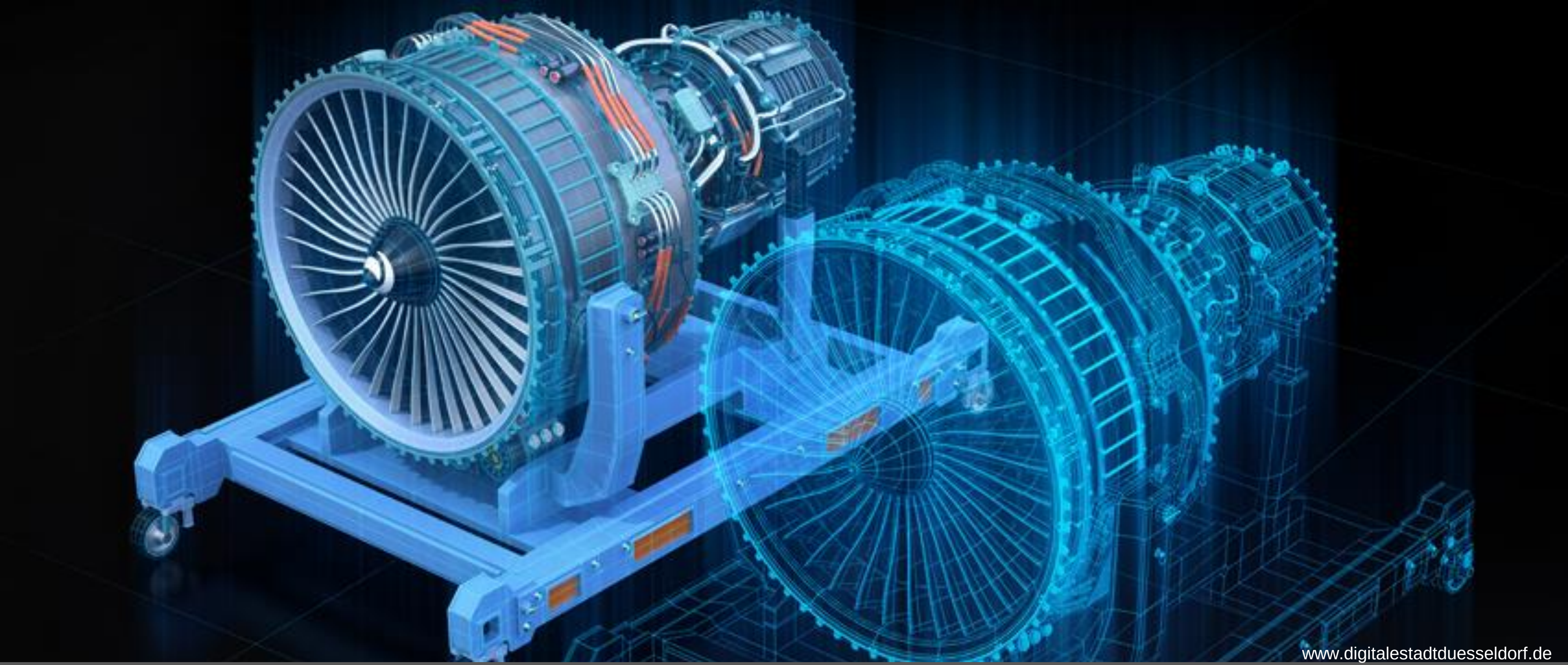


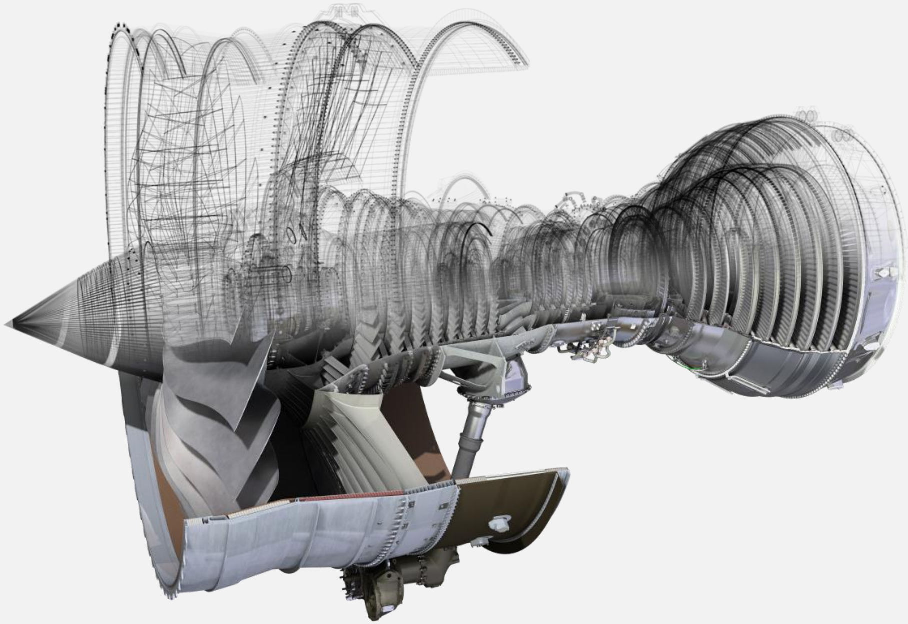
Towards the Isogeometric Aero-Engine

16th LS-DYNA Forum, October 11-13, 2022, Bamberg

Dr.-Ing. habil. Markus Kober, BTU Cottbus – Senftenberg, Chair of Structural Mechanics and Vehicle Vibrational Technology
Kai Singh, Rolls-Royce Deutschland

Outline

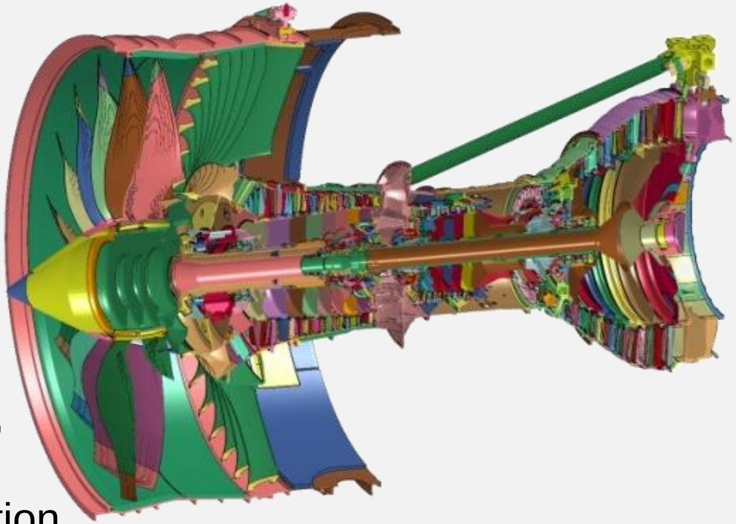
Towards the Isogeometric Aero-Engine



- Motivation
- Basic idea of IGA
- Generation of IGA models
- The isogeometric Dummy Engine
- Application, hints and examples
- Simulation results
- Computational time of IGA models
- Summary

Objective

- In aerospace industry more and more detailed FEM models are used for prediction of engine behavior
- Goal is the thermo-mechanical simulation of a running engine with almost no idealizations or simplifications over a time-span of a few seconds



Dynamic models with millions of DOF

- Many issues have to be solved (contact problems, modeling of bearings, hourglassing, efficient parallelization, model decomposition, time integration, …)

How to speed up the model creation process?

Basic Idea of Isogeometric Analysis (IGA)

Classical FEM:

- CAD systems are using non uniform rational B-Splines (NURBS) for geometry description
- CAD geometry is meshed and by this replaced by simple (linear) basis functions

CAD (NURBS) → **Meshing** → **Analysis**

Isogeometric Analysis (IGA):

- NURBS are also used as basis functions for the finite element analysis (no meshing neccessary)

CAD (NURBS) → **Analysis**

Significant time savings due to dispensed meshing step and improved accuracy!

Generation of IGA models

Real solid description of geometry

- CAD system should generate real 3D description of solids (including internal control points, not just surfaces)
- Commercial CAD systems do not have this capability up to now

➡ **Own CAD system has to be created**

- In [1] a Python package is described which is able to generate real 3D solid NURBS descriptions of geometries
- Package is available for everyone and contains many typical CAD functions (see later) but without GUI

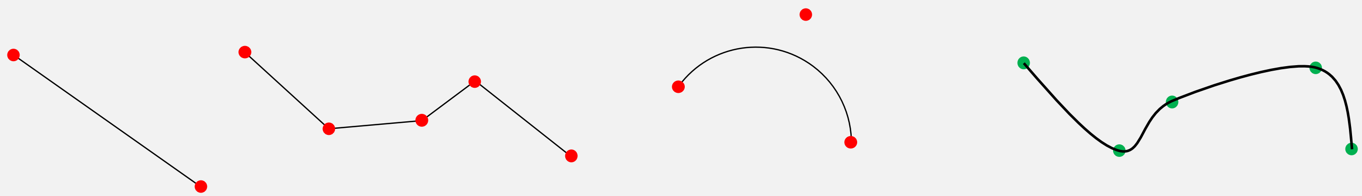
➡ **Geometry description has to be converted into suitable description for LS Dyna**

[1] Johannessen, K.A. and Fonn, E. (2020): Splipy: B-Spline and NURBS Modelling in Python. Journal of Physics: Conference Series, Volume 1669, EERA DeepWind'2020, 15 – 17 January 2020, Trondheim, Norway.

Generation of IGA models

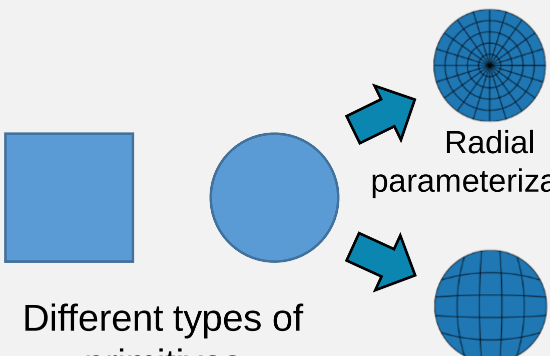
Examples for functionality of Python package for NURBS generation

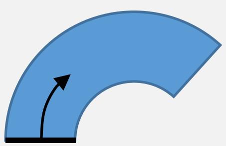
- Creation of curves:

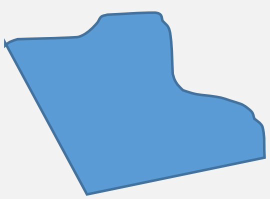


Straight lines | Polylines | Circle segments/circles | Different types of spline interpolations | + some others …

- Creation of surfaces:





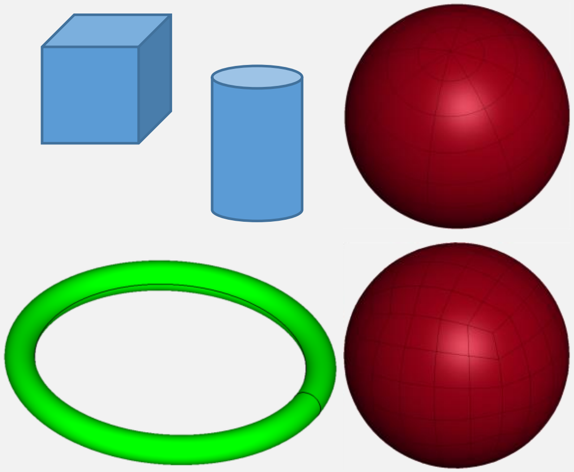


Different types of primitives | Extrusion/revolution of curves | Arbitrary surfaces from connected curves | + some others …

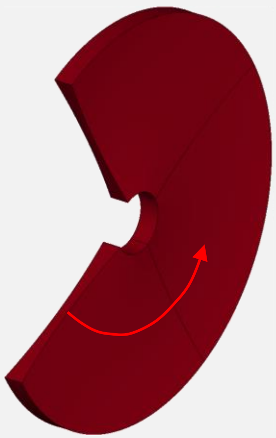
Important for explicit time-integration

Generation of IGA Models

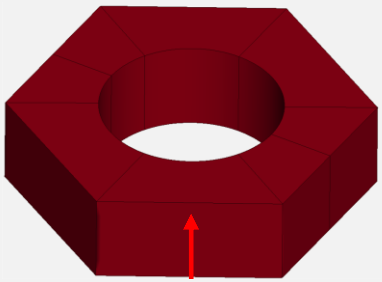
- Creation of volumes:



Predefined primitives



Revolve a surface



Extrude a surface

Interpolate between
given surfaces

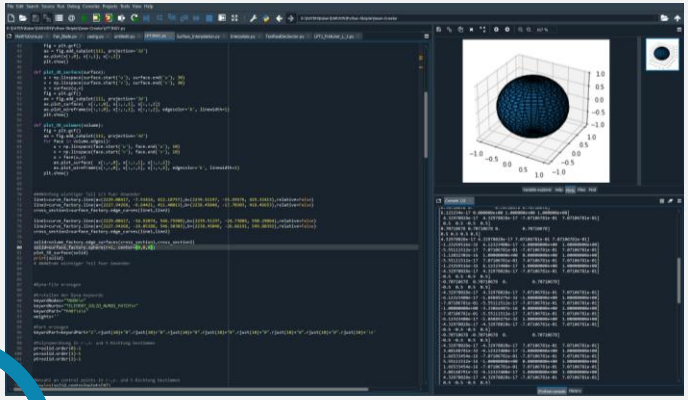
+ some others ….

Generation of IGA Models

Conversion to computable model

Python package (SpliPy) delivers mathematical description of geometry:

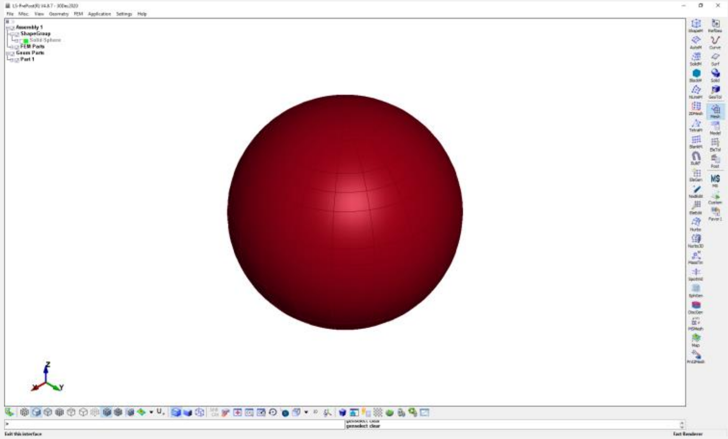
- NURBS order
- Knot vectors
- Control points
- Weights
- Periodicity



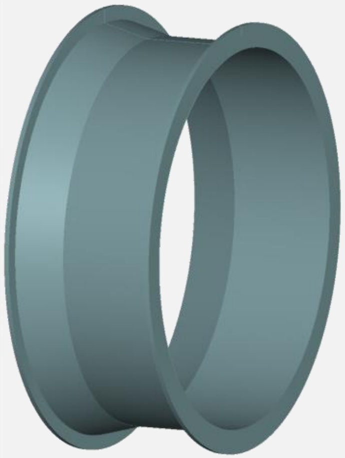
Developed Python translator

Python translator converts mathematical description of geometry into a Dyna-readable format

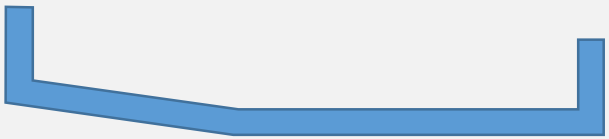
Tool for arbitrary IGA model generation (geometry and computational model are generated at the same time)



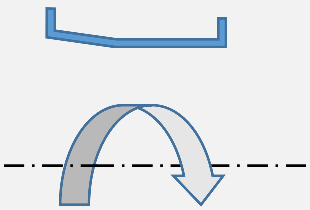
Application of CAD tool for cross-section creation



Typical CAD construction process of shown part consists of two steps:

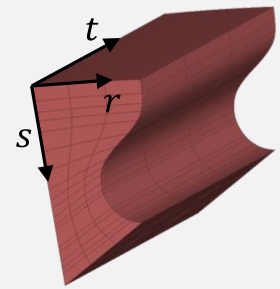


1. Definition of cross-section



2. Revolution of cross-section

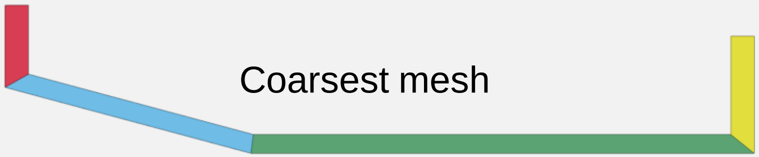
- Construction of cross-section has to be done in an IGA-proper way
- LS Dyna supports only 6-sided solid NURBS-patches
- Sides may be curved
- Each patch may consist of an arbitrary number of NURBS elements and contains its own (curvilinear) r-s-t-coordinate system

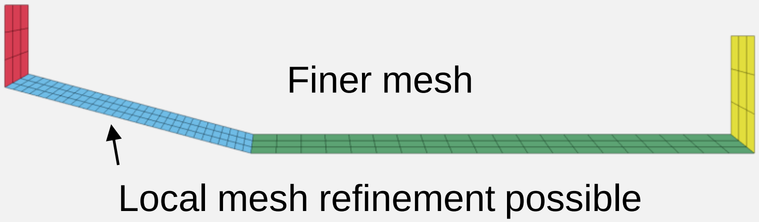


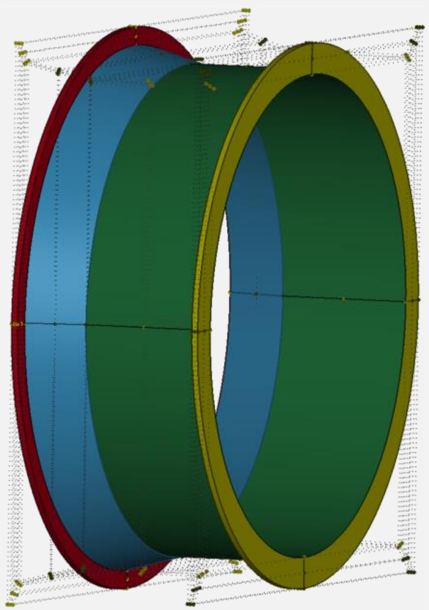
NURBS patch with elements

Application, Hints and Examples

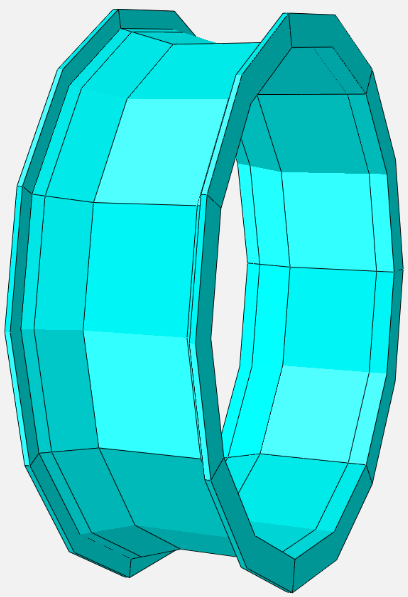
CCOC made of four patches



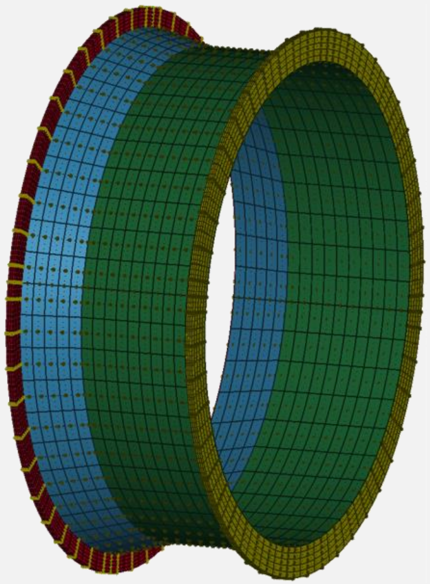




Coarsest mesh of complete casing which exactly represents geometry with 2nd-order NURBS (324 control points)



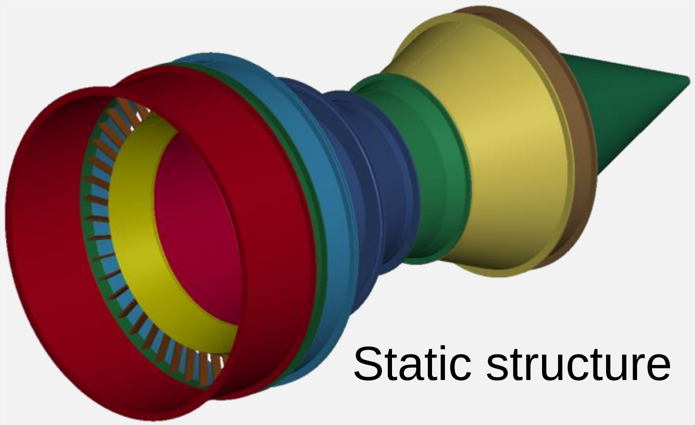
Classical FE mesh with 2nd order hex elements (329 nodes)



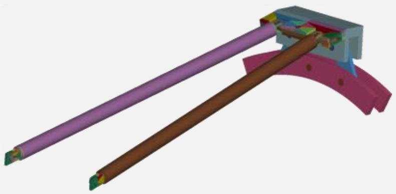
Refined 2nd-order NURBS mesh (7800 control points, geometry unchanged)

The Isogeometric Dummy Engine Model

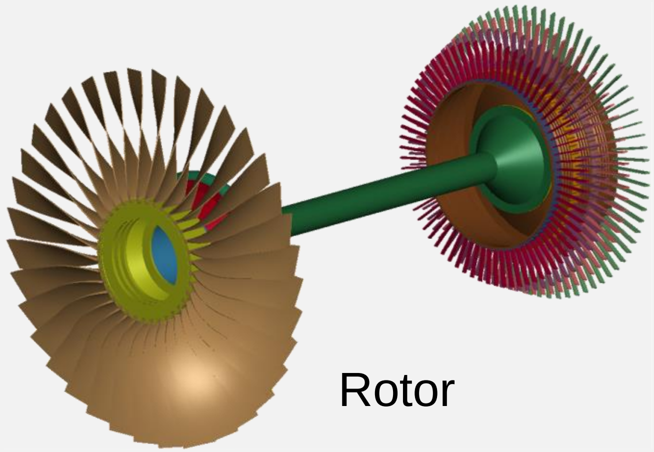
IGA Dummy Engine model



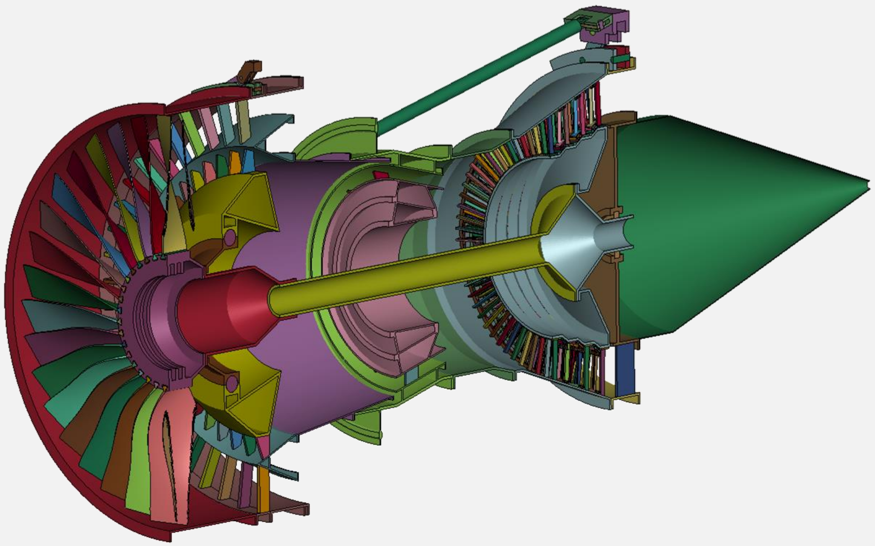
Static structure

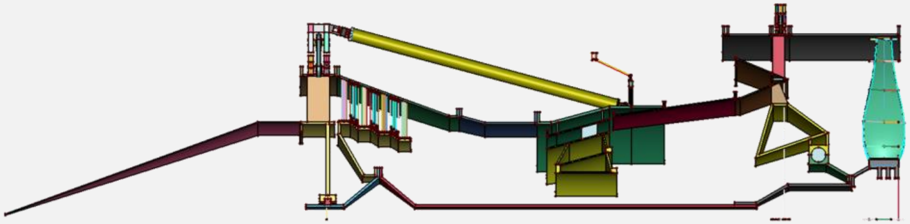


Rear mount system



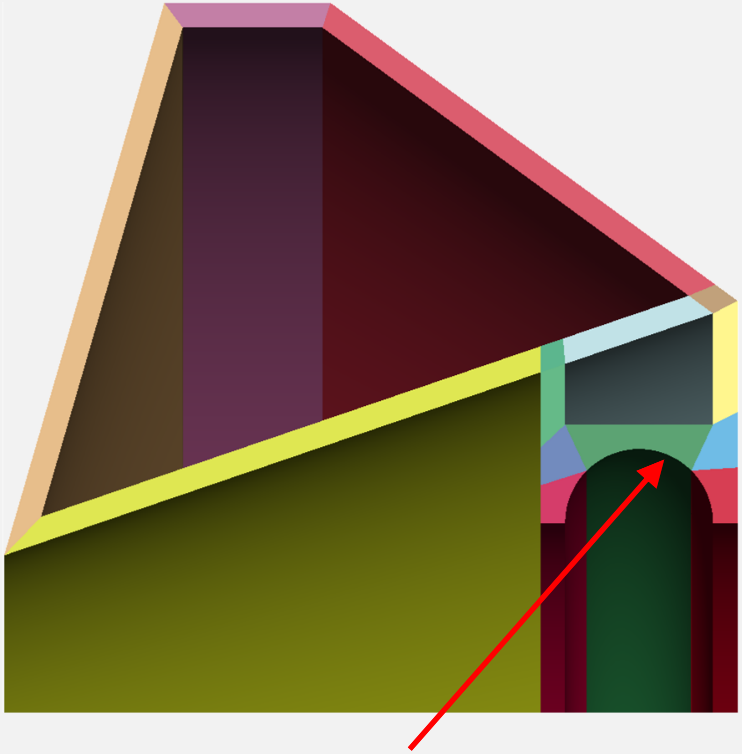
Rotor



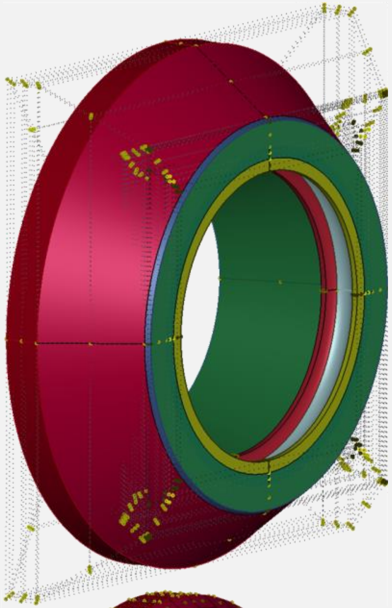


Transformation/reconstruction of geometry into isogeometric model to proof capabilities of developed tool (approx. 50 parts)

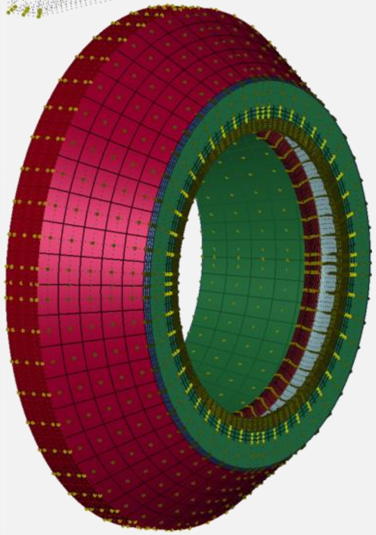
Fan blade housing hub



- Exact representation of outer race of bearing
- 14 NURBS patches



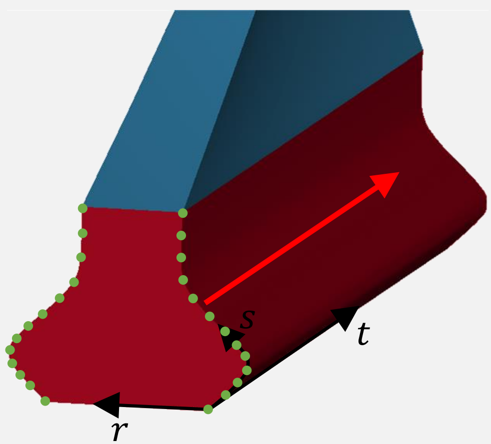
- Coarsest mesh of 2nd-order NURBS elements
- 1134 control points

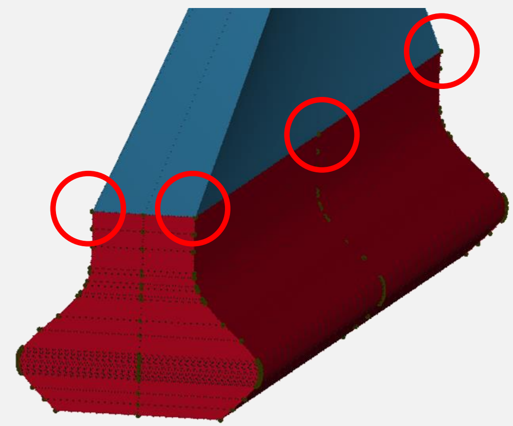


- Refined mesh (just by parameter change)
- Geometry unchanged
- 20280 control points

Fan blade

1. Description of several cross-sections of blade (by 2nd-order B-spline interpolation between given points)
2. Interpolation between cross-sections by 3rd-order B-spline
3. Description of cross-section of fan-blade root by 3rd-order B-splines by interpolation between given points



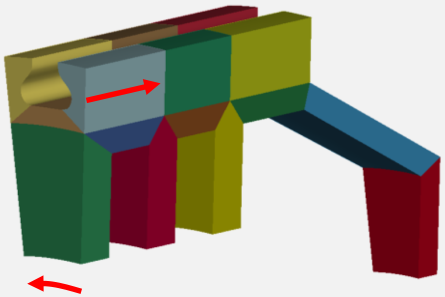


4. Extrusion of blade-root cross section
5. Merging of coincident control-points of blade and blade-root

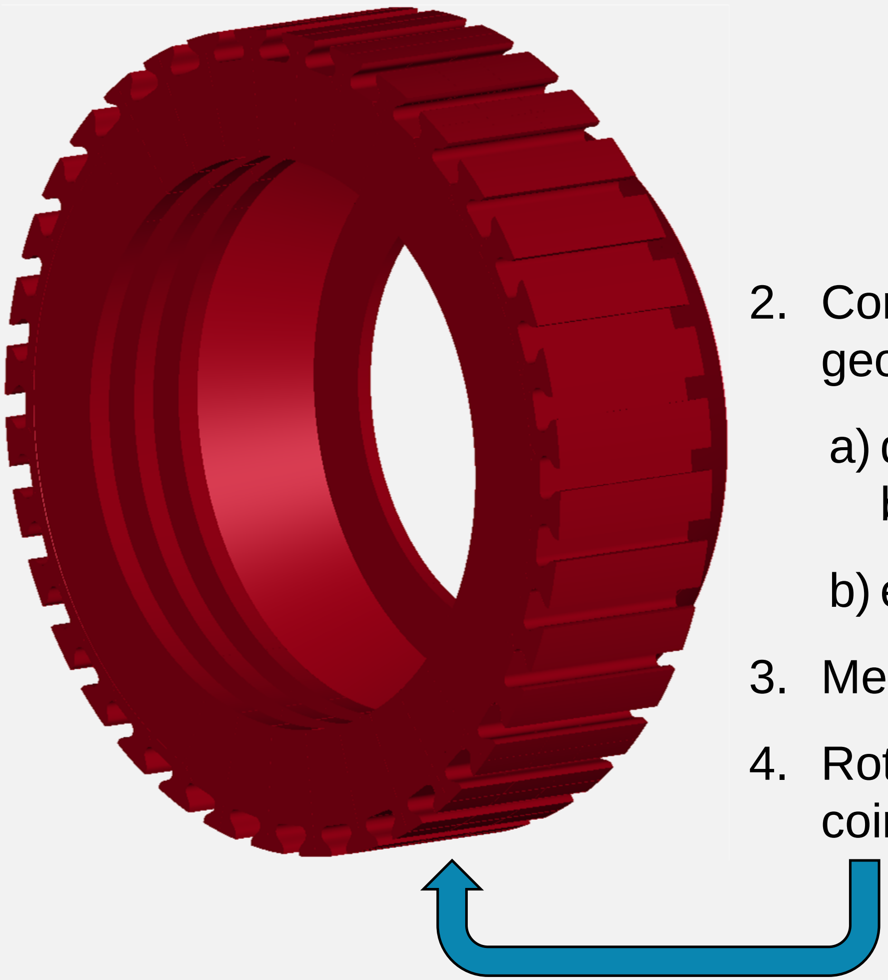
Application, Hints and Examples

Fan disc

1. Definition of NURBS-patch distribution of fan-disc sector

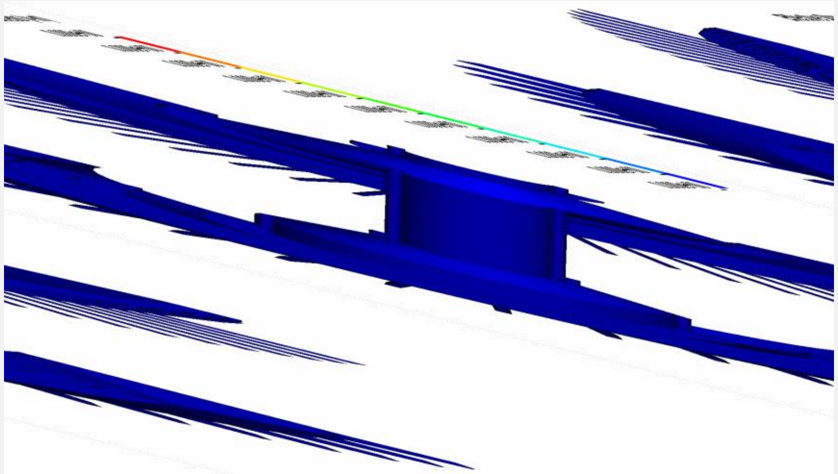


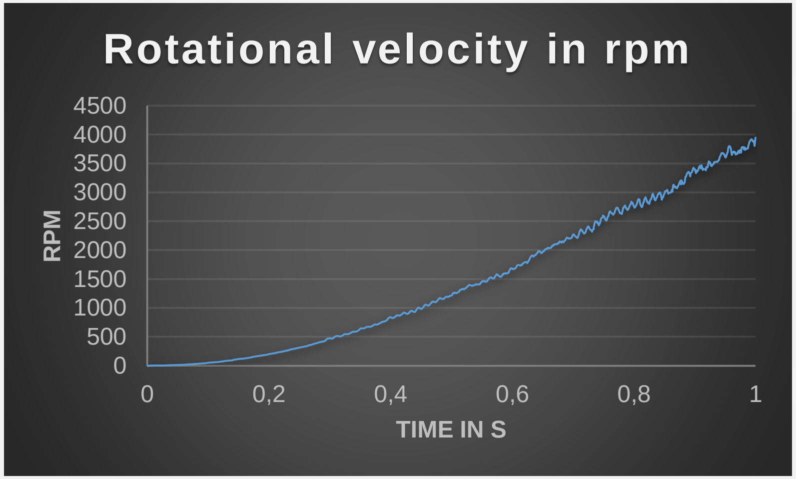
2. Construction of patches with given geometric data by
   a) description of cross section followed by
   b) extrusion or revolution
3. Mesh refinement (if necessary)
4. Rotation of sector model and merging of coincident control points

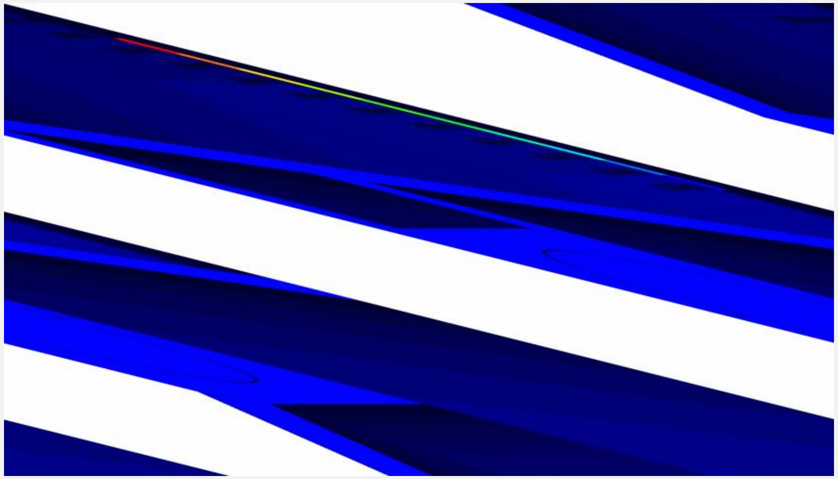


Simulation Results

Dummy Engine model simulations



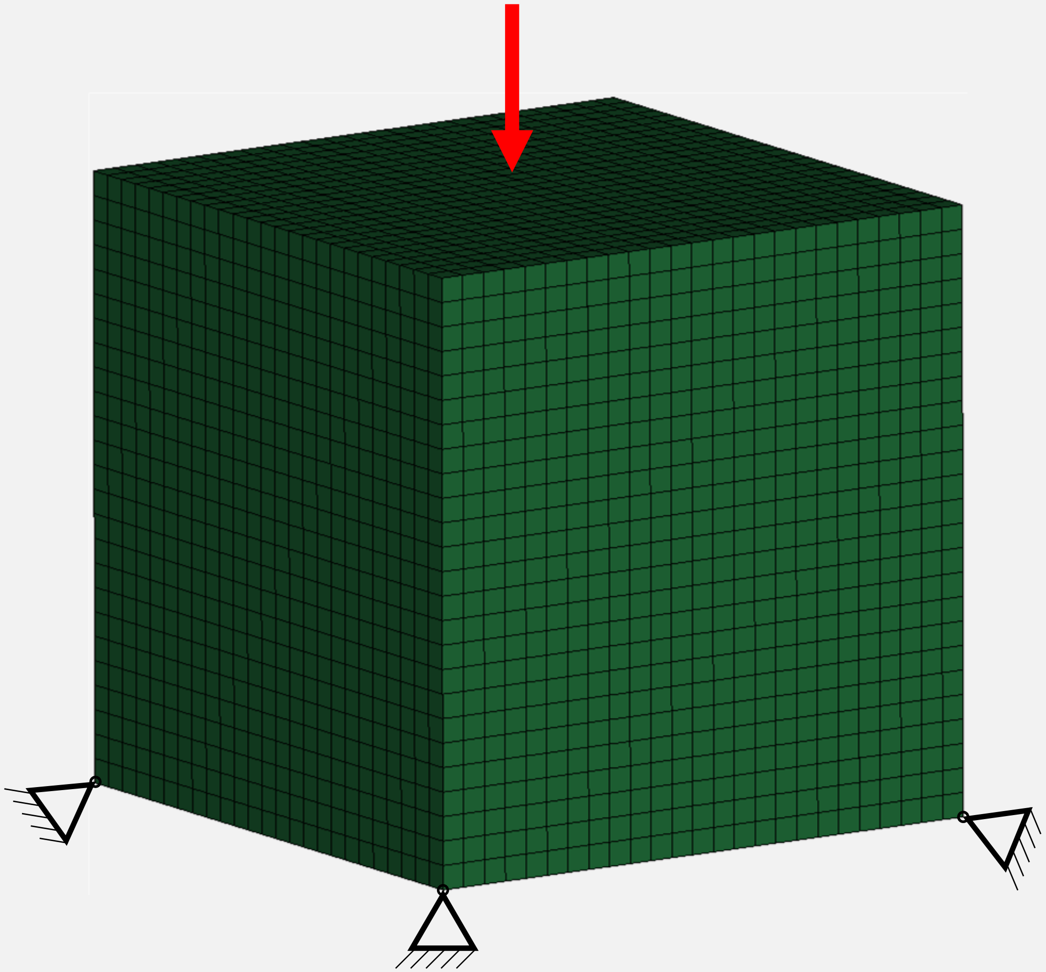




➡ Implicit transient simulation of spinning rotor runs stable and gives plausible results

Computational Time of IGA Models

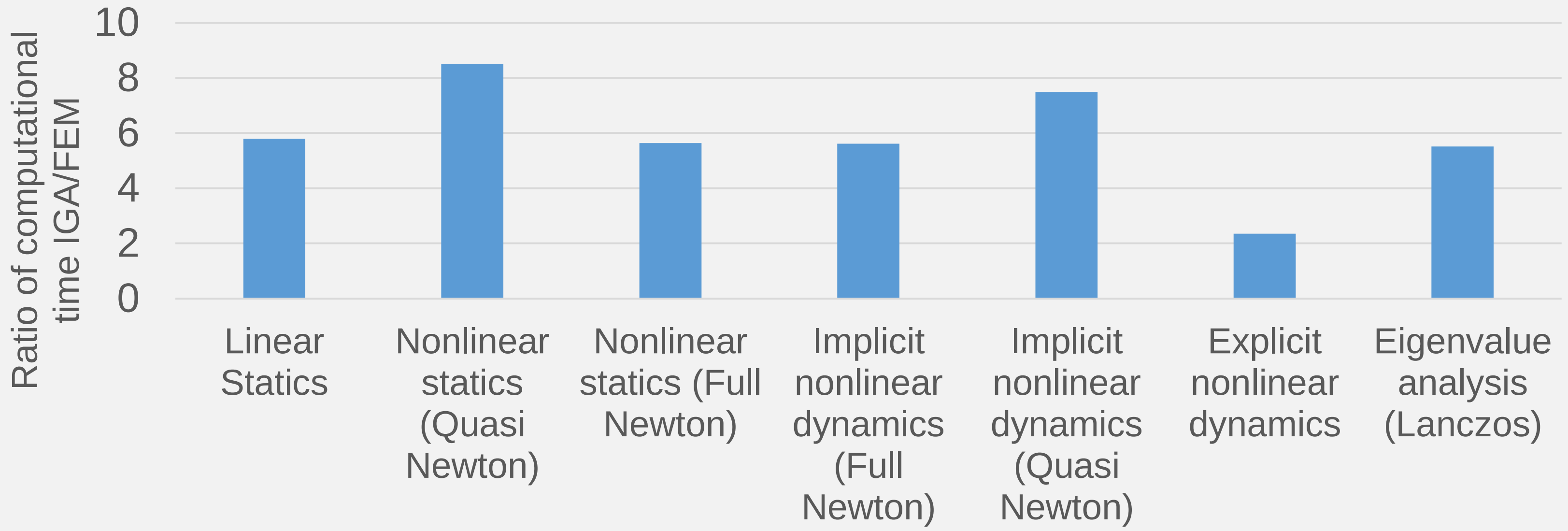
Model for determination of computational time



- 125.000 nodes or control points
- 2nd order classical finite elements or 2nd order NURBS elements

Computational Time of IGA Models

Ratio of computational time between IGA/FEM (per iteration)



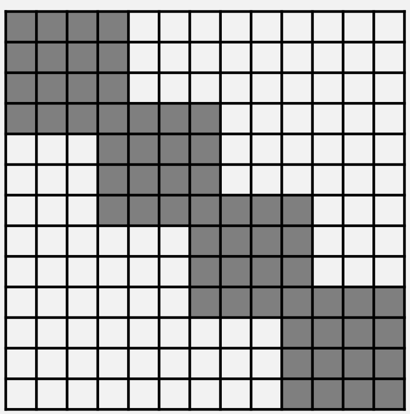
- IGA simulations are slower than classical FEM simulations for the same number of degrees of freedom
- The difference is small in terms of explicit simulations (factor of 2)
- Biggest difference if Quasi-Newton methods are used (factor of 8)
- For linear statics, nonlinear statics and dynamics with Full-Newton method factor of 6 between IGA and FEM

Computational Time of IGA Models

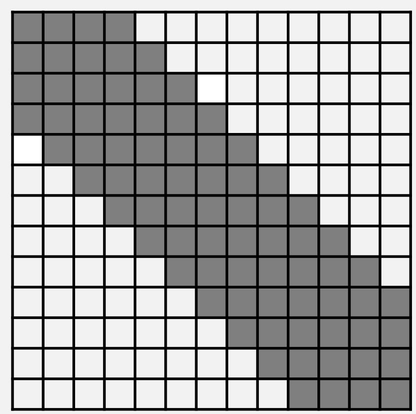
- Results are plausible since in each iteration of a nonlinear static or dynamic problem a linear problem has to be solved (factor of 6 for all analysis types)
- Quasi-Newton approximation of stiffness matrix seems to increase the computational time for the factorization process

Why is the factorization process of an IGA stiffness matrix slower?

- **Maximum bandwidth** of IGA and FEM stiffness matrix is **identical**: 2p+1=7
- But **IGA matrix is denser** due to wider support of IGA basis functions



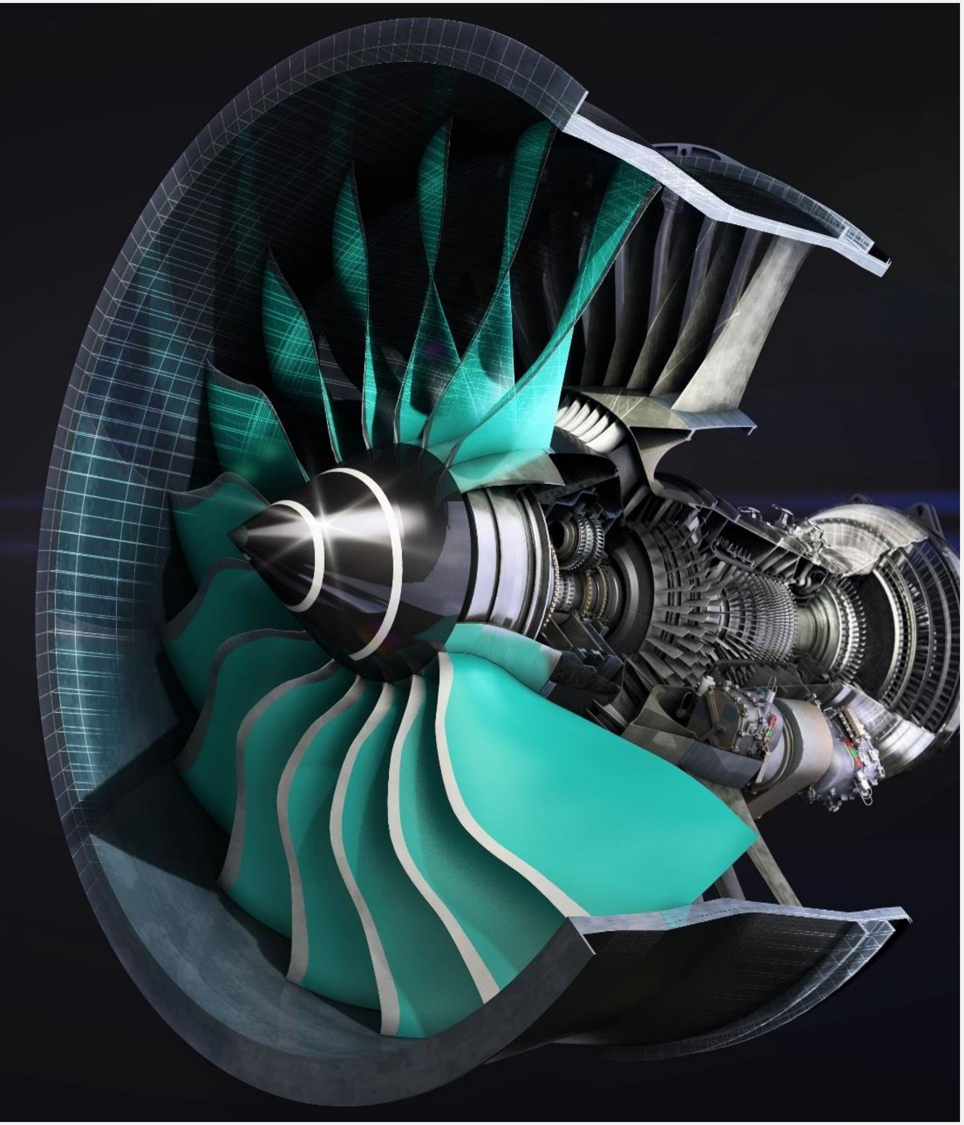
Stiffness matrix of cubic 1D **classical FE** elements



Stiffness matrix of cubic 1D **IGA** elements

Summary

- IGA has the potential of reducing the model creation-time significantly
- Method for simultaneous creation of geometrical and computational IGA models was developed
- Simplified IGA whole-engine model was created and successfully used for implicit transient computations
- Computational time for IGA models is higher than for classical FEM models (if number of DOF is identical)
- Further transient computations with Dummy Engine model are planned



Thank you very much for your attention!

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