

# HPC IN DEN INGENIEURWISSENSCHAFTEN – VON DER GRUNDLAGENFORSCHUNG BIS HIN ZUR ANWENDUNG

# LIGHTHOUSE PROJECTS

## Clean Circles

Iron as carbon-free energy carrier in a circular energy economy

Interdisciplinary cluster project aiming for Excellence Initiative

Partners: KIT, HDA, JvGU, RKU, DLR, MPI (total volume 15 M€)

HPC is key to understand the fundamental processes, e.g. in iron-air flames



## Turbulent pulverized iron-air flame

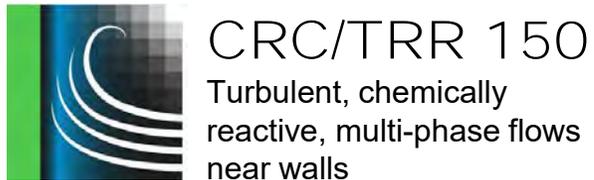
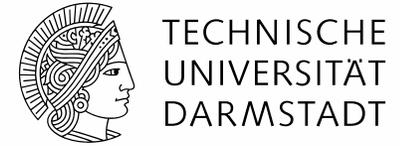


Experiment, Reactive  
Flows and Diagnostics  
Prof. Dreizler



Simulation, Simulation of  
reactive Thermo-Fluid  
Systems  
Prof. Hasse

# COLLABORATIVE RESEARCH AT STFS



The CRC/TRR 150 teams up researchers from **TU Darmstadt** and **Karlsruhe Institute of Technology**.

They aim to advance the fundamental understanding and modelling of chemical kinetics.

At STFS, Flame-Wall Interaction and Boundary Layer Flames are investigated.



The CRC/TRR 129 combines the experience of **TU Darmstadt**, **RWTH Aachen** and **Ruhr-Universität Bochum**.

The focus is on **homogeneous gas and heterogeneous biomass combustion**.

At STFS, the objective is modeling and simulation of the complete Oxy-Fuel combustion system.



TU Darmstadt is one of four **University Technology Centres (UTC)** in Germany.

In Darmstadt, the collaboration between institutes and Rolls-Royce works on **Combustor-Turbine Aerothermal interaction**.

At STFS, the focus of the UTC is **modeling of aero-engine combustion**.

# ROLLS-ROYCE UNIVERSITY TECHNOLOGY CENTRE (UTC)



TECHNISCHE  
UNIVERSITÄT  
DARMSTADT



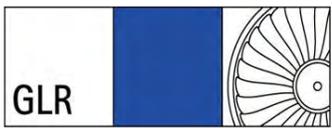
**RSM**  
Reaktive Strömungen + Messtechnik

Measurement Technology  
for Application in  
Combustion Processes



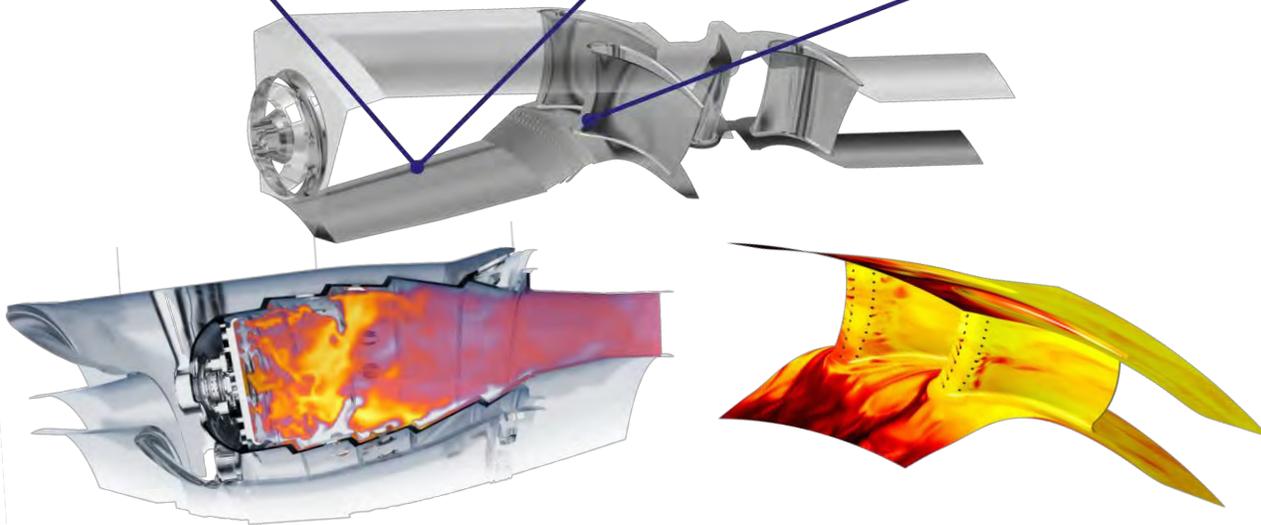
**STFS**  
Simulation of reactive Thermo-Fluid Systems

Numerical Modelling of  
Combustion Processes



**GLR**

Impact of Combustion and  
Swirl on Turbine  
Aerodynamics and Cooling



© KIT

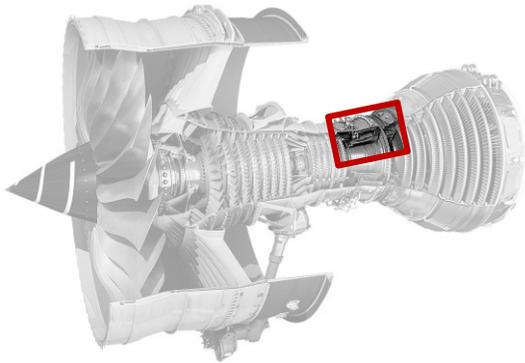
Rolls-Royce/DLR UTC Review Meeting, Karlsruhe, April 2023.



# FROM COMPLEX TO SIMPLE

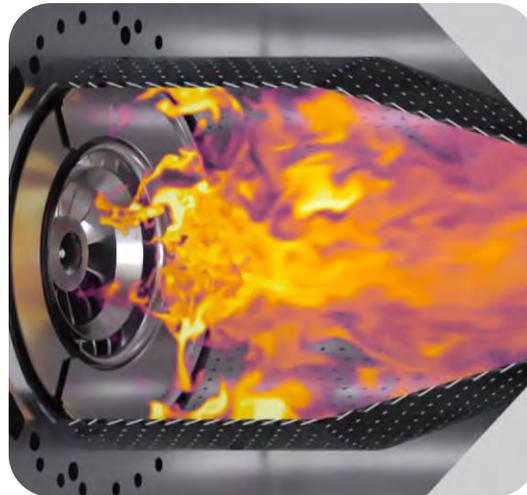
## BUILDING A DIGITAL HPC TWIN

FULL-ENGINE  
CONFIGURATION



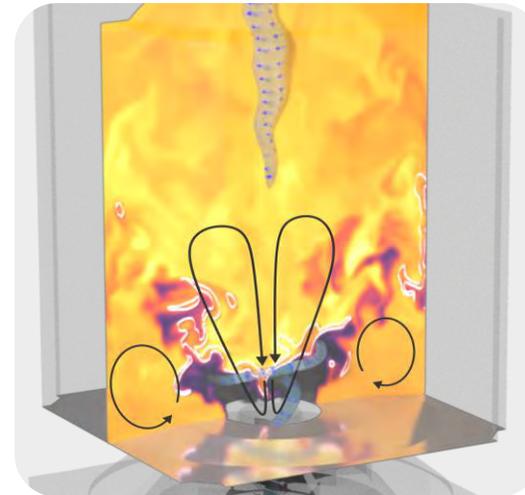
Global performance metric  
Point measurements

ENGINE-LIKE  
CONFIGURATION



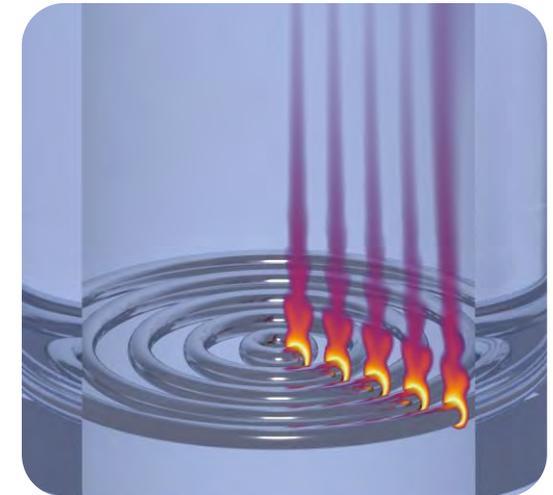
Point measurements  
Microphone probes

LAB-SCALE MODEL  
COMBUSTOR



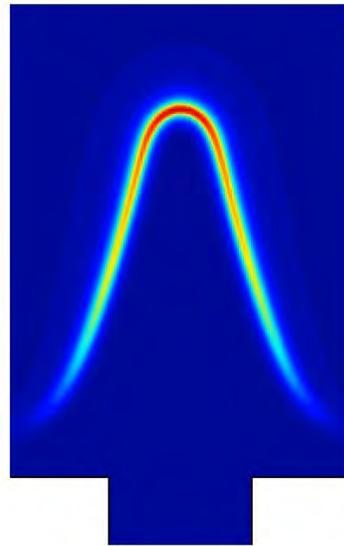
Detailed laser measurements  
Microphone probes

GENERIC ACADEMIC  
CONFIGURATION



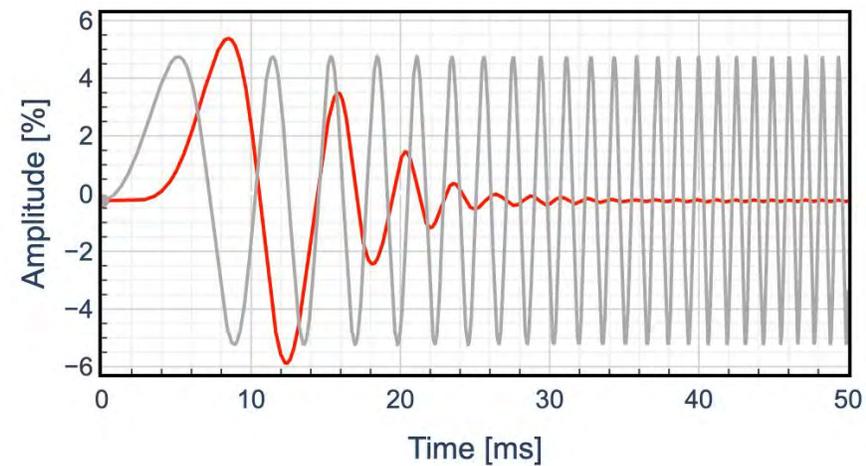
Analytical models  
Two-dimensional modeling

# THERMOACOUSTIC RESPONSE



$$u(t) = u_0 + u'(t)$$

$$\text{FTF}(\omega) = \frac{\dot{Q}' / \bar{Q}}{u' / \bar{u}}$$



# GENERIC ACADEMIC CONFIGURATION

RIJKE TUBE



YouTube, NightHawkInLight (2021), *Acoustic Energy & Surprising Ways To Harness It*. [\[Link to Full Video\]](#)

# GENERIC ACADEMIC CONFIGURATION

RIJKE TUBE

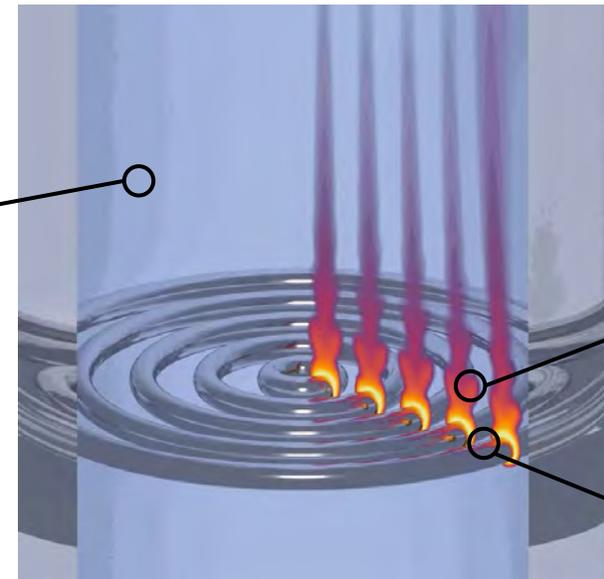
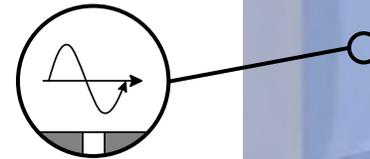


POSSIBLE MODE SHAPES [2]

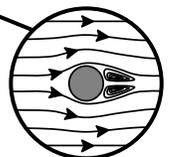
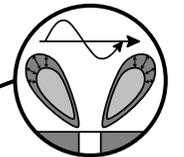


HPC Digital Twin  
generic configuration

Pressure  
Oscillations



Thermo-  
acoustic  
Oscillations



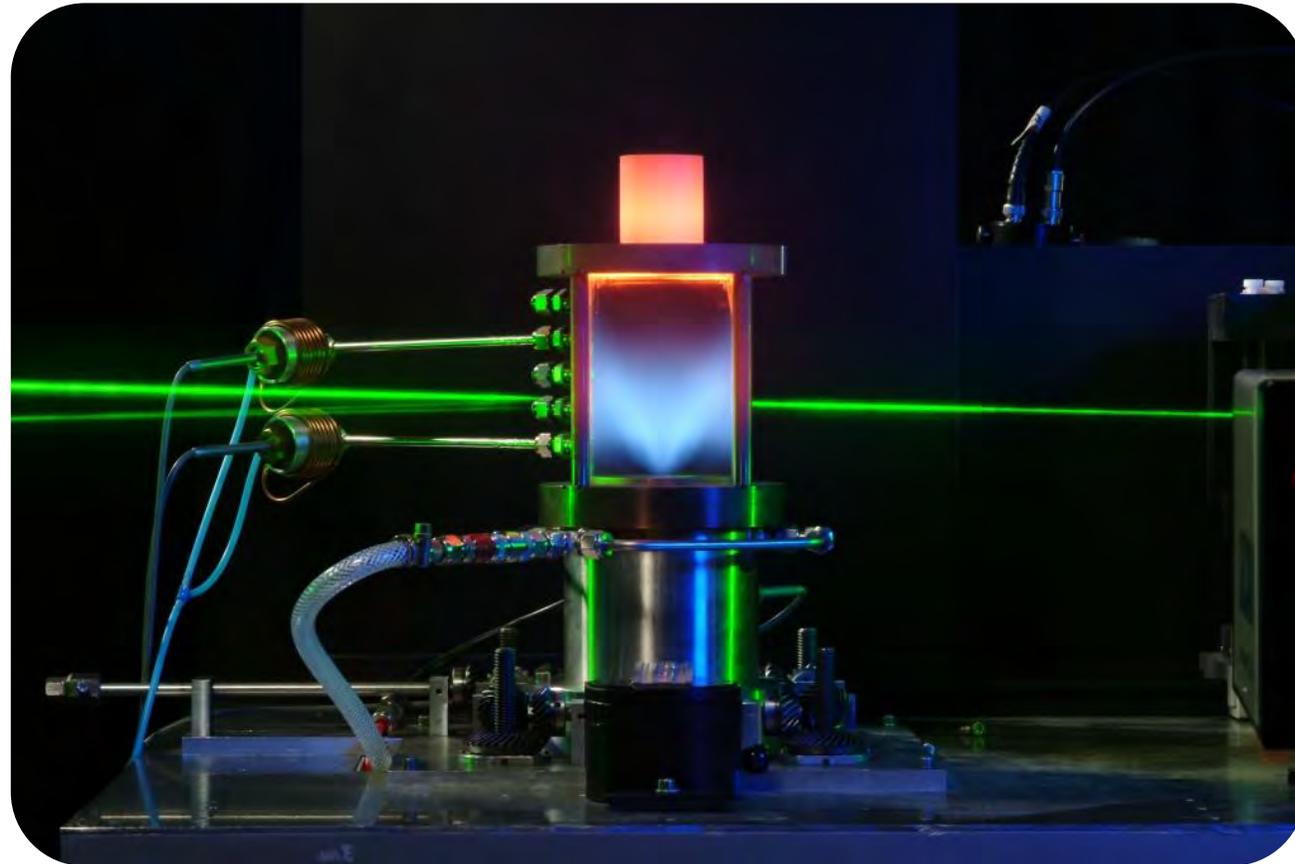
Laminar  
Flow

[1] YouTube, NightHawkInLight (2021), *Acoustic Energy & Surprising Ways To Harness It*. [\[Link to Video\]](#)

[2] YouTube, NightHawkInLight (2021), *Fire Driven Sound Waves in a Quartz Tube*. [\[Link to Video\]](#)

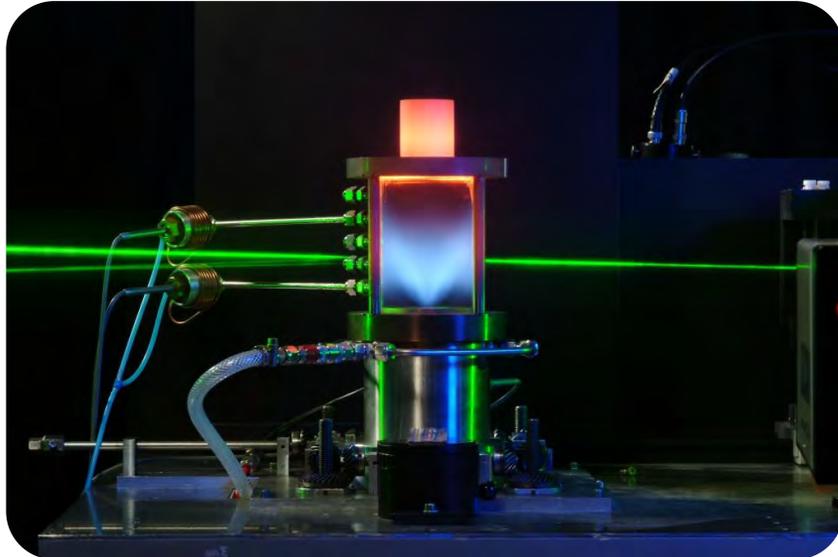
# LAB-SCALE MODEL COMBUSTOR

SFB606 GAS TURBINE MODEL COMBUSTOR



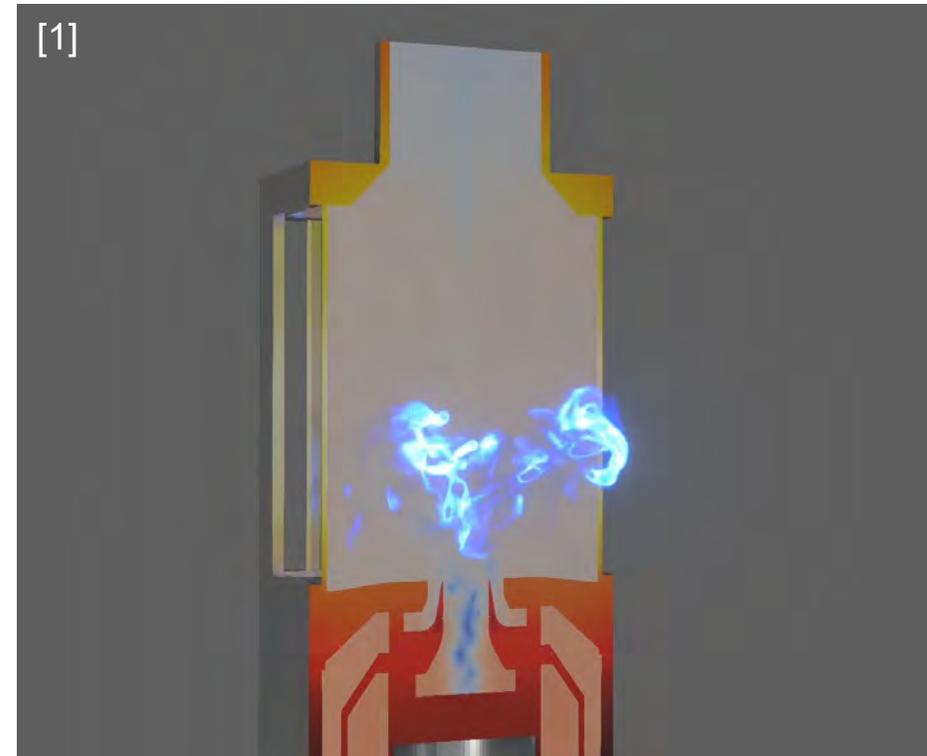
# LAB-SCALE MODEL COMBUSTOR

## SFB606 GAS TURBINE MODEL COMBUSTOR



Gas Turbine Model Combustor at DLR Stuttgart  
© DLR

## HPC Digital Twin lab-scale, atmospheric burner



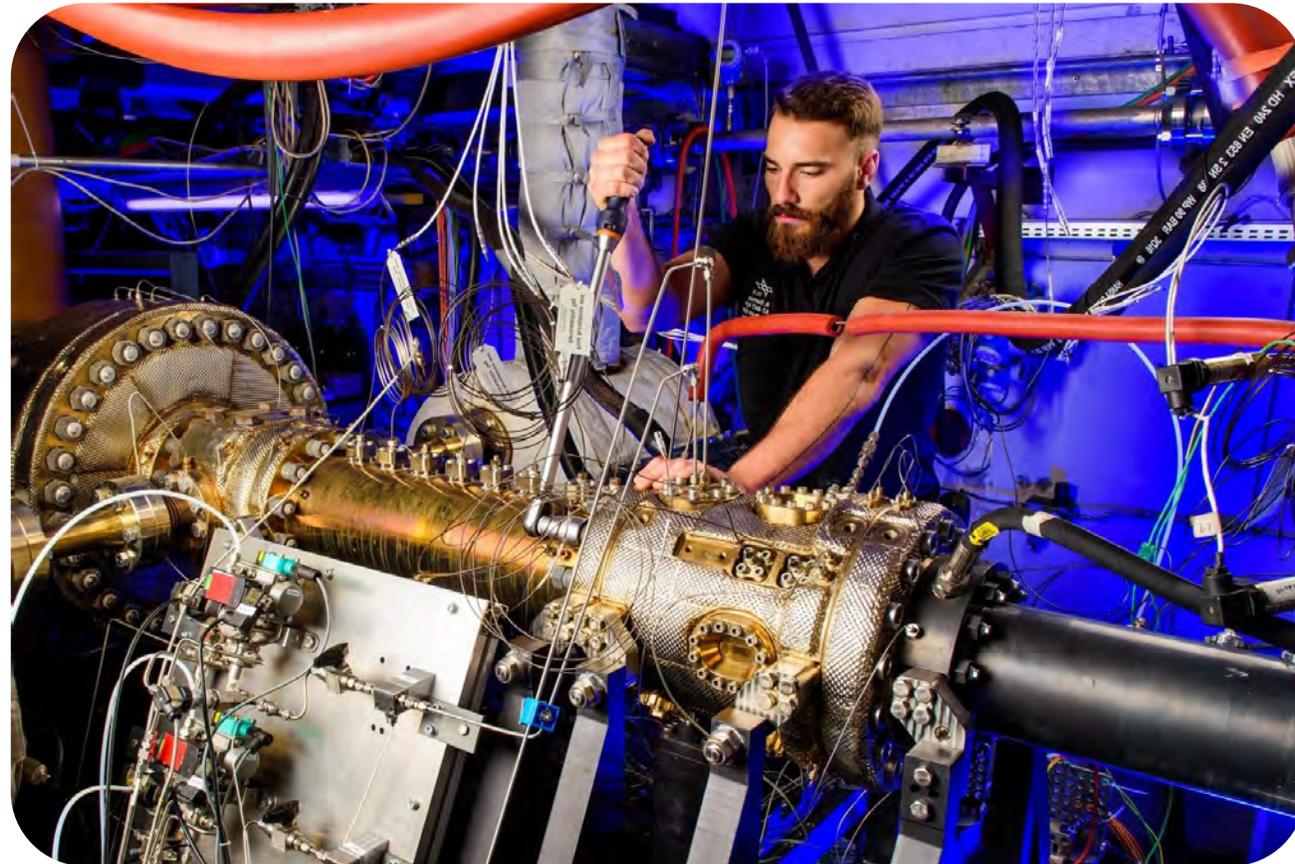
[1] Karpowski, et int., Hasse (2022), *Proc. ASME Turbo Expo 2022*.

# ENGINE-LIKE CONFIGURATION

SCARLET



TECHNISCHE  
UNIVERSITÄT  
DARMSTADT



# ENGINE-LIKE CONFIGURATION

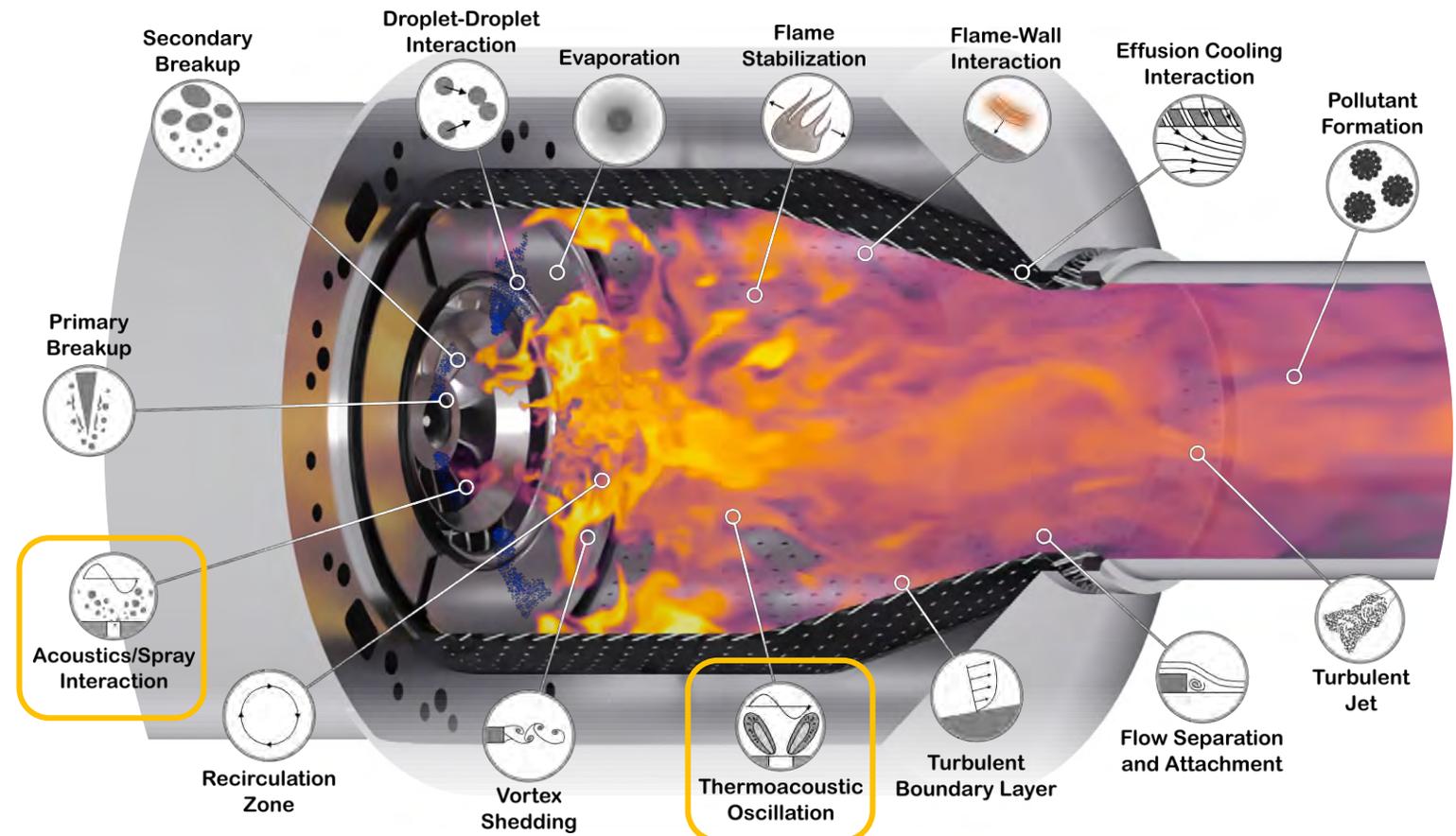
SCARLET



SCARLET test rig at DLR Cologne  
© DLR (CC-BY 3.0)

**Typical number of cores:**  
200-1000  
**Total runtime:**  
~1 million core hours per  
acoustic excitation per OP

HPC Digital Twin  
real injector, engine-like conditions



# ENGINE-LIKE CONFIGURATION

SCARLET



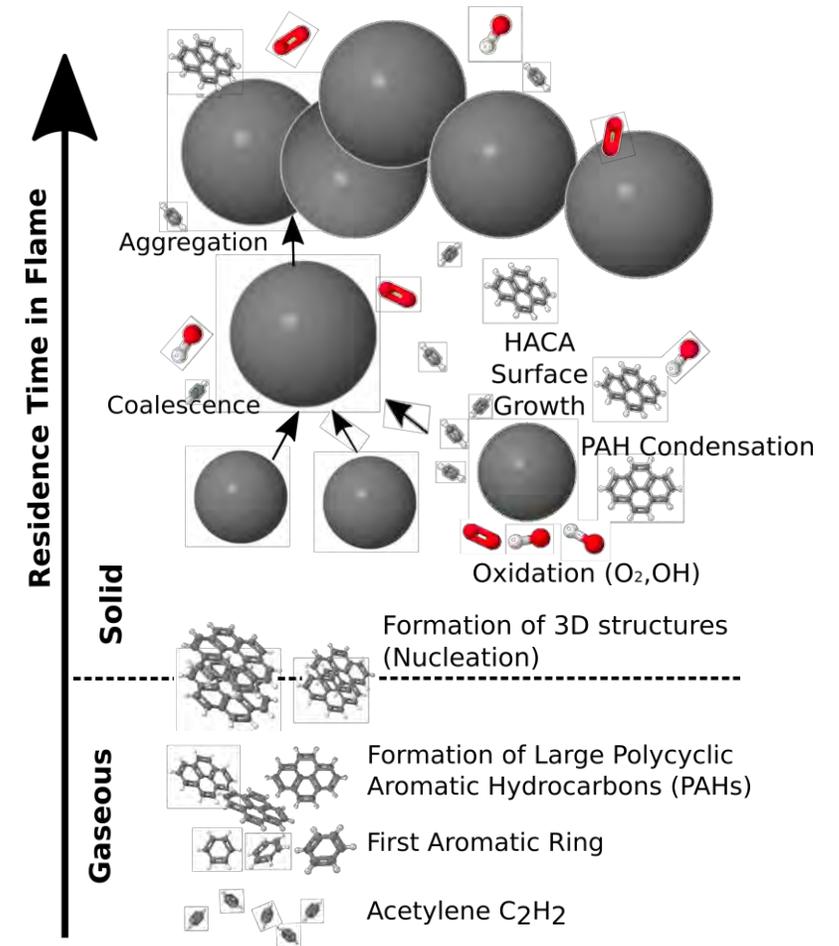
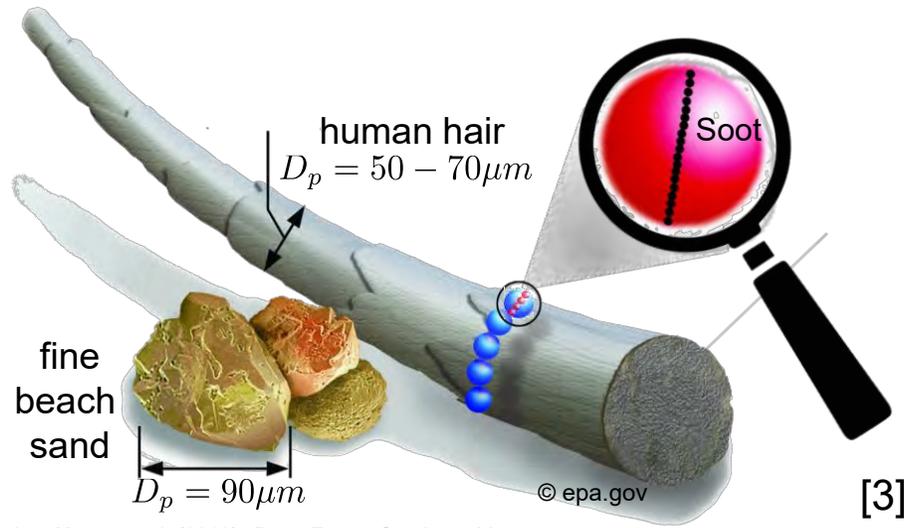
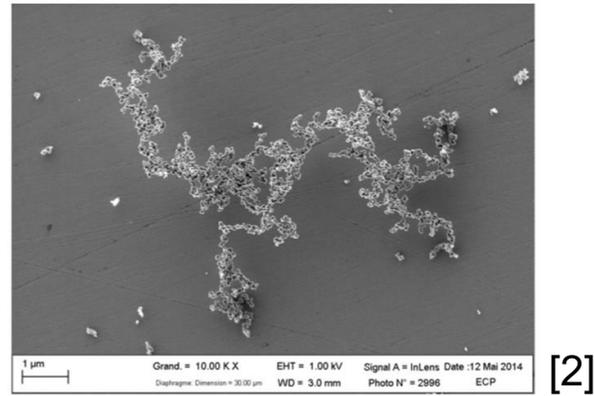
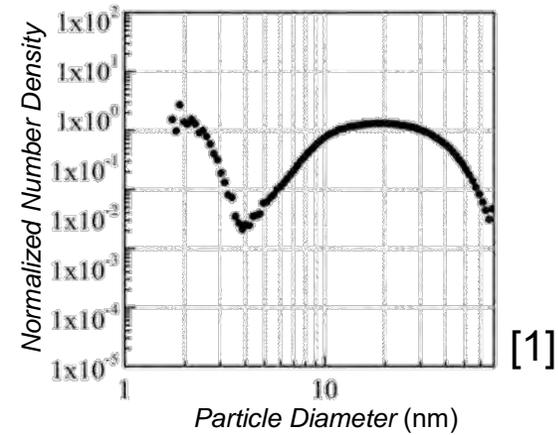
TECHNISCHE  
UNIVERSITÄT  
DARMSTADT

HPC Digital Twin  
real injector, engine-like conditions



Acoustic Energy  
Temperature  
Source Term

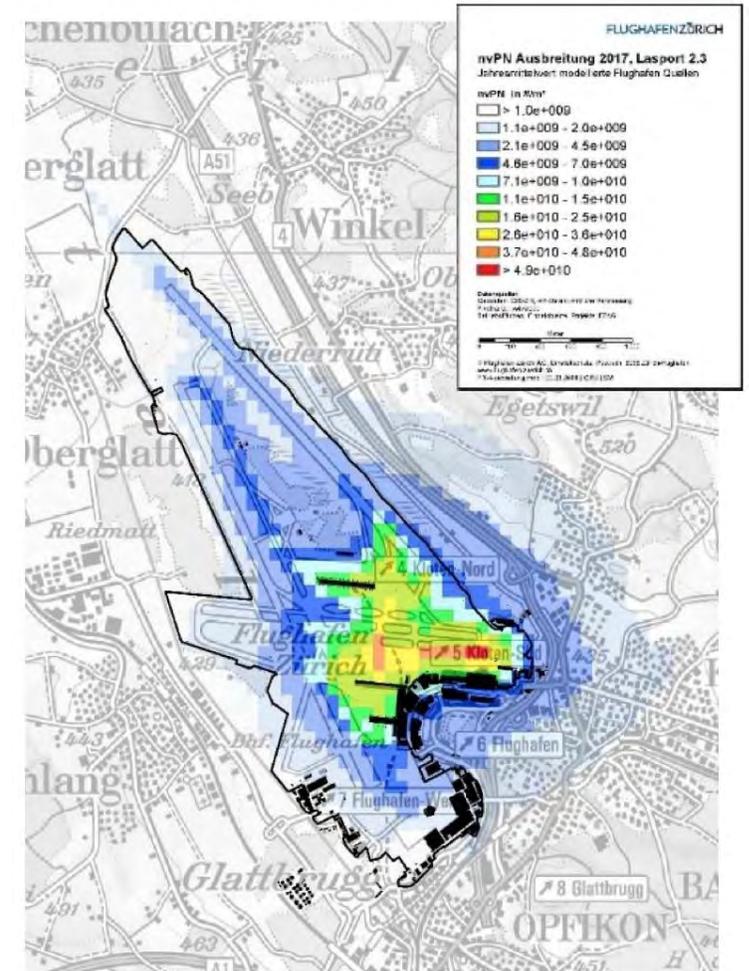
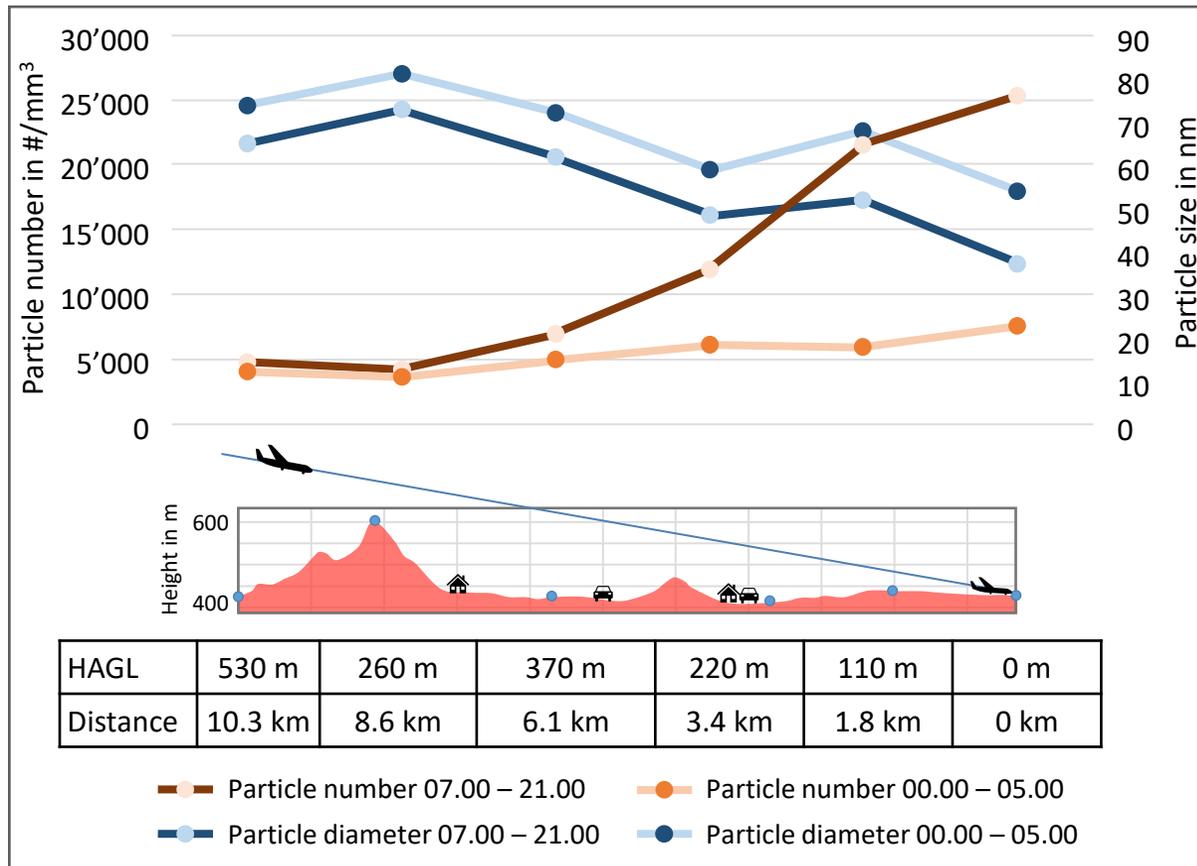
# CHARACTERISTICS OF SOOT



[1] Frenzel, et int., Hasse et al. (2013), *Proc. Europ. Combust. Meet.*  
 [2] Okyay (2016). PhD thesis. Cent. Univ. Paris-Saclay.  
 [3] adapted from <https://www.ccacoalition.org/en/slcps/black-carbon>

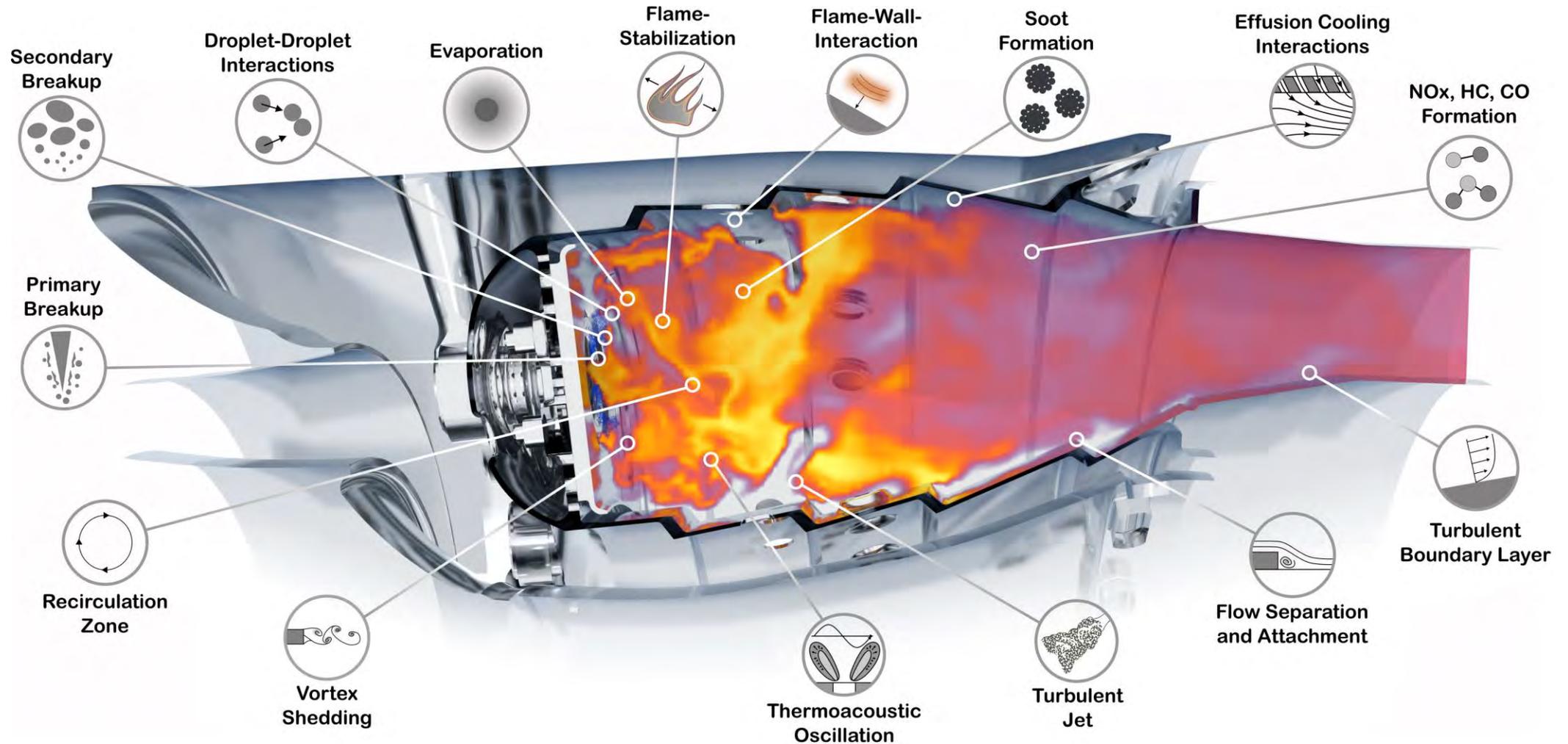
# IMPORTANCE OF SOOT PREDICTION

## EXAMPLE nvPM EMISSIONS AT ZURICH AIRPORT



Fleuti (2018), Presentation, Ultrafeinstaubstudien Flughafen Zürich, Flughafen Zürich AG, [\[Link\]](#)

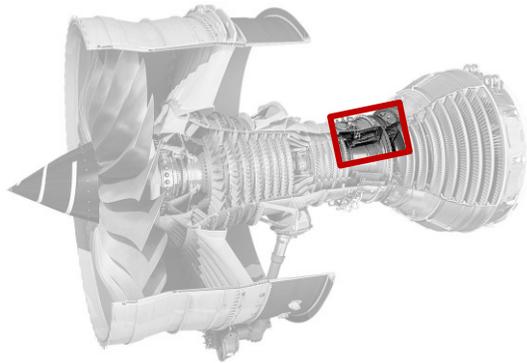
# AERO-ENGINE COMBUSTION



# FROM COMPLEX TO SIMPLE

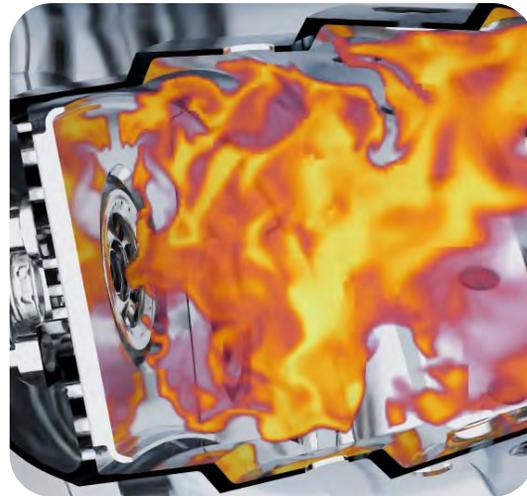
## BUILDING A DIGITAL HPC TWIN

FULL-ENGINE  
CONFIGURATION



Global performance metric  
Point measurements

REAL COMBUSTOR  
CONFIGURATION



Point measurements  
Different operating conditions

TURBULENT  
SOOTING FLAME



Detailed laser measurements  
Particle size distribution

GENERIC ACADEMIC  
CONFIGURATION

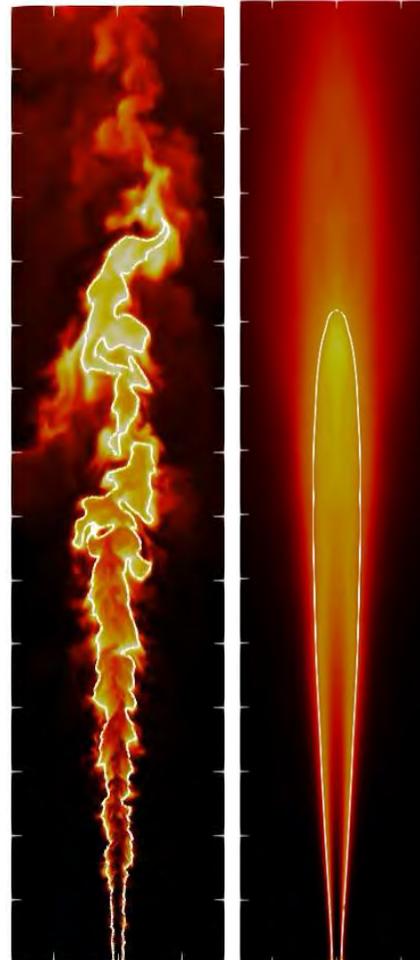


Analytical models  
Low-dimensional modeling

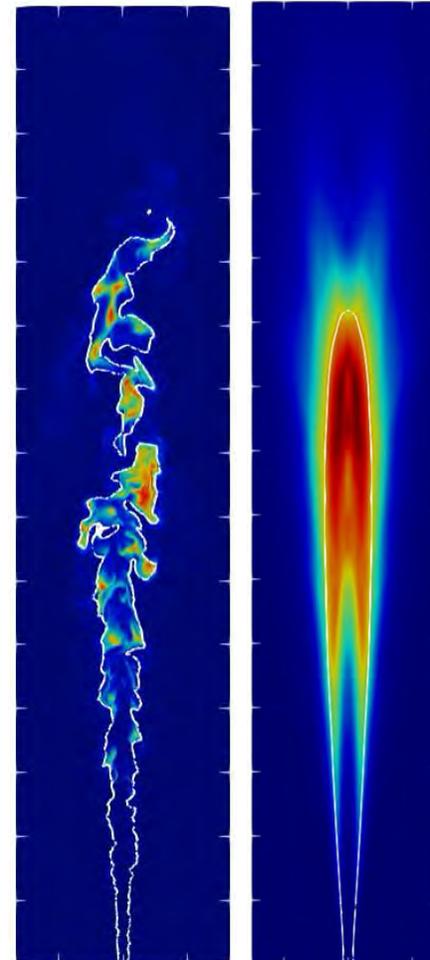
# DELFT ADELAIDE FLAME III



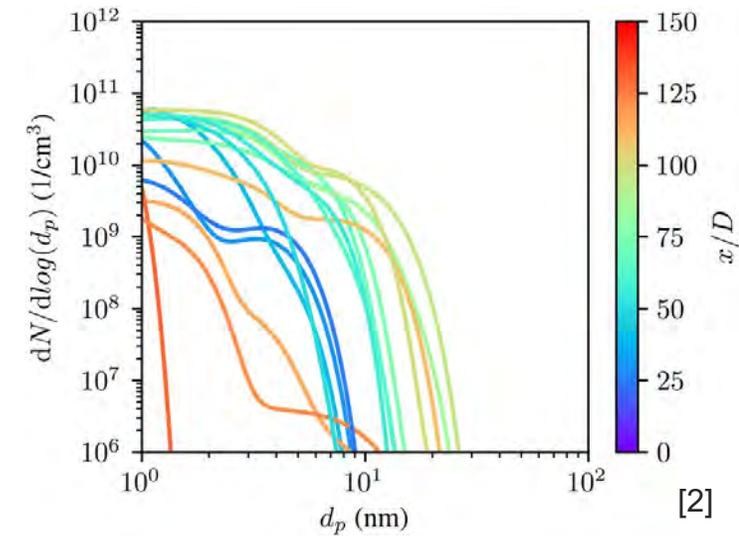
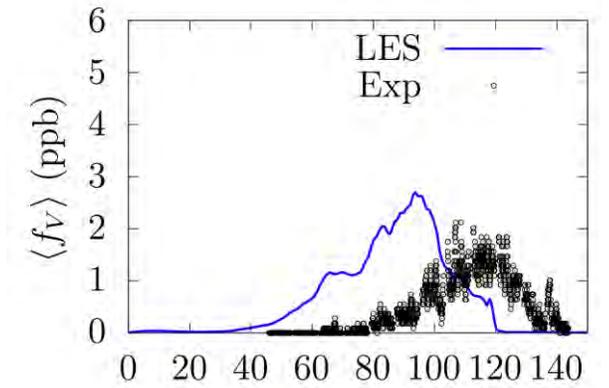
[1]



Temperature



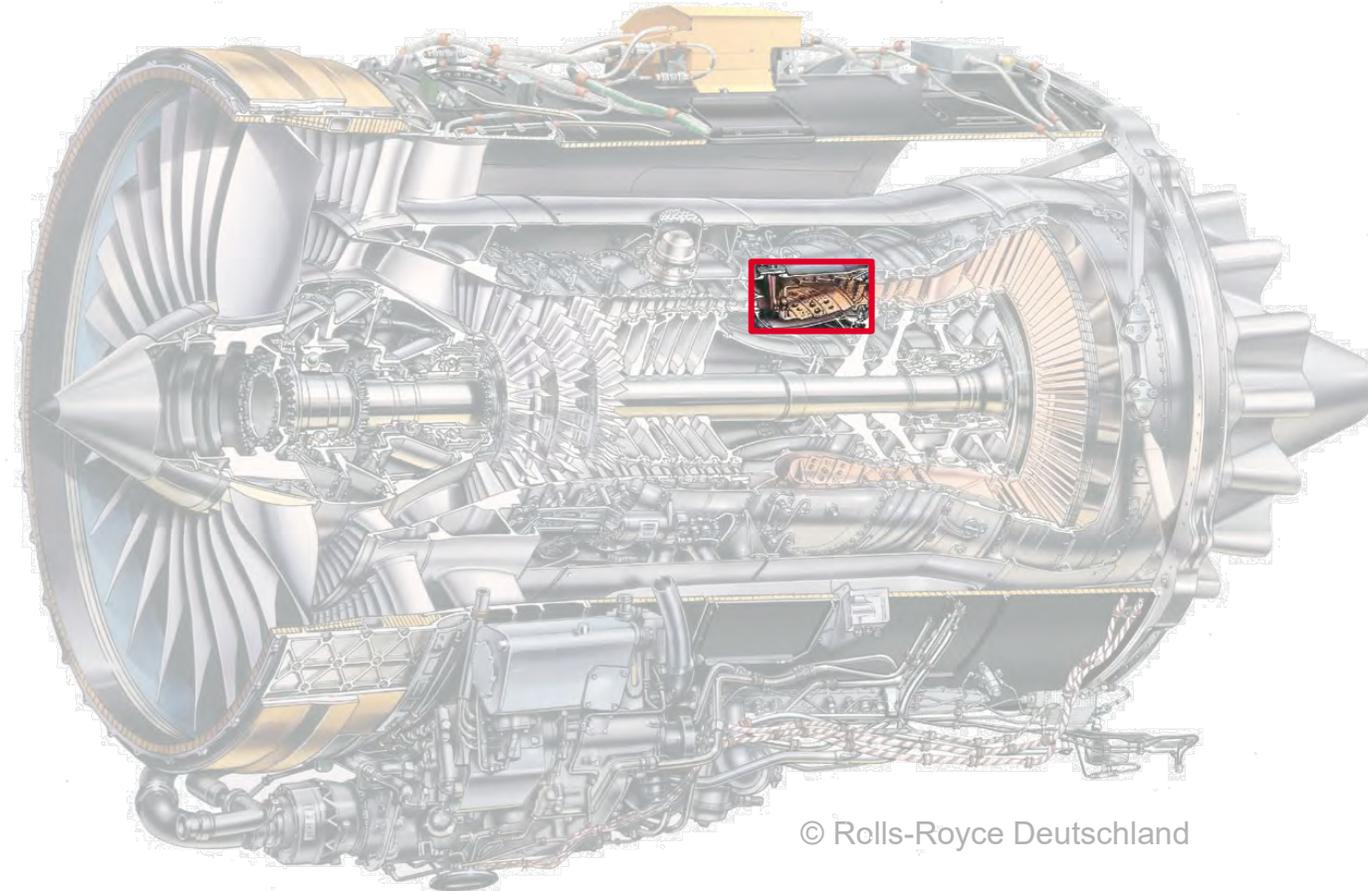
Soot number density



[2]

[1] Qamar et al. (2009), *Combust. Flame*.  
[2] Ferraro, et int., Hasse (2022), *Phys. Fluids*.

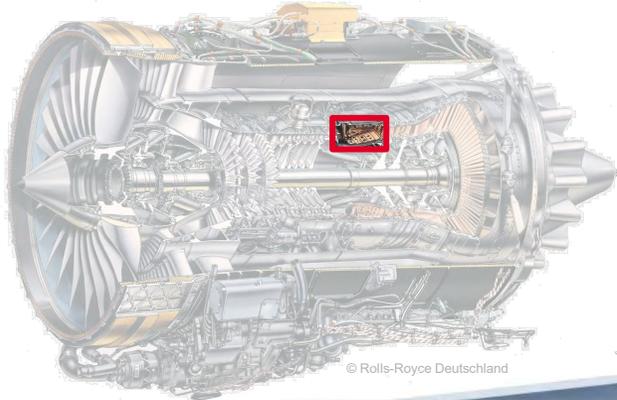
# BR710 AERO-ENGINE COMBUSTOR



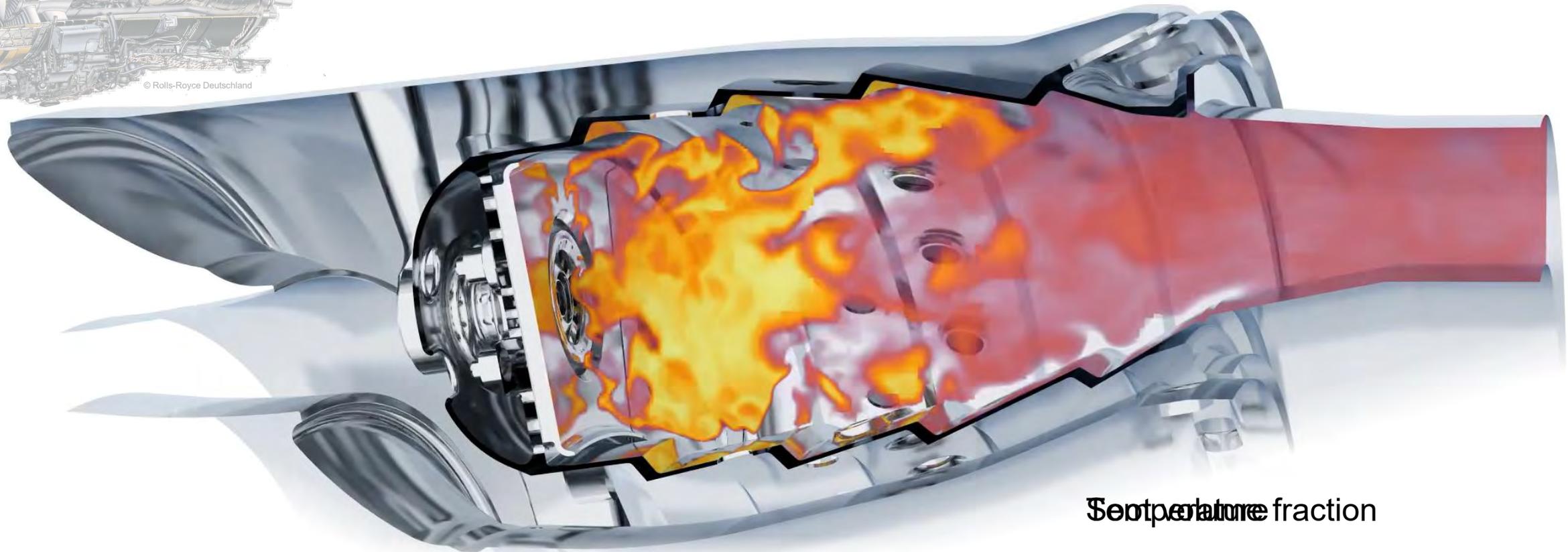
# BR710 AERO-ENGINE COMBUSTOR



Typical number of cores: 200-1000  
Total runtime: ~1 million core hours per OP



© Rolls-Royce Deutschland



Temperature fraction

# HYDROGEN COMBUSTION

## BUILDING A DIGITAL HPC TWIN



[1]

**ZEROe Hydrogen combustion demonstrator**

**Objectives**

- Mature and demonstrate a **flightworthy integrated** H<sub>2</sub> engine and aircraft
- Explore a **representative scale** for future products
- Show safe aircraft and engine system integration **operability**
- Derisk** non-CO<sub>2</sub> emissions to **calibrate** climate impact assessment models
- Condition **liquid H<sub>2</sub>** from **tank** to **combustion chamber**
- Develop new fuel system** for short and medium range aircraft

**Next steps**

- Concept phase**  
Overall architecture freeze
- Preliminary design phase**  
First loop of design
- Critical design phase**  
Final loop of design
- Manufacturing**
- Ground and flight tests**

**Overall validation and verification** during development through modeling, sub-component, component, sub-system, systems and overall integrated system tests.

**AIRBUS**

**FROM TIDES TO TAKE OFF**  
A new aviation world first for a modern aero engine

**01 THE ENERGY**  
Harness both wind and tidal power at EMEC on the Scottish Islands of Orkney in the UK to generate renewable electricity

**02 THE CHEMISTRY**  
Use this renewable electricity to power an electrolyser and generate green hydrogen via electrolysis

**03 THE SQUEEZE**  
Compress the hydrogen from 20 bar to 200 bar pressure in order to maximise the amount available in the tank, equivalent to 100 times more pressure than a typical car tyre

**04 THE POWER**  
Convert an AE 2100-A aero engine and use it to combust hydrogen instead of conventional kerosene

**05 THE LEARNING**  
Collect valuable data and further improve our understanding about how to handle and operate hydrogen as a fuel

**06 THE POTENTIAL**  
Continue to explore hydrogen as one of the technological solutions for zero-carbon flight from the mid-2030s

**[2]** Harnessing the power of hydrogen to decarbonise aviation #RACETOZERO

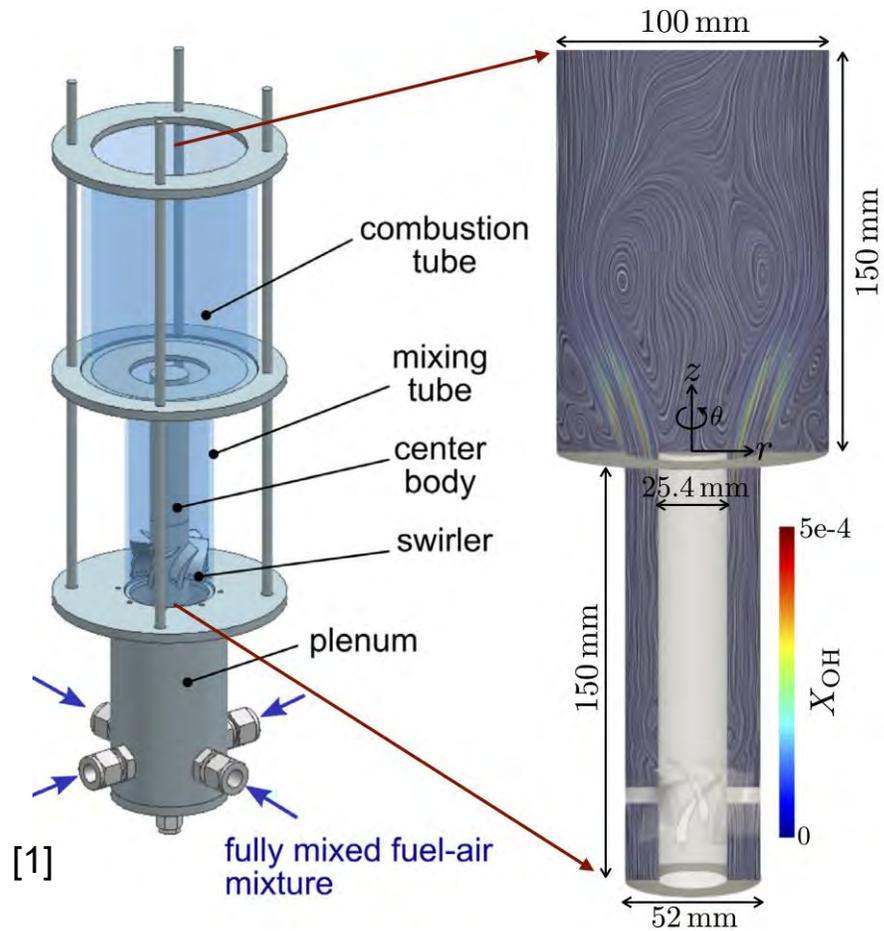
Launch of hydrogen-powered engines until 2035

[1] Airbus (2023), Press release [\[Link\]](#) (accessed: 21.06.2023).

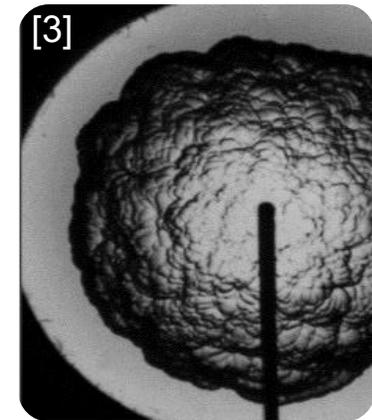
[2] Rolls-Royce plc. (2022), Press release [\[Link\]](#) (accessed: 21.06.2023)

# HYDROGEN COMBUSTION

## CHALLENGES



Boundary  
Layer  
Flashback



Thermo-  
Diffusive  
Instabilities

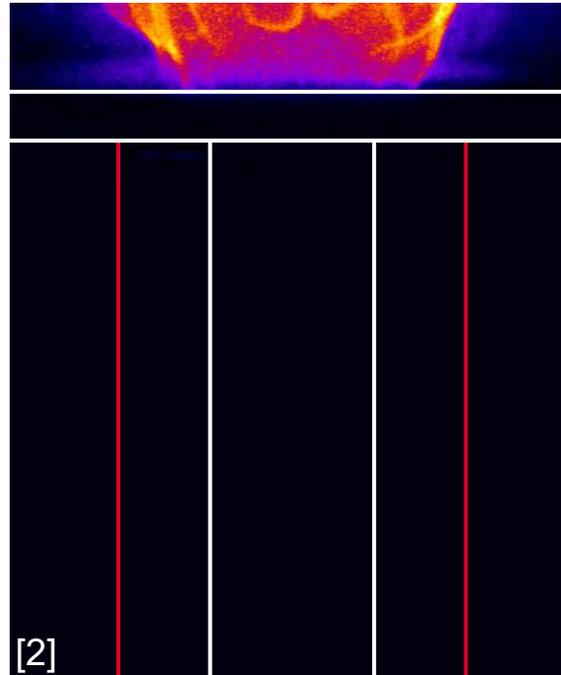
[1] ddd.  
[2] ddd  
[3] ddd

# HYDROGEN COMBUSTION

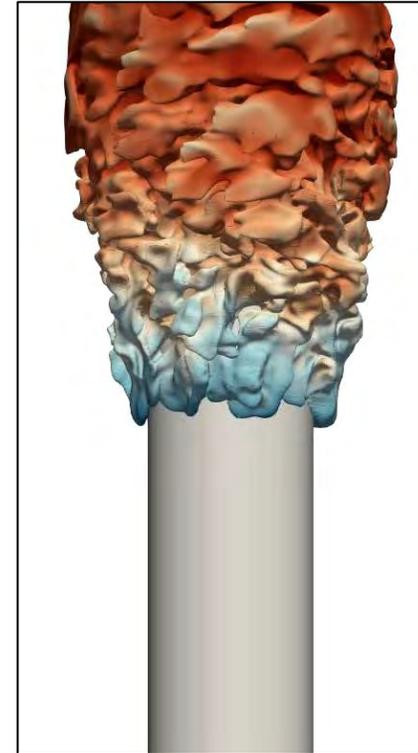
## BOUNDARY LAYER FLASHBACK



Experiment



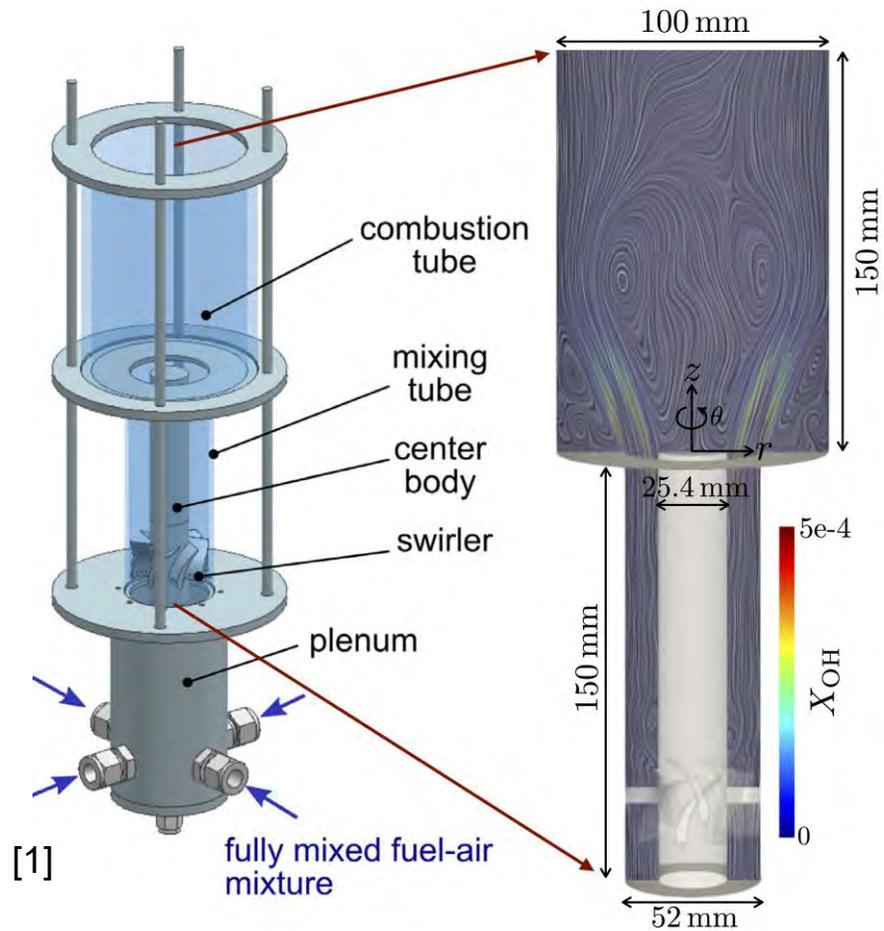
HPC Digital Twin



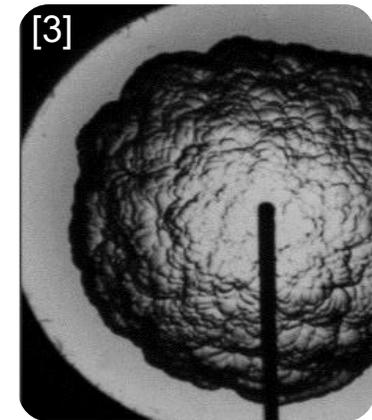
[1] ddd.  
[2] ddd

# HYDROGEN COMBUSTION

## CHALLENGES



Boundary  
Layer  
Flashback

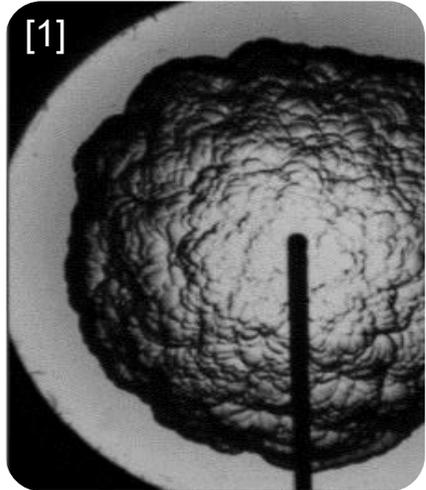


Thermo-  
Diffusive  
Instabilities

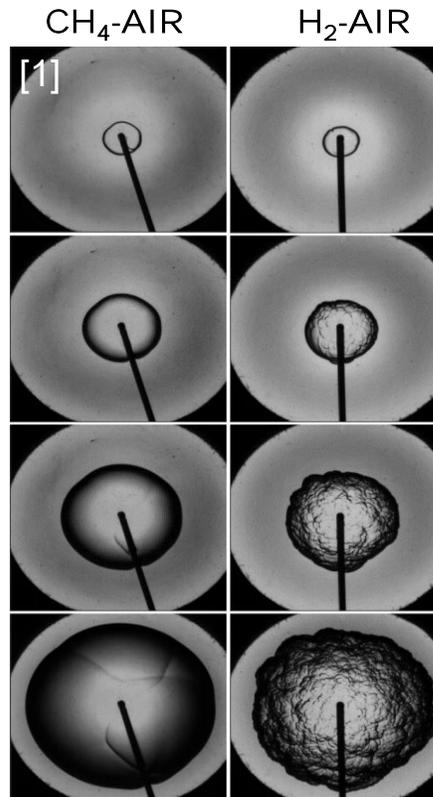
[1] ddd.  
[2] ddd  
[3] ddd

# HYDROGEN COMBUSTION

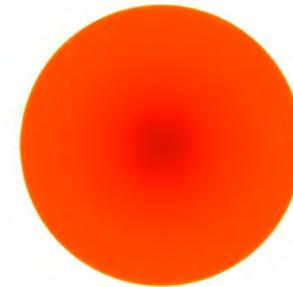
## THERMO-DIFFUSIVE INSTABILITIES



### Experiment



### HPC Digital Twin



[1] Beeckmann (2018), PhD Thesis, ITV, RWTH Aachen.

# ACKNOWLEDGEMENT

## THERMOACOUSTIC



## SOOT



## HYDROGEN

