CMC Rocket Thrust Chamber Technology
Status and Perspectives

M. Ortelt, H. Hald, D. Koch
markus.ortelt@dlr.de

German Aerospace Center (DLR)
Institute of Structures and Design

AIRBUS DS – Space Systems - 6th R&T DAYS, Paris, 19.11.2015, Session 3, WG2
Technologies for Future Liquid Propulsion

DLR

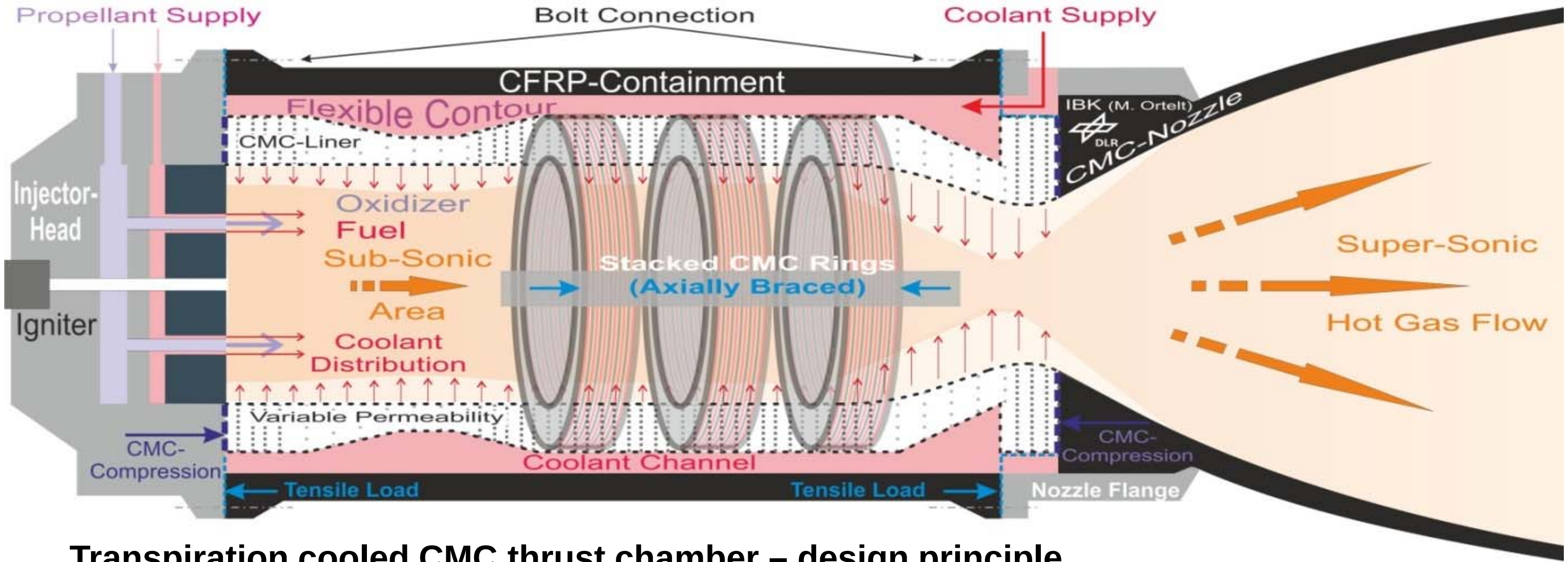
Outline

- Conceptional aspects of the transpiration cooled CMC TCA
- Development status
  - Structural components
  - Materials
  - Test data
- Some future perspectives for CMC in space propulsion components
- Summary & outlook

CMC thrust chamber – Design concept

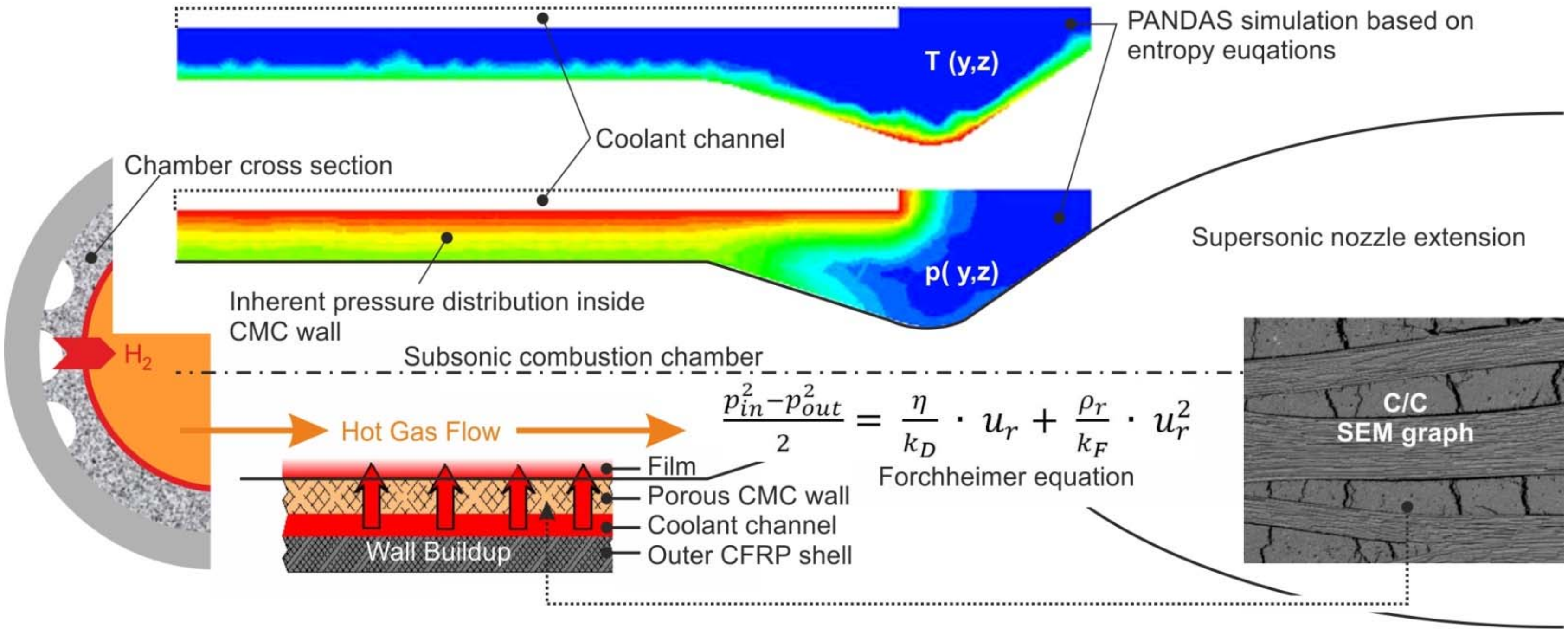
Features

- Decoupling of single components – no bonding
- Decoupling of mechanical and thermal loads
- Specific hybrid interface technologies
- Selective inner liner design

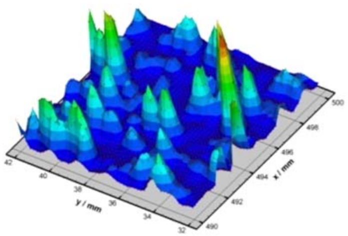


Transpiration cooled CMC thrust chamber – design principle

Functional aspects



- Standard CFD systems (FLUENT, CFX, …) are constructive (pure flow coupling)
- Ongoing tool-development for ‚structure-flow-coupling' (TAU)
- Investigations on materials out-flow homogeneity →



System analysis of transpiration cooling

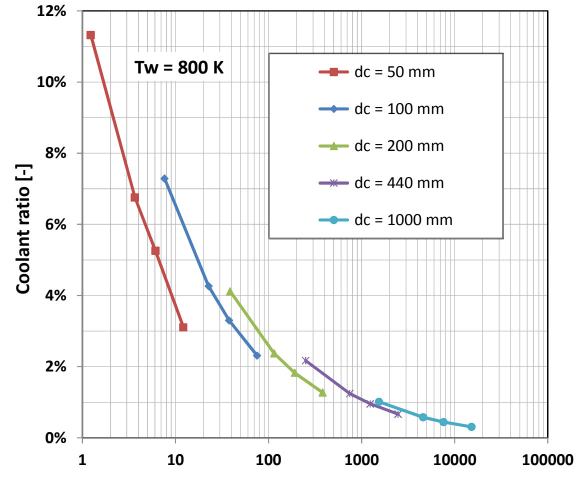
- **Comparison of chamber size (scaling)**
- **50 mm chamber demonstration**

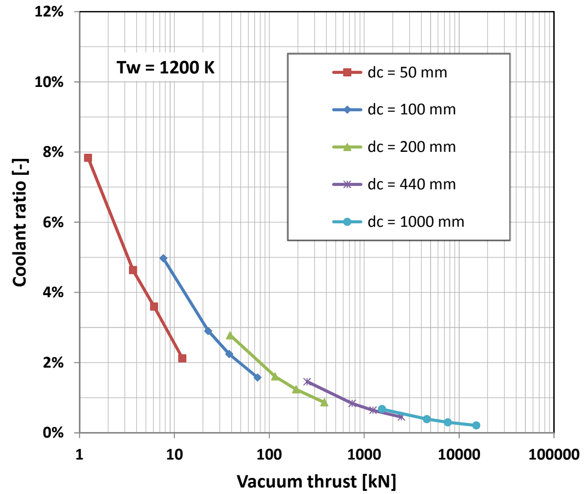
  - O/F = 5.5 (injector)
  - Contraction ratio 6.25
  - Characteristic chamber length l*=1.84 m
  - 7 % coolant ratio
  - Damage free operation

  - Amount of coolant depends on
    - Hotgas conditions, A_s, T
    - D ↗ + p ↗ → required coolant ratio ↘

  - Further coolant ratio reduction potential
  - Chamber length can be shortened

→ High operational efficiency predicted





Processes for Manufacturing of Nonoxide CMC

C, SiC fibers in C, SiC, SiC(N) matrix

- Polymer Infiltration and Pyrolysis (PIP)
- Liquid Silicon Infiltration (LSI)
- Combi-Process (PIP+LSI, CVI+LSI)
- Chemical Vapor Infiltration (CVI)

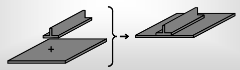
Focus at DLR Stuttgart

PIP

preform (e.g. fabrics, filament winding)
→ fibrer coating
→ infiltration (e.g. RTM) with Si-precursor (e.g. polysilazane)
→ pyrolysis (inert atmosphere, T~1000° C, e.g. polysilazane → SiCN-matrix)
→ finishing

3-6 times to decrease porosity

intermediate machining joining



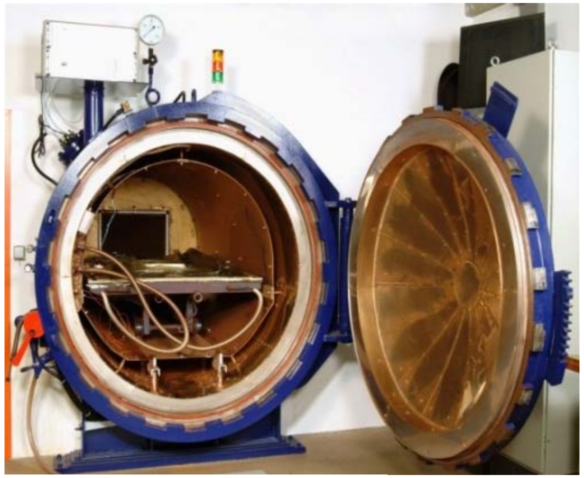
LSI

preform (e.g. fabrics, filament winding)
→ fiber-coating if necessary
→ infiltration (e.g. RTM) with C-precursor
→ pyrolysis (inert atmosphere) → carbon matrix
→ siliconisation (inert gas, T>1420° C, Si+C→SiC) → stoichiometric SiC-matrix
→ finishing

Koch et al., DLR Werkstoffkoll. 2013

DLR

Processing of Ceramic Matrix Composites (DLR-ST, BT)



- Autoclave
  30 bar, 350 °C
- Warm Press 350°C
- RTM 300°C
- Pyrolysis, LSI, 2000°C
- Machining Center

Thrust chamber – potential CMC derivatives

Initial C/C model material LOX-sensitive!

Other derivatives damage free after efficiently cooled and non-cooled operation:


Oxipol

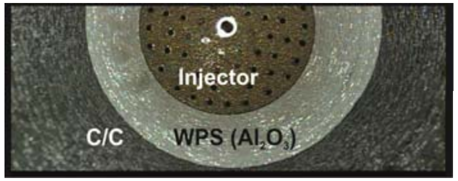

AvA-Z-ISC


C/SiCN

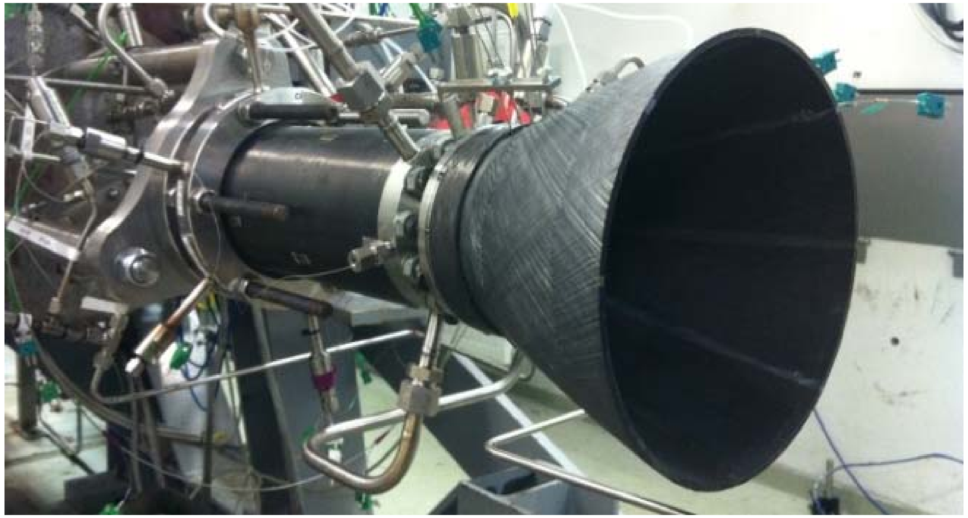

C/C (CVI)

Open porosity ε [%] (porosity + permeability k_d / k_f adaptable by manufacturing process)			
10	**35**	**18**	**7**
Density kg/cm³			
2.3	**2.6**	**1.6**	**1.6**

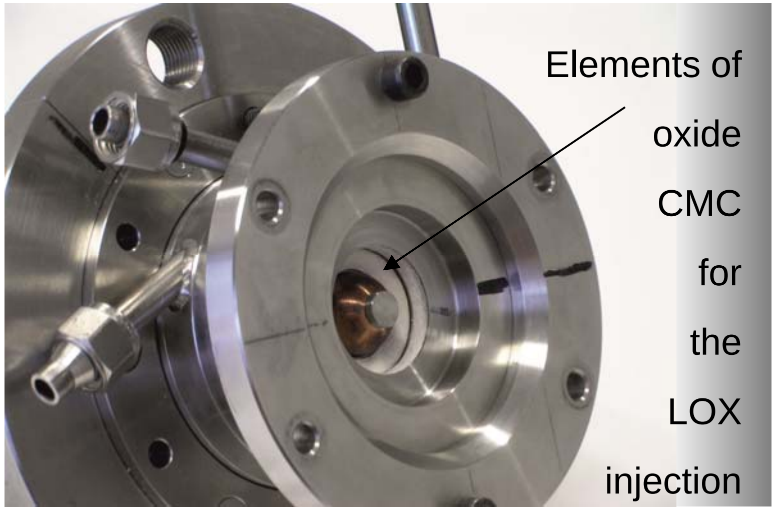
CMC thrust chamber – Components



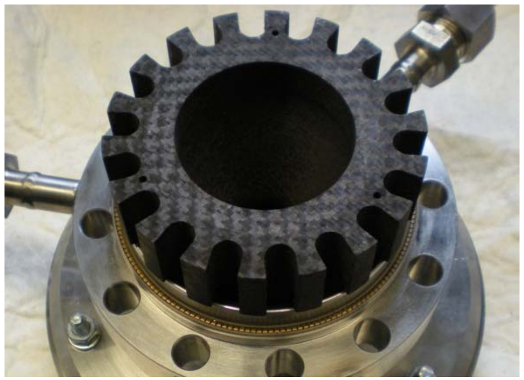
Porous metal injector



Integrated ‚BlackEngine' demonstrator, $\varnothing_{cyl.}$ 50 mm



Porous CMC injector



Inner liner segment

Applied injector systems for $\varnothing_{cyl.}$ 50 mm

Co-axial injector

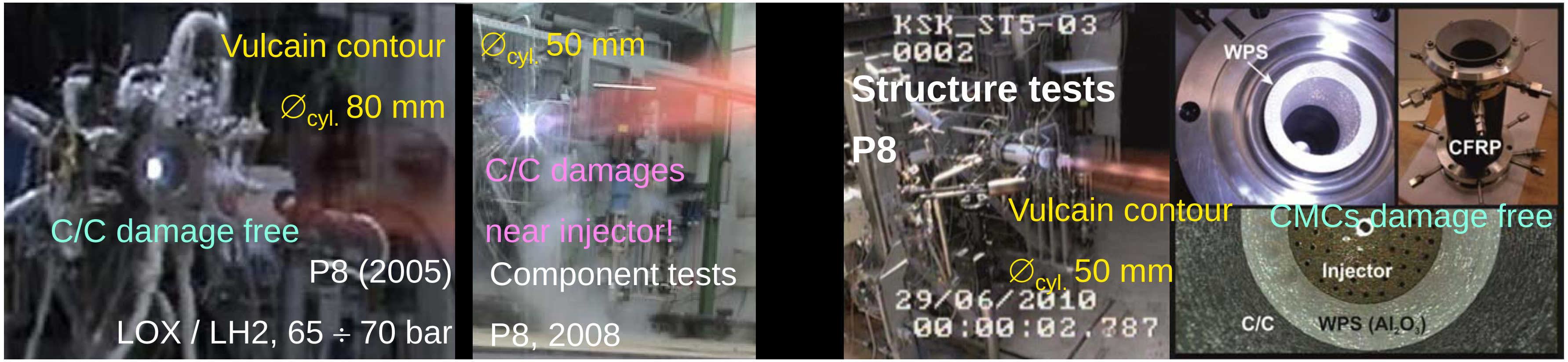
CMC thrust chamber – mechanical interfaces

Characteristic hybrid interface types

Bolt interface for CFRP-metal joining

Load-de-coupling double-shell nozzle extension
with keyed joint elements for CMC-metal joining

Thrust chamber - hot gas verification (LOX/LH2; LOX/GH2)

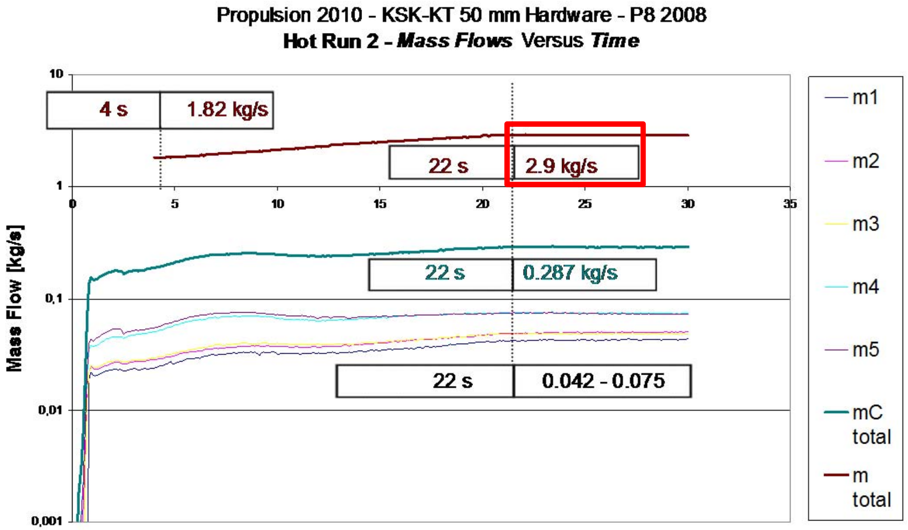


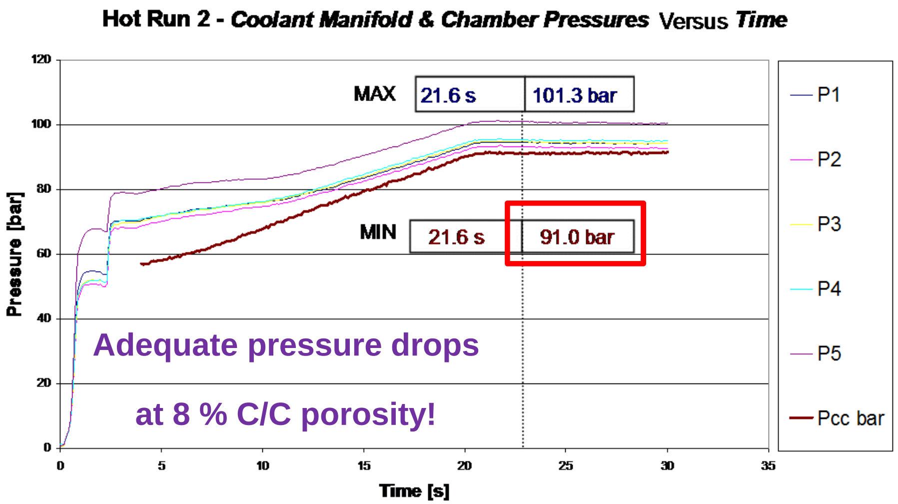
52 s, 5 ÷ 6 kg/s, τ = 4.2 % | 90 bar tests | 120 s, p_c = 55 bar, LOX / LH2 operation, τ = 15 %

20 s, p_c = 55 bar, LOX / GH2 (120 K), τ = 9 % | Demonstration of the integrated CMC TCA

DLR

Thrust chamber – pressure loads during hot-run

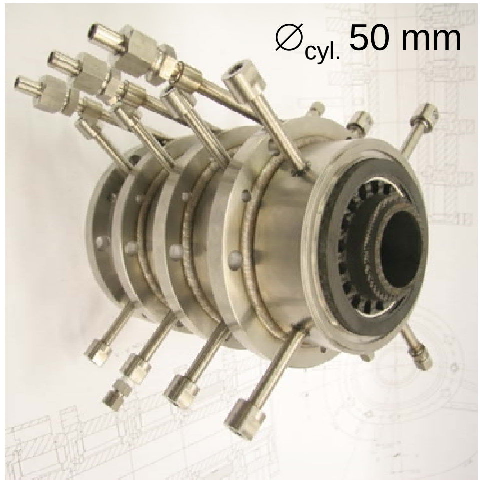


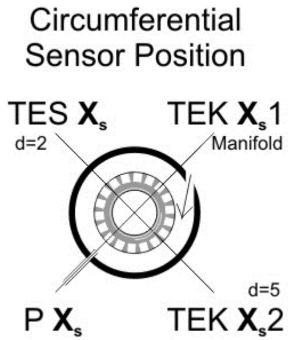


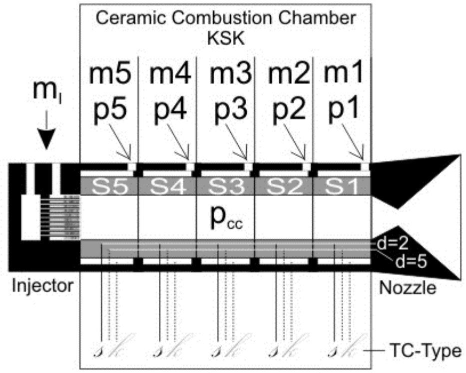
Inner liner: Initial model material C/C

O/F = 5.5

Segmented chamber module





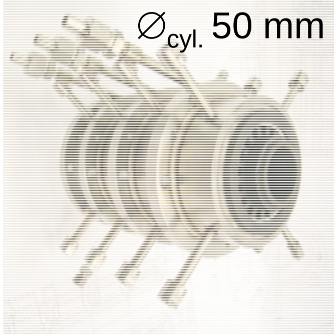


Thrust chamber – thermal loads during hot-run

P6.1, 2012

Nominal hotrun-sequence

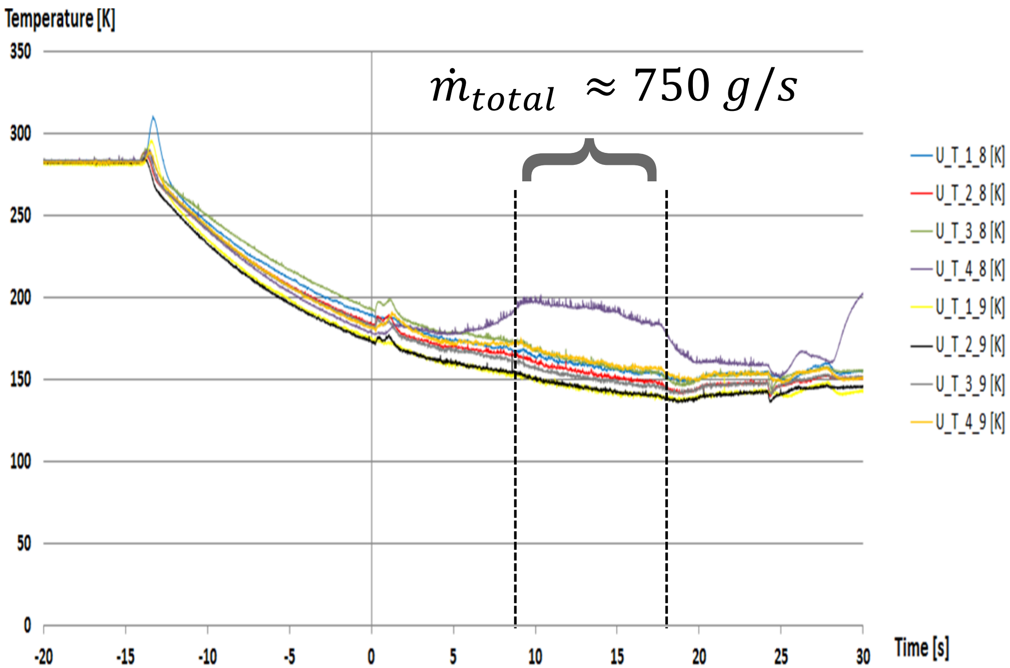
O/F = 5.5; τ = 6.72 %; $p_c \approx$ 55 bar

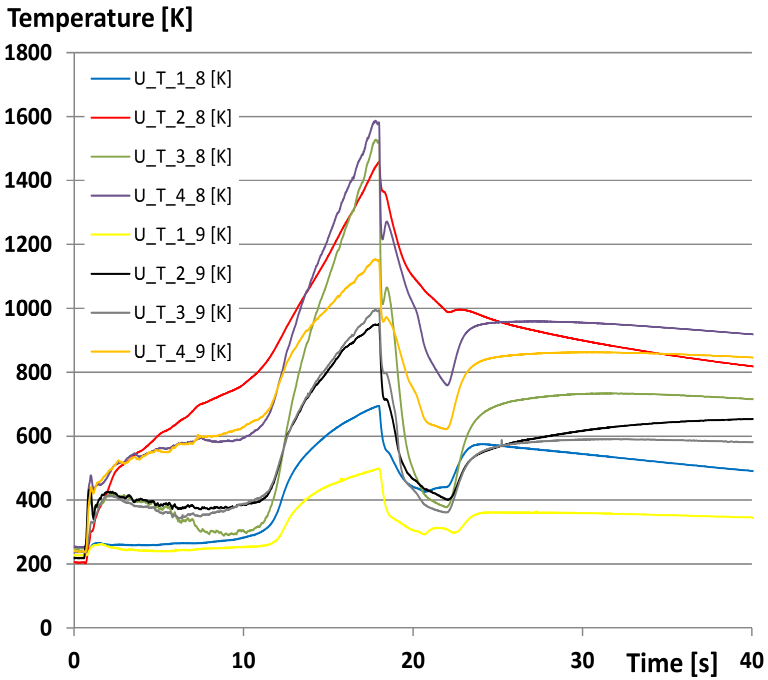


Cooling turned off

O/F = 2.0

Max. $T_{surface} \cong$ 1800 K



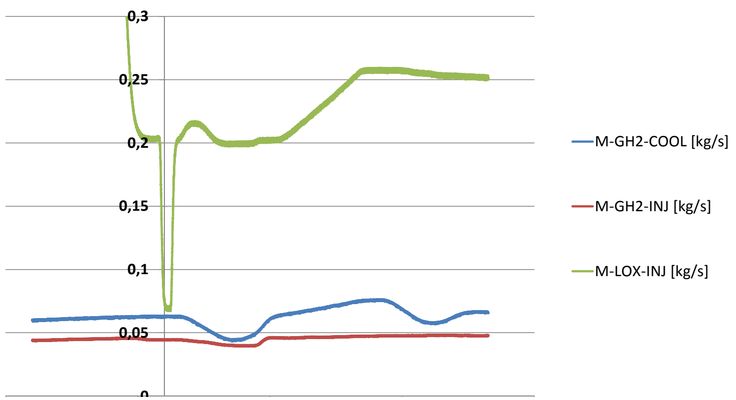


DLR

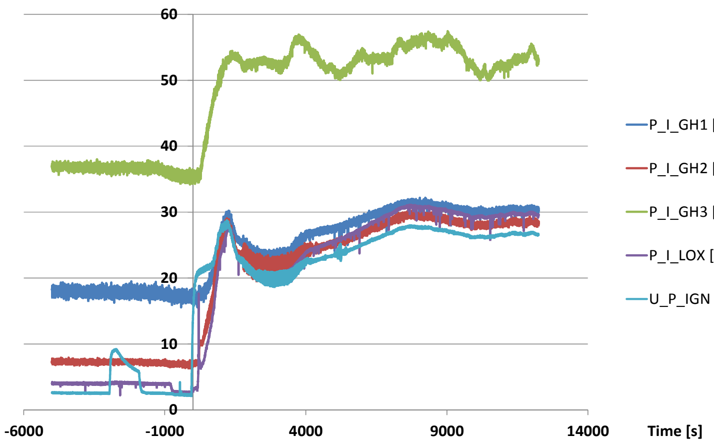
CMC injector (‚*Cone Injector*‘)

Features, goals, results

DLR - Cone Injector test campaign **'IZ2'** - **MASS FLOW CURVES**

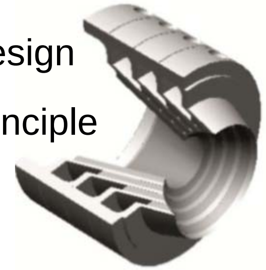


DLR - Cone injector test campaign **'IZ2'** - **PRESSURE CURVES**

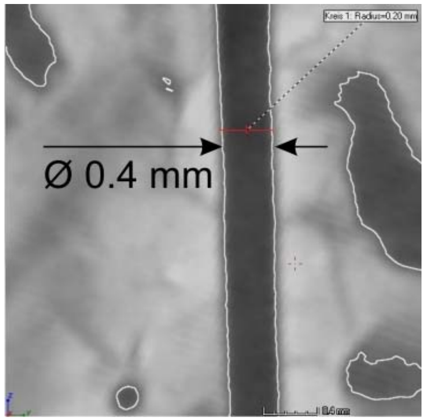


Initially successful hotruns, P6.1, Dec 2013

Design principle

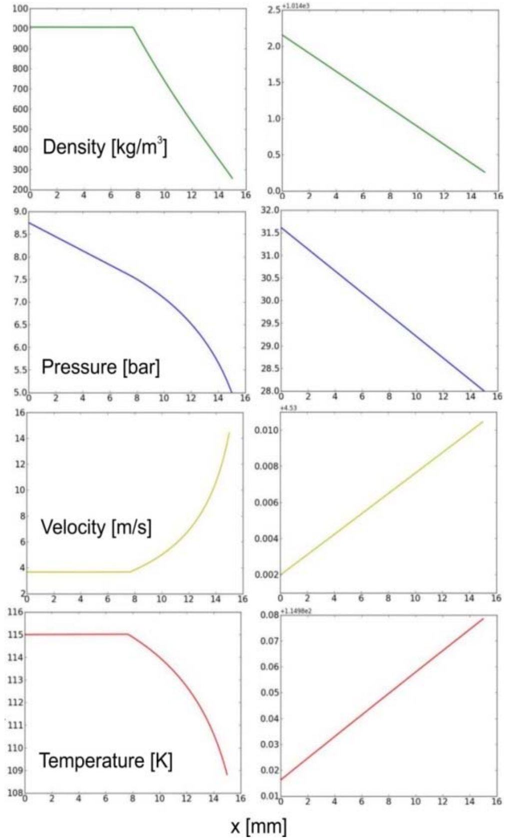


Demonstrator



Channel morphology

Mechanical design

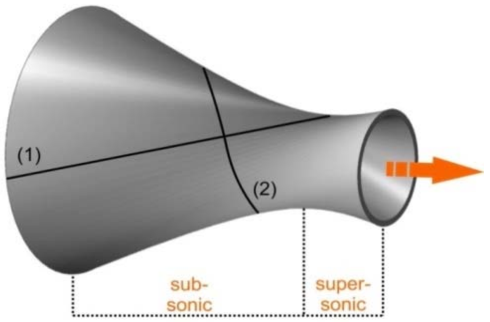


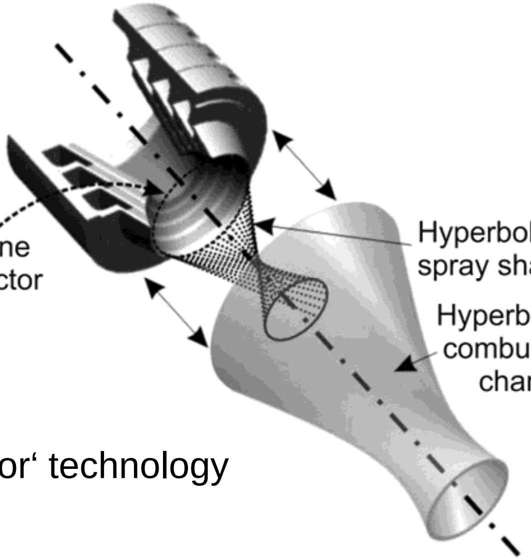
Start-up Steady state

Flow design

DLR

Hyperboloid chamber contour – Orbital propulsion size





Hyperboloid geometry

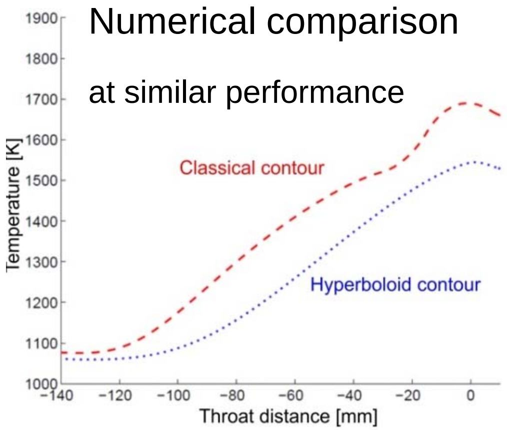
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1$$

Hyperboloid chamber design

Perfectly combined with ‚cone injector' technology

Numerical comparison

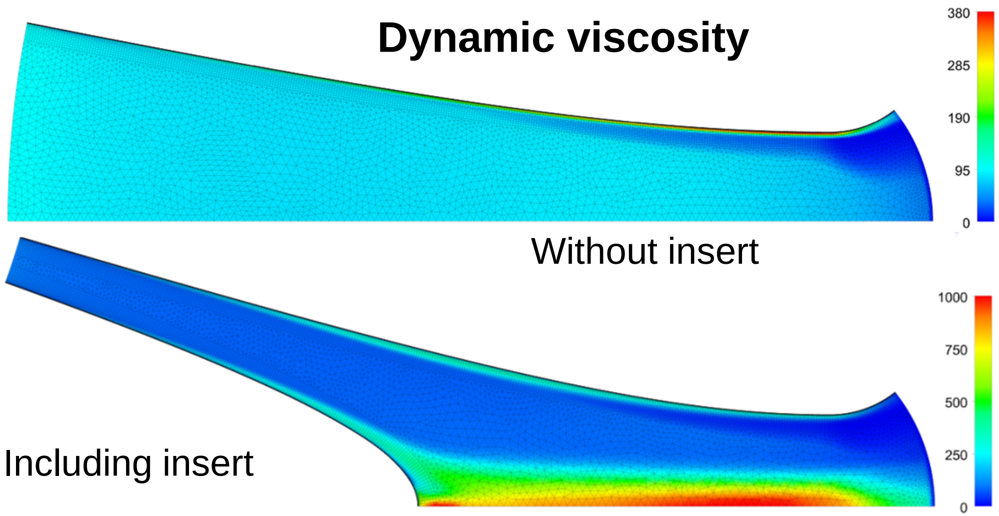
at similar performance

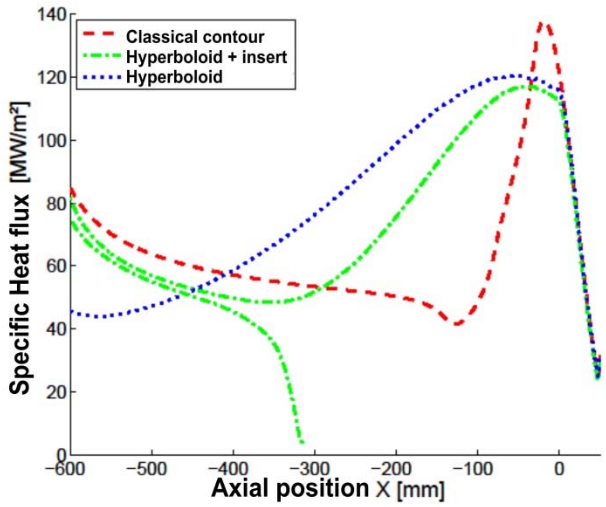


Comparison referred to typical 500 N class

- Advantages for
    - film cooling
    - transpiration cooling
- Composite affine structure manufacturing (winding technique)

Hyperboloid chamber contour – Comparison VINCI size





Heat flux

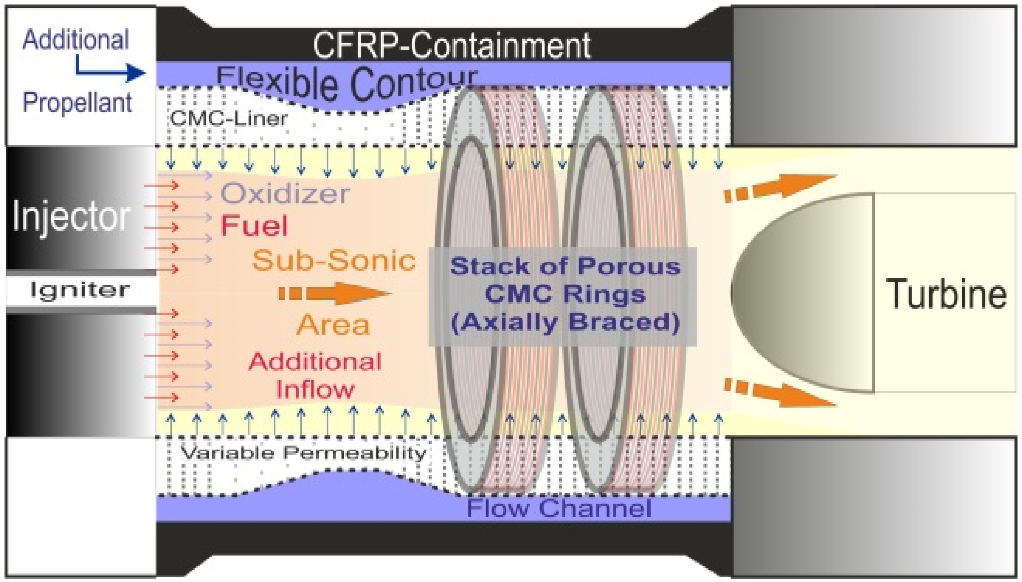
Contour	Mass flow [kg/s]	Total heat flux [MW]	Specific heat flux [MW/m^2]
Classical	43	16	55
Hyperboloid without insert	42	16	56
Hyperboloid including insert	43	27	52

Performance

Future potential - Preburner

Features

- Standard injector technology concerning …
  - functional design
  - mixture ratio
- Propellant overhead injected through chamber wall
- Long life and light weight structures, similar to CMC thrust chamber design



Application principle

(oxide CMCs for ox-rich systems)

Further activities

- ALM / SLM technology for injector systems
- CMC components for hybrid propulsion systems
- Paraffin / N_2O: Hybrid thruster
- CMC thrust chamber for an ADN orbital propulsion system
- Investigations on alternative propellants for CMC high performance thrust chamber application
    - LOX / LCH_4
    - LOX / kerosene

Summary

- The transpiration cooled CMC thrust chamber principle could be demonstrated successfully
    - a simplified and de-coupled design principle has been proven
    - no critical material degradation under efficient operation, considering scaling aspects
    - mechanically safe structures

- First firing tests of the ceramic ‚cone injector‘ concept successful and promising

- Adequate hybrid mechanical interfaces demonstrated

- New hyperboloid thrust chamber contour numerically validated

Outlook

- CMC application potential for ADN thruster (orbital propulsion)
- CMCs principally interesting for hybrid propulsion systems
- Preburner application (in particular ox-rich)
- Up-coming SLM technology
- Alternative propellants

DLR

Thank you for your attention!