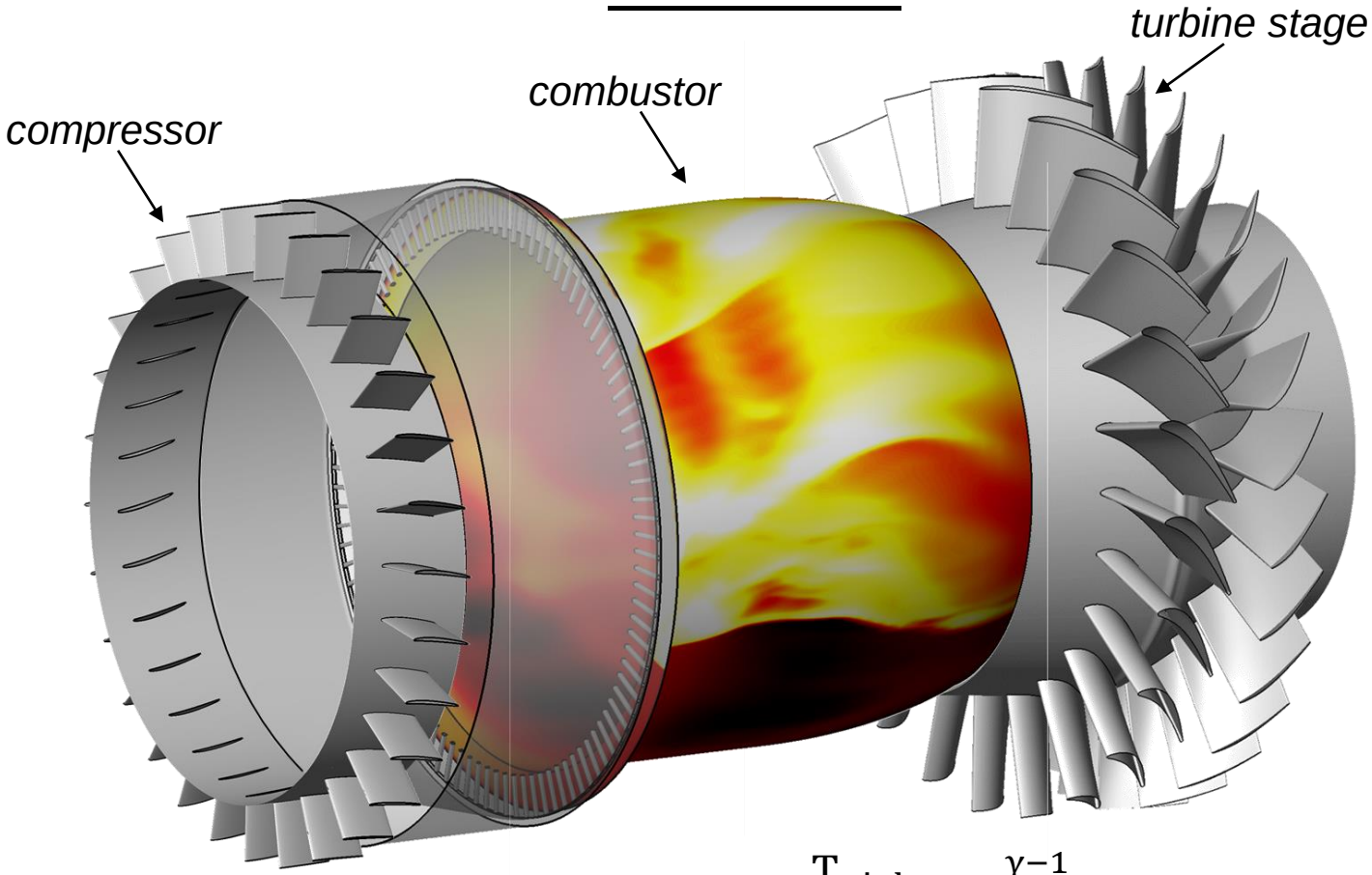
AERO-THERMAL CHARACTERIZATION OF ACCELERATING AND DIFFUSING PASSAGES DOWNSTREAM OF ROTATING DETONATION COMBUSTORS

James Braun, Guillermo Paniagua,
Purdue University, USA

Don Ferguson,
NETL

ASME Turbo Expo 2021

Motivation



compressor power ~ $\dot{m}c_p \frac{T_{0,inlet}}{\eta_c}(\Pi^{\frac{\gamma-1}{\gamma}} - 1)$

Compressor power reduction as a function of diffuser total pressure drop	**0%**	**20%**	**30%**
Π=~9	21%	~11%	~4%
Π=~7	24%	~16 %	~8%

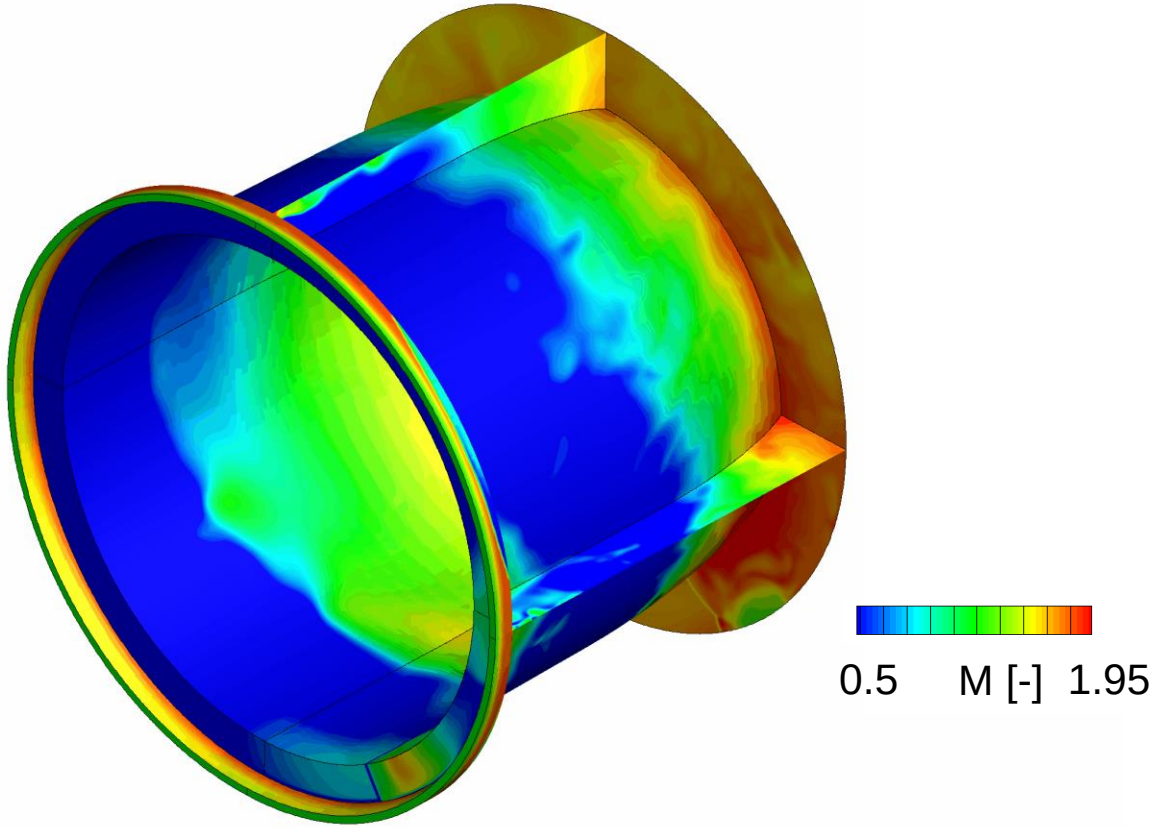
Liu Z., Braun J., Paniagua G., Thermal Power Plant Upgrade via a Rotating Detonation Combustor and Retrofitted Turbine with Optimized Endwalls, International Journal of Mechanical Sciences, 2020

Objective

1. Assess the fluctuations (i), heat load (ii) and losses (iii) occurring within the coupled combustor and downstream passage.

2. Analyze the influence of the downstream passage (accelerating or diffusing) on the combustor performance and isolated downstream passage losses

3. determine a strategy to investigate diffusers at a reduced computational cost for future optimization of diffusing elements



Outline

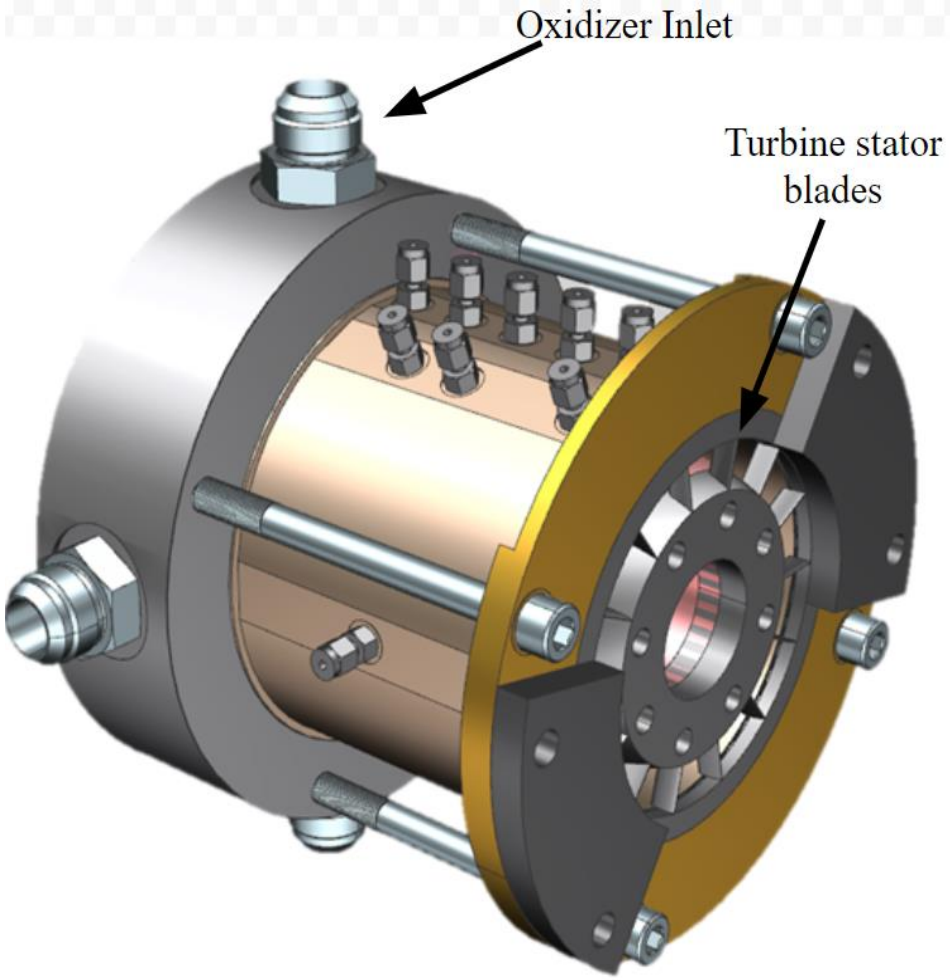
Methodology (solver description & validation)

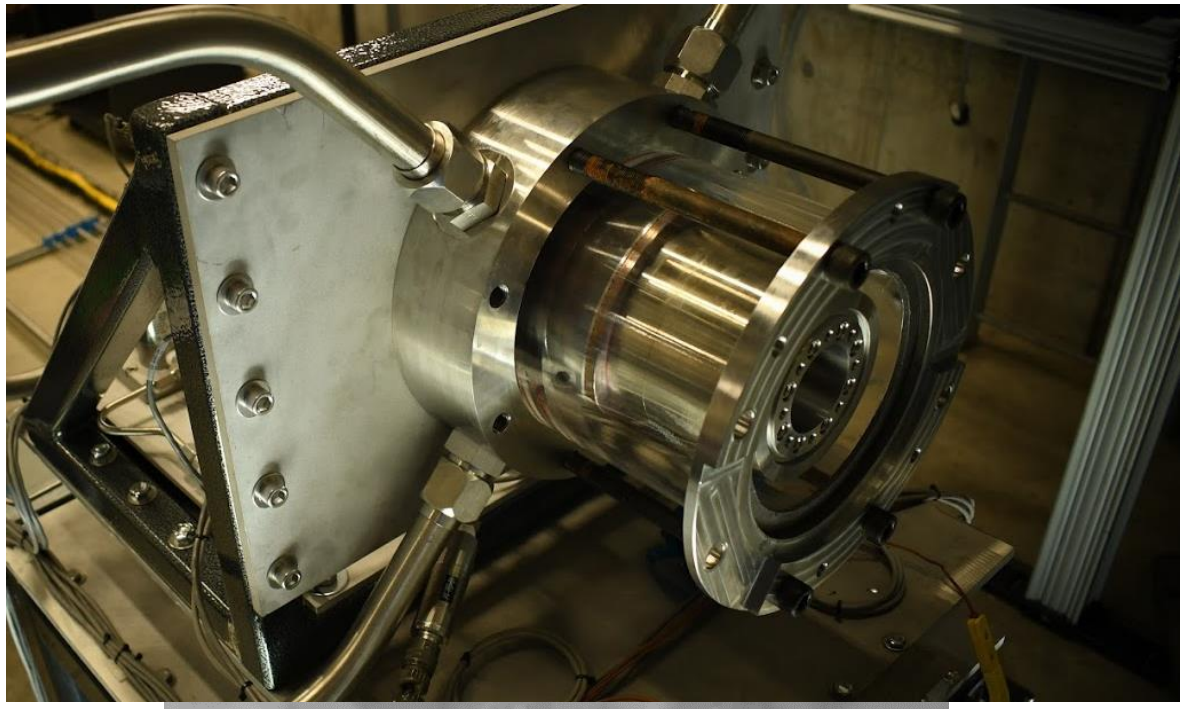
3D unsteady analysis of the outlet profiles

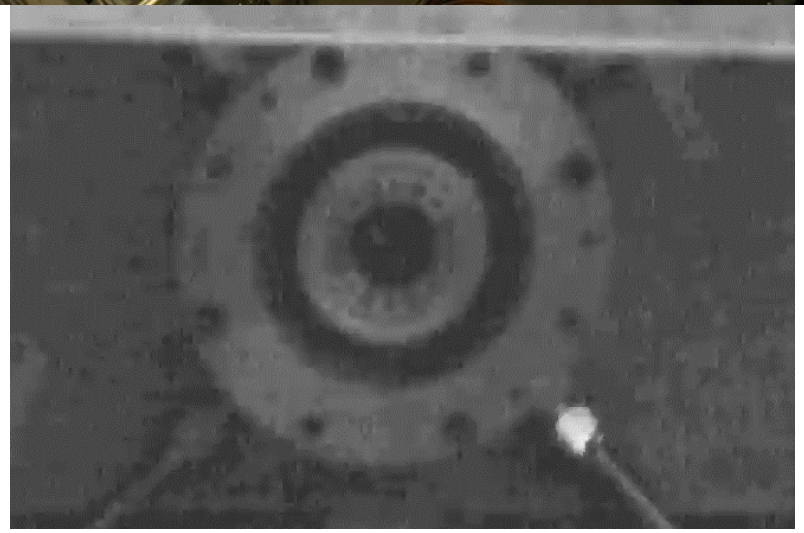
Aerodynamic performance of the passage

Simulation of the isolated diffusing passage

Turbine Integrated High Pressure RDC (Purdue)

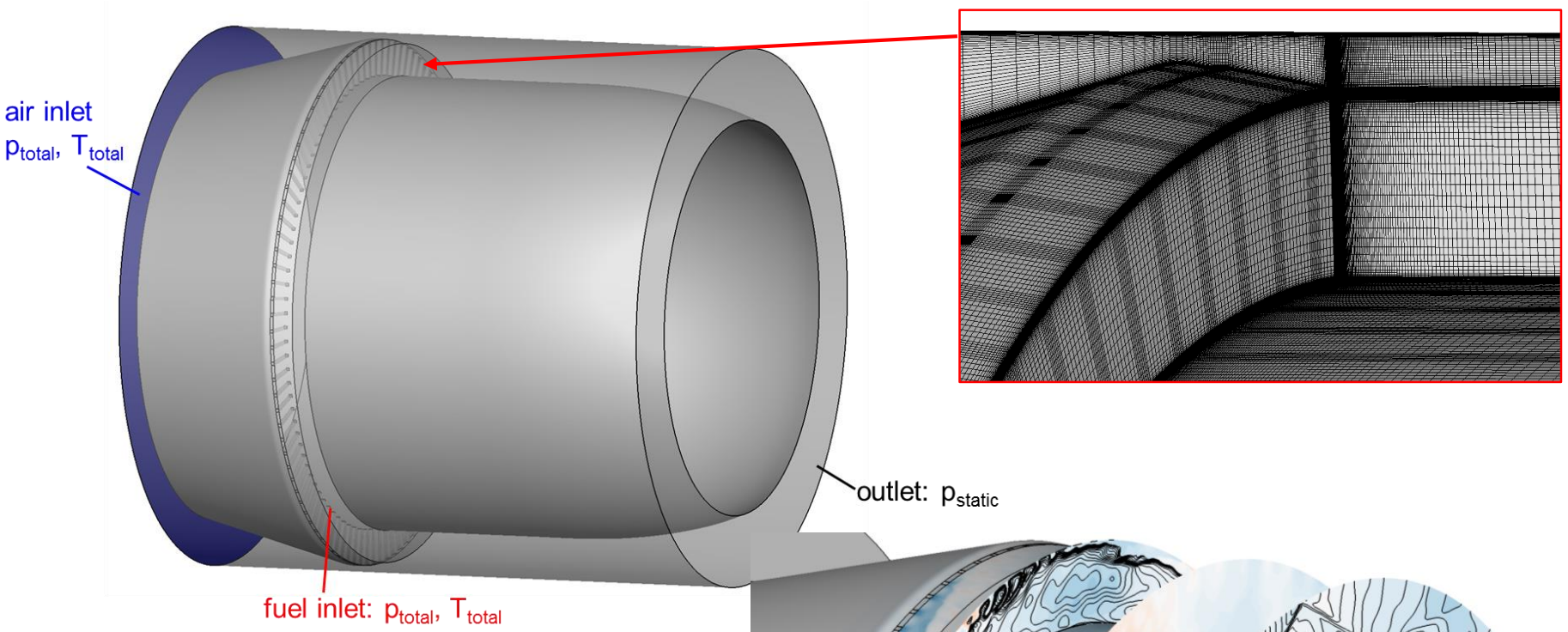




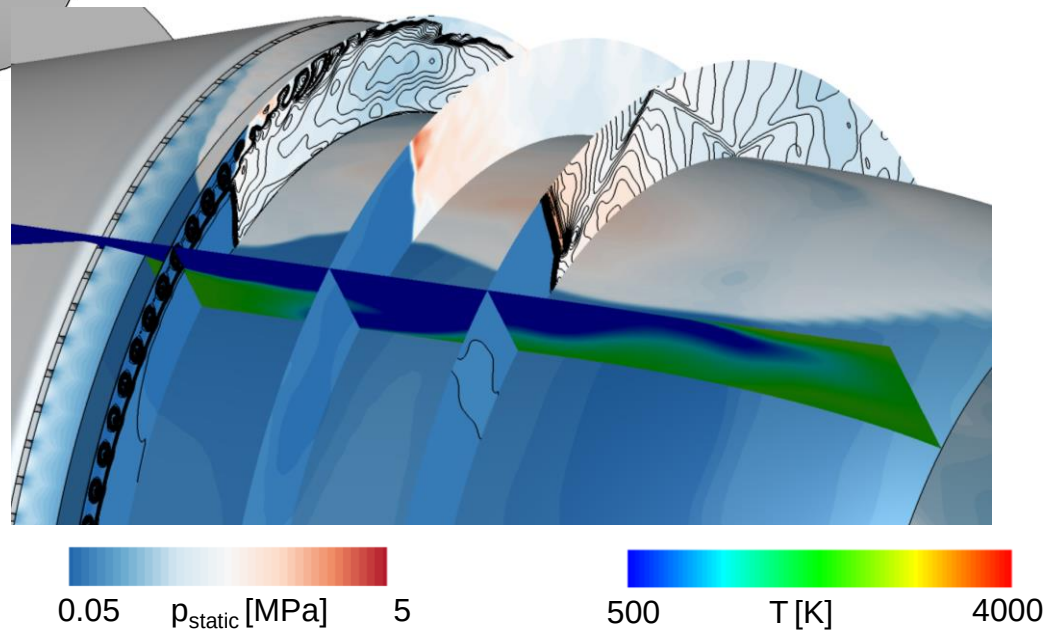


Athmanathan V., Braun J., Ayers Z., Fisher J.M., Ayers Z., Fugger C., Roy S., Paniagua G., Meyer T., Detonation structure evolution in an optically-accessible non-premixed H2-Air RDC using MHz rate imaging, AIAA Propulsion and Energy Forum

Modeling of the RDC



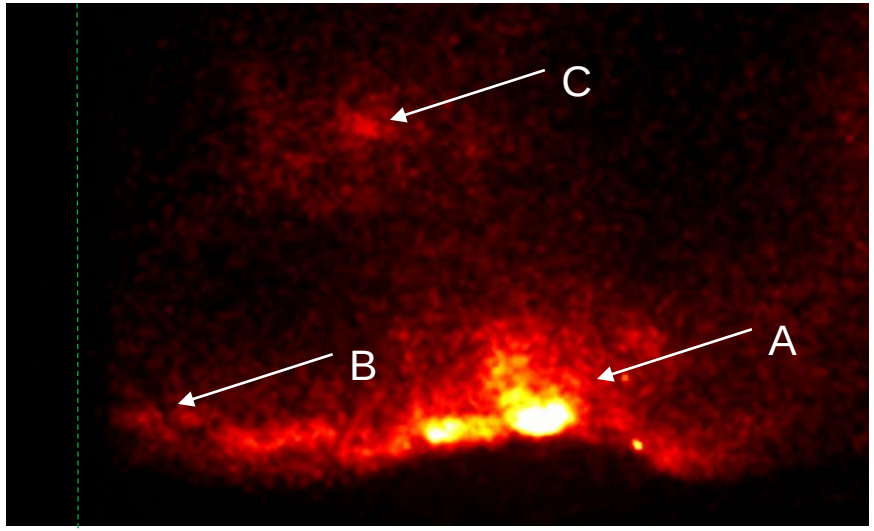
CFD++ (Metacomp) as flow solver
Unsteady Reynolds Averaged Navier-Stokes
Mesh ~ 40 million structured grid
Y+, max ~ 1
One-step reaction mechanism (H_2-air)
Ensure periodicity & convergence



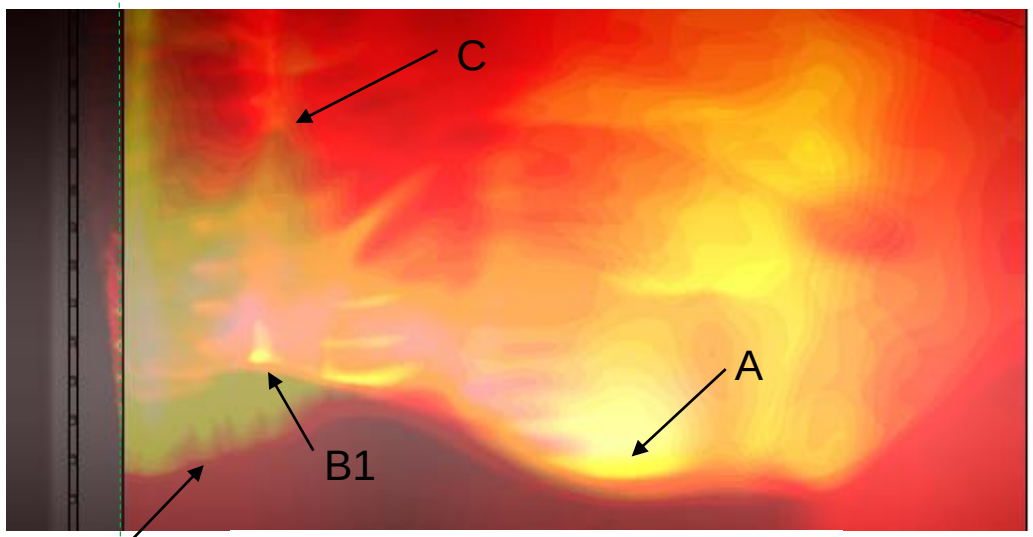
CFD vs Experiment

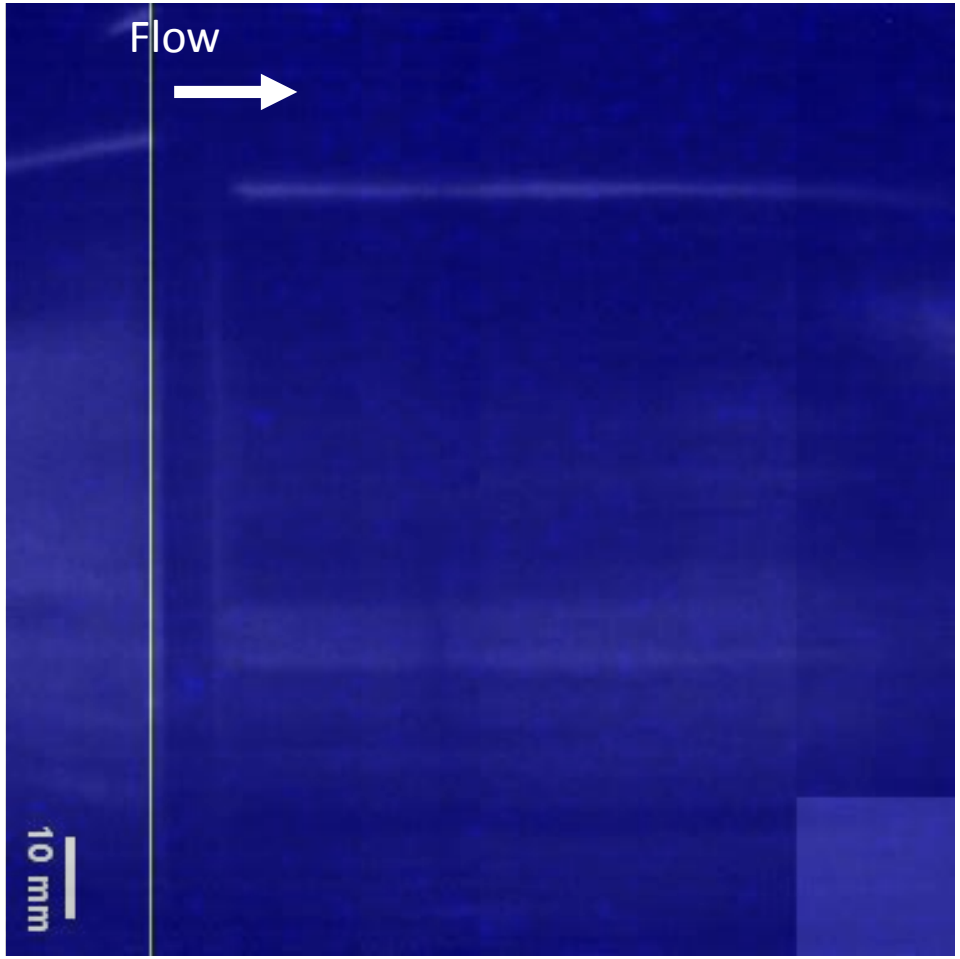
MHz imaging

flow



3D URANS



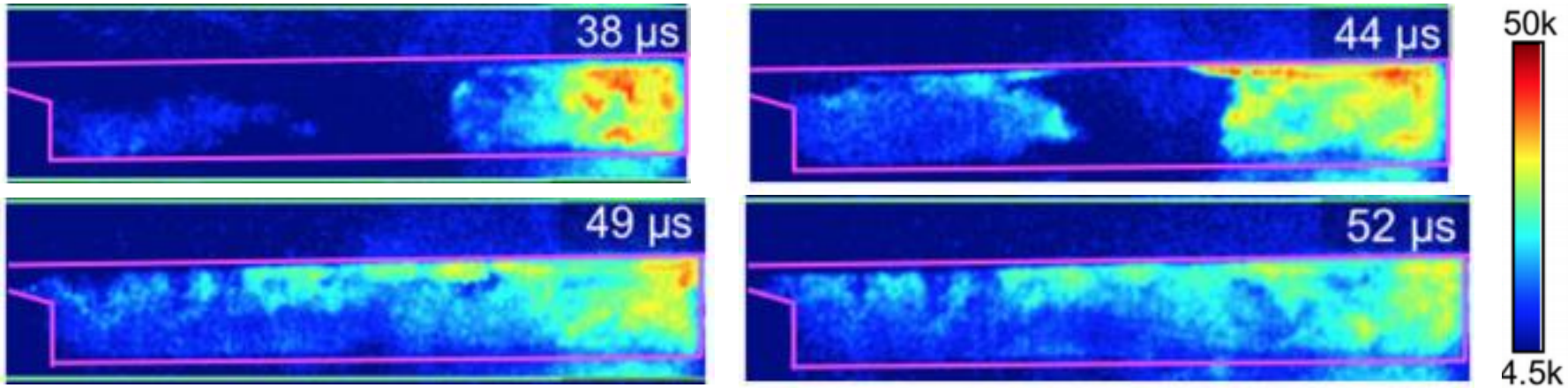


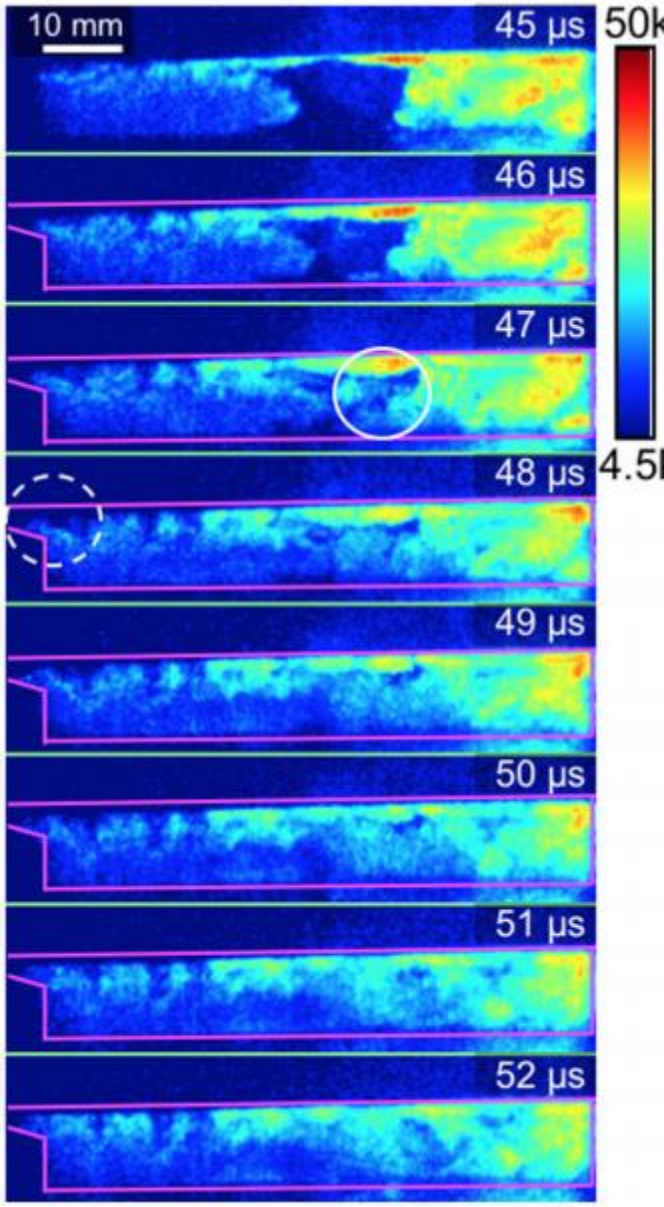
200 khz Chemiluminescence

Athmanathan V., Braun J., Ayers Z., Fisher J.M., Ayers Z., Fugger C., Roy S., Paniagua G., Meyer T., Detonation structure evolution in an optically-accessible non-premixed H2-Air RDC using MHz rate imaging, AIAA Propulsion and Energy Forum, Orlando, January 2020

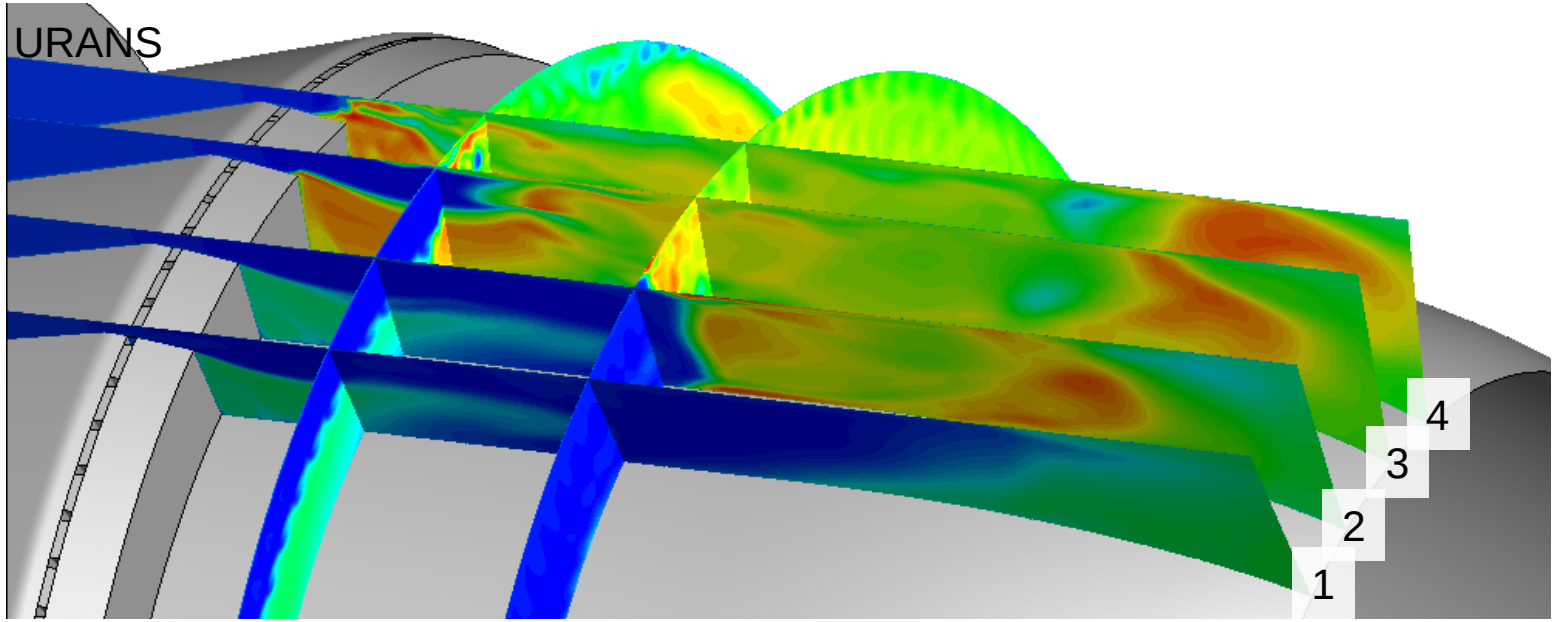
CFD vs Experiment

OHF PLIF





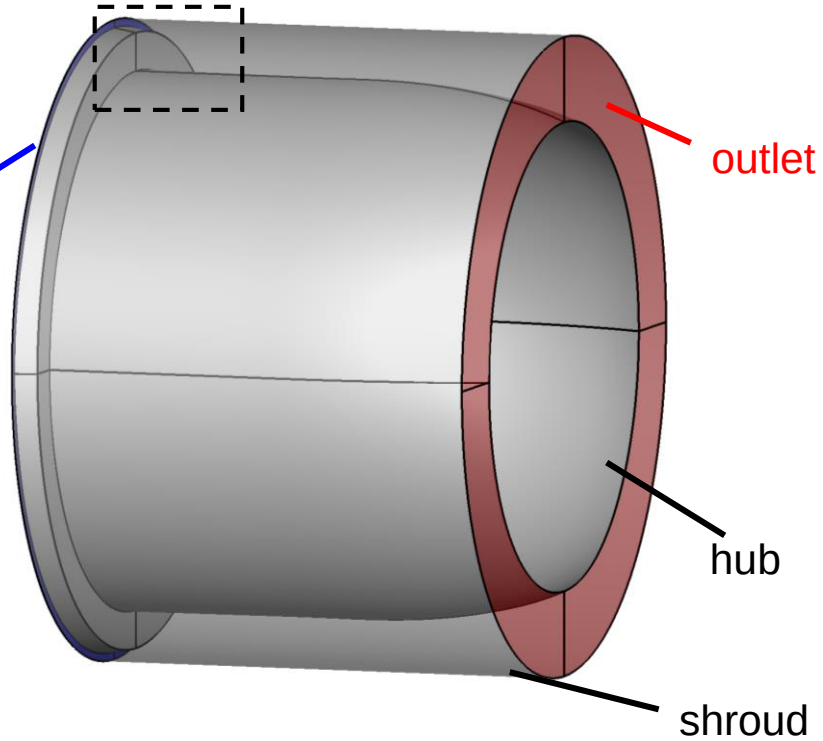
3D URANS



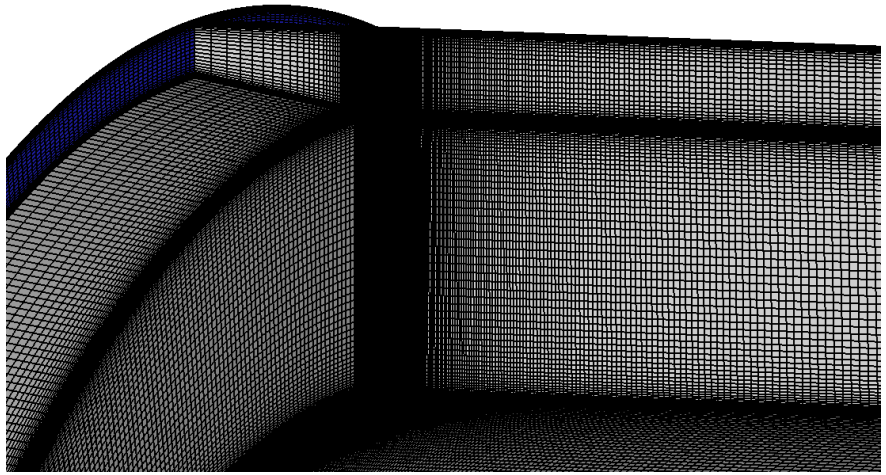
PS Hsu V Athmanathan T Meyer M Slipchenko S. Roy, "Megahertz rate OH planar laser-induced fluorescence imaging in rotating detonation combustor," *Opt. Lett.*, Oct. 2020.

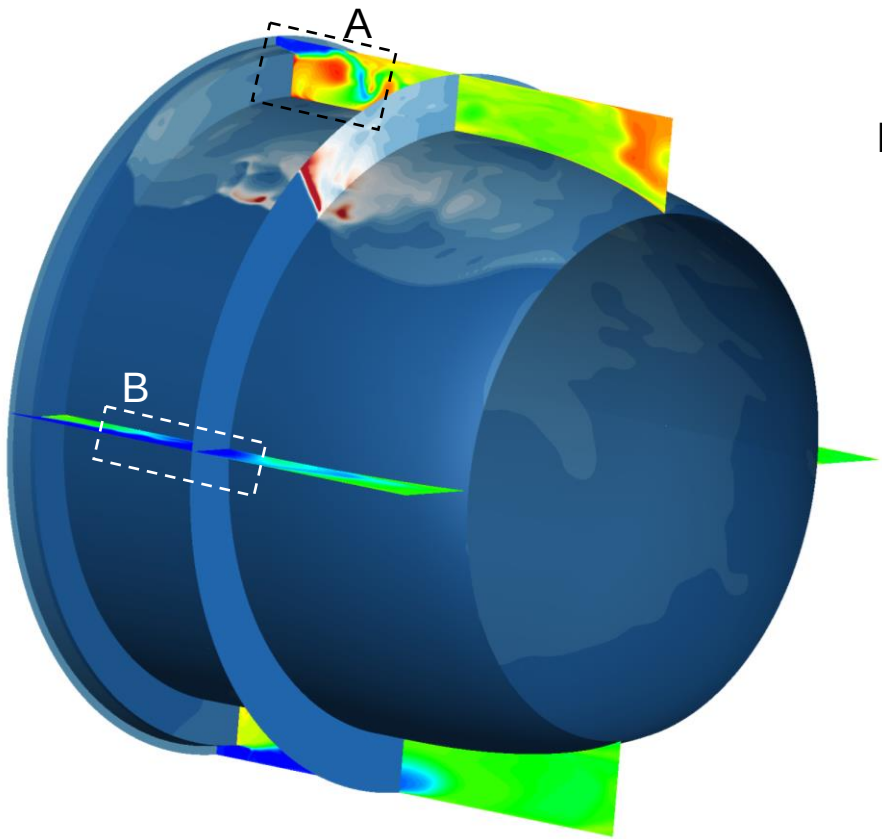
Reduced computational domain

numerical domain



mesh





Outline

Methodology (solver description & validation)

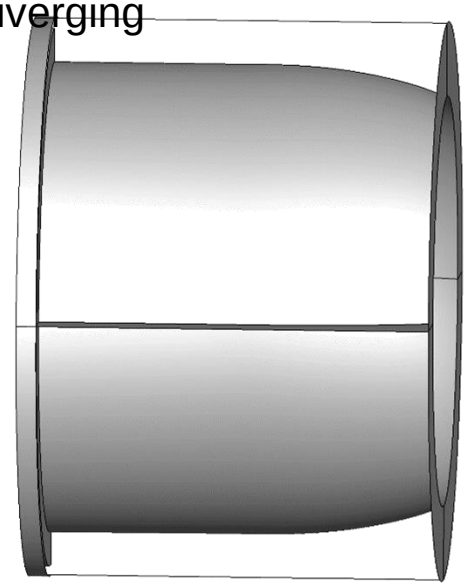
3D unsteady analysis of the outlet profiles

Aerodynamic performance of the passage

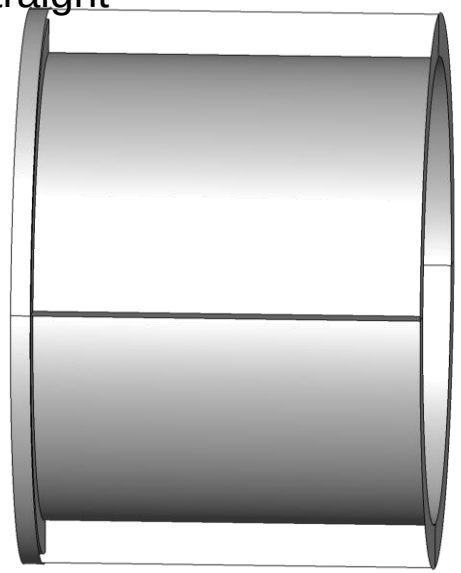
Simulation of the isolated diffusing passage

Investigated geometries

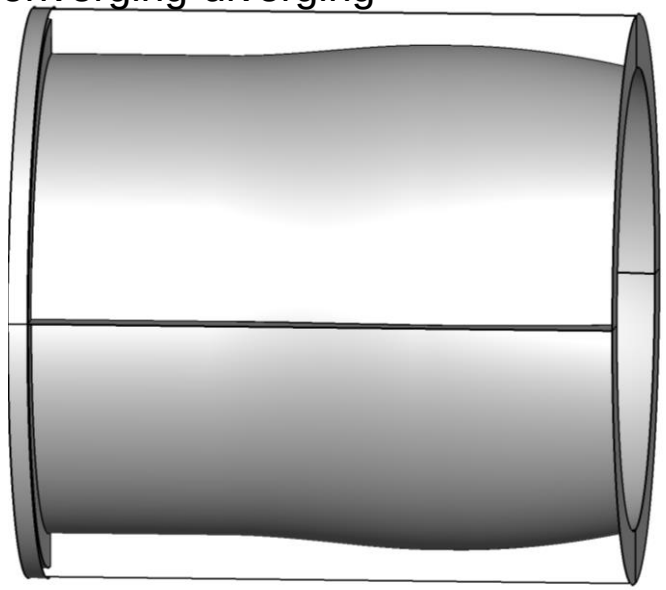
diverging



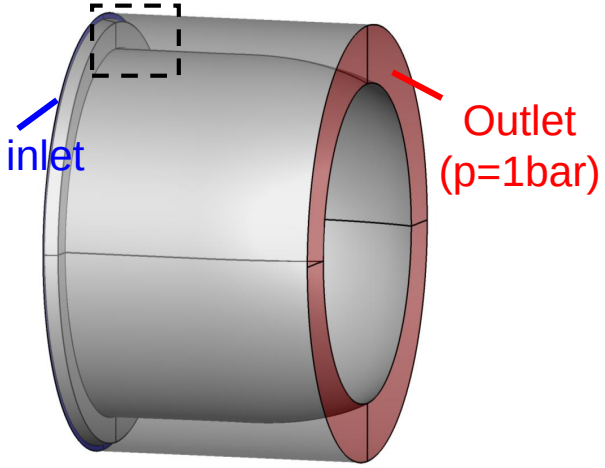
straight

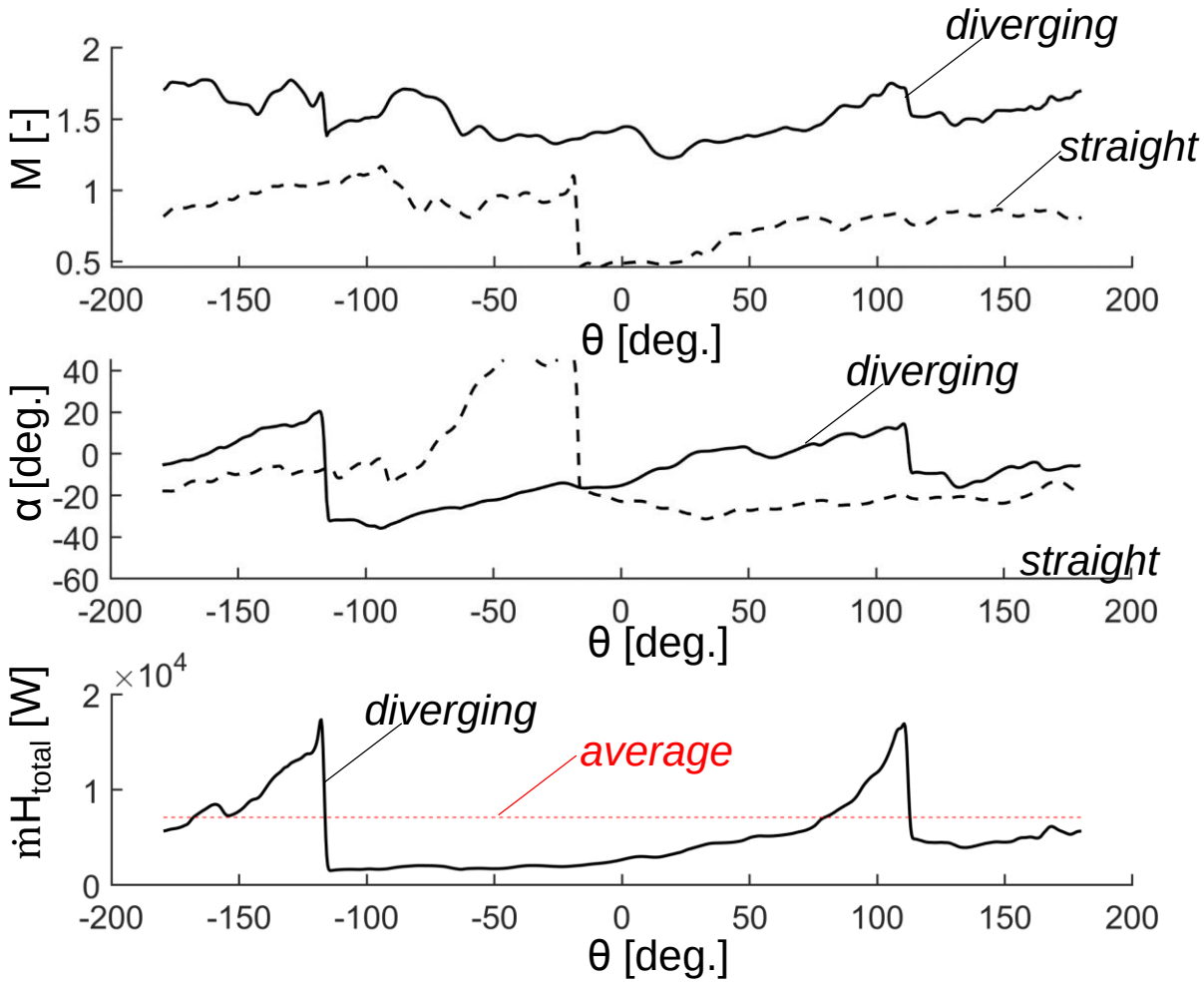


Converging-diverging

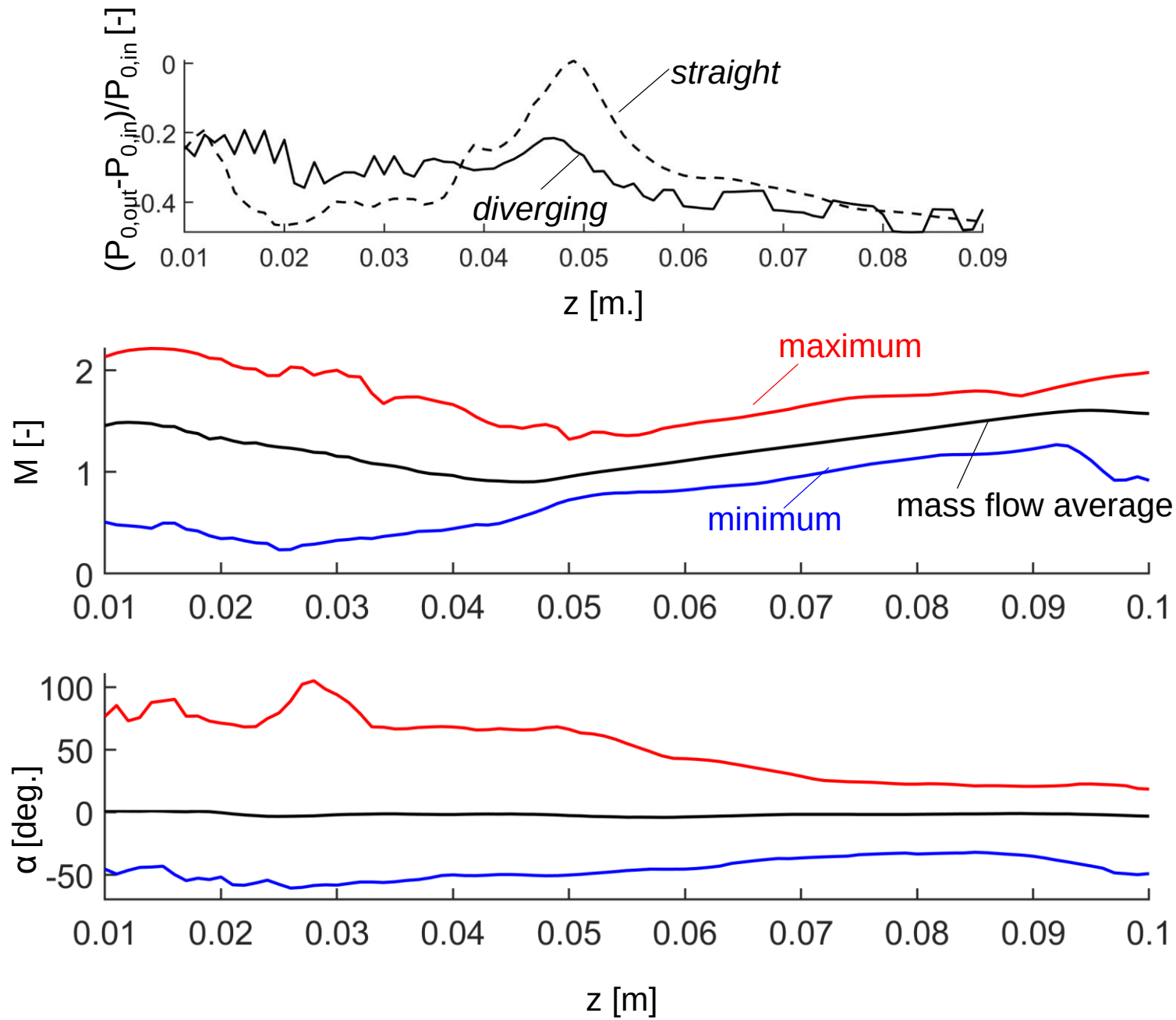


Characterization of the accelerating passage with a back pressure of one bar

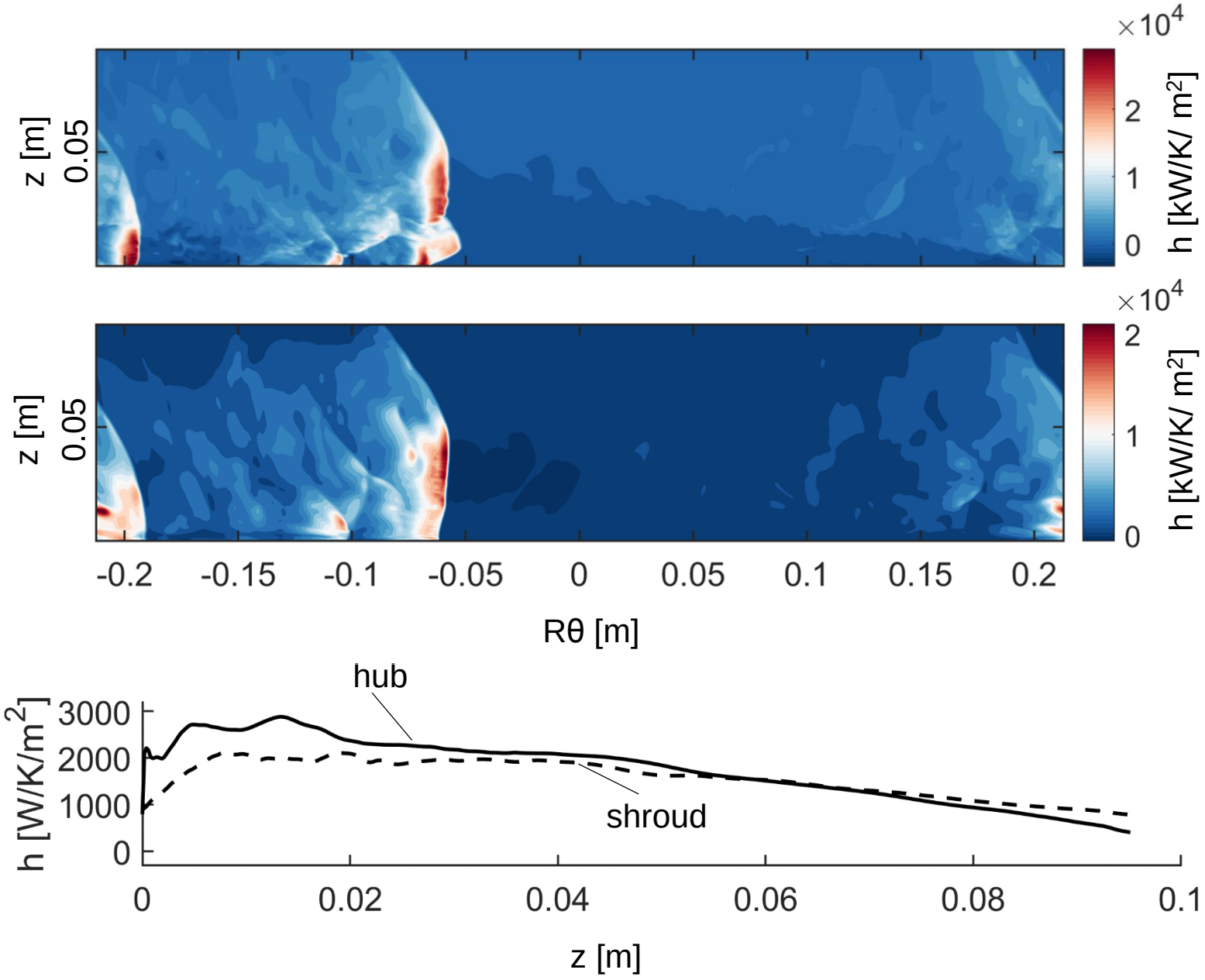




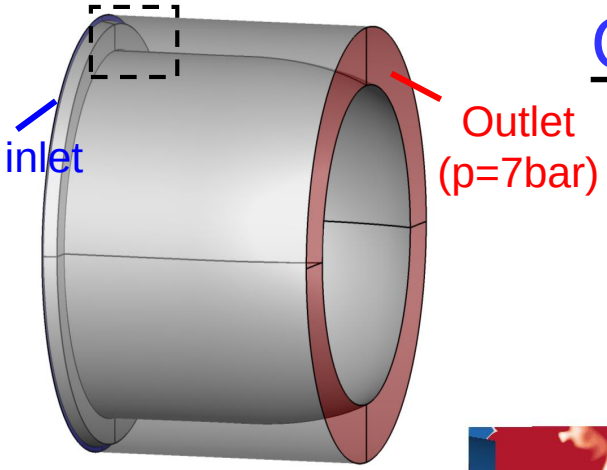
Characterization of the accelerating passage: Mach number and flow angle across the channel



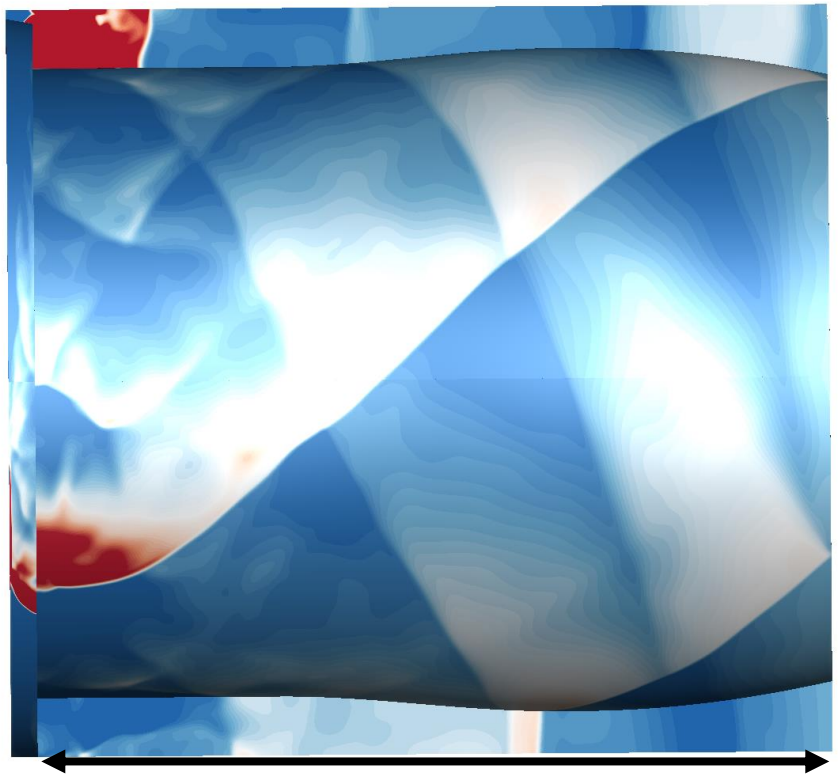
Characterization of the accelerating passage: heat flux



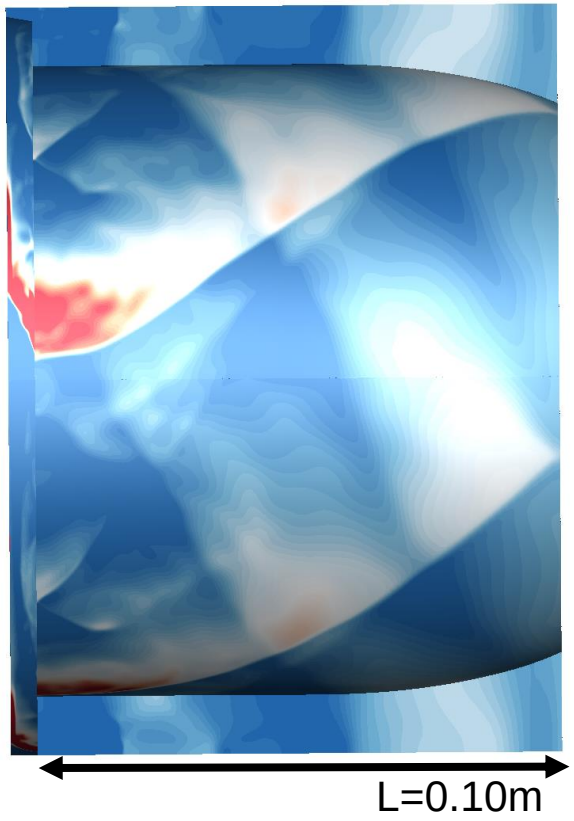
Characterization of the diffusing passage

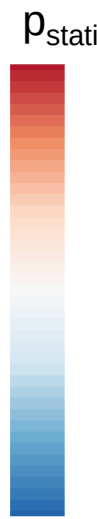


Converging-diverging

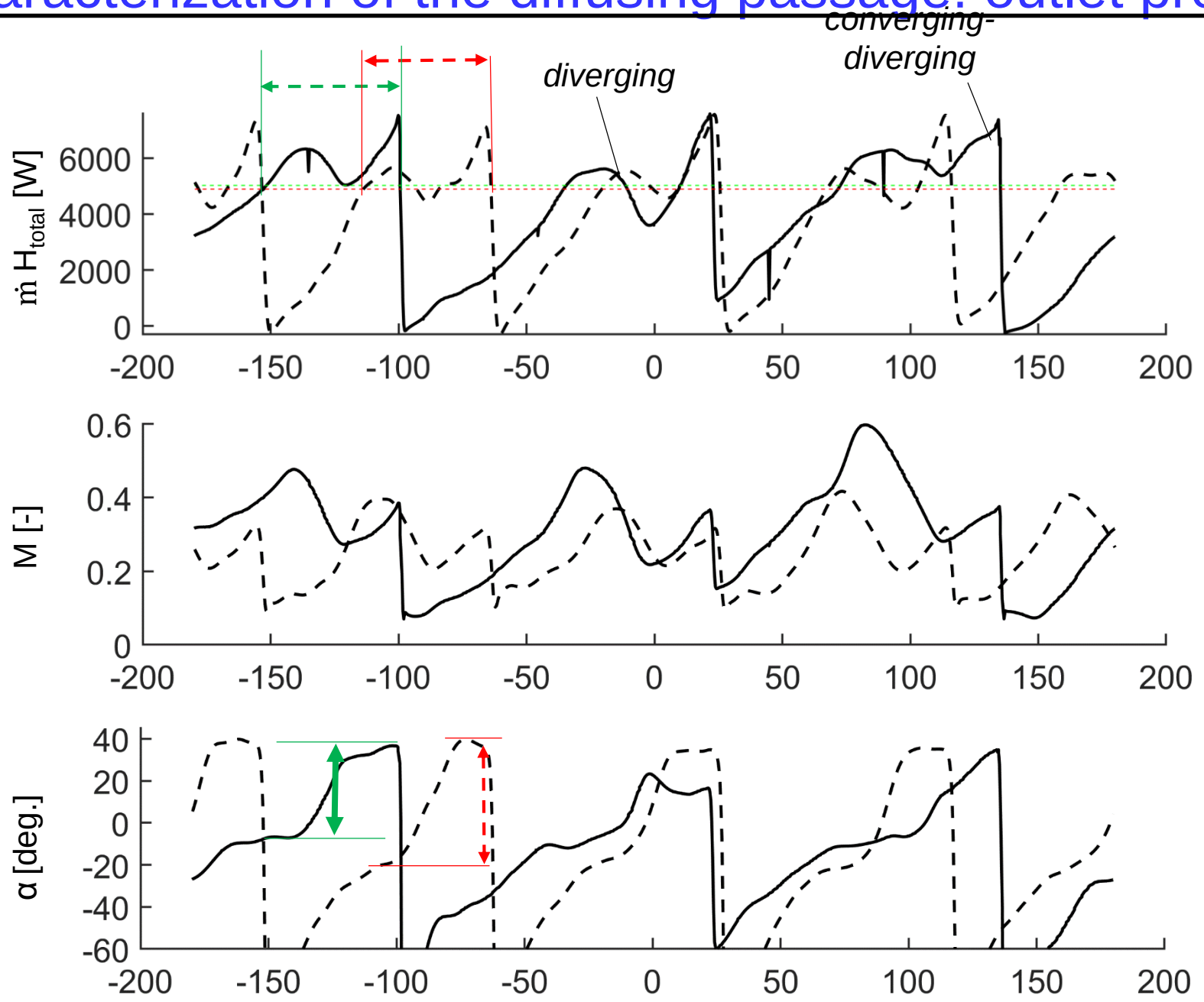


diverging

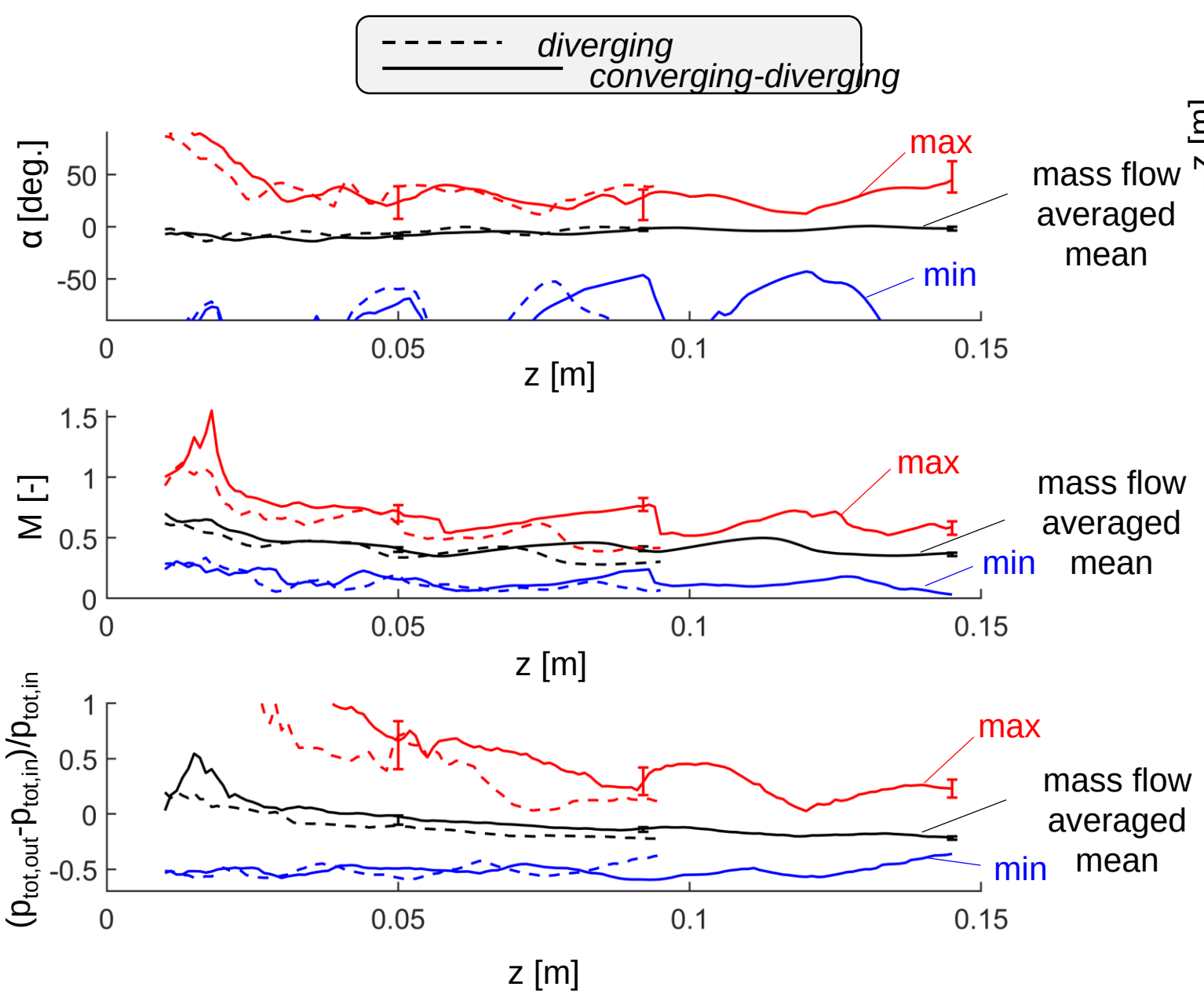




Characterization of the diffusing passage: outlet profile



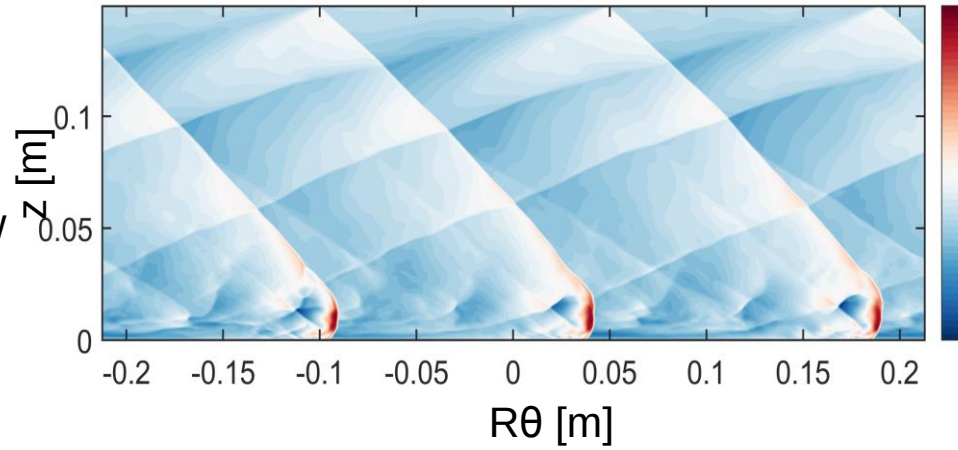
Characterization of the diffusing passage: outlet profile



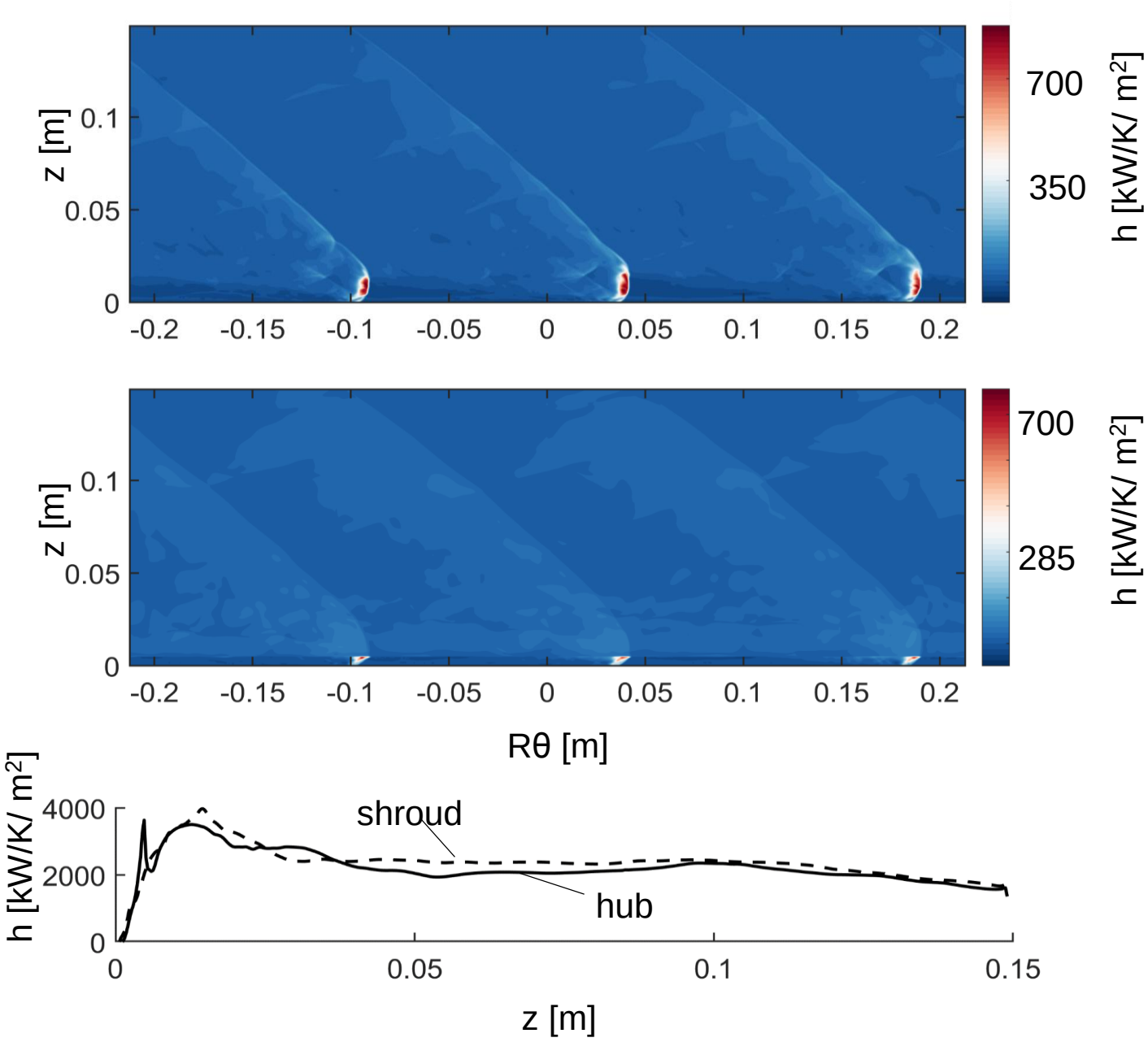
mass flow averaged mean

mass flow averaged mean

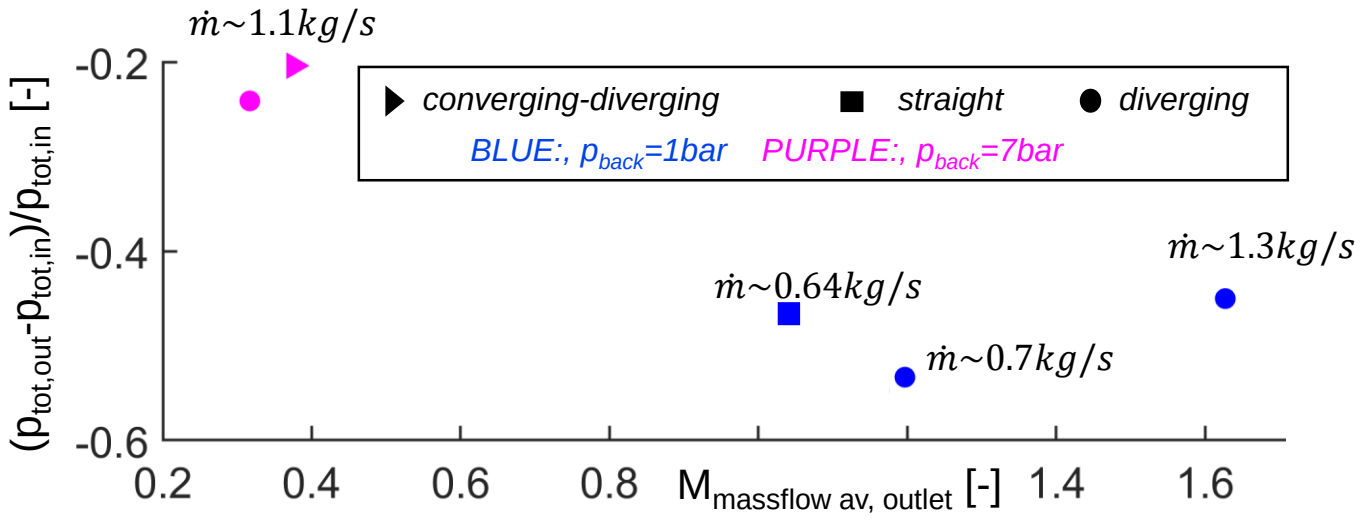
mass flow averaged mean



Characterization of the diffusing passage: heat flux



Operating map



Outline

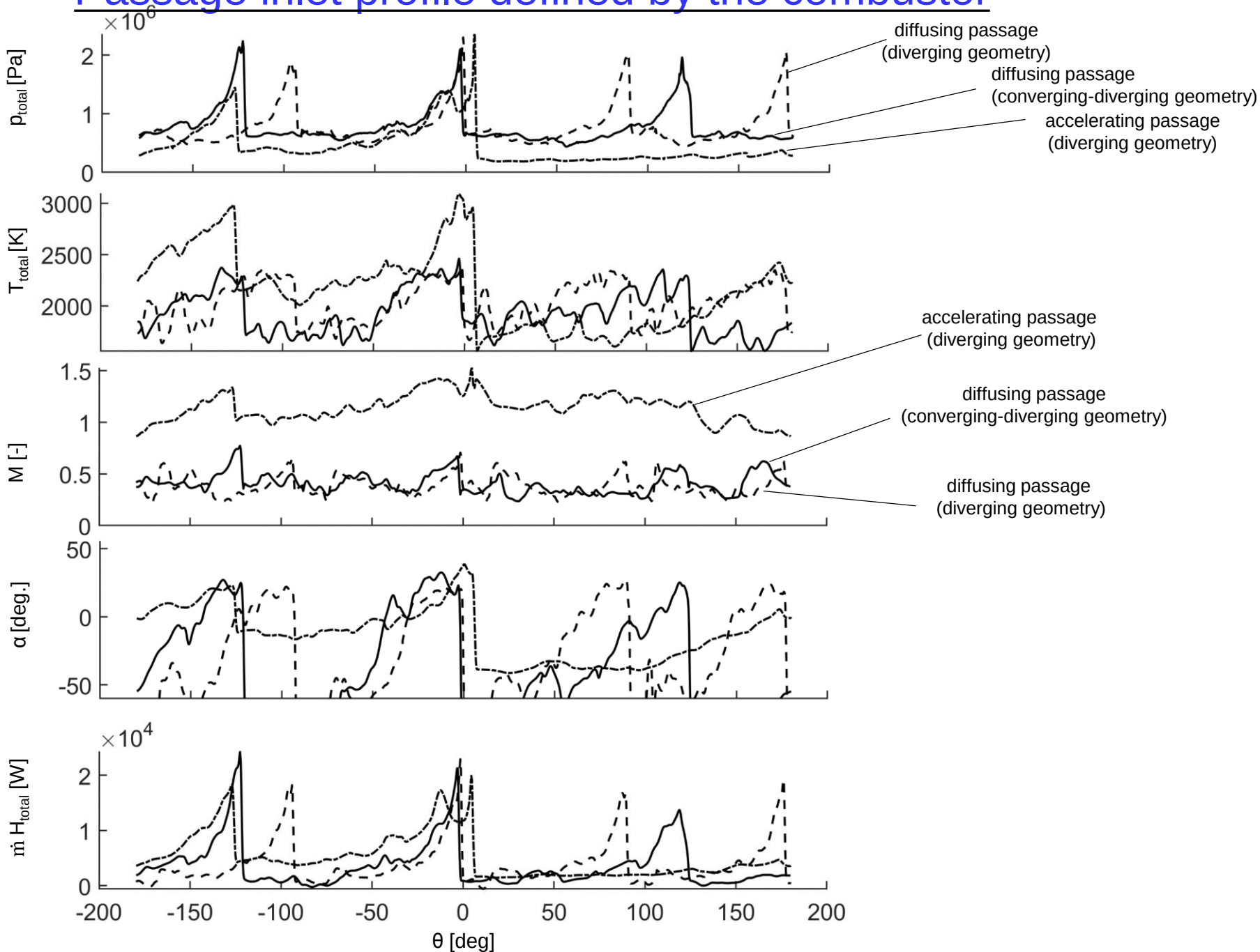
Methodology (solver description & validation)

3D unsteady analysis of the outlet profiles

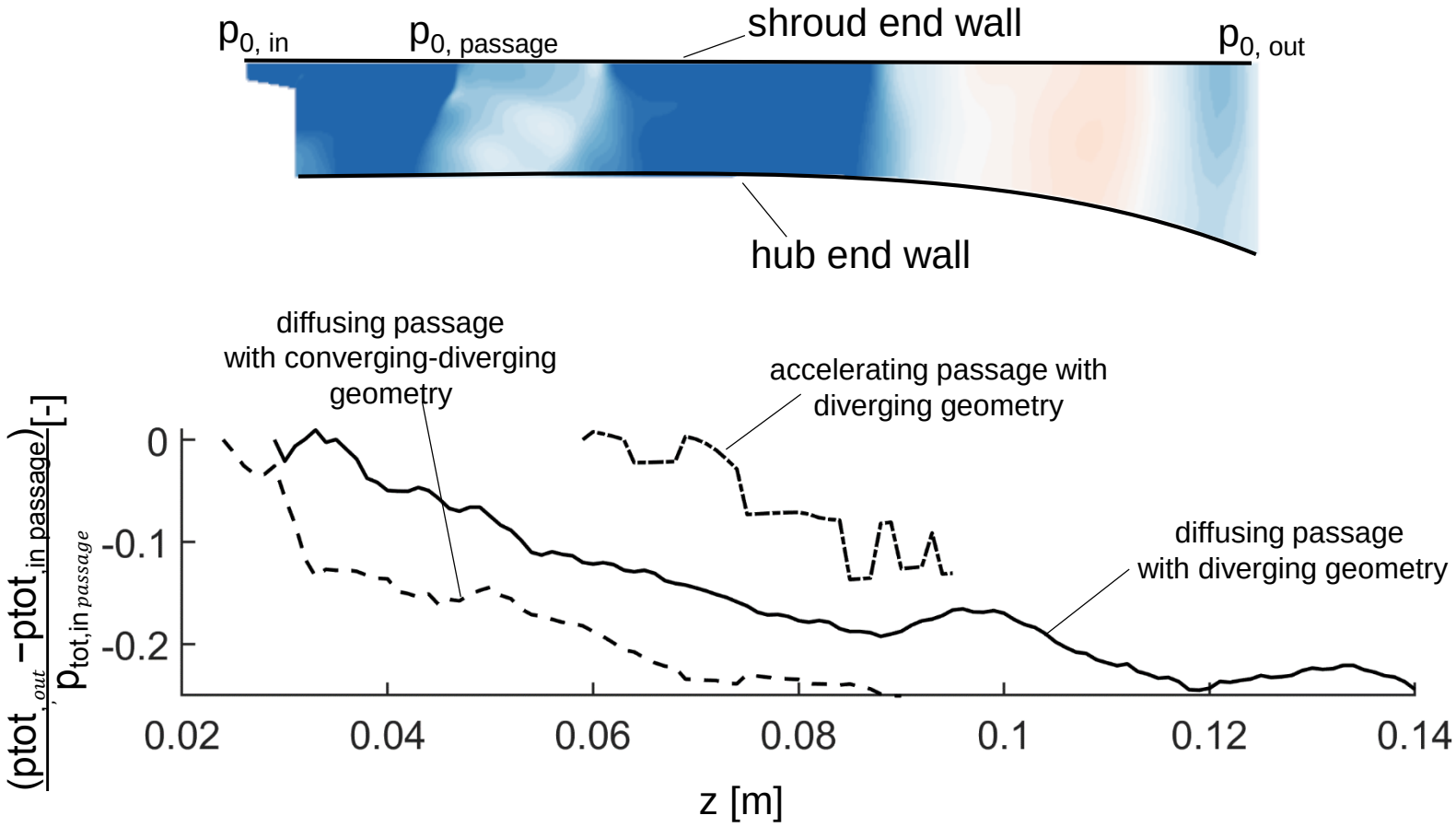
Aerodynamic performance of the passage

Simulation of the isolated diffusing passage

Passage inlet profile defined by the combustor



Pressure loss across the section



Outline

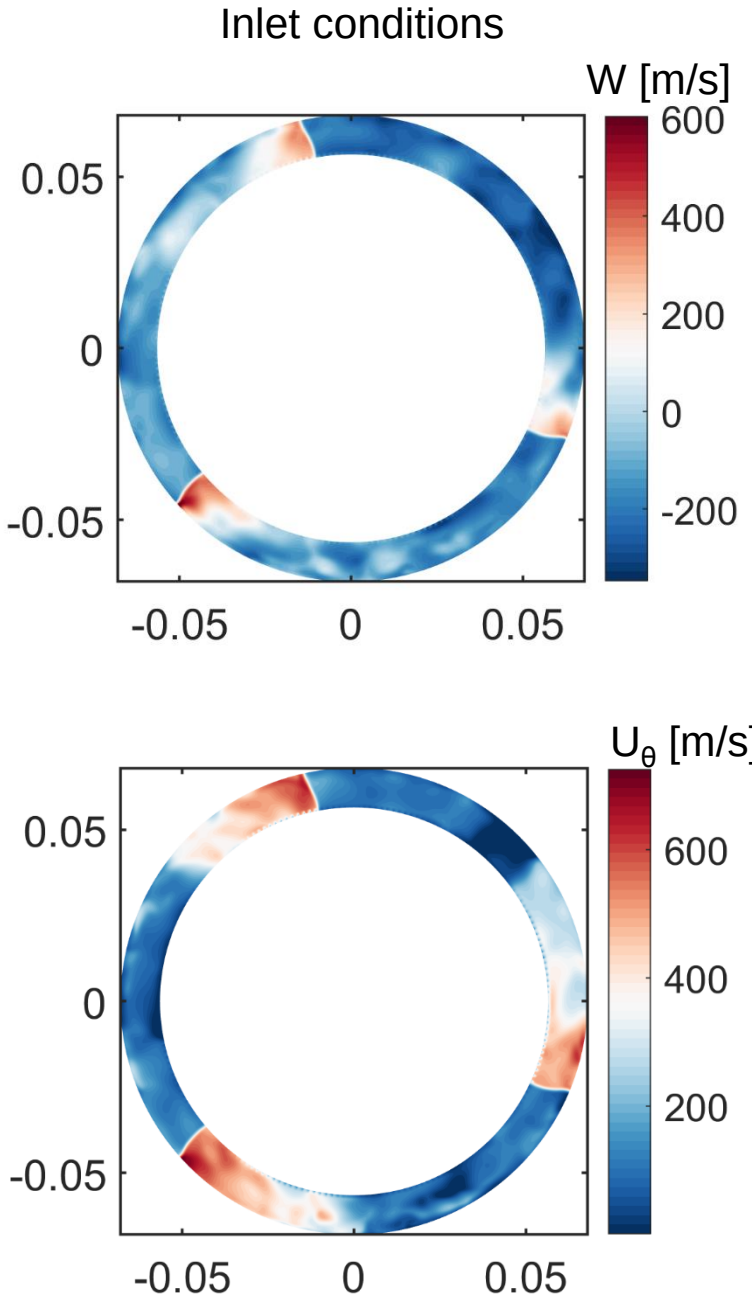
Methodology (solver description & validation)

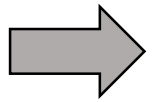
3D unsteady analysis of the outlet profiles

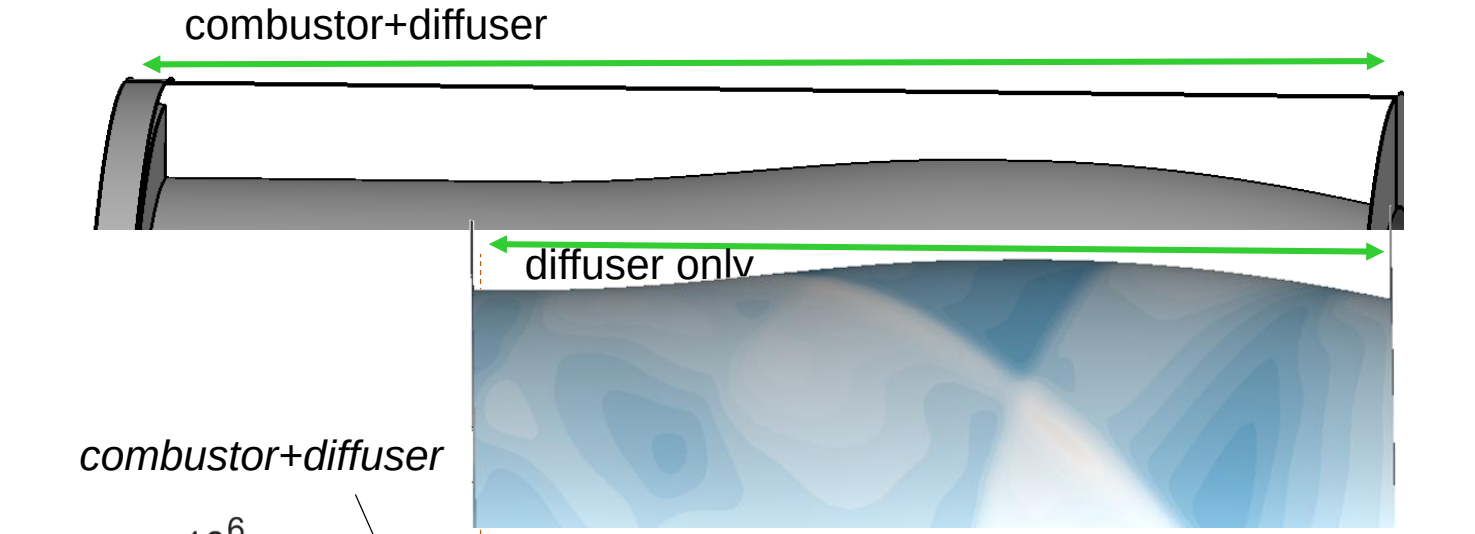
Aerodynamic performance of the passage

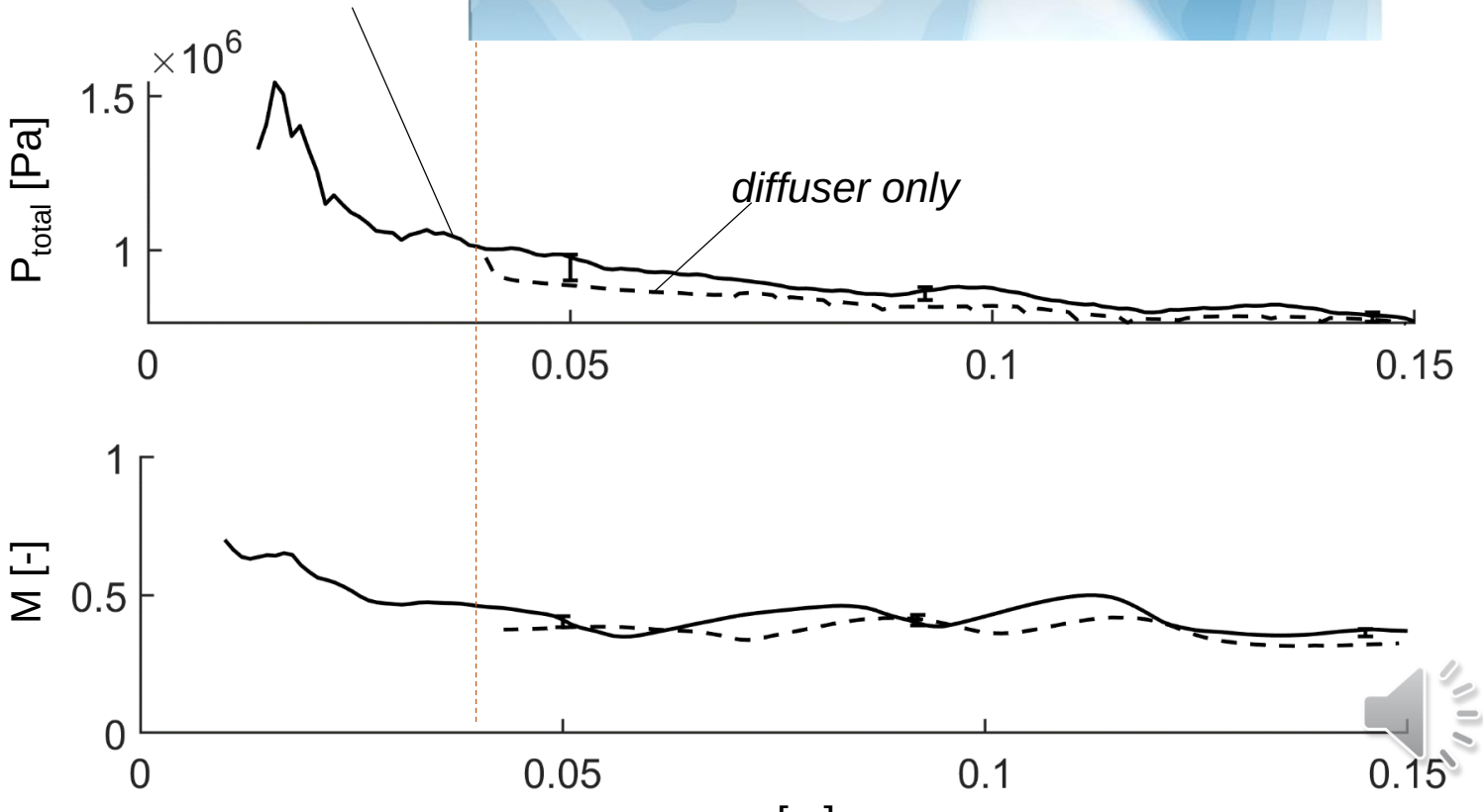
Simulation of the isolated diffusing passage

Inlet conditions to the diffusing passage









Conclusions

- Novel strategy to assess the performance of high-speed transition elements.
- Specifically, accelerating and diffusing characterized through 3D URANS
- Preliminary validation of the numerical tool was performed from published MHz chemiluminescence and OH PLIF imaging.
- The relevant quantities for the aero-thermal design of the turbine (flow angle, Mach number, total pressure, and total temperature), as well as passage cooling requirements (through time-resolved convective heat flux) quantified
- At low back pressures, resulting in accelerating passage for diverging geometries, the combustion zone covered 60% of the passage length, and complete supersonic flow across the span was achieved. The combustion zone was reduced to 20% for the diffusing passage with higher backpressure
- The profiles for two different diffusing passages were investigated, a diverging and converging-diverging passage. Significant changes were observed concerning the peak Mach numbers and flow angle variation in the flow's high enthalpy region.
- The isolated diffusing passage was modeled, and similar mass flow averaged total pressures signature across the axial length was obtained, with a tenfold reduction in computational time.