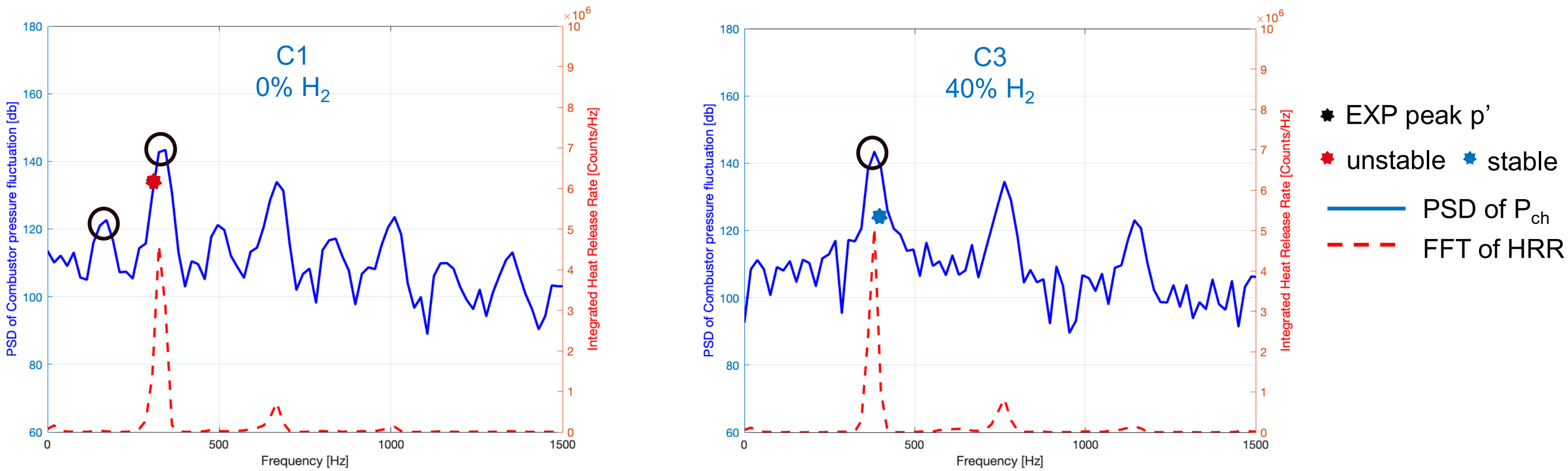


Temporal variation of P-pl and P-ch



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

PSD of P', FFT of HRR compared to EXP



- EXP p' with estimation of damping wall effect ~13dB (Lourier,2017)
- First peak frequencies matches – Helmholtz f, thermoacoustic oscillations
- Over predicted amplitude: both in C1 (8dB) and C3 (20dB)
- Coupled peak f of p' and HRR in C1 and C3
- Harmonics of dominant f in C1 and C3, subharmonic and its multiples in C1

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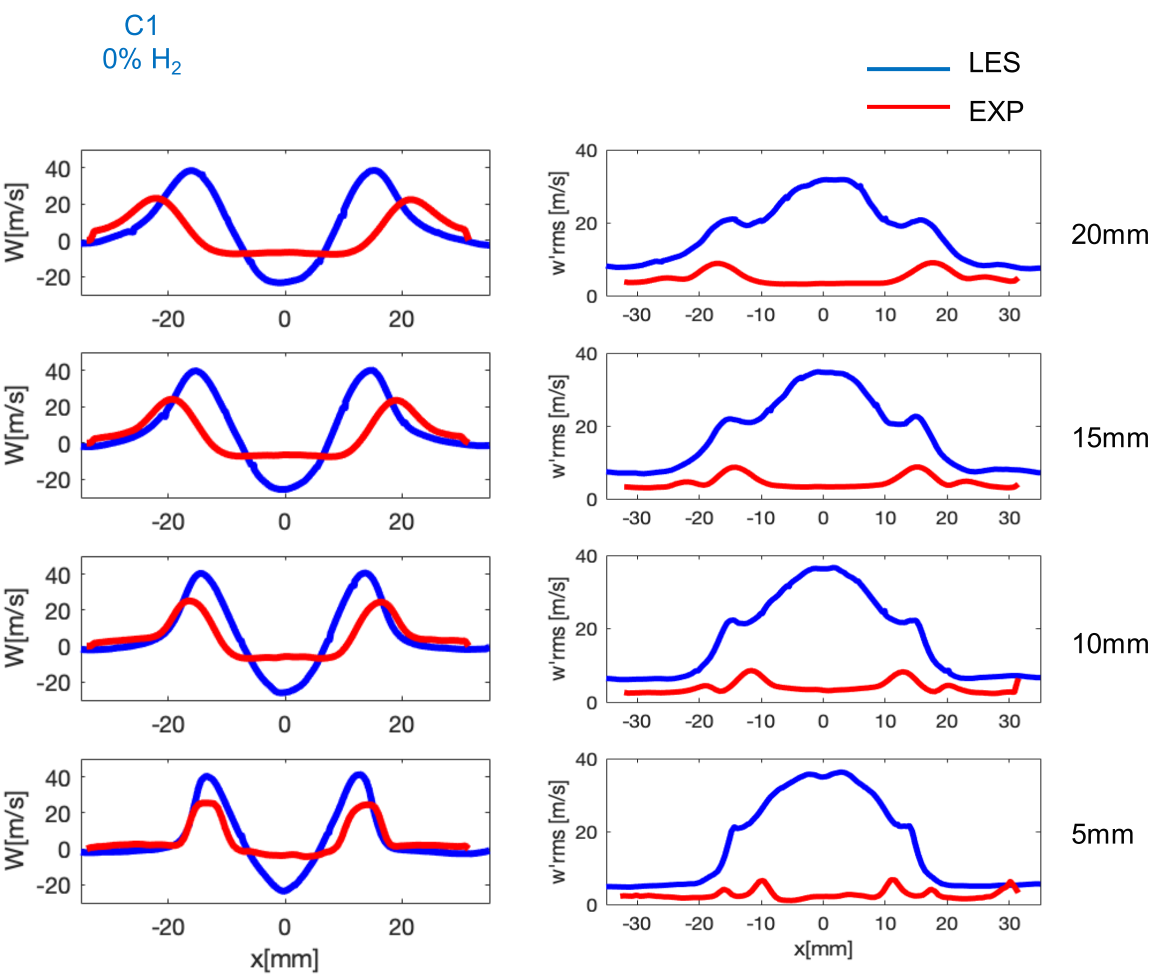
Velocity field



- Strong fluctuations coupled with pressure oscillations
- Observed in all three cases
- Mean velocity field deviation: overpredicted jet velocity, back flow in the centre region, narrower jet

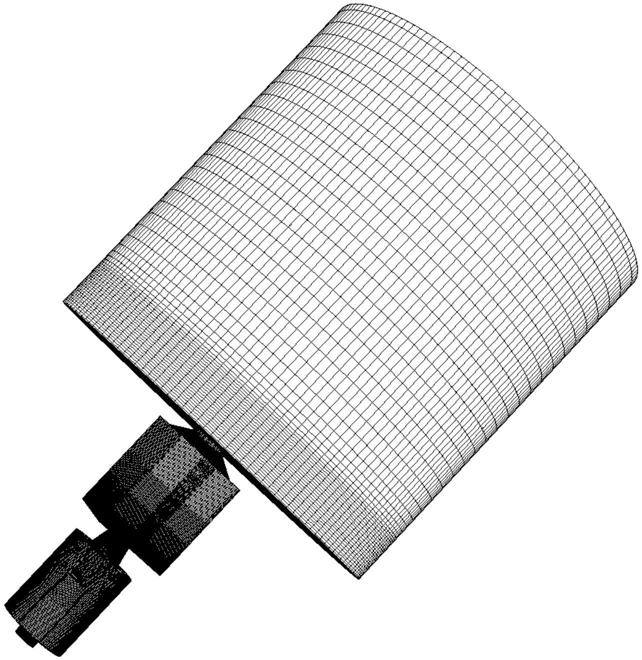
Next Step

Why so strong instabilities?

- Relative to the coupling of flame and pressure fluctuations: not observed in isothermal case
- Varies with operation conditions c

Next Step Work

- Extend the computational domain
- Different operating conditions study



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Study of Noises Generated by Compositional Perturbations using LES

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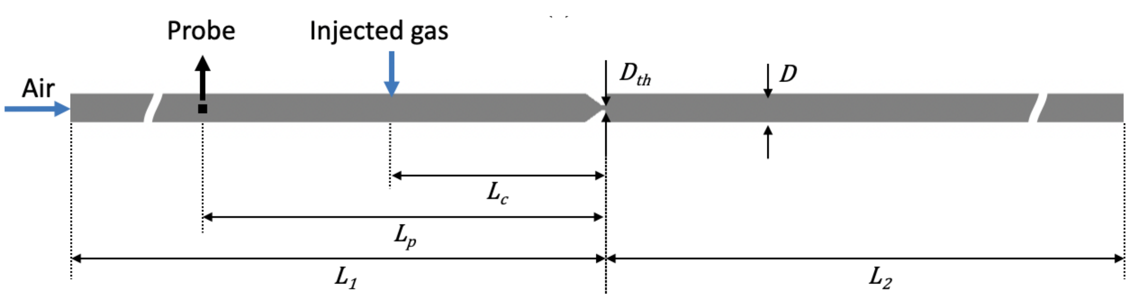
Introduction

Two categories of combustion noises in combustors (pressure fluctuations)

- Direct noise : caused by volume expansion due to unsteady heat released
- Indirect noise: unsteady heat released also generates temperature, compositional and vortical perturbations, which if accelerated can eventually generate acoustic noise

Indirect noises caused by compositional disturbances

- Incomplete premixed flames, fluctuations in equivalence ratios
- Target case: Compositional and entropy indirect noise generated in Cambridge Entropy Generator (CGW) Rig with non-isentropic convergent nozzle (Domenico,2021)



A schematic layout of the experimental configuration.

	L_1	L_2	D
length (m)	1.65	61	0.0426

D_{th}	L_p	L_c
0.0066	0.75	0.65/0.05

Dimensions for the experimental configuration.

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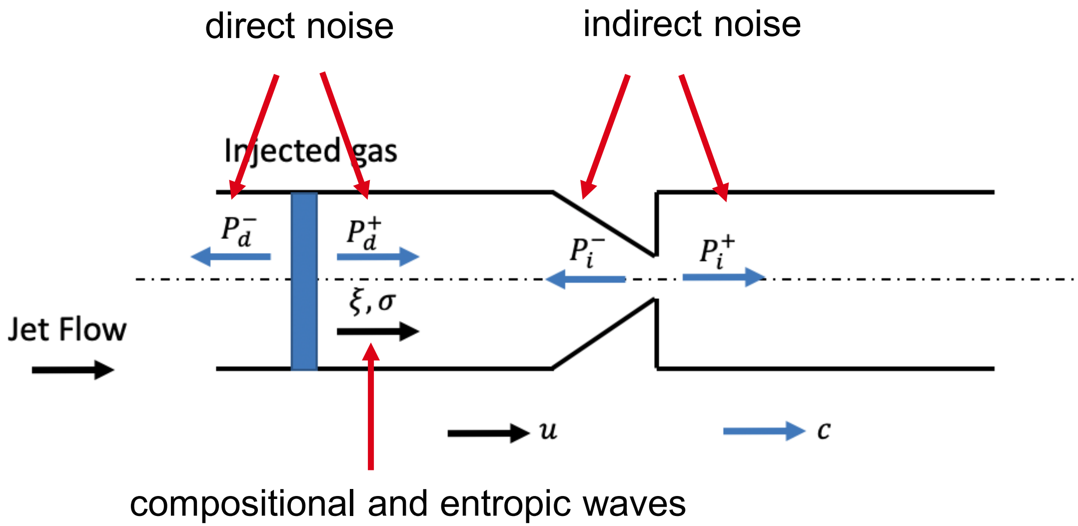
Direct and indirect noise generation

One dimensional noise generation



- Pulse injection: last for 10ms, repetition rate: 0.25Hz (every 4 seconds)
- Acoustic wave travel speed: c; entropic and compositional wave travel speed: u
- Convective time $\tau_c = L_c/u$: time interval between generation of direct and indirect noise
- Reverberation: acoustic signals reflected in a acoustic chamber repeatedly in a short period of time (Rolland, 2018)

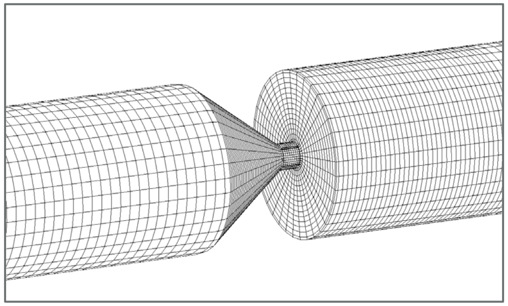
Direct and indirect noise generation

Specific Objectives

- Direct and Indirect noise generation: probe in the upstream pipe
- Compare effect of different injection gases
- Validate the capability of BOFFIN-LESc in predicting combustion noises

Test Cases: 2 gases, 2 injection positions (convective lengths)

Case	Gas	$\dot{m}(gs^{-1})$	$\dot{m}_g(gs^{-1})$	$L_c(m)$
C1	He	8.0	0.17	0.65
C2	He	8.0	0.17	0.05
C3	CO_2	8.0	1.62	0.65
C4	CO_2	8.0	1.62	0.05



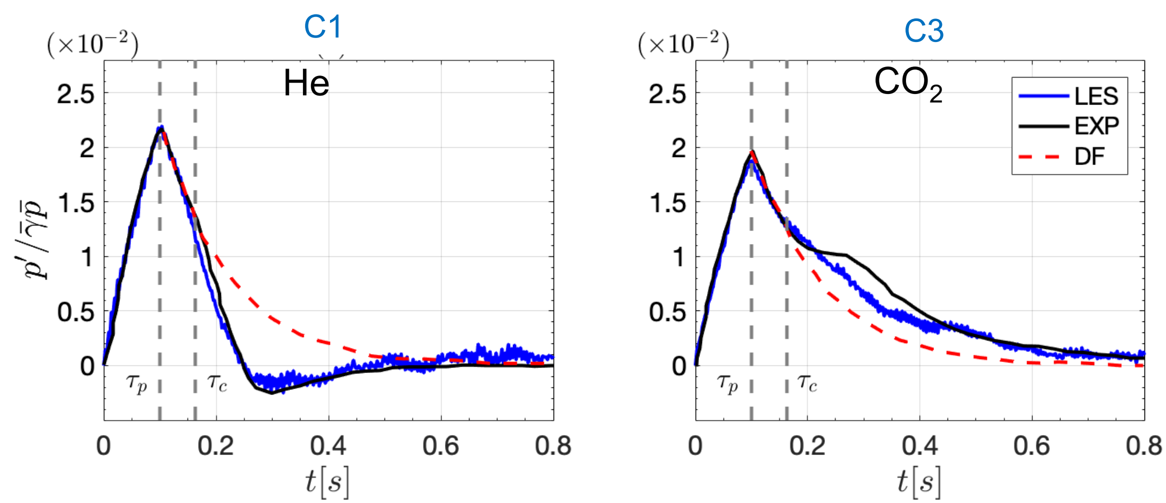
Numerical Setups

- Computational Domain covers upstream pipe, convergent nozzle and 2.1m of downstream pipe
- Fully reflective inlet boundary, non-reflective outlet boundary
- Mesh contains about 0.4m celss, clustered in nozzle and injection region
- Pressure signal phase averaged over 2 cycles

Pressure fluctuations at upstream probe

Long configuration (C1 and C3)

- 0-t_p: P_d generation
- t_p-t_c : P_d decay (decay fit line by reverberation model)
- t_c-t_c+t_p: P_i generation



- C1 and C3 have Similar direct noise amplitude
- Indirect noise: C1 negative, C3 positive caused by different gas molar mass compared to air
- Under predicted indirect noise amplitude in C3, good predicted t_c

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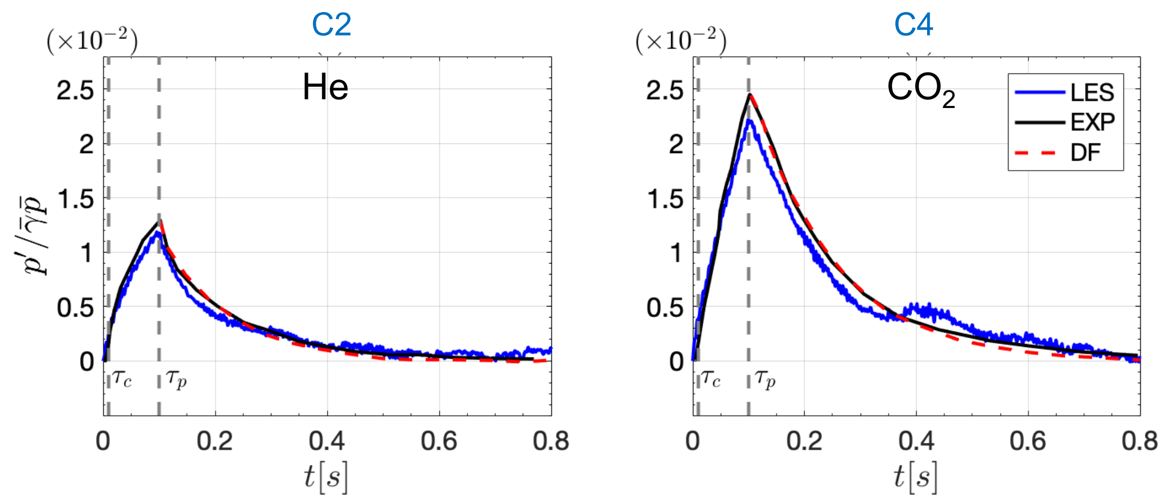
Pressure fluctuations at upstream probe

Short configuration (C2 and C4)

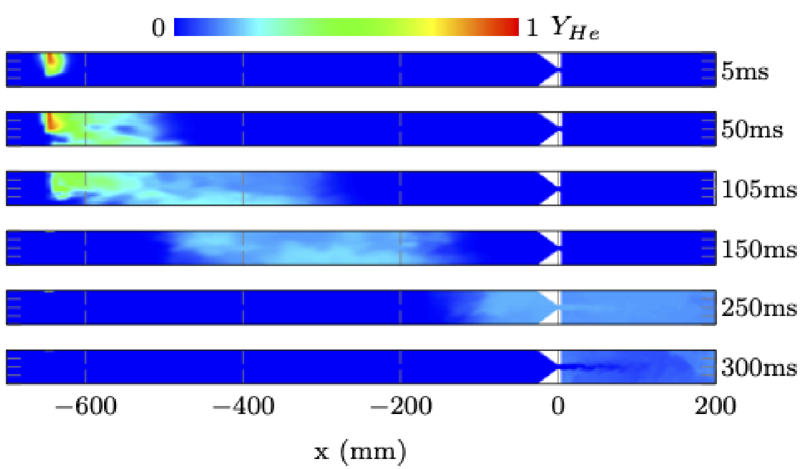
- $t_c \sim 0.01$s, P_d and P_i overlapped
- Peak slightly under-predicted due to underpredicted P_i magnitude



- Compositional entropic wave convection and dispersion
- Flow across nozzle not resolved: Mach number under predicted

Next Step

- More data for phase averaged results
- Resolve nozzle flow: indirect noise generation, noise reflection at the nozzle
- Study compositional and entropic wave propagation in the upstream pipe, effect on indirect noise generation
- Downstream probe pressure signal



Time series of Helium mass fraction in C1.

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