Flashback in Hydrogen-Fuelled Gas Turbine Combustors

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AIMS AND OBJECTIVES

Elucidate the underlying physics during flashback: Global *vs* Local dynamics

Investigate experimentally hydrogen boundary layer flashback. **Explore** the effect of hydrogen's unique physico-chemical properties on flashback limits and determine the system-governing parameters.

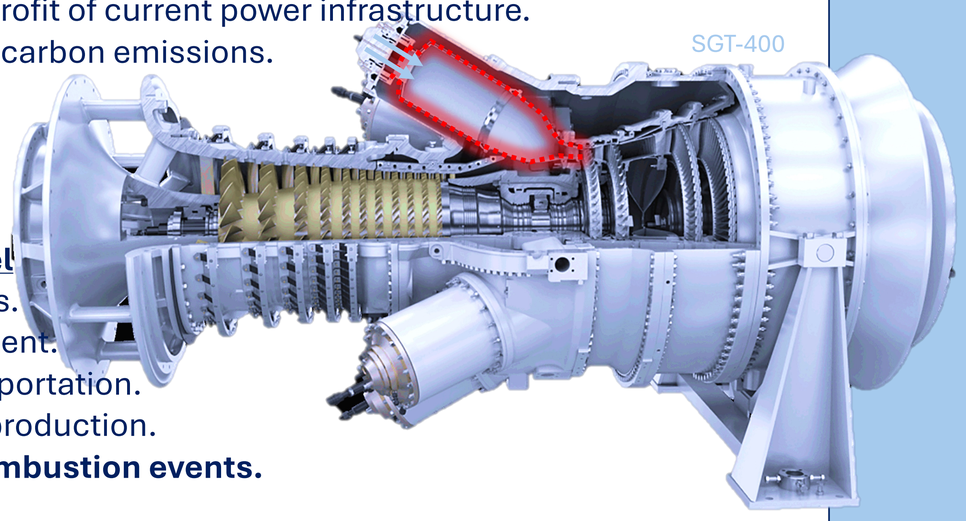
Develop methods for flashback prediction using physics-informed Machine Learning and Computer Vision models, optimising large-scale clean power generation.

BACKGROUND

The rising electricity demand and global commitments to achieving Net Zero GHG emissions are driving an urgent need for decarbonising the power sector. Hydrogen-fuelled gas turbines are now the focus of intensive research, development and investment efforts aimed at enabling safe, efficient, and commercially viable operation within the next generation of low-carbon power systems.

1 1.0079 H Hydrogen

+ Hydrogen fuel
- The most abundant element in the universe.
- Retrofit of current power infrastructure.
- No carbon emissions.



− Hydrogen fuel
- NO_x emissions.
- H_2 embrittlement.
- Storage/Transportation.
- Costly green production.
- **Abnormal combustion events.**

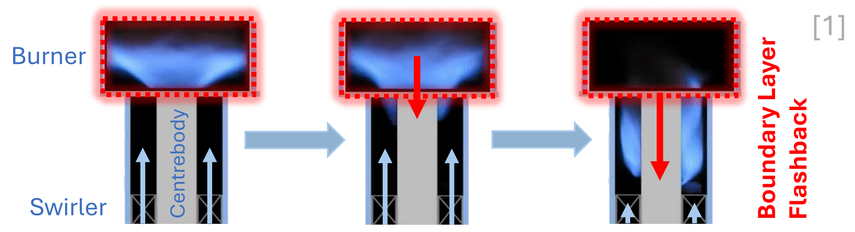
Hydrogen Combustion

Hydrogen flames are prone to flashback and thermo-acoustic instabilities. H-radicals are highly reactive and diffusive, able to modify the local mixture and govern the local system dynamics.

- High Flame Speed
- High Flame Temperature
- High Diffusivity
- Low Luminosity
- Wide Flammability Range
- Low Ignition Energy
- Low Volumetric Energy Density

BOUNDARY LAYER FLASHBACK

Flashback is the upstream propagation of a flame into regions not designed for combustion. There exist three main types of flashback depending on the mechanism: Bulk Flow, Combustion Instability, and Boundary Layer flashback.



[1]

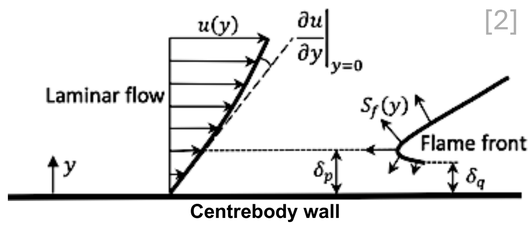
Boundary layer flashback occurs once the flame speed exceeds the bulk flow velocity near the wall, allowing it to propagate upstream, $g < g_{crit}$.

Matching Conditions:

$$S_{f\,y=\delta_p} = u_{\,y=\delta_p}$$

$$g_{crit} \equiv \left.\frac{du}{dy}\right|_{y=0} = \left.\frac{S_f}{\delta_p}\right|_{y=0}$$

[2]



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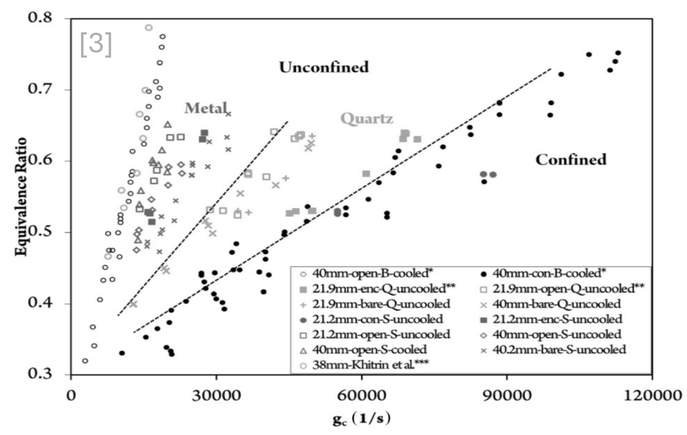

Flashback limit map:

The higher g_{crit} is for a given condition, the more difficult it is to prevent flashback occurrence.

METHODOLOGY

Experimental Configurations

Square duct burner with turbulence-generating fractal grids

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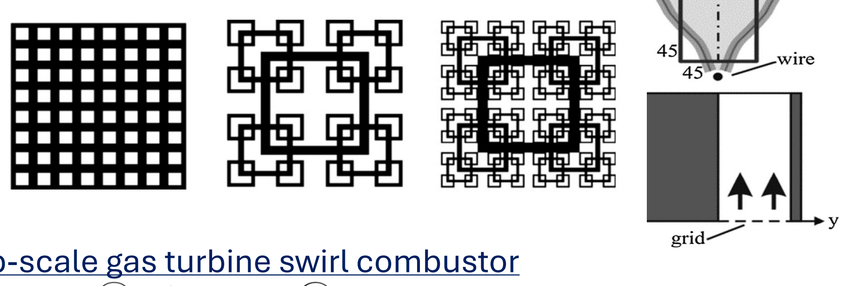

Lab-scale gas turbine swirl combustor

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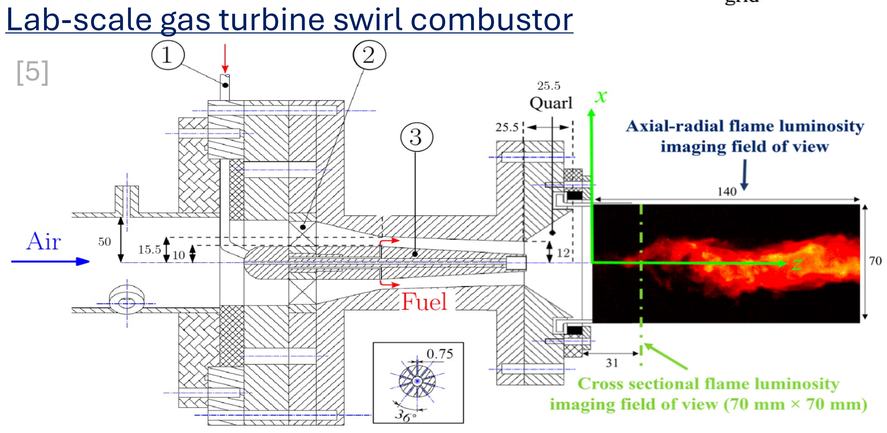


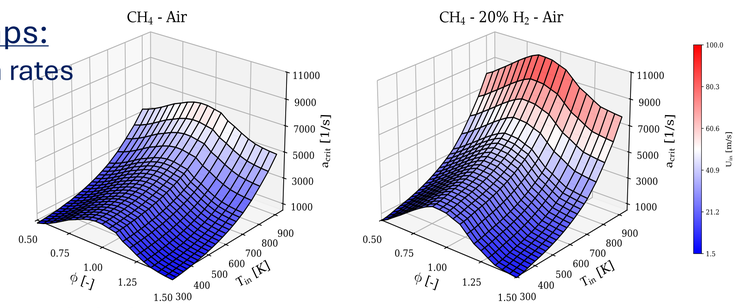
Numerical Studies
- 0D/1D simulations
- Parametric studies

Experimental Campaigns
- CH_4-H_2-Air
- PIV, PLIF
- OH* / CH*

Machine Learning
- Computer Vision
- Deep Learning
- Early Warning Methods

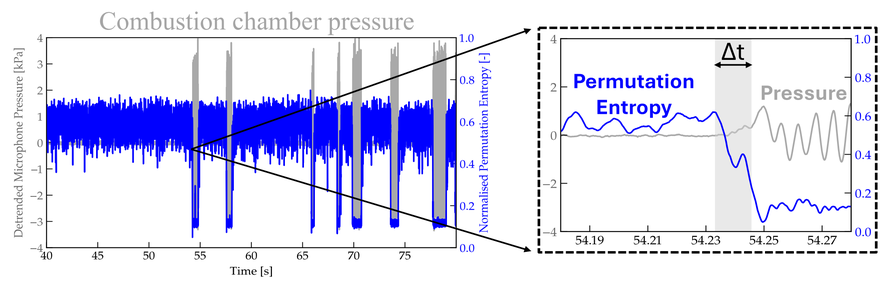
Numerical Results – Premixed Counterflow Flames

Extinction maps:
- Critical strain rates
- H_2 addition
- Lean / Rich
- Initial T, U



Highly non-monotonic behaviour.

Early Warning Methods – Permutation Entropy (PE)



PE is a stochastic method capable of identifying dynamic transitions within any system, by analysing the complexity of a representative signal (Pressure). It is also suitable for active control applications.

IMPACT OF RESEARCH

Accelerate the UK transition to Net Zero by enabling sustainable hydrogen-based energy solutions, driving innovation, informing industrial decarbonisation, and supporting resilient, low-carbon futures.

Support clean energy transitions. → Accelerate H_2-to-Power pathways. → Provide operational guidelines for hydrogen gas turbines.

Ensure safer hydrogen integration into power systems.

References:
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[2] A. Kalantari and V. McDonell, 'Boundary layer flashback of non-swirling premixed flames: Mechanisms, fundamental research, and recent advances', *Prog. Energy Combust. Sci.*, vol. 61, pp. 249–292, 2017.
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[5] S. Qui, *Transition mechanism to thermoacoustic oscillations in a swirl stabilized gas turbine combustor*. London, UK: Imperial College London, 2024.

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