High Temperature Stable Fibre Reinforced Composites for Thermal Protection of Spacecraft Vehicles

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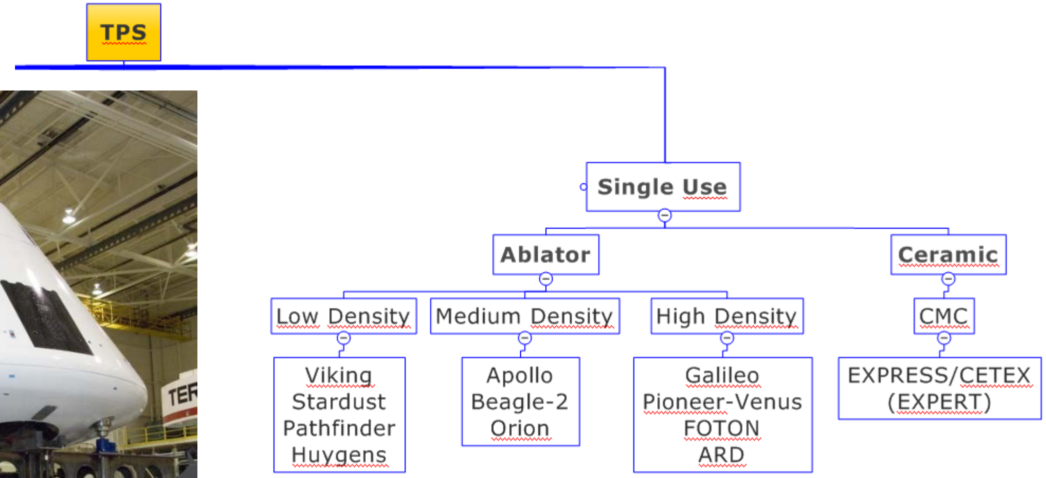
Classification Attempt of TPS Systems

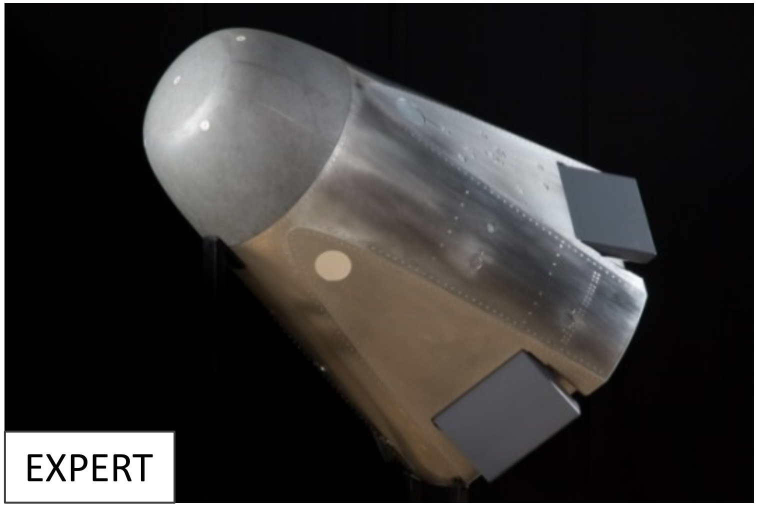

Stardust



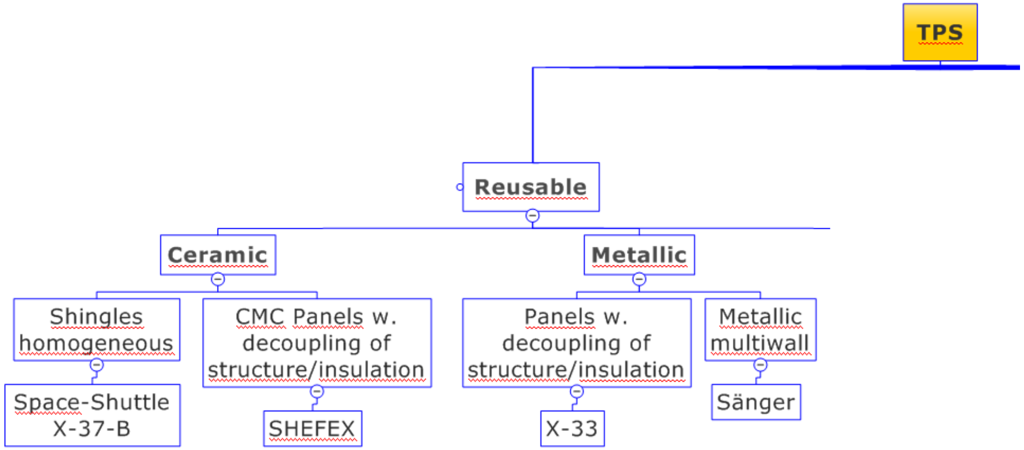

ORION

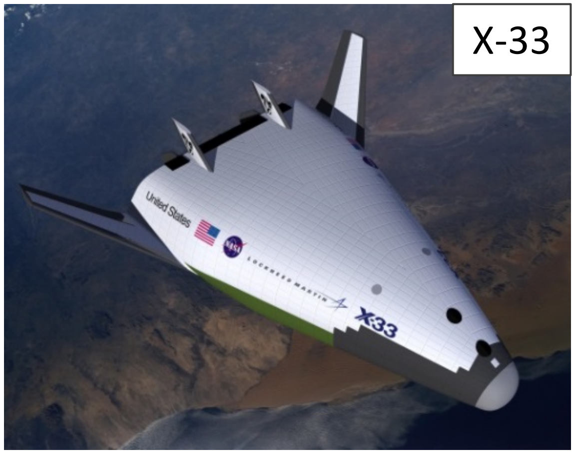

FOTON-M2


ARD


EXPERT

Classification Attempt of TPS Systems





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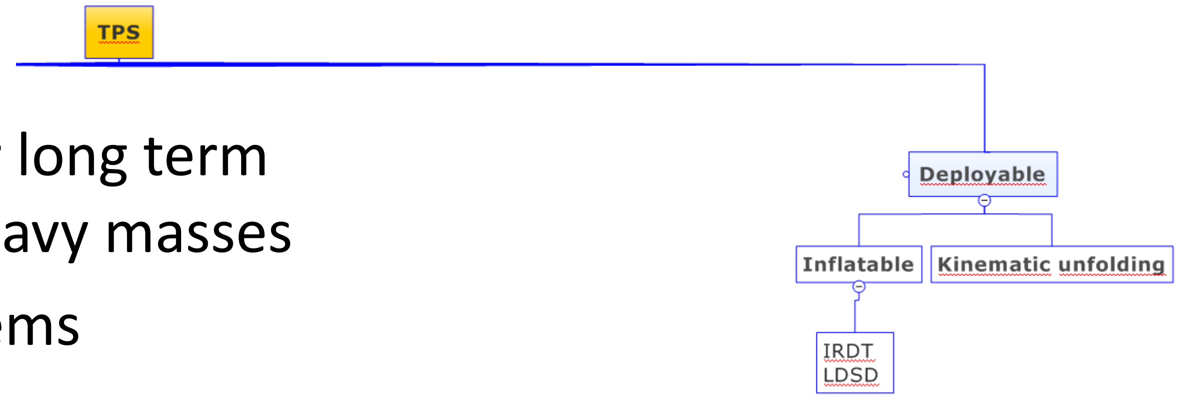
Classification Attempt of TPS Systems



- Deployable systems for long term missions (Mars) and heavy masses
- Contour changing systems

- LDSD = Low Density Supersonic Decelerator (NASA, Test 2014)
- IRDT = Inflatable Re-entry Demonstrator (ESA/Astrium, several tests 2000, 2002, 2005)

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Topics

- Ceramic Matrix Composites as thermal protection materials
  - Ultra High Temperature Ceramic Matrix Composites
  - High thermal conductive composites
- Applications
- Conclusions and Outlook

The reason for blunt body re-entry shapes

- Amount of heat generated in re-entry depends on the vehicle shape
- Heat load increases with decreasing nose curvature radius
- The minimum radius is limited by available materials

factor

Actual velocity normalised with orbital velocity = speed term

$$\dot{q} = \frac{a}{\sqrt{R_n}} \left(\frac{\rho_\infty}{\rho_{sl}}\right)^{0,5} \left(\frac{U_\infty}{U_{co}}\right)^{3,15}$$

Nose radius

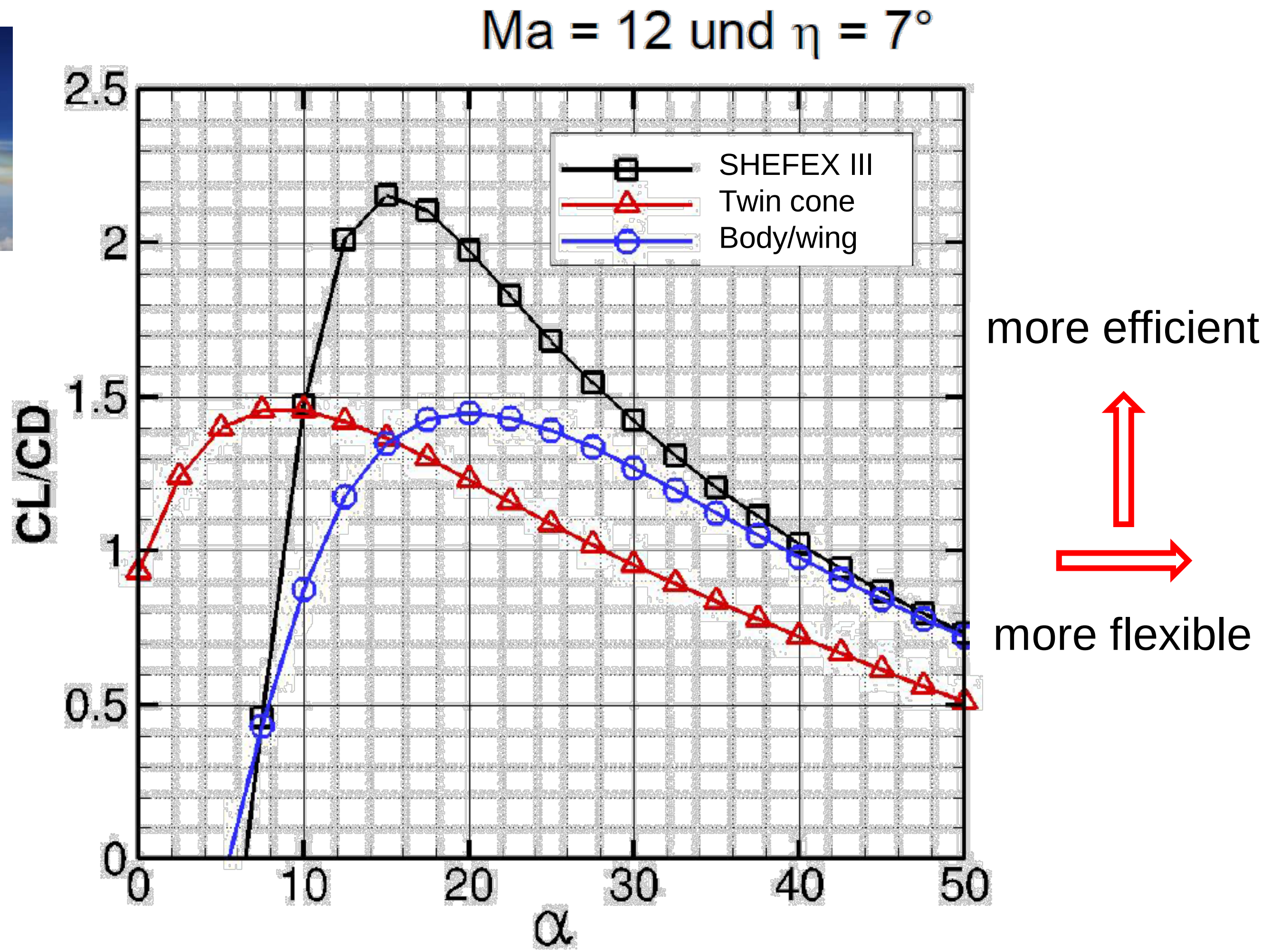
Actual density normalised with sea level density = altitude term

Vision of Hypersonic Cruise


Spaceliner

Source: NASA, X43


Shefex II



Vision of Hypersonic Cruise

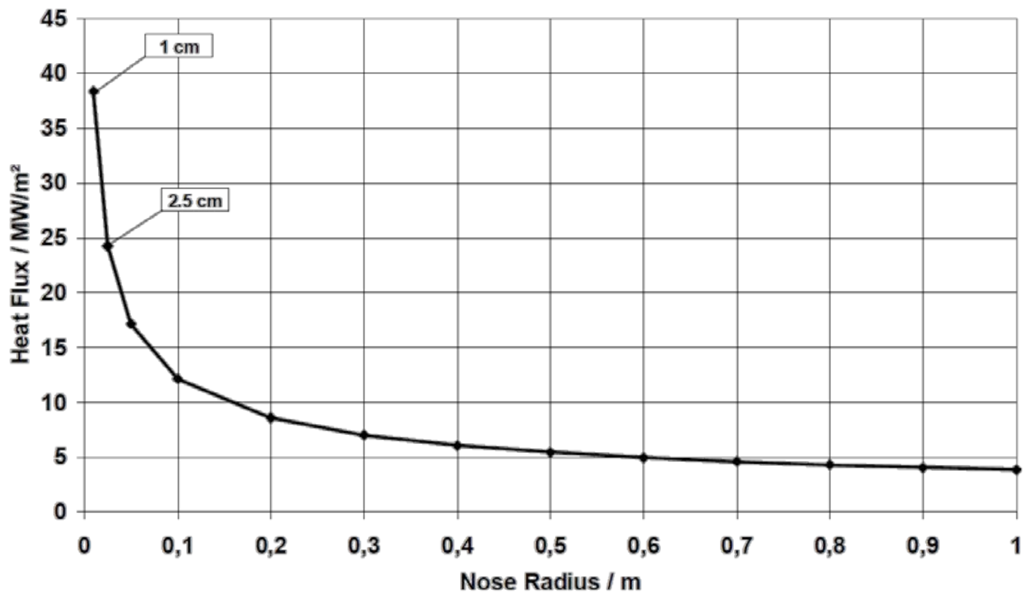
ZrB_2 (3400°C)

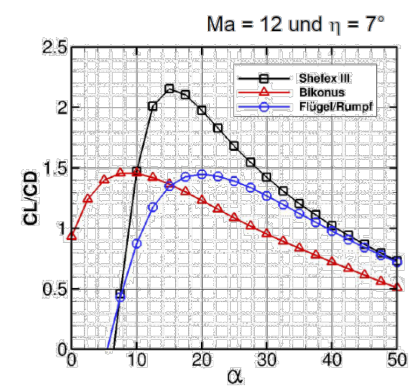
HfB_2 (3400°C)

HfC (3900°C)

TaC (3800°C)

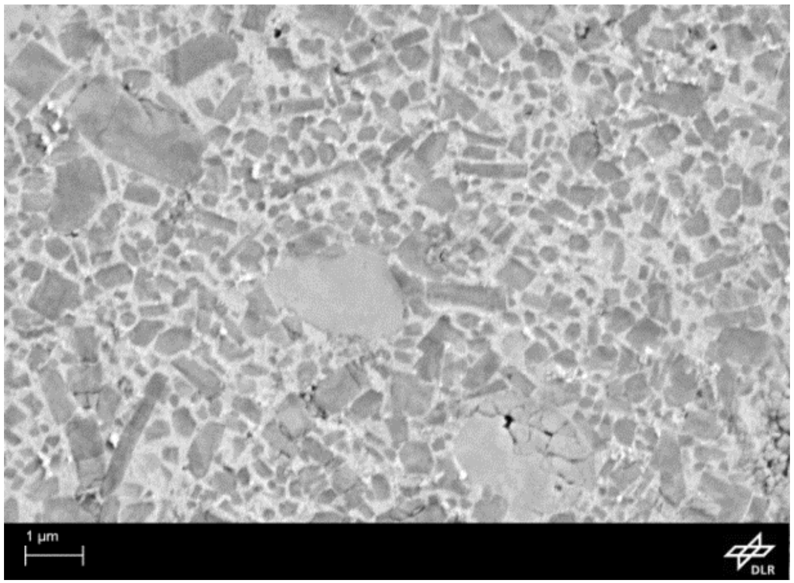
...





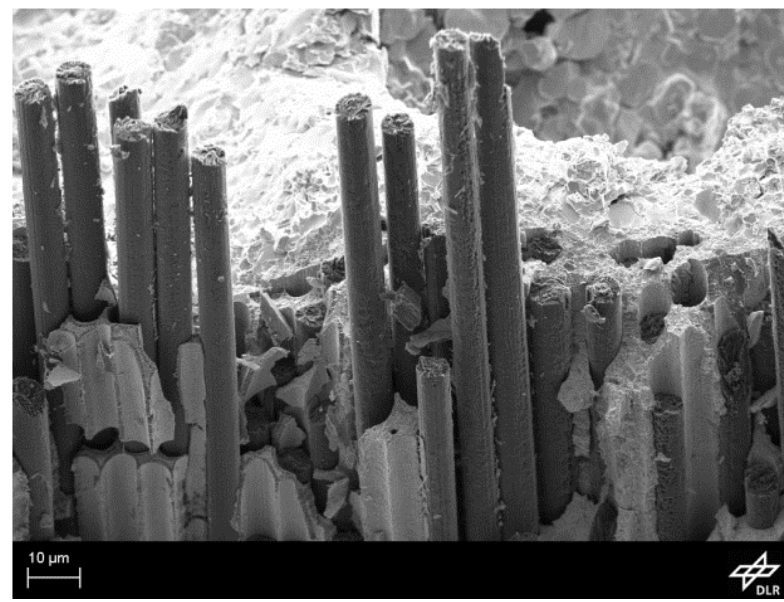
From: Gasch et al. , Handbook of Ceramic Composites, 2005, pp. 197–224

Ultra High Temperature stable CMC – UHTCMC



UHTC

Low fracture toughness



UHTCMC

keep promising properties

enhance fracture toughness by fiber reinforcement

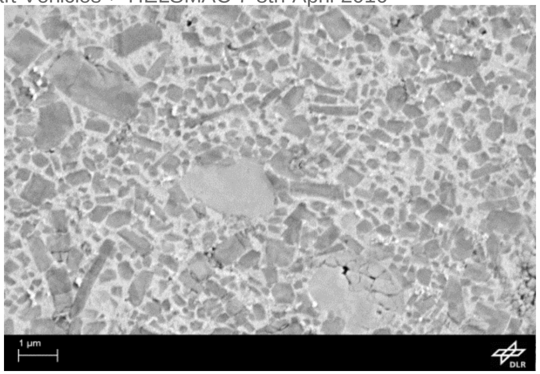
Processing of UHTCMC

- Manufacturing of
  porous fiber preform
- Reactive Melt Infiltration RMI
  via capillary forces
- reduced processing temperature
  without mechanical pressure
- good formation of ZrB2
  in between fiber bundles
  to achieve low porosity

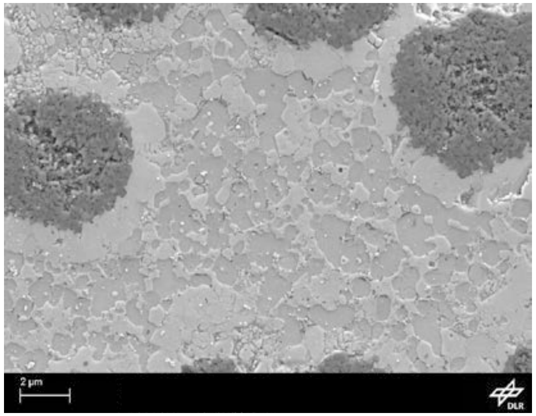
Development Stages

- Processing of monolithic ZrB2 by RMI
  Use of thermo softening plastic (TP), Polycarbosilane (PCS), Depleted phenolic (PFA)
- Fiber reinforced ZrB2 by RMI
  Slurry Infiltration of Boron in SiC fiber with adapted porosity
- C fiber coating as protection against Zr melt

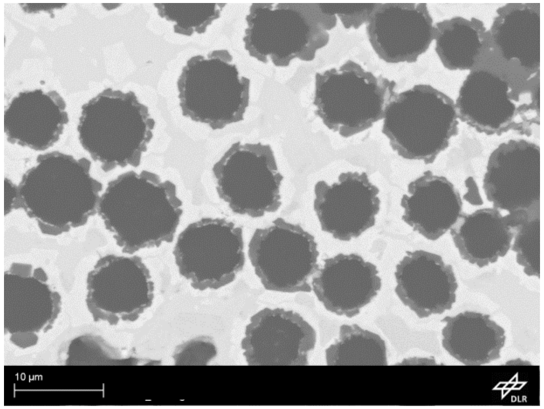
ZrB2



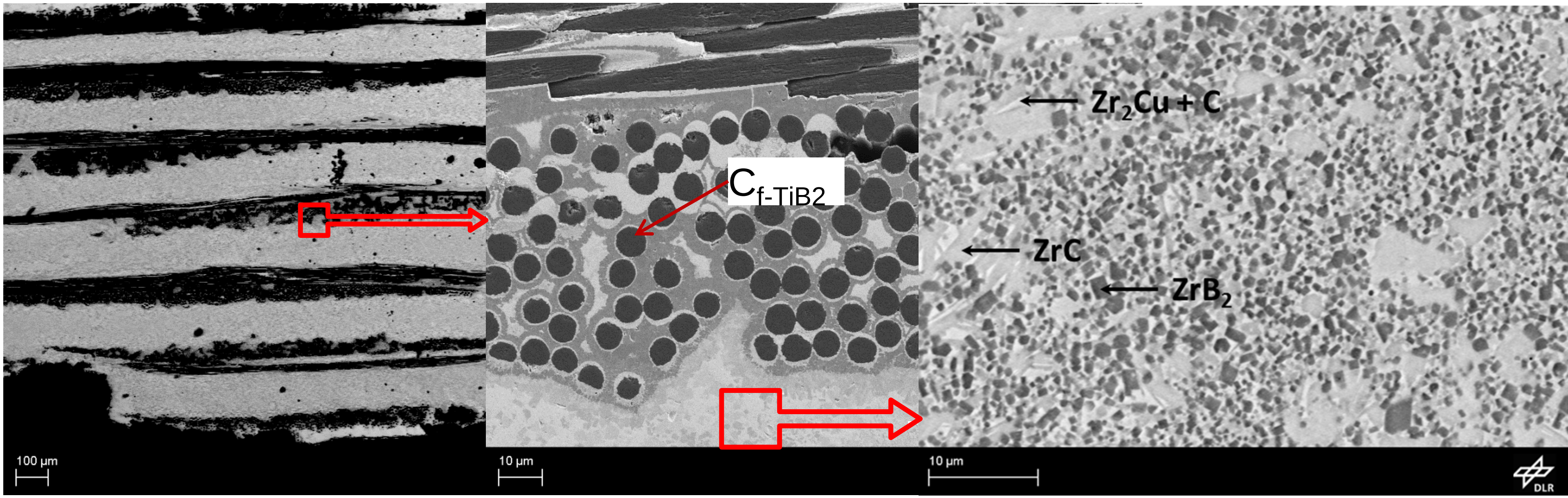
SiC(f)/ZrB2+ZrC



$C_{f\text{-}TiB2}/ZrB_2\text{-}ZrC$



$C_{f\text{-}TiB2}/ZrB_2\text{-}ZrC$



Carbon fiber with TiB_2 coating withstand Zr melt infiltration

Phase	C_f	TiB2	ZrB2	ZrC	Residual melt	∑UHTC	Porosity
Vol%	38	14	19	13	11	47	5

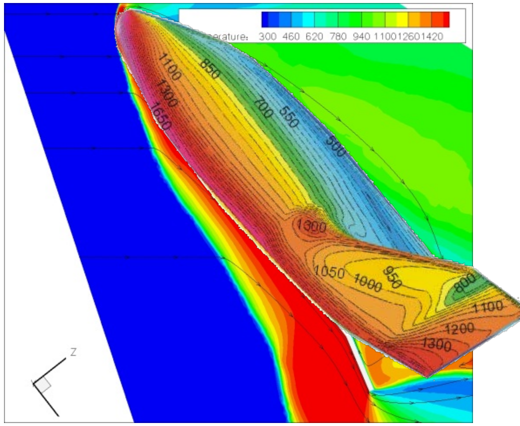
Applications

EXPERT TPS CMC Nose by DLR

- CMC material provides for clean flight environment
- Platform for 4 experiments
- Technology demonstration for complex CMC structures with joints

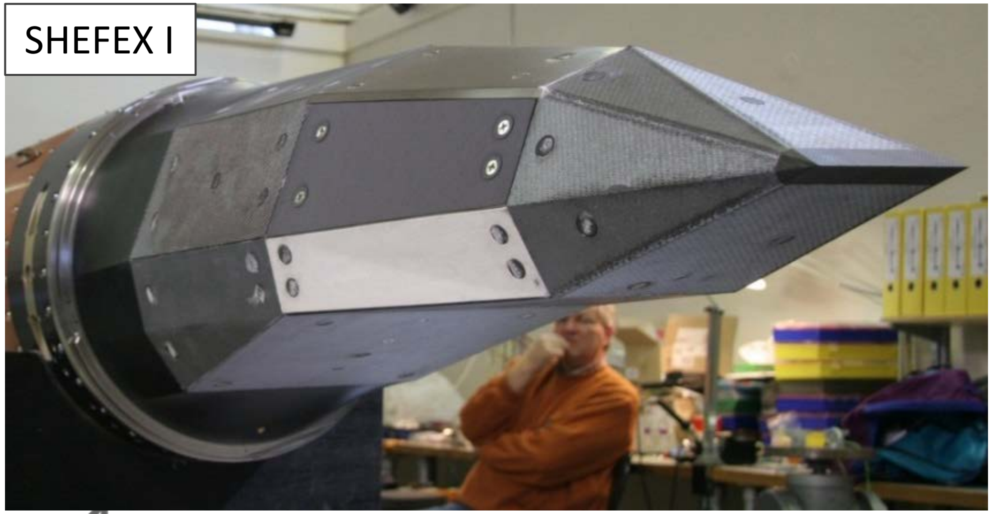
SHEFEX – Sharp Edge Flight Experiment

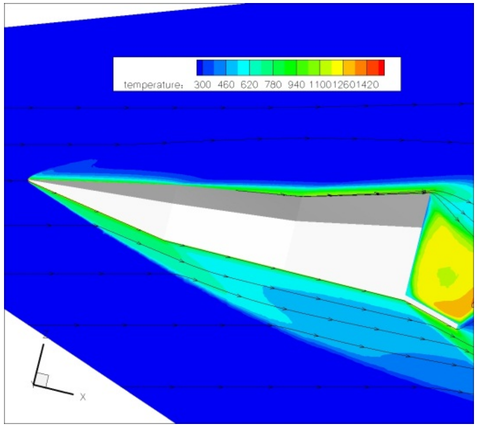
- Optimised aerodynamics in hypersonic regime with low drag and increased lift
- Mission flexibility due to greatly increased crossrange
- Low angle of attack and defined shock position for reduced black-out times
- Cost reduction for TPS elements due to facetted shape with flat panels



Classic way to go: high angle of attack

SHEFEX I

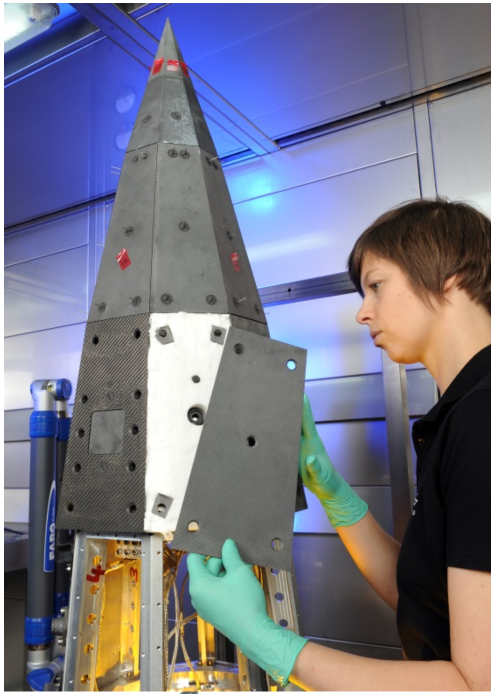


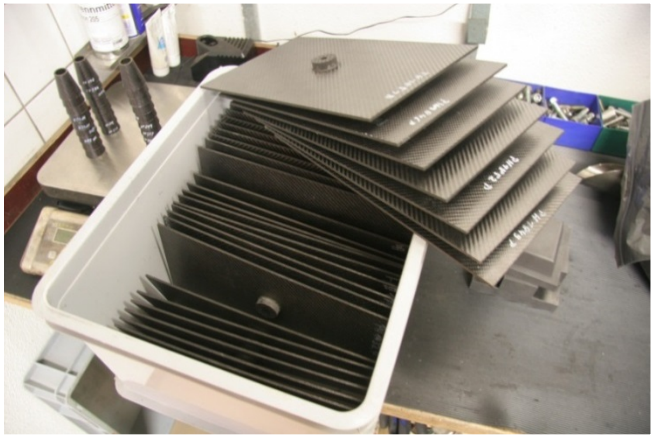


Optimised way: low angle of attack

Segmented CMC TPS for SHEFEX II

- CMC panels on CMC load introductions
- Lightweight dedicated insulation
- Focus on serial production aspects





SHEFEX II Successful Flight Testing

- Launch 22 June 2012, Andoya, Norway
- Trajectory deviation < 1%
- Flight manoeuvers successful
- High quality experimental data
- Mach 10 resp. 2.8 km/s top velocity

Conclusions

- Various TPS are available for specific applications
- New vehicle designs (sharp edges, hypersonic cruisers) need improved TPS
- Current activities focus on UHTC and UHTCMC based TPS for even higher thermal loading and long term use

Outlook

- Development of highly efficient ablator systems with low density


Thank you or your attention

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