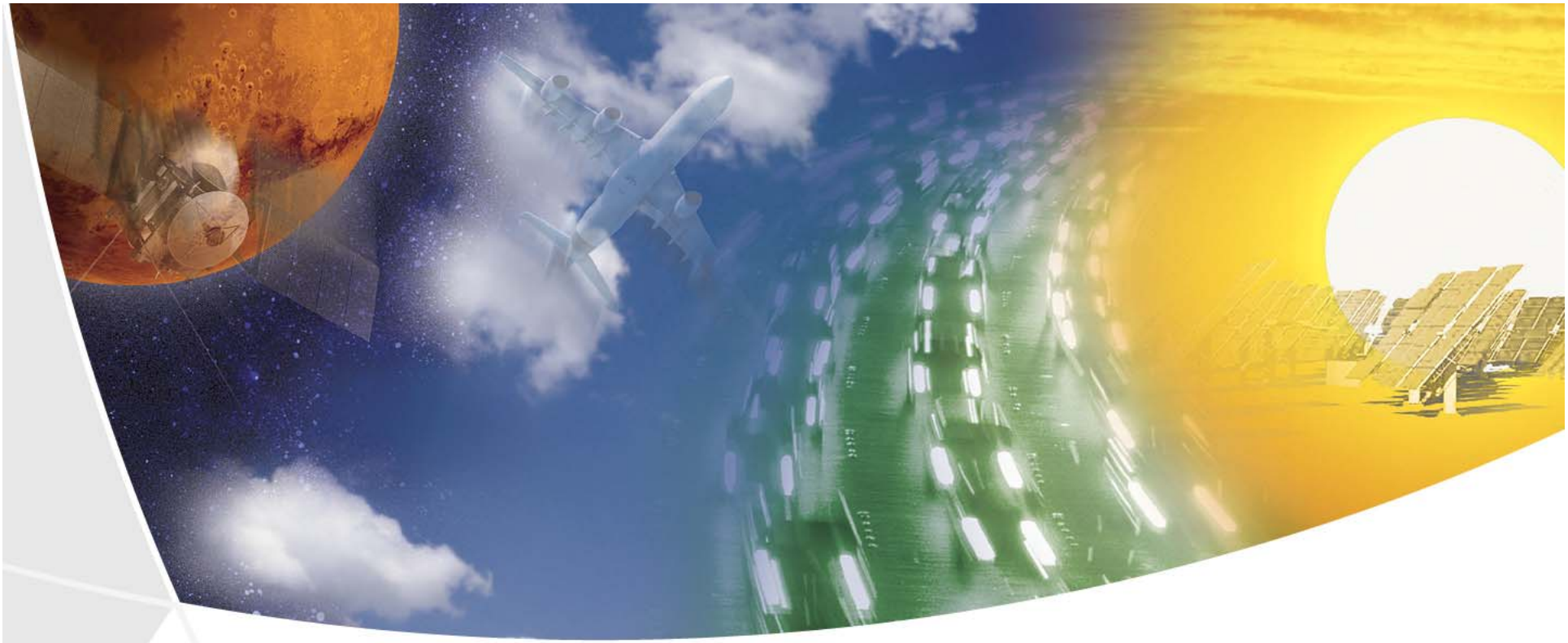


Hybrid Materials and Construction Principles for Aero Engine Components

Materials Day@ILA 2006

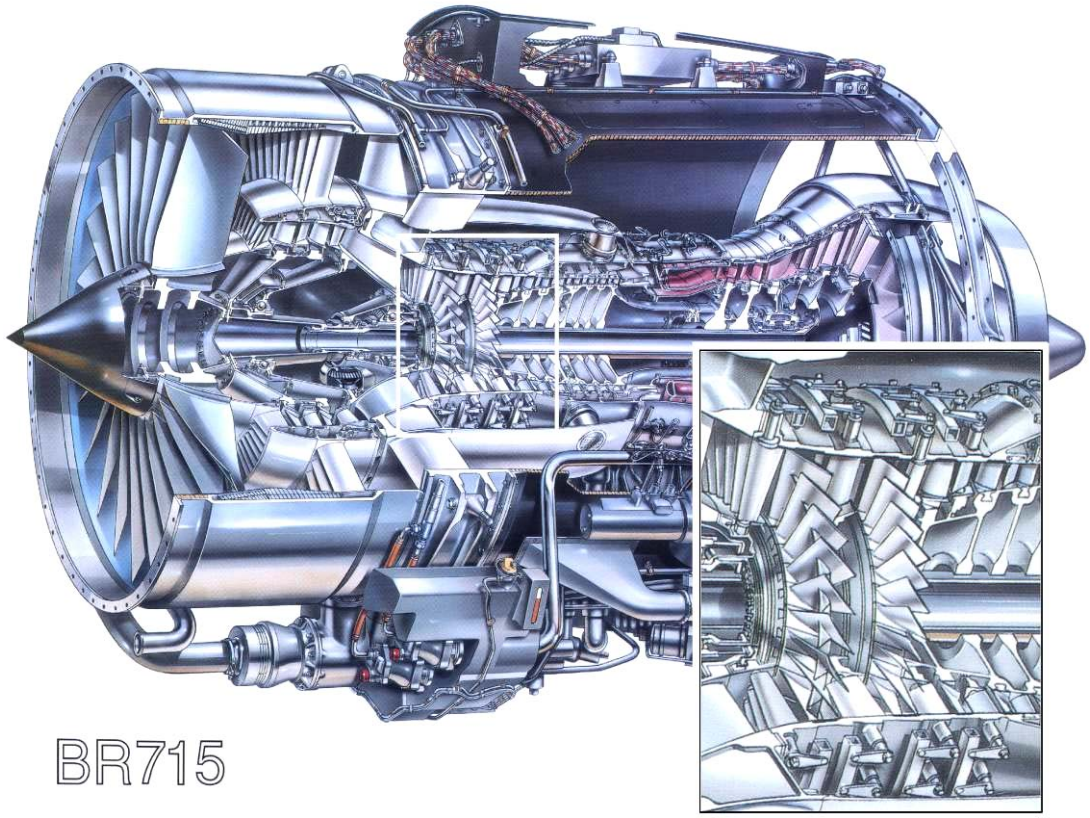
Frank Kocian, Joachim Hausmann DLR – German Aerospace Center

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Content

- Hybrid Unison Ring for a High Pressure Compressor
- Hybrid Fan Blade – Two Different Approaches
  - CF-PEEK Titanium Hybrid Fan Blade
  - Continuously Reinforced Titanium Matrix Composites (TMC)
- High Performance Shaft for an Aero Engine

Hybrid Unison Ring - A component for BR700 HP compressor



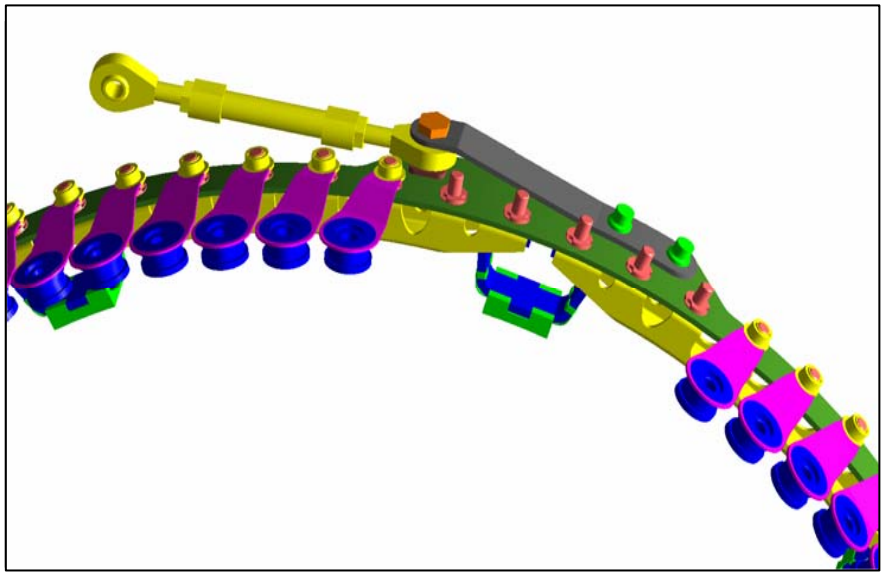
Aims:

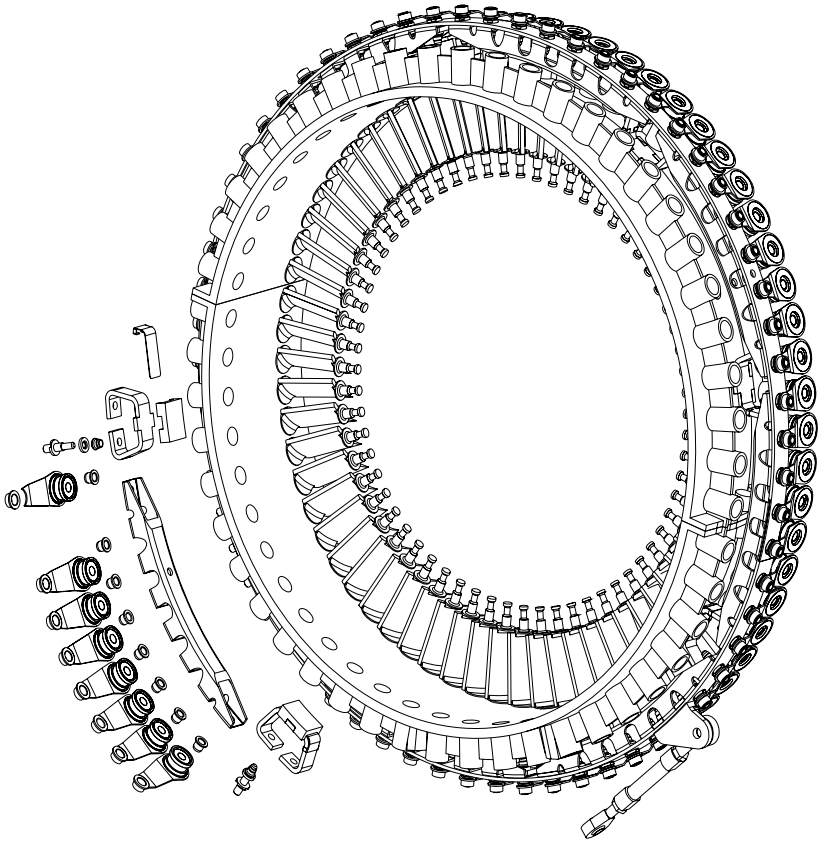
- better functionality
- reduced weight
- reduced cost

Project partners:

- RR-Deutschland as end user
- Fa. Ensinger as prospective supplier
- DLR Stuttgart as developer

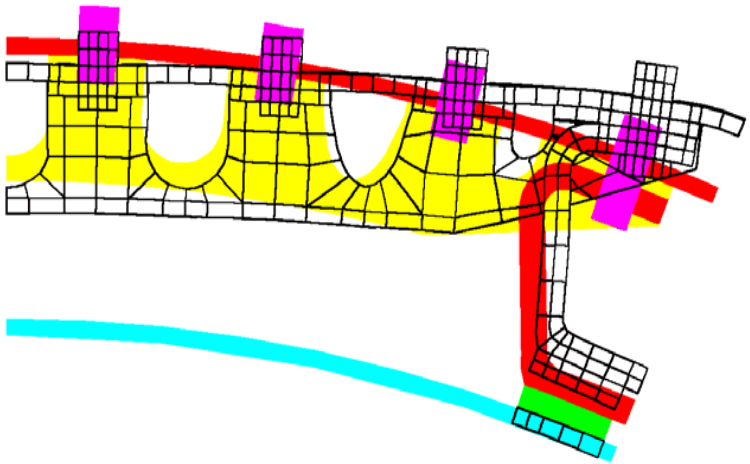
Hybrid Design - A new Approach





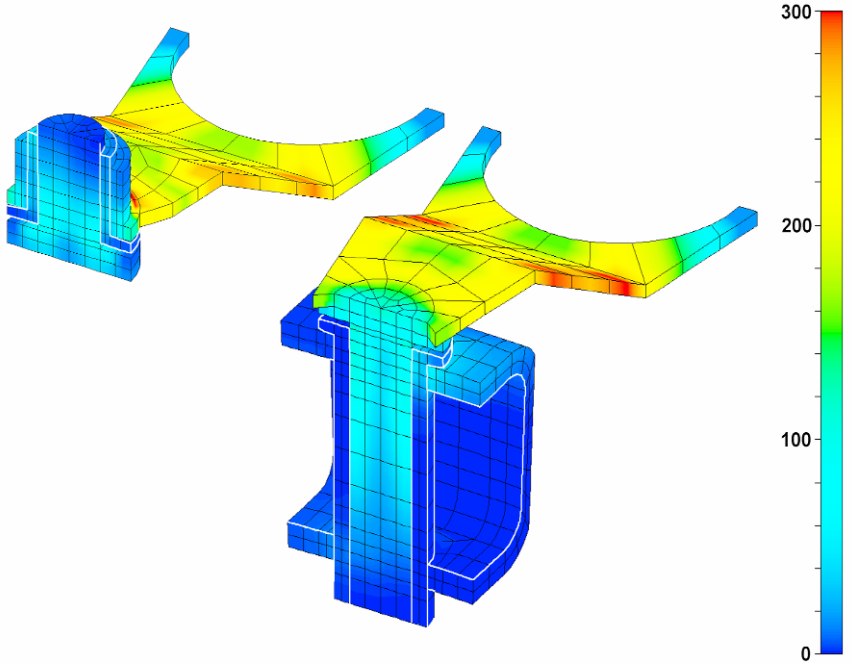
- Implementation of adjustable thermal strain compatibility
- Simple multifunctional substructures
- Optimised combination of high performance materials

Theoretical Investigation of Design Principles

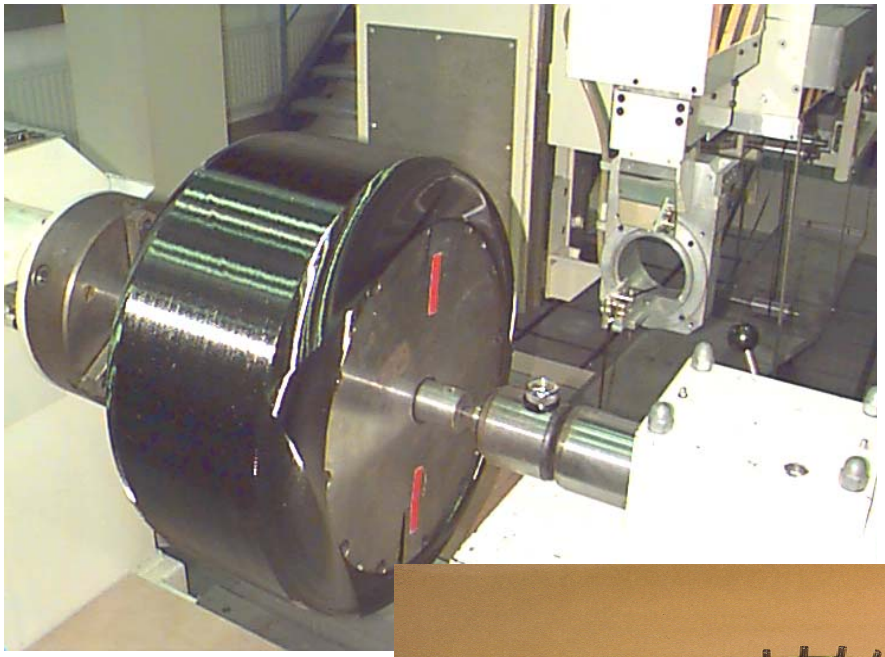


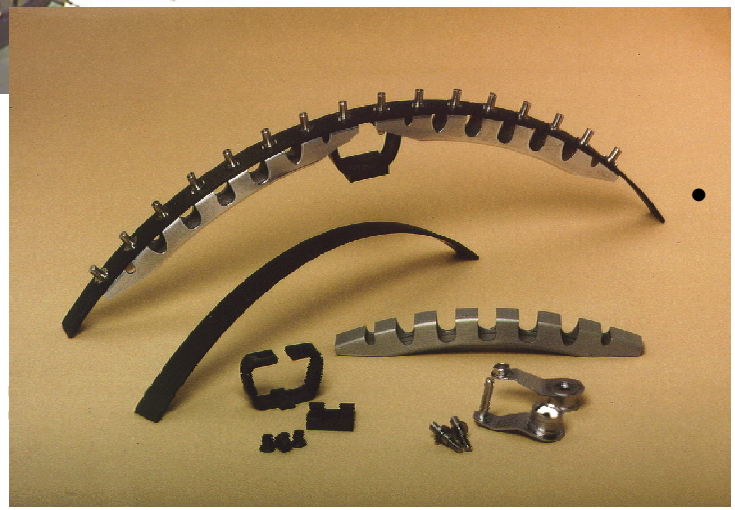
- Thermal strain compatibility by use of a CFRP band in combination with aluminium segments
- Avoiding internal stress by efficient usage of thermal strain

- Solution of specific joining problems with the help of universal mechanical fasteners
- Usage of DLR competence to demonstrate technical feasibility



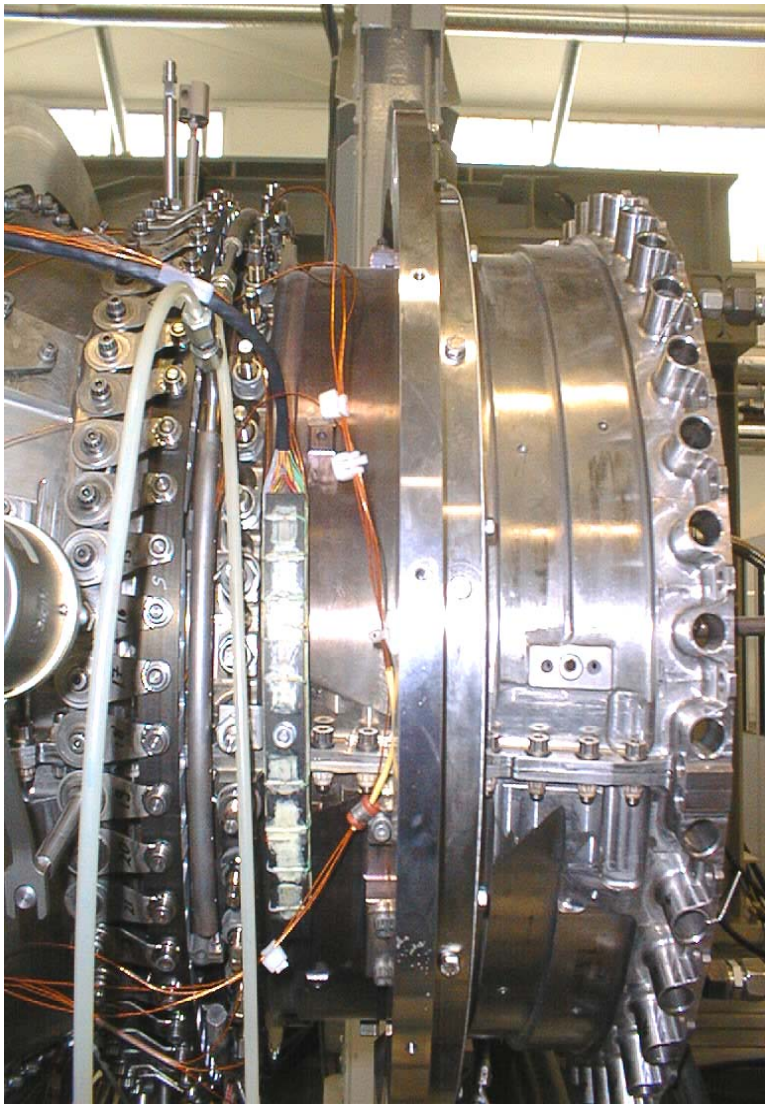
Manufacturing of the Hybrid Unison Ring





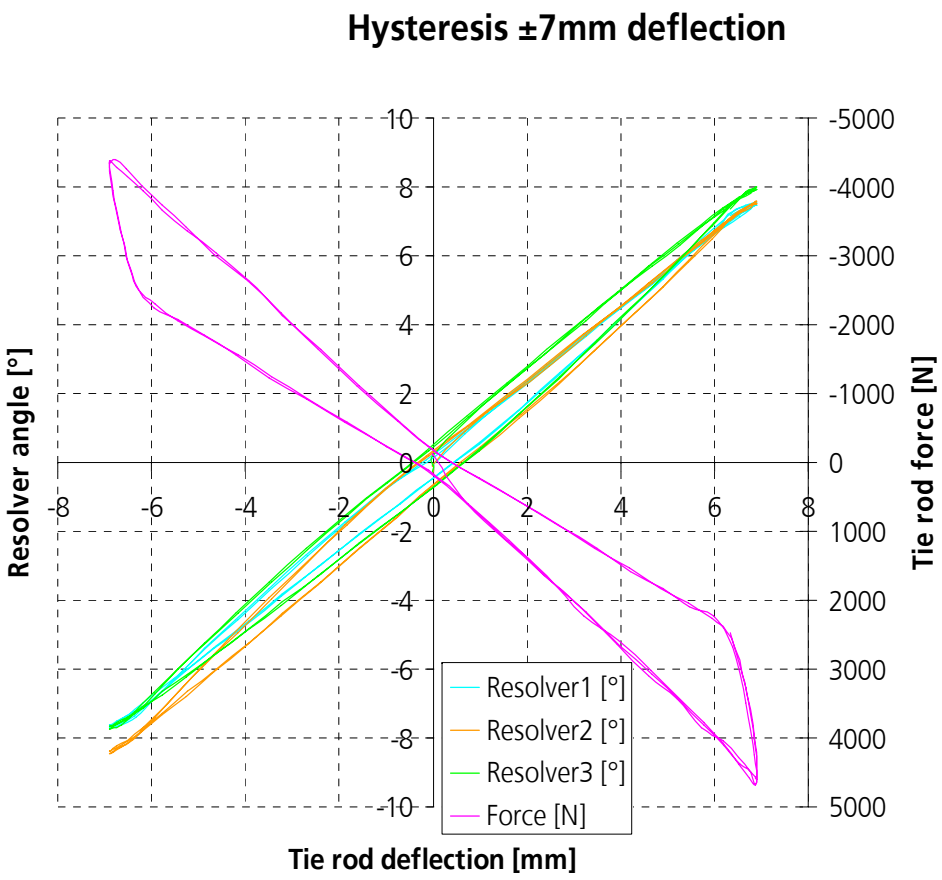
- Manufacturing of CFRP components in the Institute
- Testing of several manufacturing procedures
  - Wet filament winding
  - Dry filament winding in combination with RTM
  - Tape laying technology
- Manufacturing of metal and HT- plastic components by the industrial partner

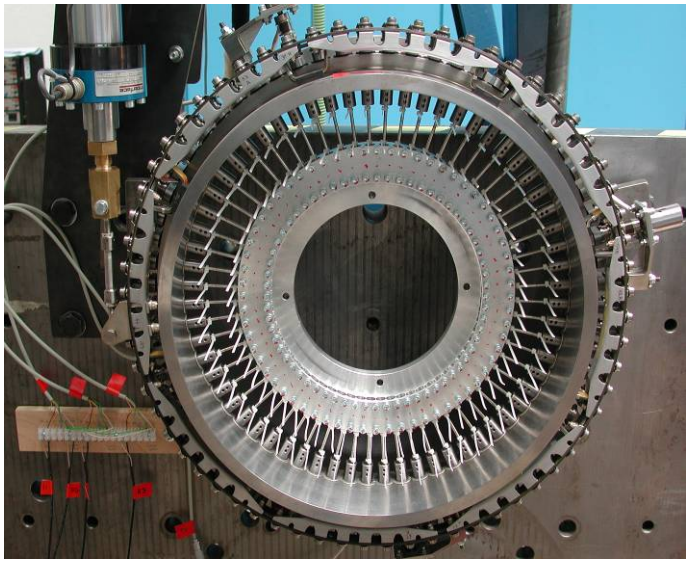
Verification of the Whole System



- Assembly tests at RR Deutschland in Dahlewitz with the help of RR-technicians
- Successful mechanical rig-test at RR-Deutschland in Oberursel
- Confirmation of functionality of the Hybrid Unison Ring concept during a core-engine-test at the Institut für Luftfahrtantriebe (ILA) in Stuttgart

Verification of Structural Durability





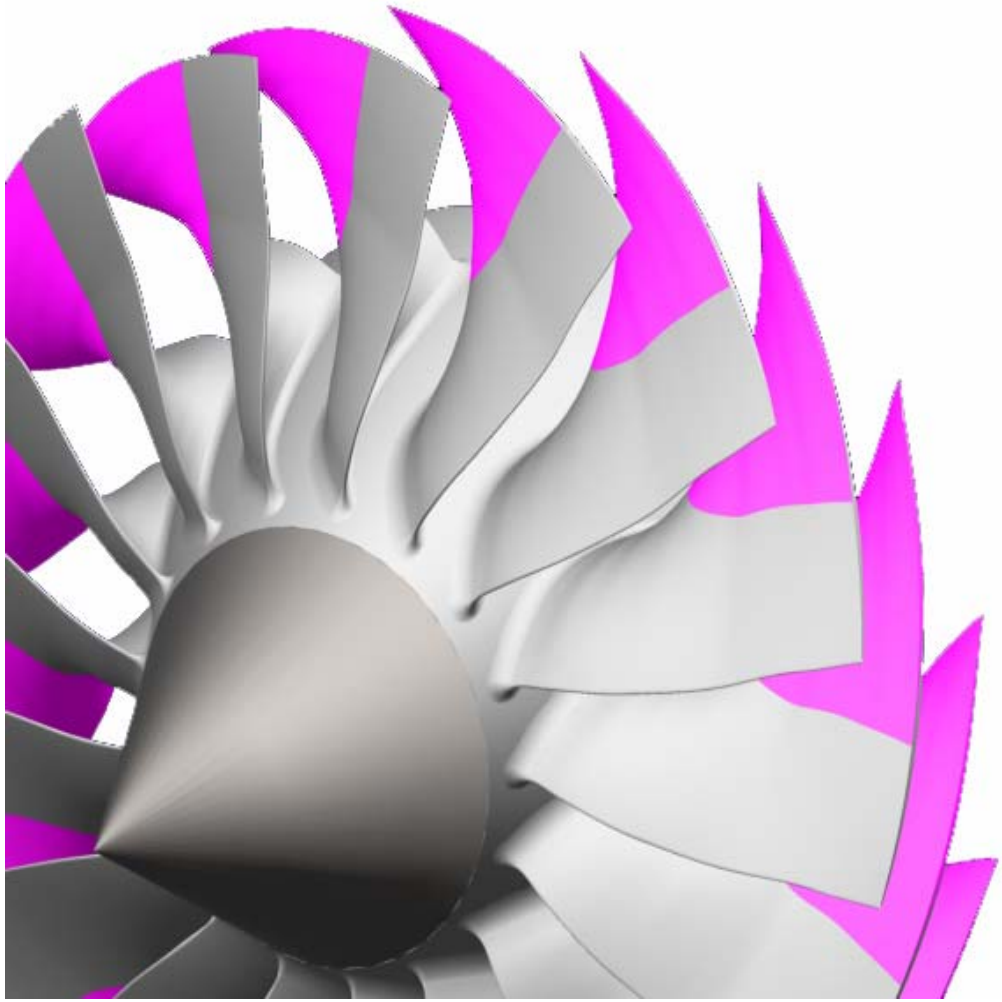
- Evidence of three life time cycles on a test rig regarding maximum loads of all compressor stages
- Evidence of damage tolerance of CFRP parts
- Evidence of surge loads

Results

Hybrid Unison Ring (CHUR)

- 40% reduction of structural weight
- Improved functionality due to efficient management of thermal strain
- Reduction of component cost
- Demonstration of practicable manufacturing routes
- Material appropriate hybrid design
- Hybrid Unison Ring is an option for future aero engine development at RR Deutschland

Hybrid Fan Blade – Two different Approaches

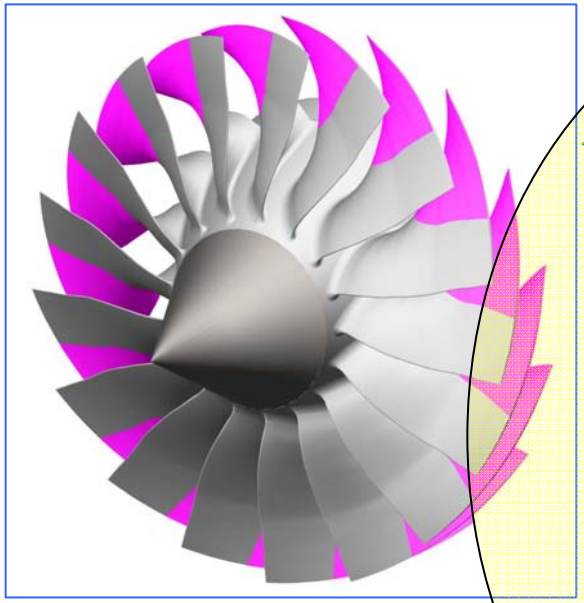


Interdisciplinary collaboration of several DLR institutes within the project NDV 4.5

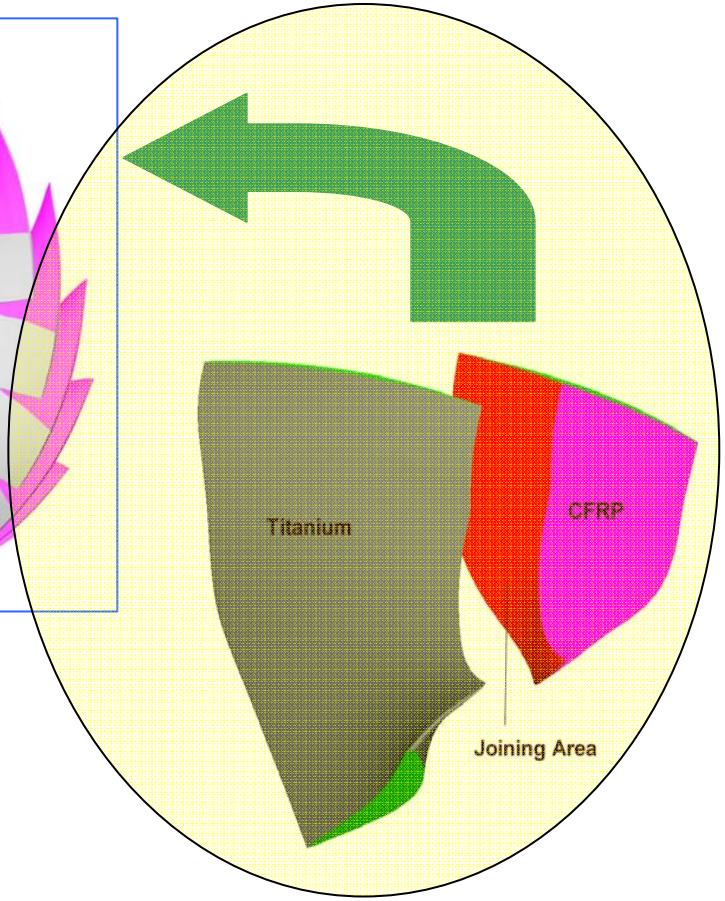
- Institute of Propulsion Technology
- Institute of Aeroelasticity
- Institute of Materials Research
- Institute of Structures and Design

Material and Design Concepts

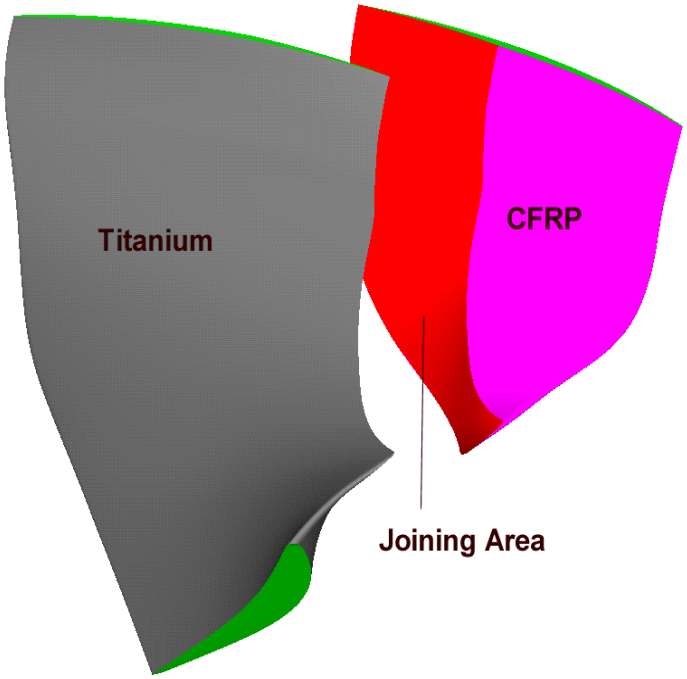
Continuously reinforced Titanium Matrix Composites (TMC)



CF-PEEK / Titanium hybrid blade



Basic Concept or a CFRP Hybrid Fan Blade



Hybrid fan blade for NDV 4.5

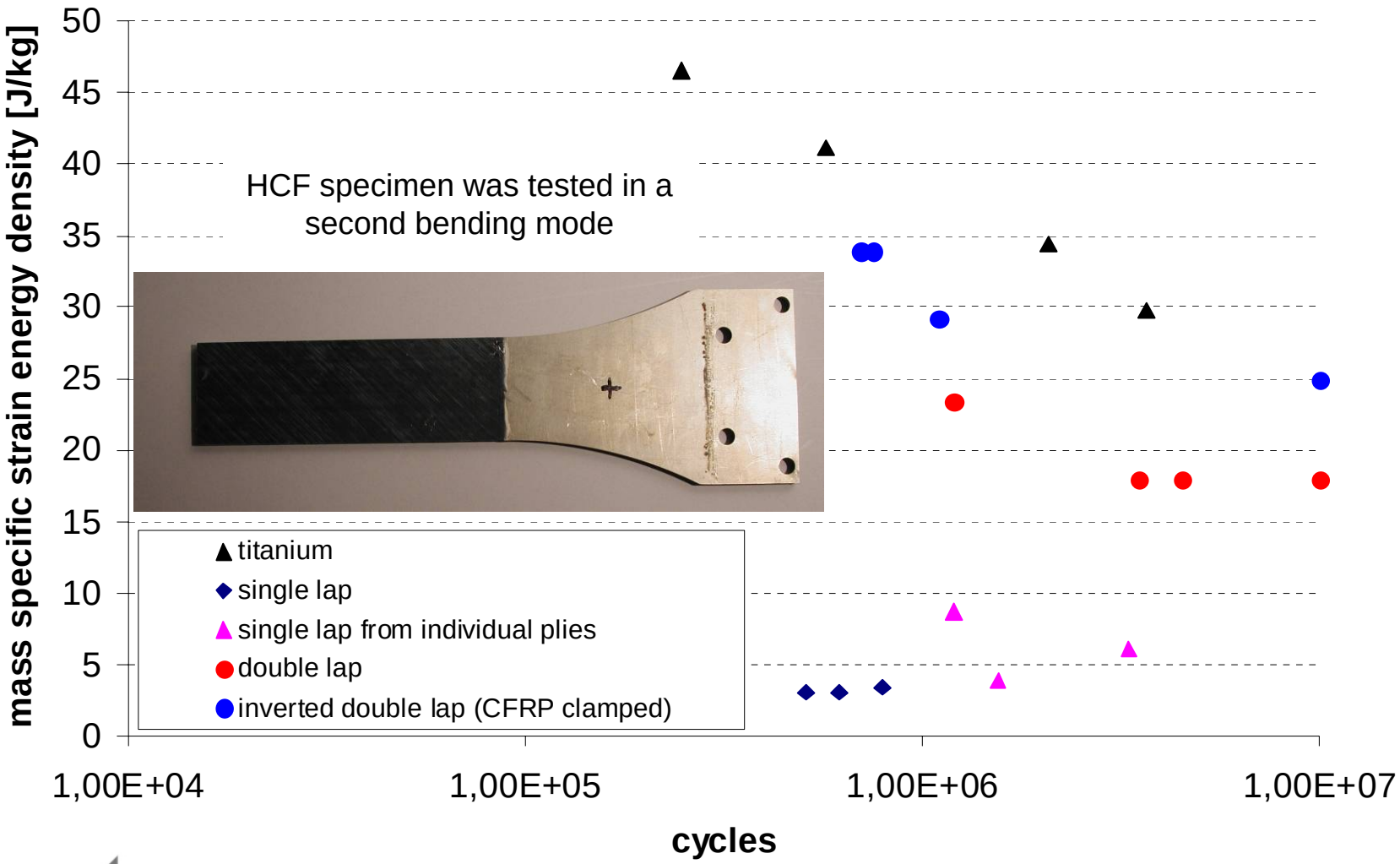
Aims:

- Reduction of structural weight
- Resistance against erosion and FOD by having a metal leading edge
- Reduced rotational blade energy with view on a fan blade off
- Increasing structural damping

Design Principles:

- Usage of high inherent bonding strength between CF-PEEK and Titanium
- Usage of an extended bonding area which is not primary loaded due to its radial orientation

Verification of Material Interface in a HCF test



Realised Compressor Blade

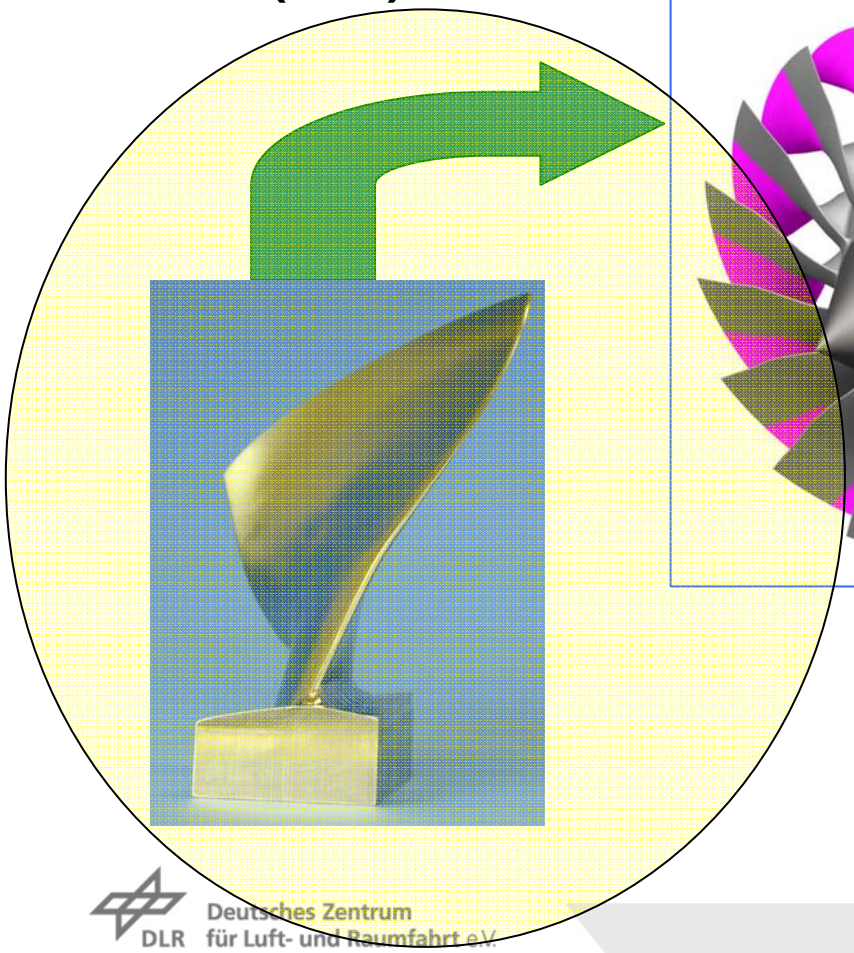
Hybrid fan blade for NDV

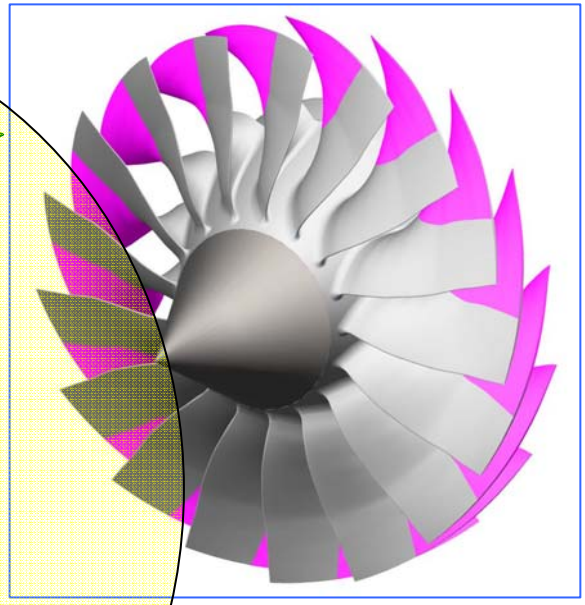
Present development status:

- Experimental verification of joining technique and assessment of load carrying capacity on specimen level is completed
- Preparation of FE modelling technique for hybrid structures is successfully demonstrated
- Demonstration of a material appropriate manufacturing technique
- Tests of a complete structure is projected
- Mass of the blade can be reduced in the range of 15% to 20%

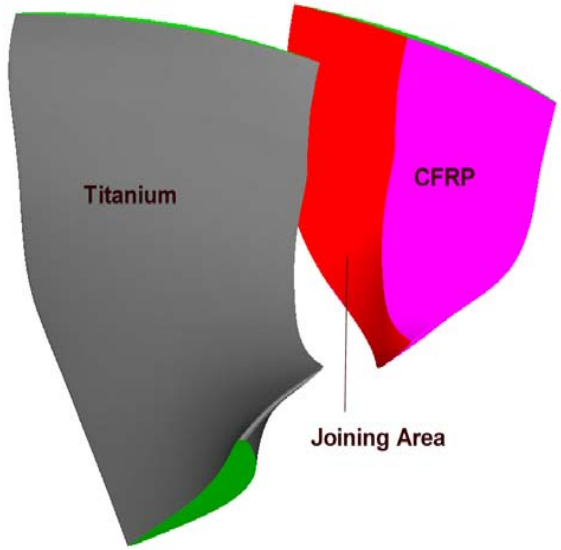
Material and Design Concepts

Continuously reinforced Titanium Matrix Composites (TMC)

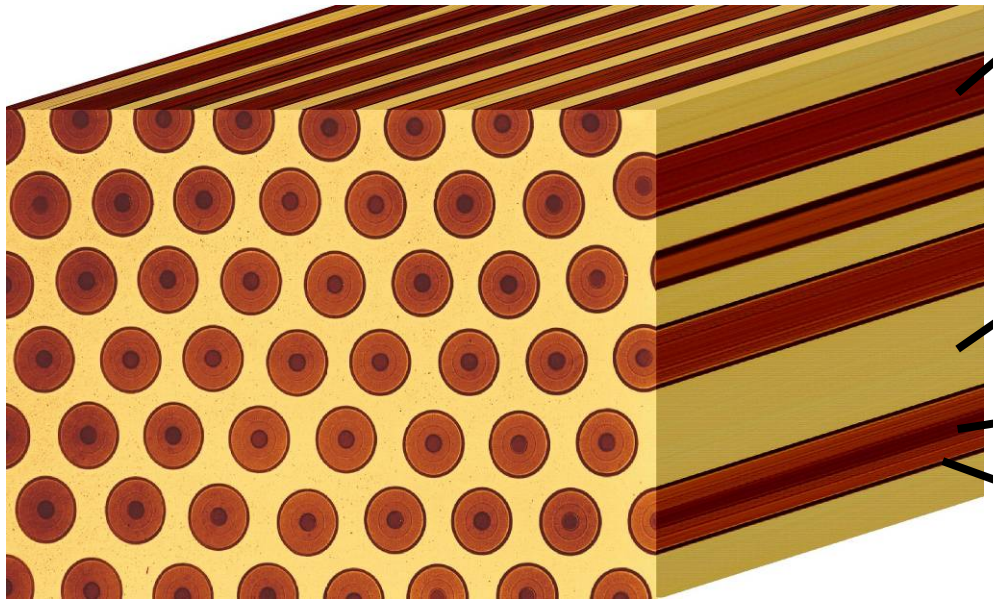




CF-PEEK / Titanium hybrid blade



Continuously Reinforced Titanium Matrix Composite (TMC)



E = ~ 400 GPa
σ = > 4000 MPa
α = 3 – 4 ppm/K

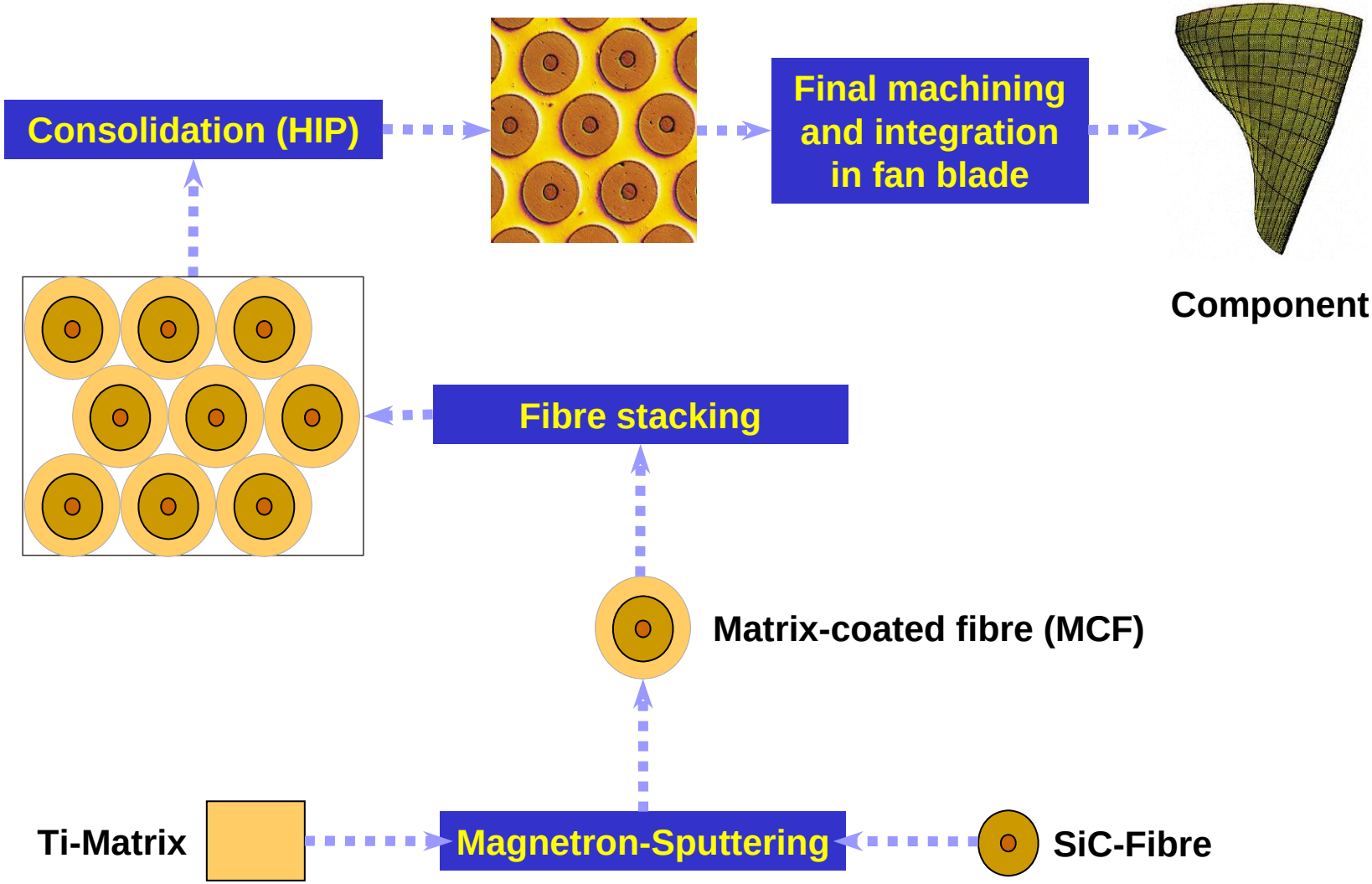
E = ~ 115 GPa
σ = ~ 1000 MPa
α = ~ 11 ppm/K

Carbon core

Reaction barrier coating

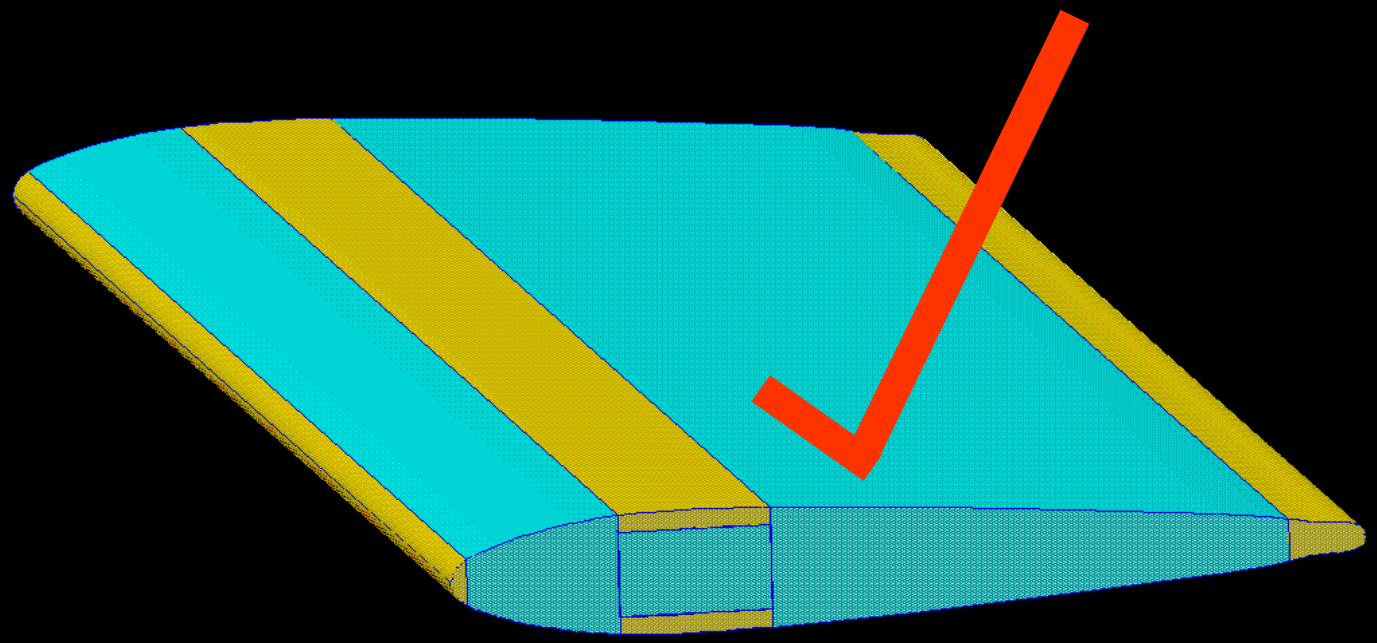
1 mm

TMC-Production by the MCF-Route



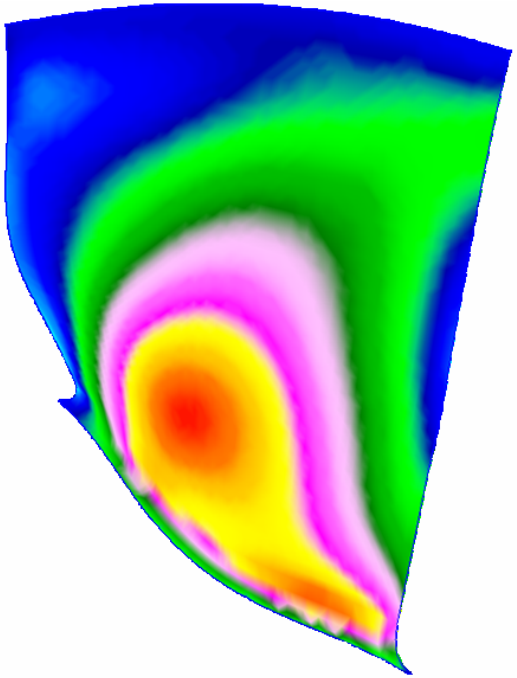
Design Principles for TMC

- **Specimens properties in the application**



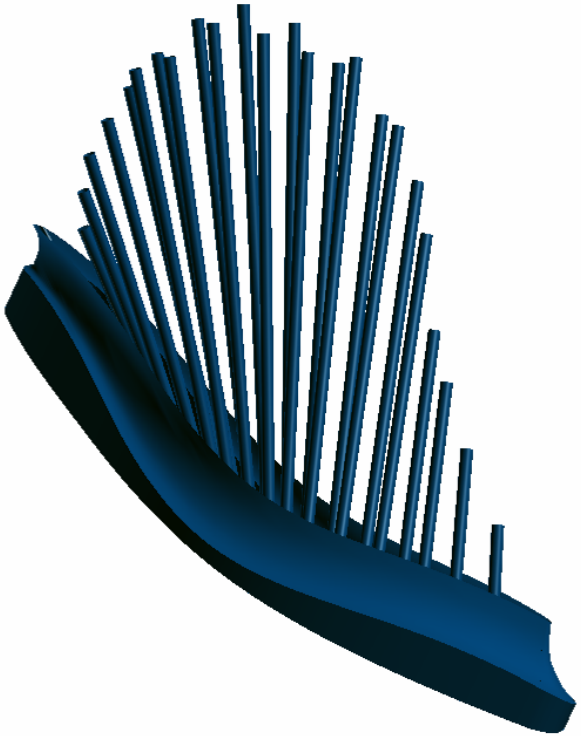
- **Suitable for relaxation process**
- **Reinforcement where needed**

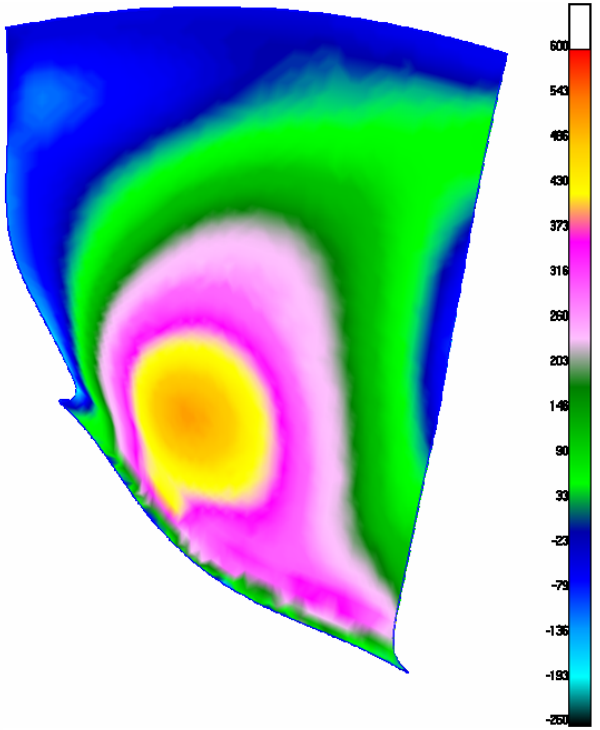
Implemented Design Principles for a Fan Blade



Calculation of monolithic Titanium fan blade with maximum stress in root section an in the middle of the blade

Integration of local reinforcement in terms of TMC sticks



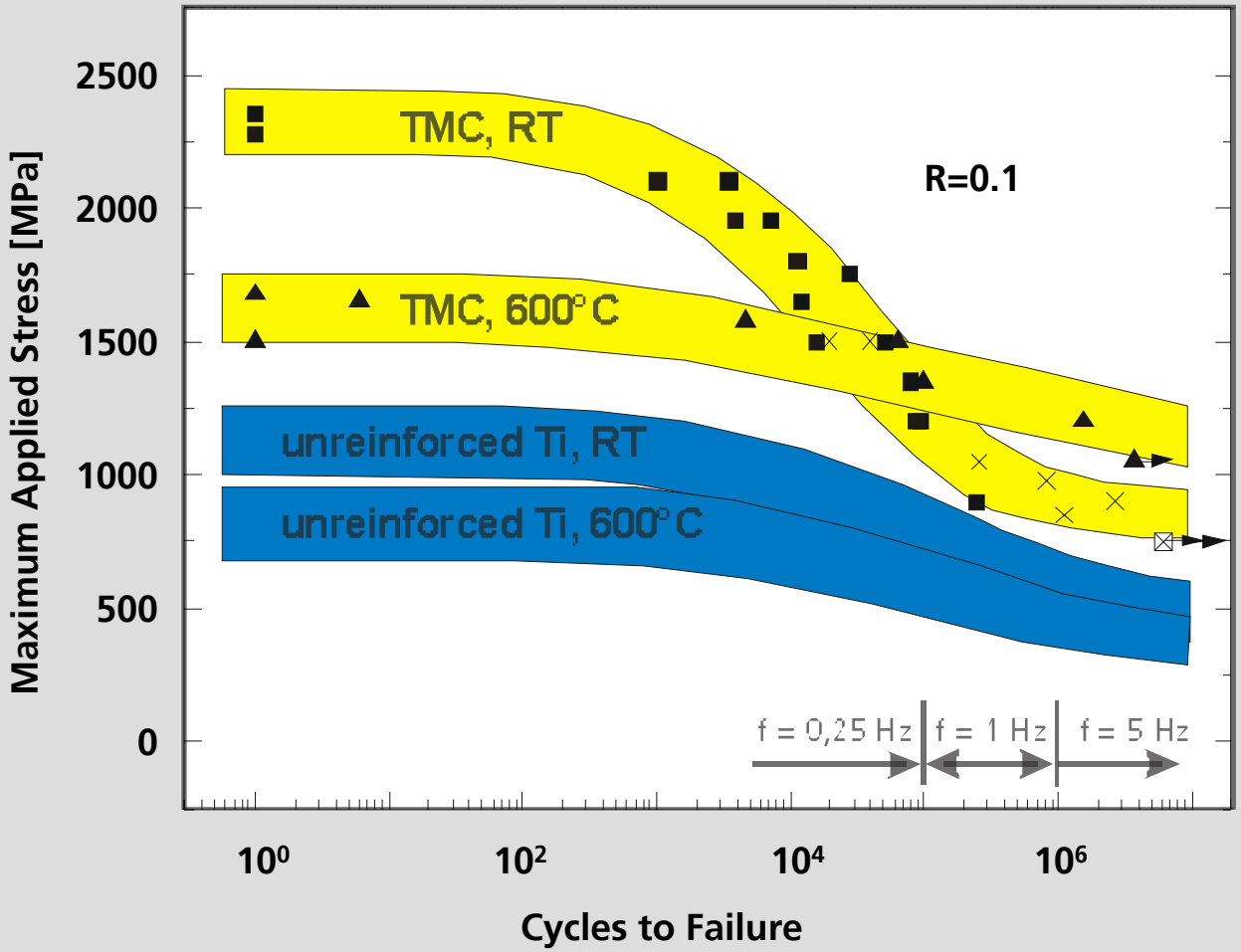


Confirmation of stress reduction

Data and Experiments for Blade Applications

- **High cycle fatigue under reversed loading (R=-1)**
- **Improvement of HCF strength by residual stress modification**
- **Influence of fibre ends on strength**
- **Strain rate sensitivity under tensile loading**
- **Foreign object damage resistance**

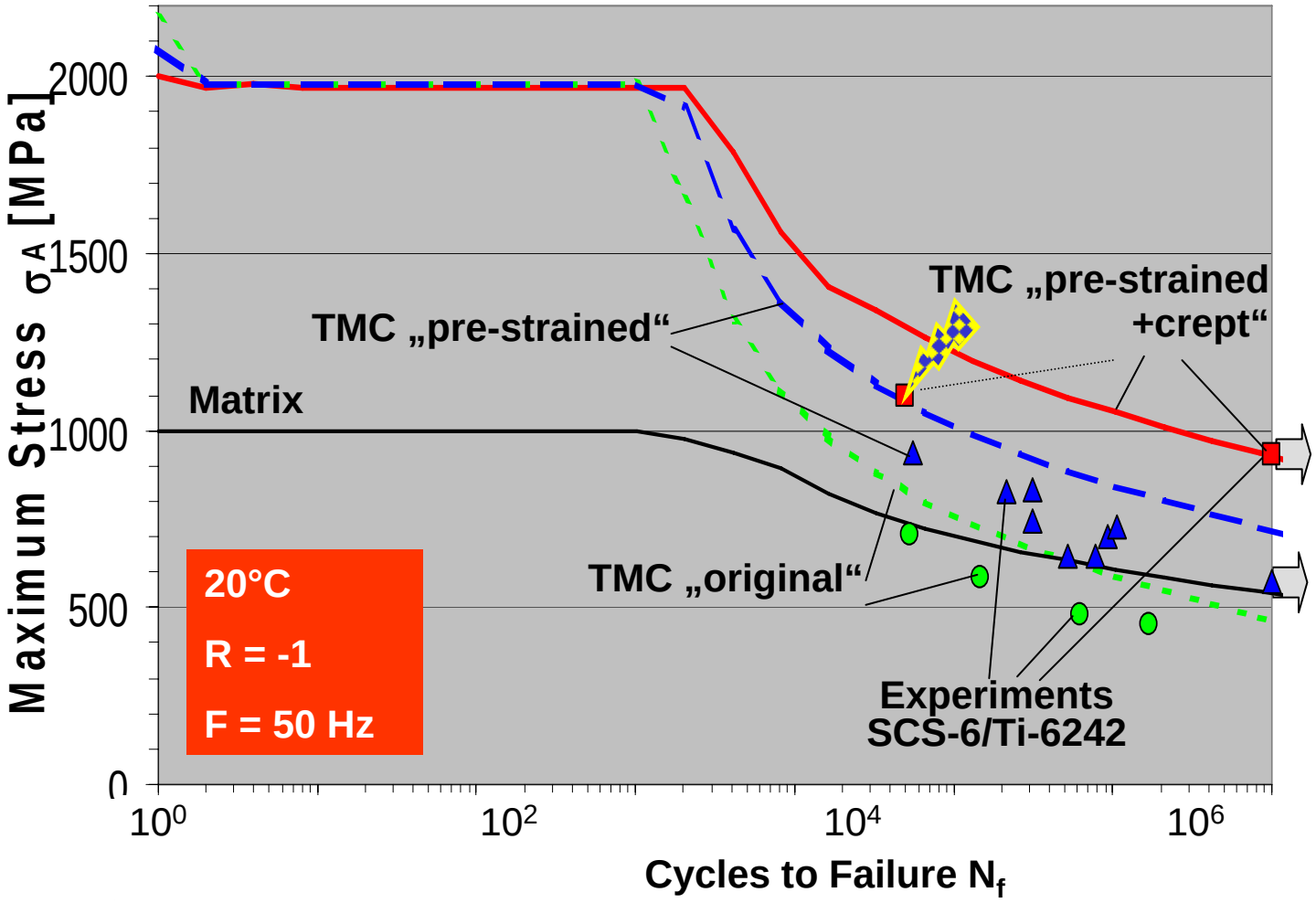
Longitudinal Fatigue Behaviour of SiC/Timetal834



Excellent longitudinal fatigue resistance in general!

- R = 0.1
- 0.25 - 5 Hz
- lab air
- load controlled

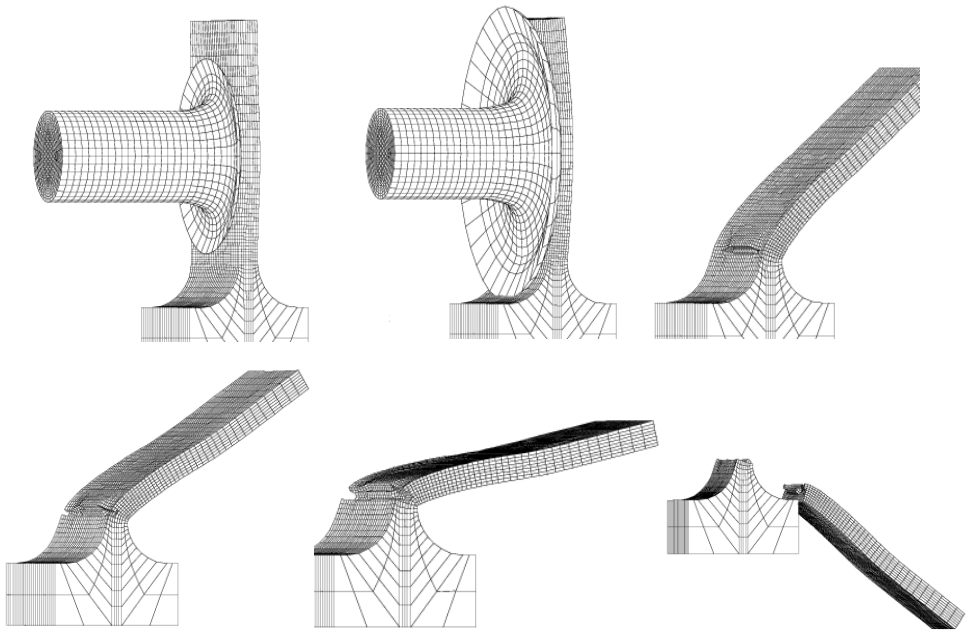
Life Prediction and Fatigue Experiments of TMC



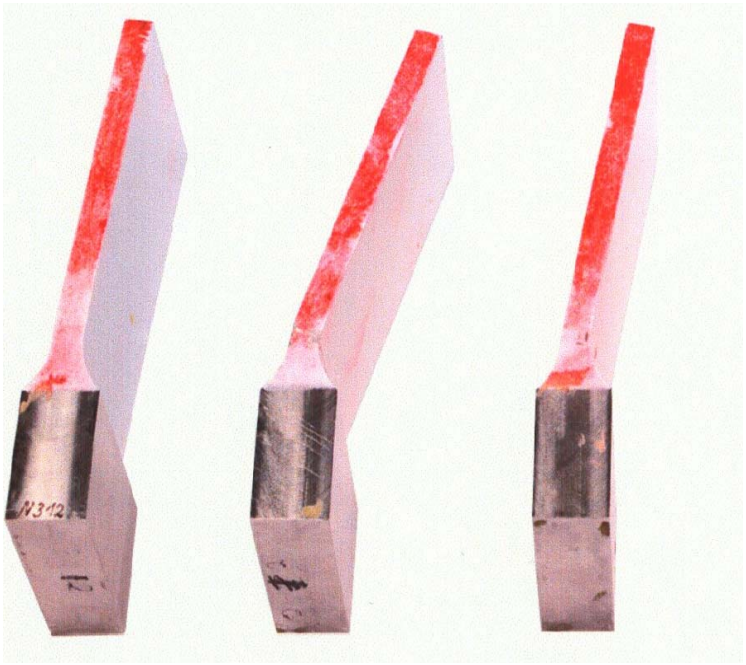
Prediction reveals upper limit

Multiaxial effects and irregularities are neglected

High Strain Rate Loading



Explicit FEA of TMC specimen
impacted with 450 m/s



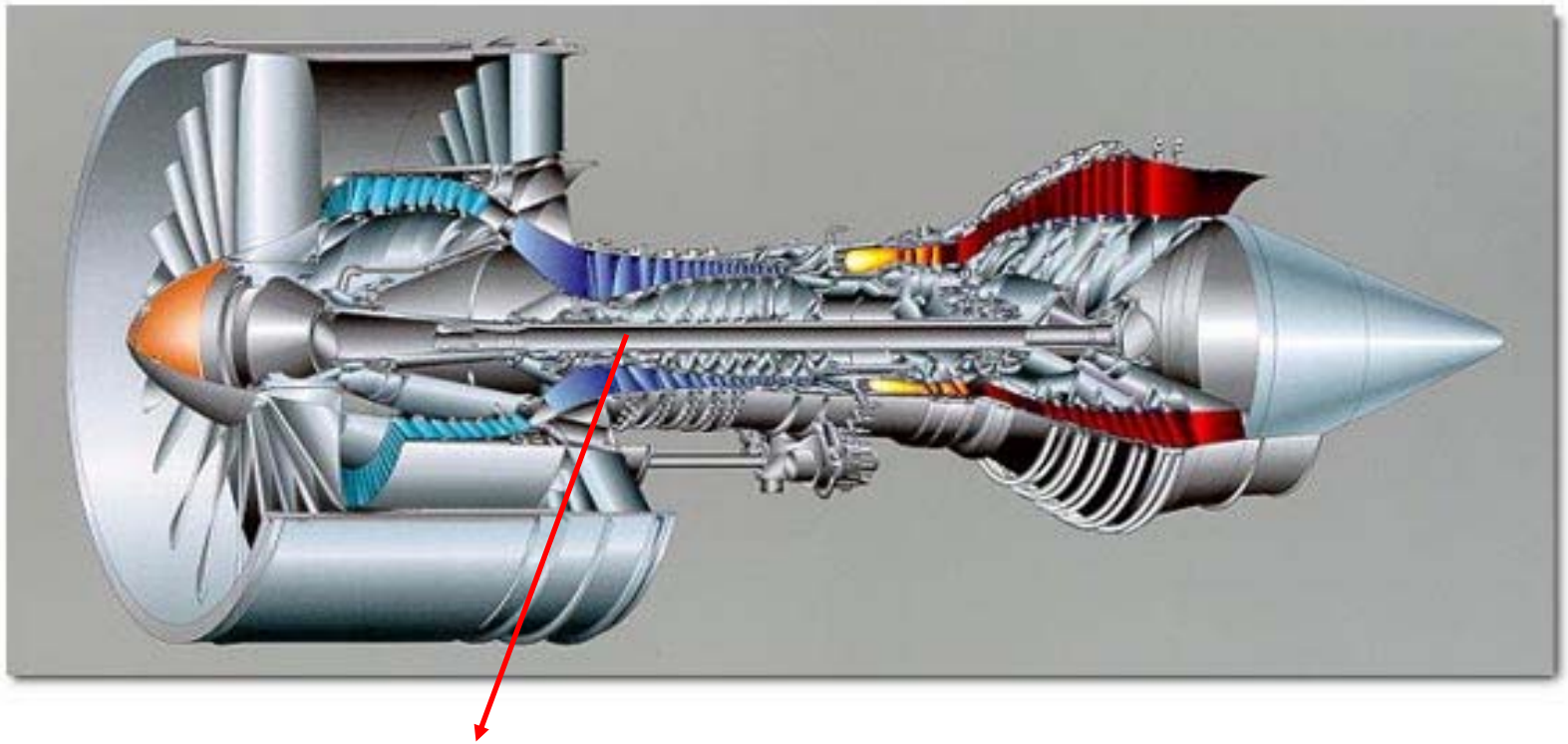
TMC
305 m/s

TMC
345 m/s

solid titanium
342 m/s

Impact resistance is reduced but may be sufficient for intended application

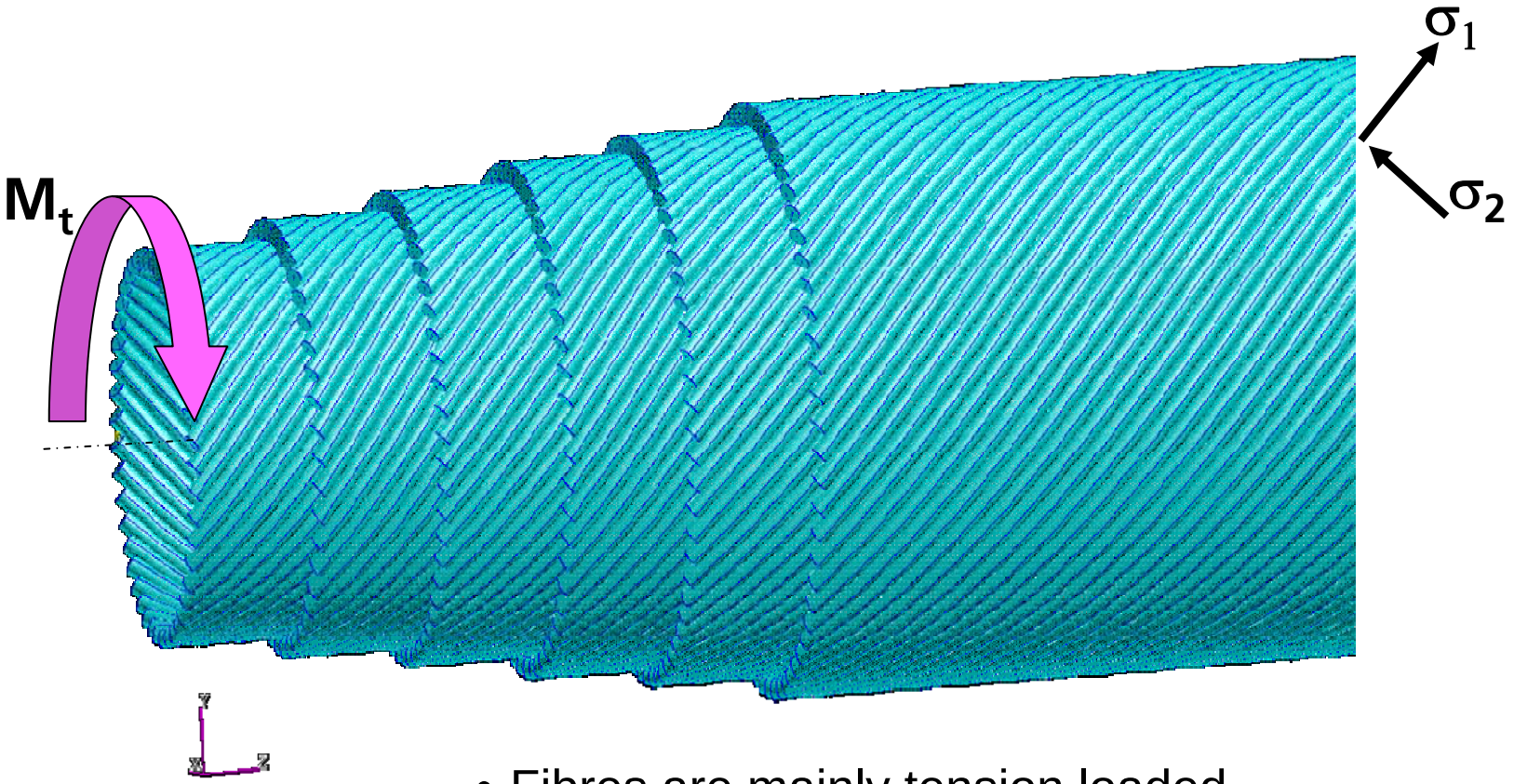
High Performance Shaft for an Aero Engine



Design principles:

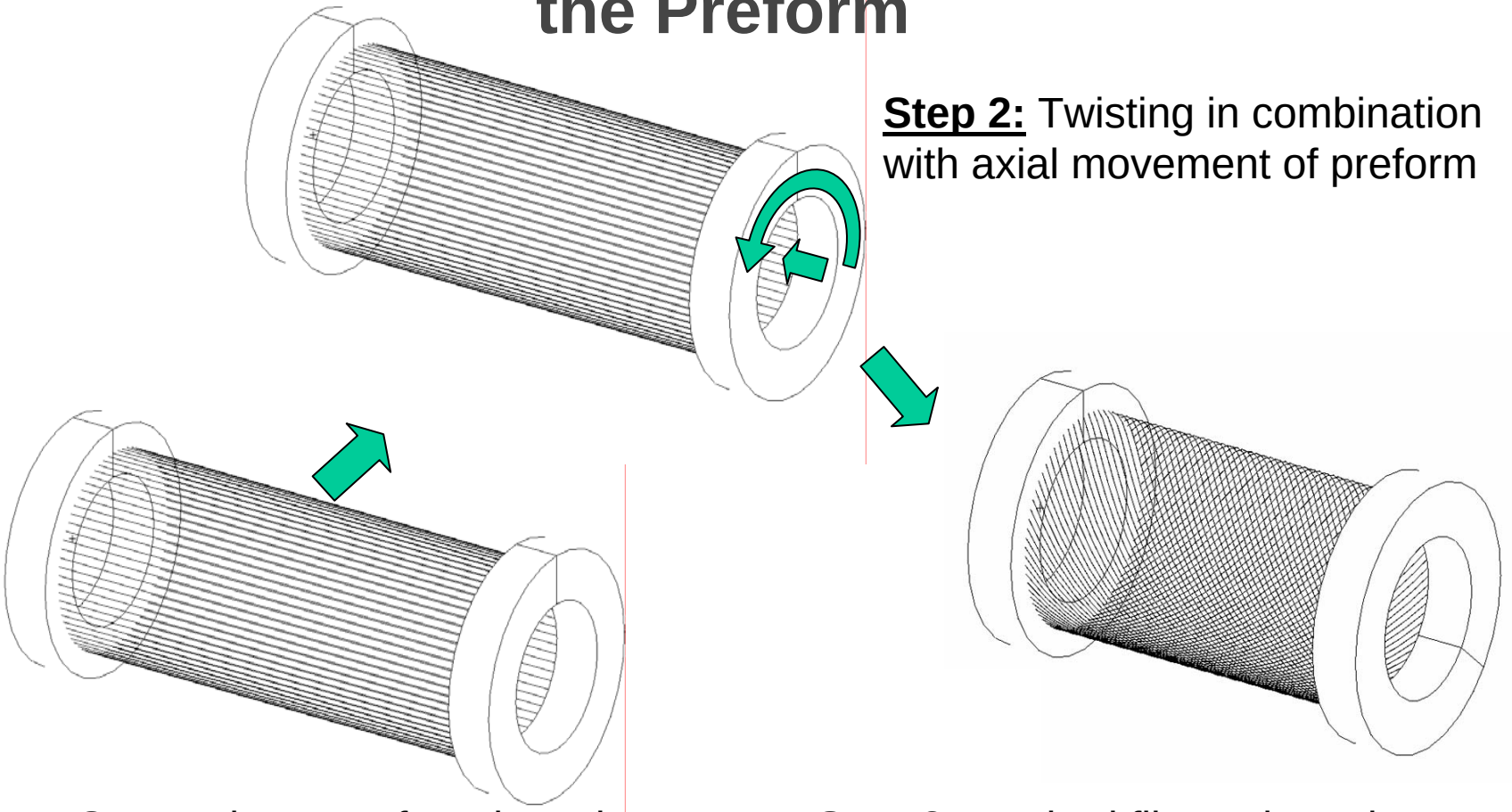
- Fibre reinforcement only where necessary with view on maximum torque in one preferred direction
- Compensation of material rearrangement due to HIP process
- Adaptability of stress reduction process for maximum strength

Unidirectional Lay-Up for a TMC Shaft



- Fibres are mainly tension loaded
- Matrix is mainly compression loaded with view on efficient usage of fibre matrix interface

Scheme of Realizing the Fibre Orientation within the Preform

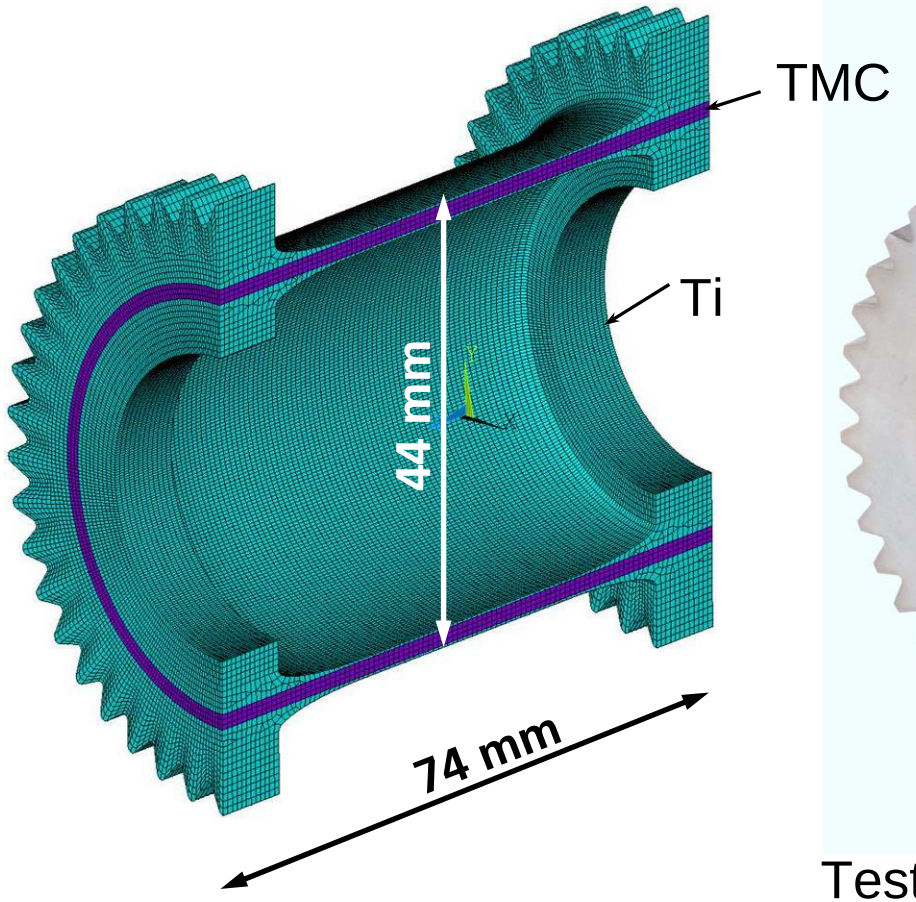


Step 2: Twisting in combination with axial movement of preform

Step 1: Generation a preform by using coated fibres – fibre orientation in this stage parallel to rotation axis

Step 3: Desired fibre orientation and pre consolidated structure

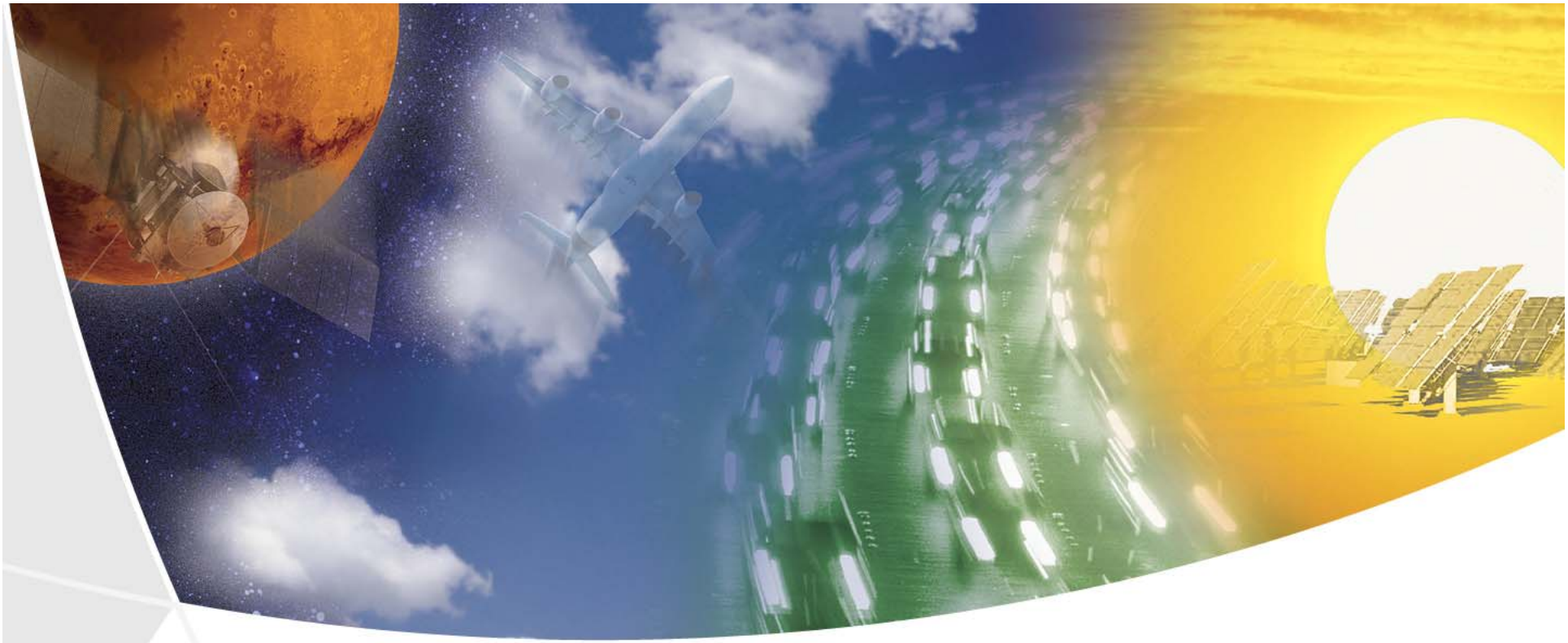
Realized Test Specimen



Testable tube structure with attached tooting for load introduction

Results

- Several small shaft specimens have been manufactured
- D 39/44 mm failed beyond 6 kNm [σ1/2=+/-980 MPa]
- Unidirectional angle ply lay-up is most promising for aero engine applications
- Other applications require special design methodologies
- Larger shaft demonstrators are in production
- DLR is partner of EU project „Vital“



Thank you for your attention!