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Fuel and Load Flexibility of a Single-Nozzle Jet-Stabilized Combustor Operated with Hydrogen and Hydrogen-Methane Blends

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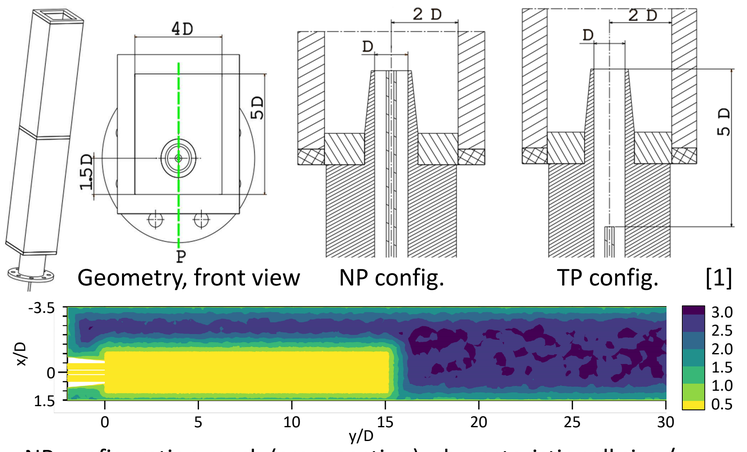
SPANNING THE BRIDGE: FROM COMBUSTION SCIENCE TO COMBUSTION TECHNOLOGY
DLR-VT

Motivation

- Open up the use of **carbon-free fuel** hydrogen to reduce CO_2 emissions
- Utilize the **FLOX®** burner concept to ensure combustion stability while keeping down possible NO_x emissions
- Validate the simulations using data from **single-nozzle** experiments [1]
- Ready the numerical design process for **more complex** hydrogen combustors

Geometry and Numerical Setup

- Concentric fuel tube ($d_{\mathrm{in}} = 0.2$ D) in air nozzle , **Non-** and **Technically-Premixed** configurations (NP, TP)
- Tetrahedra-based meshes, refined zones for reactions, approx. 20M cells
- DLR code **ThetaCOM** for combustion/ CFD simulation: RANS, Std. k-ω turb., adiabatic walls, finite-rate chemistry, mechanism DLR Concise v1/2021 [2]

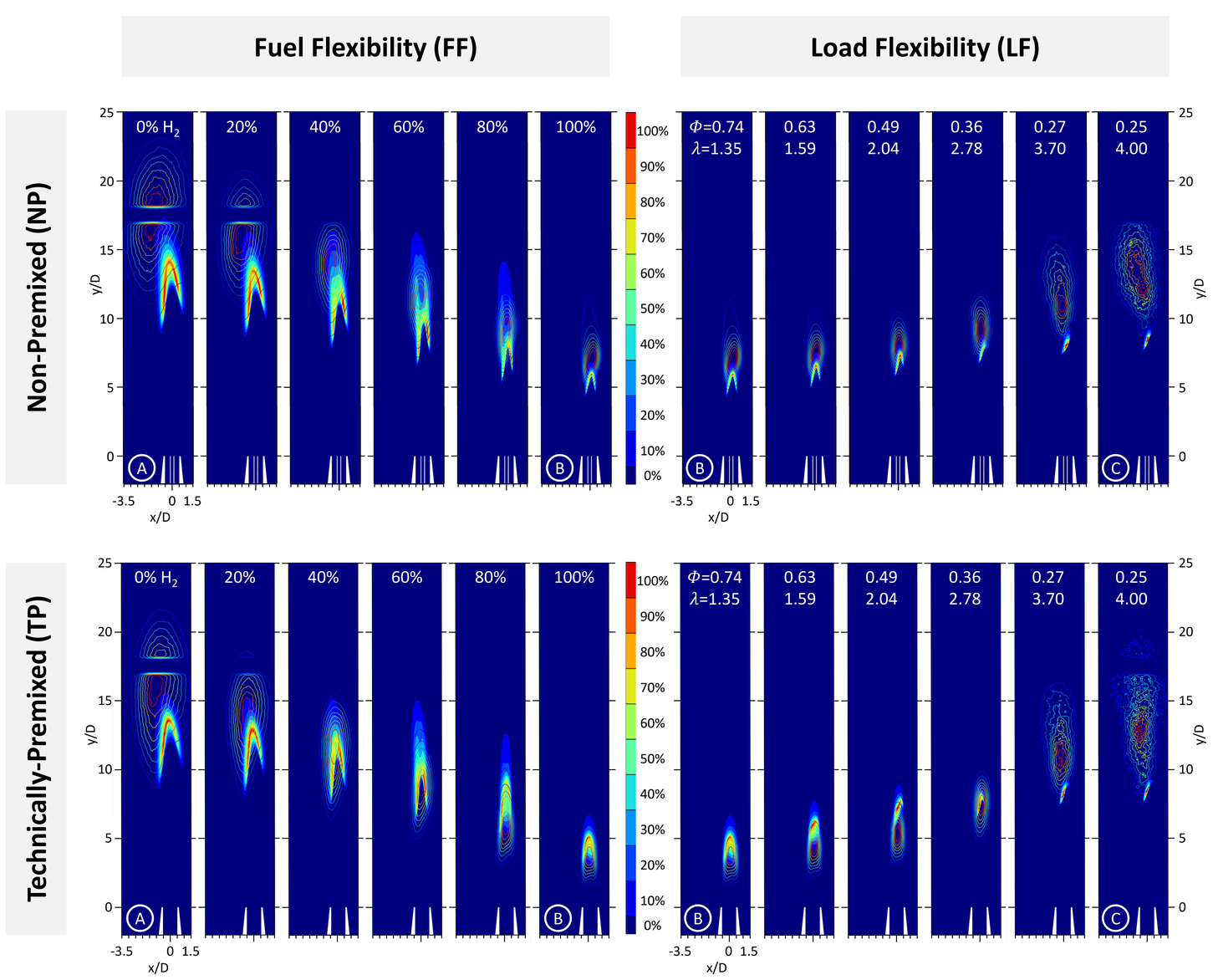


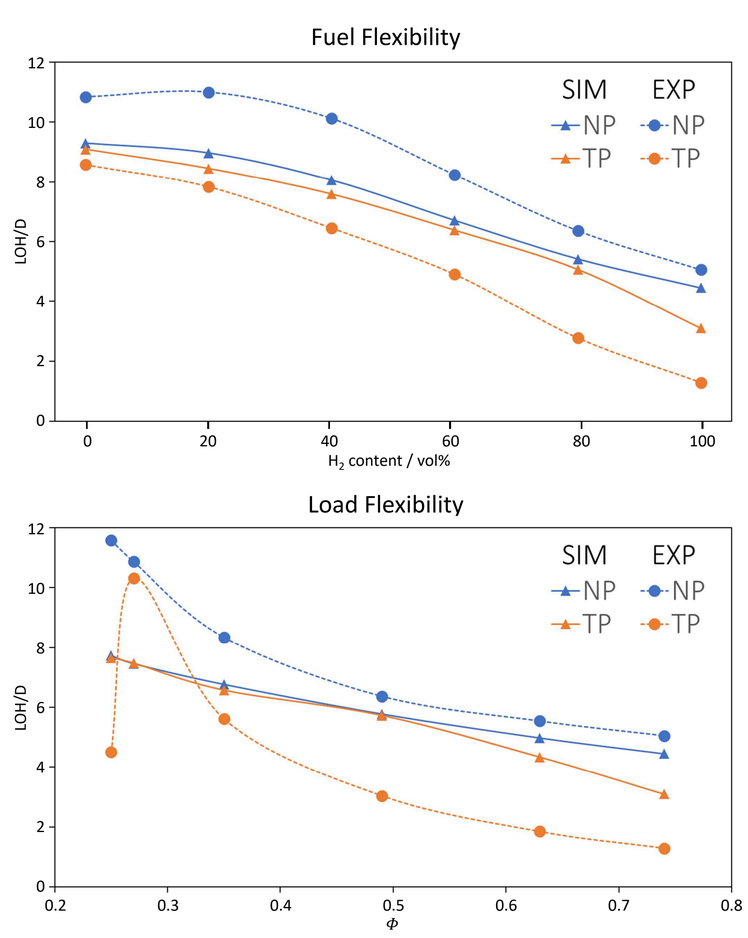
Results

- Range of **Operating Points** for Fuel and Load Flexibility (FF, LF) investigations, see Table
- **FF** starts at 100% methane CH_4 (Operating Point A) continuing towards 100% H_2 (OP B), constant equivalence ratio Φ and thermal power P_{th}, shown here in steps of 20 vol% H_2
- **LF** varies Φ $(0.74 \rightarrow 0.25)$ by reducing P_{th} $(10.5\ \mathrm{kW} \rightarrow 4.0\ \mathrm{kW})$ from OP B to OP C
- Flame shape/position (**Lift-Off Height** LOH) are validated using experimental data [1]

Selection of Operating Points (OP)

OP	fuel -	$\dot{m}_{\mathrm{fuel}}$ g/min	$\dot{m}_{\mathrm{air}}$ g/min	v_{air} m/s	Φ -	P_{th} kW
Ⓐ	CH_4	12.6	291	110	0.74	10.5
Ⓑ	H_2	5.2	241	105	0.74	10.5
Ⓒ	H_2	2.0	266	107	0.25	4.0





- Contours are simulation results (SIM), Lines are experimental data (EXP), SIM and EXP data are normalized to their respective maximum values, EXP shown in steps of 10%
- Simulation of OH* chemiluminescence using the line-of-sight integrated product of the species mass fractions of oxygen radical O and hydrogen radical H as marker for OH*

- Comparing NP and TP, technical pre-mixing lowers the LOH, see EXP data
- trend is captured by the simulation for FF and LF, limited agreement regarding absolute values of LOH
- LOH decreases with H_2 content (FF) and Φ (LF) respectively, for both EXP / SIM
- in general, simulation yields shorter flames that are less distributed in space

Conclusions

- Combustion properties of hydrogen are fundamentally different from methane, which has major implications on burner design, hydrogen can help keeping combustors short
- DLR Concise reaction mechanism[2] shows promising results for various equivalence ratios (LF) and fuel compositions (FF) ranging from 100% methane to 100% hydrogen
- Controlling the fuel-air mixing is the key to fuel- and load-flexible combustor systems

References

[1] Petry, N. et al., ASME Turbo Expo (2023), 102392.
[2] Kathrotia, T. et al., Fuel 302 (2021), 120736.

DLR Project
H_2-GT – Hydrogen Utilisation in Gas Turbines

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