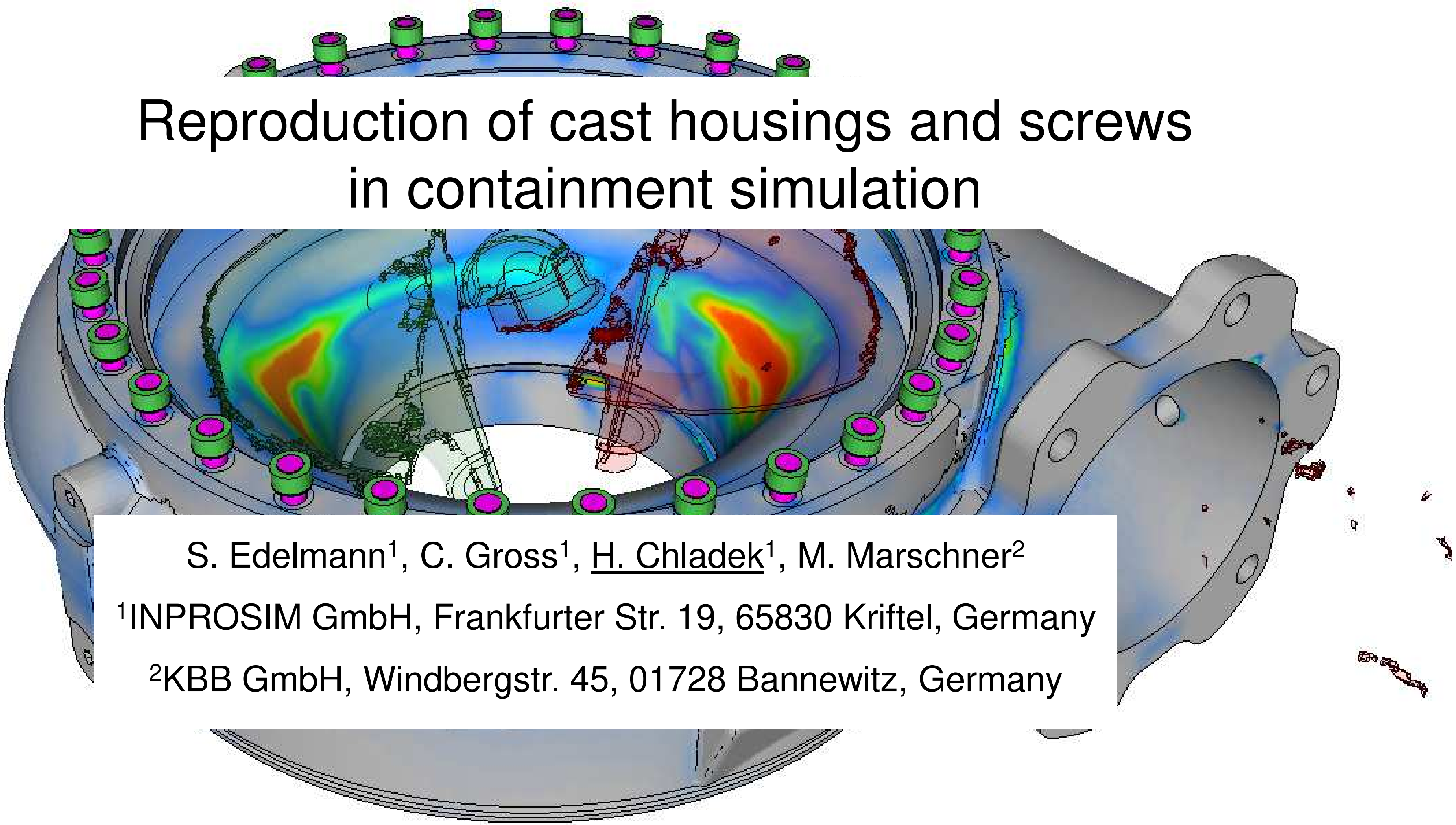
14th German LS-DYNA Forum

October 10 - 12, Bamberg

Innovative Produkt Simulation



Reproduction of cast housings and screws in containment simulation

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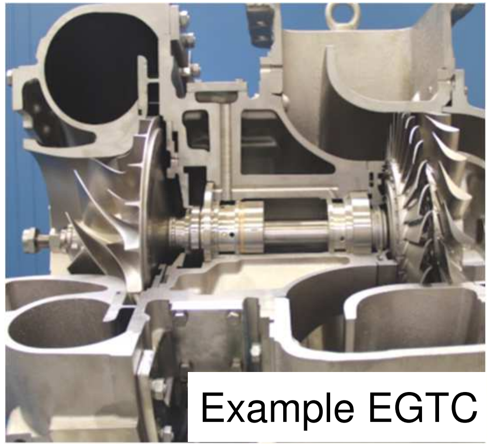
- Introduction
- Geometry Modelling
  - Reproduction of casings and screws
- Material Description
  - Parameters in containment simulation
- Comparison to test
  - Comparison of simulation and test
- Summary
- Appendix

Introduction

- Requirement
  - Supercharging allows to achieve the goals in the motor area, concerning power density, efficiency and environmental protection
  - Requirements in containment safety at the disk burst apply when supercharging by an exhaust gas turbocharger
  - The aim is to protect man and goods
- Implementation
  - Containment safety, formerly verified by tests only, is increasingly examined by simulation in the motor area

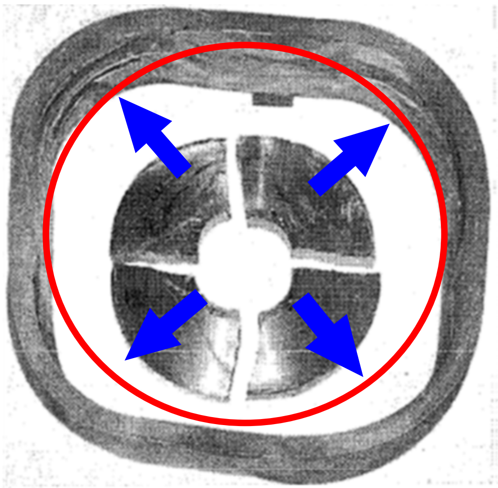


Example EGTC

Example engine damage

Introduction

- Requirement
  - In case of a disk burst the fragments need to be contained, which calls for a balance of
    - high kinetic energy of the disk‘s fragments
    - high containing capacity of the structure (internal energy)
    - interaction of the components within few milliseconds
  - Simulation needs to capture non-linearities in geometry, contacts and materials



- Implementation
  - Certain guidelines in CAE techniques established for a high validity of containment simulation

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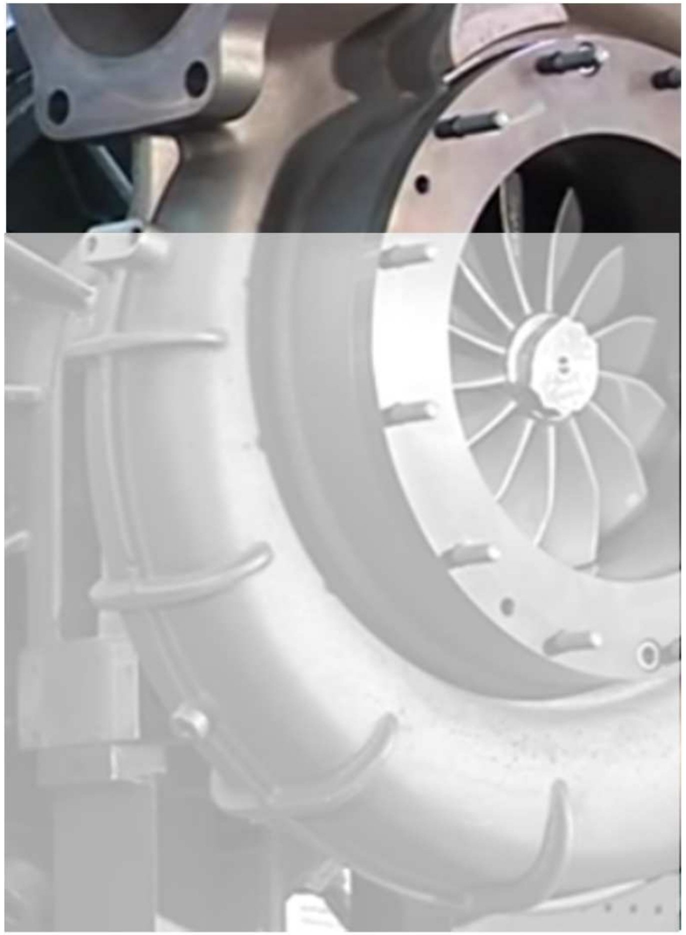
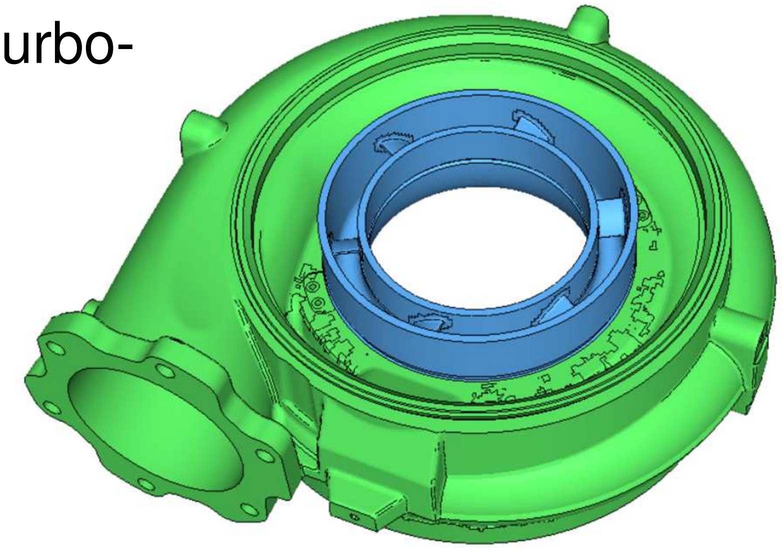


Geometry

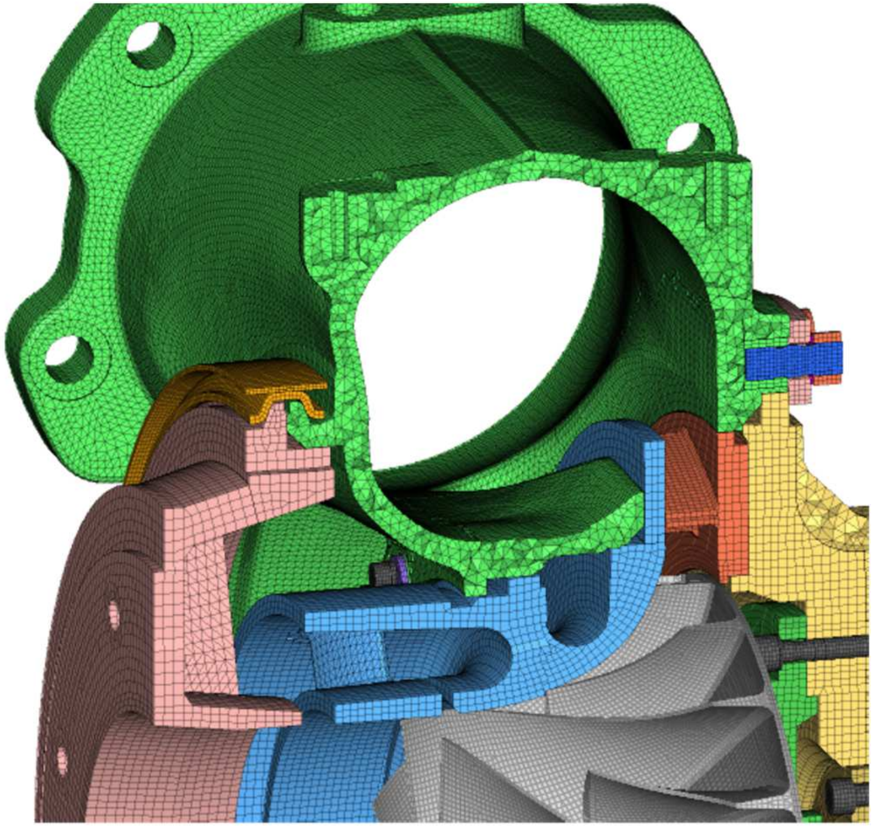
- Requirement
  - Modelling of the geometry follows the turbo-charger‘s design and the burst load
    - Asymmetry and highly complex casing parts with spiral compressor and turbine housings
    - Local load at impact area



- Implementation
  - Meshing in CAE model to appropriately meet design and load
    - Meshing of components and connections accurate to the geometry, i.e. 3D solid meshing using bricks and tetra elements
    - Rotationally symmetric 2.5D meshing in concept studies only

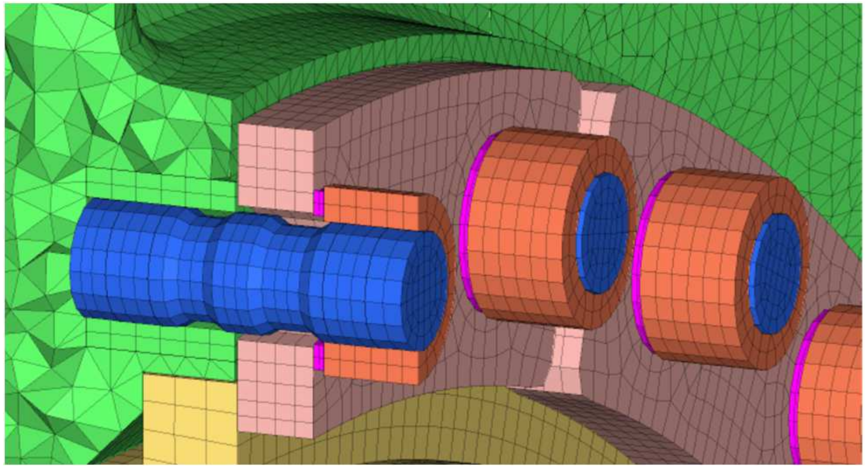
Geometry

- Modelling of casings
  - Accurate to the geometry 3D SOLID meshing is state of the art
    - BRICK meshing in rotationally symmetric areas
    - TETRA meshing in complex areas
  - Meshing rules
    - Minimum of 3, better 5 elements over thickness in relevant areas
    - Higher number of element rows in the penetration area
    - 2 element rows at boreholes
    - Consideration of clearance

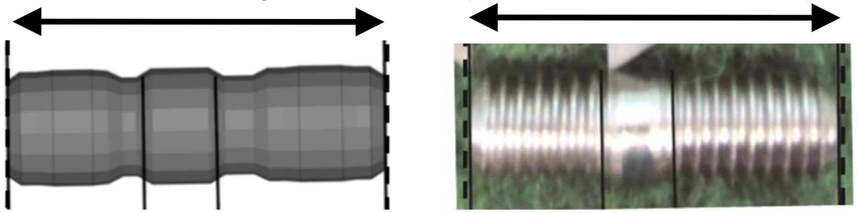


Geometry

- Modelling of screws
  - Accurate to the geometry 3D SOLID meshing is state of the art
    - BRICK meshing of all relevant screws and connections
  - Meshing rules
    - Consideration of thread and screw tensile stress area
    - Reproduction of cross sections of expansion, notch, and joining
    - Minimum of 4, better 6 elements over screw diameter
    - Simplified, circular reproduction of screw heads and nuts
    - TIED connection to structure

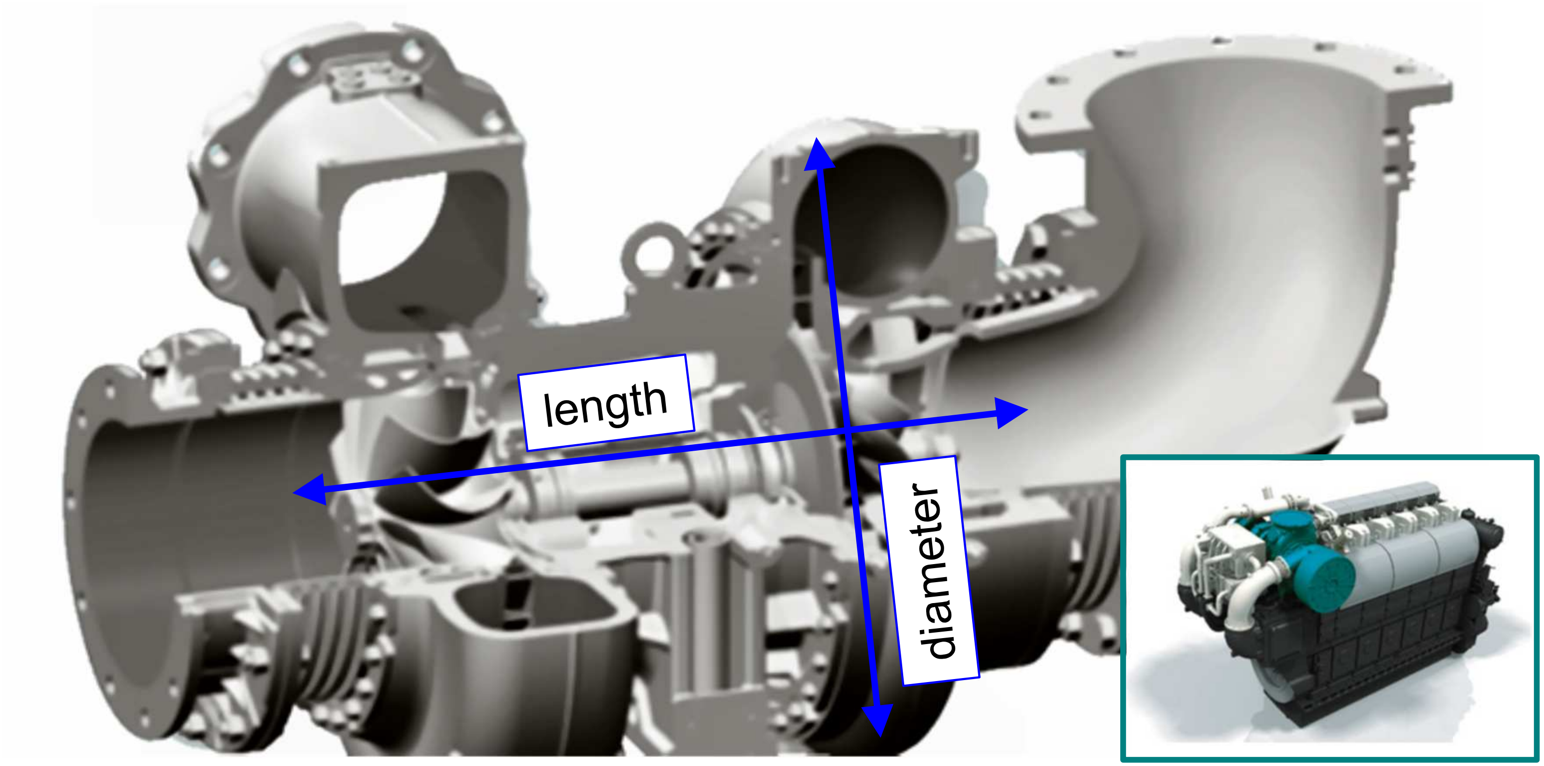


Detail screw reproduction (length, cross section)



Geometry

- CAD basic design
  - Typical design of a modern exhaust gas turbocharger for big diesel, heavy duty and gas engines

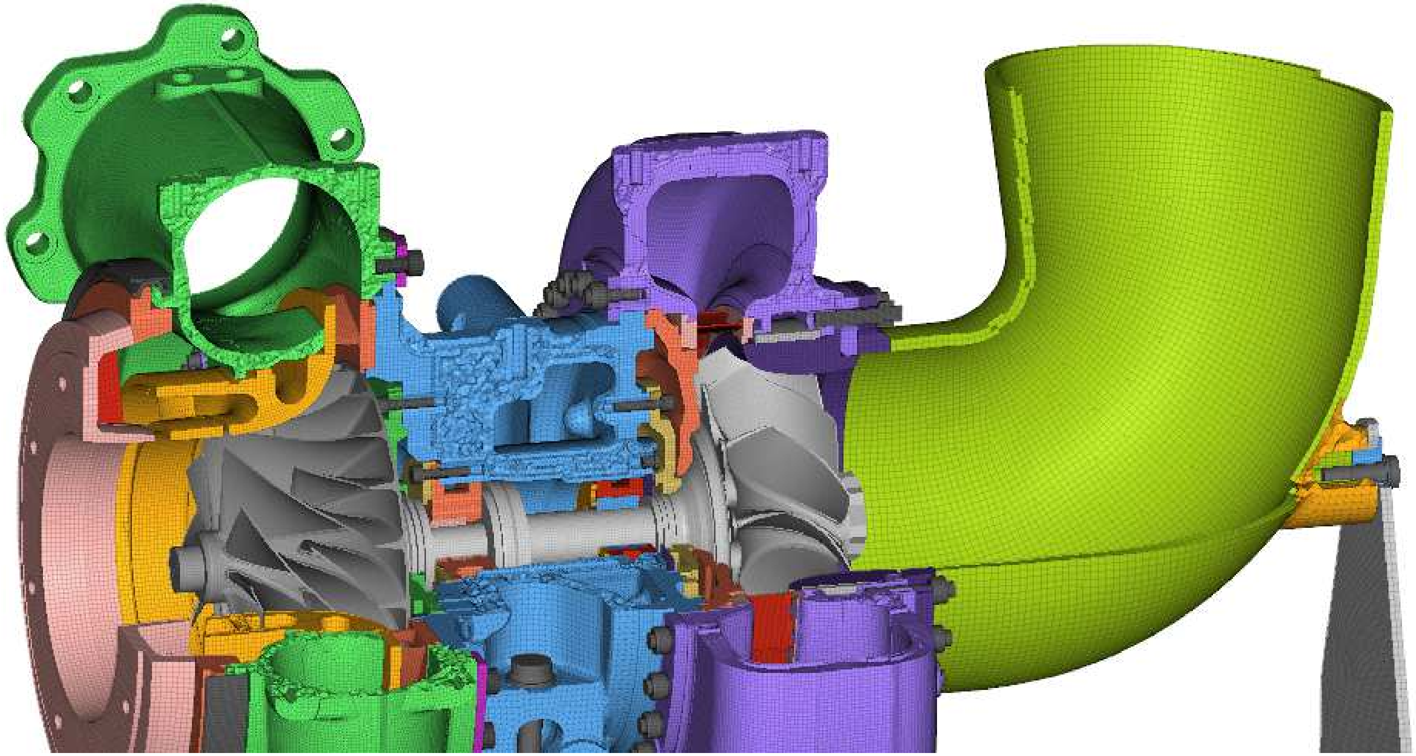


exemplary dimensions

- Length 500-800 mm
- Diameter 500-700 mm
- Weight 300-500 kg
- Example of use on an engine

Geometry

- CAE MASTER Model
  - State of the art, accurate to the geometry CAE Model of the fully assembled turbocharger, comprising rotor, casings and connections



Typical data of CAE model

- 4 - 8 millions of elements
- 3 -7 millions of nodes
- edge length 0,5 - 5mm
- 100 - 200 parts
- 50 -100 materials

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- Geometry Modelling
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- **Material Description**
  - **Parameters in containment simulation**
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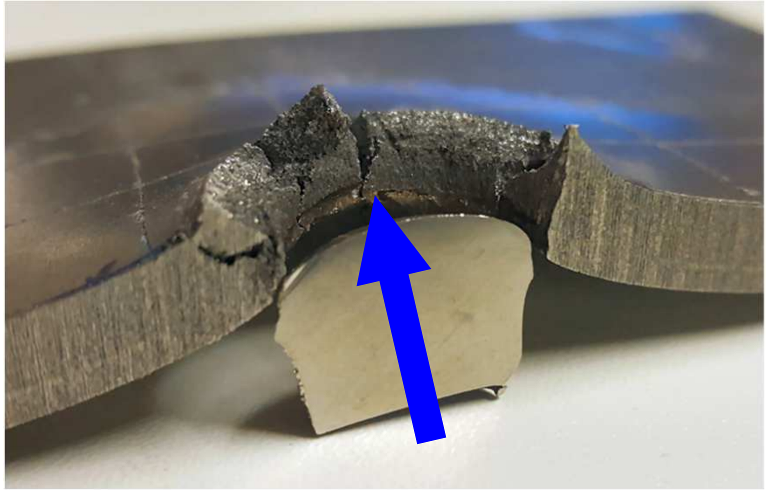
Material description

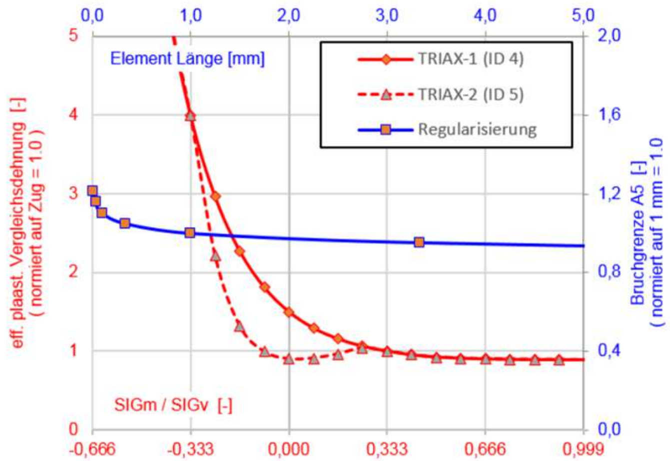
- Requirements
  - Modelling of the dynamic deformation and failure behaviour up to rupture
  - Influence of the part‘s temperature
  - Reproduction of local effects in the meshing of the components



- Implementation
  - Modelling of temperature-dependent yield curves under highly dynamic and multiaxial load up to failure
  - LS-DYNA offers diverse material descriptions for this definitions, for example Johnson-Cook and its derivatives, GISSMO with softening and MAT224 with comprehensive tabulated input

Material description

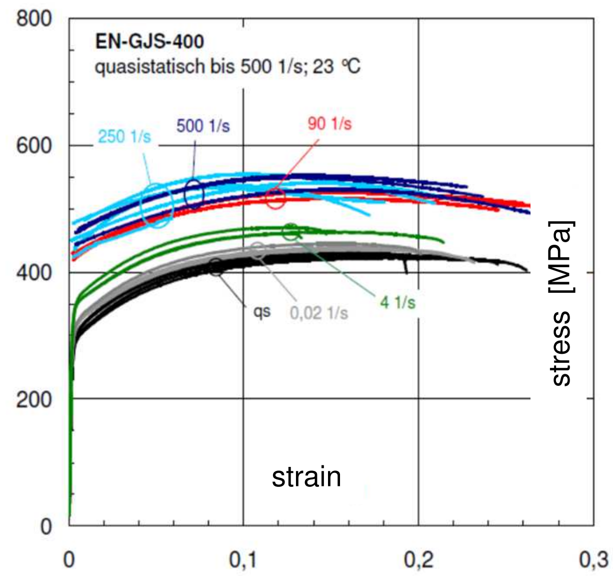
- Modelling as MAT120_JC
  - MAT120_JC (Gurson) with its Johnson-Cook approach has established as one possible material description in recent years
    - Tabulated yield curves and strain rates
    - Effective plastic failure criterion
    - Tabulated entry of element size
    - Stable and fast running behaviour in containment simulation
    - Simple structure, user-friendly



    - Hardening due to pressure captured indirectly by triaxiality only
    - Description for single temperatures, no inner warming
    - Limited applicability for brittle materials

Material description

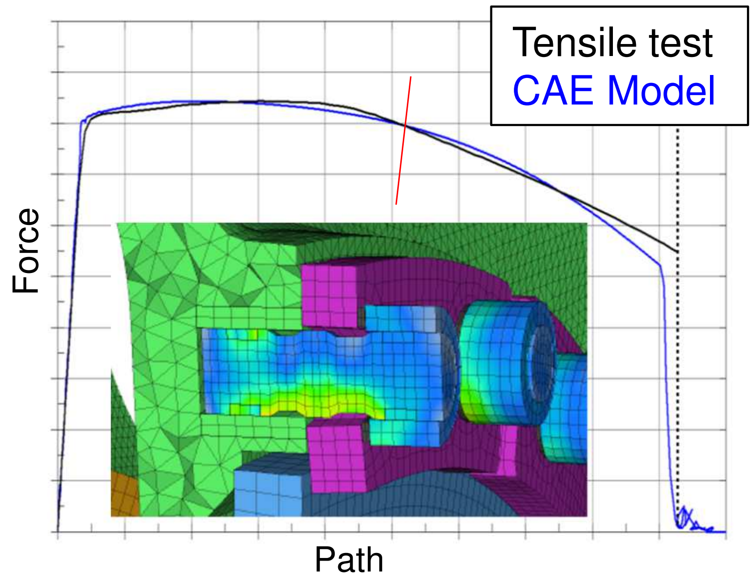
- Example for a housing
  - The yield curve with its supporting points σ_y, σ_u, A_g and A_5 is the basic parameter for the material description
    - Standardisation, literature, research findings
    - Individual specimen test (tension, bending)
    - Overlap of other parameters from tests, and often just from analogy



  - Compressor housing
    - Spheroidal graphite cast iron EN-GJS-400, a material with high strength and ductility
    - Comprehensive data for characterisation available by standardisation and by diverse research documentation (DIN EN 1563, FVV 0936, etc)

Material description

- Example for a screw
  - The yield curve with its supporting points σ_y, σ_u, A_g and A_5 is the basic parameter for the material description
    - Analogue approaches for parameters of data basis as in housing
    - Conservative approach by strength classes 8.8, 10.9, 12.9
  - Screws
    - Recommendation of validation of tensile test and simulation in the run-up for containment relevant screws
    - For diagonal pull over 3 degrees the superimposed bending load is relevant
    - Influence of turbine's high temperature
    - Design limit in utilisation



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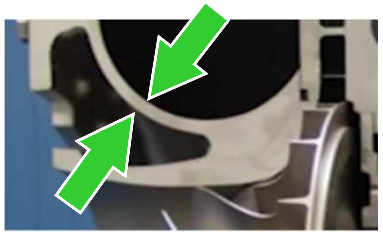
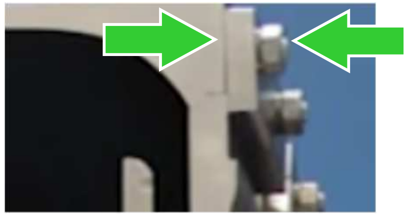
Comparison to test

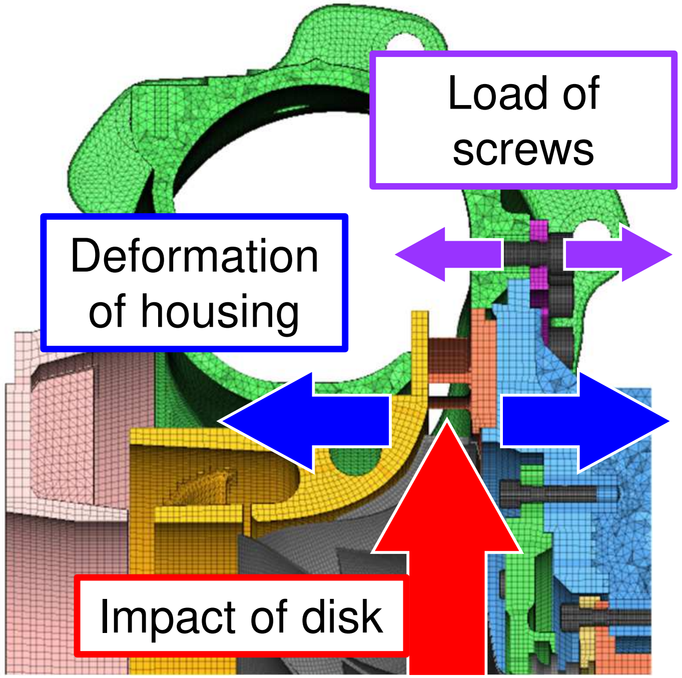
- Requirement
  - In order to meet the producer's responsibility, containment safety must be taken into account in the turbocharger's development
  - Simulation allows for a consideration at an early stage
  - Testing finally confirms the success in design
- Implementation
  - Simulation was used for the technical design of containment safety in the development of a new compressor stage
  - The comparison of simulation forecast to a burst test finally verified the development's success

Comparison to test

- Consideration of containment
  - Containment Safety requires the retention of the fragments within the housings when a rotor disk bursts
  - Producer's responsibility: Protection of men and goods in environs
  - Simulation allows for the analysis and optimisation of the design
  - Design parameters
    - Structural design and wall thickness of relevant housings
    - Connecting elements e.g., number and size of the screws







Comparison to test

InProSim
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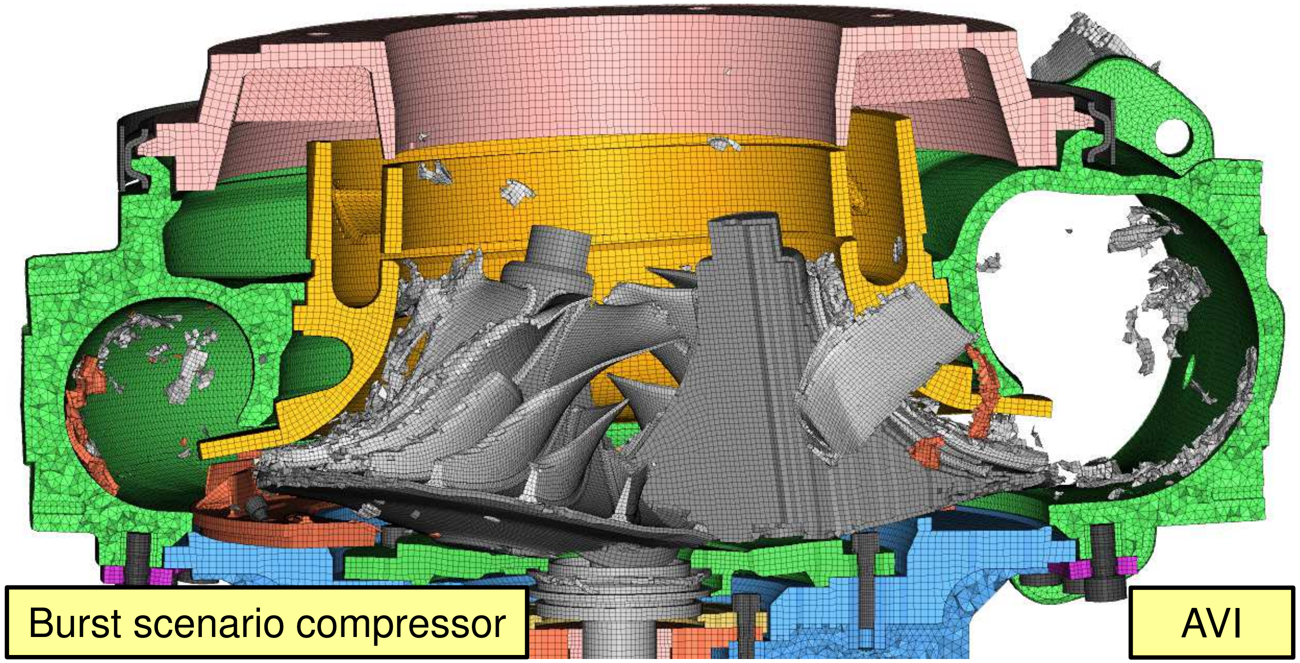
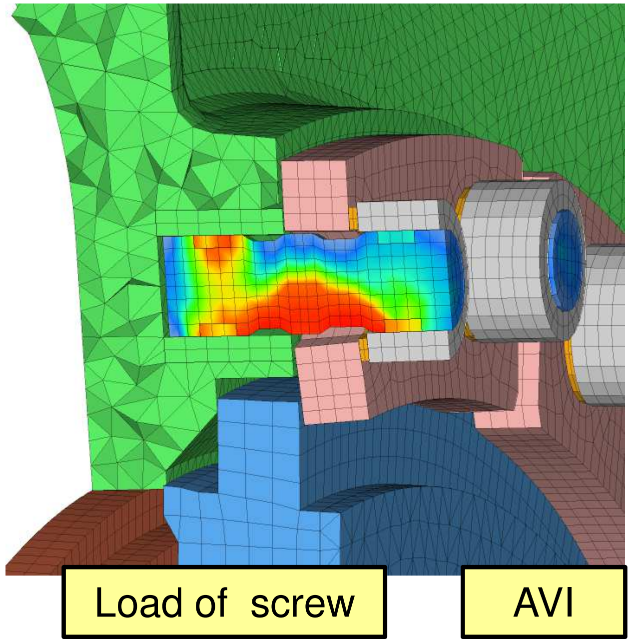
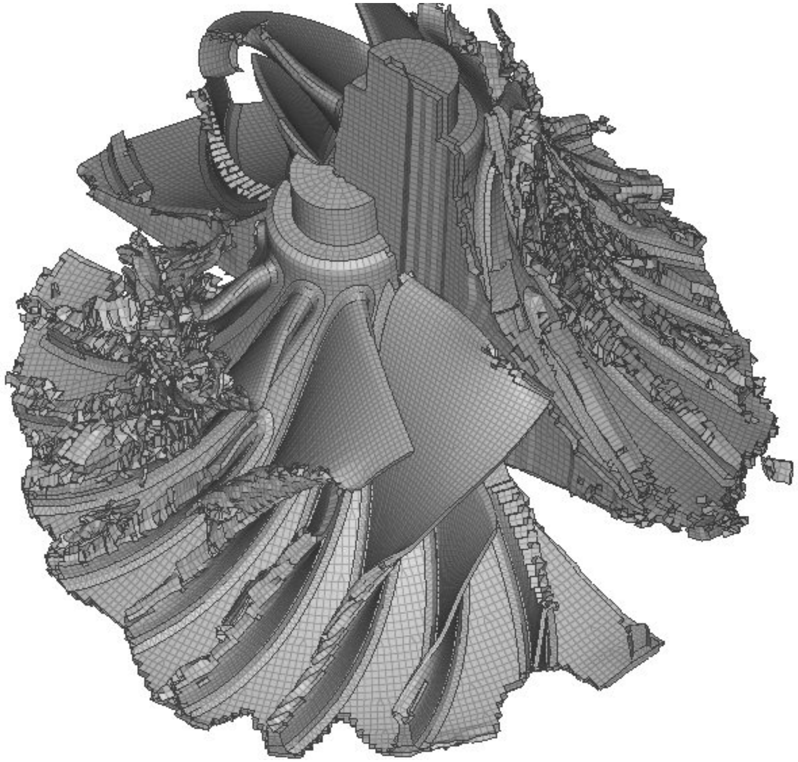
- Comparison of simulation and test
  - To achieve the disk's burst at test speed the disk needs to be prepared, in simulation as well as in test
    - No CAE tuning was carried out in simulation for comparison to test





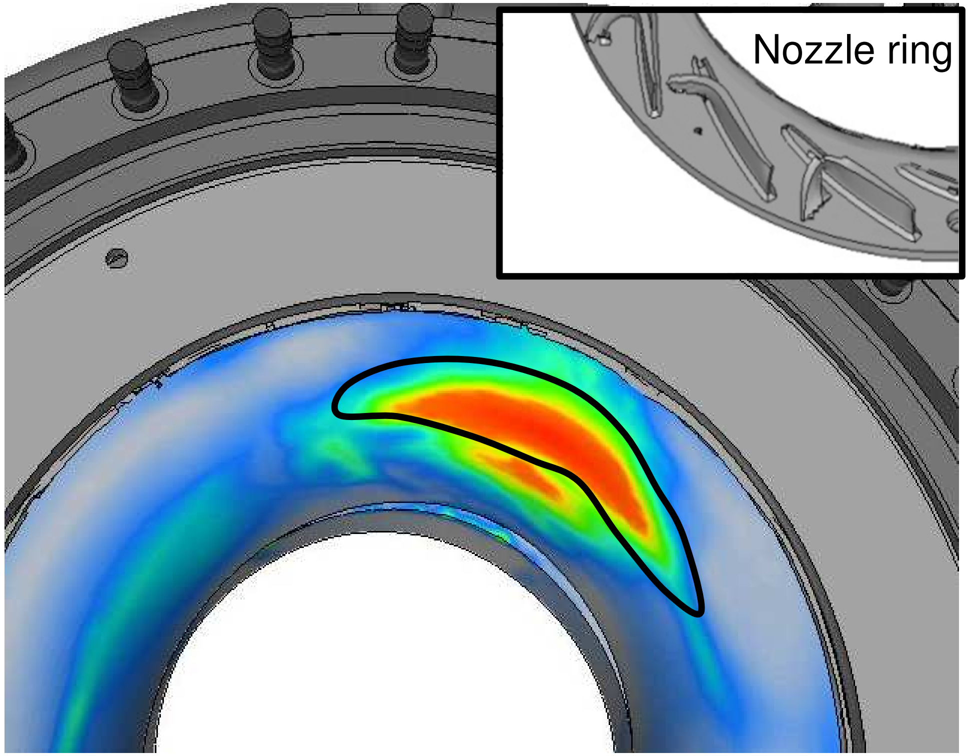
Comparison to test

- Comparison of simulation and test
  - Damage result of a 2-hub-burst of the compressor disk
    - Deformation of the disk up to rupture of the blades structure



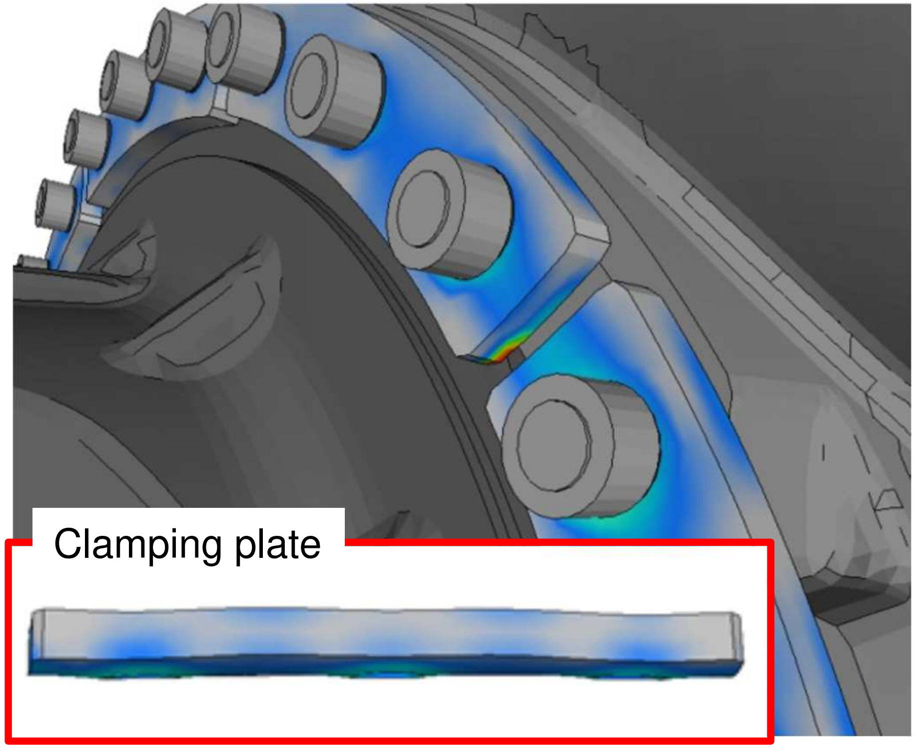
Comparison to test

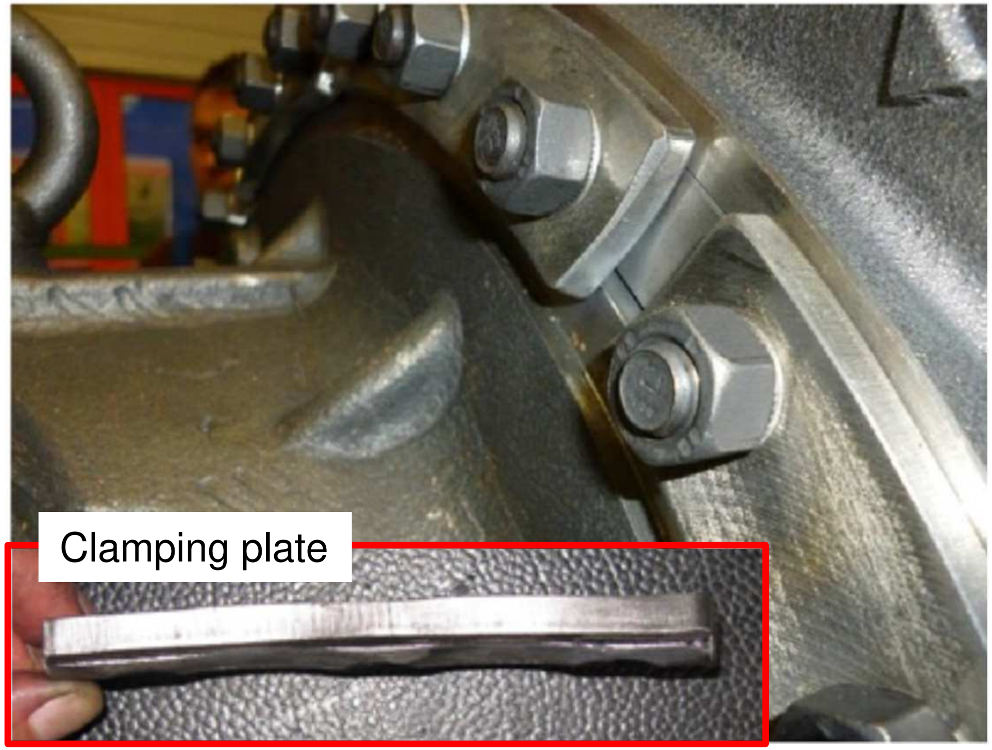
- Comparison of simulation and test
  - Local deformation at impact area in compressor casing insert
    - Plastic deformation close to rupture in the cast housing



Comparison to test

- Comparison of simulation and test
  - Highly loaded clamp connection of compressor and bearing casing
    - Local deformation of the screws and the connection plates



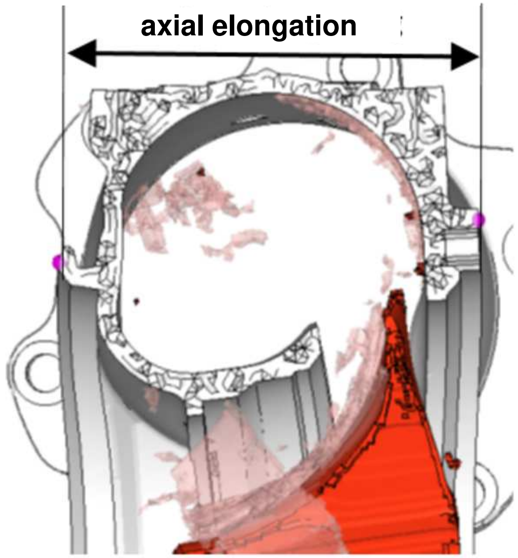


Comparison to test

- Comparison of simulation and test
  - Axial elongation of compressor stage after burst test
    - Necessity of reproduction of the 3D circumferential geometry

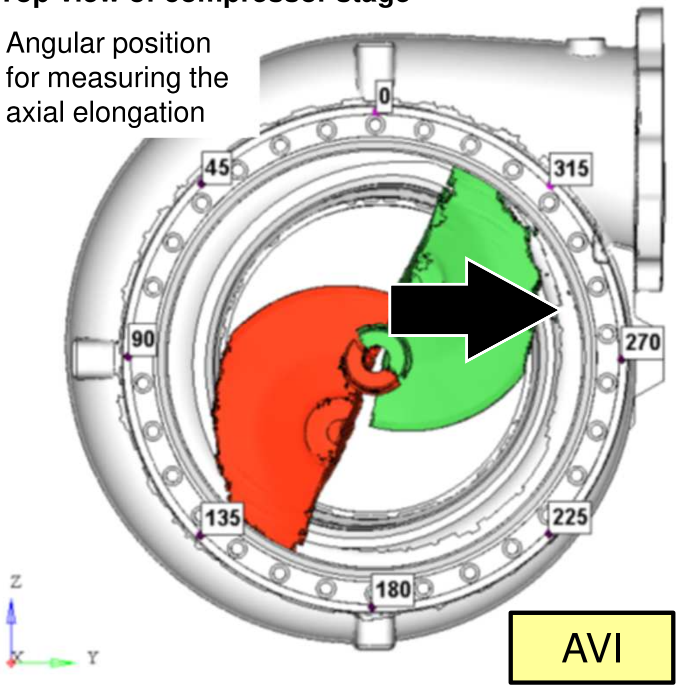
Cut of compressor stage

Displays housing and disk only
-> axial elongation

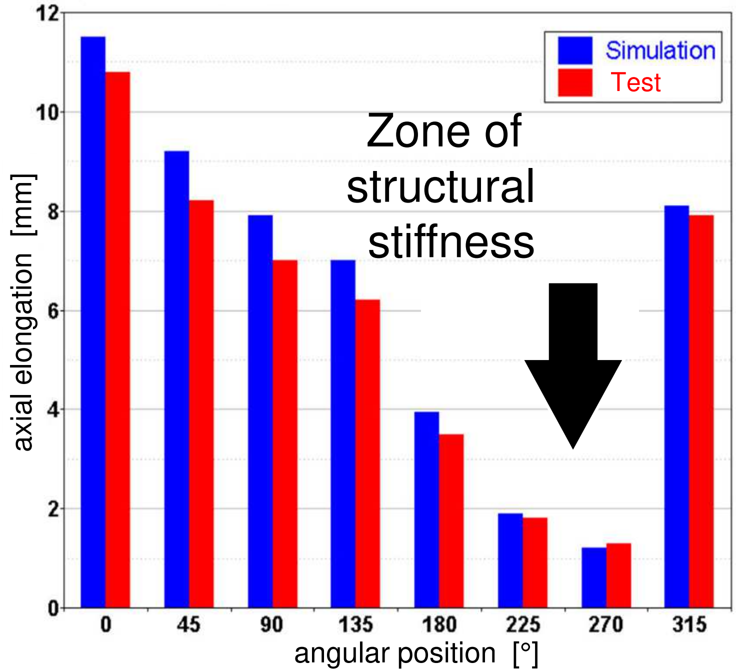


Top view of compressor stage

Angular position
for measuring the
axial elongation



Comparison of simulation and test



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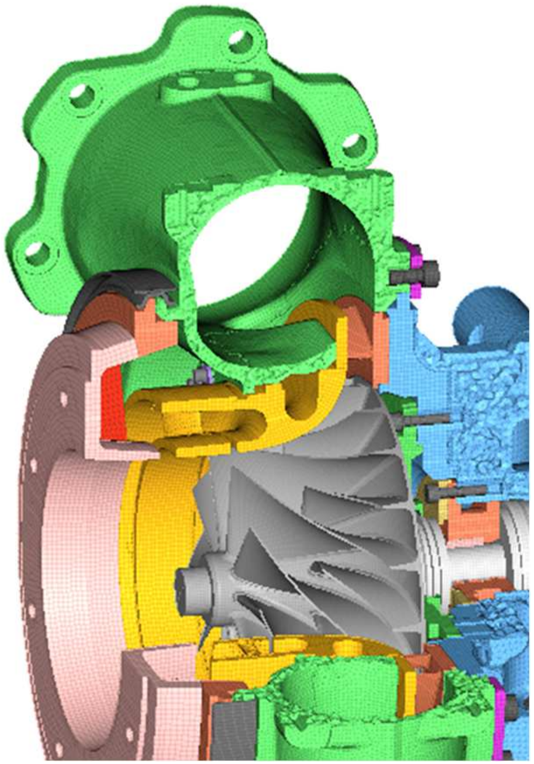
Summary

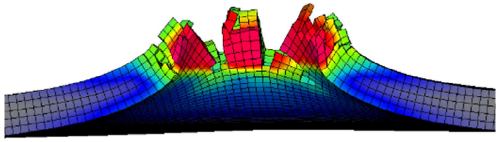
- Requirement
  - An efficient development of turbochargers requires a high validity simulation concerning the safety requested
- Implementation
  - Certain CAE techniques established as state of the art
    - Accurate to the geometry, 3D SOLID reproduction with high element density for all relevant parts
    - Deformation and failure behaviour considering dynamic hardening, triaxiality, regularisation
    - Validation of containment-relevant screws by screw-tension-test till failure

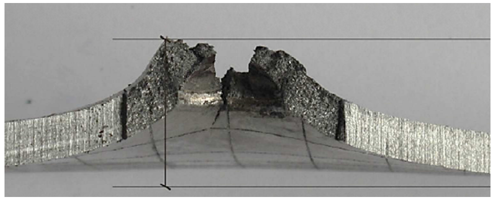


Summary

- Outlook
  - Containment simulation with its current CAE techniques is state of the art in the development of turbochargers
  - The comparison of simulation and tests confirms the evaluation's validity concerning safety-related components
  - Simulation allows for the approval of single turbochargers within a product family

  - Ongoing development of CAE techniques in damage description up to failure
  - Long-term aim is the approval of a turbocharger by containment simulation solely





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- Acknowledgements
  - Forschungsvereinigung Verbrennungskraftmaschinen (FVV) e.V.
    - Many thanks for realizing research project FVV 0936 „Containment Safety“, examining turbochargers’ cast materials and the influence of strain rates, temperature, and multiaxiality
    - Many thanks to the federal ministry of economics and technology as well as to the participating companies, who provided materials and funds
    - www.fvv-net.de
  - Kompressorenbau Bannewitz (KBB) GmbH
    - Many thanks for supporting us by providing test results in a compressor stage’s development. This enabled us to examine carefully and in detail the CAE techniques we developed concerning their validity and to verify the quality of the state-of-the-art approaches
    - www.kbb-turbo.de

Appendix

- List of references / literature

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Appendix

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Anhang

Innovative Produkt Simulation

- List of references / literature

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