Contents of Work Package 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03: Solutions for Flow Component/System Testing and Analysis

Coordinator of the WP

České vysoké učení technické v Praze, Ing. Petr Hatschbach, CSc., Ing. Libor Červenka, Ph.D., prof. Ing. Jiří Fürst, Ph.D.

Participants of the WP

EATON – doc. Ing. Jiří Vávra, Ph.D.

ŠKODA AUTO – Ing. Ladislav Adámek

Main Goal of the WP

Novel test bench architecture for testing of hydrogen management components for fuel cells with innovative closed loop design to testing of high hydrogen flowrates with a small hydrogen supply unit only. The test bench also include temperature, pressure and gas composition conditioning. Virtual prototype – digital twins of test bench.

Improved design of restrictor attached to the input of the turbocharger compressor optimized by experimental investigation and advanced numerical simulations. This will increase efficiency of turbocharger and in overall reduce CO2.

Partial Goals for the Current Period

Final design of hydrogen recirculation blower test bench, 1D thermodynamics simulations. Restrictor model flow field measurement using various methods and pressure measurement on real restrictor. Numerical simulations and studies of 2D a 3D in-restrictor flow and experimental verification.

Contents of Work Package 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03: Solutions for Flow Component/System Testing and Analysis

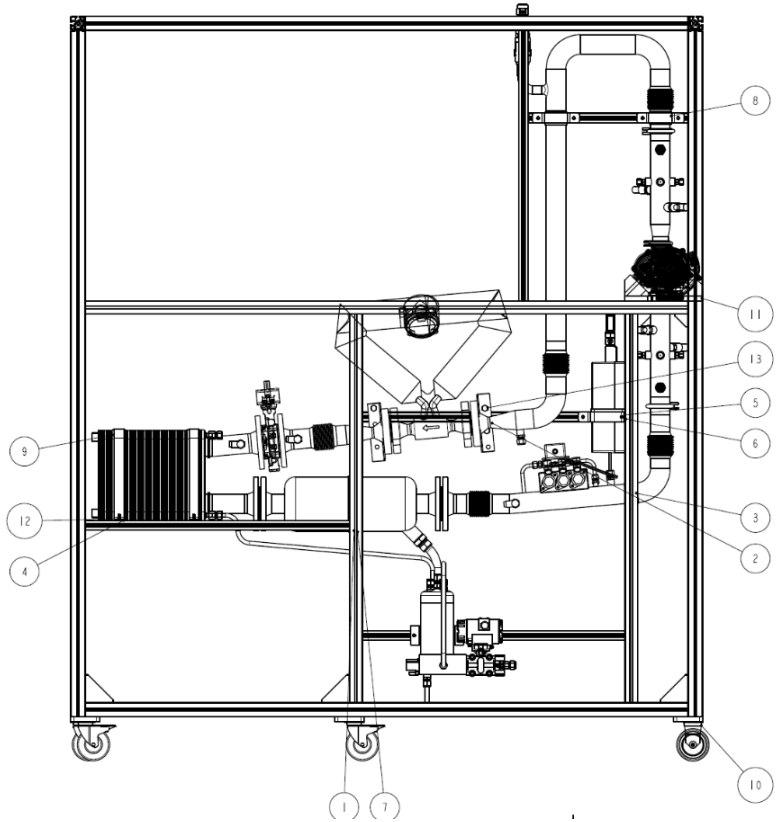
Official 4-WP03 Deliverables:

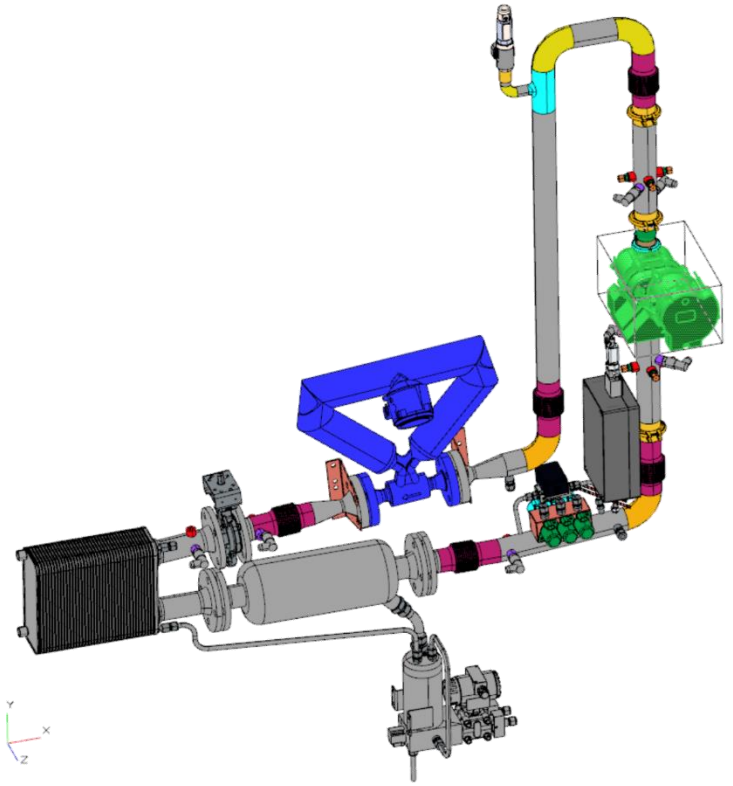
- 4-WP03-001 | **Test bench for hydrogen fuel cell system components**,
  G-funk, XII./2025, CTU 0.5; EATON 0.5
- 4-WP03-002 | **Optimized restrictor of the compressor for turbocharged high-power SI ICE**,
  G-funk, XII./2025, CTU 0.5; SKODA AUTO 0.5
- 4-WP03-003 | **Database of subsonic flow simulations**,
  O, XII./2025, CTU 0.95; SKODA AUTO 0.05

Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-001: Test bench for hydrogen fuel cell system components

Final 3D CAD Design of a complete HRB (hydrogen recirculation blower) testing loop





- Most component defined and ordered
- Some important components are already delivered (mass flow meter, gas-liquid separator, throttle valve, temperature sensors, ...)
- Production of custom designed components are in preparation

Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-001: Test bench for hydrogen fuel cell system components

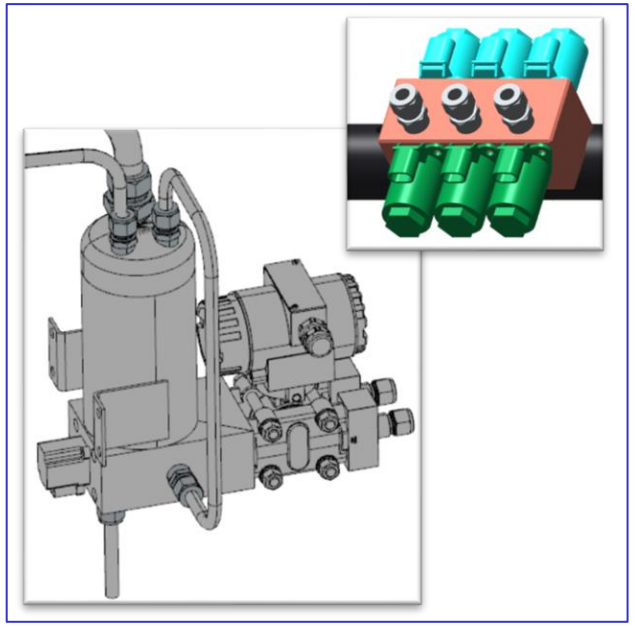
System design – based on calculations & simulations

Purchased Components:

- Mass Flow Meter
- Evaporator (+ pumps)
- Sensors (H2 Concentration, Relative Humidity, Pressure, Temperature)
- Heat Exchanger
- Gas-Liquid Separator
- Valves
- Fittings (Parker)

Custom Designed Components:

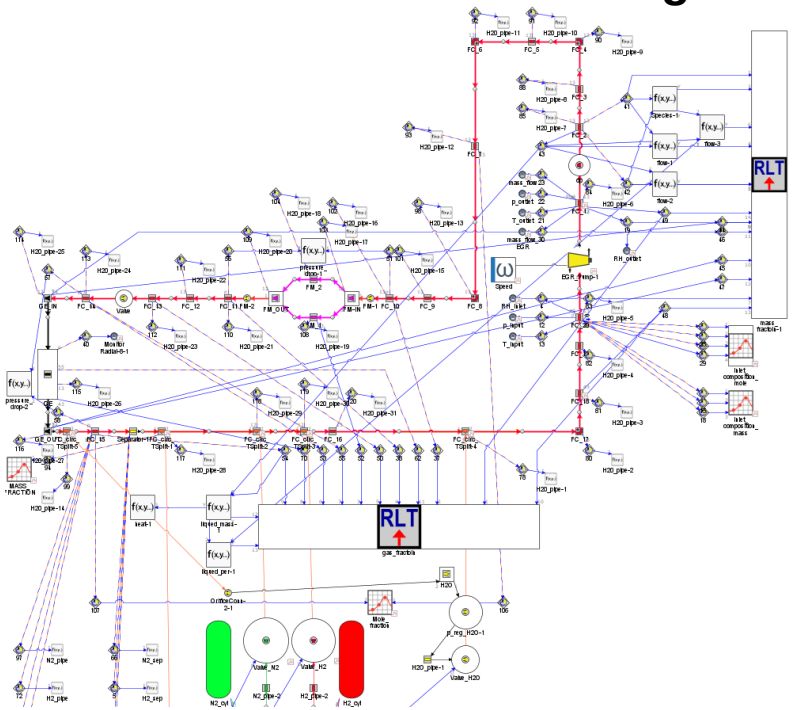
- Valve Manifold (intake – exhaust)
- Condensate Catch Tank
- Water Level Measurement



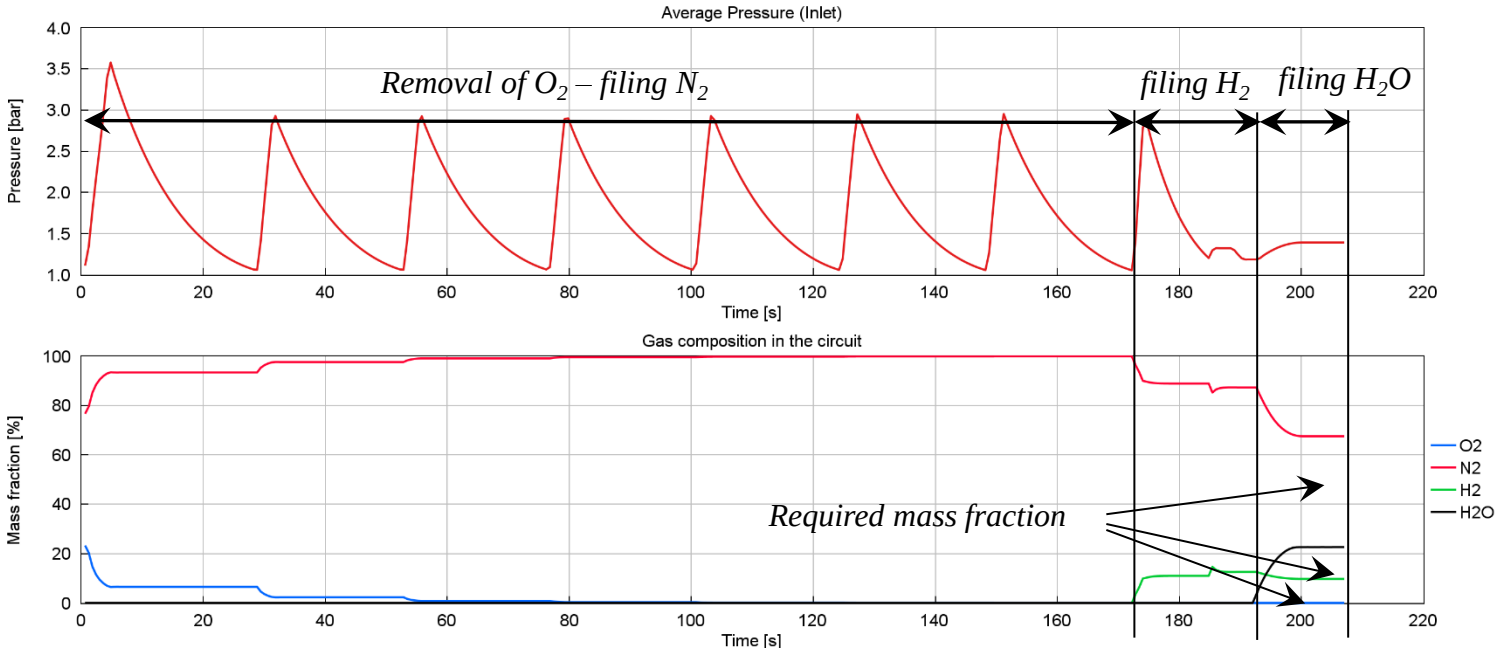
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-001: Test bench for hydrogen fuel cell system components

Mathematical model describing the behavior of the system when the circuit is filled with working gas. Initial removal of O2 and gradual filling with N2, H2 and steam until steady state.



1D GT-Power model of complete circuit with all devices

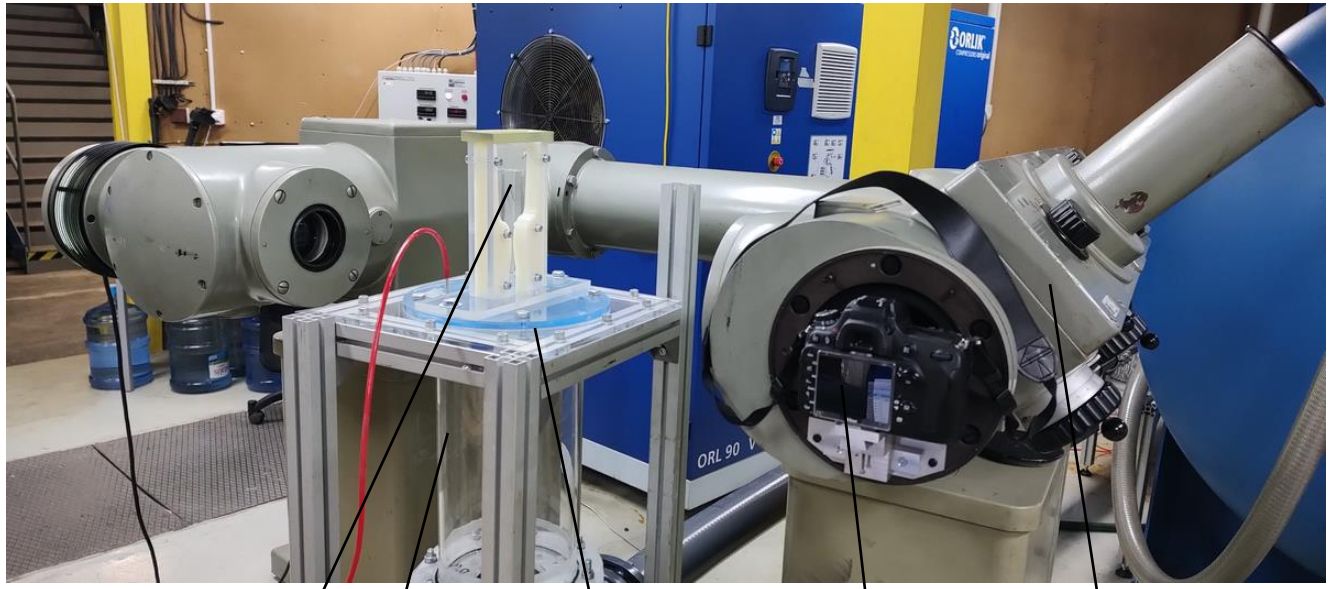


Scavenging and filling the circuit with N2, H2 and steam

Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-002: Optimized restrictor of the compressor for turbocharged high-power SI ICE

Flow field measurement on the 2D model using Schlieren met



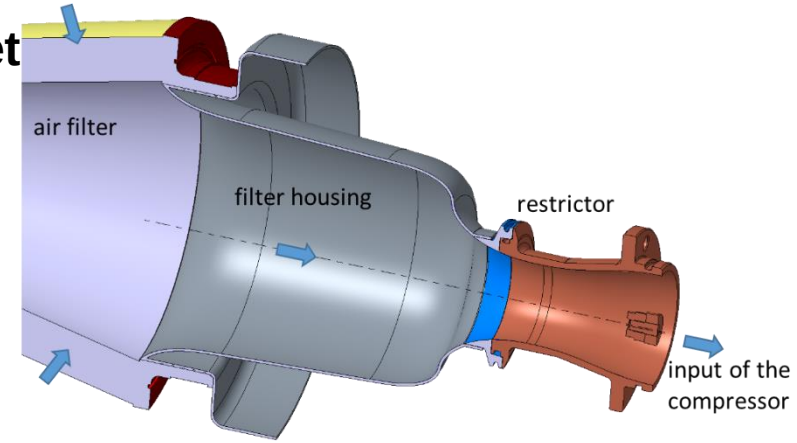
transparent 2D model of the restrictor

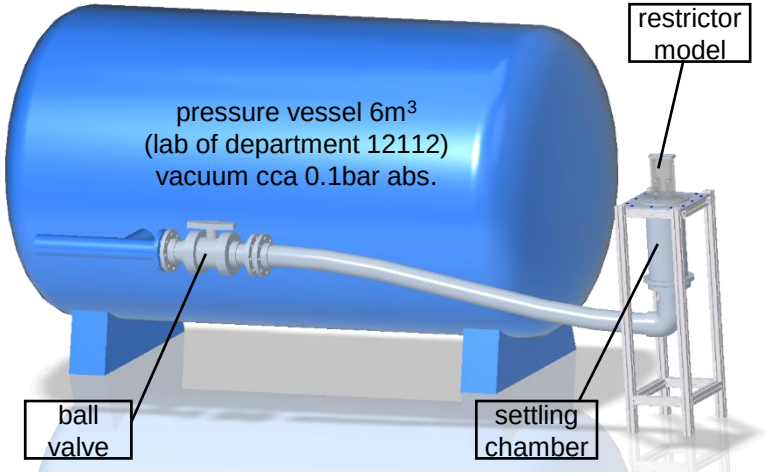
settling chamber

stand with mounting plate

camera Nikon D600

Schlieren device Zeiss 80

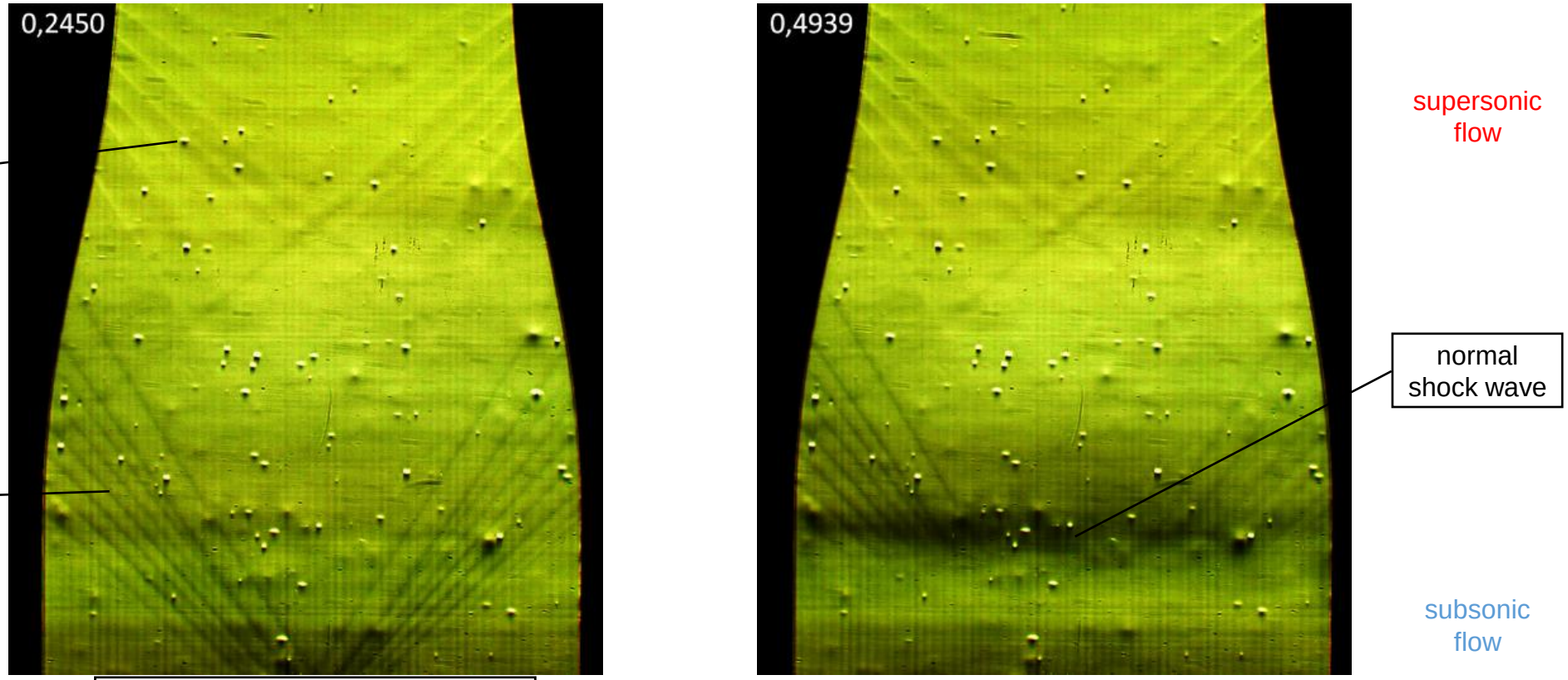




Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-002: Optimized restrictor of the compressor for turbocharged high-power SI ICE

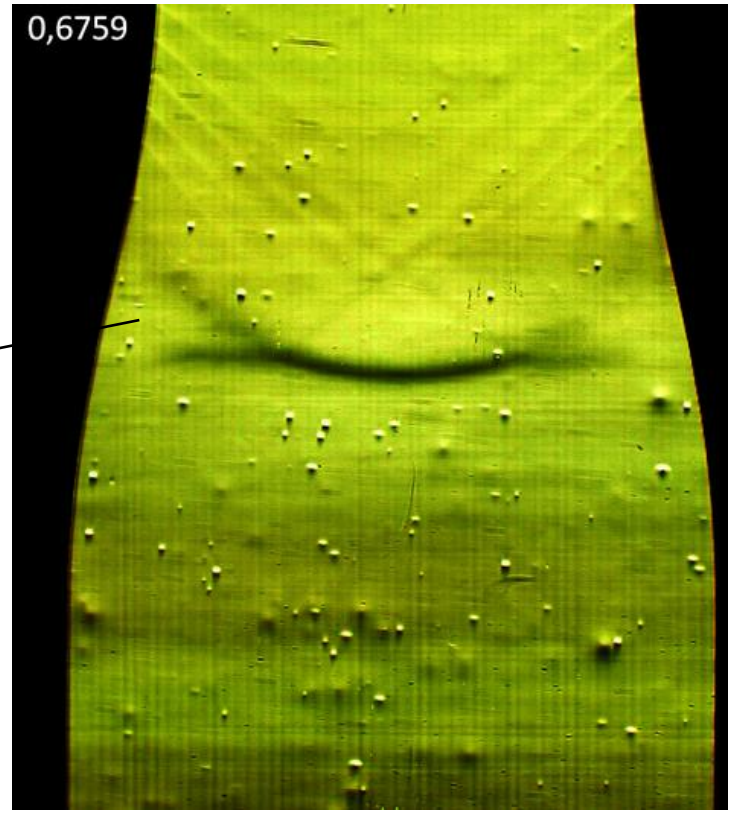
Flow field measurement on the 2D model using Schlieren method



Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-002: Optimized restrictor of the compressor for turbocharged high-power SI ICE

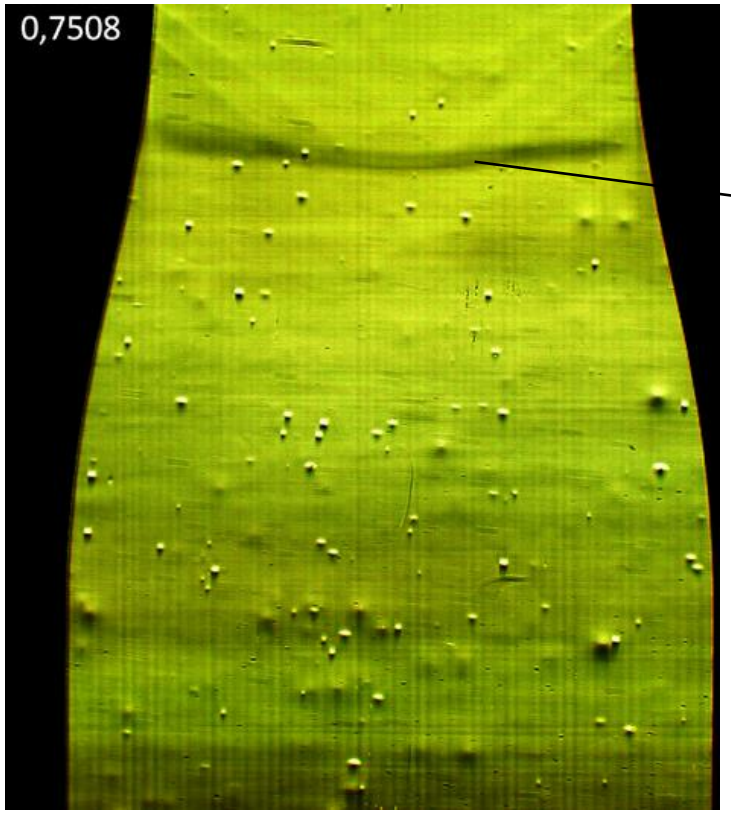
Flow field measurement on the 2D model using Schlieren method



supersonic flow

λ shock waves

subsonic flow



supersonic flow

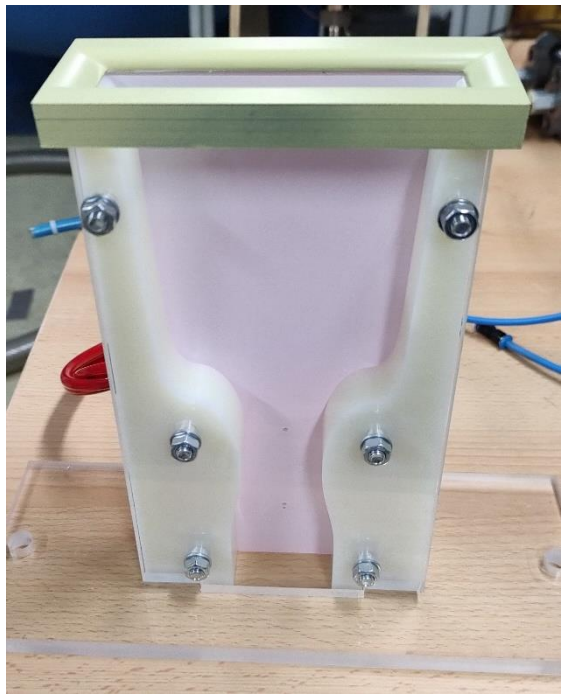
normal shock wave

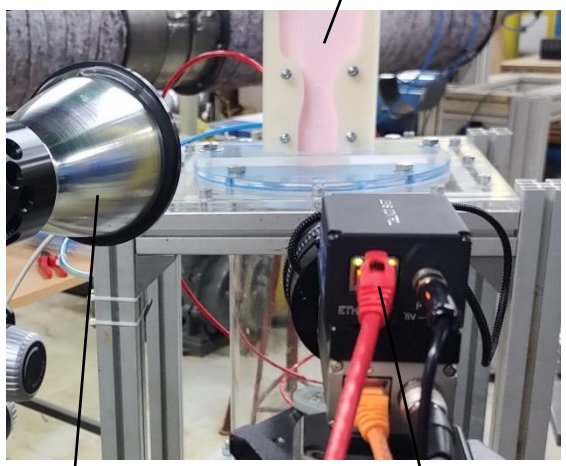
subsonic flow

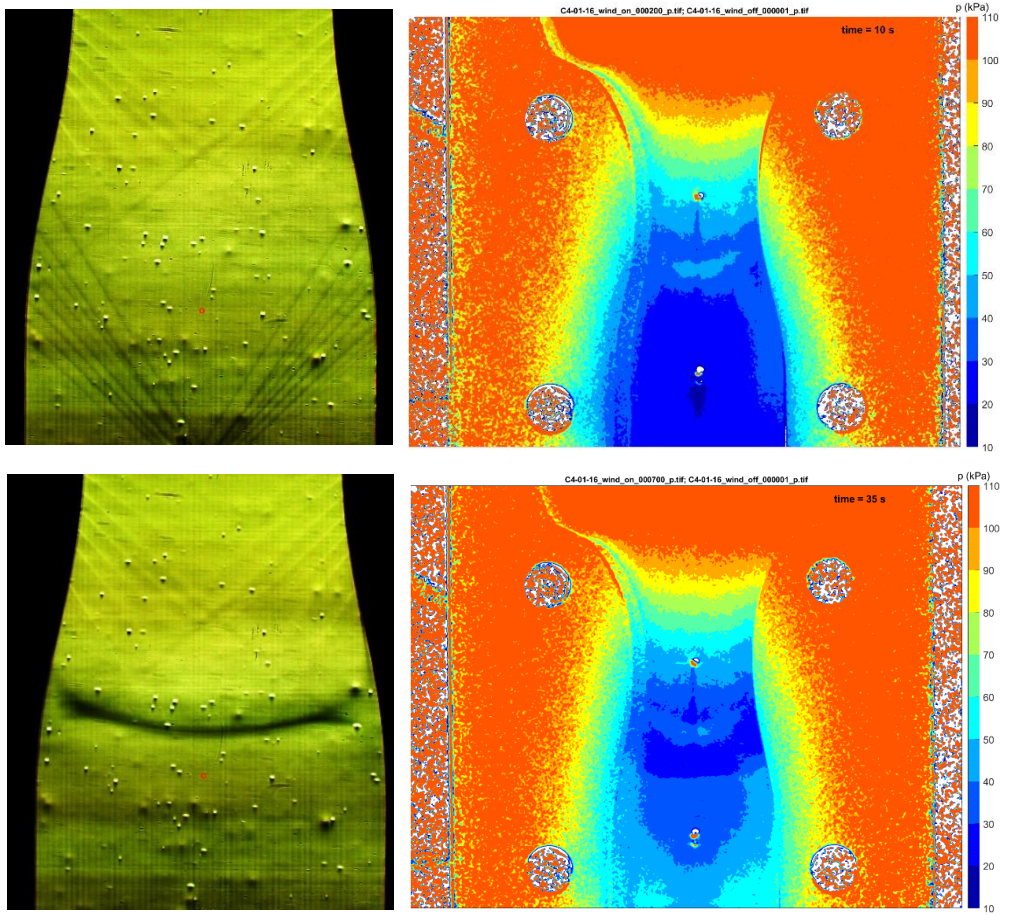
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-002: Optimized restrictor of the compressor for turbocharged high-power SI ICE

Flow field measurement on the 2D model using pressure sensitive paint







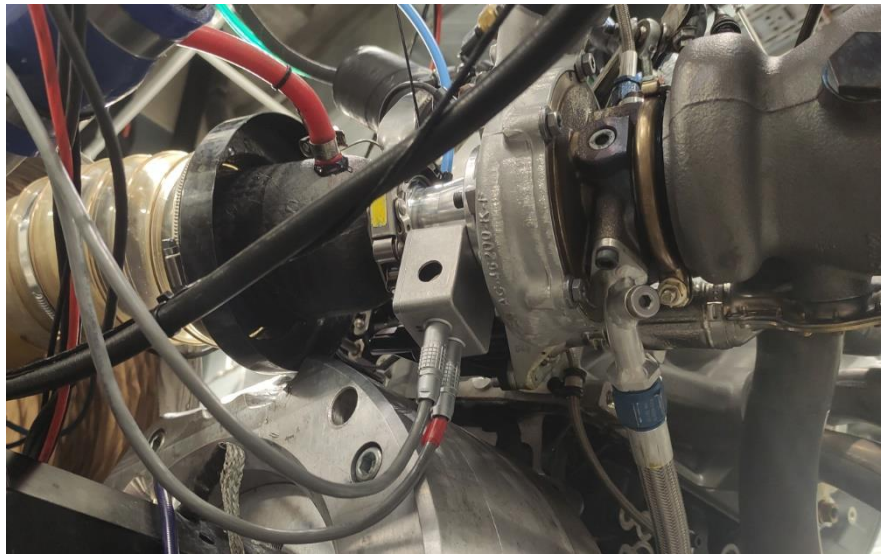
Comparison Schlieren method vs. pressure sensitive paint

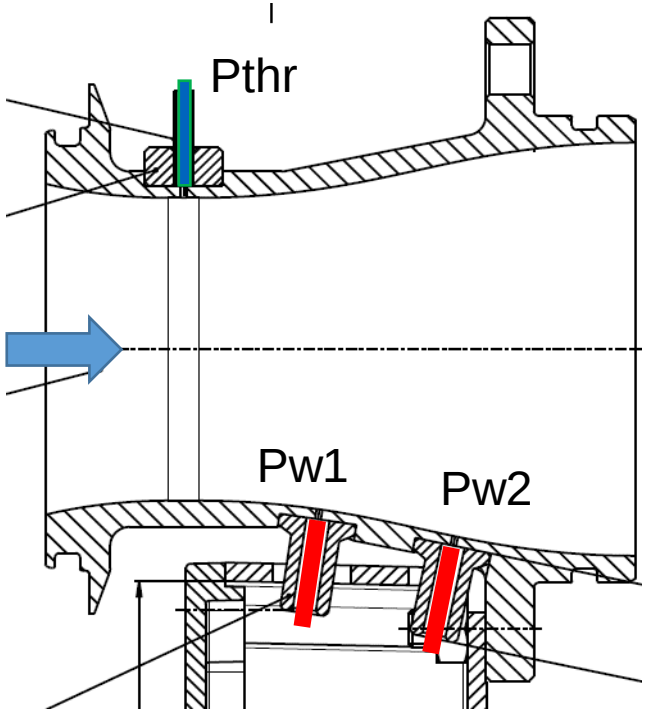
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-002: Optimized restrictor of the compressor for turbocharged high-power SI ICE

Real restrictor measurement (evaluation is underway)

- Pw1, Pw2 – wall pressure in difusor - fast data acquisition (pressure transducers Kulite XCS-062) – 25 kHz
  + Pthr – wall pressure in throat of the restrictor
- Engine data – via CAN bus - standard pressure transducers – slow acquisition – 1kHz





Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

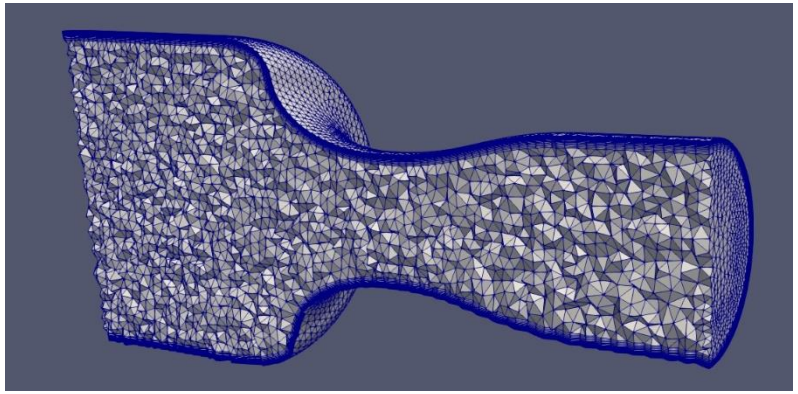
4-WP03-003: Database of subsonic flow simulations

Activities in 2024:

- 2D model restrictor - flow simulations, comparison with experiment (schlieren imaging measurement)
- 2D numerical study - variation of outlet pressure, grid topology, length of outlet cylindrical part (database)
- Numerical simulations for real (3D) restrictor

Numerical method developed on own platform Orion:

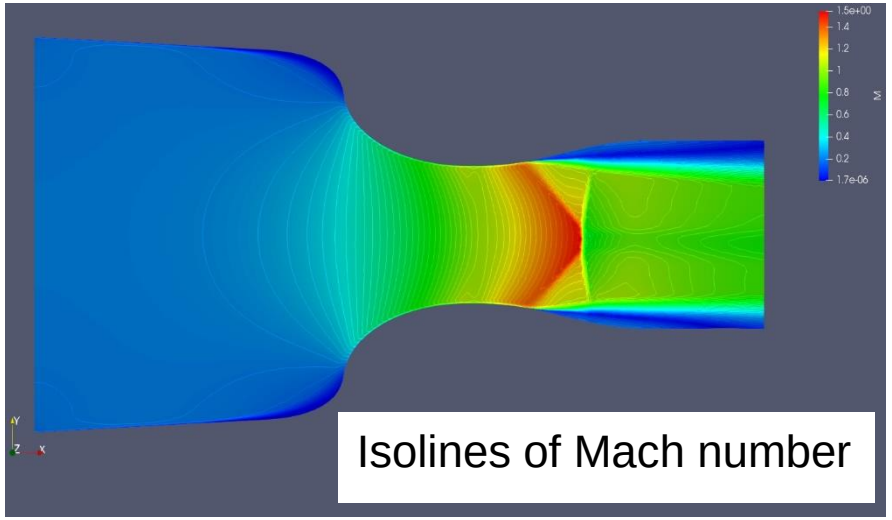
- Finite volume method on hybrid unstructured grids
- Averaged Navier-Stokes equations with γ-SST turbulent model
- 3D simulations - the same numerical method as for 2D simulations, hybrid grid



Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-003: Database of subsonic flow simulations

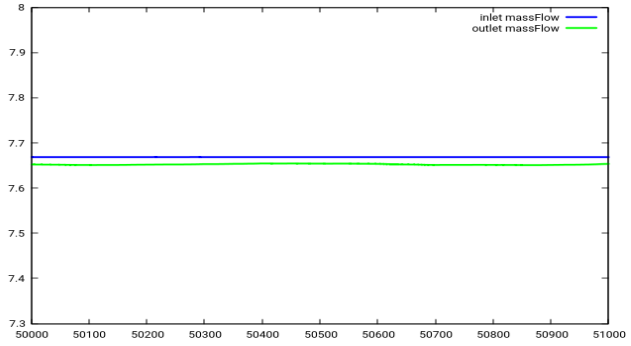
Comparison with measurement (p2/p0 = 0.6)

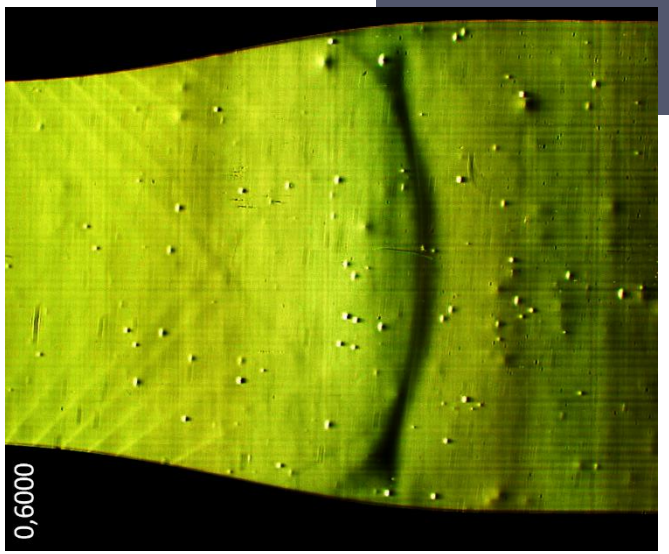


Isolines of Mach number

Schlieren images Simulation

Mass flow





Schlieren images Measurement

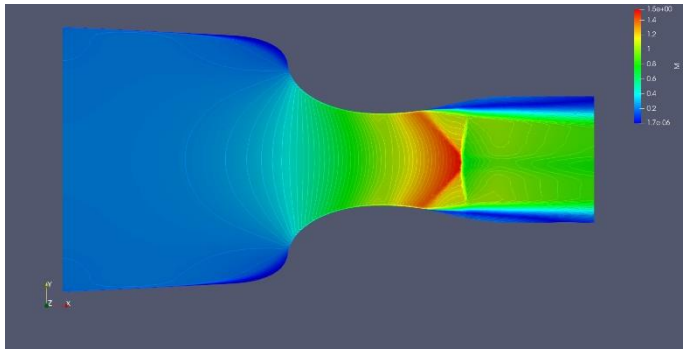
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

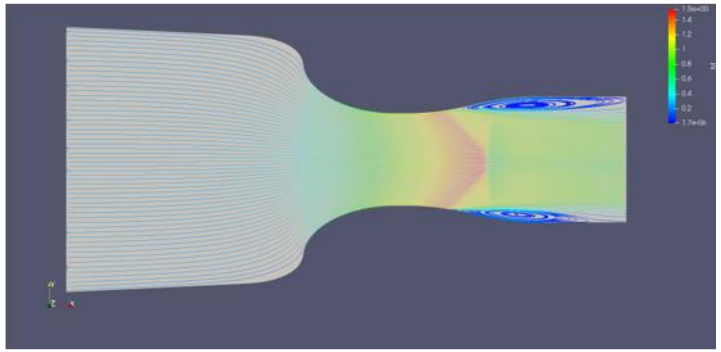
4-WP03-003: Database of subsonic flow simulations

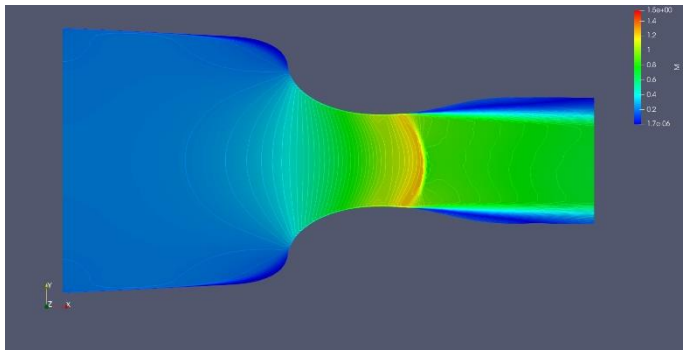
Numerical study A – outlet pressure – hybrid grid, output lenght 30mm

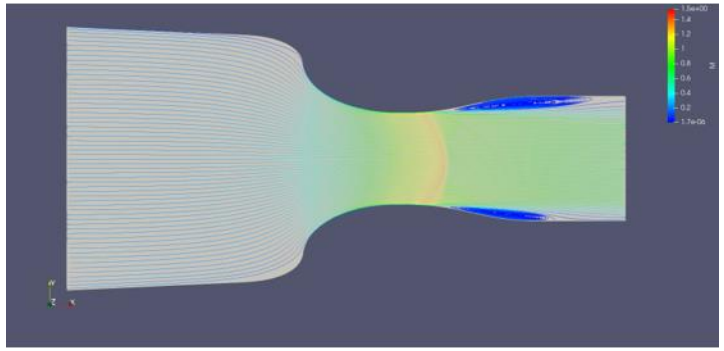
p2/p0 = 0.6

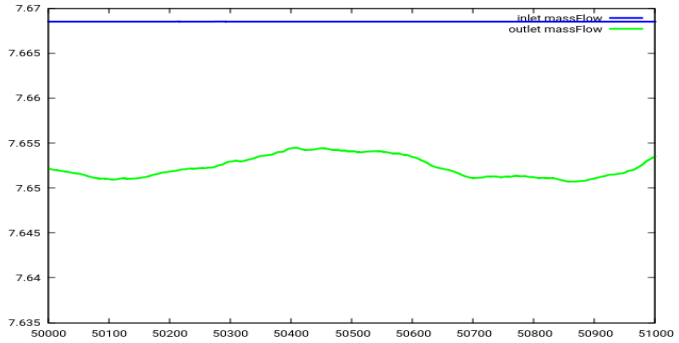
p2/p0 = 0.71

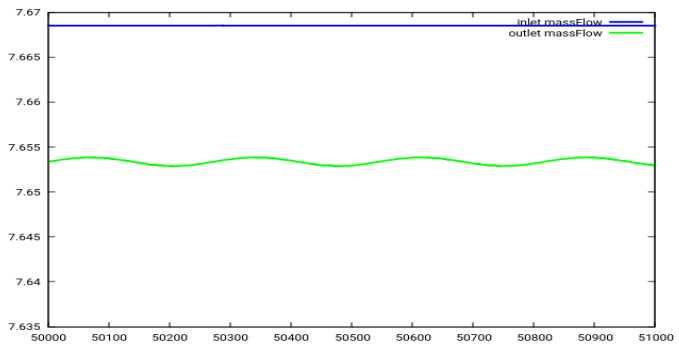












isolines of Ma

streamlines

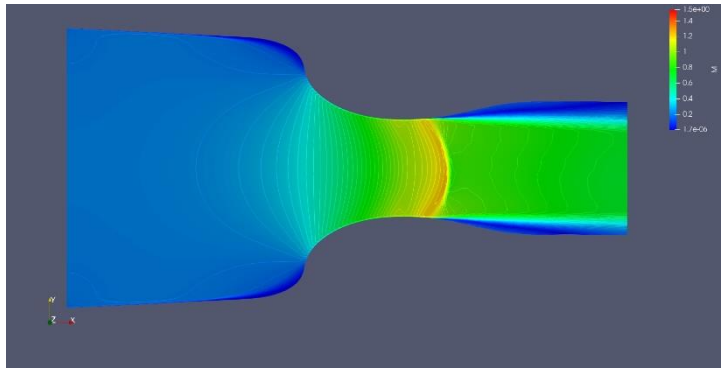
mass flow

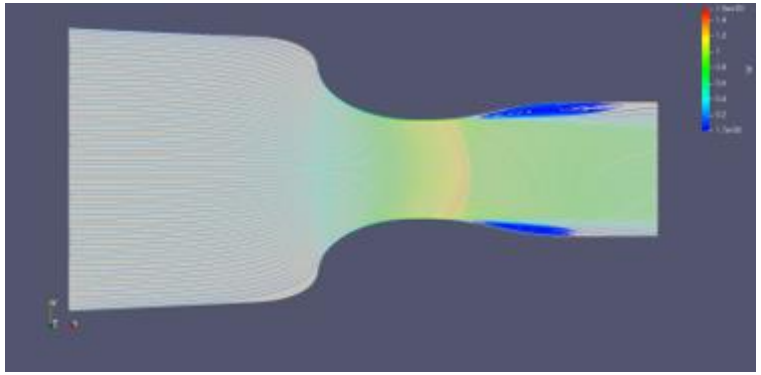
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

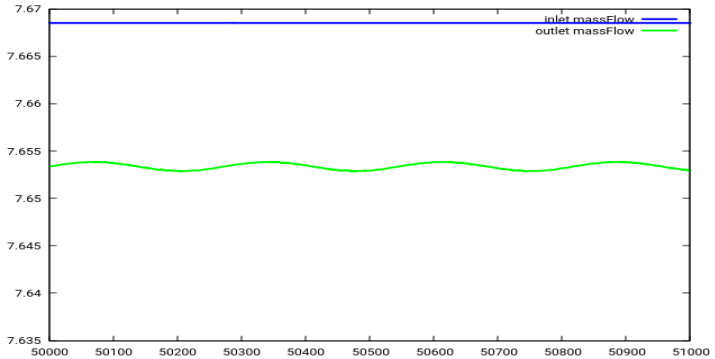
4-WP03-003: Database of subsonic flow simulations

Numerical study B – output lenght

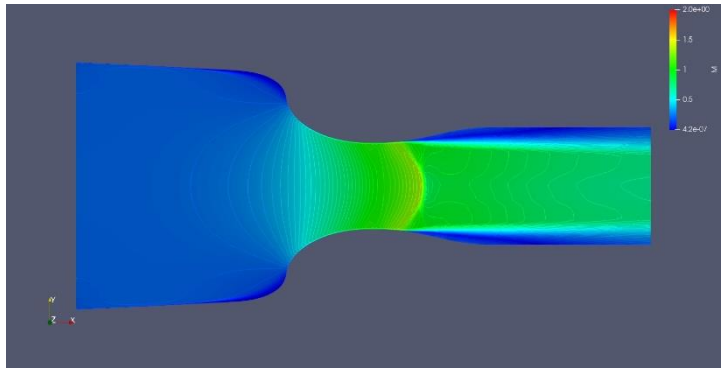
30 mm

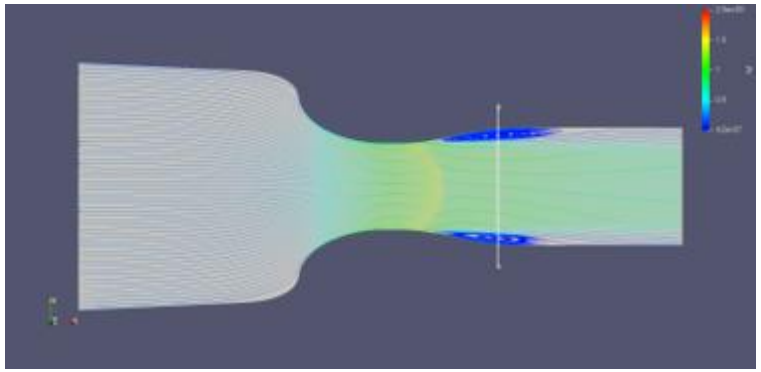


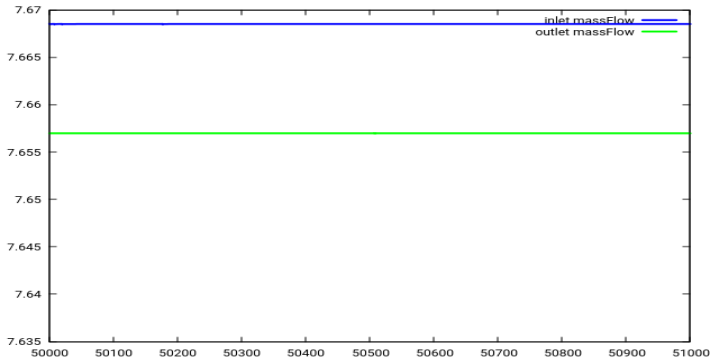




60 mm







isolines of Ma

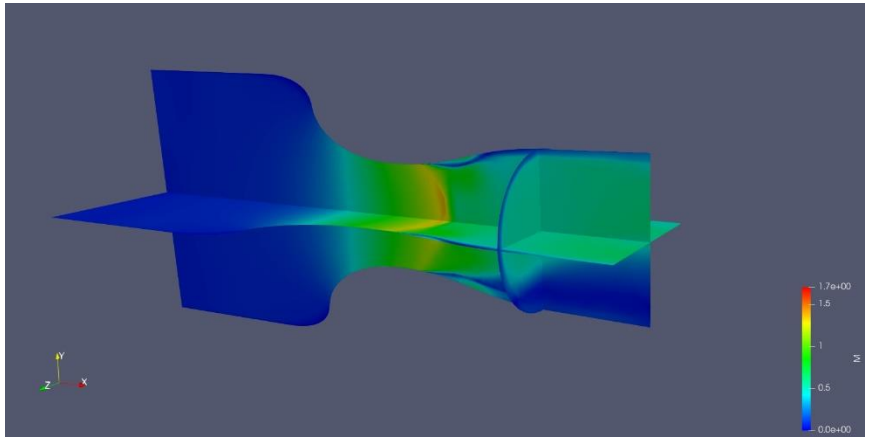
streamlines

mass flow

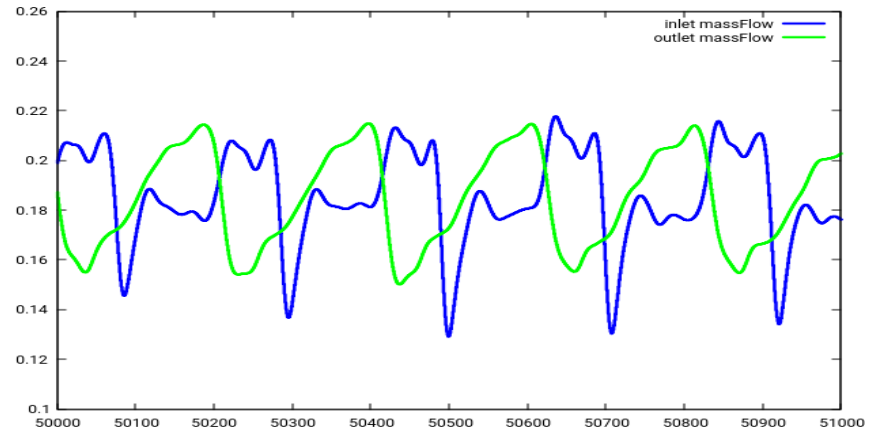
Activities in 4-WP03 Solutions for Flow Component/System Testing and Analysis

4-WP03-003: Database of subsonic flow simulations

3D simulations p2/p0 = 0.75

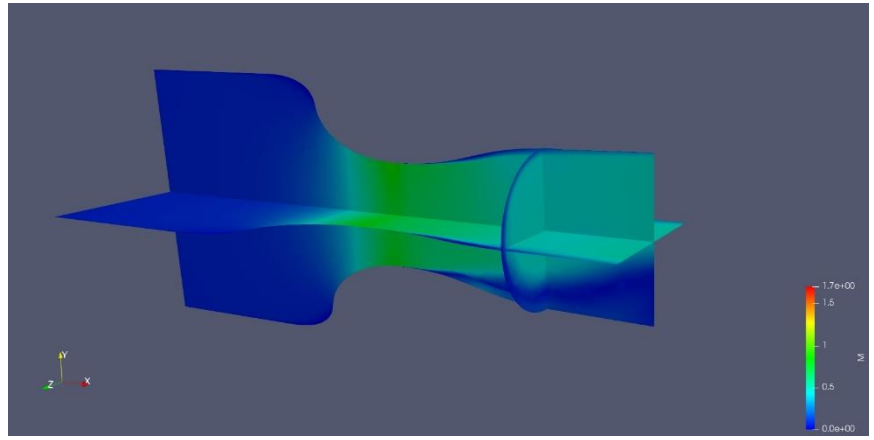


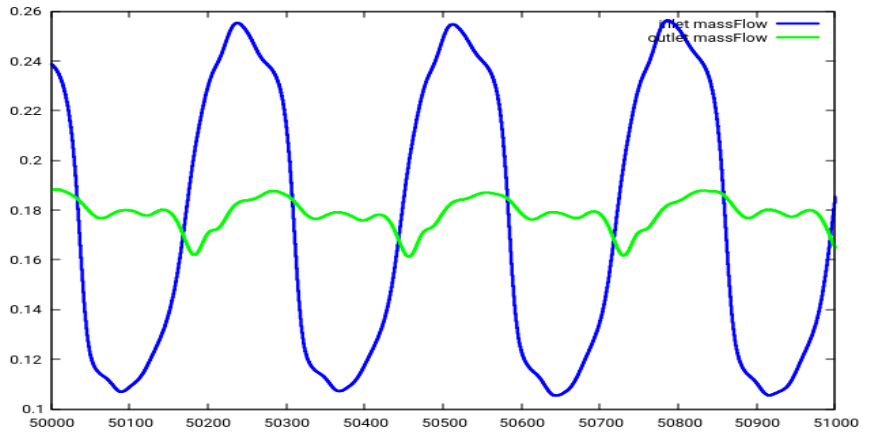
isolines of Ma 3D



mass flow 3D

3D simulations p2/p0 = 0.85





Fulfillment of goals and deliverables of 4-WP03 Solutions for Flow Component/System Testing and Analysis

Current State of Deliverables and Fulfillment of Goals

- 4-WP03-001 | Test bench for hydrogen fuel cell system components,
  G-funk, XII./2025, CTU 0.5; EATON 0.5 – **in progress & no major delays:**
  - Final 3D CAD design of a complete HRB testing loop
  - Purchase components based on calculations & simulations, design of custom designed components
  - 0D and 1D CFD Model of a start phase (inertization, mixture control of H2 & N2 & H2O), leakage simulations for ATEX assessment

- 4-WP03-002 | Optimized restrictor of the compressor for turbocharged high-power SI ICE,
  G-funk, XII./2025, CTU 0.5; SKODA AUTO 0.5 – **in progress & no major delays:**
  - Flow field measurement on the 2D model using Schlieren method on experimental equipment
  - Pressure field measurement on the 2D model using pressure sensitive paint on experimental equipment
  - Fast wall pressure measurement on existing restrictor and on real turbocharged engine

Fulfillment of goals and deliverables of 4-WP03 Solutions for Flow Component/System Testing and Analysis

Current State of Deliverables and Fulfillment of Goals

- 4-WP03-003 | Database of subsonic flow simulations,
  O, XII./2025, CTU 0.95; SKODA AUTO 0.05 – **in progress & no major delays:**
  - 2D model restrictor - flow simulations, comparison with experiment (schlieren imaging measurement)
  - 2D numerical study - variation of outlet pressure, grid topology, length of outlet cylindrical part (database)
  - Numerical simulations for real (3D) restrictor

List of Due Deliverables and Their Added Value

Current contribution of 4-WP03 Solutions for Flow Component/System Testing and Analysis

Assessment of the Contribution of Deliverables

- Fuel Cells and Energy Management for Future Vehicles: 4-WP06
- New ICE Combustion Concepts: 3-WP07
- ICE turbocharging: 3-WP05 a 3-WP06

Current contribution of 4-WP03 Solutions for Flow Component/System Testing and Analysis

Assessment of the Formal/Administrative Goals of the Work Package

	CTU	EATON	SKODA AUTO
Finances (reporting/spending)	OK	OK	OK
Commercialization (the whole organization)	OK	OK	OK
Deliverables	OK	OK	OK

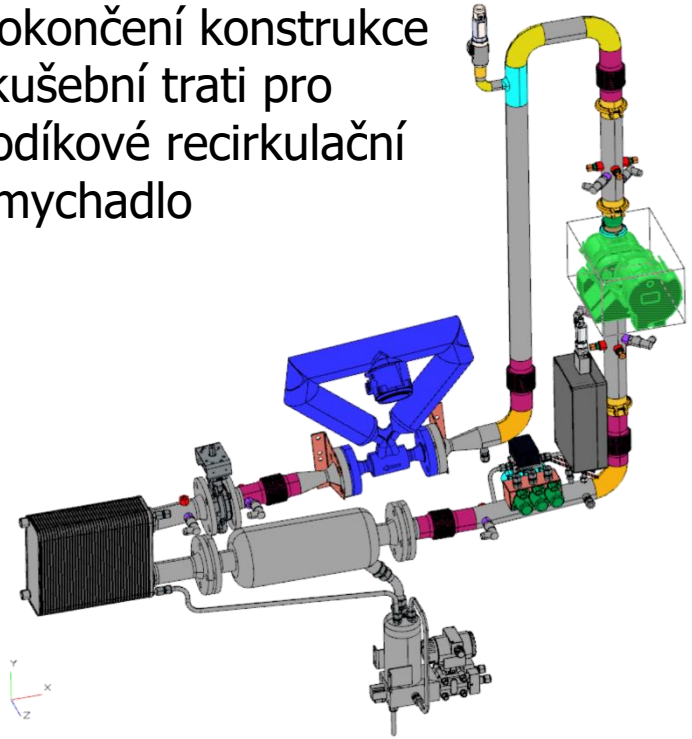
Current contribution of 4-WP03 Solutions for Flow Component/System Testing and Analysis

Acknowledgment

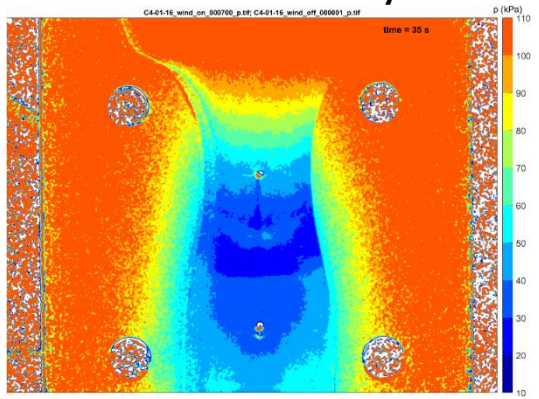
This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

Výtah z prací 2024 na 4-WP03 Řešení pro testování a analýzu komponent průtokových systémů

Dokončení konstrukce zkušební trati pro vodíkové recirkulační dmychadlo

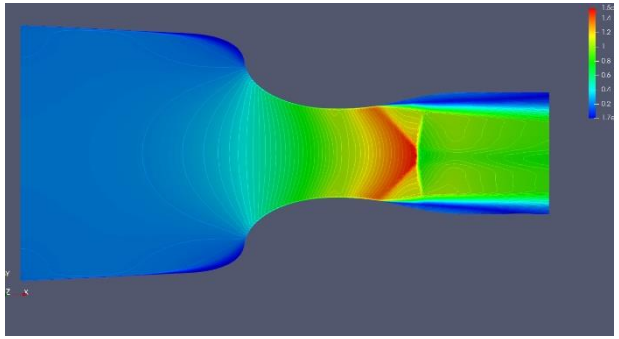


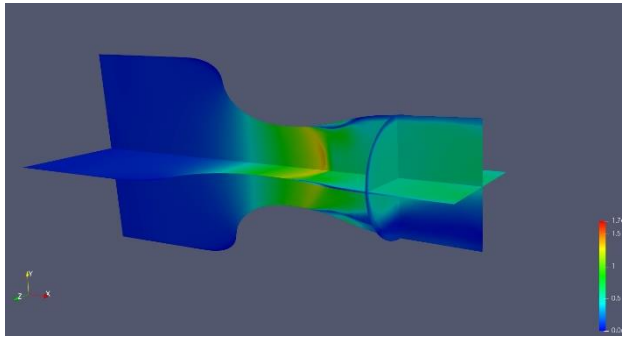
Měření proudového pole v modelu restriktoru šlírovou metodou a metodou tlakových nátěrů



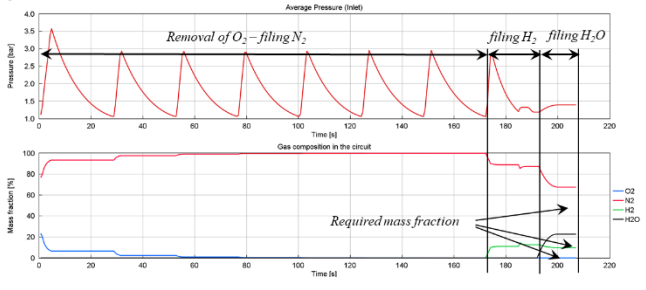
Měření tlaků na skutečném restriktoru

Databáze 2D a 3D numerických studií simulací proudění restriktorem



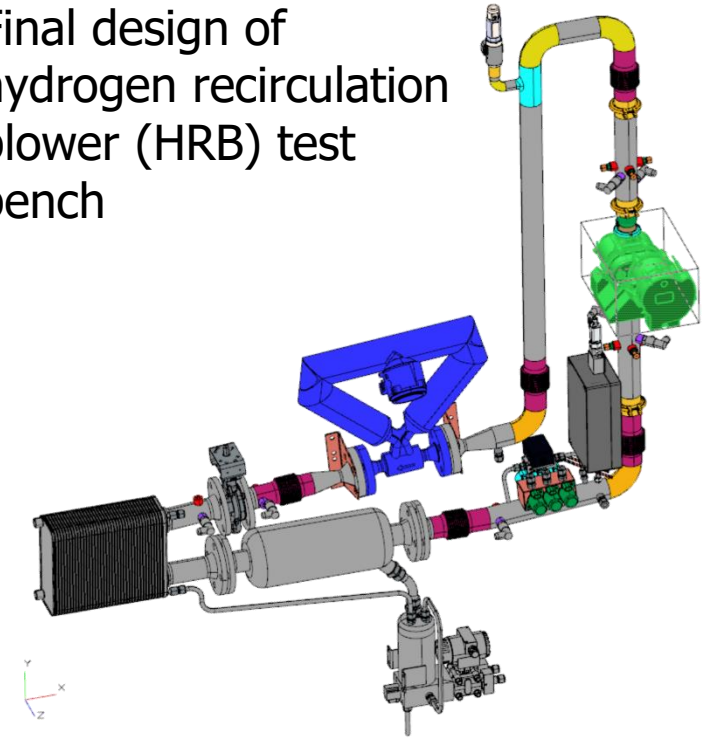


Simulace spouštění trati (inertizace, řízení složení směsi), simulace úniků (ATEX)

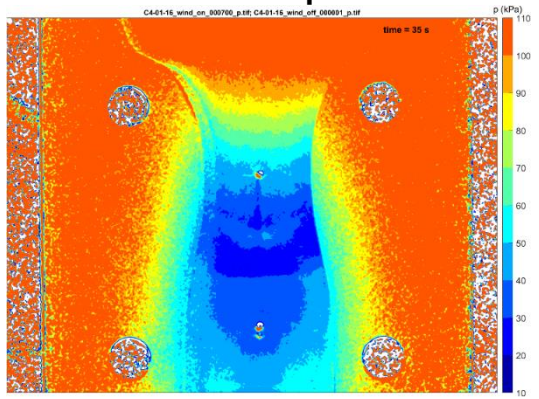


Results of 4-WP03 Solutions for Flow Component/System Testing and Analysis – achieved 2024

Final design of hydrogen recirculation blower (HRB) test bench

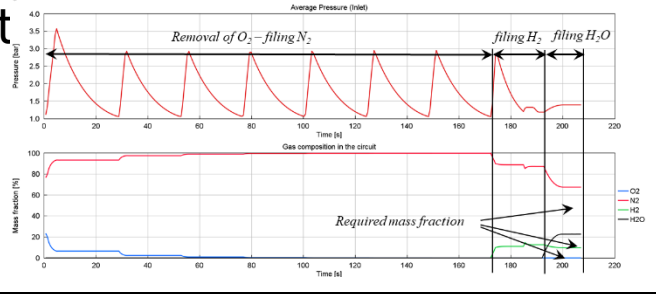


Restrictor model flow field measurement using Schlieren and pressure sensitive paint method

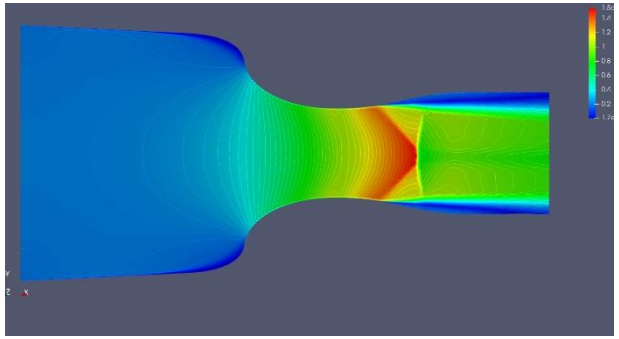


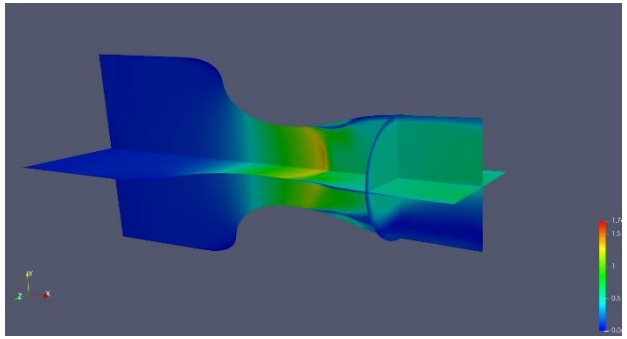
Pressure measurement on real restrictor

Simulation of a start phase (inertization, mixture control, leakage simulations for ATEX



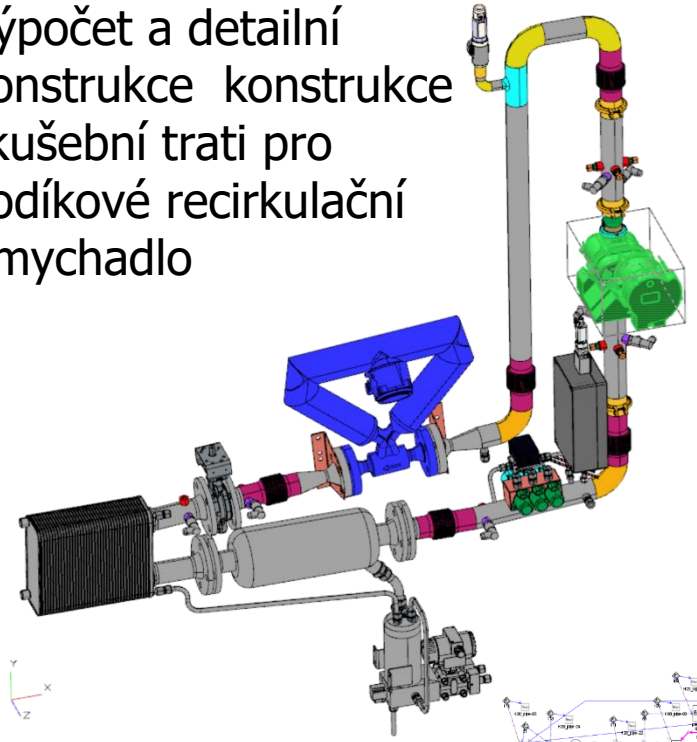
Database of 2D a 3D studies of in-restrictor flow numerical simulation



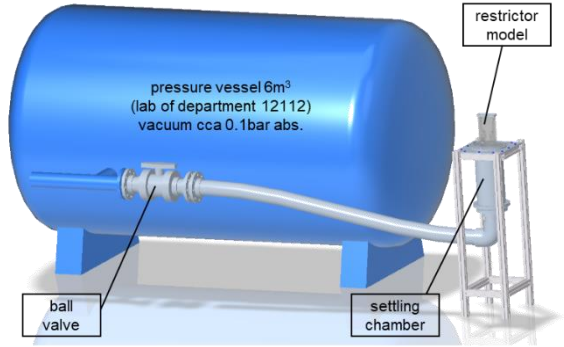


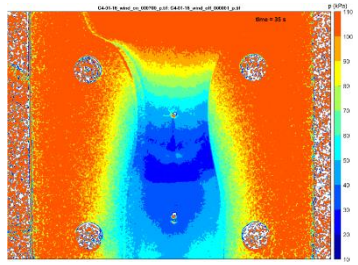
Výtah z prací 2023-2025 na 4-WP03 Řešení pro testování a analýzu komponent průtokových systémů

Výpočet a detailní konstrukce konstrukce zkušební trati pro vodíkové recirkulační dmychadlo



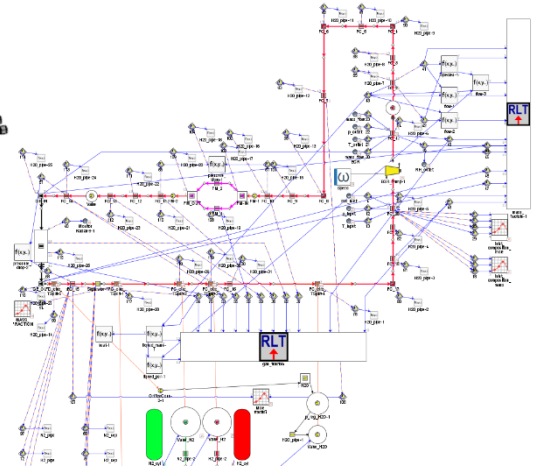
Měřicí trať pro testování modelů restriktoru, měření proudového pole různými metodami



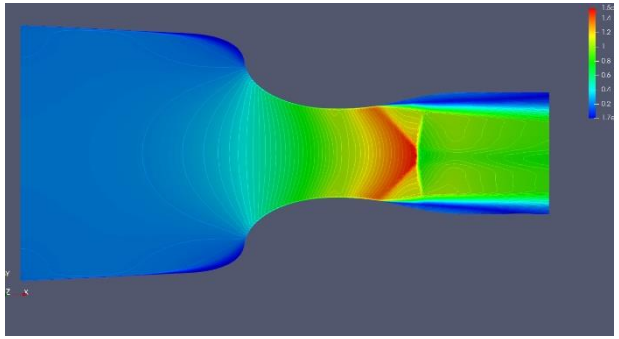


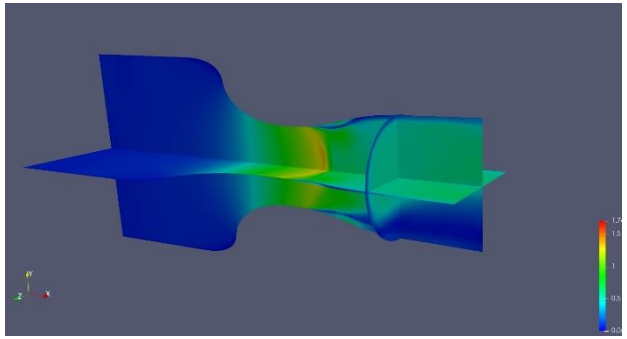
Měření tlaků na skutečném restriktoru

Simulace provozu a spouštění trati bezpečnostní simulace



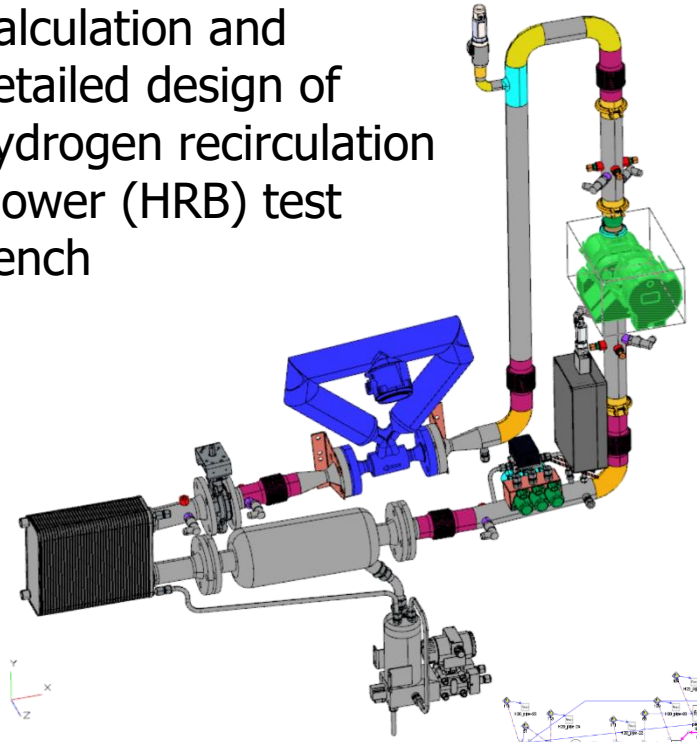
Databáze 2D a 3D numerických studií simulací proudění restriktorem



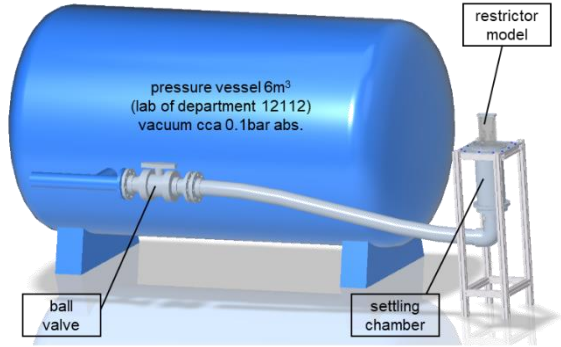


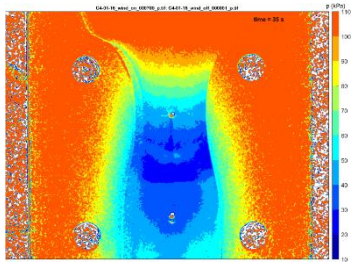
Results of 4-WP03 Solutions for Flow Component/System Testing and Analysis – achieved 2023-2025

Calculation and detailed design of hydrogen recirculation blower (HRB) test bench



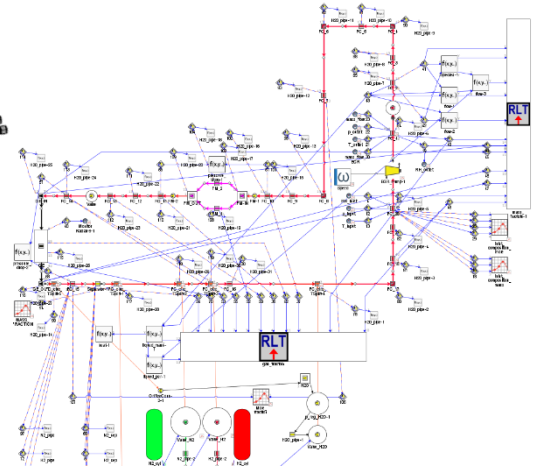
Experimental test bench for restrictor flow field measurements by various methods





Pressure measurement on real restrictor

Simulation of HRB bench operation and start, safety simulation



Database of 2D a 3D studies of in-restrictor flow numerical simulation