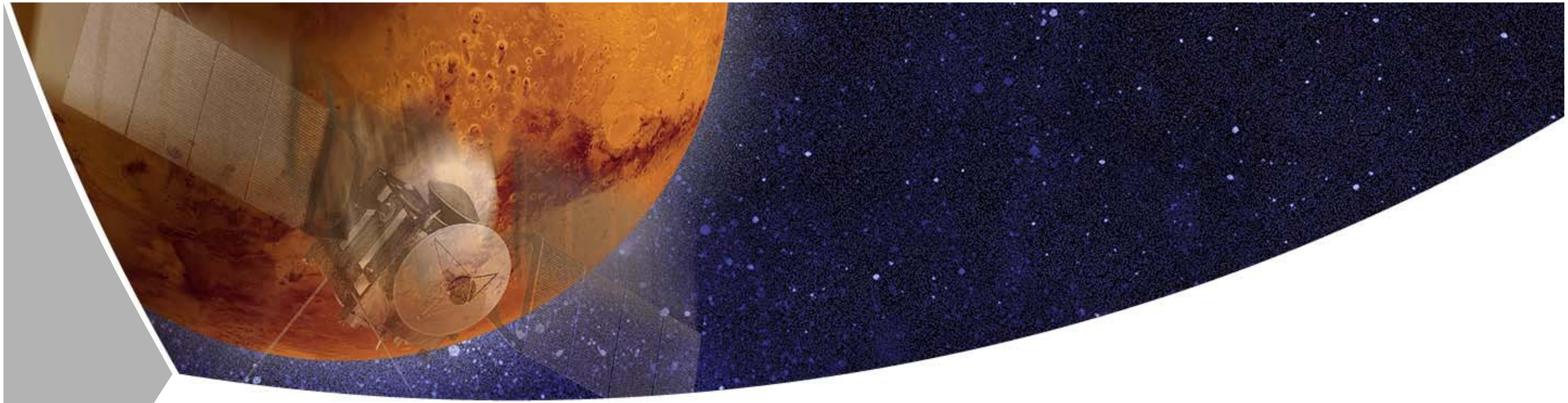

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CMC Design Approach for Cryogenic Injector Heads of Rocket Thrust Chambers

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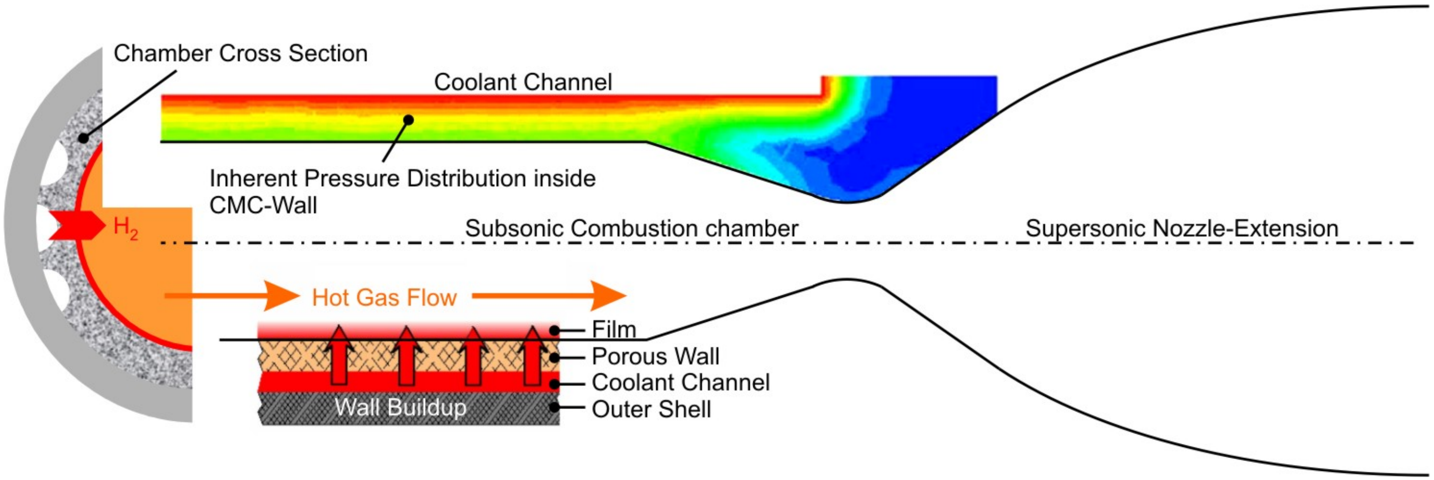
Outline

- Motivation
- CMC Injector Concept Approach
  - Functional Aspects
  - Design Features
  - Structural Analysis
- Technology Screening Tests
  - Spray Evaluation
  - Flow Calibration / Throttling Potential
  - Laser Cut System
- Summary and Outlook
- (References)

Motivation

Primary Idea: Effusion Cooled CMC-Combustion Chamber

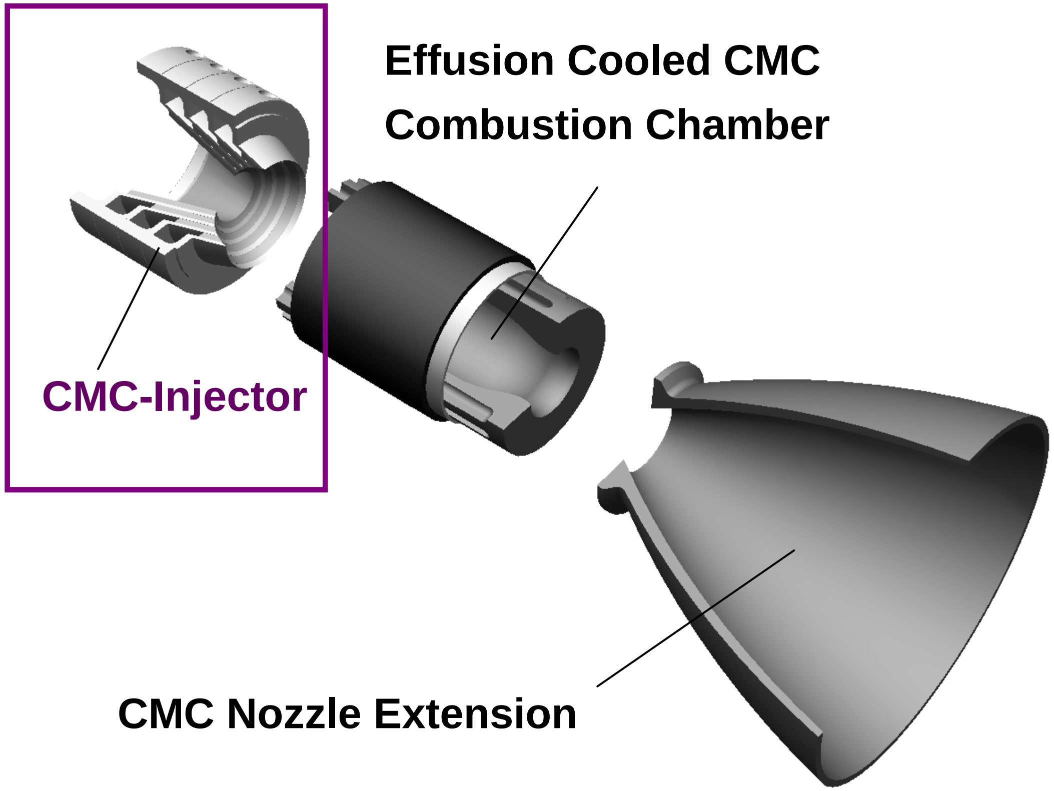


- Inner liner made of porous carbon based CMC
- Effusion cooling through porous CMC-wall
- High system efficiency by achieving maximum reduced coolant mass flow ratio
- Prevention of thermo-chemical wall attack

→ **Assumption: Highly optimized combustion**

Motivation

CMC-Injector-Head in Conjunction with CMC Combustion Chamber

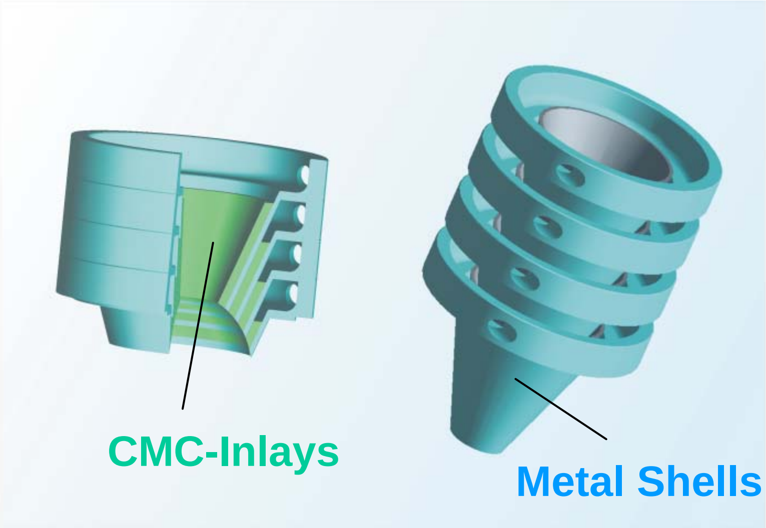


Technological Goals

- Rapid spray forming
- Use of highly permeable and high temperature stable CMC
- Generation of homogeneous LOX-droplet-pattern
- Prevention of large LOX-droplets
- CMC-wall-protection against LOX-agression
- Prevention of Combustion instabilities
- Permit of cold injection

Motivation

Design Simplification



Design Principle of the Cone Injector.
Stack of similar conical shells, developed at the Institute of Structures and Design.

- Easy segment stack by replication of similar injector elements
- Exploitation of advantageous thermo-mechanical CMC material properties
- Prevention of mechanical extreme-tolerance-requirement

CMC Injector Concept Approach

Functional Aspects (1) → *Spray-Conditioning*

	combustion chamber C with coaxial injector		CMC thrust chamber with 'cone-injector'	
d_{LOX} [m]	0.004		0.031	
T_g [K]	125		125	
p_C [MPa]	3	6	3	6
$\rho_g(T_g, p_C)$ [kg/m³]	5.7338	11.235	5.7338	11.235
U_g [m/sec]	270	310	270	310
T_f [K]	127		127	
$\sigma_f(T_f)$ [N/m]	0.0046507		0.0046507	
We_g [---]	3.57E+05	9.29E+05	2.77E+06	7.20E+06

[Rf. 22]

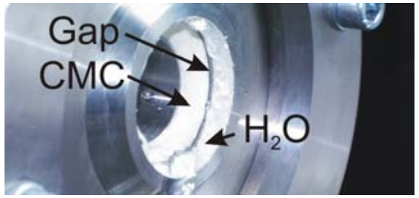
Comparison between

the resulting Weber numbers with coaxial injection as experienced from a DLR standard combustion chamber

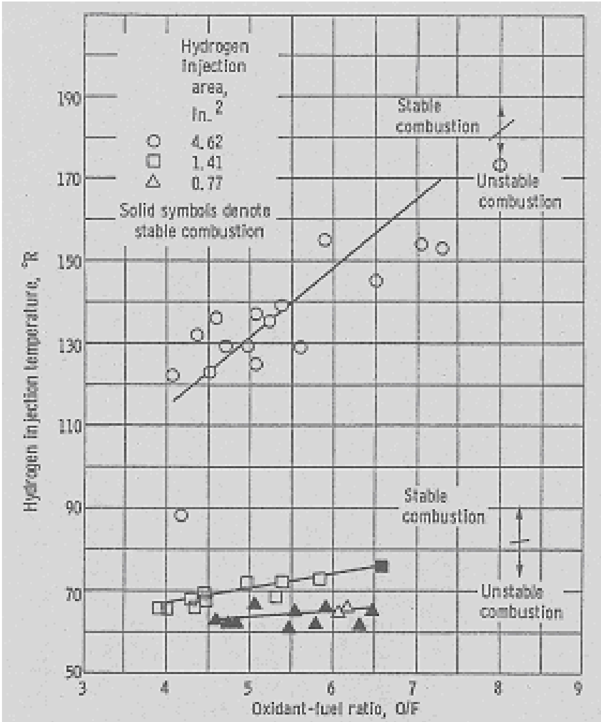
and the calculated Weber numbers for the 'cone-injector' as expected from the operation of the CMC thrust chamber at identical process parameters.

$$We_g = \frac{\rho_g * U_g^2 * L}{\sigma_f}$$

CMC Injector Concept

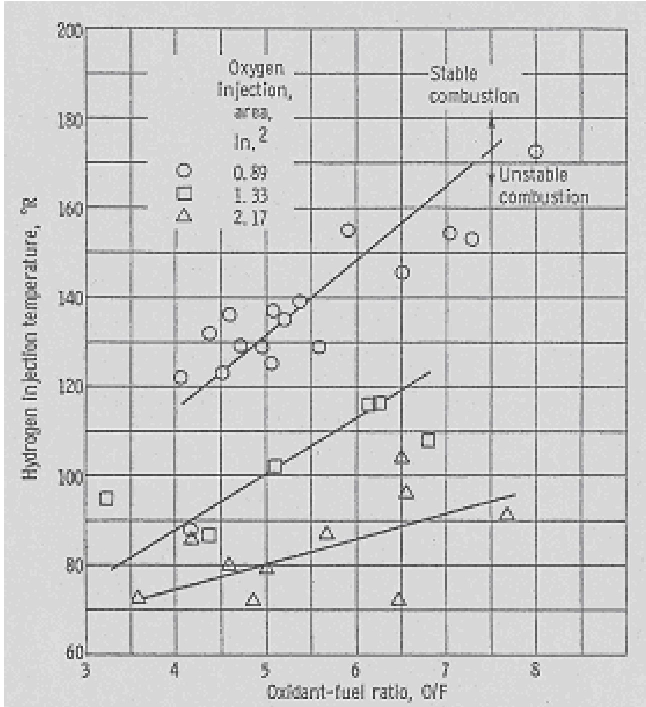


Functional Aspects (2) → ***Combustion Stability***



[Rf. 1]

Investigation on co-axial injector elements



LH2-Injection Area ↘

Stable Injection Temperature ↘

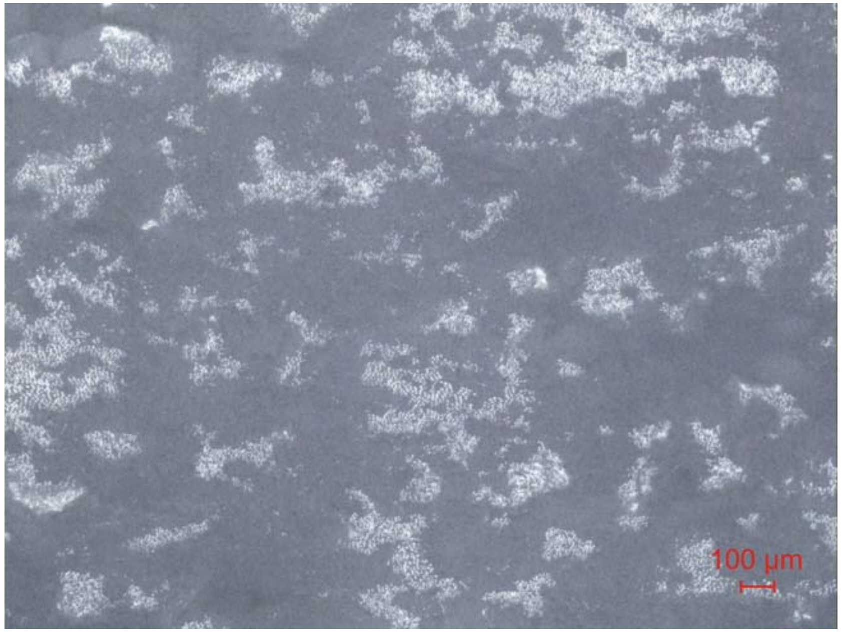
LOX-Injection Area ↗

Stable Injection Temperature ↘

CMC Injector Concept Approach

Functional Aspects (3) → ***Permeable Materials***

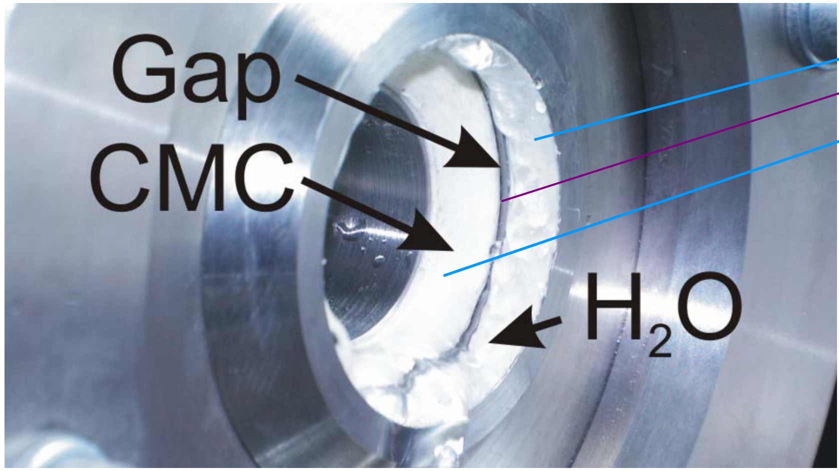
CMC-Sample of WPS-P50. Material based on Nitivy fibers and diluted oxidic matrix showing 50% porosity.



Grinding pattern. The medium pore diameter perpendicular to the fiber plies amounts about 200 µm.

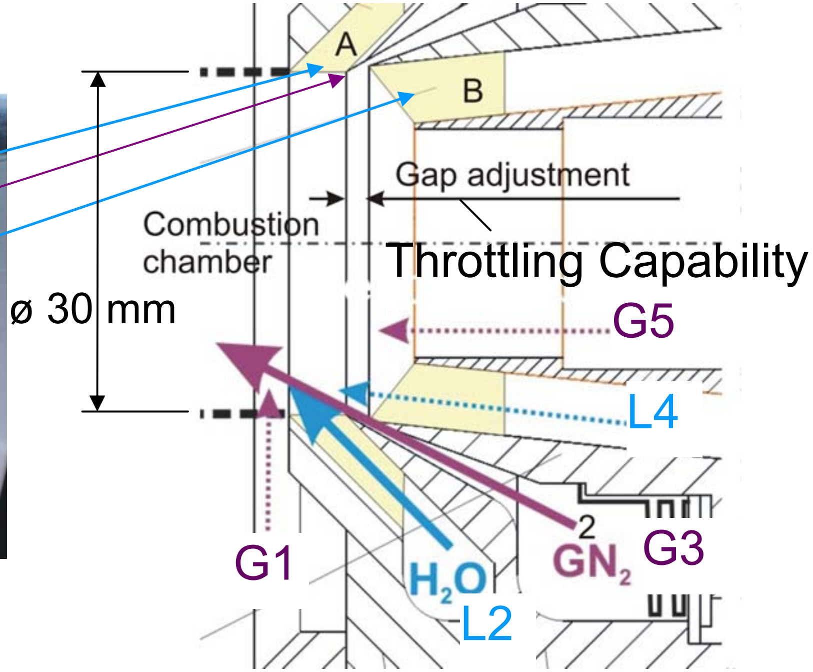
CMC Injector Concept Approach

Design Features



Functional Demonstrator INJEX01.

Planned for Micro-Combustor (ø 30 mm)



Longitudinal Section

First experimental investigations:

- Use of H2O and GN2 for replacement of oxidizer LOX and fuel LH2

CMC Injector Concept Approach

Structural Analysis (1) → *Material Characteristics*

	In Plane	Perpendicular	Steel 7,9 [g/cm³]
Young's-Modulus	16 [kN/mm²]	3 [kN/mm²]	200 [kN/mm²]
Schear-Modulus	1,3 [kN/mm²]	6,2 [kN/mm²]	77 [kN/mm²]
Poisson-Ratio	0,02	0,03	0,3
Thermal Conductivity	0,7 – 0,8 [W/mK]	0,26 – 0,32 [W/mK]	15 [W/mK]
Thermal Expansion	1*10-5 [1/K]	2,4*10-5 [1/K]	1,8*10-5 [1/K]

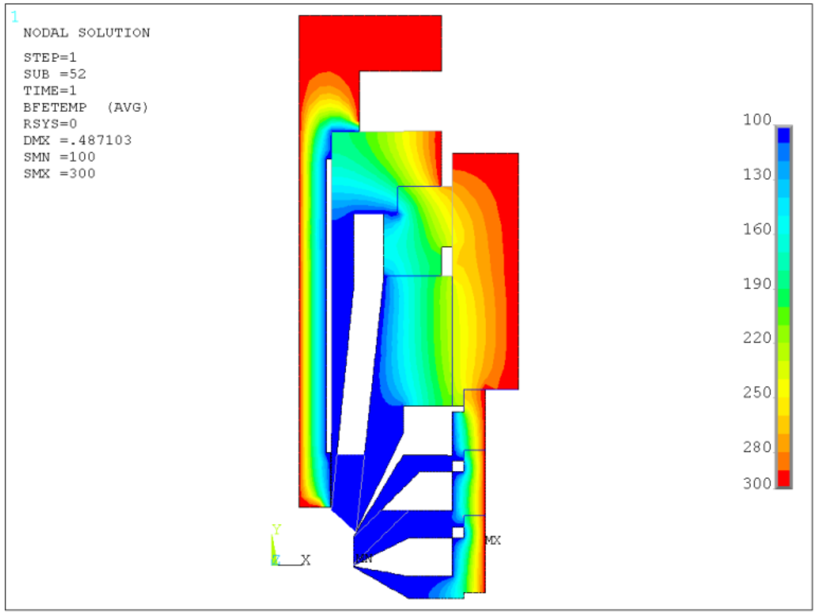
CMC Injector Concept Approach

Structural Analysis (2) → ***Thermal Assumption***

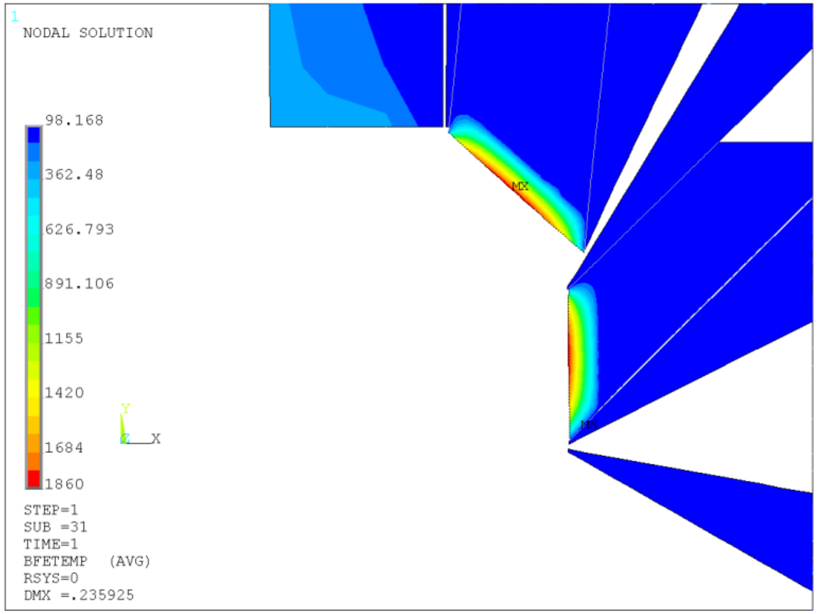
$\dot{q}_{\text{radiation}}$	=	$\varepsilon \cdot \sigma \cdot T_f^4 = 3.4\ \text{MW/m}^2$
$\dot{q}_{\text{heat conduction}}$	=	$\frac{\lambda}{d} \cdot \left(T_W - T_{LOX}\right)$
$\dot{q}_{LOX}$	=	$\frac{\dot{m}_f \cdot c_{p_f}}{A_{ref}} \cdot \Delta T$
$\dot{q}_{\text{radiation}}$	=	$\dot{q}_{\text{heat conduction}} + \dot{q}_{LOX}$

CMC Injector Concept Approach

Structural Analysis (3) → ***Thermal Simulation***



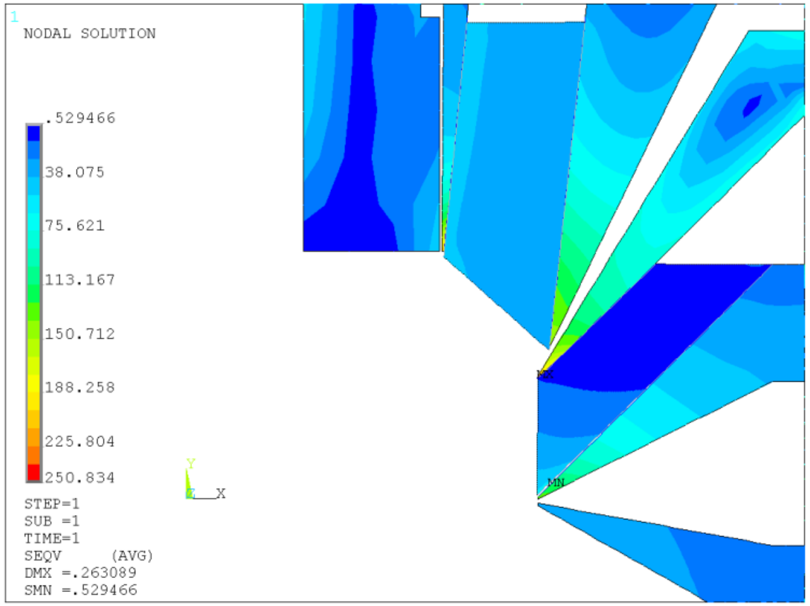
Thermal boundary conditions during start-up phase at the overall system.



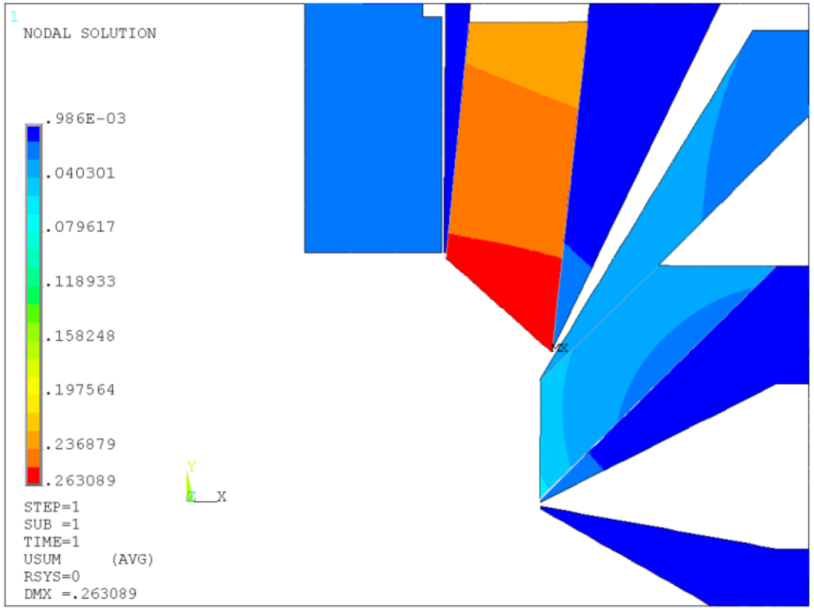
Thermal boundary conditions during steady-state phase at the faceplate.

CMC Injector Concept Approach

Structural Analysis (4) → ***Mechanical Simulation (1)***



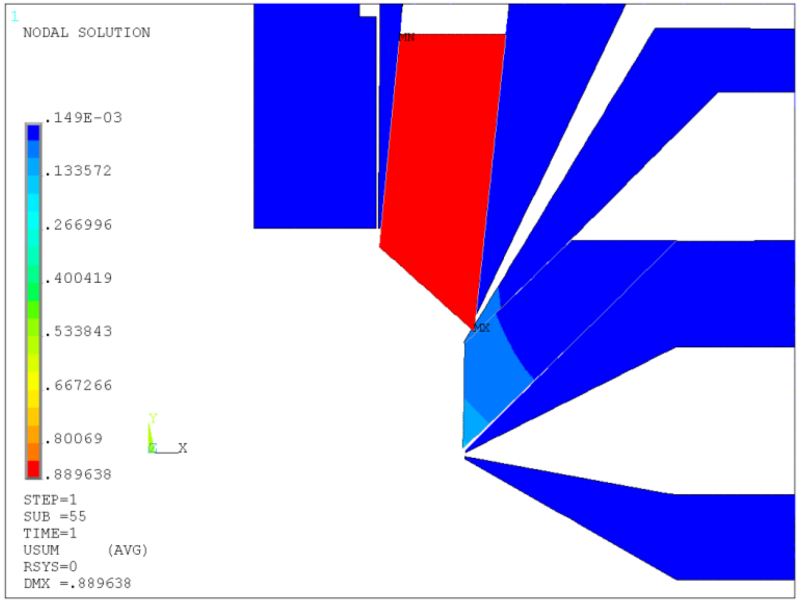
V. Mises stresses at 10 bar chamber pressure.



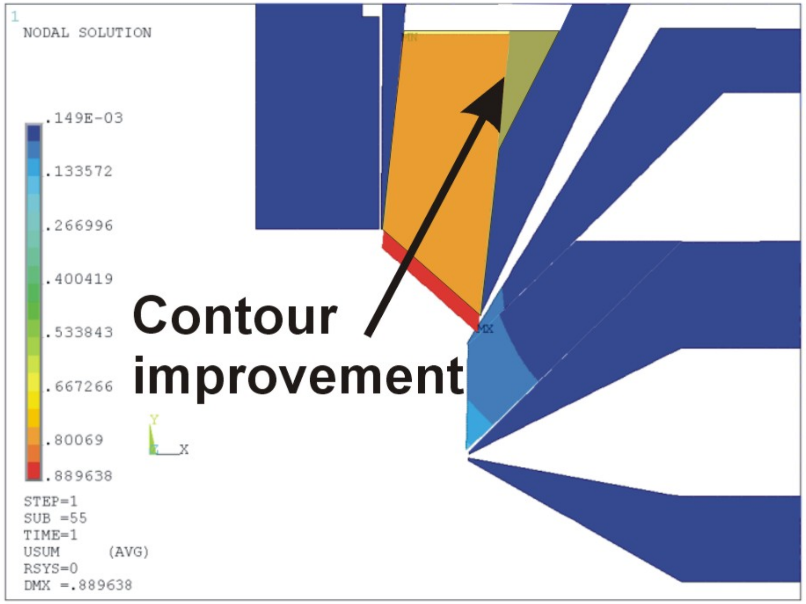
CMC-displacement at 10 bar chamber pressure non-critical.

CMC Injector Concept Approach

Structural Analysis (5) → ***Mechanical Simulation (2)***



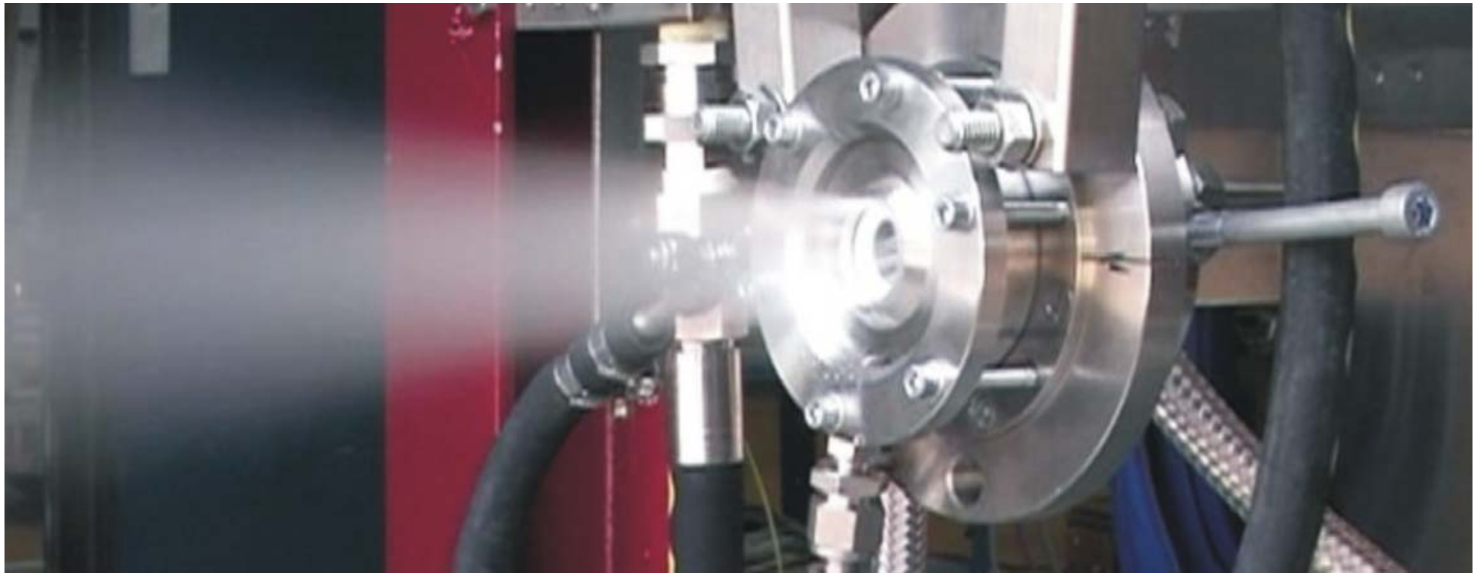
Displacement of inner CMC element.
Critical at 60 bar pressure loss caused by low clamping angle.



Approach for structural improvement.
Design change.

Technology Screening Tests

Tests at M3 Test Bench (DLR-Lampoldshausen) → *Spray Evaluation (1)*



Qualitative view of spray formation using Water and Nitrogen.

Nitrogen sweeps over the readily available water and the sharp shear stream forms a finely mixed spray.

Technology Screening Tests

Tests at M3 Test Bench (DLR-Lampoldshausen) → *Spray Evaluation (2)*

Full flow *Water without Nitrogen*. Mass flow amounts about 900 g/sec.

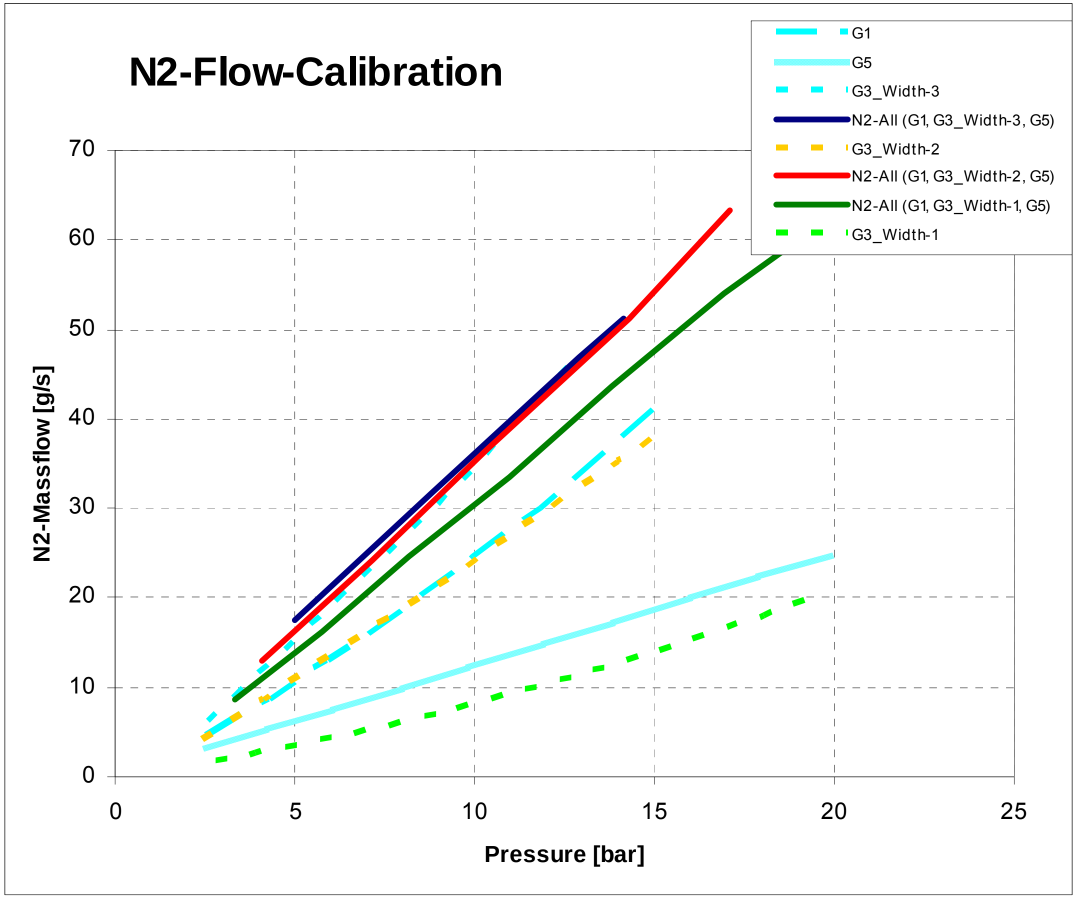
Current design specifics even enable high mass flow rates to feed a 50 mm chamber (relevant DLR research level) running 60 bars with the 30 mm INJEX01.

Full flow Water + Nitrogen. Overall mass flow about 900 g/sec.

Partial flow Water + Nitrogen. Inner circle only in operation.

Technology Screening Tests

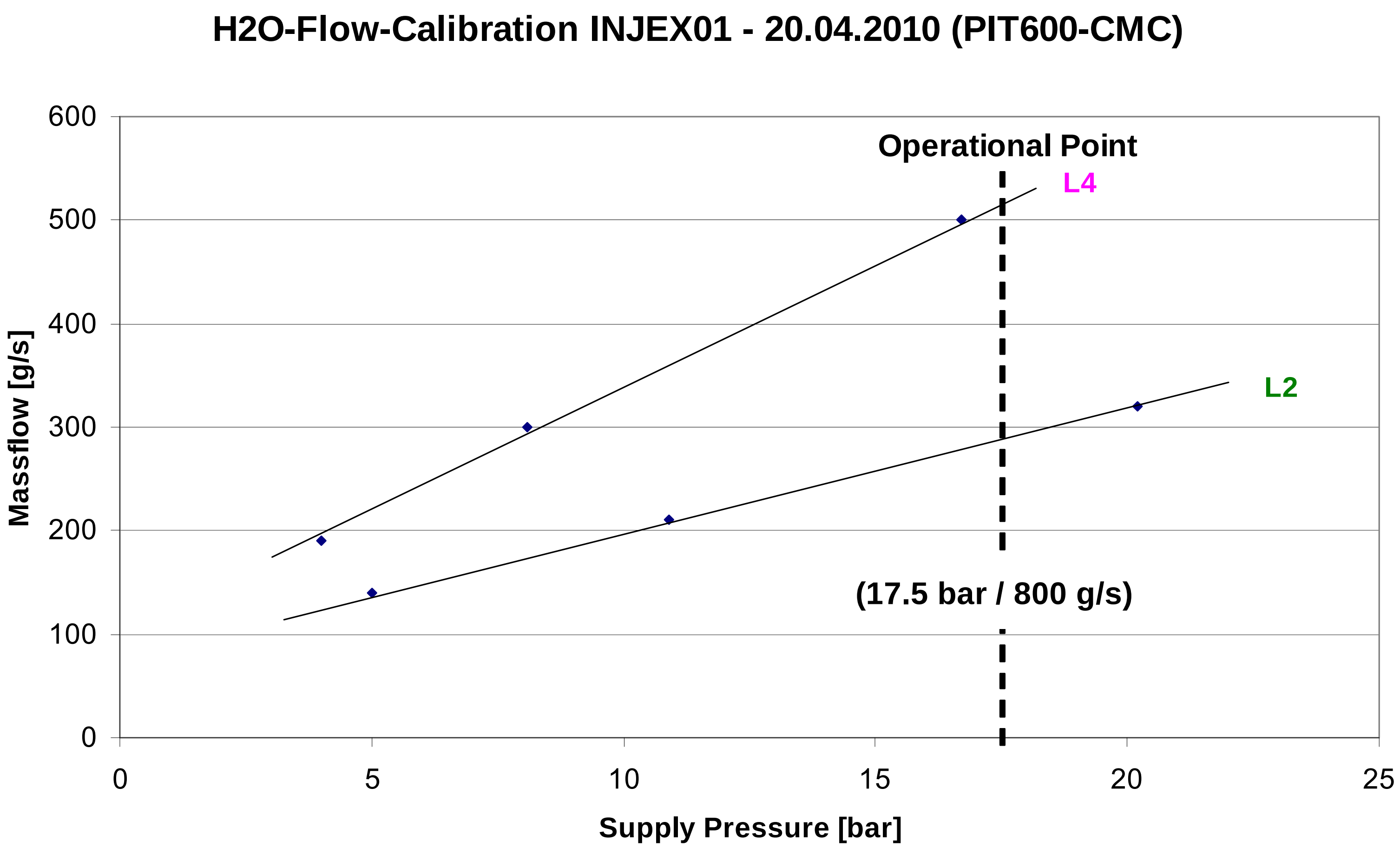
Spray Tests at M3 Test Bench → *Flow Calibration N2*



Nitrogen flow calibration.
Linear slopes.

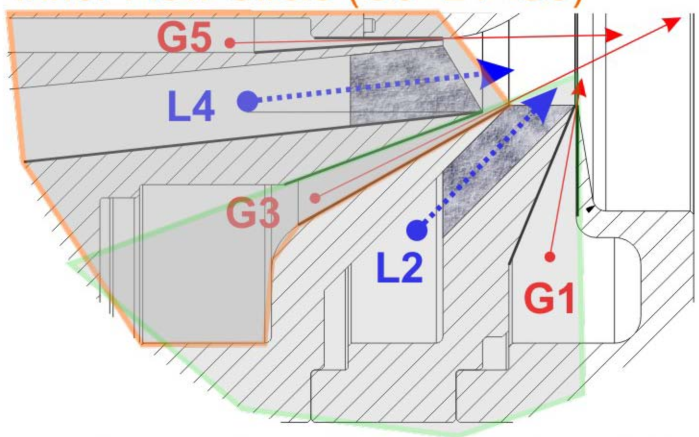
Technology Screening Tests

Spray Tests at M3 Test Bench → *Flow Calibration H2O*



Technology Screening Tests

Throttling Potential



Half section of demonstrator INJEX01.

Examples of Discrete Throttling Mechanisms

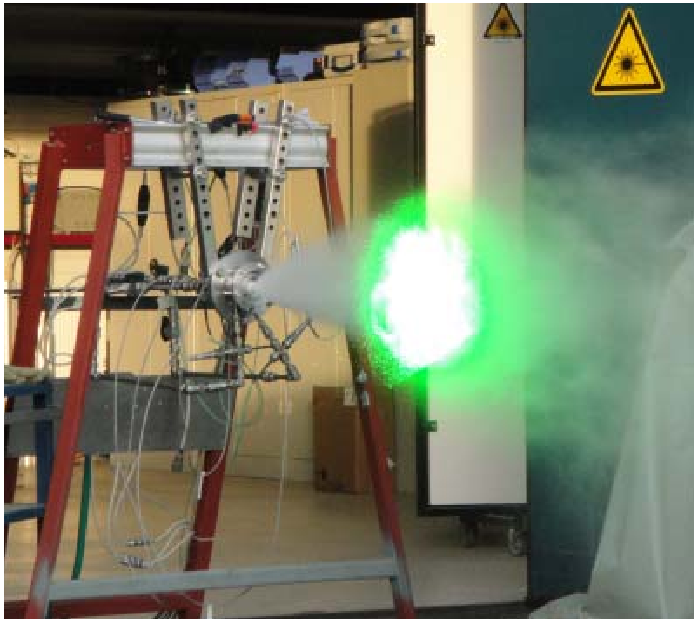
- Connection of dircrete flow circles (inner/outer)
- Geometrical gap adjustment
- Discrete reduction of mass flow by valves

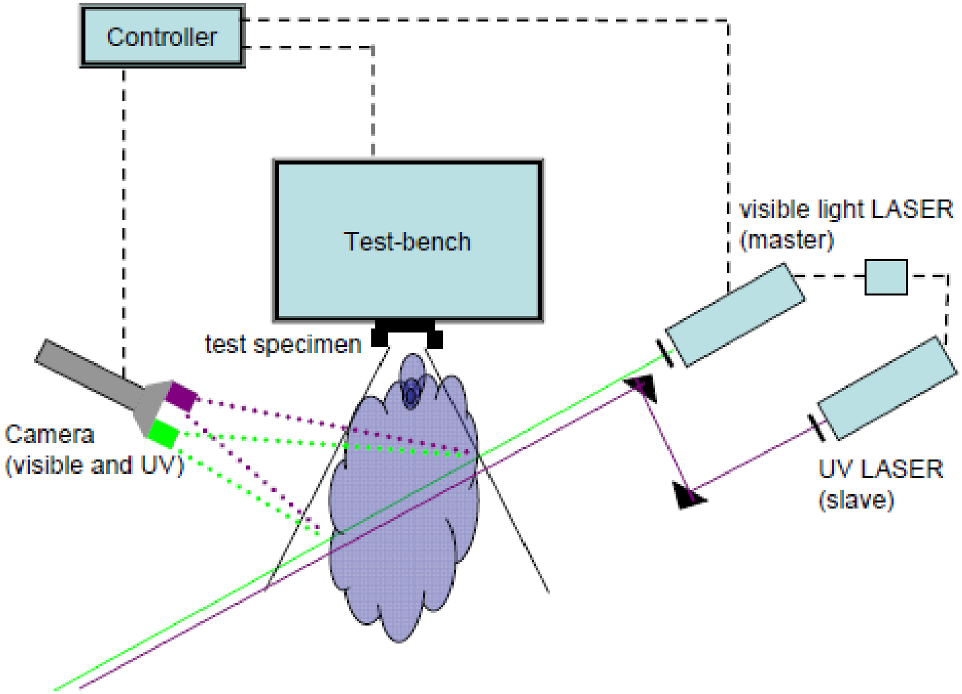
→ **Expected throttling potential:**

Mass flow reduction down to 20 % conceivable, while retaining good spray-patterns!

Technology Screening Tests

Laser Measurement





Check runs of the laser cut measurement system.

Summary and Outlook

Summary

- New injector concept + functional features presented
- Structural integrity demonstrated
- Flow characteristics adjusted at conditions of 50 mm chamber (60 bars)
- Preliminary droplet investigations conducted

Outlook

- Further tests using cryogenic substitute media (LN2 + He)
- Improved laser tests → droplet distribution + droplet speed
- First ignition tests + short hot runs at P6.1 test bench

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