



Analysis and Optimization of a Hybrid Fan Blade

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**DLR German Aerospace Center, Stuttgart
Institute of Structures and Design**

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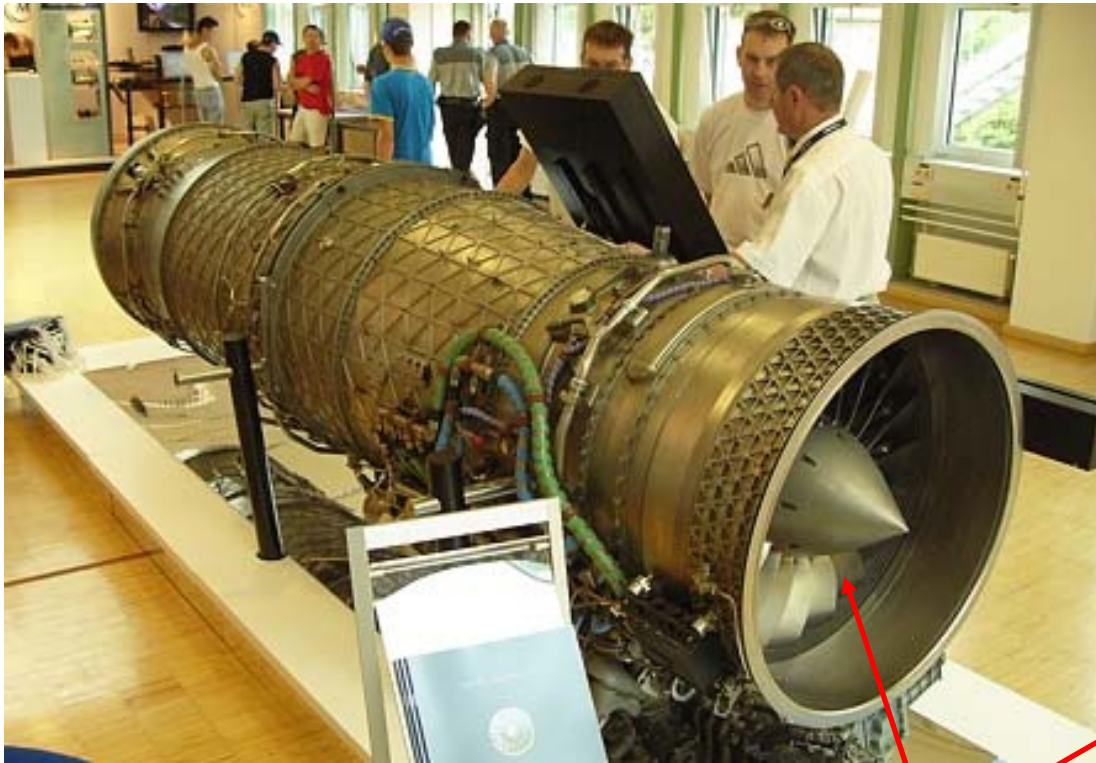




Topics

- Single spool LPC (Low Pressure Compressor) based on EJ200 turbo jet engine
- Mass reduction in first stage by implementation of CFRP (Carbon Fibre Reinforced Plastics)
- FEM modelling and structural analysis of a hybrid blade
- Modification of dynamic response of a titanium blade by topology optimization
- Introduction of a new monolithic stacked rotor

LPC Low Pressure Compressor (EJ200 Turbo Jet Engine)



Titanium BLISK

Hybrid Blade

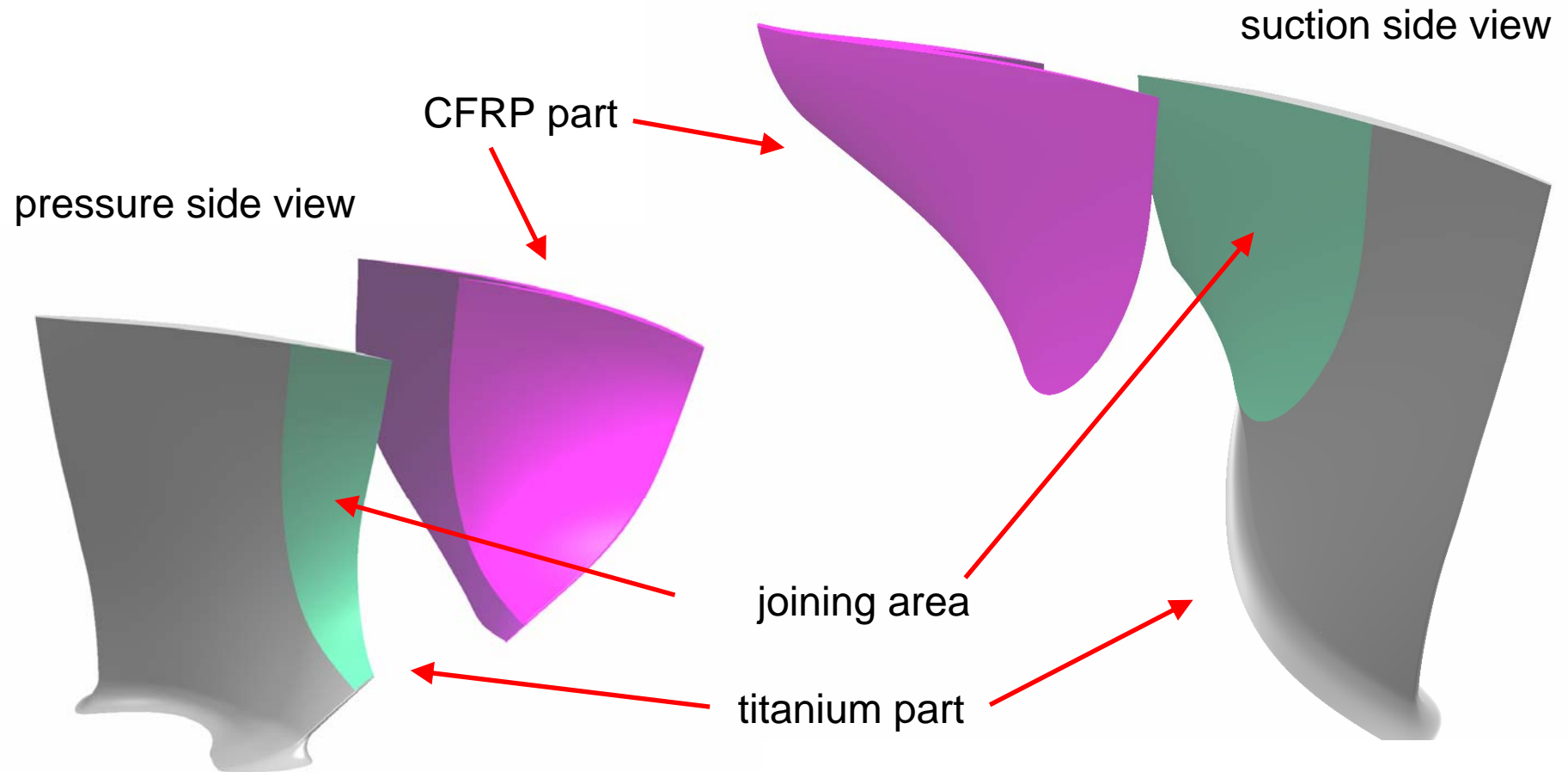
- Titanium in the front region due to erosion and foreign object damage
- CFRP (Carbon Fibre Reinforced Plastics) in the rear region for mass reduction (CF-PEEK Prepreg)
- $\pm 45^\circ$ and 0° lay-up optimized for torsion and bending stiffness
- Consolidation of CFRP and joining to the titanium in one process step

Target: mass reduction

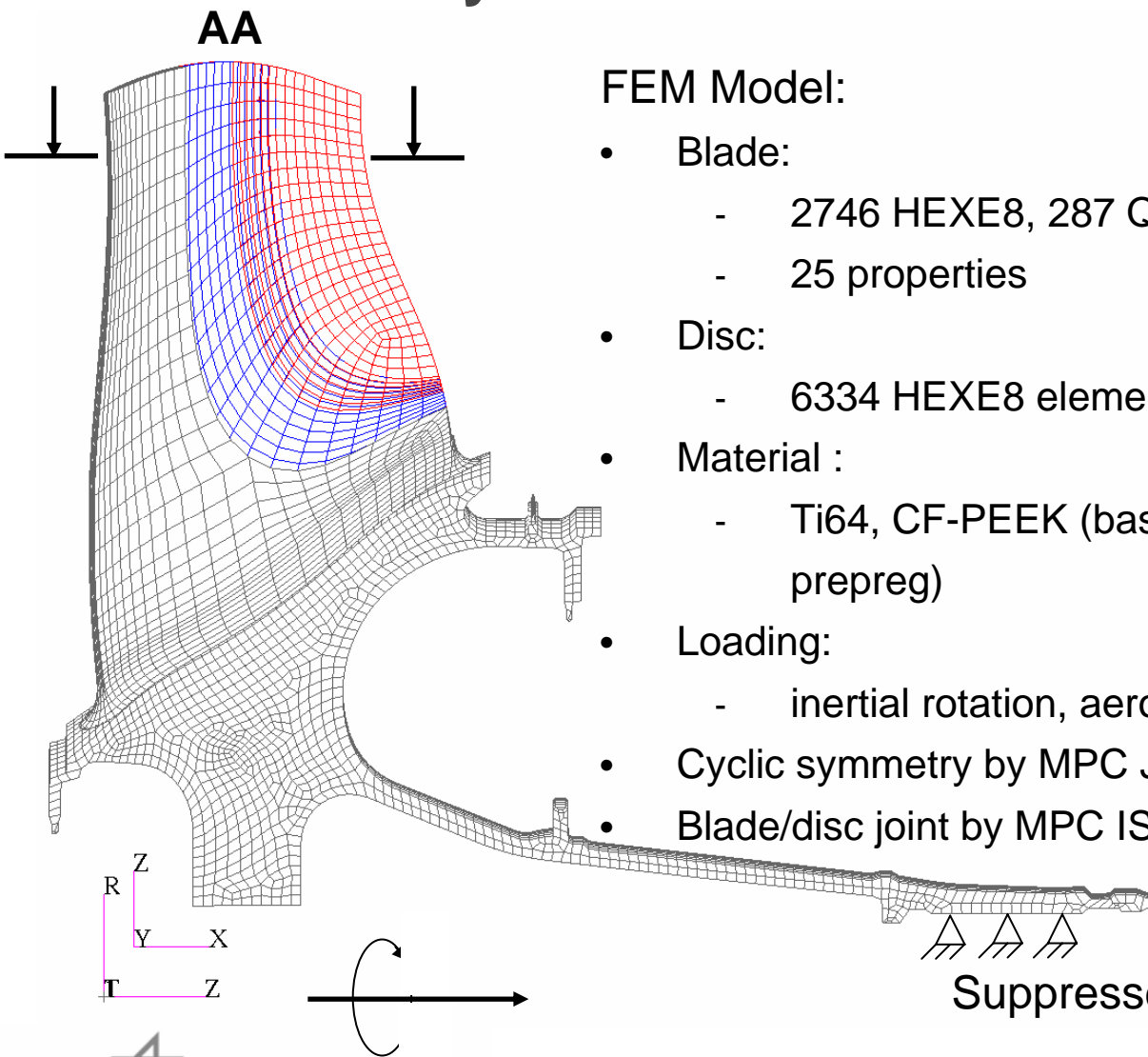


Hybrid Blade

Asymmetric Double Lap Shear Joint



Hybrid Blisk: Pressure Side View



FEM Model:

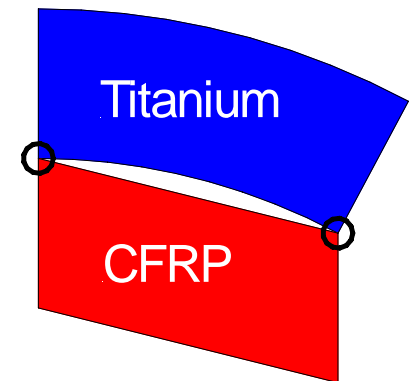
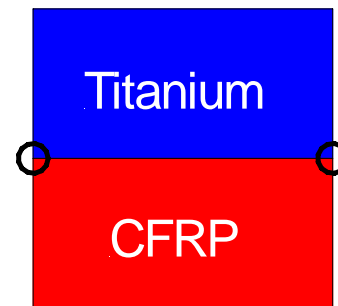
- Blade:
 - 2746 HEXE8, 287 QUAD4, 782 SHELL4 elements
 - 25 properties
- Disc:
 - 6334 HEXE8 elements
- Material :
 - Ti64, CF-PEEK (based on unidirectional thermoplastic prepreg)
- Loading:
 - inertial rotation, aerodynamic pressure, temperature load
- Cyclic symmetry by MPC JOIN
- Blade/disc joint by MPC ISURFACE

Suppressed DOF 2,3 (cyl. coord. system)



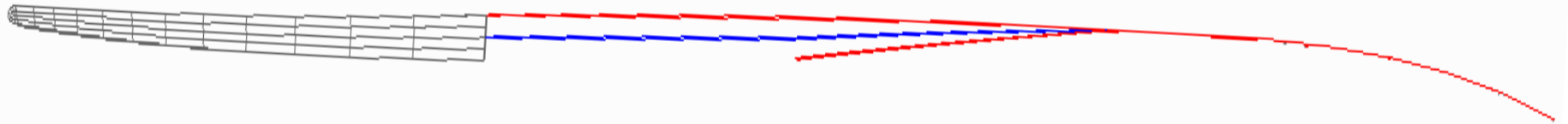
Approach for QUAD4 (Ti) - SHELL4 (CFRP) Coupling in Double Lap Shear Joint Region

- Different deformation mechanisms of isotropic and orthotropic materials by transverse loading
- Dominance of bending deformation in titanium and shear deformation in CFRP leads to different rotation at element nodes
- Incorrect increase of stiffness by coupling of all DOFs
 - => MPC RIGID only DOFs 1,2,3
- Separation of element reference and laminate middle surface in SHELL4 elements by $\xi = 1$
- Using forces on dependent nodes for further evaluation of joining area



Hybrid Blade: Meshing of Double Lap Shear Joint Region

Section AA (scaled)



HEXE8

MPC RIGID (1,2,3)

suction side

outer ply (first ply in stacking sequence)

$\xi = 1$

$\xi = 1$

QUAD4

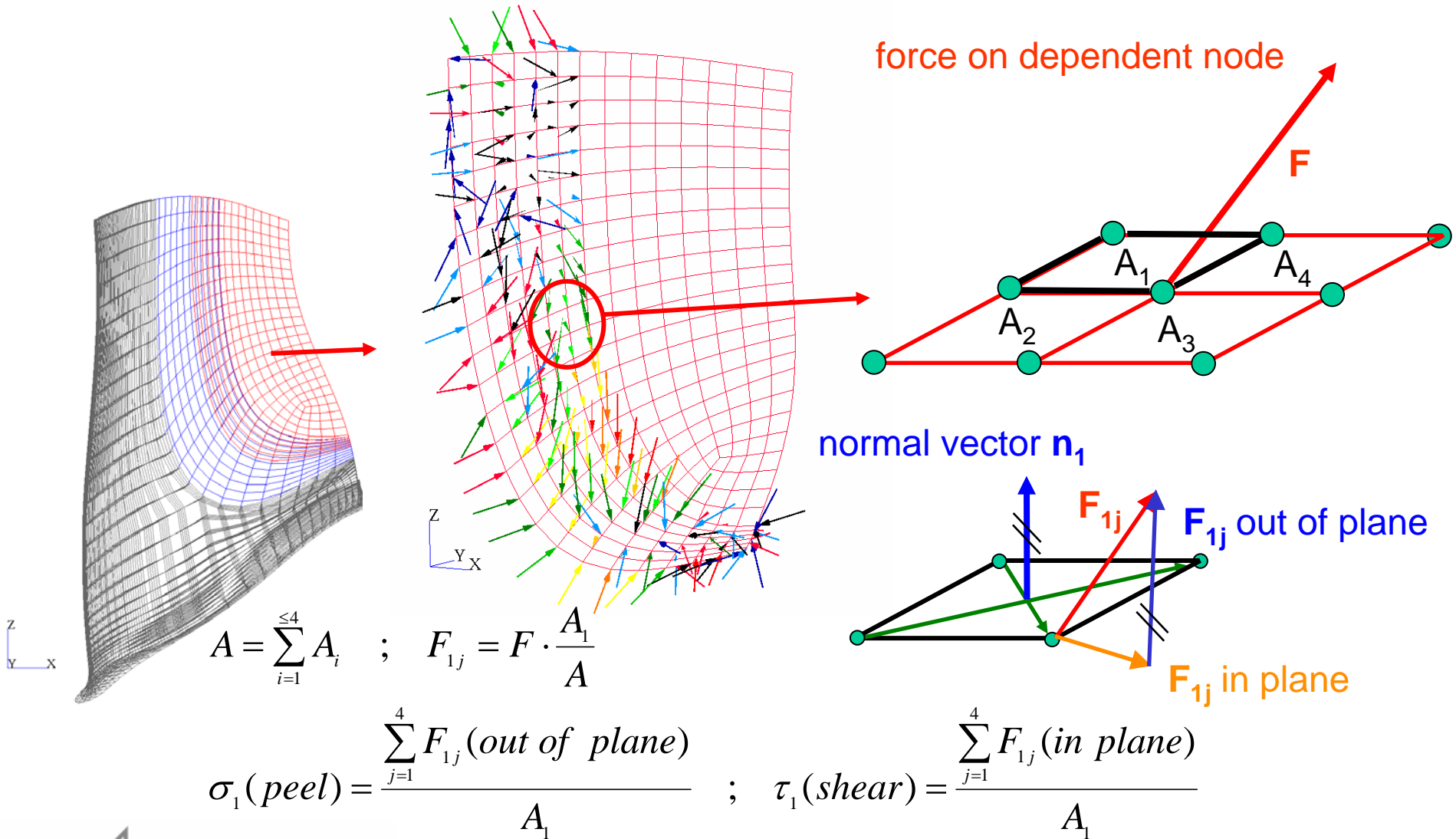
SHELL4

MPC RIGID (1,2,3)

pressure side

MPC ILIN2 (1,2,3) MPC VST (1,2,3,4,5,6)

Stress Distribution in Double Lap Shear Joint Region



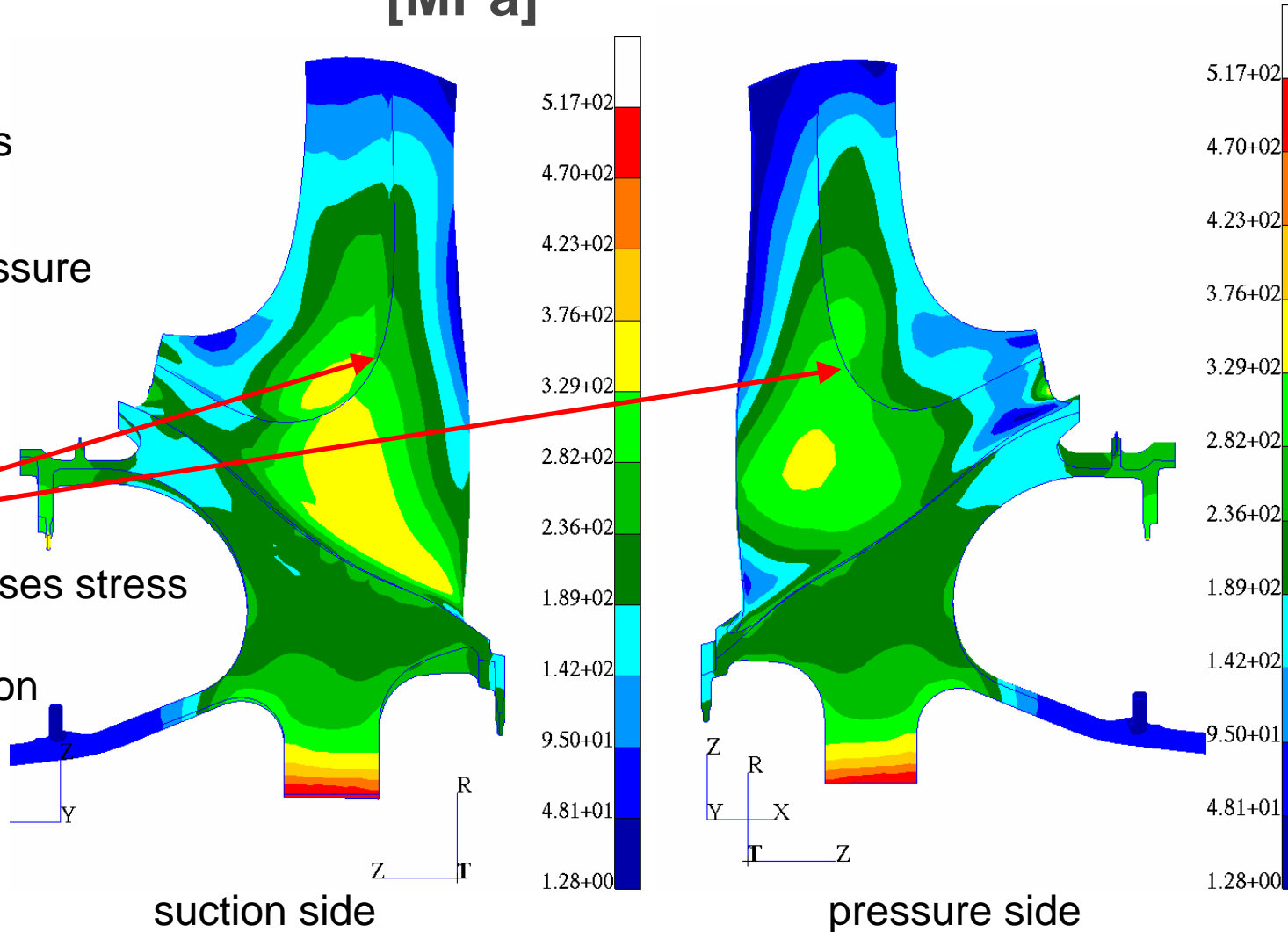
Summary for FEM Modelling of Hybrid Joints

1. HEXE8 elements in the front titanium region
2. QUAD4 elements for titanium in joining area
3. SHELL4 elements for CFRP
4. HEXE8 - QUAD4 transition by MPC VST and MPC ILIN2
5. QUAD4 - SHELL4 coupling in joining area by MPC RIGID (1,2,3)
6. Evaluation of forces on dependent nodes for stress calculation in the joining area
7. Conversion of forces on dependent nodes to element forces
8. Splitting of element forces in “in plane” and “out of plane”
9. Calculation of peeling and shear stresses

Hybrid Blisk: V. Mises Stress Distribution in Titanium Part [MPa]

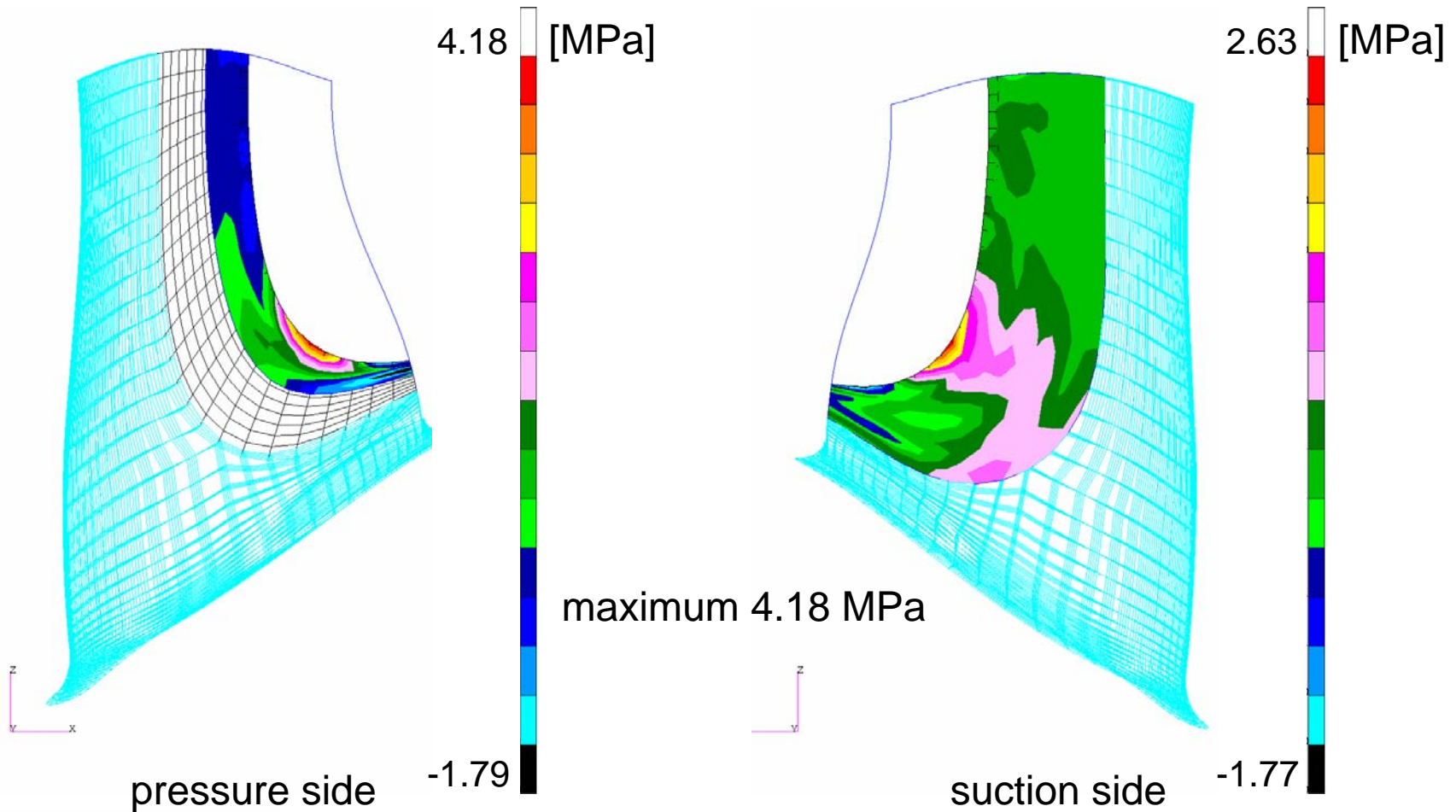
- nonlinear analysis
- inertial rotation,
- aerodynamic pressure
- temperature load

“continuous” v. Mises stress distribution in the volume/shell region



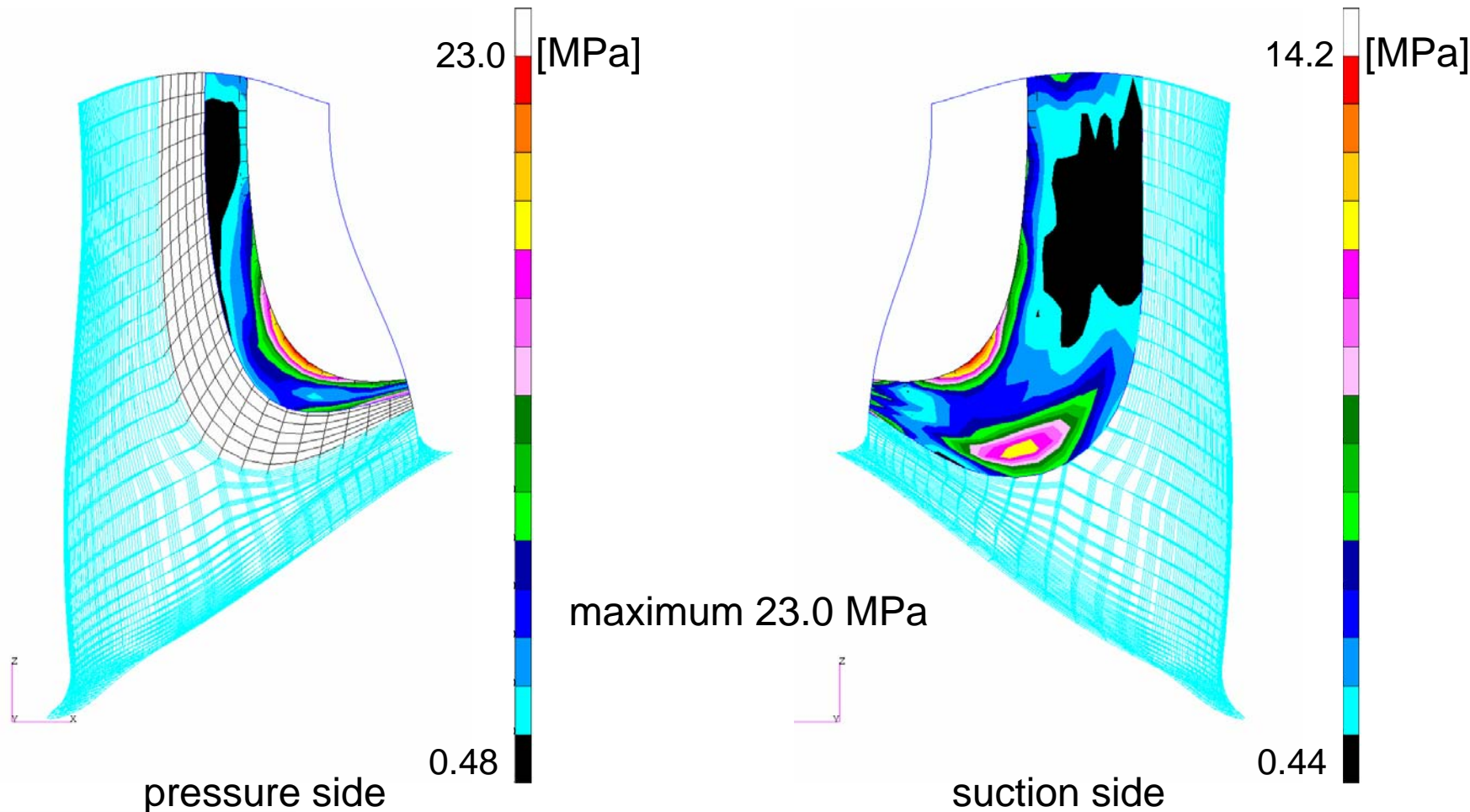
Peeling Stress Distribution in Double Lap Shear Joint Region

nonlinear analysis, inertial rotation, aerodynamic pressure and temperature load



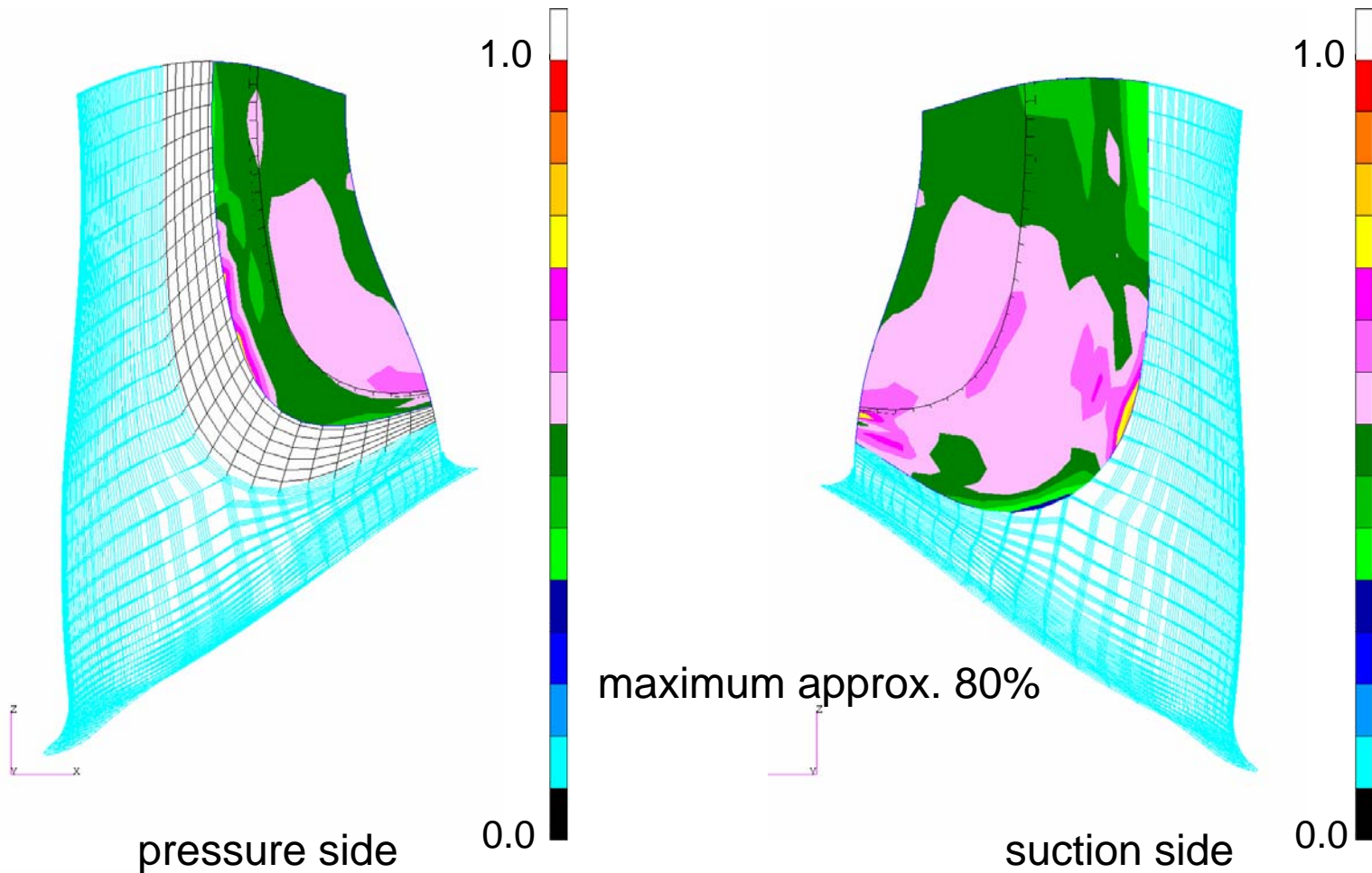
Shear Stress Distribution in Double Lap Shear Joint Region

nonlinear analysis, inertial rotation, aerodynamic pressure and temperature load



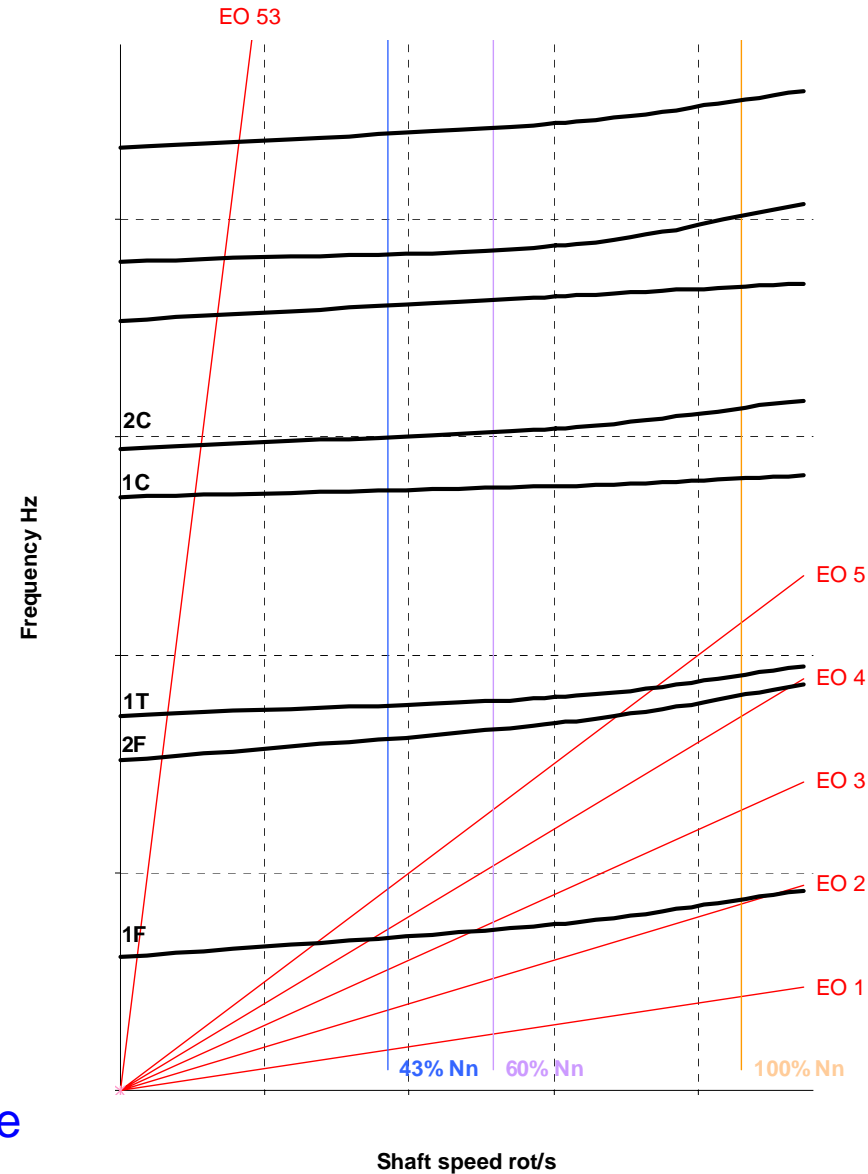
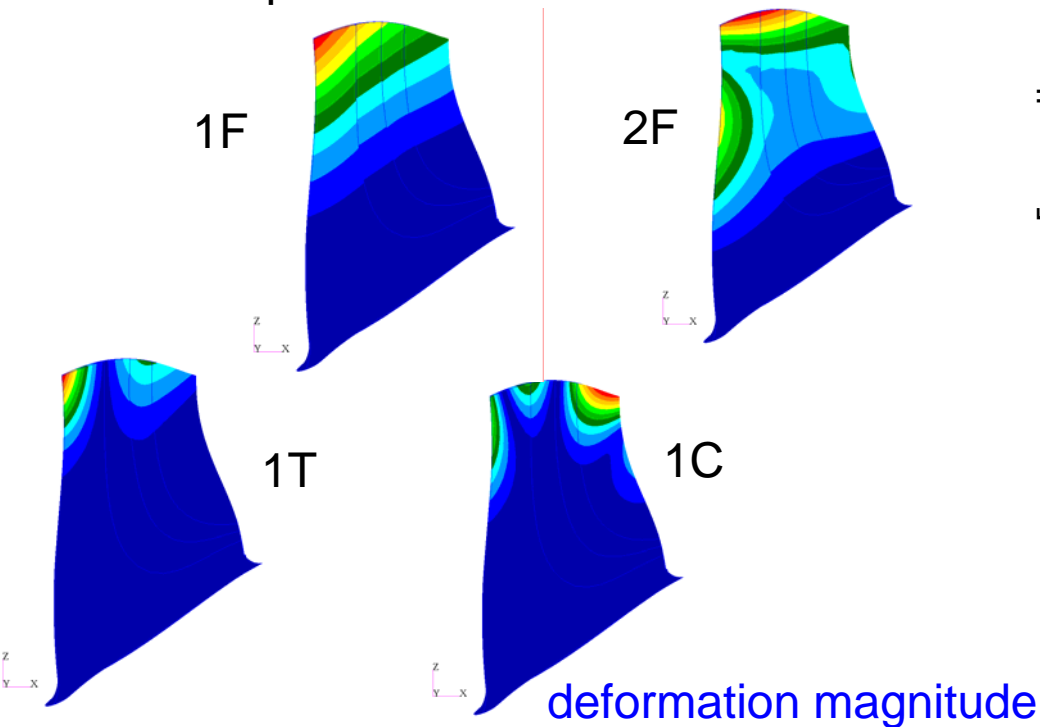
Utilisation Factor in CFRP Region Tsai-Wu Criterion

nonlinear analysis, inertial rotation, aerodynamic pressure and temperature load



Hybrid Blade: Campbell-Diagram

- Vibration analysis
- Consideration of nonlinear effects caused by inertial rotation, aerodynamic pressure and temperature load

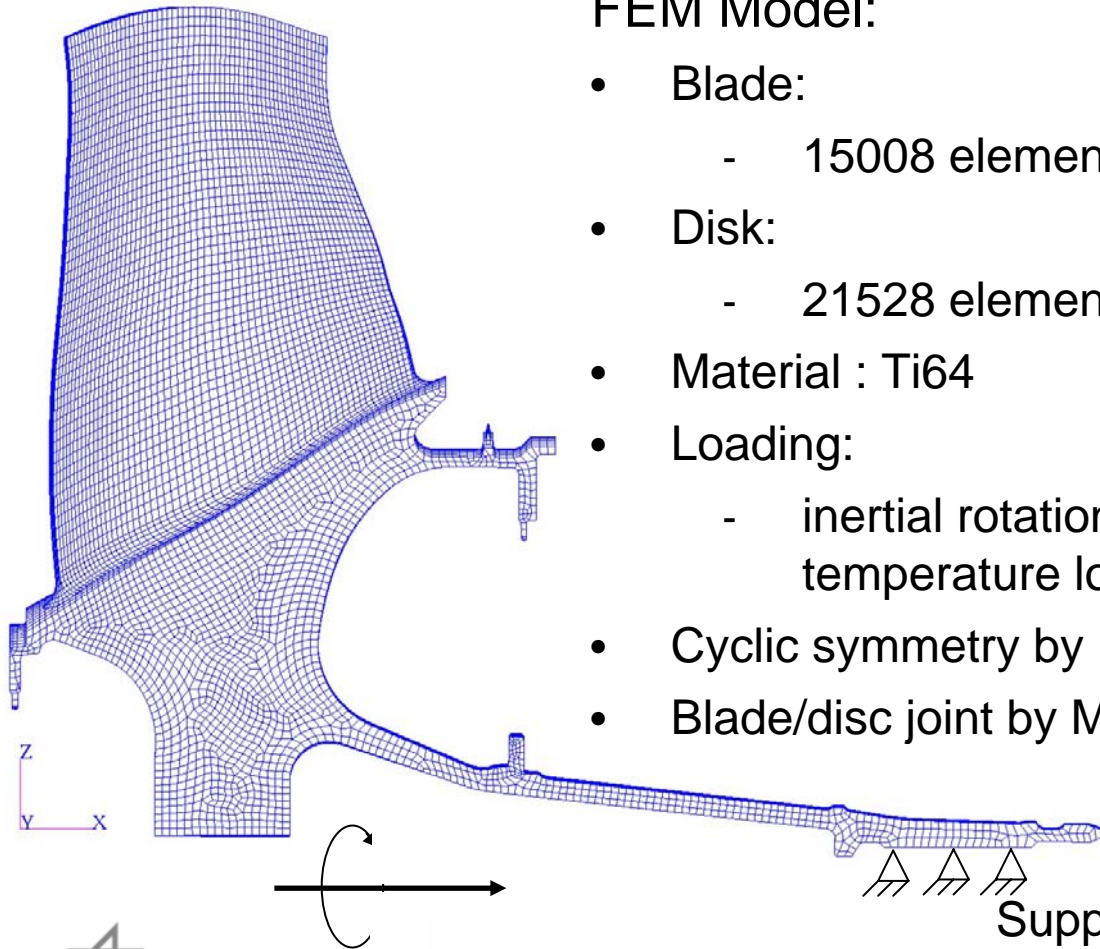




Topics

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- ✓ Mass reduction in first stage by implementation of CFRP (Carbon Fibre Reinforced Plastics)
- ✓ FEM modelling and structural analysis of a hybrid blade
- Modification of dynamic response of a titanium blade by topology optimization
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Modification of Dynamic Eigenfrequencies of Titanium Blade using Topology Optimization



FEM Model:

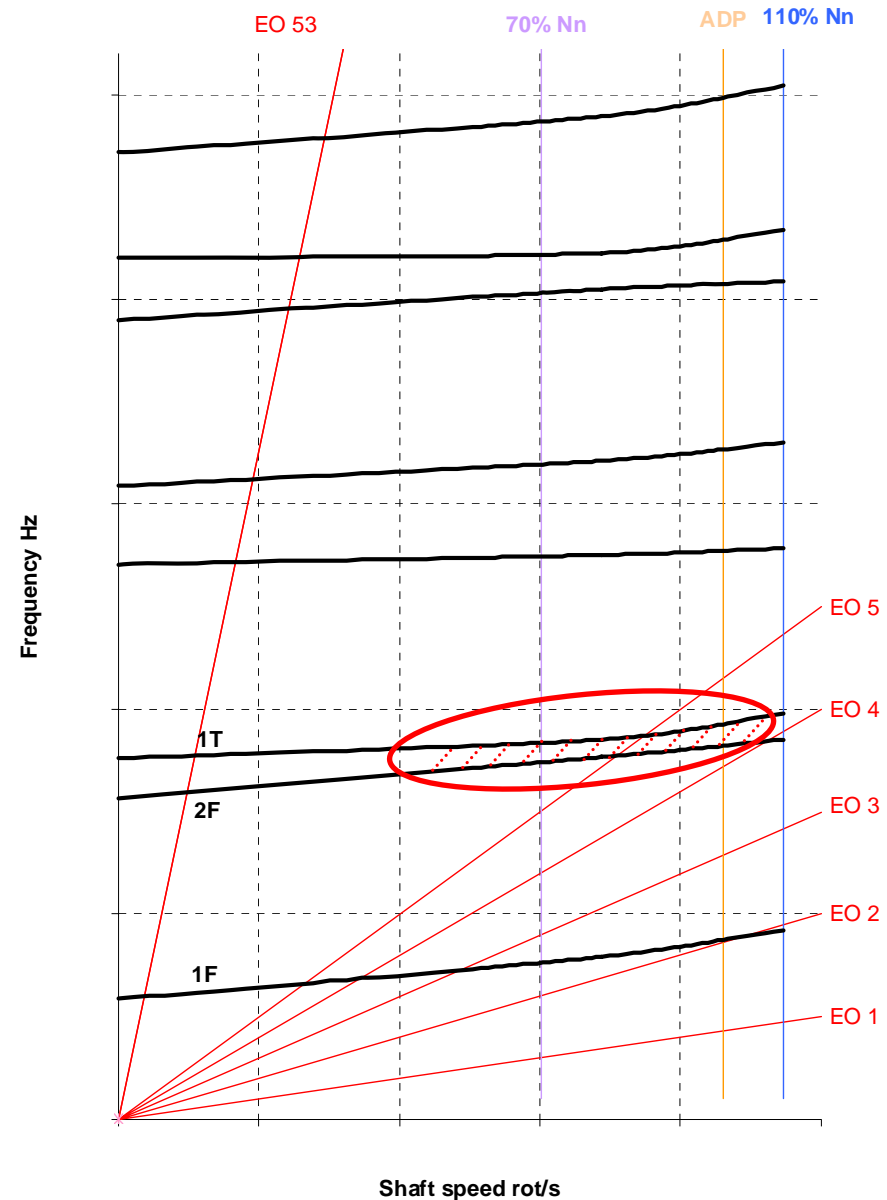
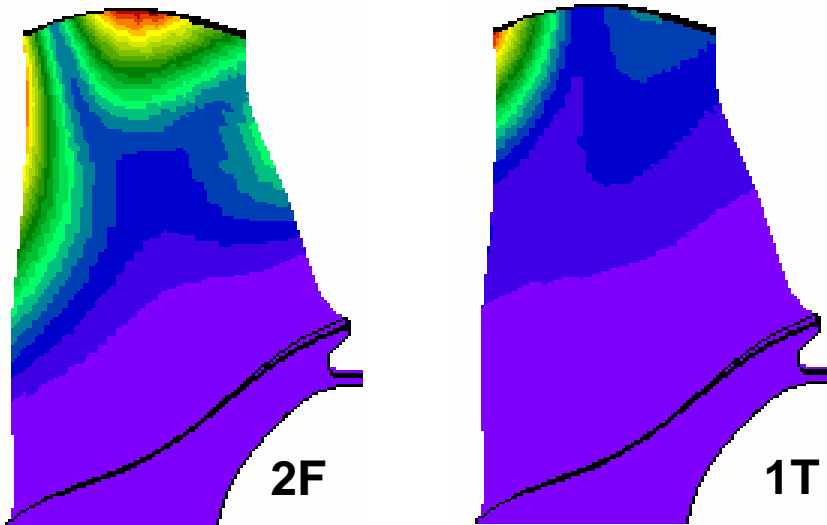
- Blade:
 - 15008 elements (HEXE8)
- Disk:
 - 21528 elements (HEXE8)
- Material : Ti64
- Loading:
 - inertial rotation, aerodynamic pressure, temperature load
- Cyclic symmetry by MPC JOIN
- Blade/disc joint by MPC ISURFACE

Suppressed DOF 2,3 (cyl. coord. system)



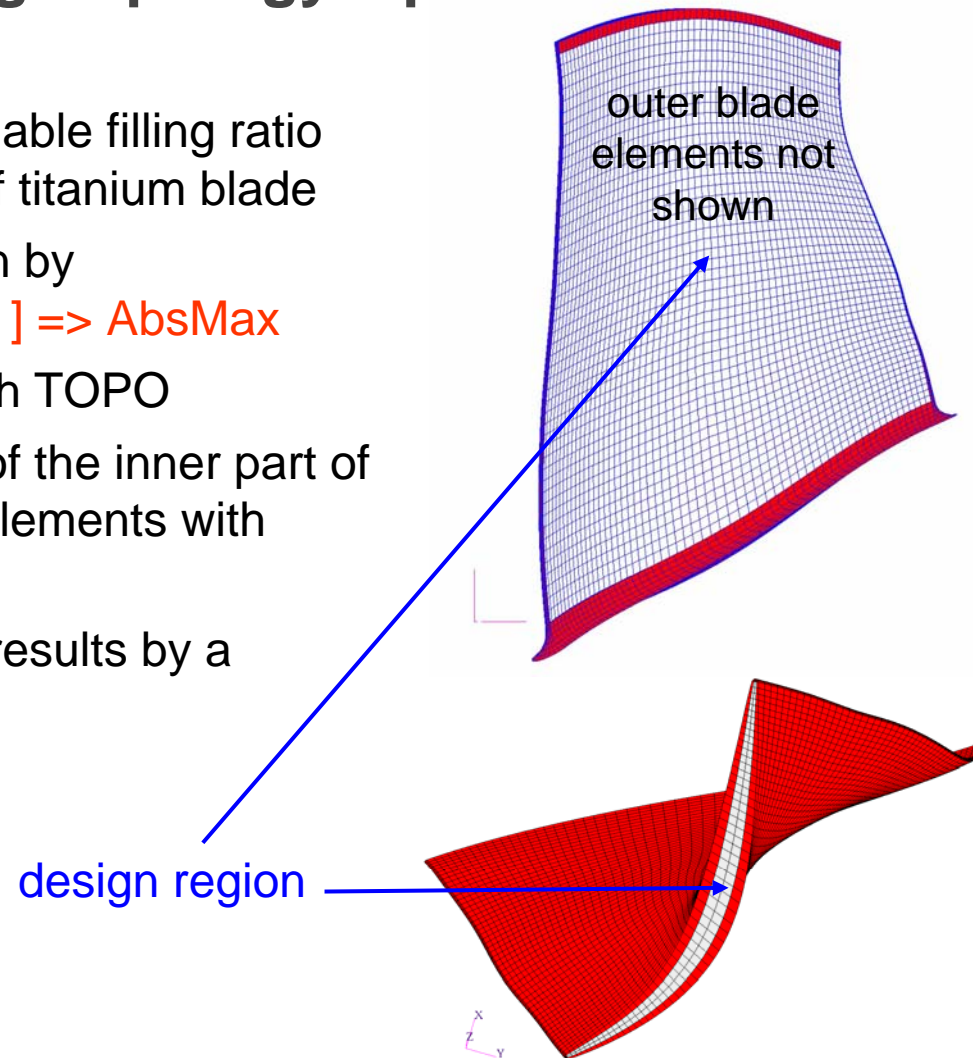
Titanium Blade: Campbell Diagram

- Vibration analysis
- Consideration of nonlinear effects caused by inertial rotation, aerodynamic pressure and temperature load
- Interaction between second flexural and first torsion mode in the whole operating range (risk of twist bend coupling)



Modification of Dynamic Eigenfrequencies of Titanium Blade using Topology Optimization

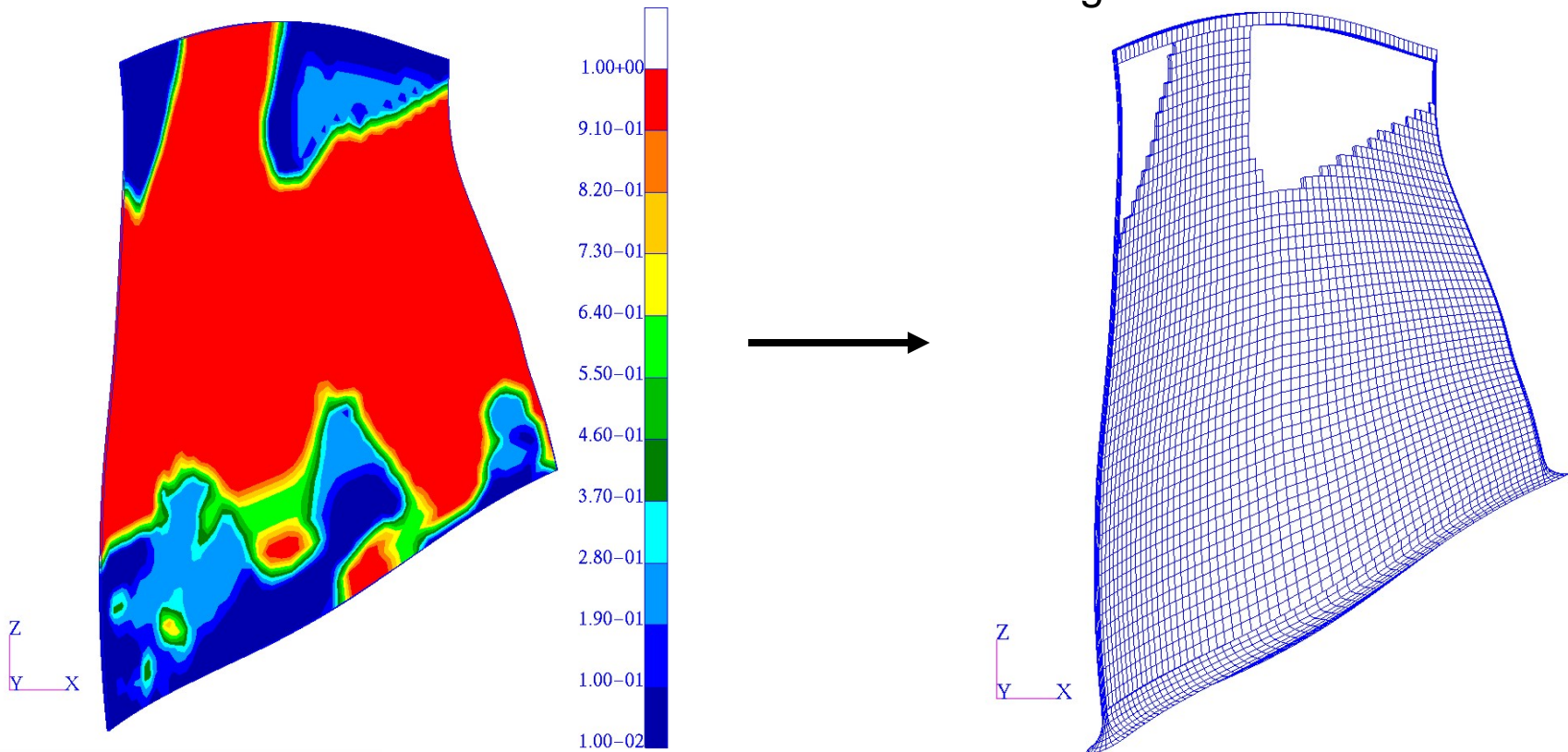
- Design elements (DHEXE8) with variable filling ratio (density, stiffness) in the inner part of titanium blade
- Definition of design objective function by \$DCFUNCTION: $[f(1T) - f(2F)] \Rightarrow \text{AbsMax}$
- Combination of vibration analysis with TOPO
- Analysis of results and modification of the inner part of the titanium blade by deleting FEM-elements with negligible filling ratio
- Verification of topology optimization results by a vibration analysis



Modification of Dynamic Eigenfrequencies of Titanium Blade using Topology Optimization

filling ratio f after 30 iterations, convergence achieved

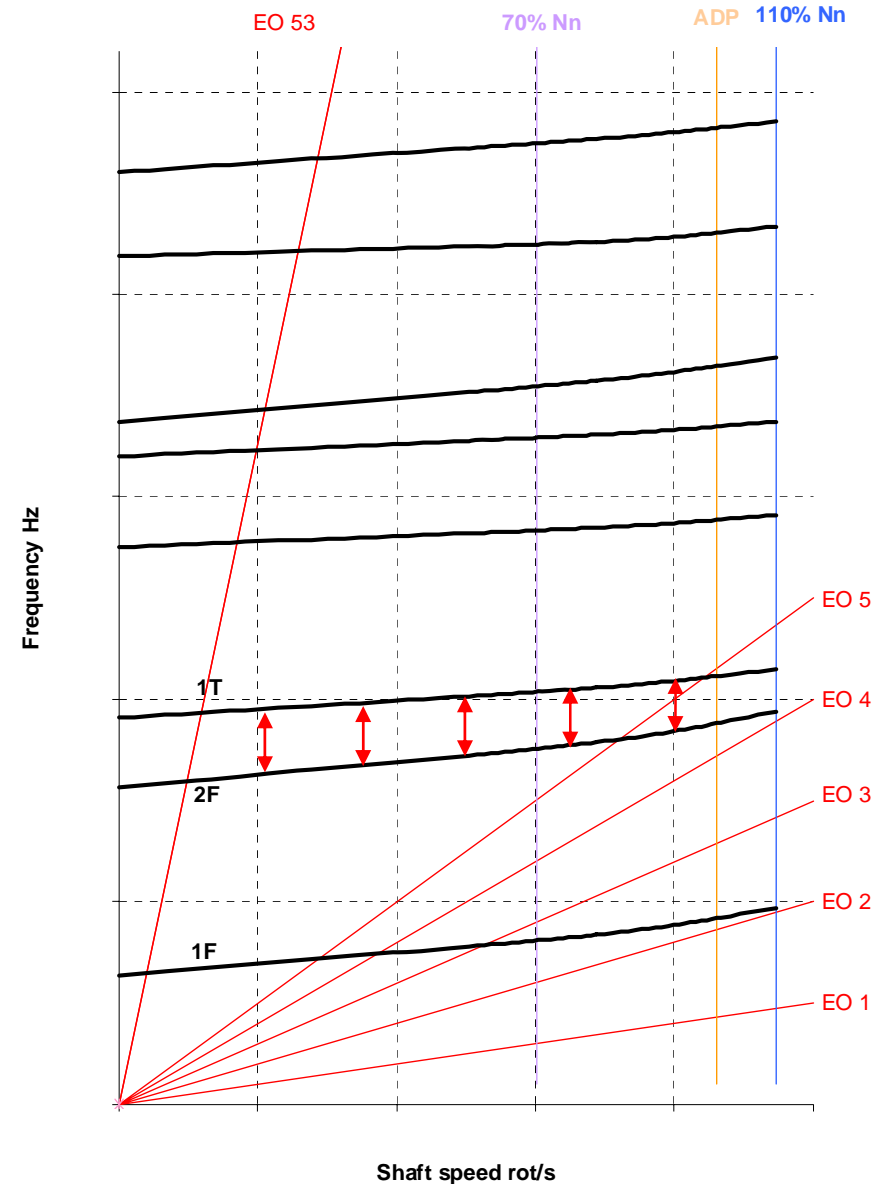
deleting of FEM elements with negligible filling ratio in the top blade region



Optimized Titanium Blade: Campbell Diagram

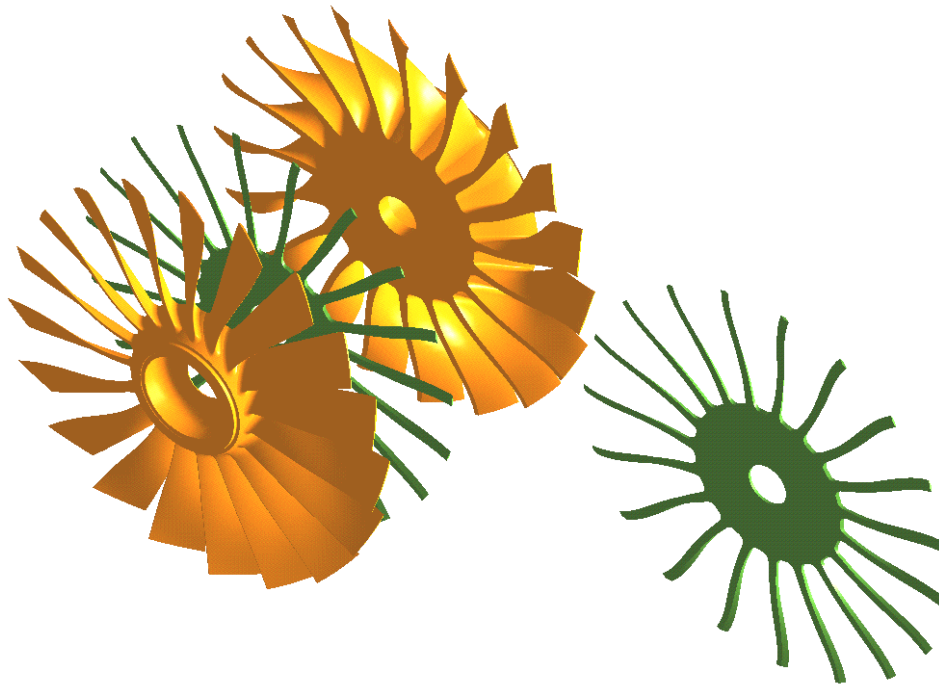
Separation of second flexural and first torsion mode in the whole operating range !

Campbell Diagram C03i4_h23_ti_topo_1



Realization Concept of Optimized Rotor: Monolithic Stacked Rotor

- Several planar discs building the whole rotor
- Each planar disc is sustainable of its own
- Accessibility allows any cavities in blades and discs



- Repair of the rotor by replacing any planar discs
- Joining of the planar discs by brazing or welding
- Combination of different materials to hybrid structures
- Implementation of damping mechanisms

Conclusion:

- Simple approach for modelling of hybrid joints leads to good results
- Approach for QUAD4 (Ti) - SHELL4 (CFRP) coupling applicable to similar joining structures
- Successful verification of approach for QUAD4 (Ti) - SHELL4 (CFRP) coupling by simple test specimens
- Dynamic eigenfrequencies separation of titanium blade achieved by topology optimization



Thank you for your attention



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in der Helmholtz-Gemeinschaft