

Magnetresonanz-Velocimetrie in Wasserstoff Brennkammern – Ein erster Vergleich mit CFD

Swantje Romig, Nina Paulitsch,
Fabrice Giuliani, Sven Grundmann,
Robert Krewinkel, Martin
Bruschewski

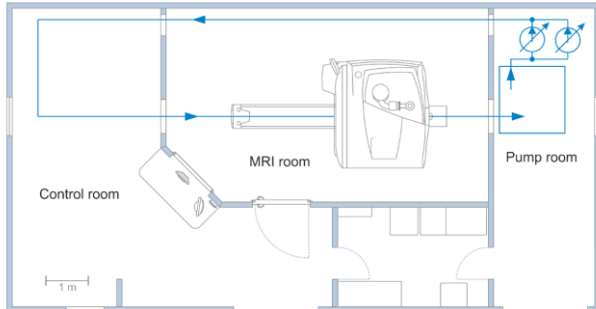
Gefördert durch:



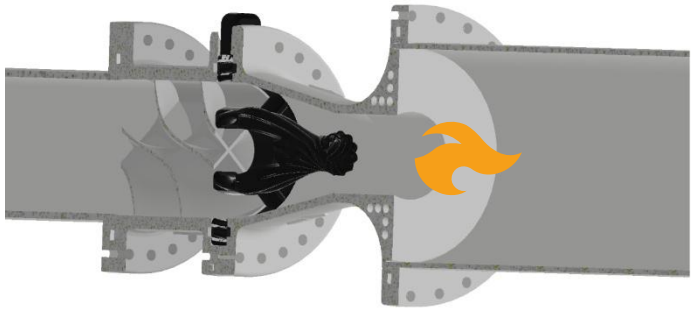
Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

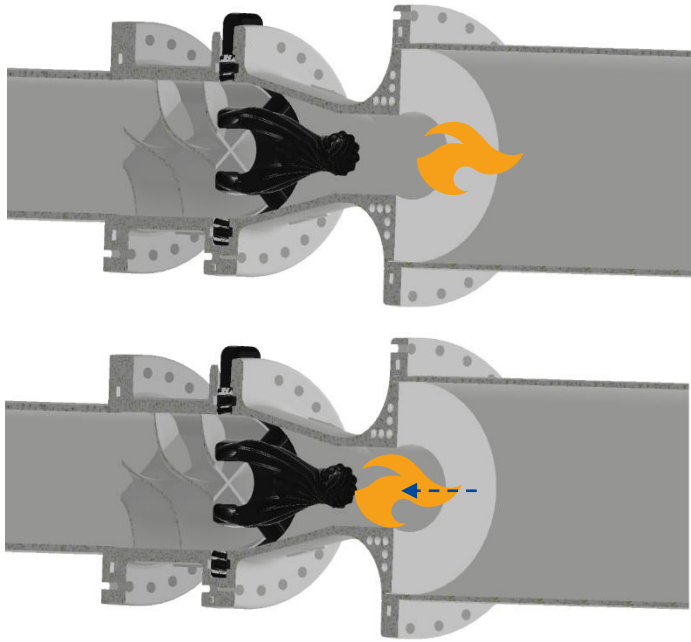
MRI flow lab Universität Rostock



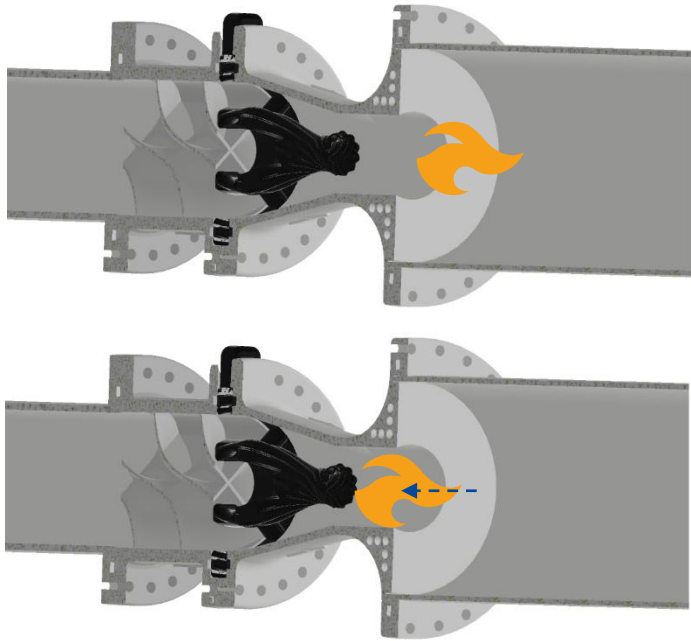
Wasserstoff in Gasturbinen



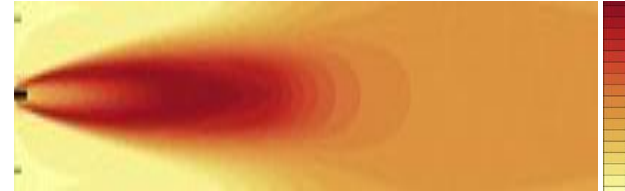
Wasserstoff in Gasturbinen



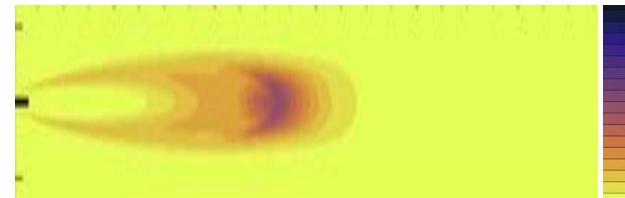
Wasserstoff in Gasturbinen



Temperatur

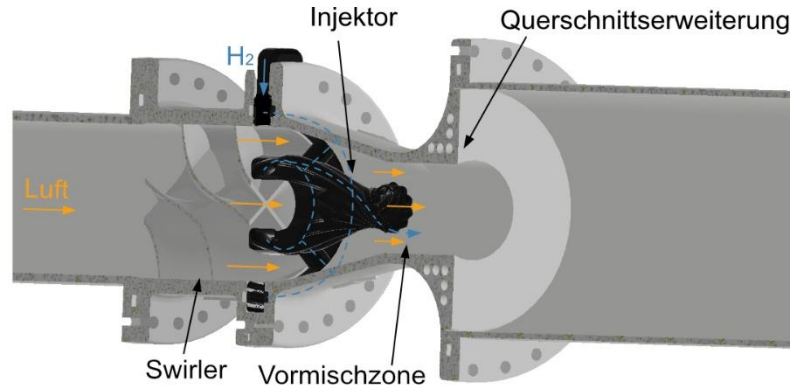


NOx-Emissionen



Cellek, 2022: The decreasing effect of ammonia enrichment on the combustion emission of hydrogen, methane, and propane fuels

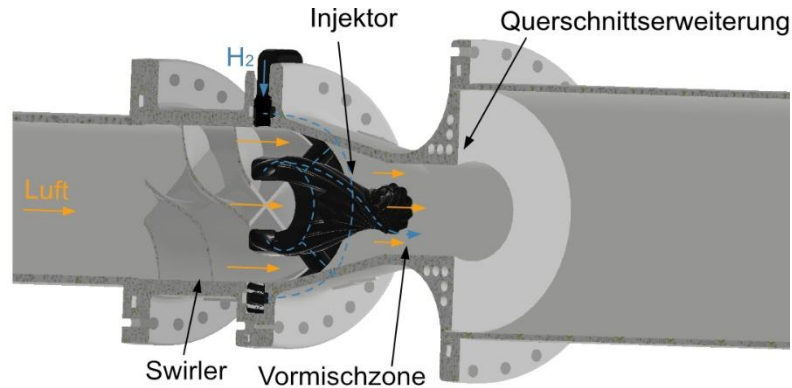
Mischungsprozesse in Wasserstoffbrennkammern



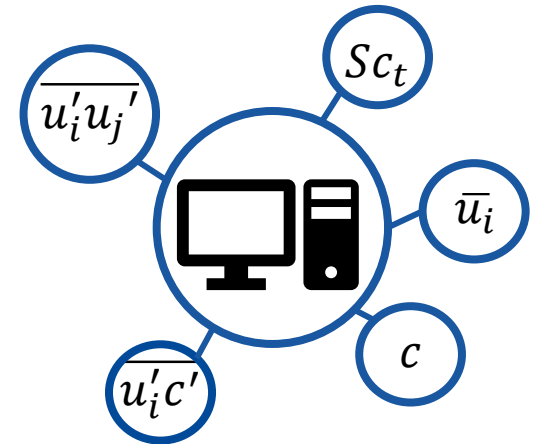
Paulitsch, 2023: Validation of a combined optic-acoustic probe on hydrogen flames using an atmospheric lean premix pilot burner



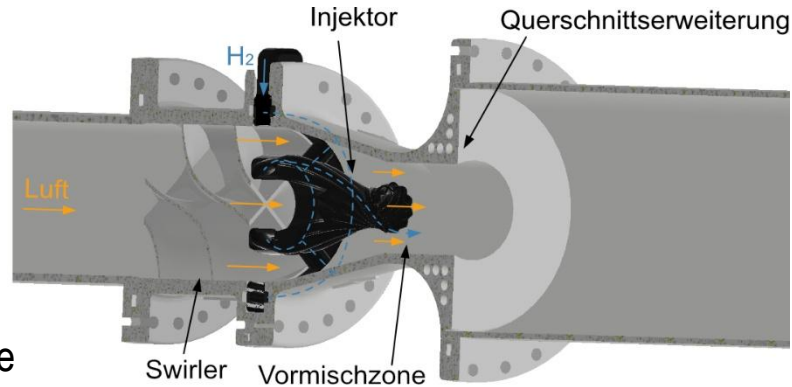
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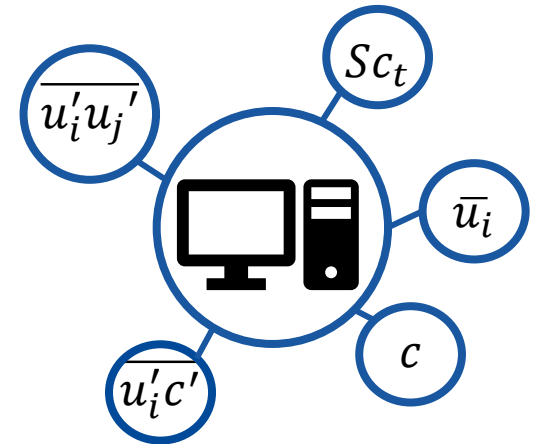
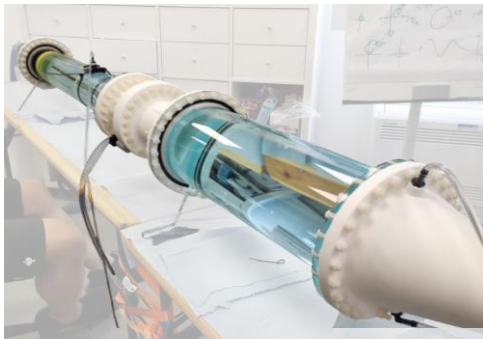
Mischungsprozesse in Wasserstoffbrennkammern



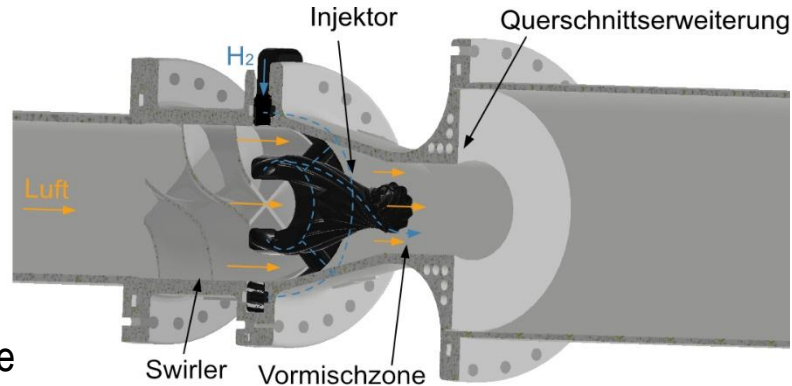
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Wasserkanalexperimente



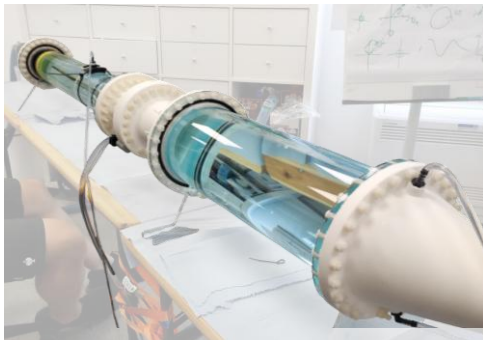
Mischungsprozesse in Wasserstoffbrennkammern



Paulitsch, 2023: Validation of a combined optic-acoustic probe on hydrogen flames using an atmospheric lean premix pilot burner

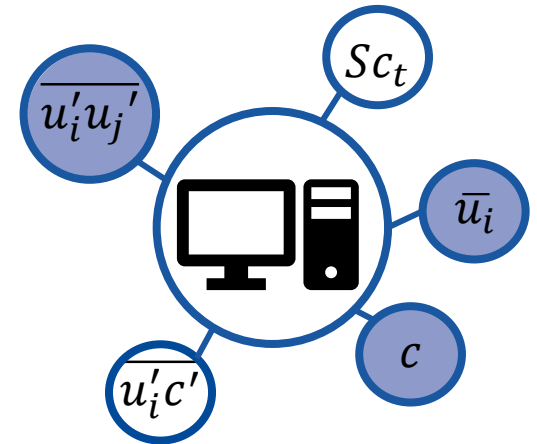


Wasserkanalexperimente



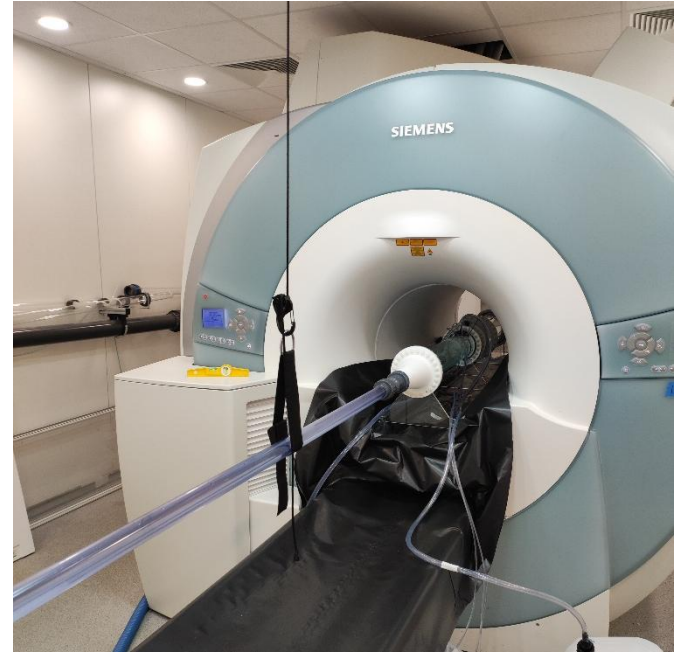
Validierung

Strömungstopologie
Brennstoffplatzierung



MRT-Messtechnik

- Arbeitsfluid: Wasser

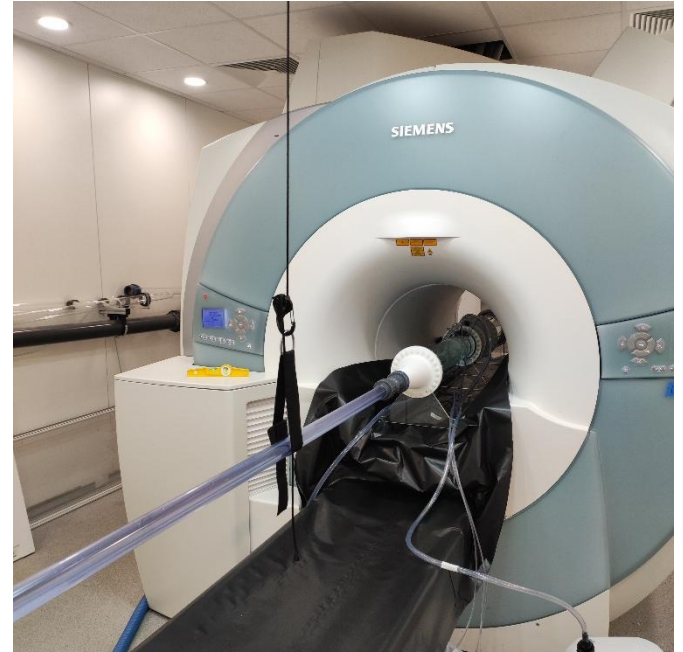


MRT-Messtechnik

- Arbeitsfluid: Wasser

$$Re = \frac{u d}{\nu}$$

$$J = \frac{\rho_{H_2} u_{H_2}^2}{\rho_{Luft} u_{Luft}^2}$$



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- MR-kompatible Materialien



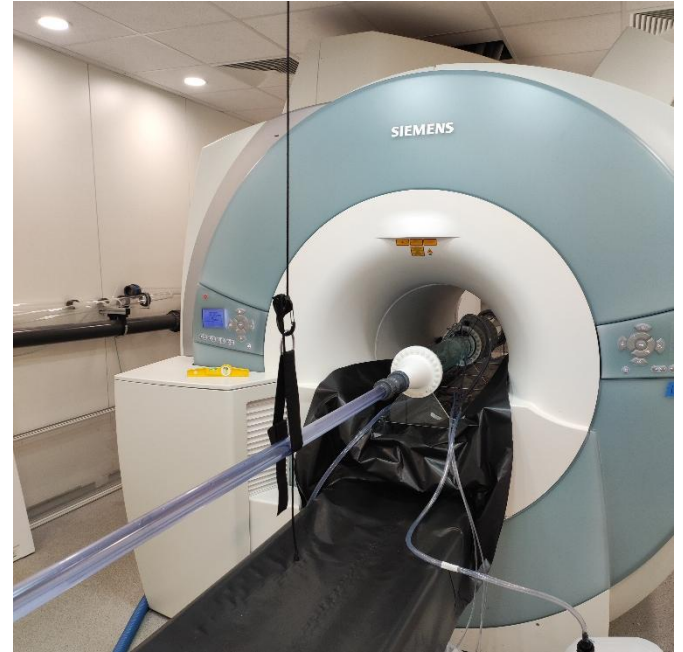
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- MR-kompatible Materialien
- kein optischer Zugang nötig



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- kein optischer Zugang nötig
- komplexe 3D Messvolumen



MRT-Messtechnik

- Arbeitsfluid: Wasser

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$$J = \frac{\rho_{H_2} u_{H_2}^2}{\rho_{Luft} u_{Luft}^2}$$

- MR-kompatible Materialien
- kein optischer Zugang nötig
- komplexe 3D Messvolumen
- zeitgemittelt

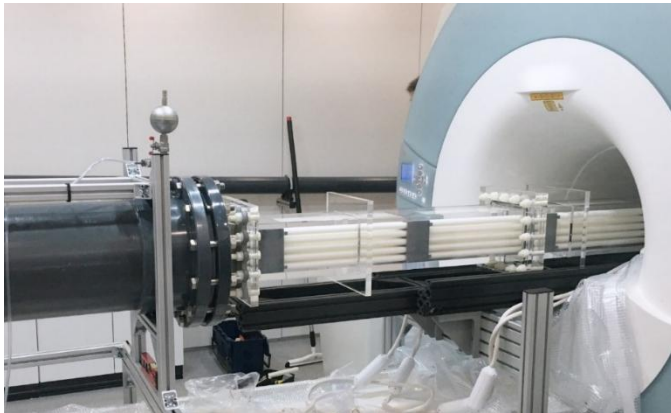


Magnetresonanz-Velocimetrie (MRV)

John, 2023: Improved Magnetic Resonance Velocimetry to Acquire Velocity and Turbulence Statistics for Nuclear Reactor Safety Problems



Mittlere Geschwindigkeit in einem Kernreaktor Mockup



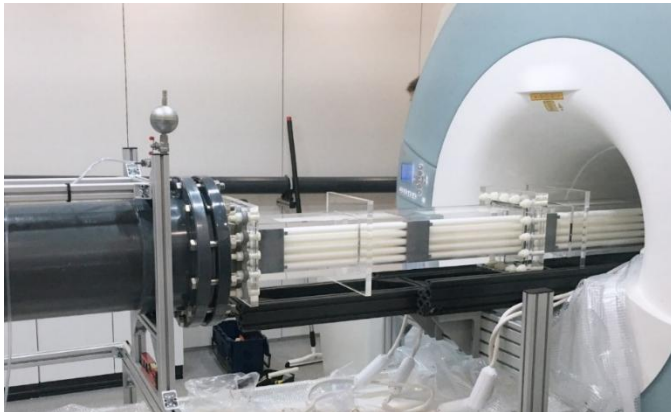
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Mittlere Geschwindigkeit in einem Kernreaktor
Mockup

Linearer Zusammenhang
mittlere Geschwindigkeit - Signalphase



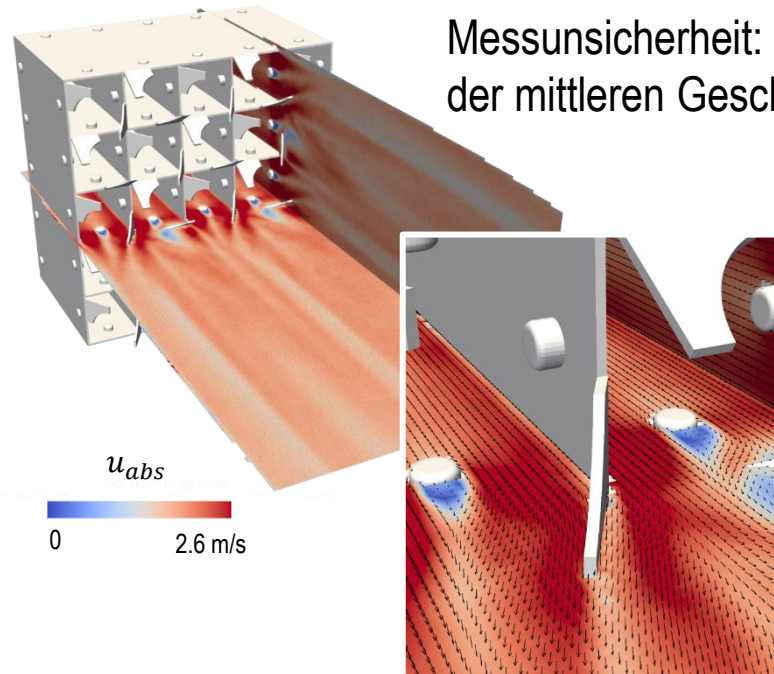
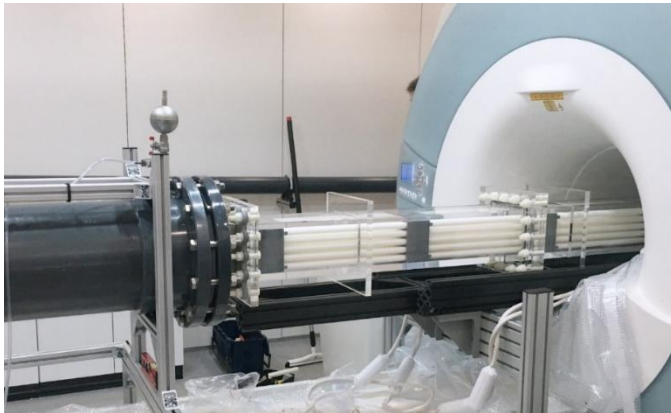
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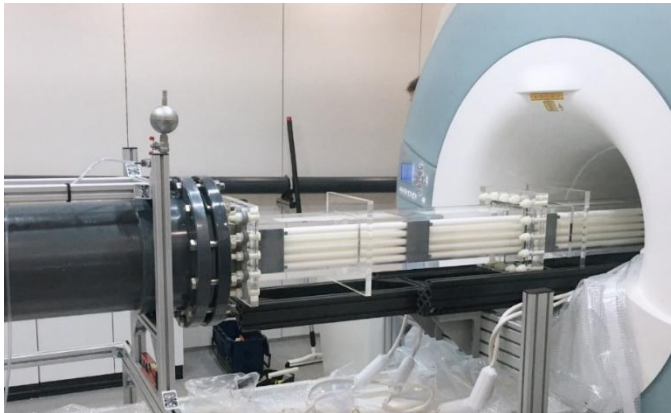
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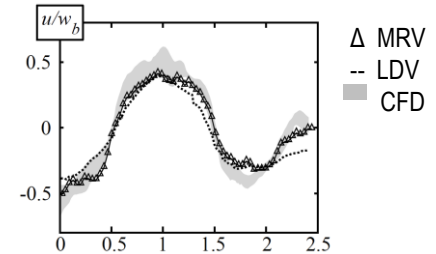
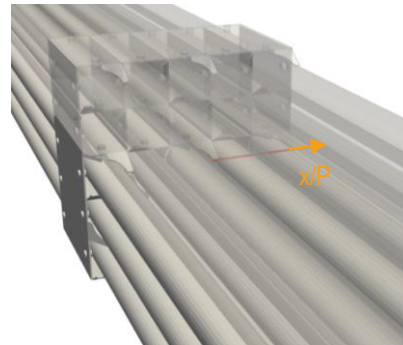


Mittlere Geschwindigkeit in einem Kernreaktor Mockup

Linearer Zusammenhang
mittlere Geschwindigkeit - Signalphase

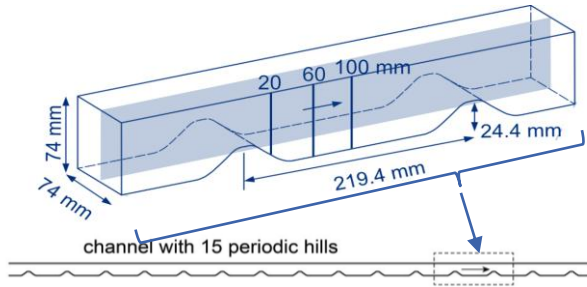


Validierung mittels LDV



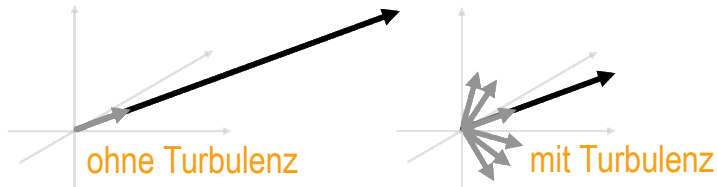
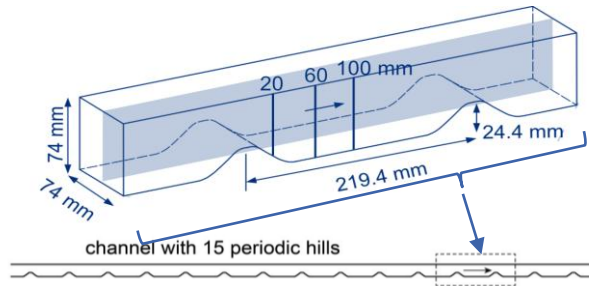
Turbulenzquantifizierung

Romig, 2025: Improving MRI turbulence quantification by addressing the measurement errors caused by the derivatives of the turbulent velocity field – Sequence development and in-vitro validation



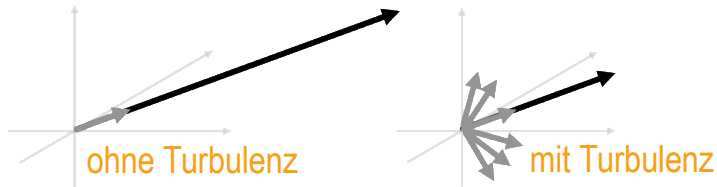
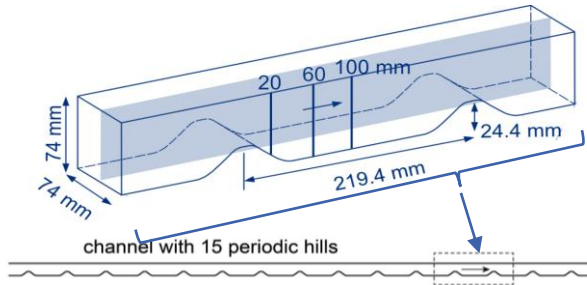
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Turbulenzquantifizierung

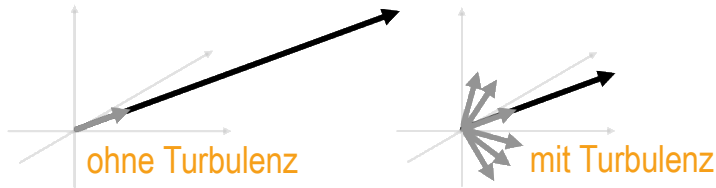
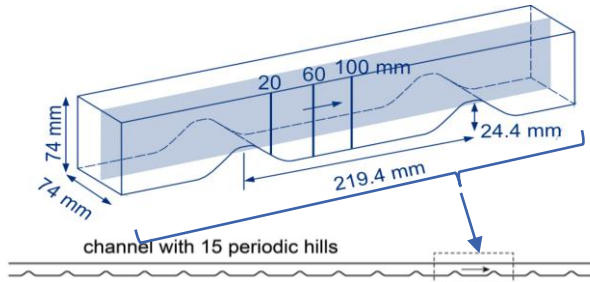
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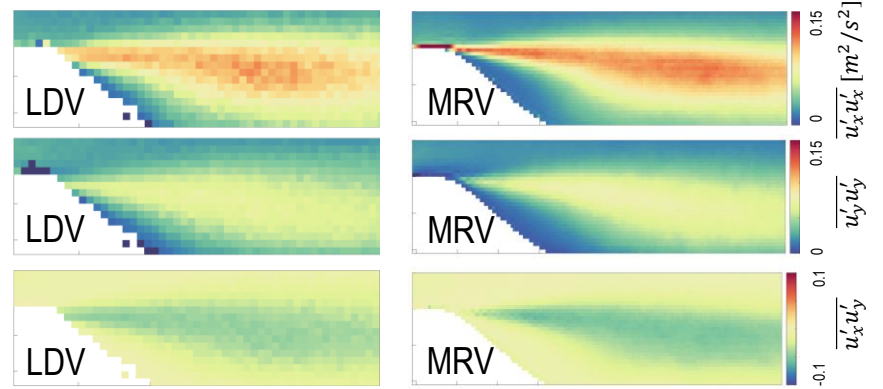
Zusammenhang Signalintensität -
Geschwindigkeitssensitivität, Turbulenz

Turbulenzquantifizierung

Romig, 2025: Improving MRI turbulence quantification by addressing the measurement errors caused by the derivatives of the turbulent velocity field – Sequence development and in-vitro validation



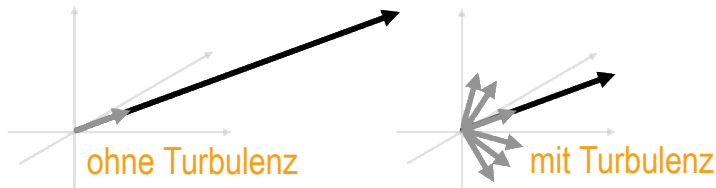
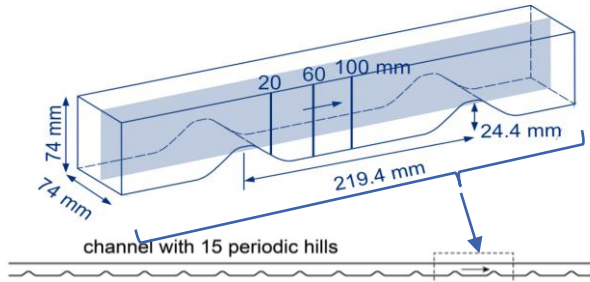
Zusammenhang Signalintensität -
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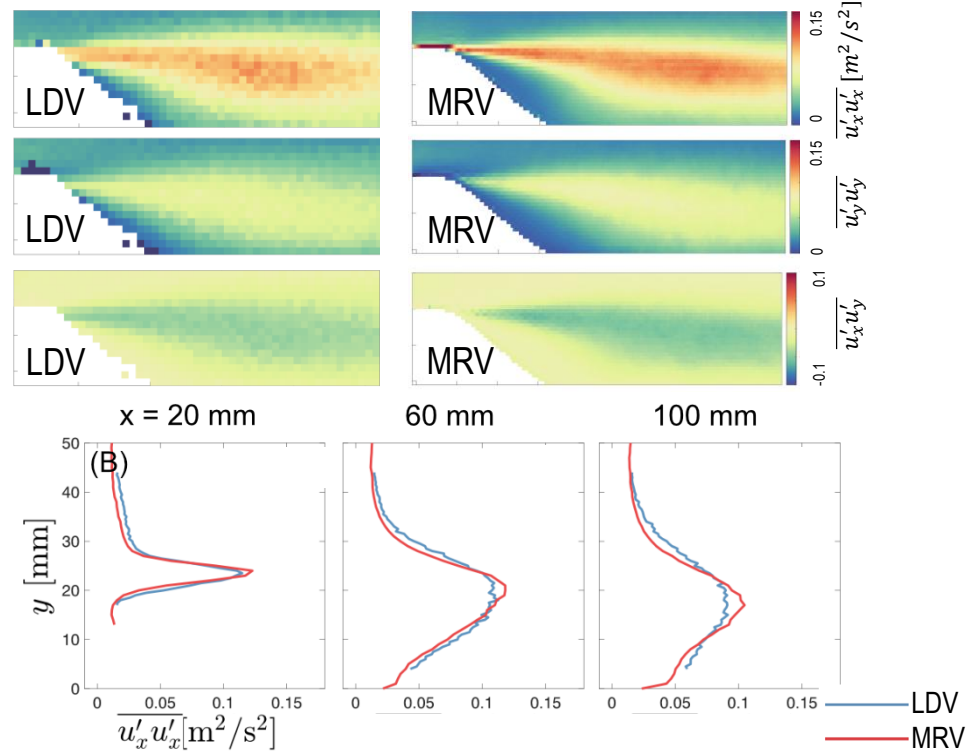
Messunsicherheit: 1 %
der Maximalwerte

Turbulenzquantifizierung

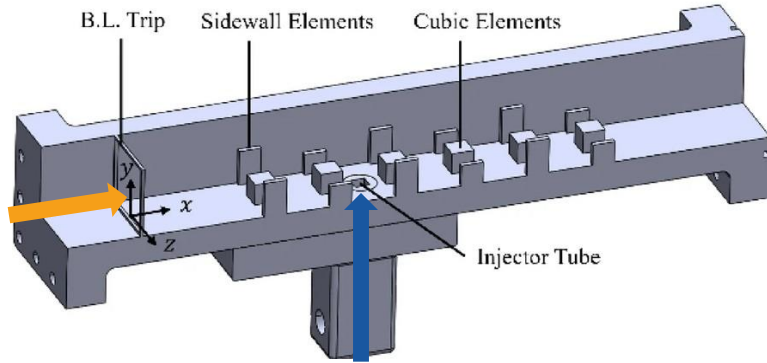
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Zusammenhang Signalintensität -
Geschwindigkeitssensitivität, Turbulenz



Magnetresonanz-Konzentrationsmessungen (MRC)



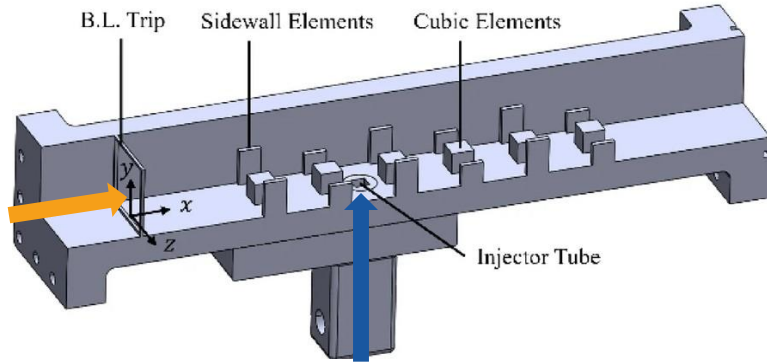
Benson, 2023: MRV challenge 2: phase locked turbulent measurements in a roughness array



Destilliertes Wasser

+ CuSO₄

Magnetresonanz-Konzentrationsmessungen (MRC)



Benson, 2023: MRV challenge 2: phase locked turbulent measurements in a roughness array

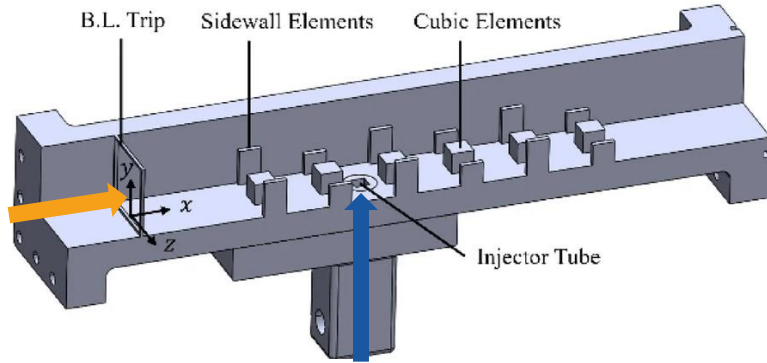


Destilliertes Wasser

+ CuSO₄

Linearer Zusammenhang
Konzentration CuSO₄ - Signalintensität

Magnetresonanz-Konzentrationsmessungen (MRC)



Benson, 2023: MRV challenge 2: phase locked turbulent measurements in a roughness array

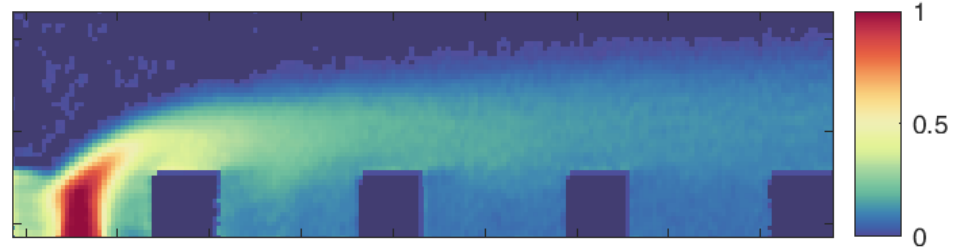


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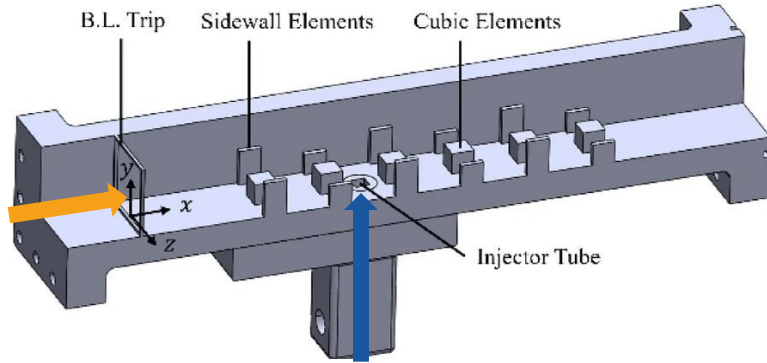
Linearer Zusammenhang
Konzentration CuSO₄ - Signalintensität

normierte gemessene CuSO₄-Konzentration



Messunsicherheit 0,46 % der maximalen Konzentration

Magnetresonanz-Konzentrationsmessungen (MRC)



Benson, 2023: MRV challenge 2: phase locked turbulent measurements in a roughness array

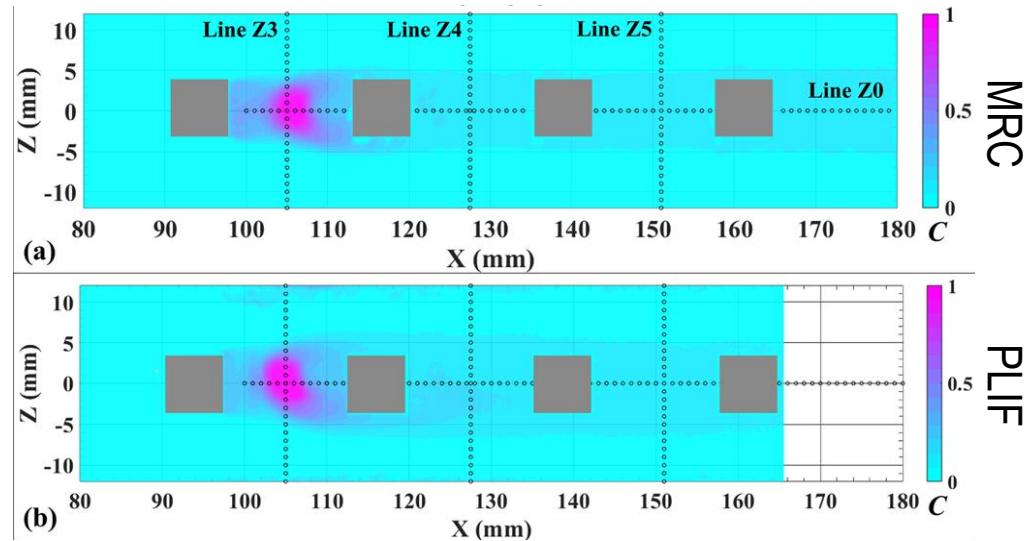


Destilliertes Wasser

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Linearer Zusammenhang
Konzentration CuSO₄ - Signalintensität

Validierung mittels PLIF

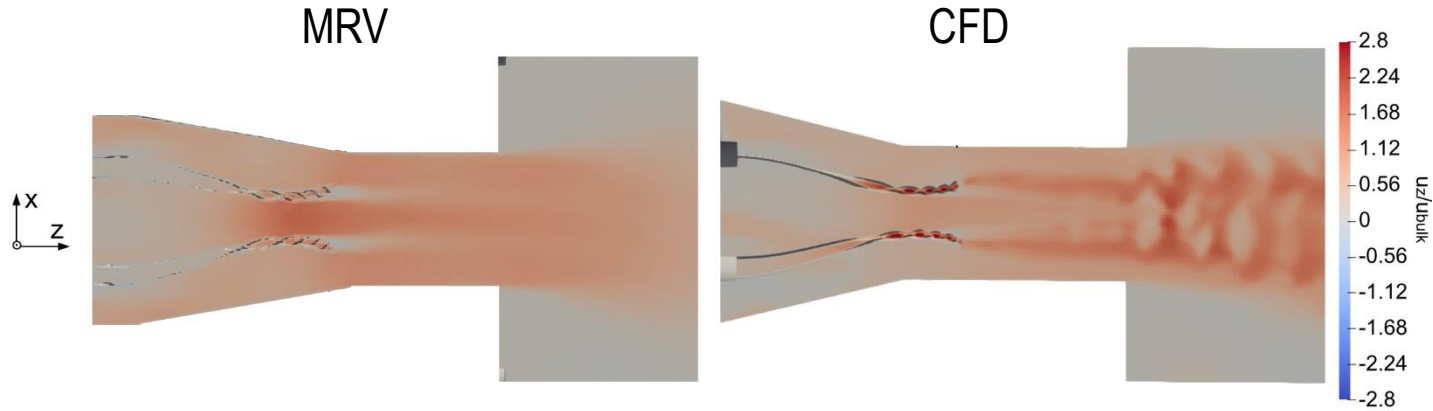


Nguyen, 2025: Multimode turbulent flow measurements using magnetic resonance imaging- and laser-based techniques and computational fluid dynamics simulations



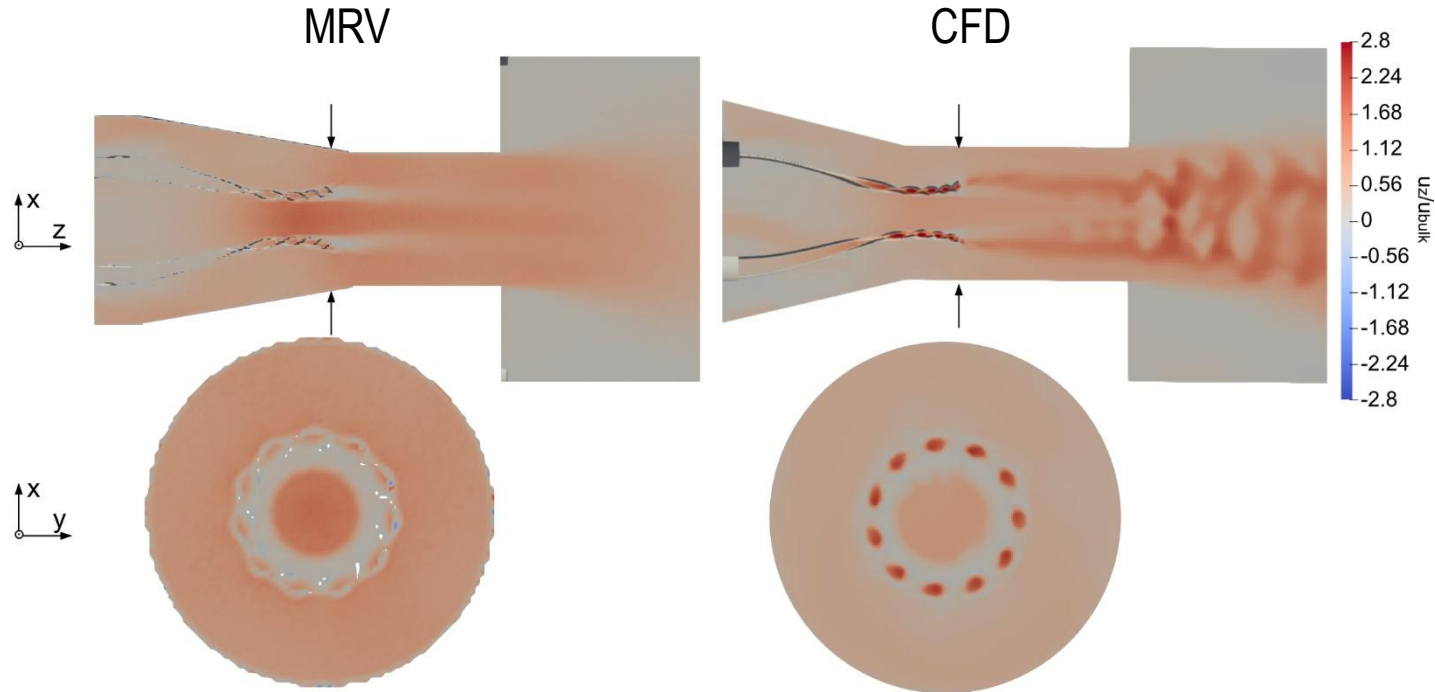
Geschwindigkeitsfelder

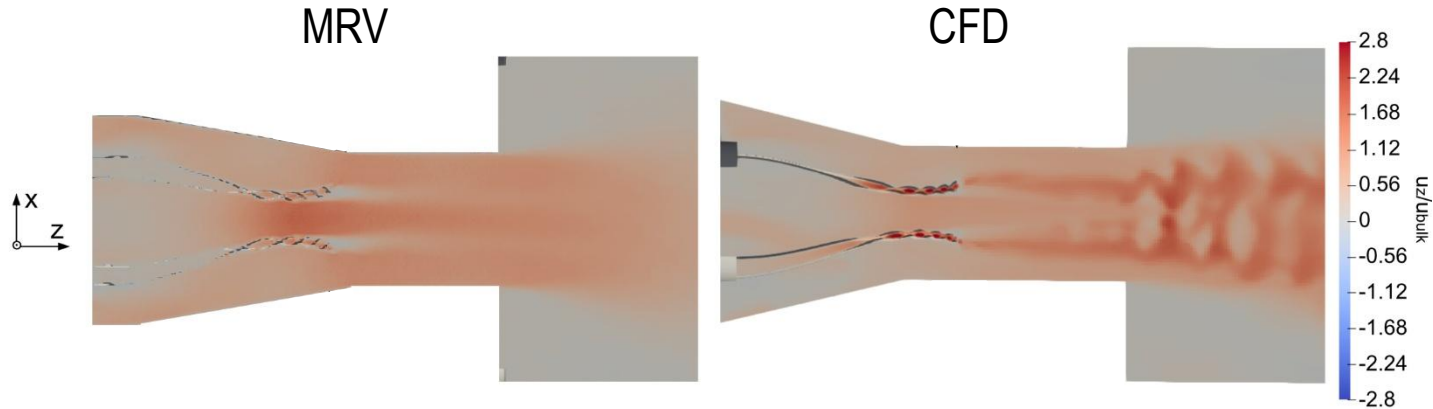
CFD: RANS mit Flamelet-Methode
(Verbrennung) in OpenFoam



Geschwindigkeitsfelder

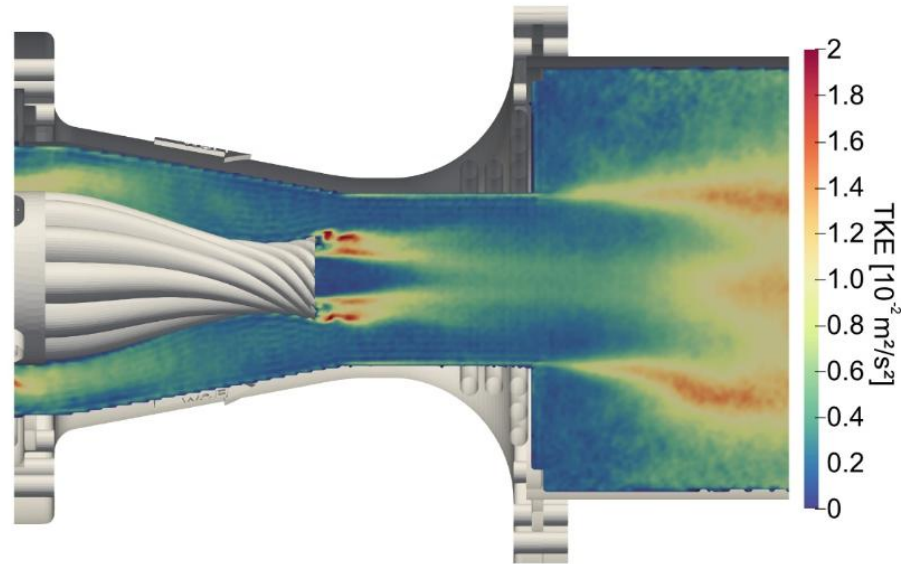
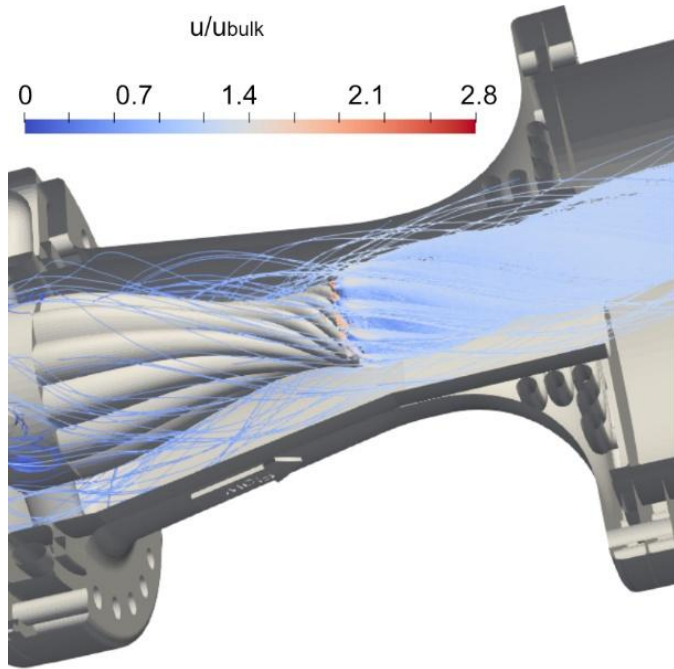
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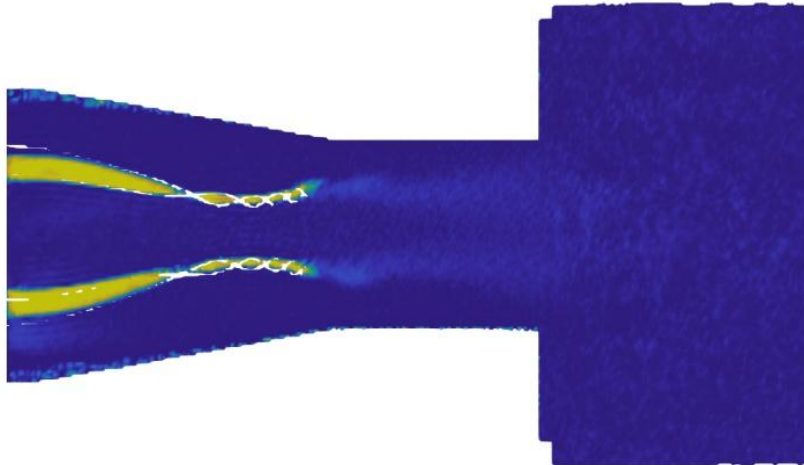
Drallzahl $S = \frac{\int_0^R \rho u_{ax} u_{tan} r^2 dr}{R \int_0^R \rho u_{ax}^2 r dr}$	0.3 ... 0.5	0.3 ... 0.15
Reynoldszahl $Re = \frac{u d}{\nu}$	22.368	12.012

Strömungsfeld MRV

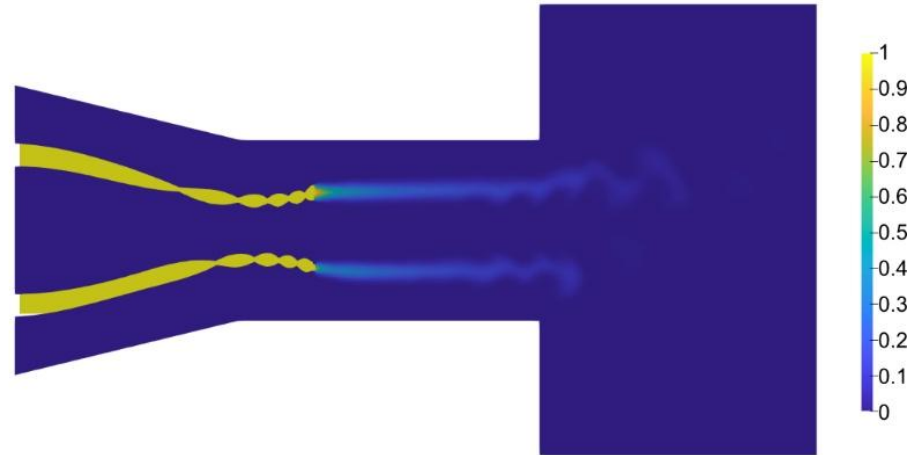


Mischungsverhalten

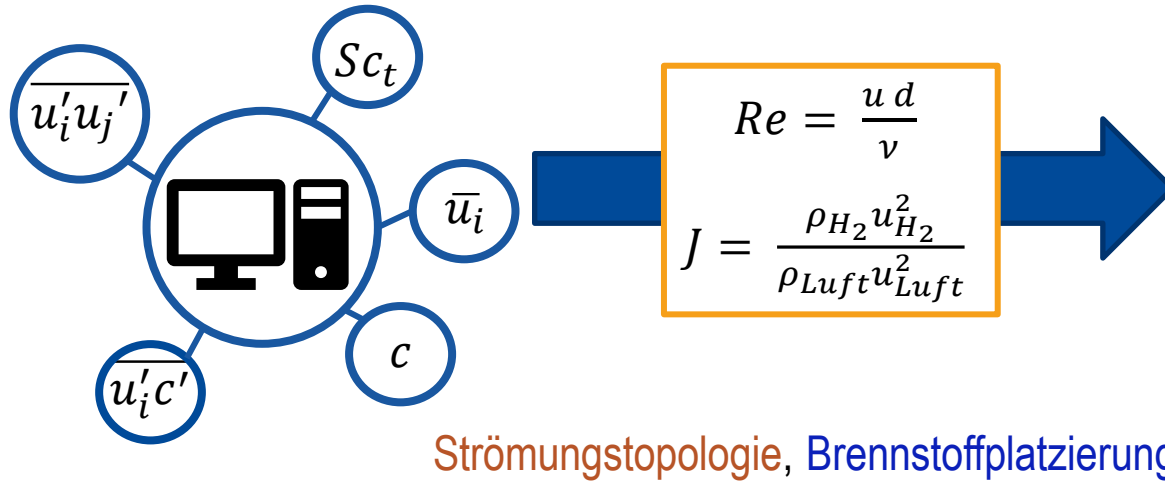
MRC



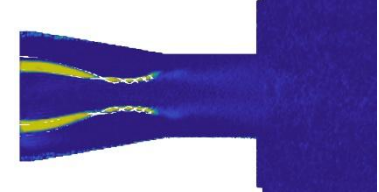
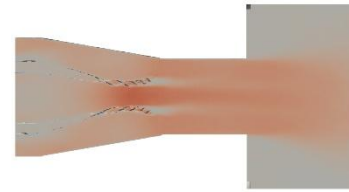
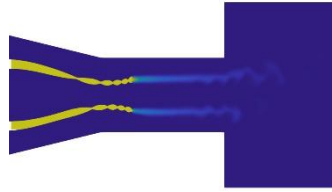
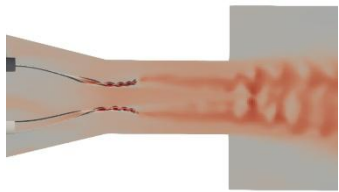
CFD



Zusammenfassung



Strömungstopologie, Brennstoffplatzierung



Vielen Dank für Ihre Aufmerksamkeit!

Gefördert durch:



Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

