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

TECHNISCHE UNIVERSITÄT DARMSTADT

CRC/TRR 150

Turbulent, chemically reactive, multi-phase flows near walls

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.

CRC/TRR 129

Oxyflame

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.

University Technology Centre

ROLLS ROYCE

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

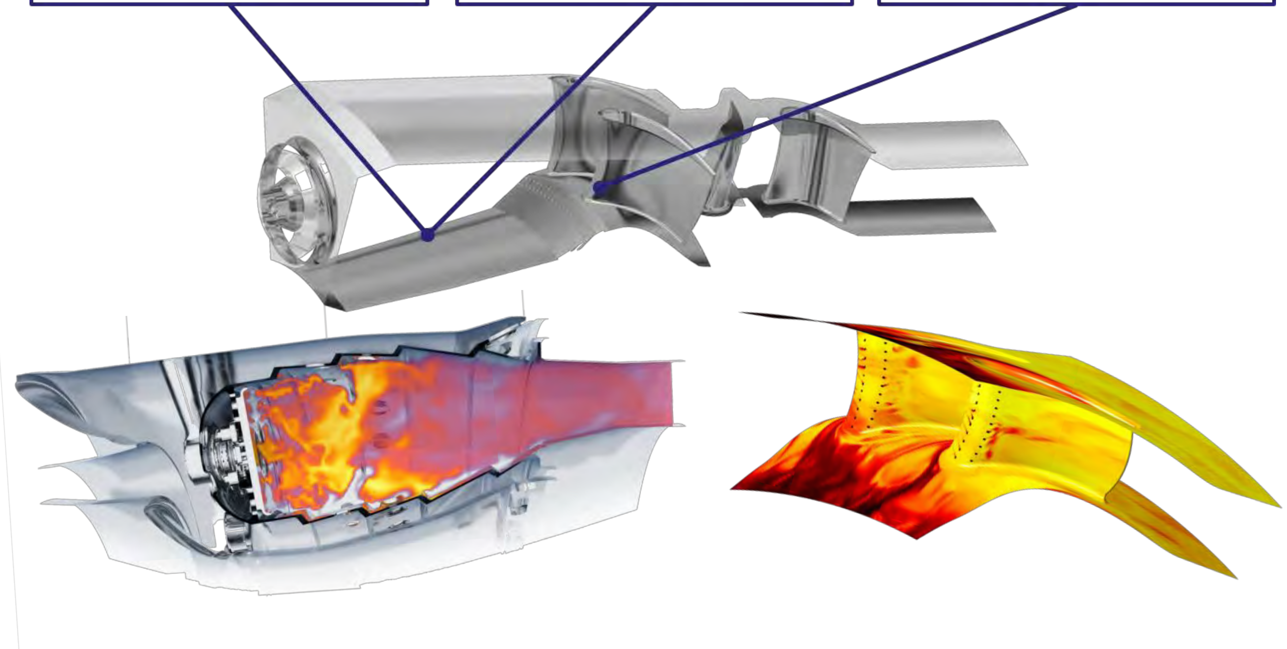
Measurement Technology for Application in Combustion Processes

STFS Simulation of reactive Thermo-Fluid Systems

Numerical Modelling of Combustion Processes

GLR

Impact of Combustion and Swirl on Turbine Aerodynamics and Cooling



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

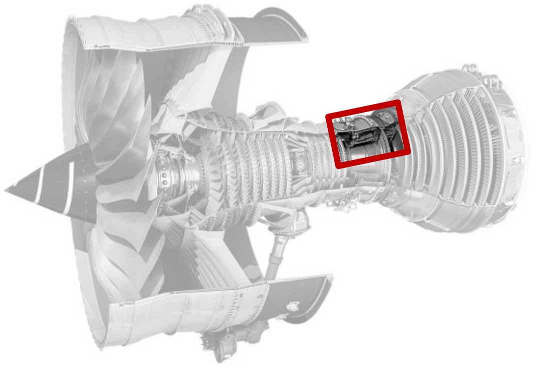
Check out the UTC

FROM COMPLEX TO SIMPLE

BUILDING A DIGITAL HPC TWIN

TECHNISCHE UNIVERSITÄT DARMSTADT

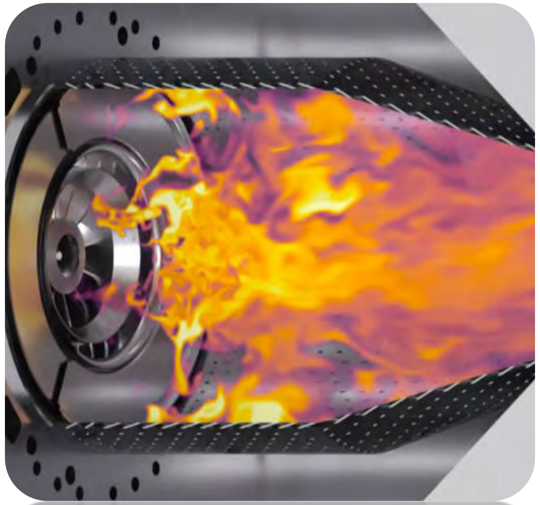
FULL-ENGINE CONFIGURATION



Global performance metric

Point measurements

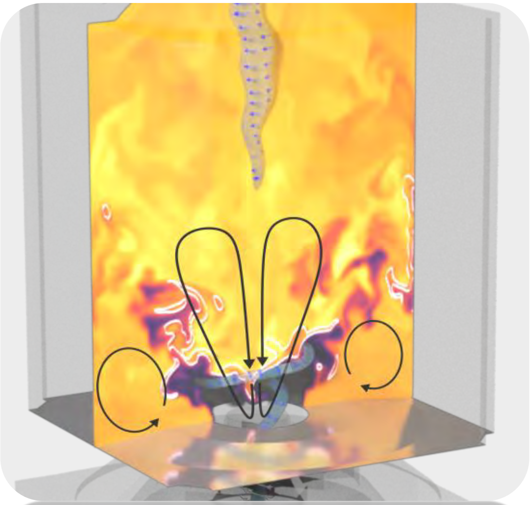
ENGINE-LIKE CONFIGURATION



Point measurements

Microphone probes

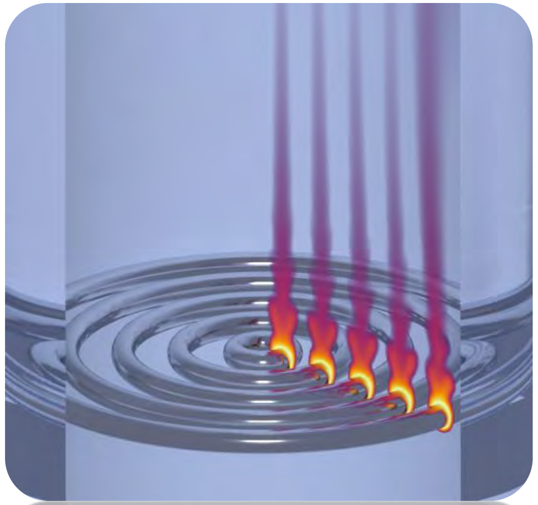
LAB-SCALE MODEL COMBUSTOR



Detailed laser measurements

Microphone probes

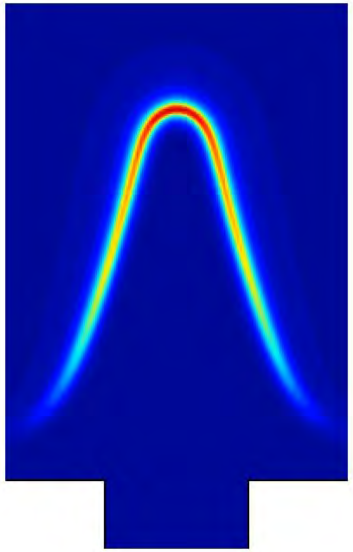
GENERIC ACADEMIC CONFIGURATION



Analytical models

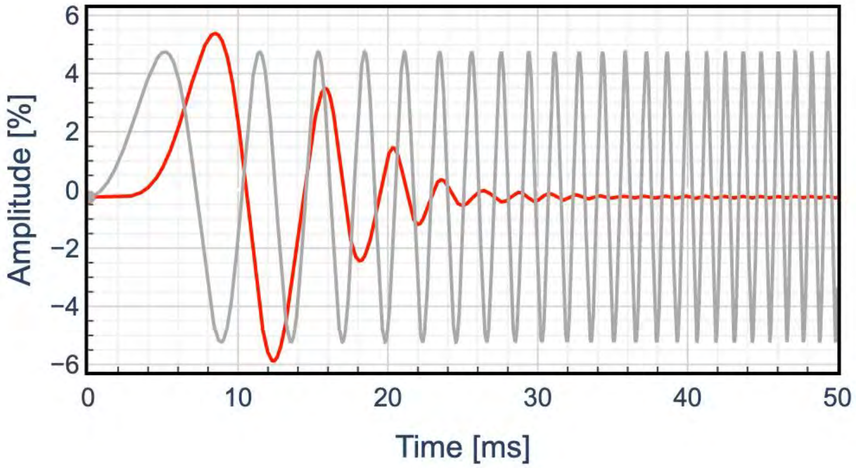
Two-dimensional modeling

THERMOACOUSTIC RESPONSE



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

$$\mathrm{FTF}(\omega) = \frac{\dot{Q}'/\overline{\dot{Q}}}{u'/\overline{u}}$$



GENERIC ACADEMIC CONFIGURATION

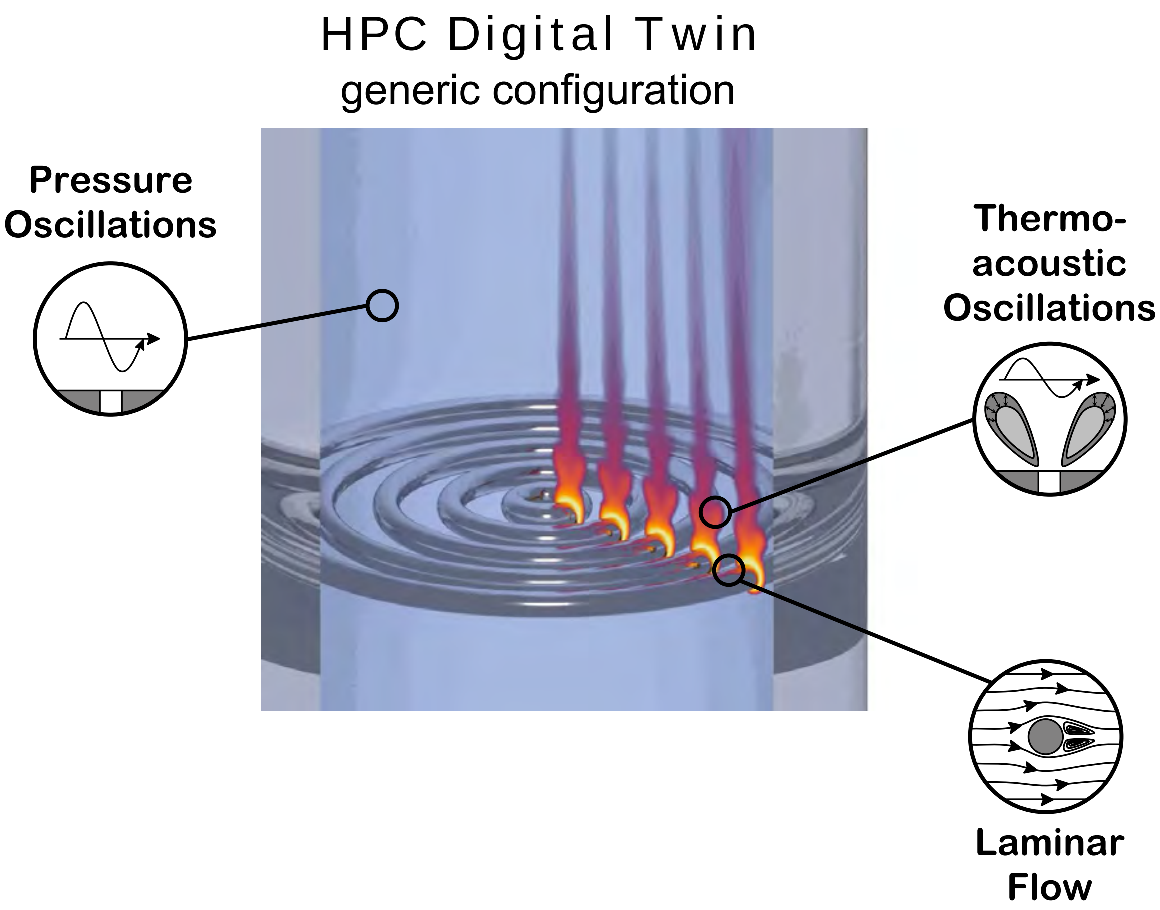
RIJKE TUBE

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

GENERIC ACADEMIC CONFIGURATION

RIJKE TUBE

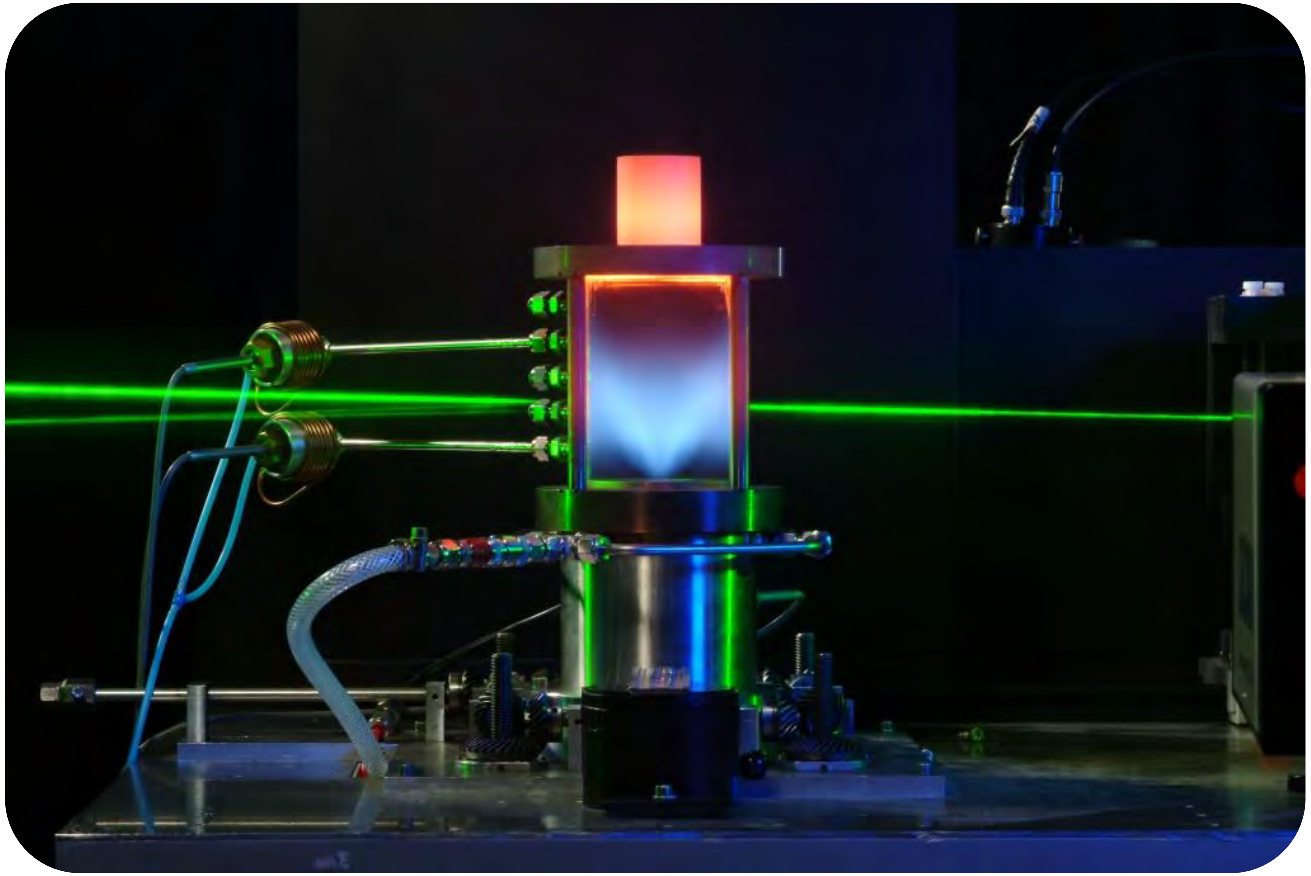
POSSIBLE MODE SHAPES[2]



[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]

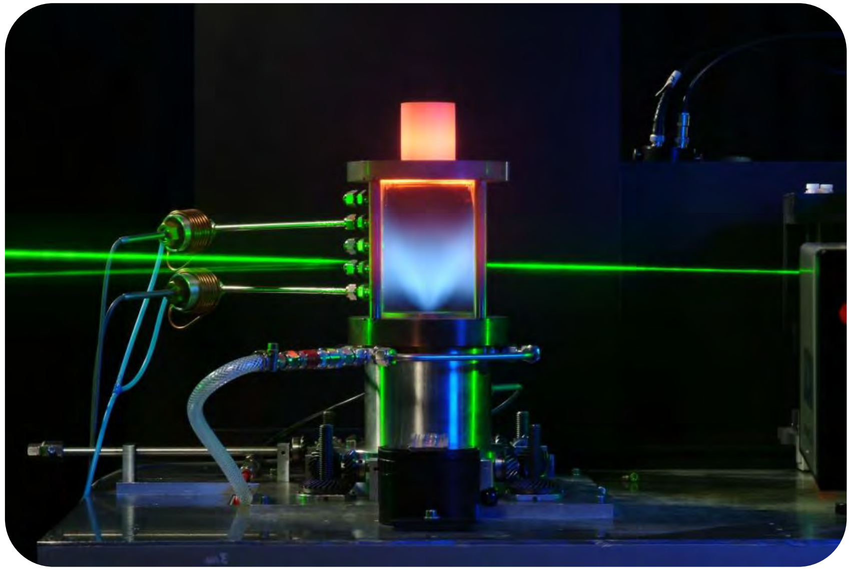
LAB-SCALE MODEL COMBUSTOR

SFB606 GAS TURBINE MODEL COMBUSTOR



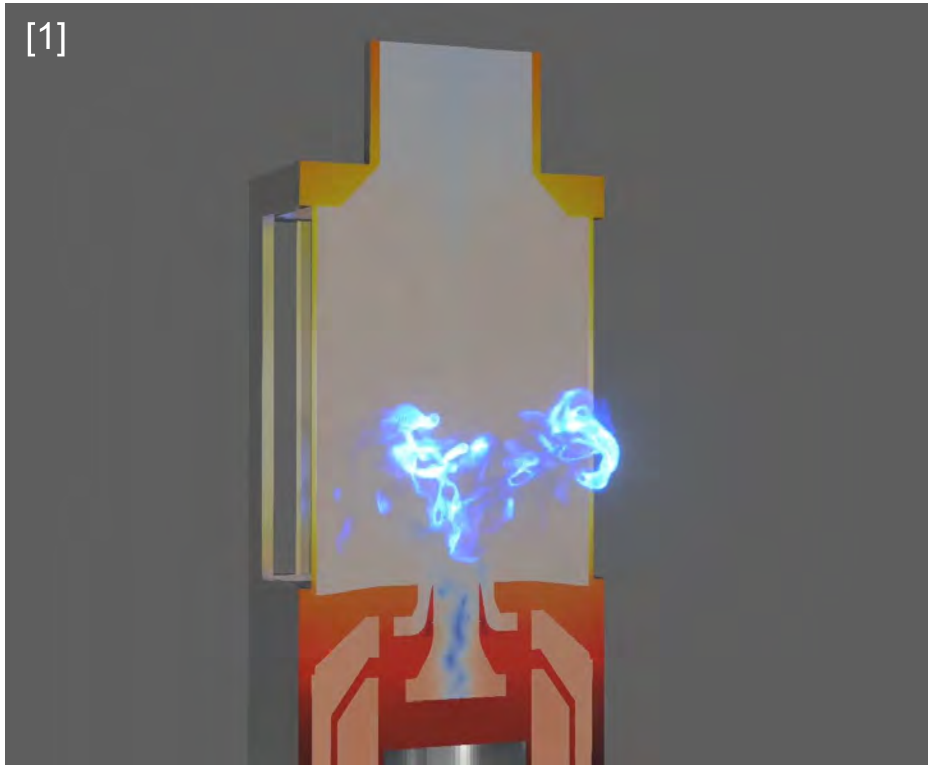
LAB-SCALE MODEL COMBUSTOR

SFB606 GAS TURBINE MODEL COMBUSTOR



Gas Turbine Model Combustor at DLR Stuttgart
© DLR

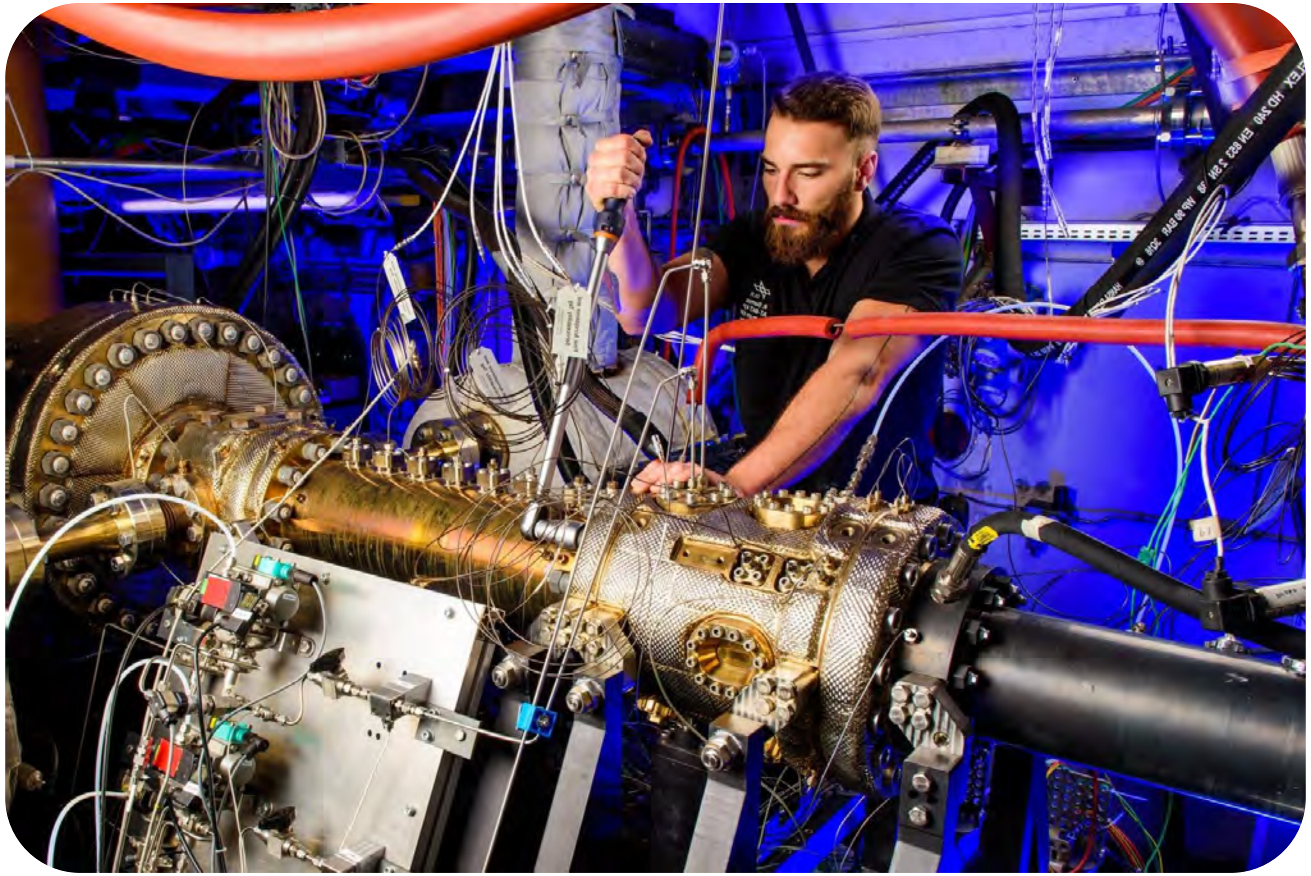
HPC Digital Twin
lab-scale, atmospheric burner



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

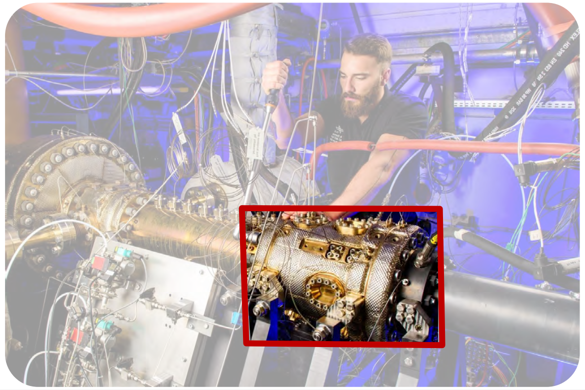
ENGINE-LIKE CONFIGURATION

SCARLET



ENGINE-LIKE CONFIGURATION

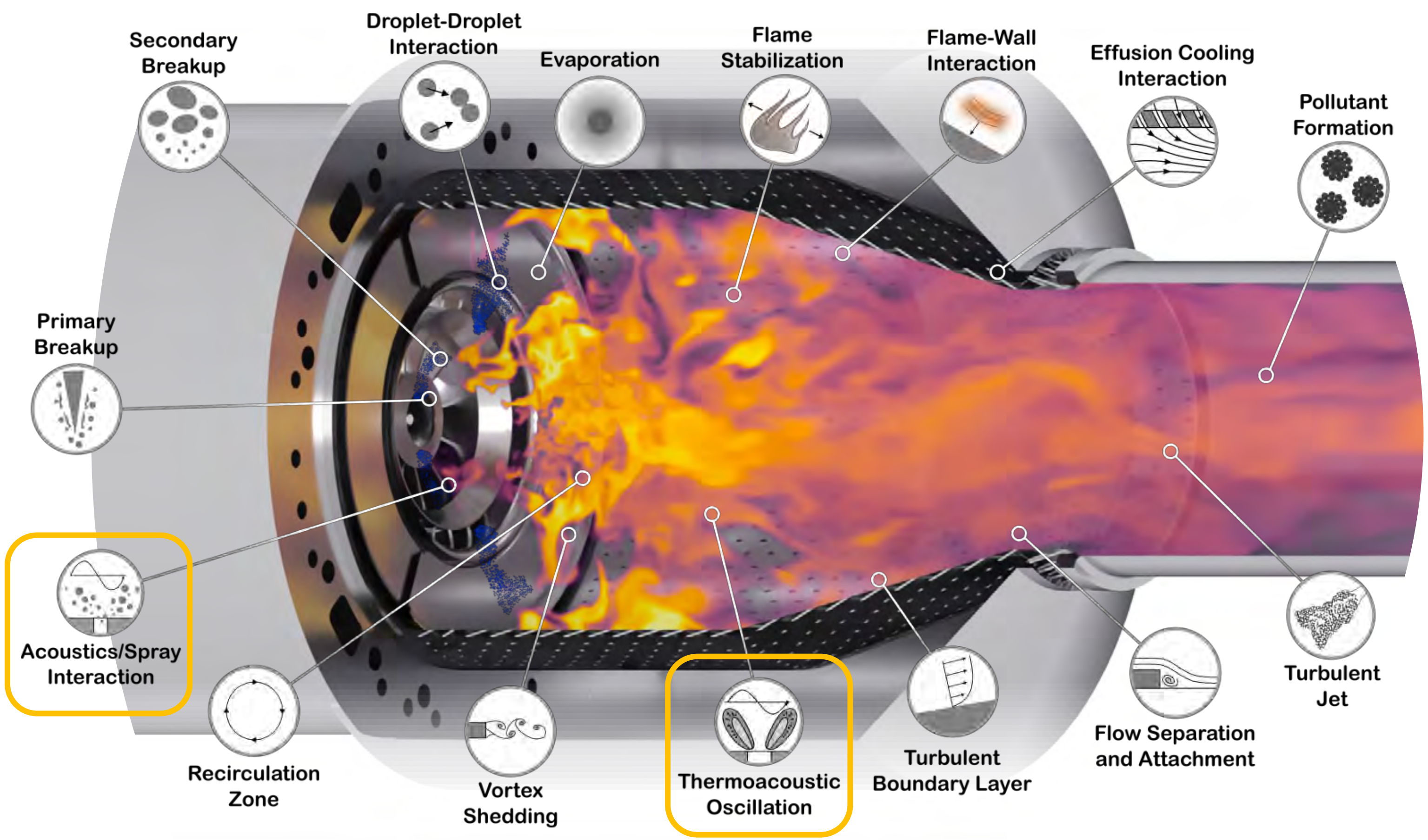
SCARLET



SCARLET test rig at DLR Cologne

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

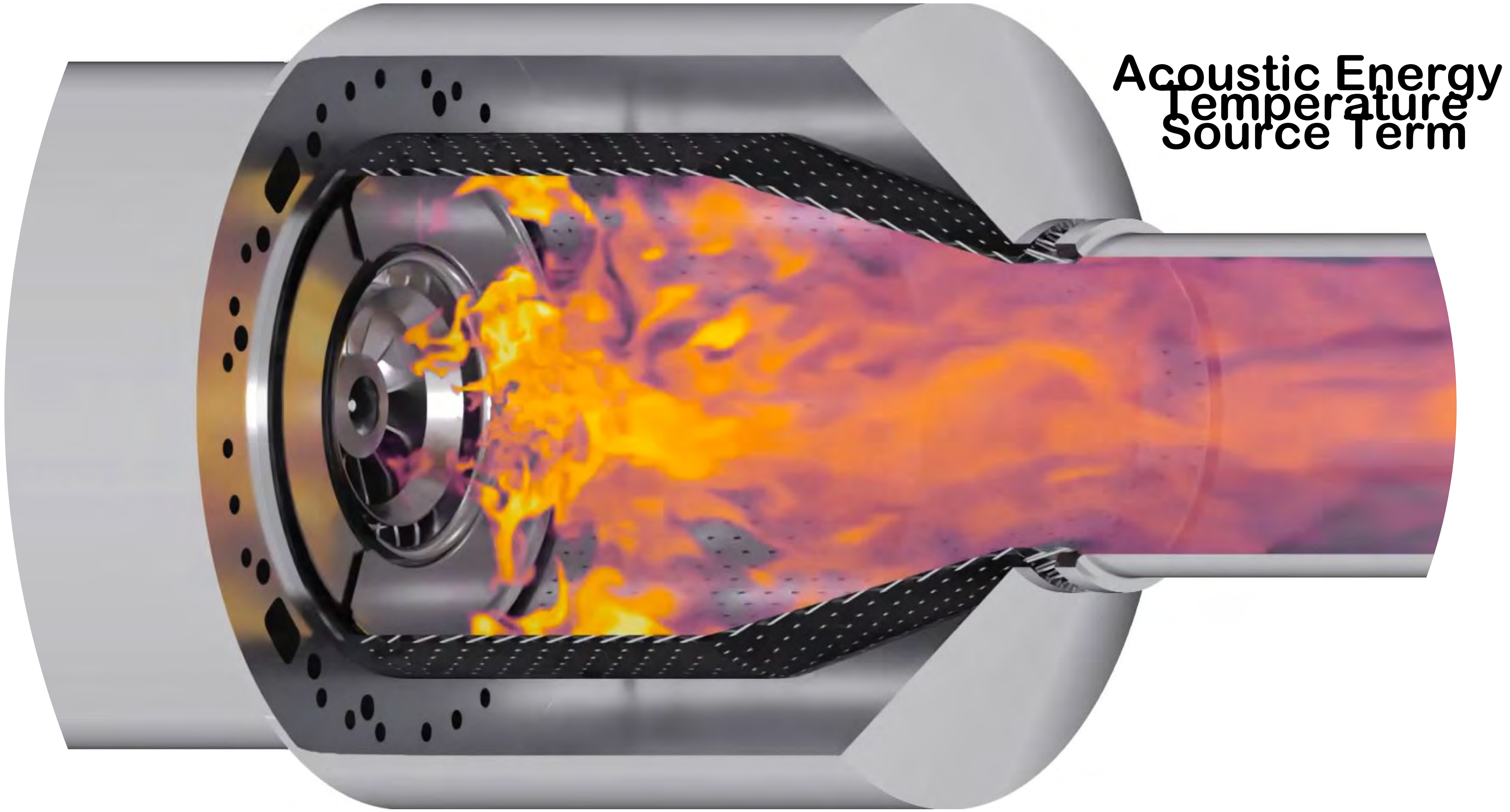
HPC Digital Twin
real injector, engine-like conditions



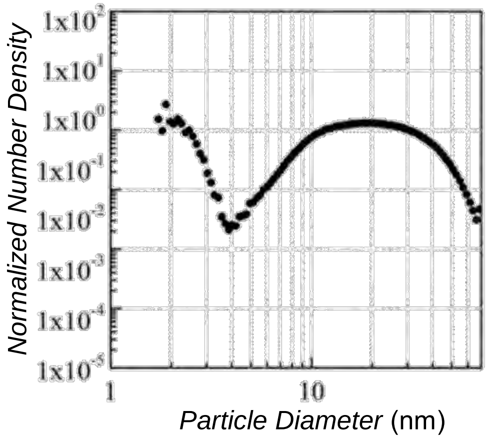
ENGINE-LIKE CONFIGURATION

SCARLET

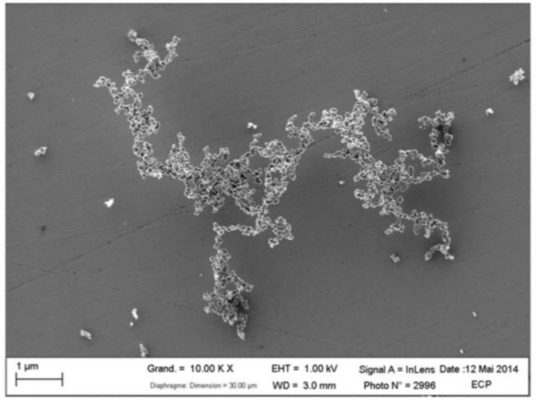
HPC Digital Twin
real injector, engine-like conditions



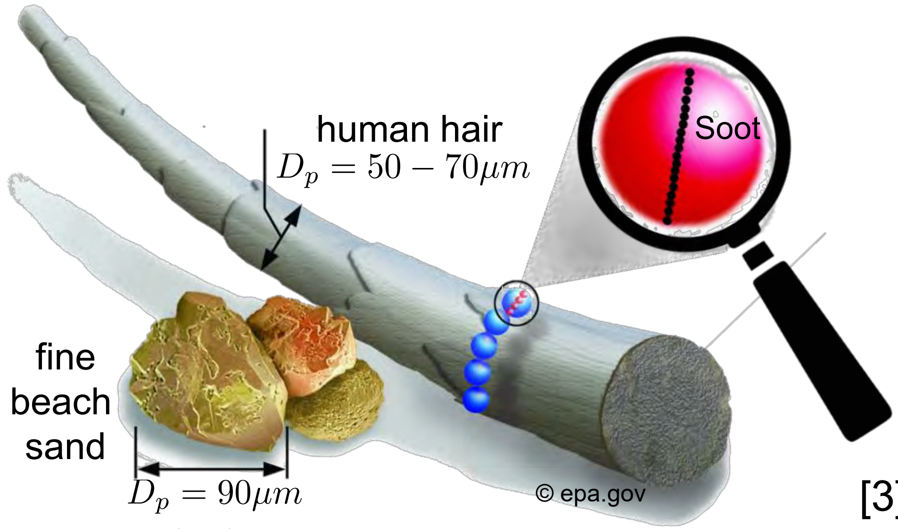
CHARACTERISTICS OF SOOT



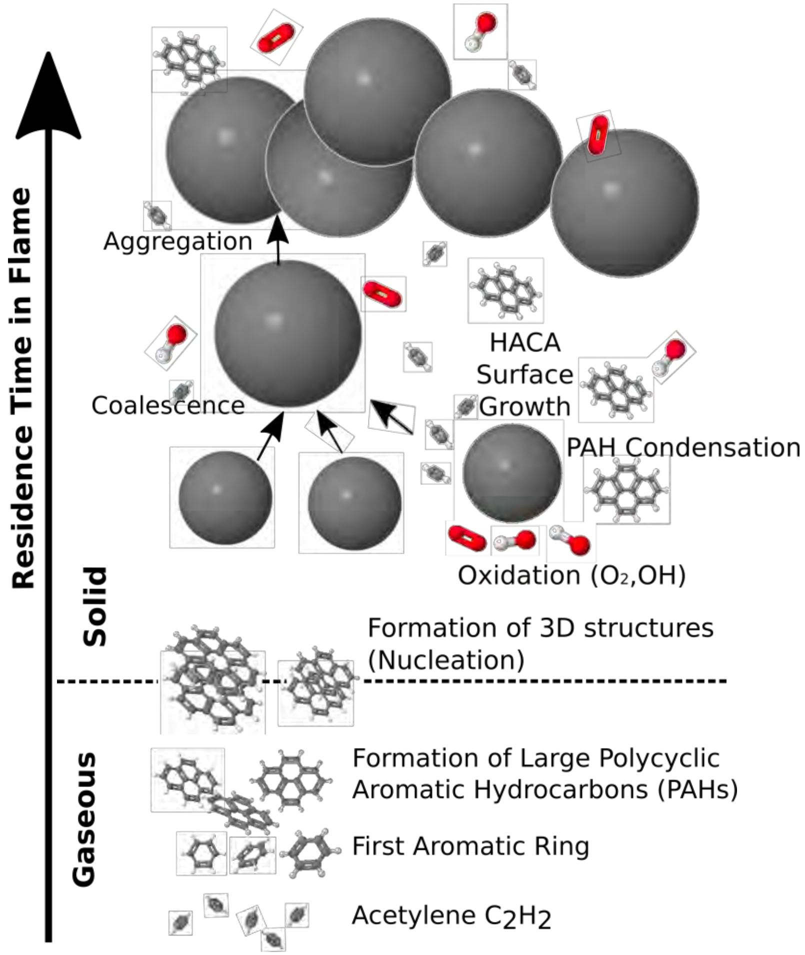
[1]



[2]



[3]

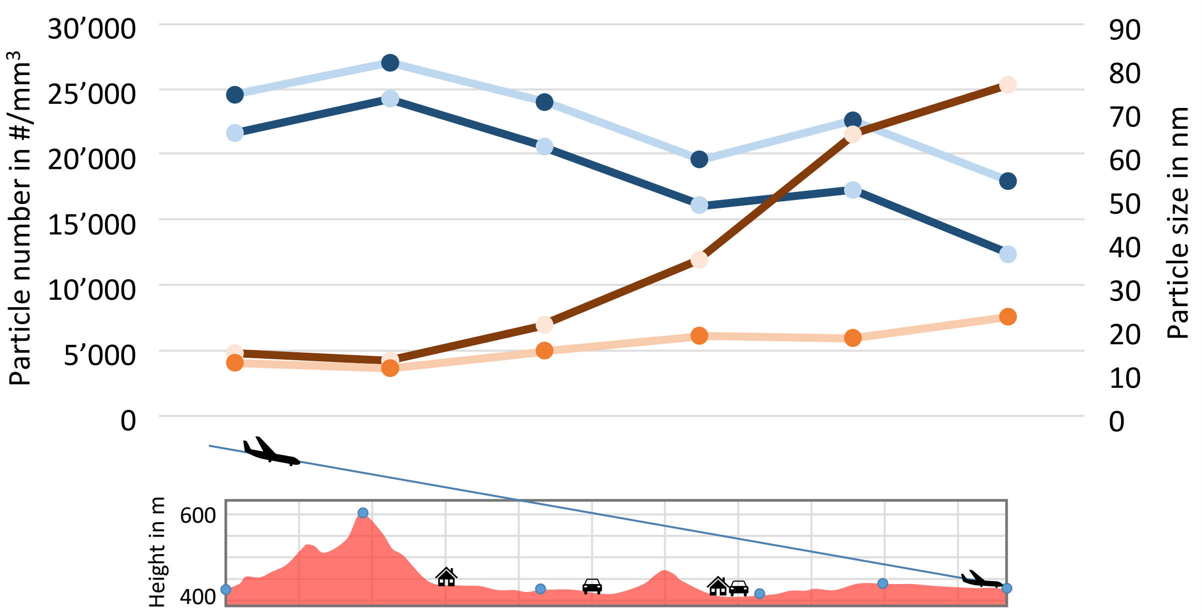


[1] Frenzel, et int., **Hasse** et al. (2013), *Proc. Europ. Combust. Meet.*
[2] Okyay (2016). PhD thesis. Cent. Univ. Paris-Saclay.
[3] adapted from https://www.ccacoalition.org/en/slcps/black-carbon

IMPORTANCE OF SOOT PREDICTION

TECHNISCHE UNIVERSITÄT DARMSTADT

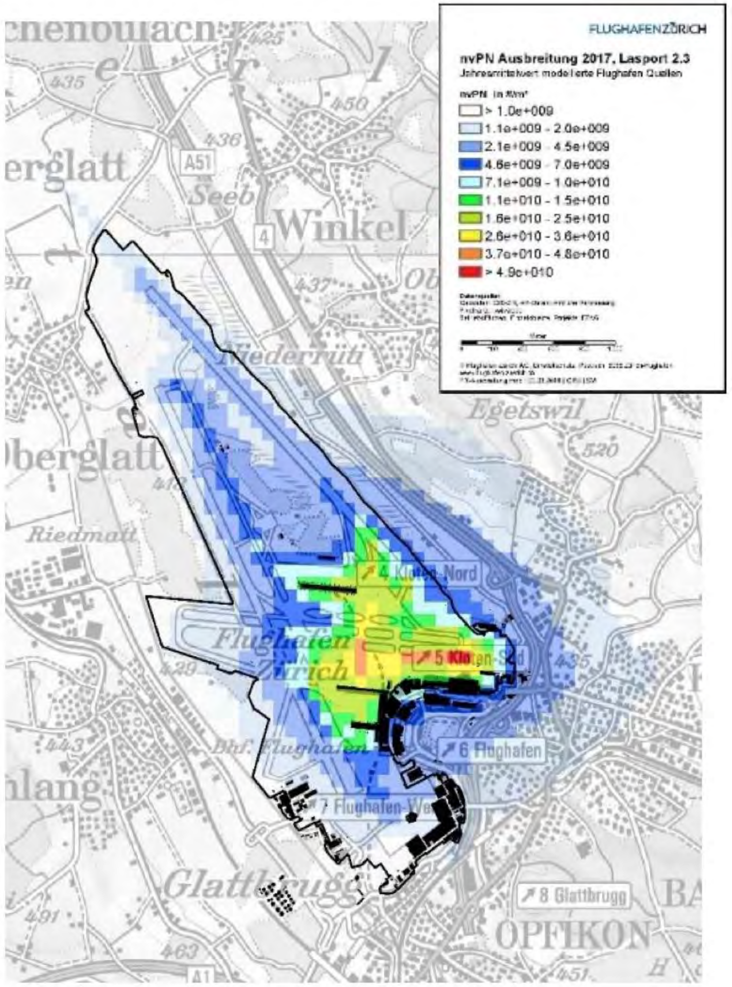
EXAMPLE nvPM EMISSIONS AT ZURICH AIRPORT



HAGL	530 m	260 m	370 m	220 m	110 m	0 m
Distance	10.3 km	8.6 km	6.1 km	3.4 km	1.8 km	0 km

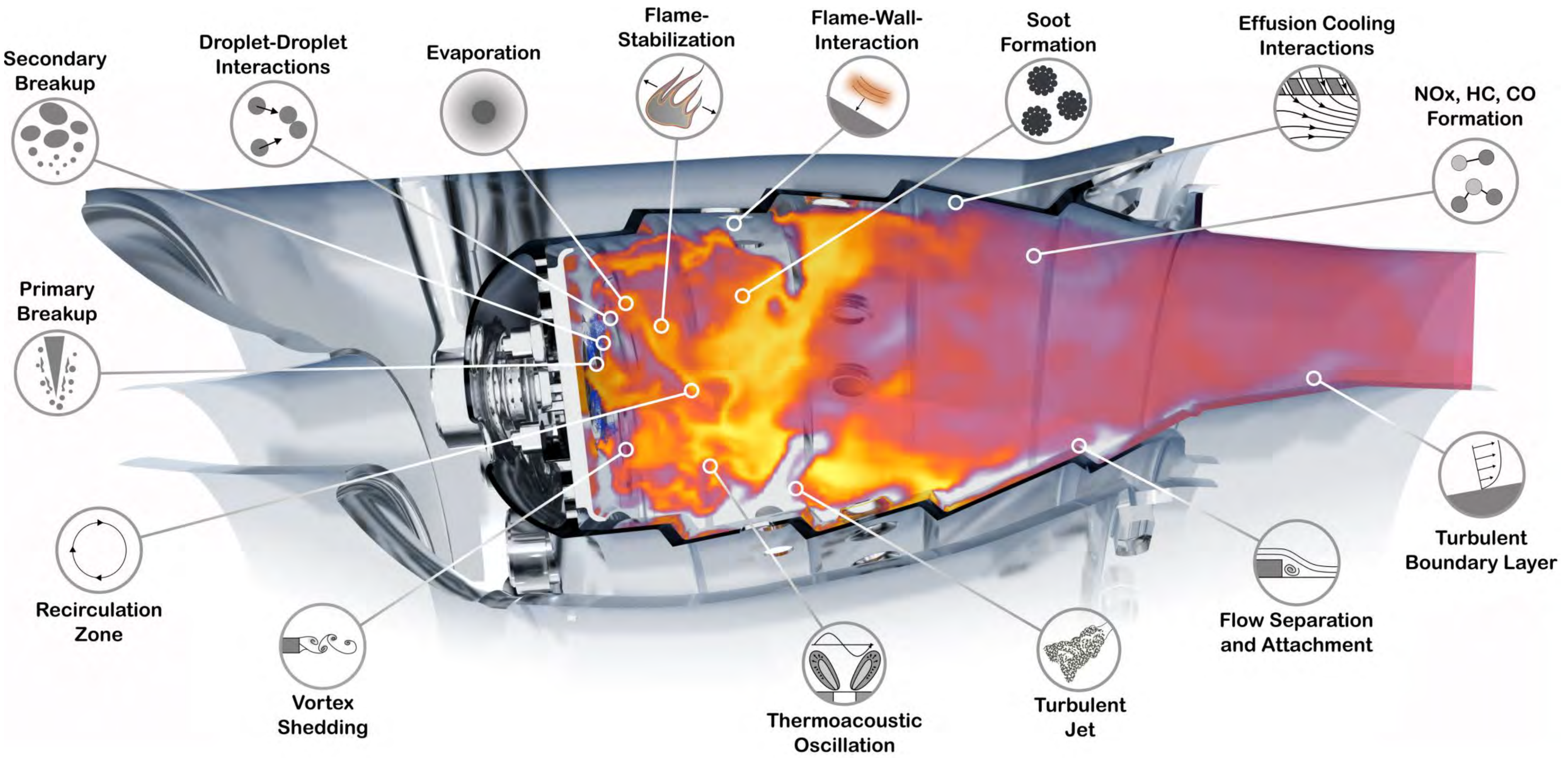
Particle number 07.00 – 21.00 | Particle number 00.00 – 05.00

Particle diameter 07.00 – 21.00 | Particle diameter 00.00 – 05.00



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

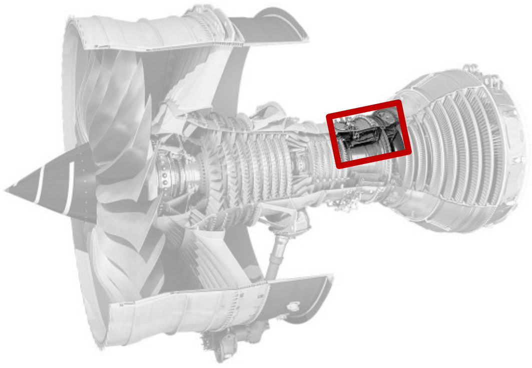
AERO-ENGINE COMBUSTION



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

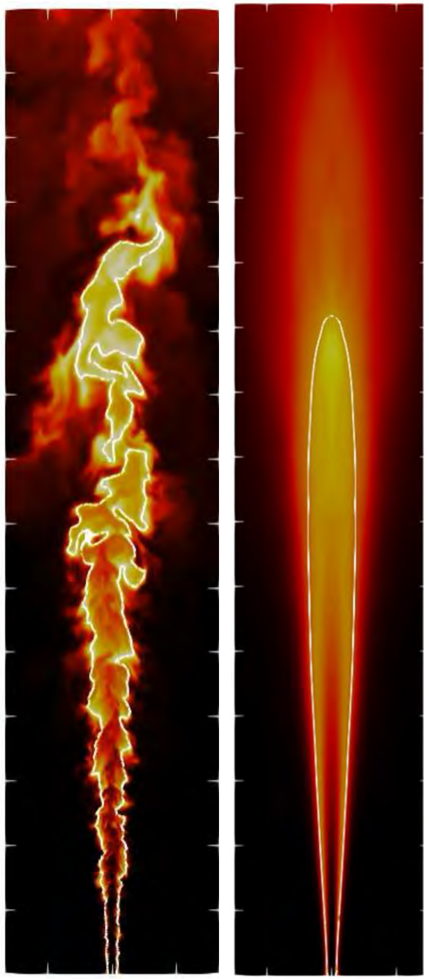
Analytical models

Low-dimensional modeling

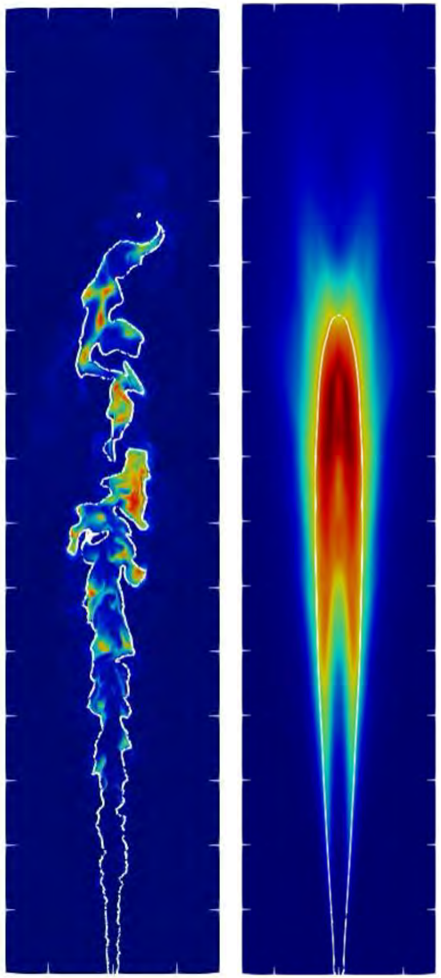
DELFT ADELAIDE FLAME III

TECHNISCHE UNIVERSITÄT DARMSTADT

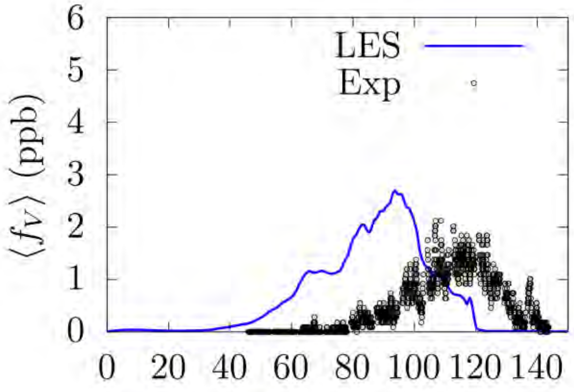
[1]

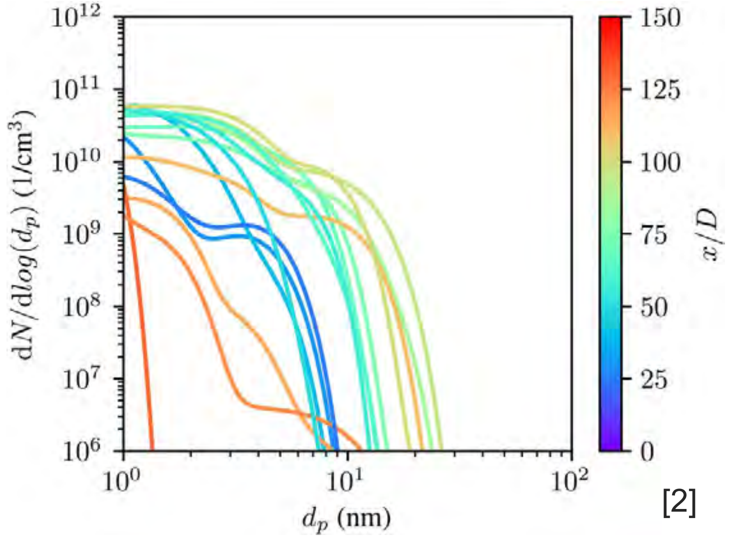


Temperature



Soot number density

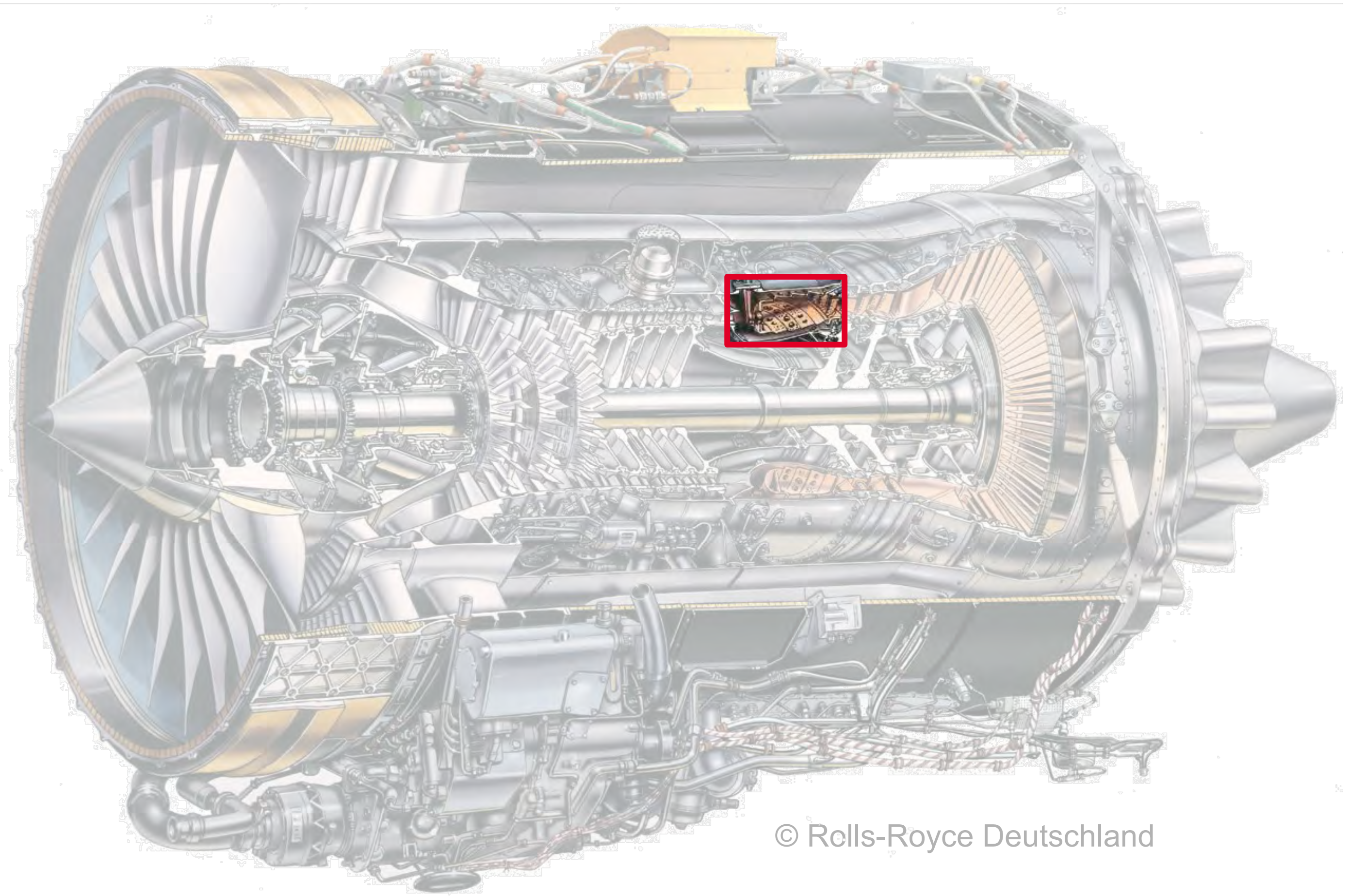




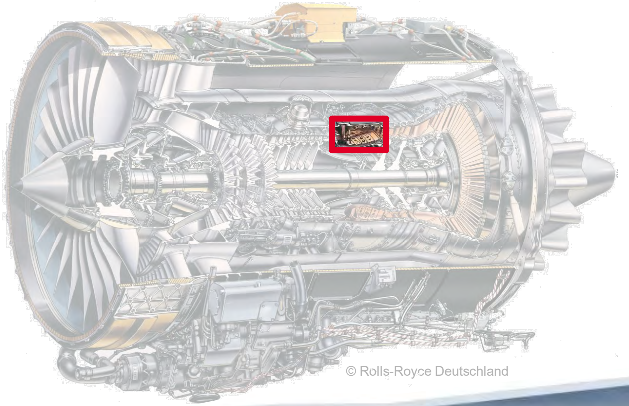
[2]

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

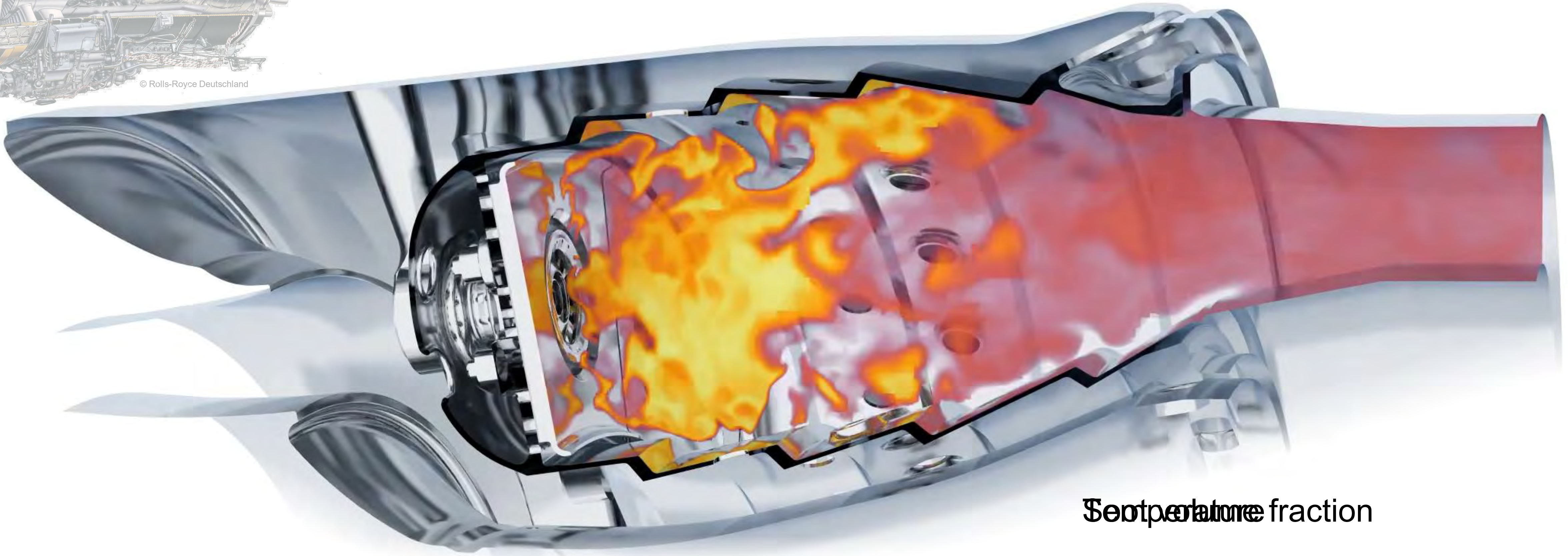
BR710 AERO-ENGINE COMBUSTOR



BR710 AERO-ENGINE COMBUSTOR



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

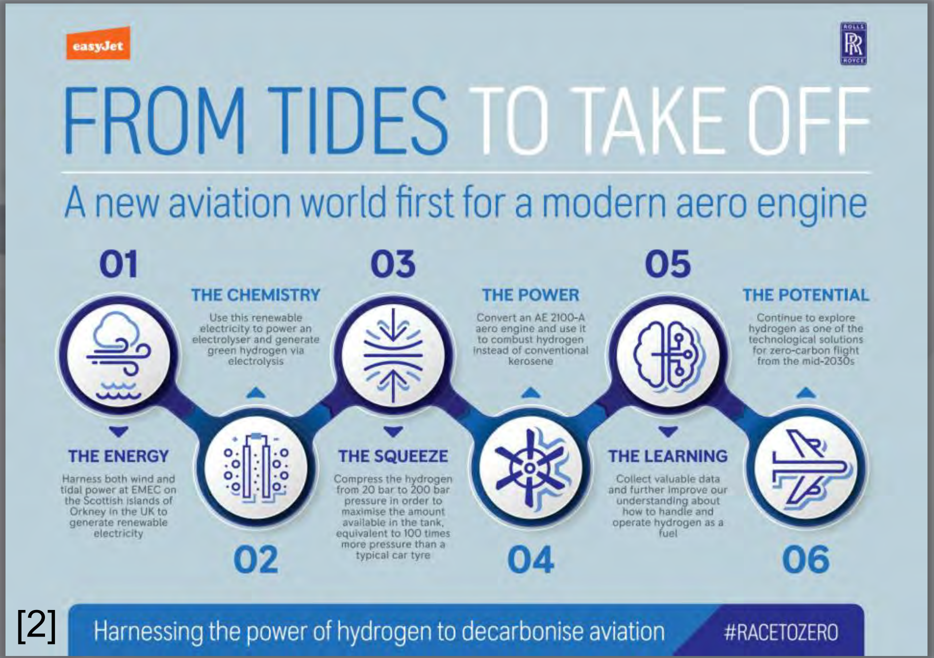


HYDROGEN COMBUSTION

BUILDING A DIGITAL HPC TWIN

[1]

[1]



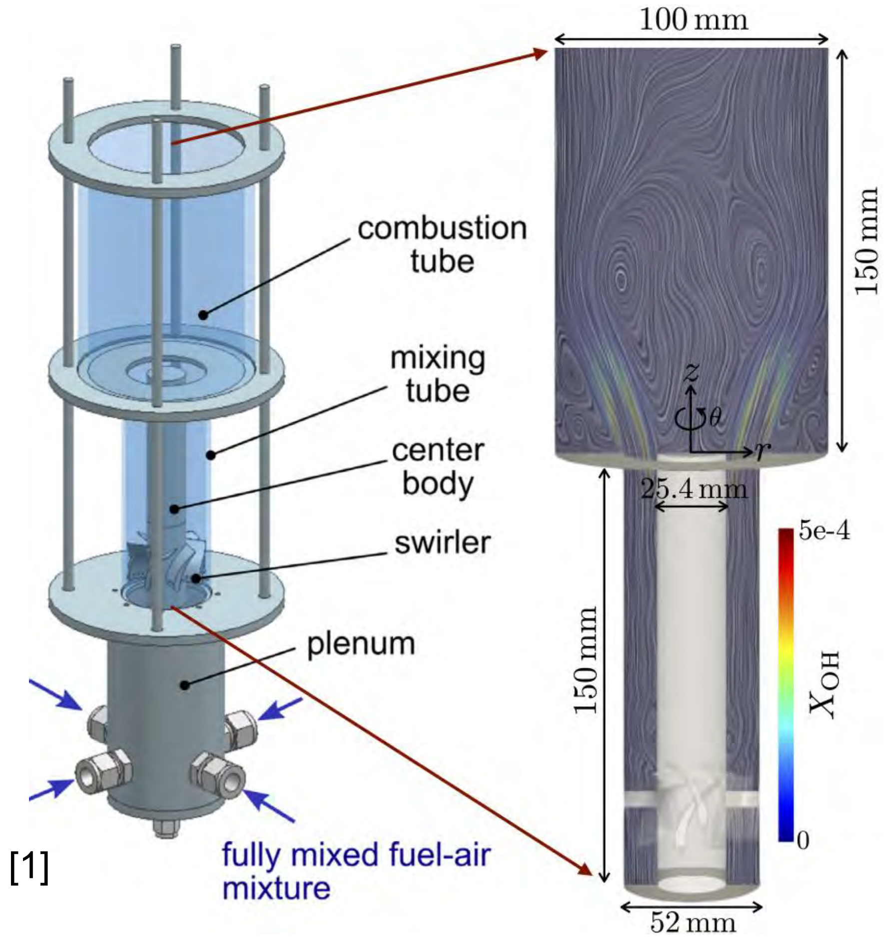
[2]

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)

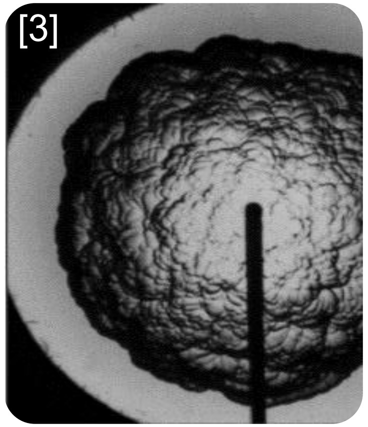
HYDROGEN COMBUSTION

CHALLENGES



Boundary Layer Flashback

Thermo-Diffusive Instabilities

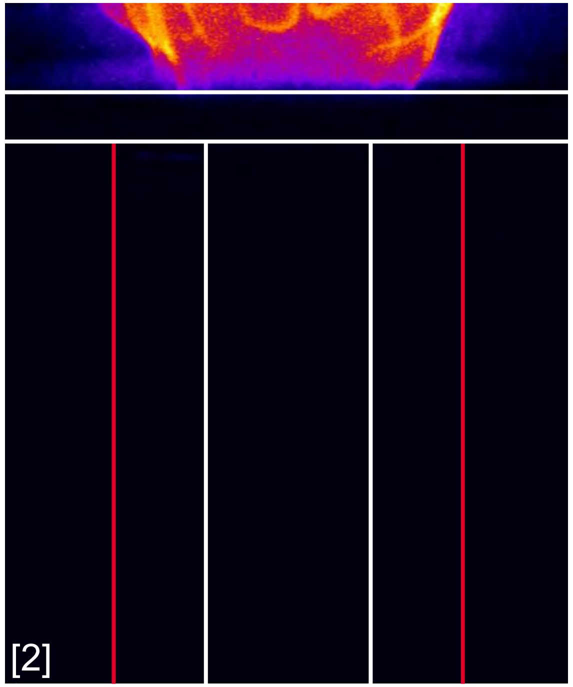


[1] ddd.
[2] ddd
[3] ddd

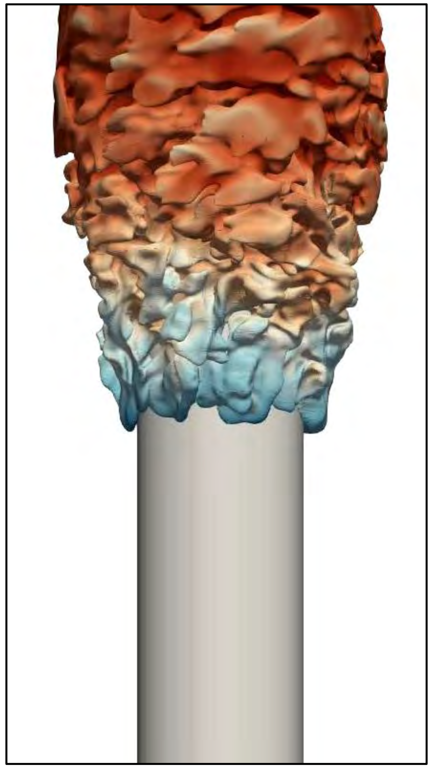
HYDROGEN COMBUSTION

BOUNDARY LAYER FLASHBACK

Experiment



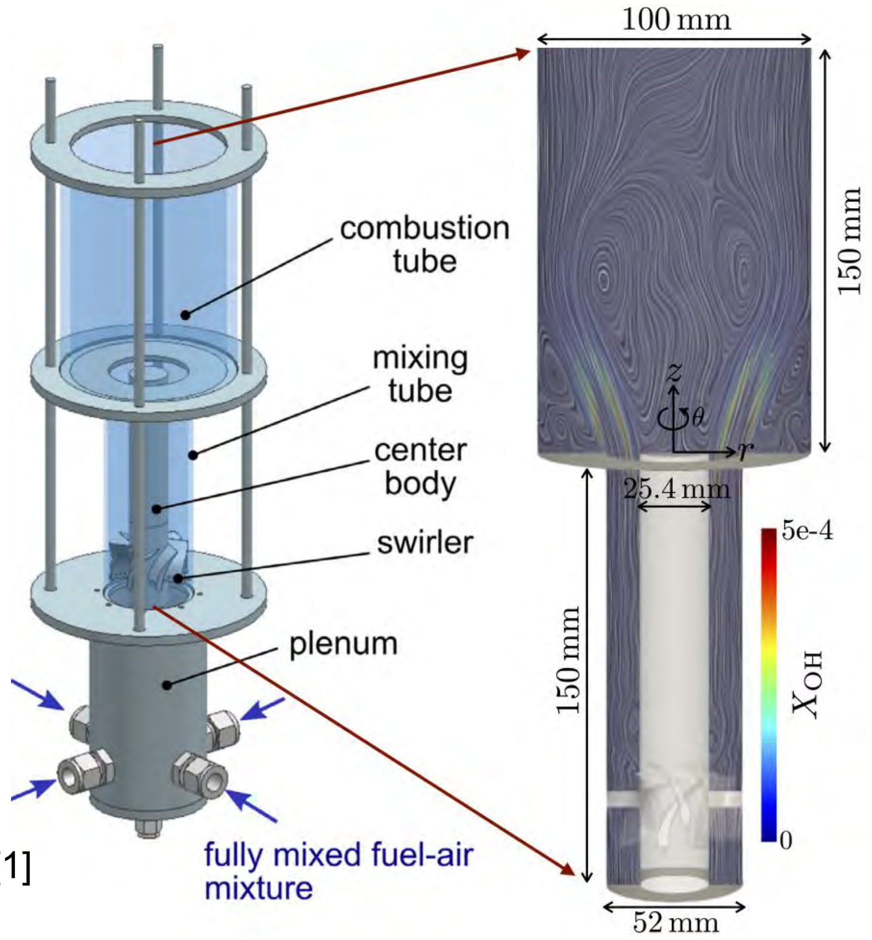
HPC Digital Twin



[1] ddd.
[2] ddd

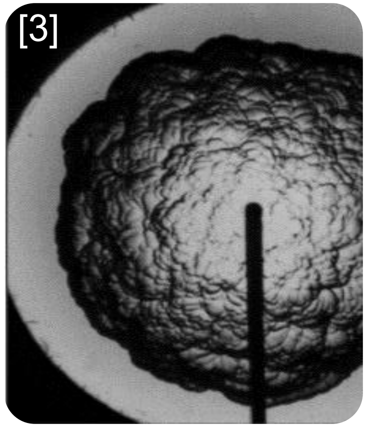
HYDROGEN COMBUSTION

CHALLENGES



[1]

Boundary Layer Flashback

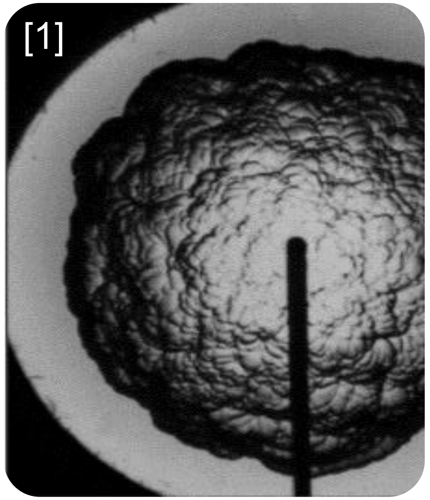


Thermo-Diffusive Instabilities

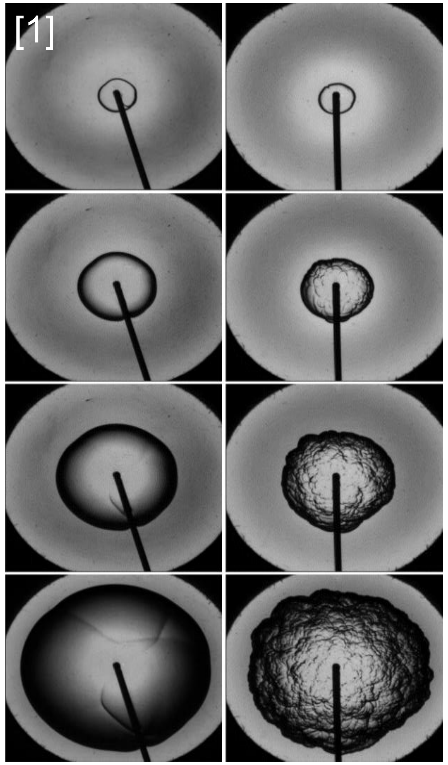
[1] ddd.
[2] ddd
[3] ddd

HYDROGEN COMBUSTION

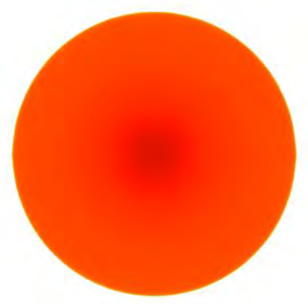
THERMO-DIFFUSIVE INSTABILITIES



Experiment



HPC Digital Twin



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

ACKNOWLEDGEMENT

THERMOACOUSTIC

SOOT

HYDROGEN