HILITE INTERNATIONAL

Analysis and optimization of an ejector for a fuel cell recirculation module

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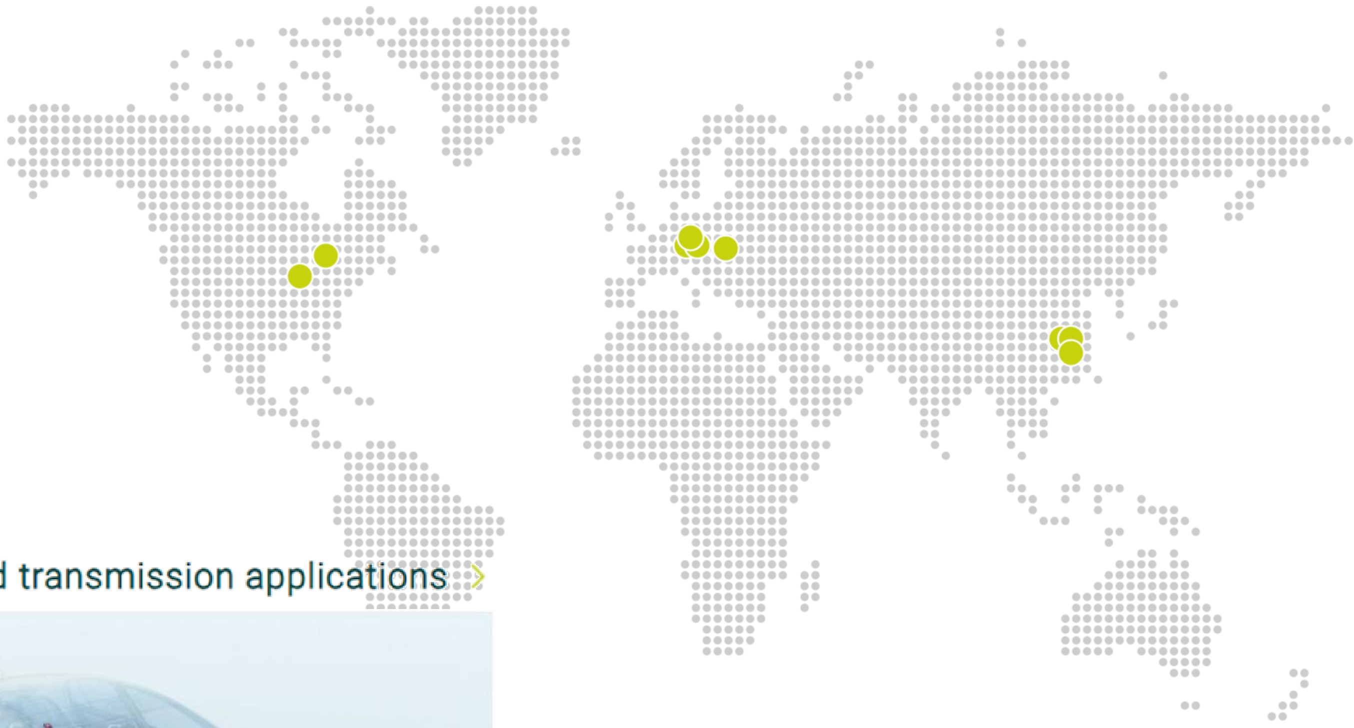
Thursday, 22.06.2022

Agenda

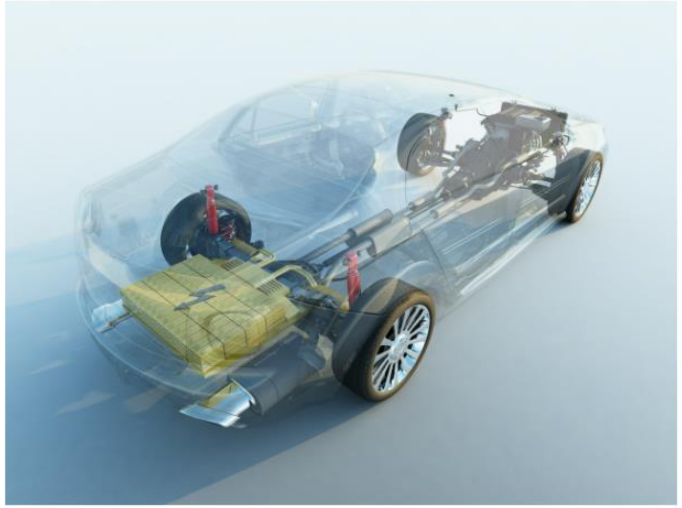
1. Short introduction of Hilite
2. Introduction to the task
3. Initial analysis of the module
4. Details of the optiSLang system
5. First optimization loop
6. Second optimization loop
7. Conclusion

01 Hilite International

- automotive company
- founded in 1930
- about 1700 employees
- 9 locations on 3 continents
- 550 Mio. € turnover



Electric, hybrid and hydrogen drives ›

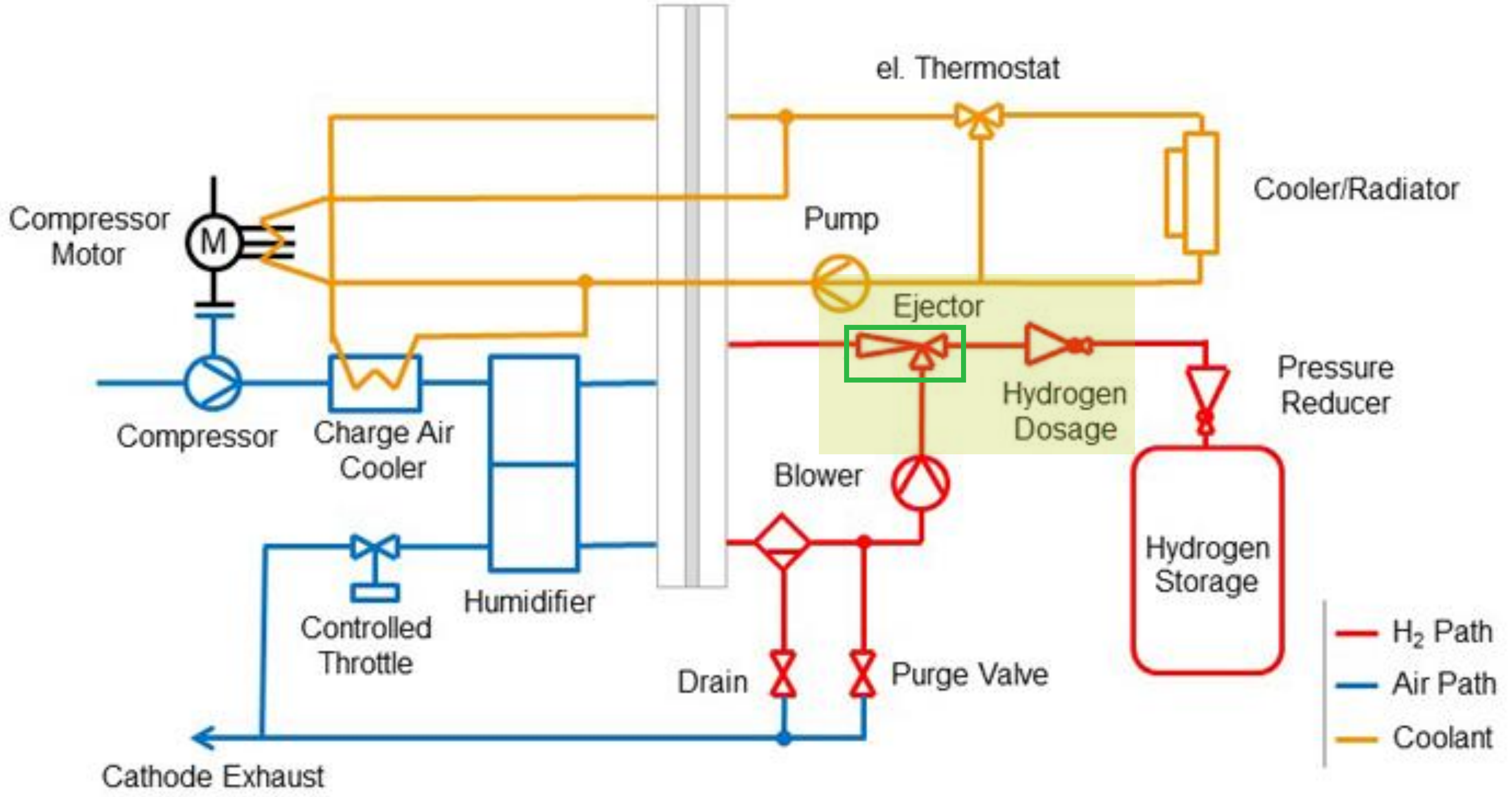


Engine and transmission applications ›

Introduction

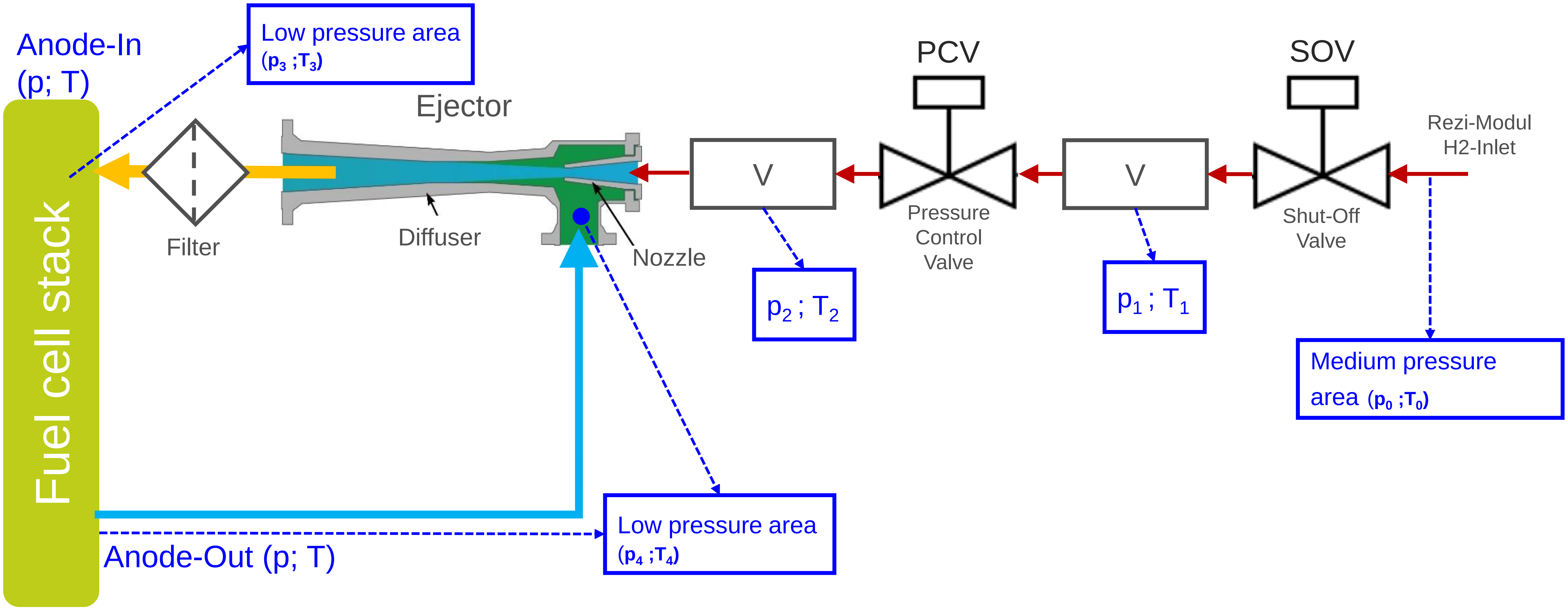
Task, starting conditions and system setup

Overview fuel cell system



Quelle: [Fuel cell and hydrogen technologies - RWTH AACHEN UNIVERSITY Center for Mobile Propulsion - English (rwth-aachen.de)]

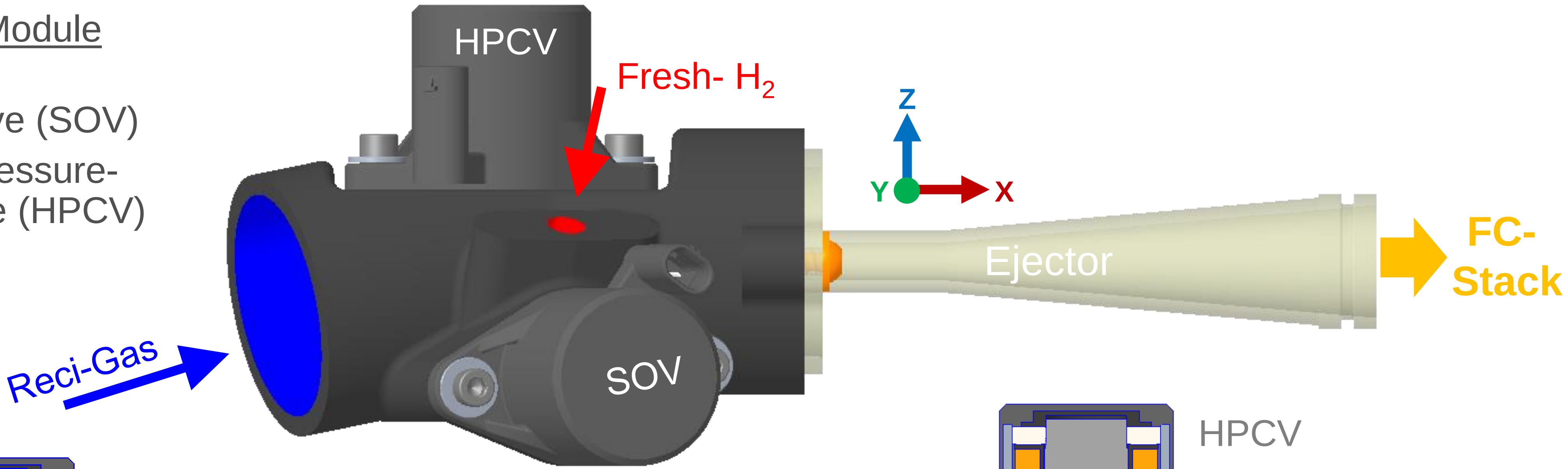
System overview

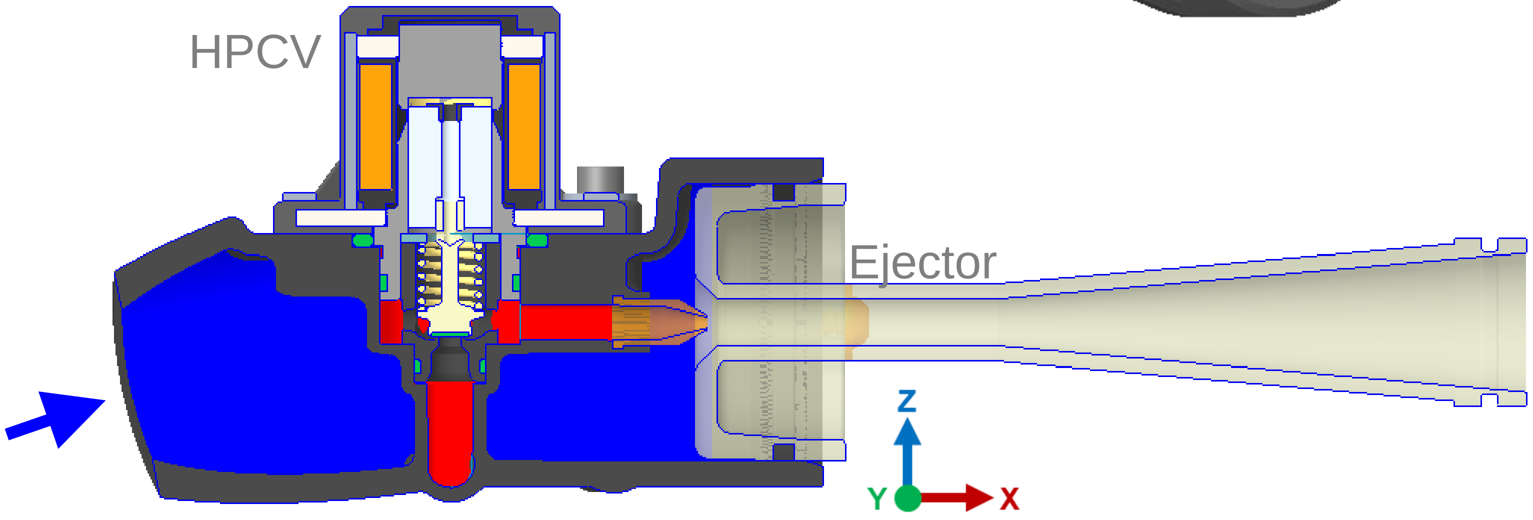


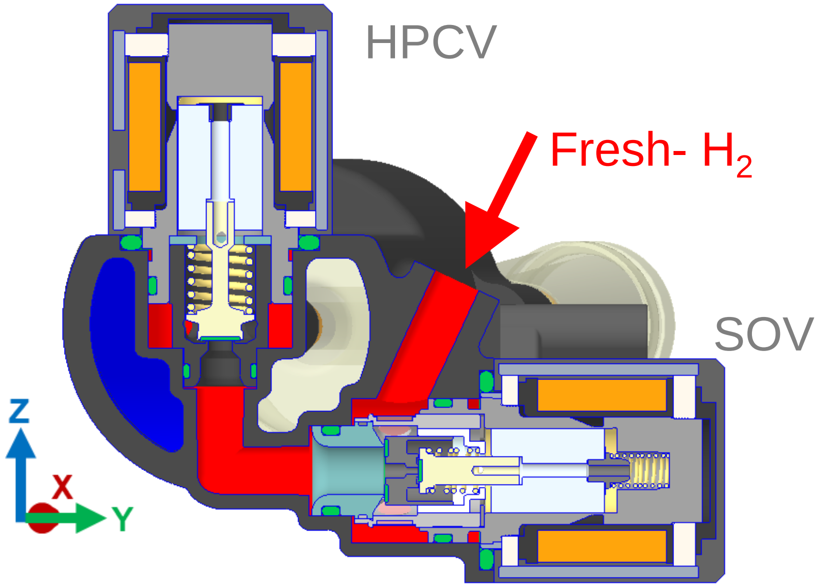
Module overview

Recirculation Module Components:

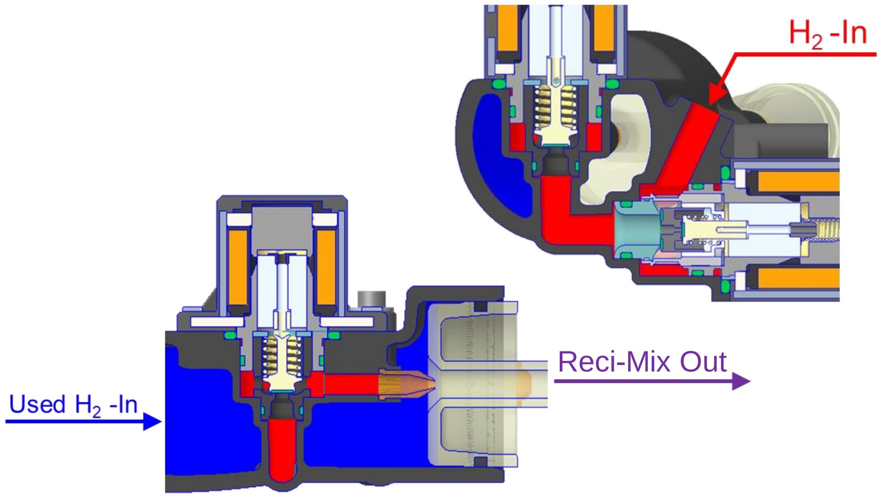
- Shut-Off-Valve (SOV)
- Hydrogen-Pressure-Control-Valve (HPCV)
- Nozzle
- Ejector







Starting condition

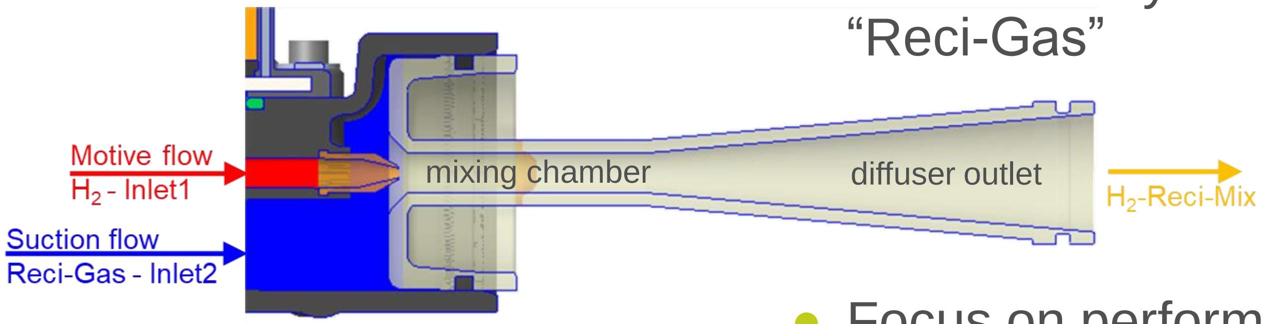


Computation1:

- Initial analysis of the primary (driving flow) mass flow required by the system
- Calculation with basic geometry as full model
- Analysis with load points specified by the customer

Computation2:

- Second analysis with target maximum secondary mass flow of the "Reci-Gas"



- Dimensions of the basic geometry of the ejector with a simplified symmetry model as starting point
- Focus on performance at low propellant gas mass flow rates
- Aim to meet customer specifications at all operating points
  (two Worst-Case load cases for optimization)

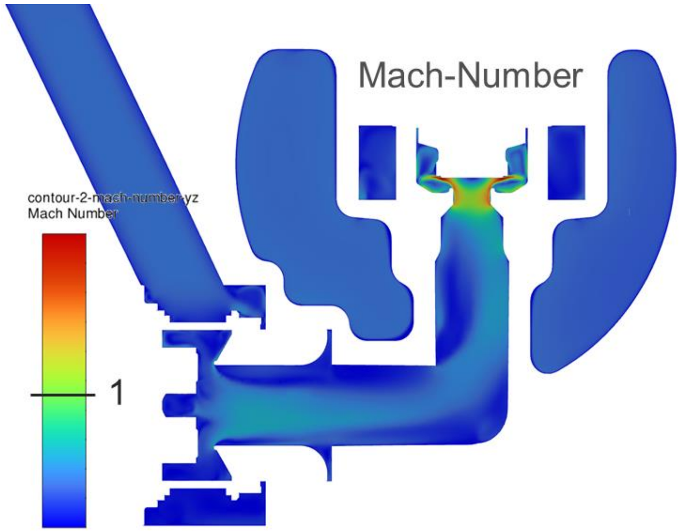
Initial analysis

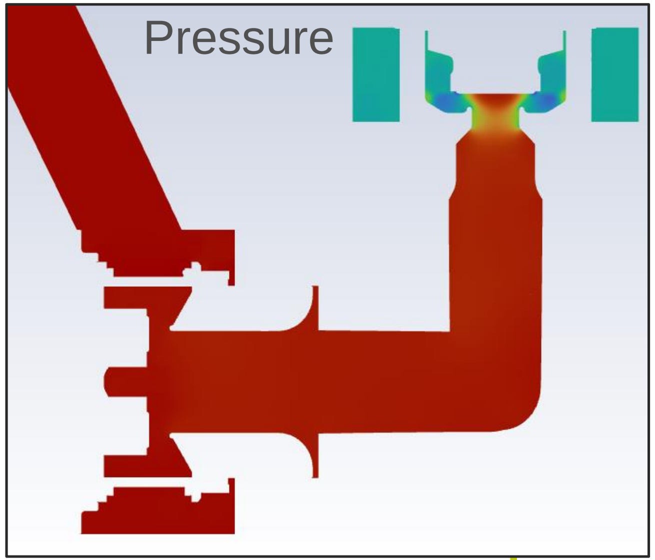
Flow analysis of the full recirculation module

Computation with full model

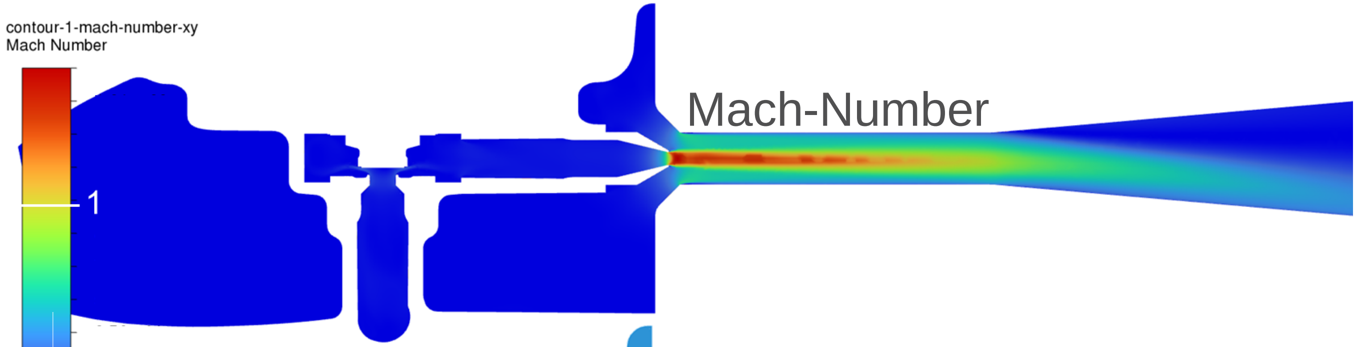
- Resulting mass flow for driving flow (nozzle) lower than required
- Pressure pulses present and detectable
- Low pressure loss due to valves (SOV, HPCV)
- Long computing time → Symmetry model for optimization

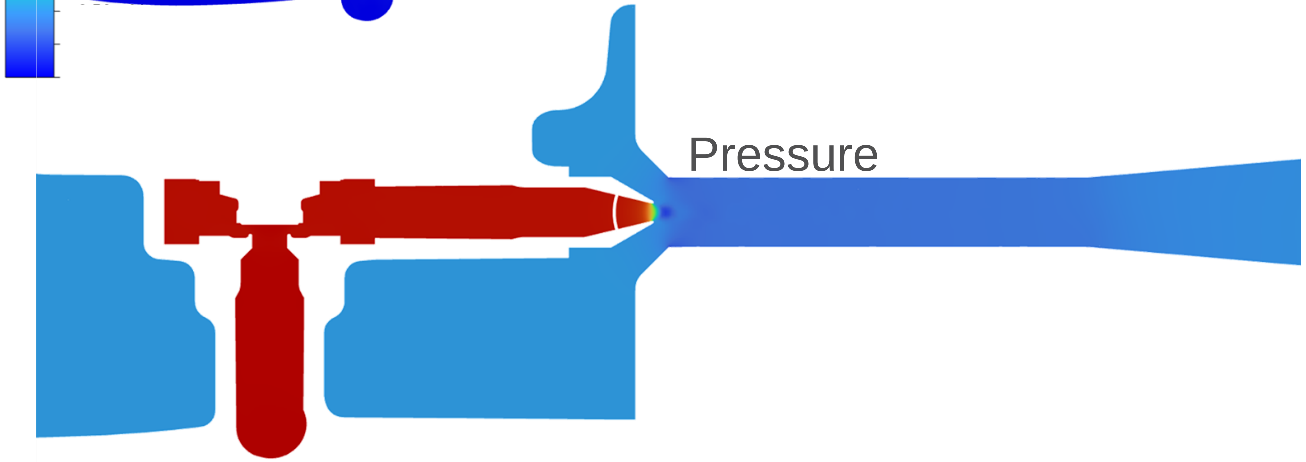
Y-Z Plane





X-Z Plane

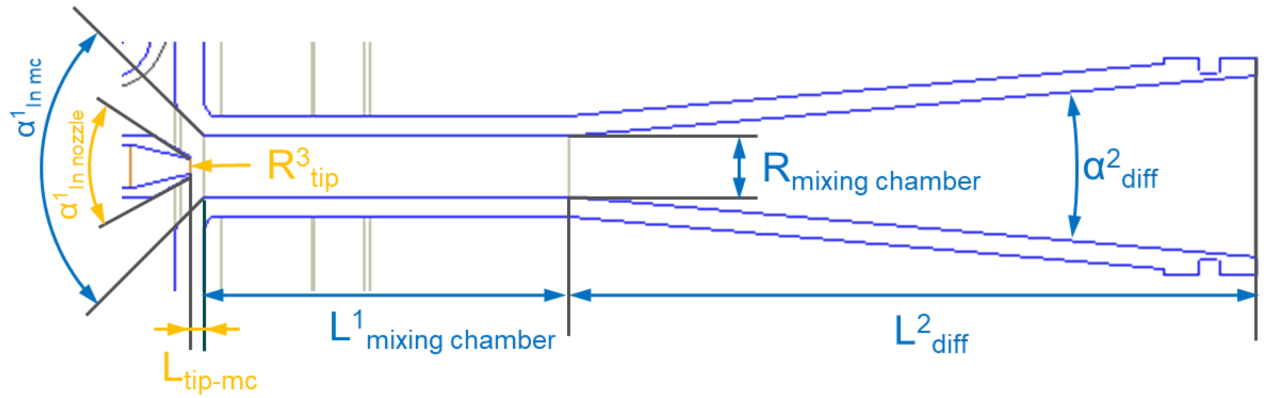




OptiSLang systems

Sensitivity analysis and optimizations setups

Parametrization of the model

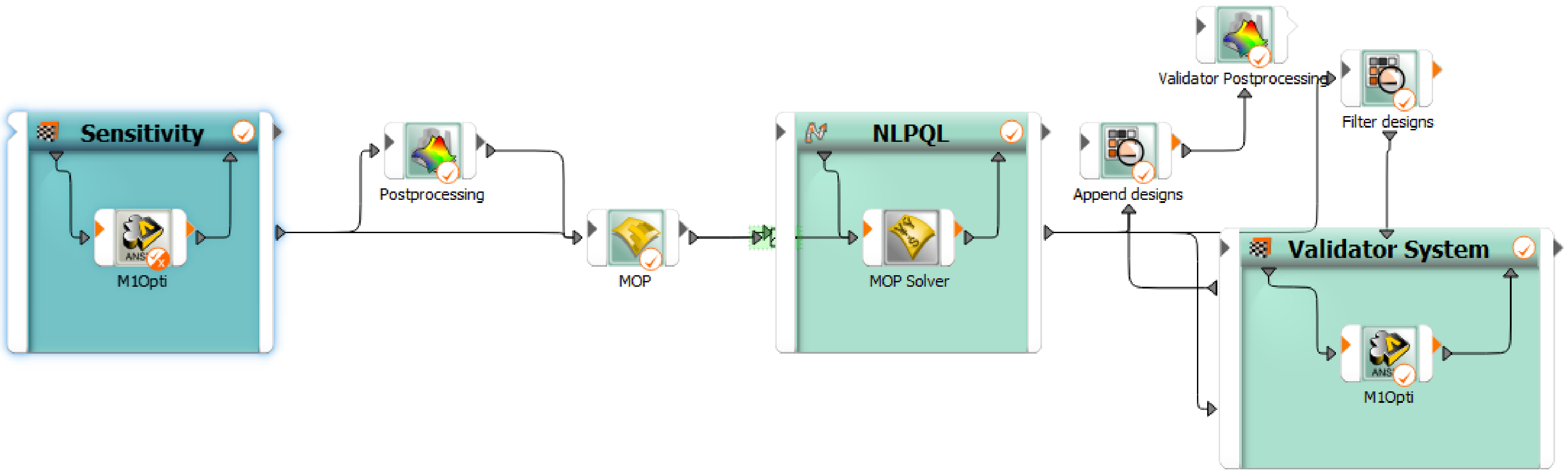


- 100 designs with „*Advanced Latin Hypercube Sampling*“
- Up to 7 variable geometry parameters
- 3 dependent geometry parameters
- 2 constant geometry parameters

	Name	Parameter type	Constant	Operation	Value type	Resolution	Range plot
1	Duese_P_zuM	Optimization	☐		REAL	Continuous	
2	Duese_R1_a	Dependent	☐	Duese_R2_i+1.25			
3	Duese_R2_i	Optimization	☑		REAL	Continuous	
4	Duese_R3_spitze	Optimization	☐		REAL	Continuous	
5	Duese_W1a	Dependent	☐	30-WinkelDiff_in2			
6	Duese_W2_i	Optimization	☑		REAL	Continuous	
7	Ejektor_L1_Bohr	Optimization	☐		REAL	Continuous	
8	Ejektor_L2_Diff	Optimization	☐		REAL	Continuous	
9	Ejektor_R_Bohr	Optimization	☐		REAL	Continuous	
10	Ejektor_W1_In	Dependent	☐	45+WinkelDiff_in2			
11	Ejektor_W2_Diff	Optimization	☐		REAL	Continuous	
12	mf_in1_c2_sym	Optimization	☑		REAL	Ordinal discrete (by index)	
13	molFrac_H2_c2	Optimization	☑		REAL	Ordinal discrete (by index)	
14	molFrac_H2O_c2	Optimization	☑		REAL	Ordinal discrete (by index)	
15	P_in2_rezi_c2_P4	Optimization	☑		REAL	Ordinal discrete (by index)	
16	P_out_c2_P3	Optimization	☑		REAL	Ordinal discrete (by index)	
17	Temp_in1_h2_c2_T0	Optimization	☑		REAL	Ordinal discrete (by index)	
18	Temp_in2_rezi_c2_T4	Optimization	☑		REAL	Ordinal discrete (by index)	
19	WinkelDiff_in2	Optimization	☐		REAL	Continuous	

04 Optimization setup

- Boundary conditions of load points fixed by 7 constant parameters
- 2 constraints to ensure correct results (mass flow)
- Sensitivity analysis with different optimization strategies (ARSM, NLPQL) on MOP-Solver
- Validation of the optimal design with ANSYS-Fluent

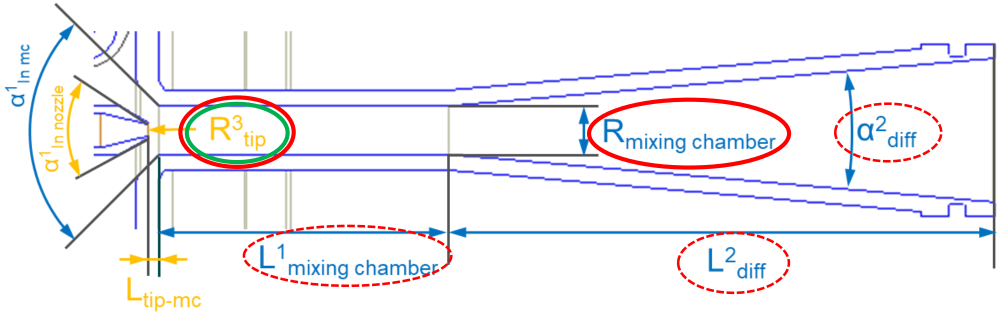


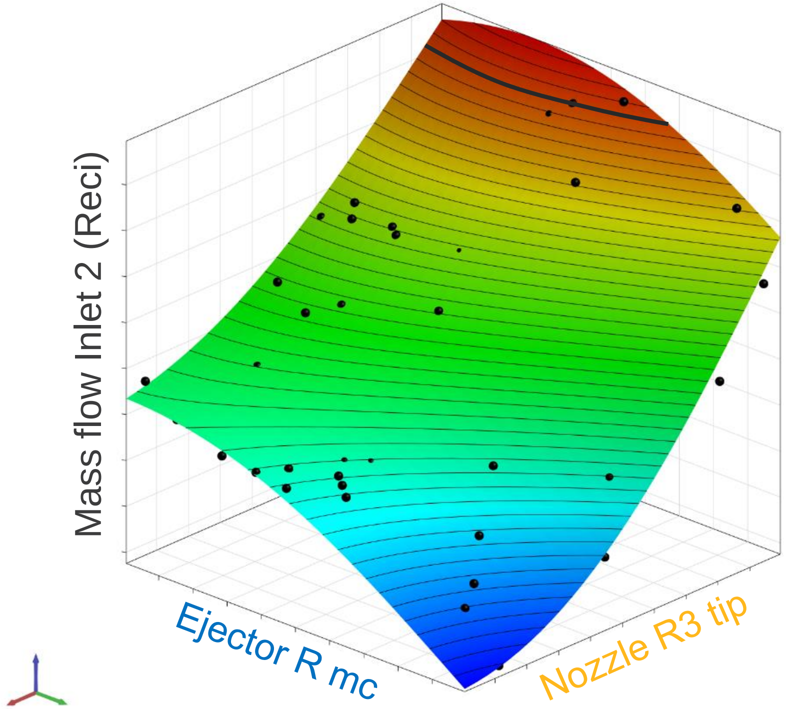
First optimization loop

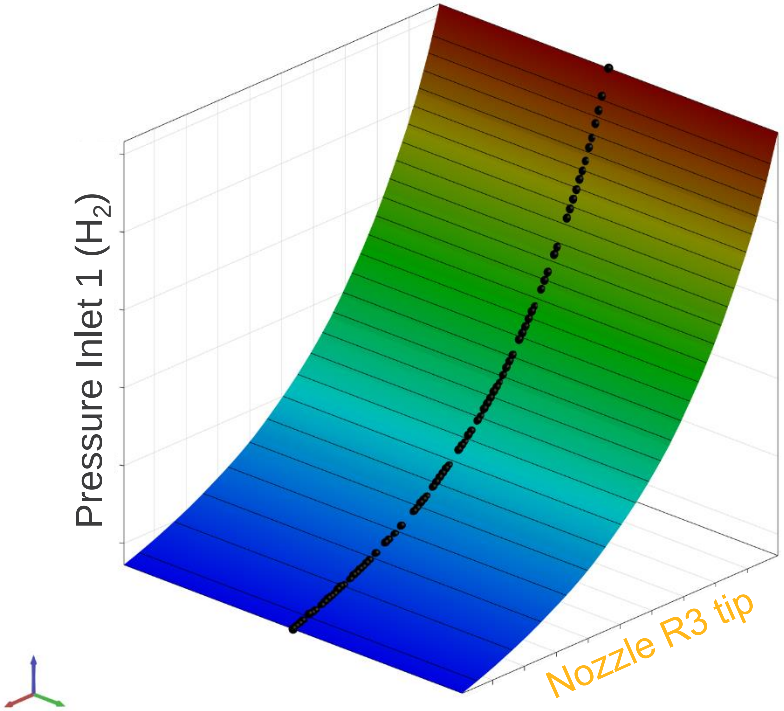
Sensitivity analysis, optimization and system simulation

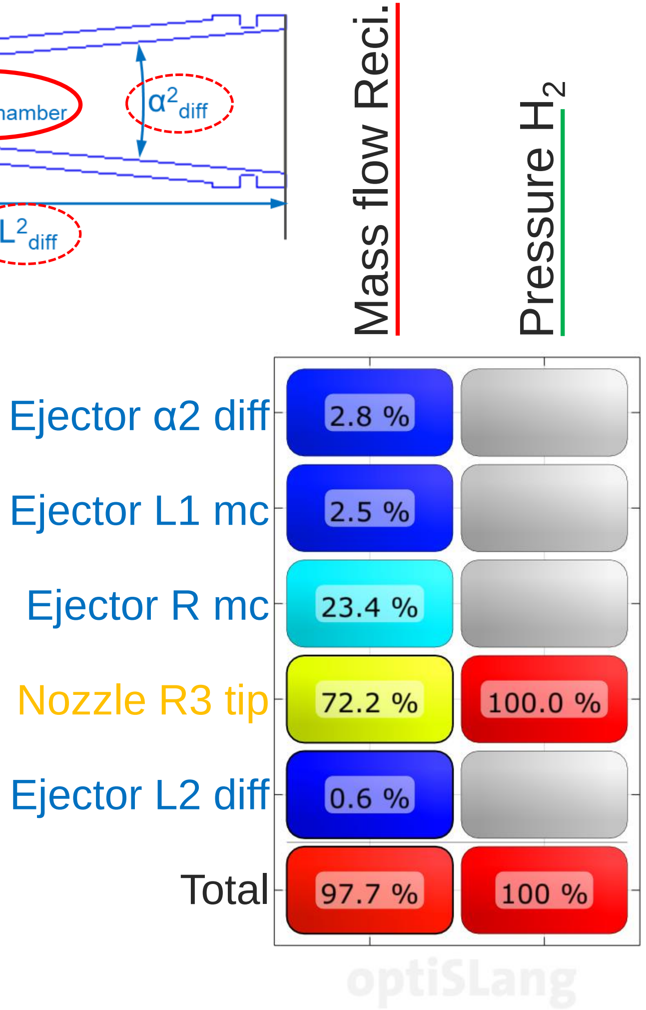
First sensitivity - load case A

- **Pressure in nozzle** only influenced by **size of nozzle tip (R^3_{tip})**
- Influence on **mass flow** of the recirculation flow (Reci.) mainly by **radius of the ejector mixing chamber ($R_{mixing\ chamber}$)** and by **the tip of the nozzle (R^3_{tip})**



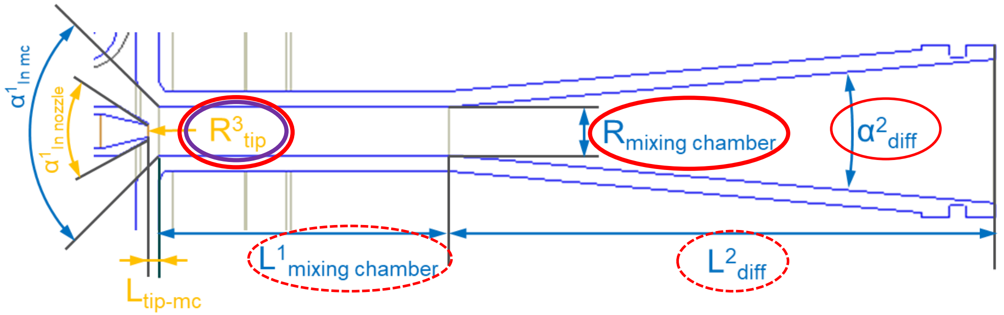


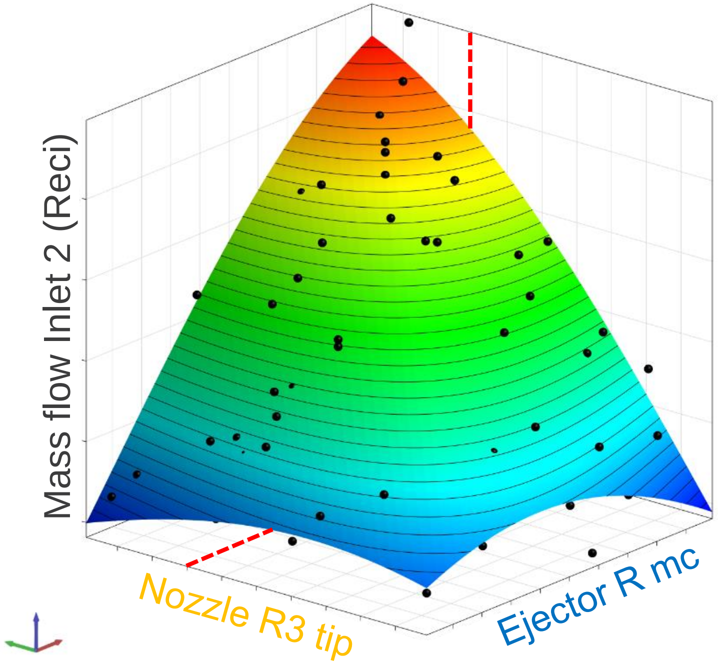


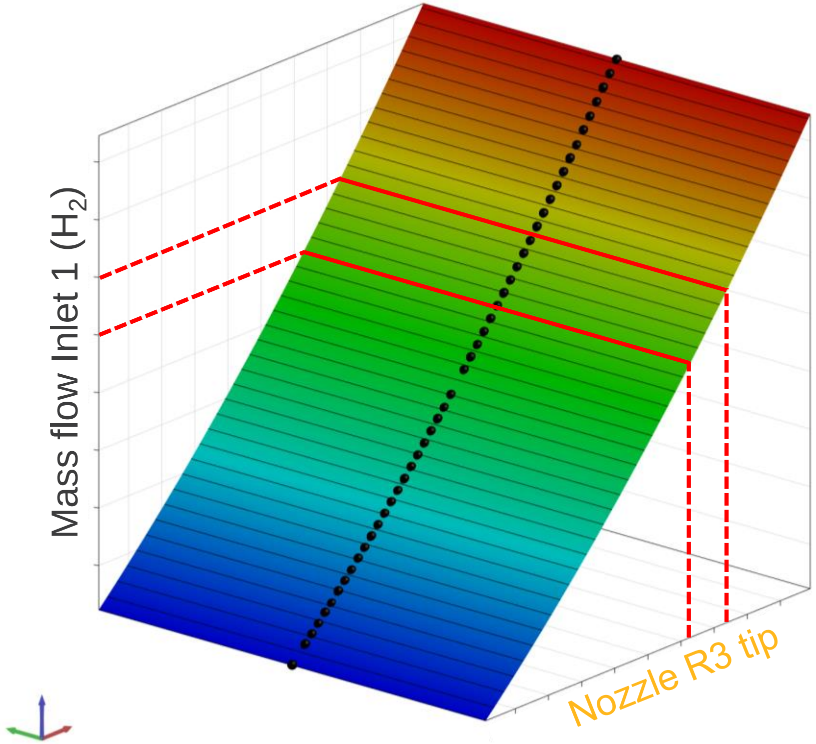


First sensitivity - load case B

- **Mass flow in nozzle** only influenced by **size of nozzle tip (R^3_{tip})**
- Influence on recirculation **mass flow (Reci.)** mainly by **ejector $R_{mixing\ chamber}$** and **nozzle R^3_{tip}**
- Different influence on the mass flow dependent on the load case A / B



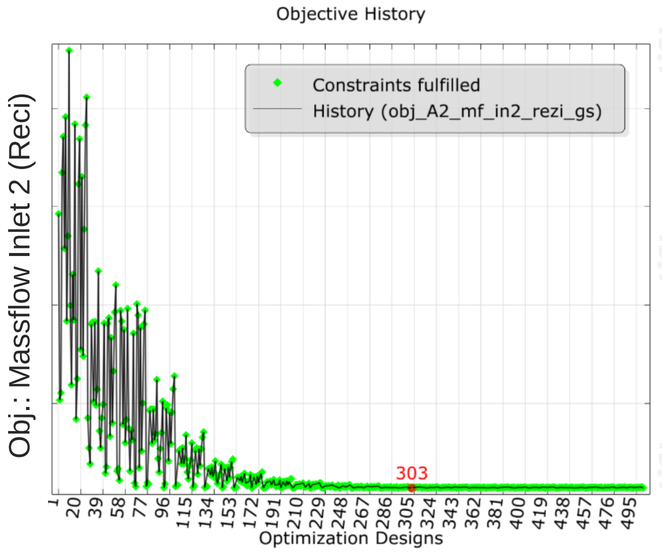




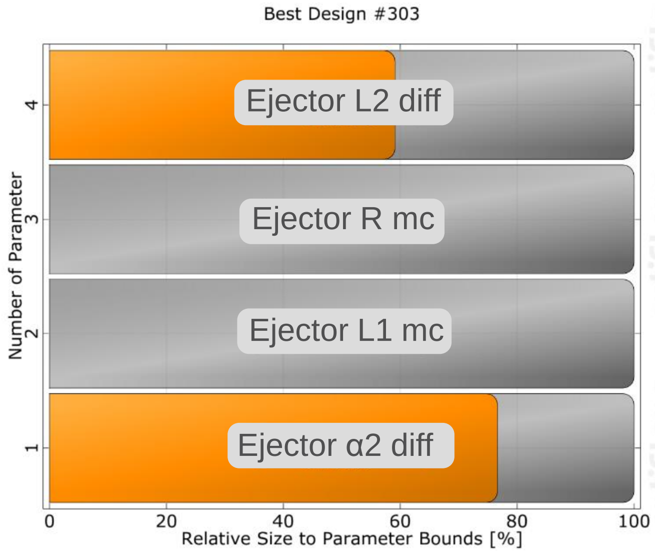
	Mass flow H_2	Mass flow Reci.
Nozzle R3 tip	100.0 %	45.8 %
Ejector L1 mc		2.4 %
Ejector L2 diff		5.4 %
Ejector R mc		48.3 %
Ejector α2 diff		11.7 %
Total	100 %	94.5 %

First optimization

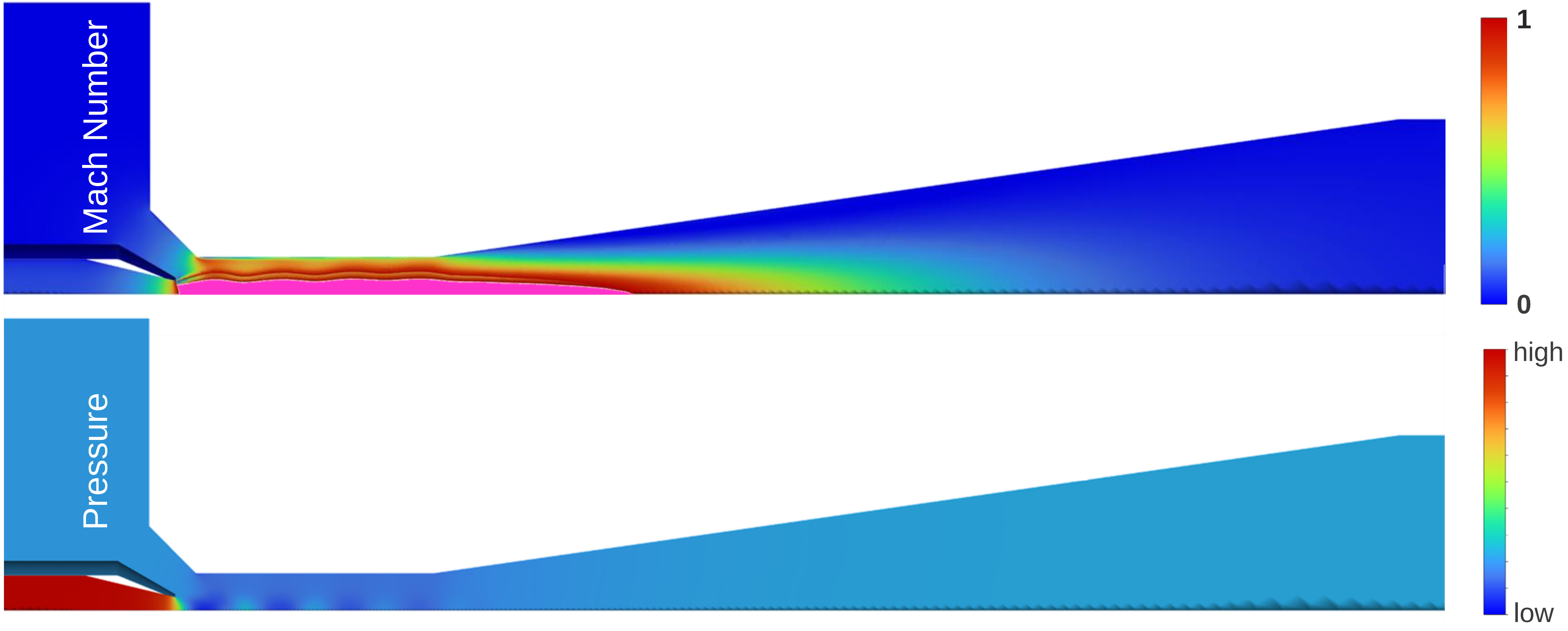
- „Reci-Gas“ mass flow optimization of Inlet 2
- Two computation passes with different constant radii for the tip of the nozzle (R^3_{tip})
- Mass flow target as constraint for the optimizer
- Similar designs and results for both optimizations with difference of about 3%
- Major increase of mass flow for Inlet 2
- Target value for Inlet 2 not fulfilled by the optimized designs (-70%)



	Name	Parameter type	Constant	Value type	Resolution	Range plot
1	Duese_P_zuM	Optimization	☑ filtered	REAL	Continuous	
2	Duese_R3_spitze	Optimization	☑	REAL	Continuous	
3	Ejektor_L1_Bohr	Optimization	☐	REAL	Continuous	
4	Ejektor_L2_Diff	Optimization	☐	REAL	Continuous	
5	Ejektor_R_Bohr	Optimization	☐	REAL	Continuous	
6	Ejektor_W2_Diff	Optimization	☐	REAL	Continuous	
7	WinkelDiff_in2	Optimization	☑ filtered	REAL	Continuous	



Optimized ejector design

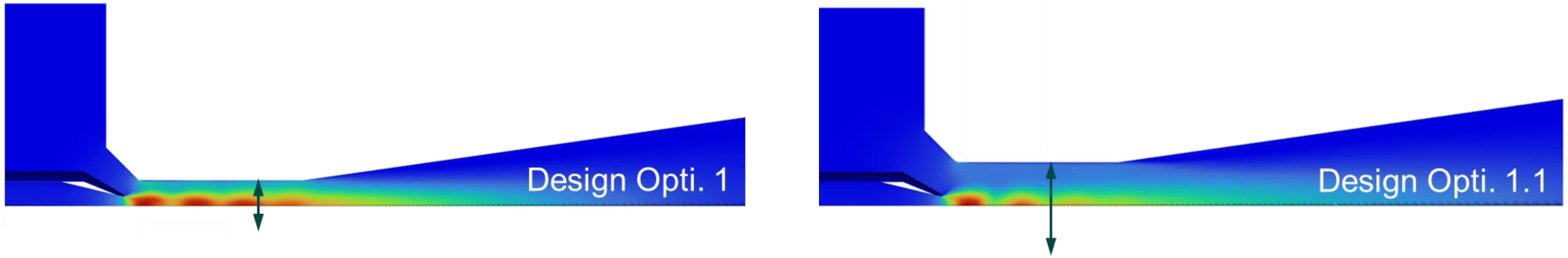


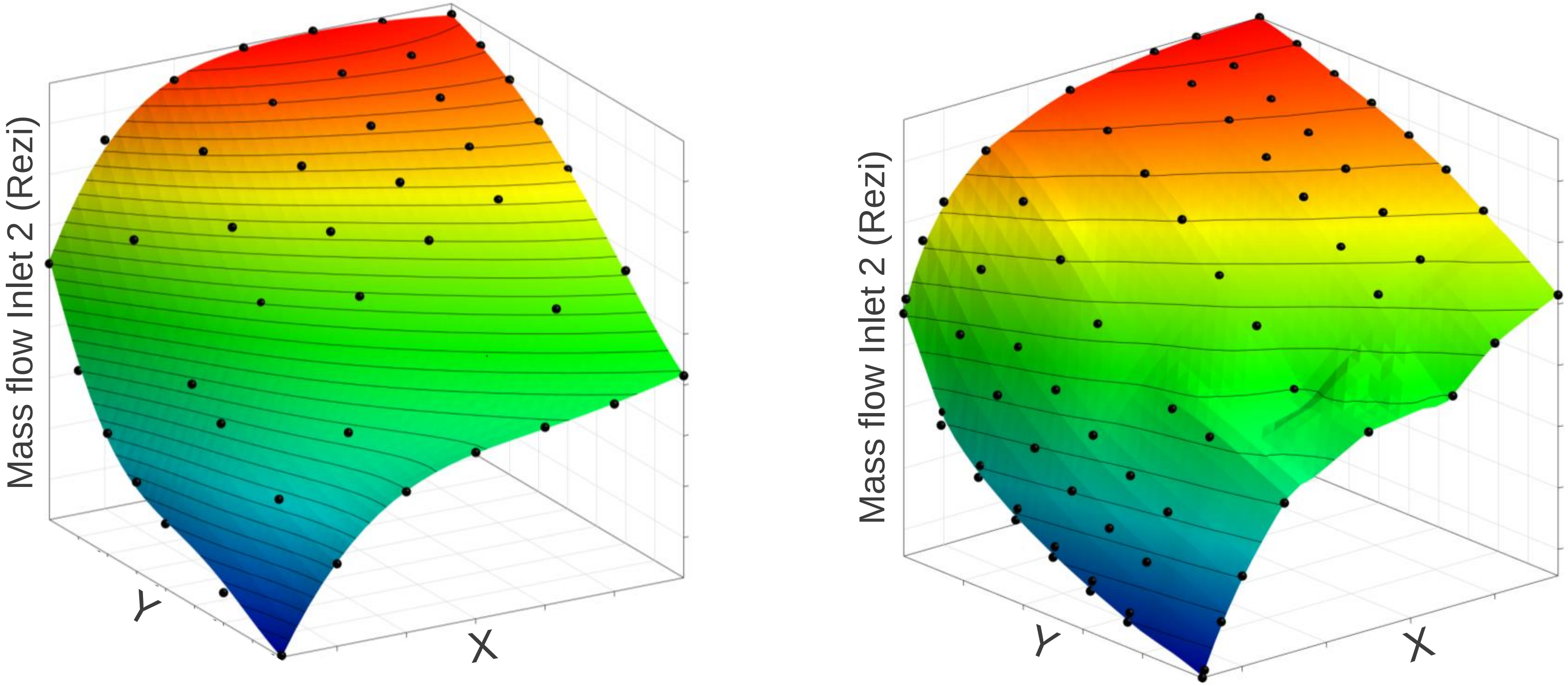
- Total diffuser bore (mixing chamber) with high speed fluid
- Supersonic stream of motive fluid reaches into the diffuser outlet
- High speed of the recirculation gas

05 Flow rate field

- Two fields and designs for continuous and pulsed operation
- Computation of mass flow and flow rate
- Pressure ratio for X- and Y-axis
- Data generated for H_2-Inlet1, Reci-Gas-Inlet2 and Outlet

$X = p_{Inlet1} / p_{outlet}$
$Y = p_{Inlet2} / p_{outlet}$





05 First system simulation – Opti.1

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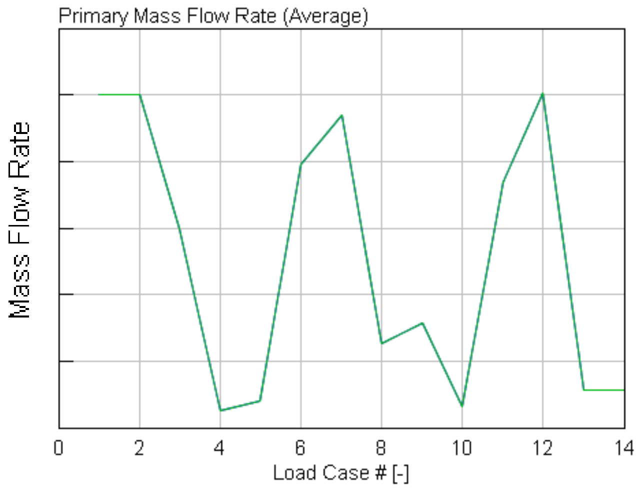
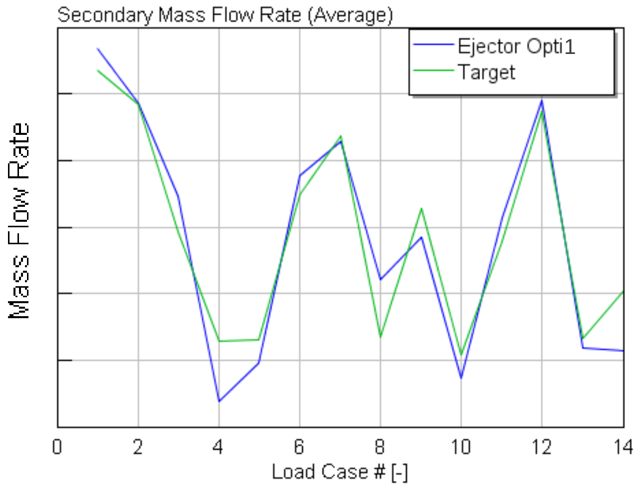
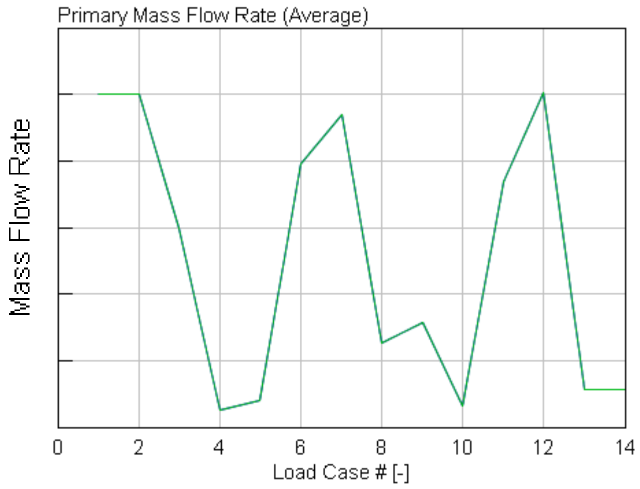
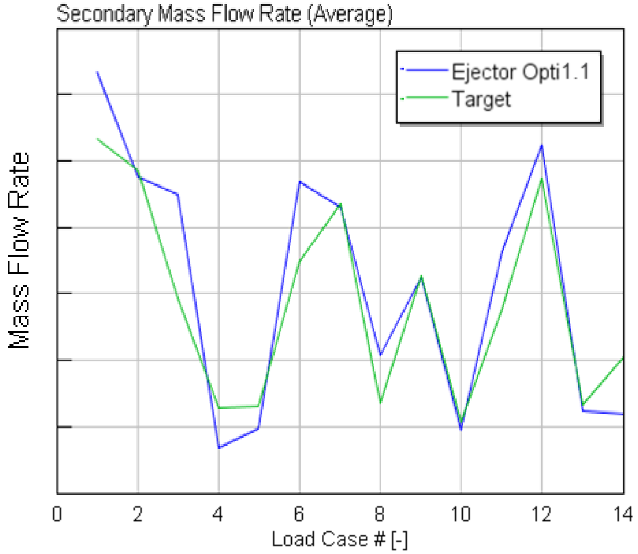
Continuous





Pulsed



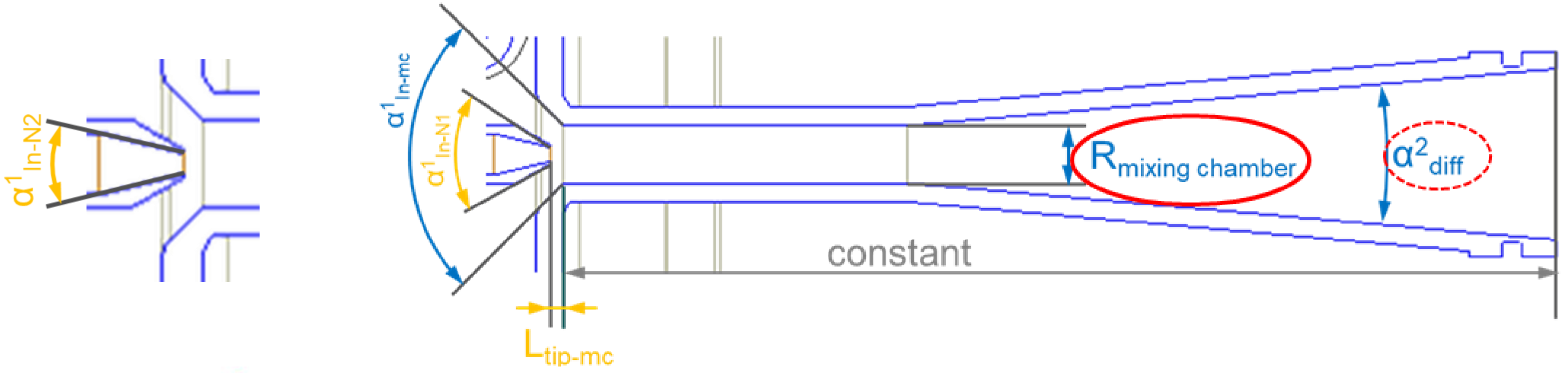


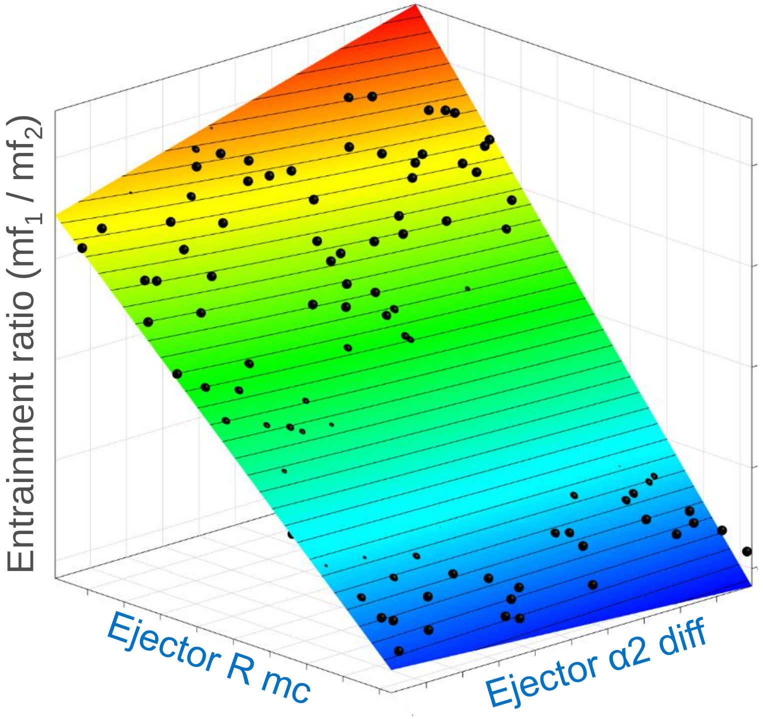
- Good performance for high load cases
- Insufficient suction flow for low load cases
- Performance gain (+74%) with pulsed operation and modified model (1.1)

Second optimization loop

Sensitivity analysis, optimization and system simulation

Second sensitivity analysis

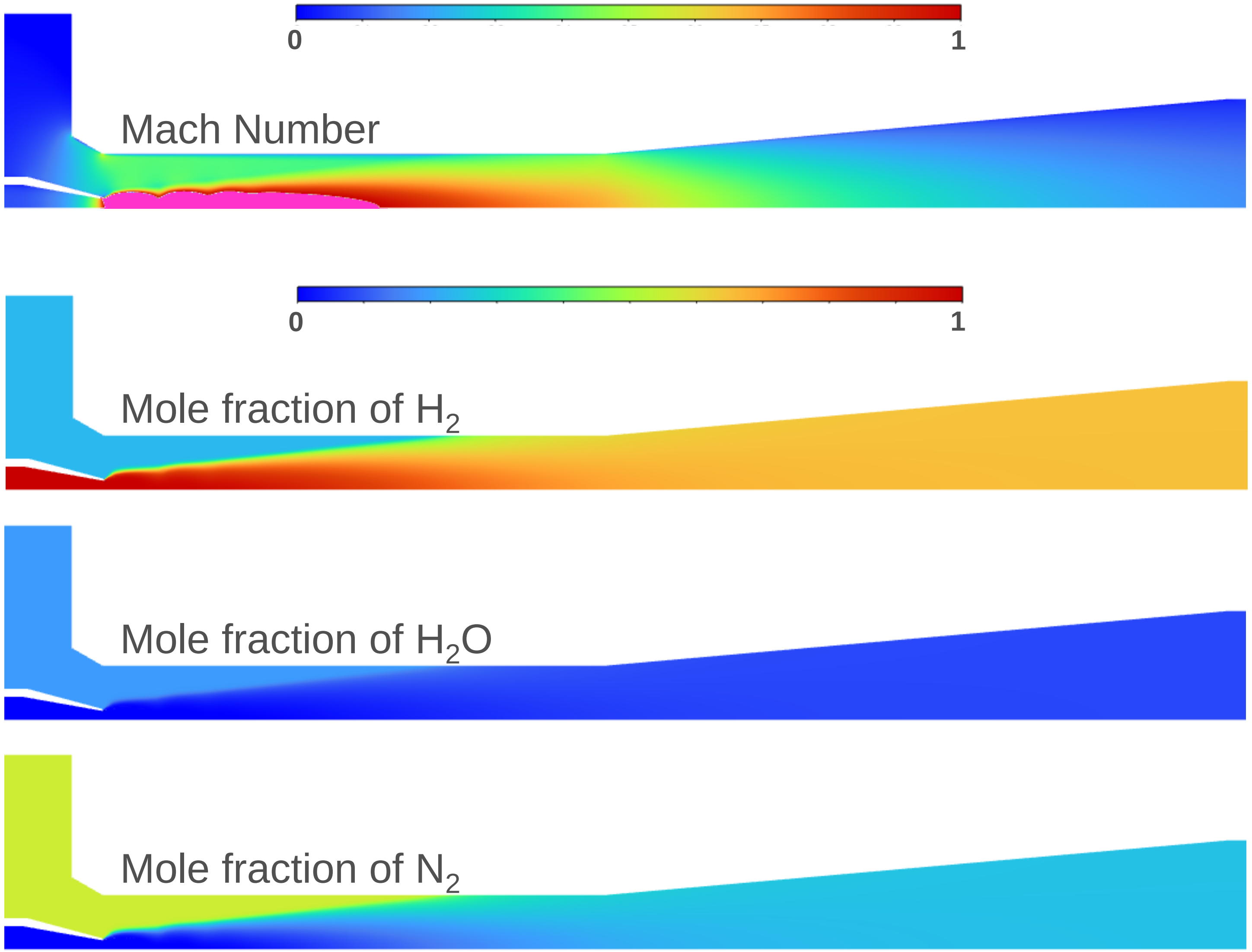


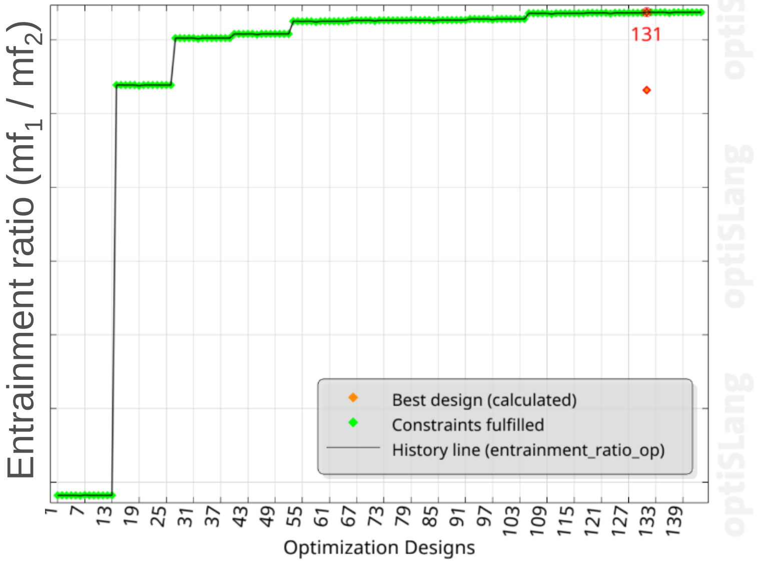


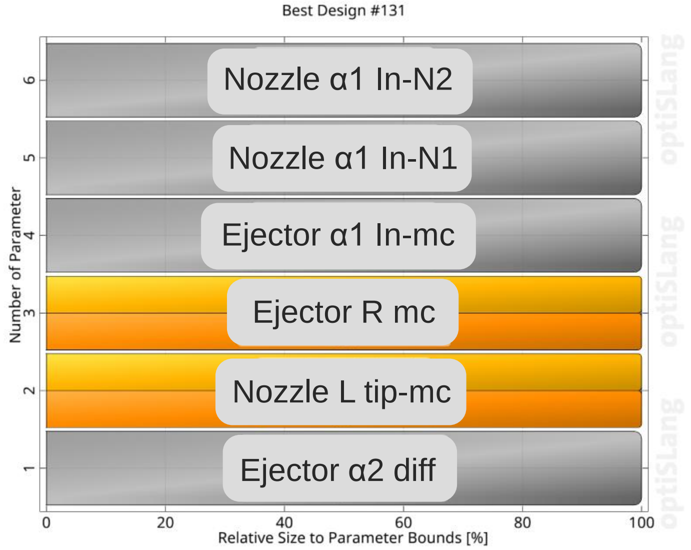
- Additional analysis of entrainment ratio
- Adjusted parameters and variation ranges
- Optimization for pulsed operation (boundary conditions)

	Entrainment ratio	Mass flow H_2 (mf_1)	Mass flow Reci. (mf_1)
Nozzle L tip-mc	0.3 %	0.3 %	0.3 %
Ejector R mc	96.0 %	97.6 %	98.6 %
Ejector α1 In-mc	0.1 %	0.0 %	0.1 %
Nozzle α1 In-N1	0.0 %	0.0 %	0.0 %
Nozzle α1 In-N2	0.1 %	0.2 %	0.1 %
Ejector α2 diff	1.2 %	1.2 %	1.4 %
Total	99.3 %	99.3 %	99.3 %

Second optimization

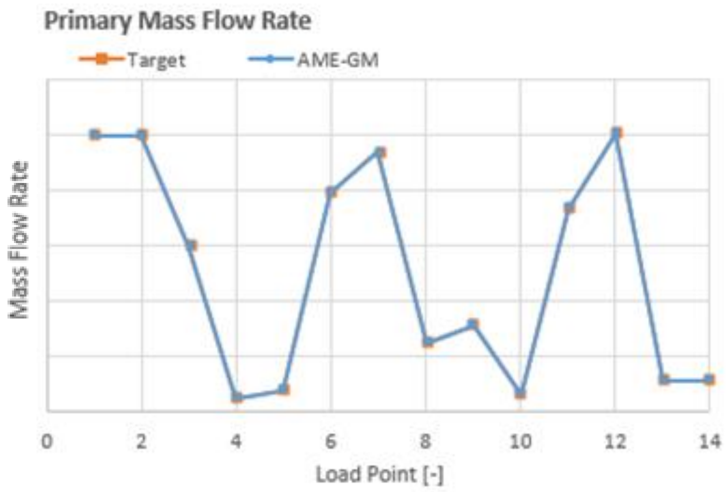


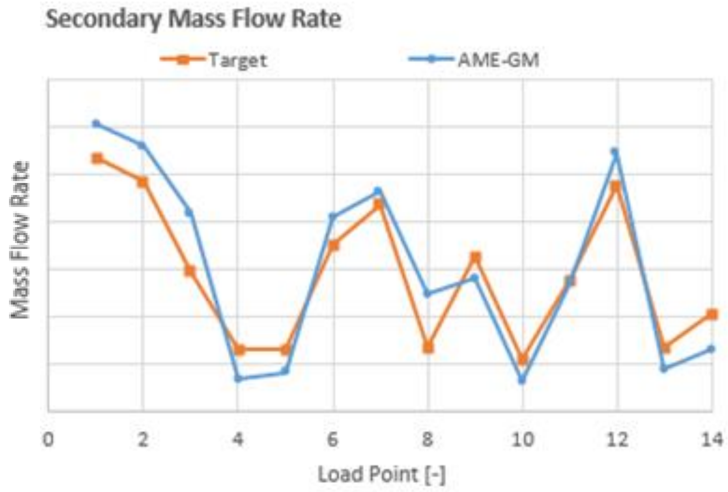




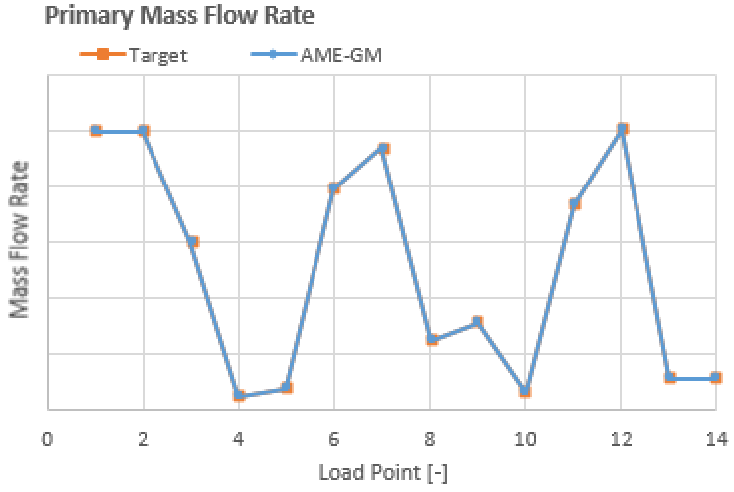
06 Second system simulation

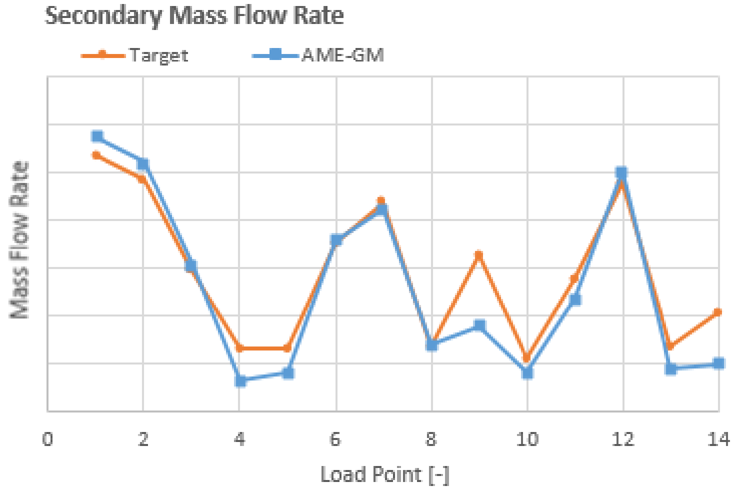
Continuous





Pulsed





- High secondary mass flow for high load points
- Targets not achieved for low loads
- No further improvements for low load points compared to Opti.1

Conclusion

Summary of the analysis and optimization

07 Conclusion

- Successful creation of a development tool for new technologies
- Successfully calculated and analyzed recirculation-module
- Identification of important parameters
- Optimization of the ejector part of the module in two passes
- Successful integration of optimization result in system simulation

Thank you for your attention!

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