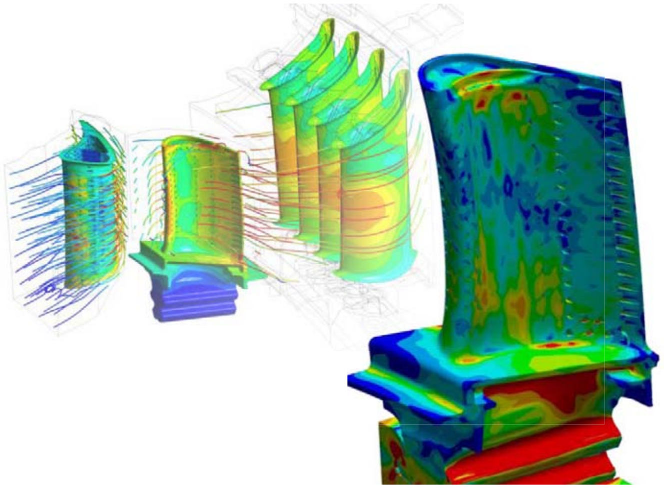


Predictive Maintenance

LHT: *Motivation*

ITB: *Technical Solution*

WOST 2018

Presented by H. Schulze Spüntrup – ITB

WOST 2018 – Predictive Maintenance

LHT Motivation

C. Werner-Spatz | HAM T/ES-Z
M. Zschieschank | HAM T/ES 21

22.03.2018

Lufthansa Technik

Lufthansa Group – The business segments

Passenger transportation

The Lufthansa Group airlines rank among the world’s leading carriers.

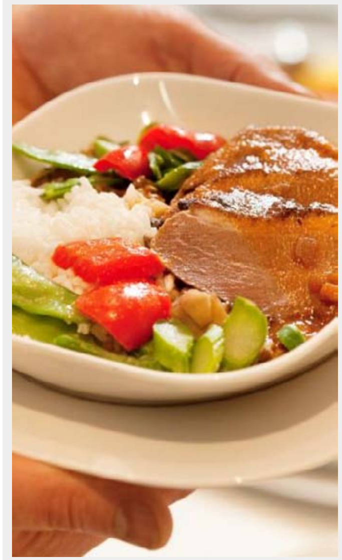
Logistics

Lufthansa Cargo – one of the world's leading cargo carriers in international air traffic.

Lufthansa Technik
Maintenance, Repair, Overhaul

Lufthansa Technik – leading provider of MRO services in the world's airline business.

Catering



LSG Sky Chefs – leading provider of airline catering and integrated in-flight solutions.

Other activities

Lufthansa Aviation Training
Lufthansa AirPlus
Lufthansa Industry Solutions
(and many more)

Lufthansa Technik Product Divisions

Aircraft Services (Maintenance, Overhaul)	Engine Services	Component Services	Landing Gear Services	VIP & Special Mission Aircraft Services
				

Number of employees:

3,800*

11 Engine Services **facilities** and **7 test cells** around the world for **~40 engine** and **APU types**

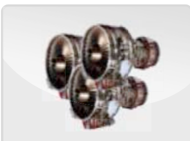
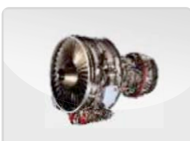
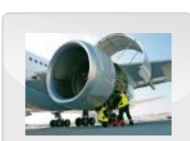
31.000 Engine and APUs overhauls in over **60 years**

Certified by **FAA** and **EASA** as **Maintenance Organization, Design Organization** and **Manufacturer**

* as of 31.12.2016

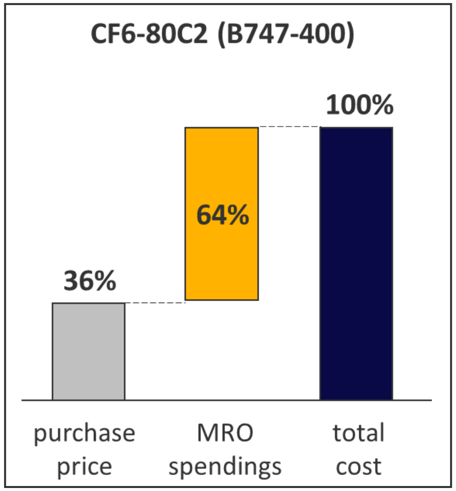
Lufthansa Technik Engine Services

We are designed to meet our customers demands

Products		Center	Customer
	Qualified provider of single and fleet contracts	OVH	Airline, Lessor
	Highly efficient engine shop, responsible for Disassembly, Assembly and Engine Test	DAT	OEM
	Leading Center of Excellence for Engine Parts Repair	EPAR	OEM, MRO-Shop, Parts Trader
	Immediate support On-wing and On-site – any time and anywhere	Mobile Engine Services	Airline, OEM, MRO-Shop

Why do we need prognostic methods?

- Contracts covering maintenance for engine fleets increasingly complex. Often flat-rate contracts or fixed / not-to-exceed price elements included → MRO supplier shares technical and financial risks with operator



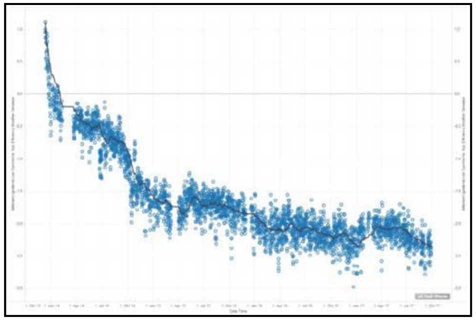
- Fleet management becomes increasingly important
  - Removal and maintenance planning
  - Monitoring: plan vs. actual performance

  → Manage risk through early detection of problems

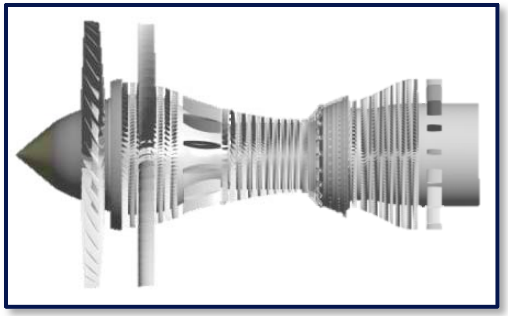
  → Improve cost per flight-hour

- Removal and maintenance planning requires prognosis: How will engines behave over several years under expected operating conditions?
  - Performance deterioration
  - **Damage to critical components**

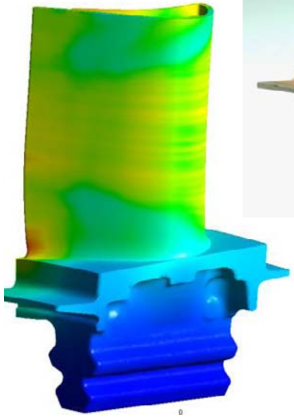
  → Expected removal reason; time on wing; required maintenance workscope

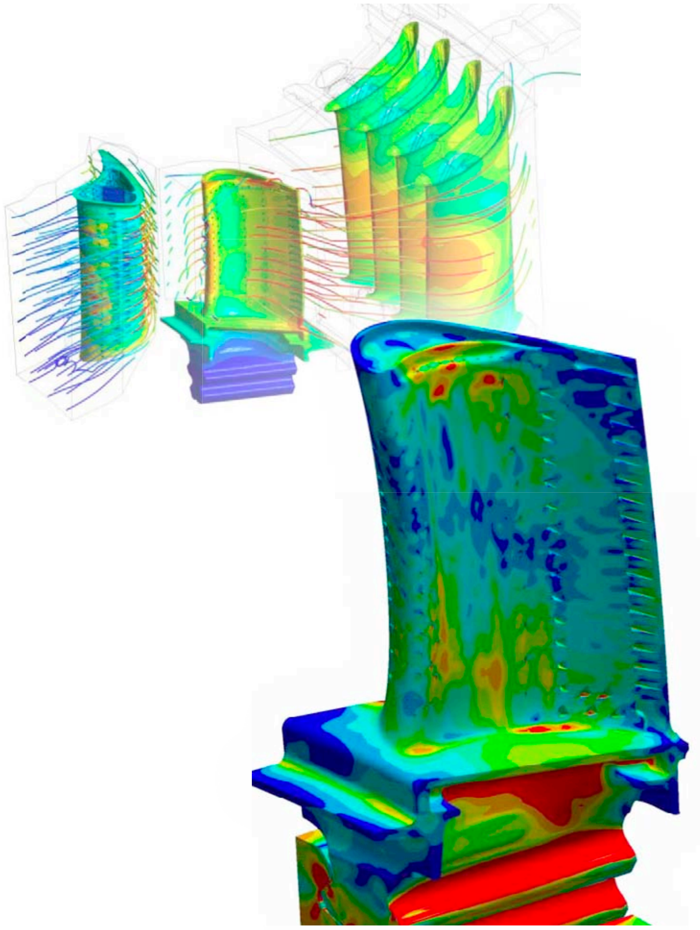


How do we apporach the subject?



- Issue complex and highly non-linear; many parameters involved
- „Normal“ approach nowadays: Big data → statistical analysis as basis for identifying relevant sensitivities and for surrogate model
- But:
  - Available data from operation doesn‘t qualify as „big data“ if filtered properly
  - Statistical methods may solve the problem, but don‘t provide thorough understanding of the sensitivities → who supervises the model?
- LHT approach: physics-based model based on thermodynamic cycle and numerical simulation
  - Accurate representation of engine geometry and engine behaviour
  - Determine loads throughout actual operation
  - Determine damage / life consumption resulting from these loads for critical components of the engine
  - Efficient implementation for routine application requires use of high-quality surrogate models





Ingenieurgesellschaft für technische Berechnungen mbH

WOST 2018 - Predicitive Maintenance

Technical Solution
for Lufthansa Technik

Lufthansa Technik
dynardo dynamic software & engineering
itb

The Task

- LHT approach: physics-based model based on thermodynamic cycle and numerical simulation
  - Accurate representation of engine geometry and engine behaviour
  - Determine loads throughout actual operation
  - Determine damage / life consumption resulting from these loads for critical components of the engine
  - Efficient implementation for routine application requires use of high-quality surrogate models

<u>Solution</u>

✓ CFX & FE 1-way FSI Simulation

✓ Actual operation parameters as input

✓ Simulation output fed into LHT fatigue assessment software

- „high-quality surrogate models" :

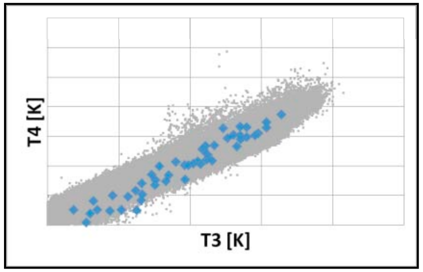
✓ FMOP created by *Statistics on* Structures and *optiSlang*

- „Efficient implementation for routine application"

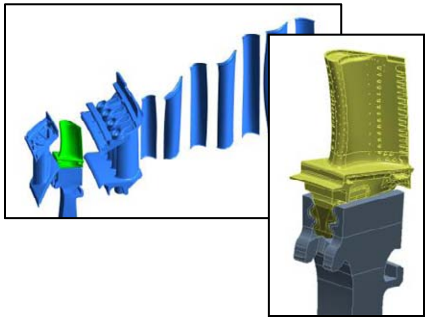
✓ Export and implementation of FMOP in third party software *(NEW)*

FMOP created by Statistics on Structures and optiSlang

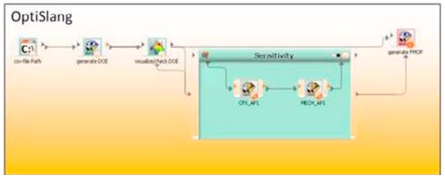
- The Plan:
  - Screening of actual flight data (half a million datasets) and reduction into a manageable, representative set of flight variants
    Here 50 representative variants of engine operation at cruise



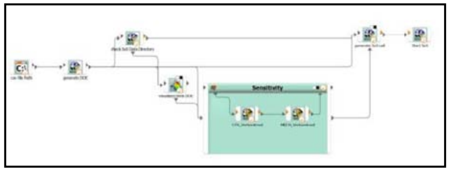
  - Setting up the 1-way FSI simulation models:
    - Parametrization of available & validated turbine CFX-model
    - Creation of a FE-model of the High-Pressure-Turbine-Blade (HPTB) suitable for fatigue assessment
    - Optimizing the setup for fast processing



  - Implementing the simulation models in an *optiSlang* workflow



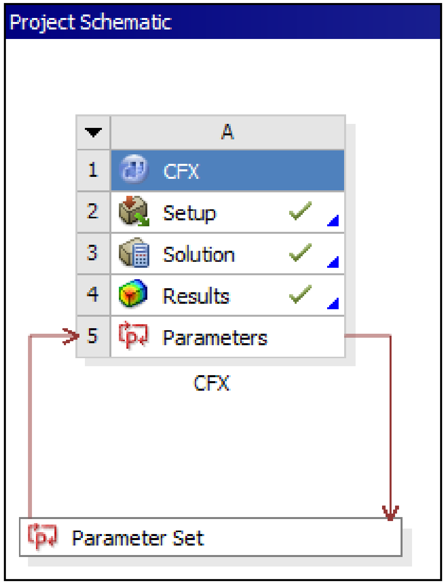
  - Improving the *optiSlang* workflow for maximum flexibility in order to easily apply it on future simulations
    (e.g. other engine parts)

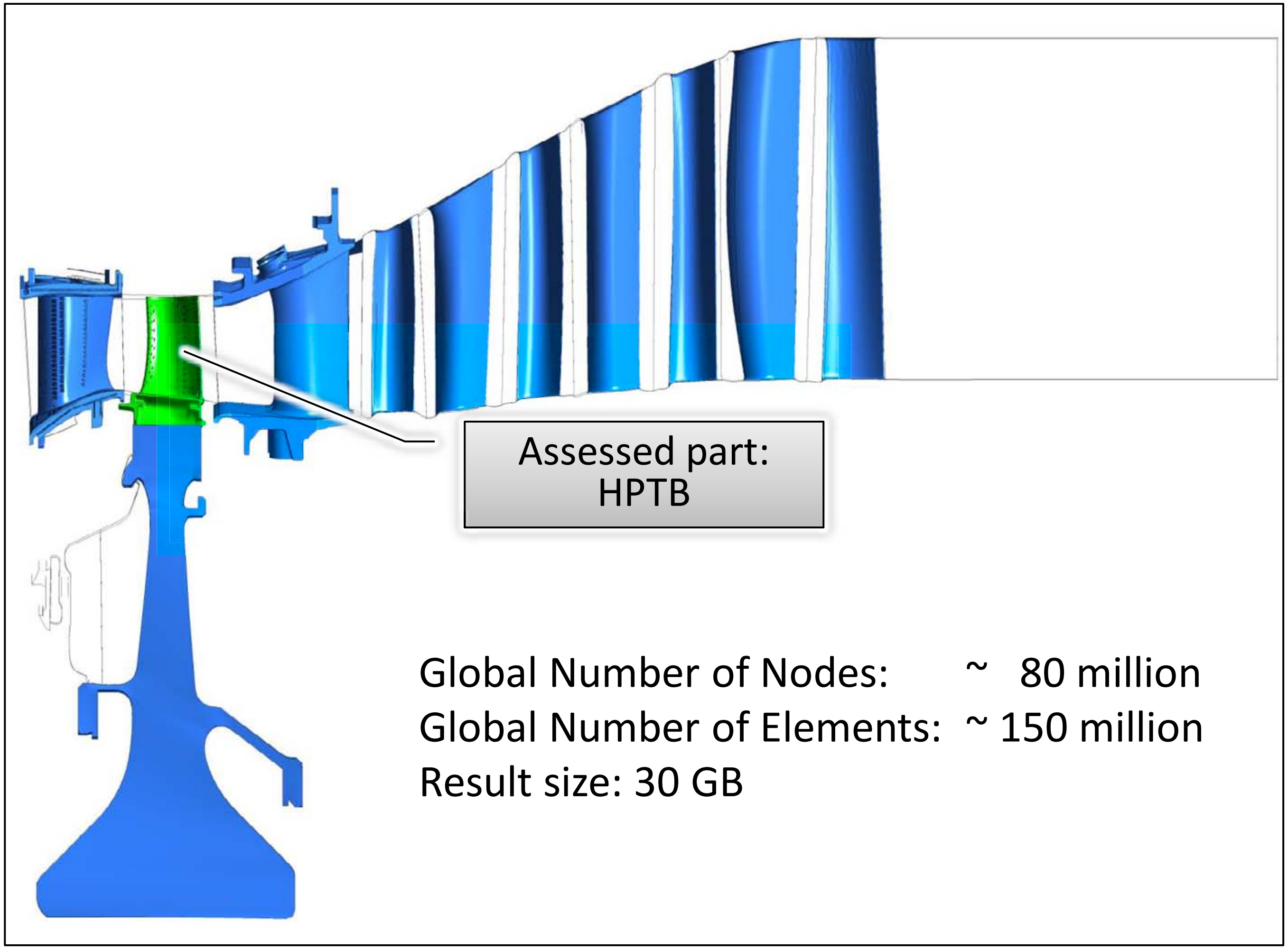


Lufthansa Technik dynardo dynamic software & engineering itb

Setting up the 1-way FSI simulation models

- Parametrization of available & validated turbine CFX-model



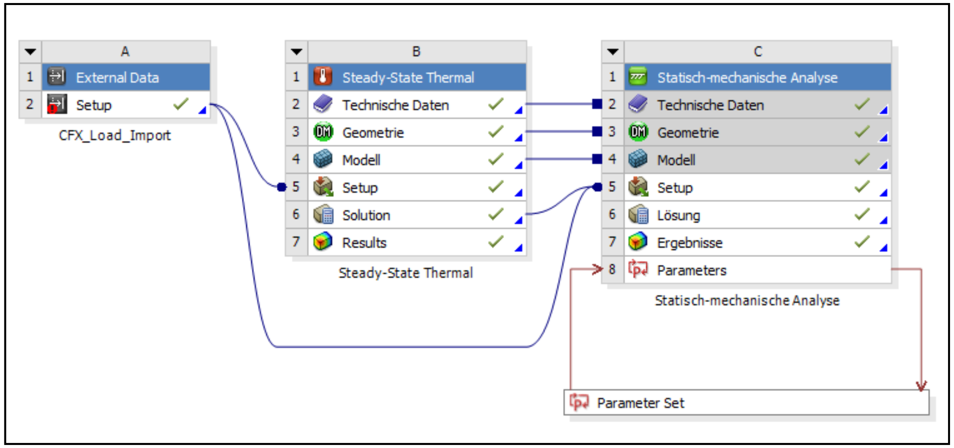


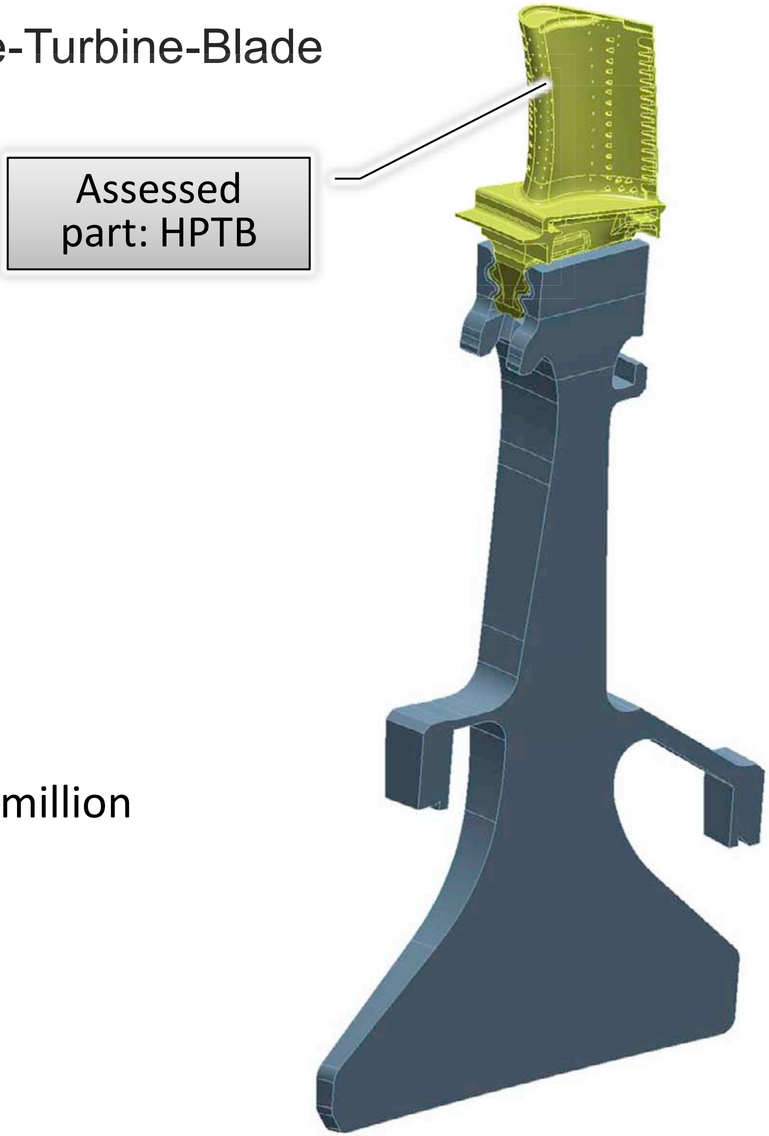
Global Number of Nodes: ~ 80 million
Global Number of Elements: ~ 150 million
Result size: 30 GB

Lufthansa Technik dynardo dynamic software & engineering itb

Setting up the 1-way FSI simulation models

- Creation of a FE-model of the High-Pressure-Turbine-Blade

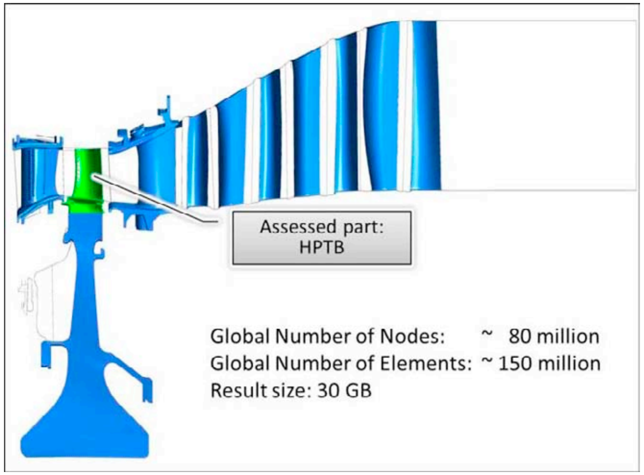


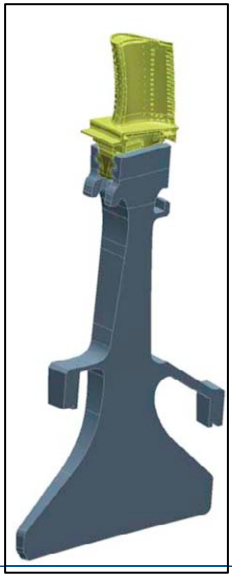


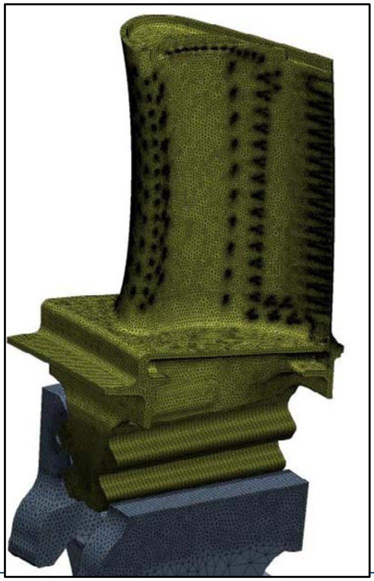
Global Number of Nodes: ~ 6 million

Setting up the 1-way FSI simulation models

- Optimizing the setup for fast processing



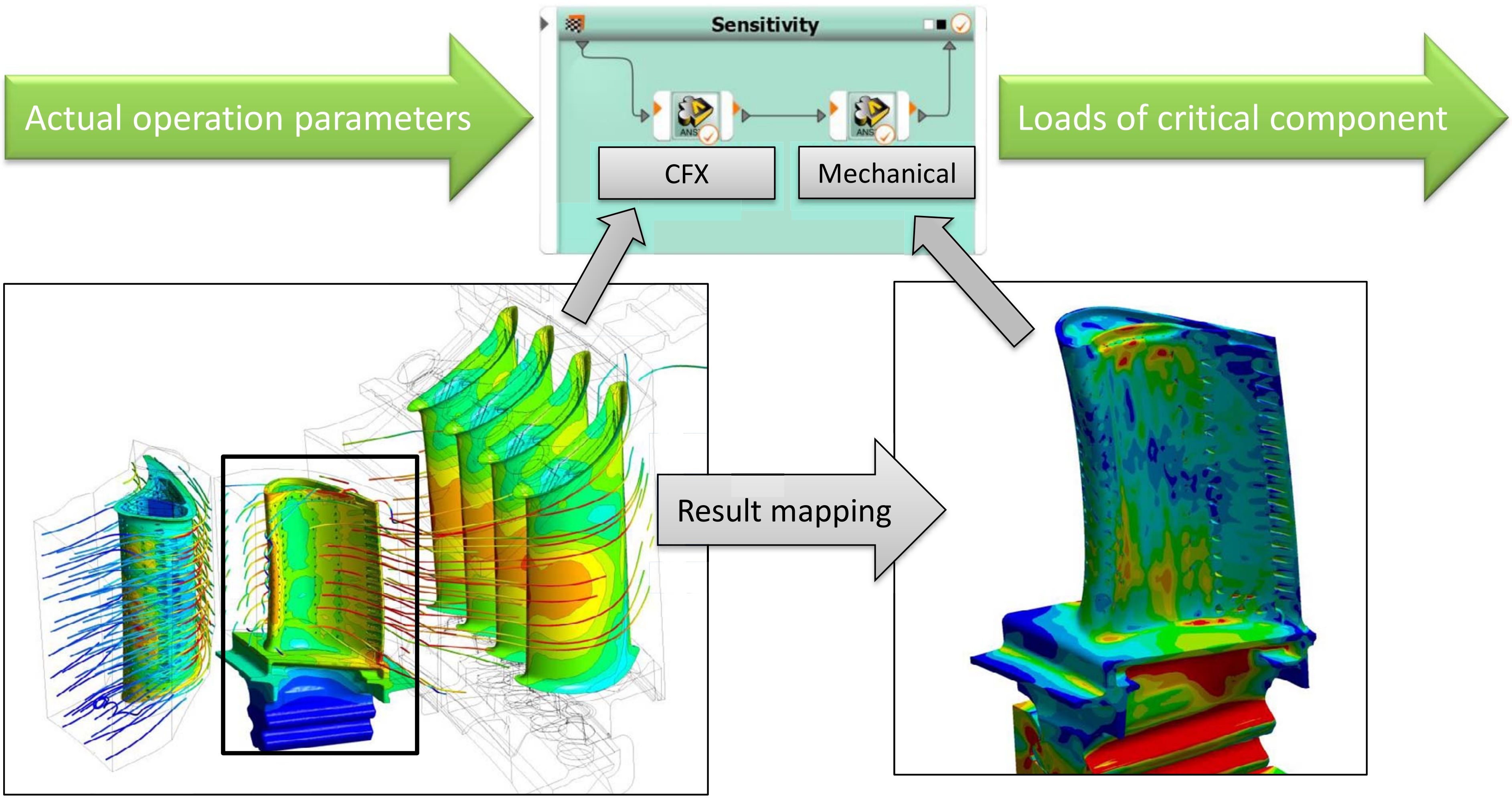




- Reduction of output to the required minimum (location & result)
- Definition of tight convergence values based on the remaining output values
- Automated selection of the best available initial solution, depending on the design-point parameters, for further decrease of solution time
- Optimized mesh density & solver settings

Implementing the simulation models in an optiSlang workflow

- Simulation loop in *optiSlang*



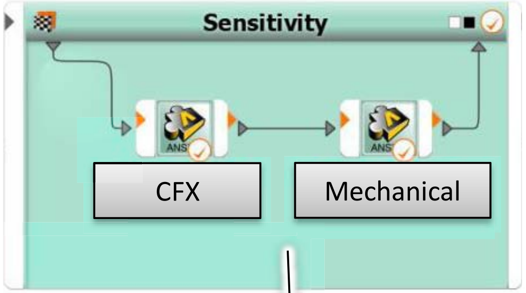
Implementing the simulation models in an optiSlang workflow

- Setup in *optiSlang*

Check underling file integrity (esp. scripts)

Input DOE

Visulize input DOE

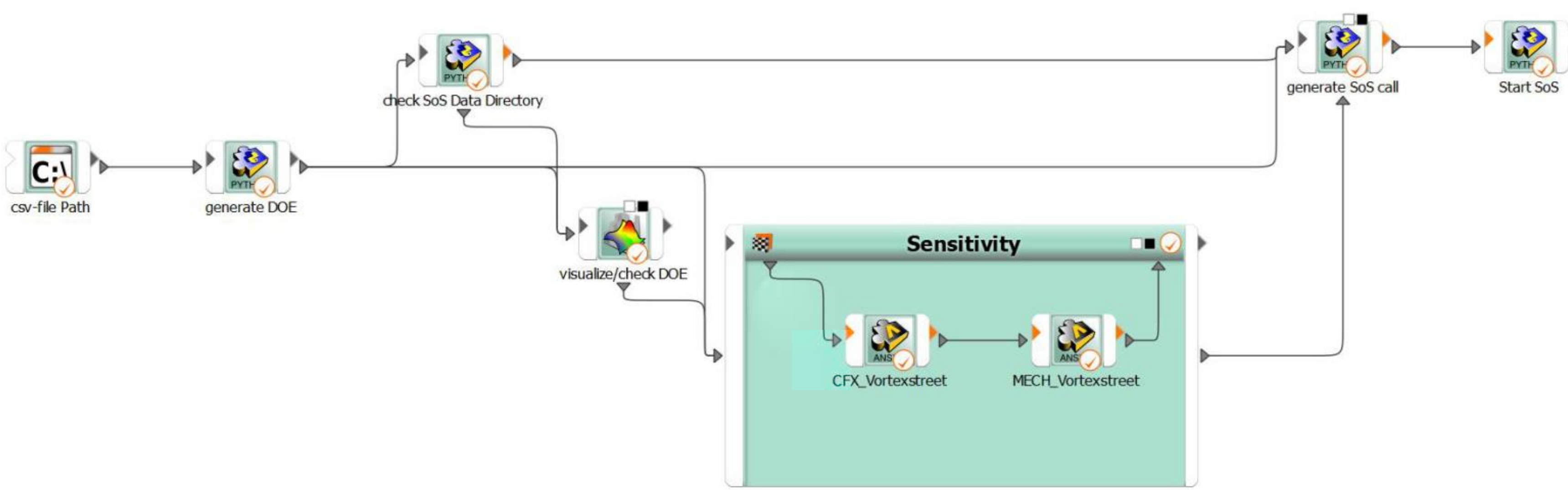


Simulation loop

FMOP generation by SoS

Implementing the simulation models in an optiSlang workflow

- Setup in *optiSlang*



Run workflow!

~ 15 hours per design point → 1 Month process time (50 design points total)

Result: FMOP in separate file:

Results

- FMOP in *Statistics on Structures*

List of available individual objects/samples:

	S1	S2	S3	SX	SXY	SXZ	SY	SYZ	SZ	TEMP
Capped_dif50_data										
F-CoP[Input_N1]	0.52 %	0.65 %	0.63 %	0.04 %	0.12 %	0.11 %	0.09 %	0.13 %	0.07 %	
F-CoP[Input_N2]	5.29 %	3.75 %	3.84 %	6.53 %	5.53 %	4.35 %	3.81 %	4.00 %	3.56 %	0.03 %
F-CoP[P25]	0.72 %	1.01 %	0.95 %	0.13 %	0.24 %	0.24 %	0.25 %	0.30 %	0.20 %	
F-CoP[P3]	1.53 %	2.89 %	2.28 %	5.46 %	5.48 %	5.40 %	5.41 %	5.51 %	4.86 %	0.20 %
F-CoP[P4soll]	18.02 %	17.26 %	14.49 %	16.67 %	14.70 %	17.62 %	14.32 %	17.52 %	18.33 %	
F-CoP[P5Vorgabe]	1.65 %	1.58 %	1.43 %	0.06 %	0.19 %	0.20 %	0.17 %	0.18 %	0.15 %	
F-CoP[T25]	0.66 %	1.64 %	1.07 %	0.50 %	0.99 %	0.93 %	1.94 %	1.21 %	0.79 %	0.02 %
F-CoP[T3]	1.88 %	5.66 %	4.59 %	1.68 %	3.57 %	2.26 %	11.31 %	4.87 %	2.60 %	49.88 %
F-CoP[T4soll]	82.83 %	64.32 %	62.67 %	78.36 %	70.11 %	72.26 %	56.74 %	63.67 %	64.44 %	49.02 %
F-CoP[Total]	95.37 %	91.52 %	91.96 %	96.49 %	92.38 %	93.27 %	92.00 %	92.08 %	95.01 %	99.21 %
mean[FMOP]										
sigma[FMOP]										

Sensitivity of input (left) and output (top) values

Results

- FMOP in *Statistics on Structures*

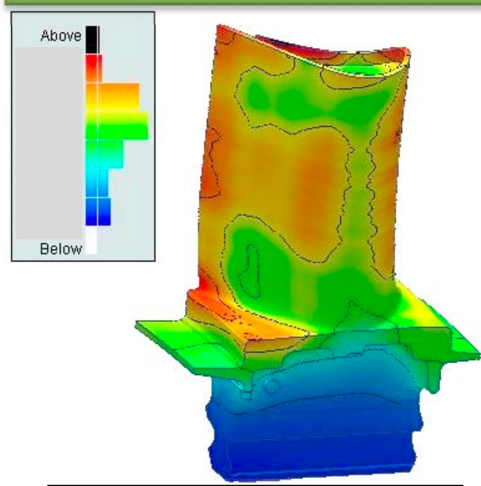
List of available individual objects/samples:

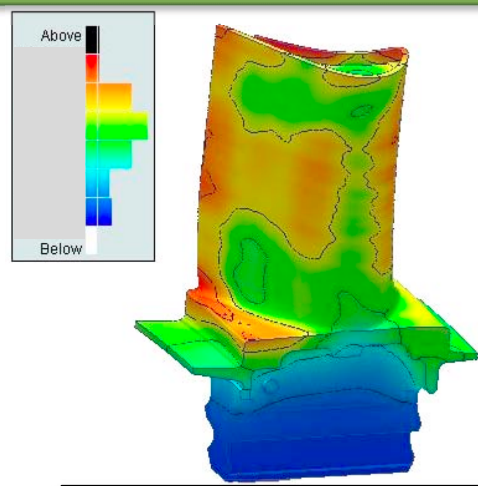
	S1	S2	S3	SX	SXY	SXZ	SY	SYZ	SZ	TEMP
F-CoP[Total]	95.37 %	91.52 %	91.96 %	96.49 %	92.38 %	93.27 %	92.00 %	92.08 %	95.01	99.21 %

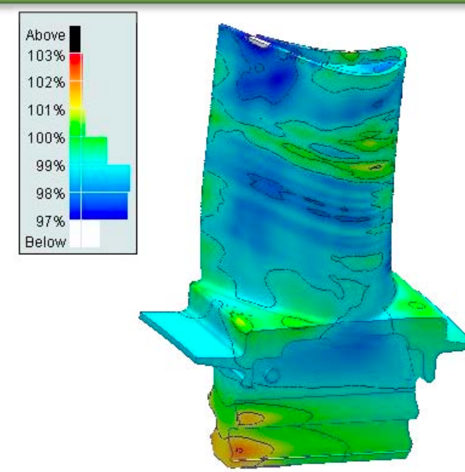
FMOP_VALIDATED
Statistics on Structures 3.3.1
4,90 GB

File includes the FE-results of the validation points for direct comparison

Temperatures [K]







FE-Results

FMOP

Result accuracy
Perfect match = 100 %

Results

- FMOP in *Statistics on Structures*

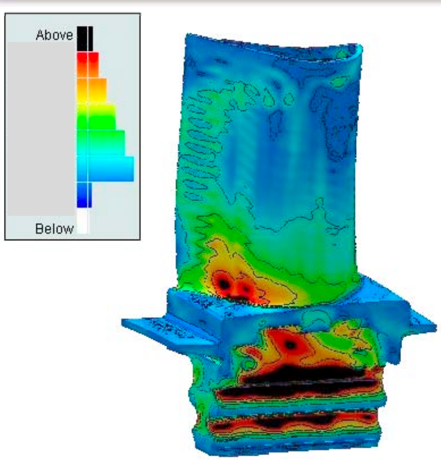
List of available individual objects/samples:

	S1	S2	S3	SX	SXY	SXZ	SY	SYZ	SZ	TEMP
F-CoP[Total]	95.37 %	91.52 %	91.96 %	96.49 %	92.38 %	93.27 %	92.00 %	92.08 %	95.01 %	99.21 %

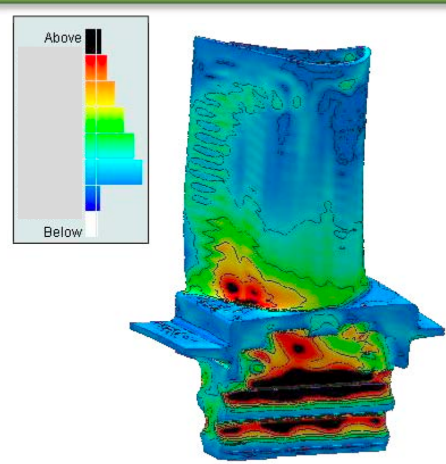
FMOP_VALIDATED
Statistics on Structures 3.3.1
4,90 GB

File includes the FE-results of the validation points for direct comparison

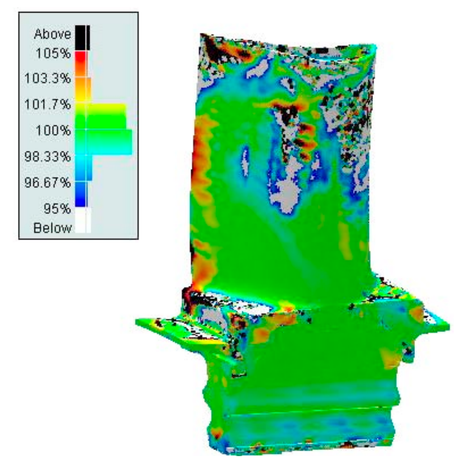
Maximum Principle Stress S1 [MPa]



FE-Results



FMOP



Result accuracy
Perfect match = 100 %

Outlook

- Since Statistics on Structures 3.3.3 (2017):
  - Shared library for Windows & Linux for evaluation of FMOP
  - ANSI C interface for usage in C, C++, Python, Matlab, …
- Ability to approximate (predict) the complete FEM solution for new support points within very short time, i.e.:
  - Approximate temperature and stress tensors for every FEM node
    - Data exchange through vectors (binary)
    - Limited functionality to access FEM mesh connectivity information for advanced evaluation
- With the FMOP as a high quality surrogate model, the structural responses from actual flight data can be predicted within seconds
  Contrary, direct simulation of the setup takes half a day on a 128-Core HPC-cluster
- In future applications this allows close to real time insight on wear, paving the way for a digital twin

- Thank you for your attention!