Hydrodynamic Bearing Analysis of a Planetary Gear in a Geared Turbofan

Date: 28 – 30 June 2011

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Project leader: Dr.-Ing. Volker Rombach
Assistant: Dipl.-Ing. Sebastian Popel

Outline

- Introduction
  - Motivation / Geared turbofan concept
  - Specifications / Problems
- Approach
  - Reliability / Dimensioning tools
  - Modeling technique
- Results
- Summary and Conclusion

Aeronautical research program

Project goals:

- Reduced fuel consumption
- Reduced pollutant emission
- Reduced noise

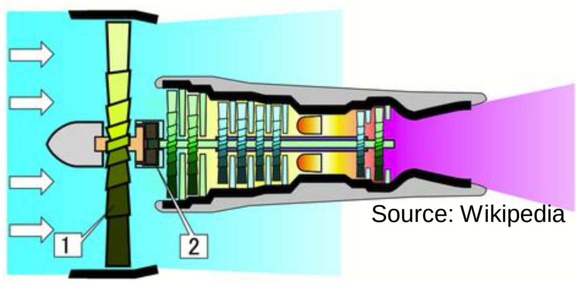
Strategy:

- Developing an efficiency-improved **geared turbofan**

Geared turbofan

Characteristics*:

- The fan is driven through a reduction gearbox **2**
- No direct connection to the rest of the engine
- It allows the turbine and fan shaft operating in an optimal range of speed



Source: Wikipedia

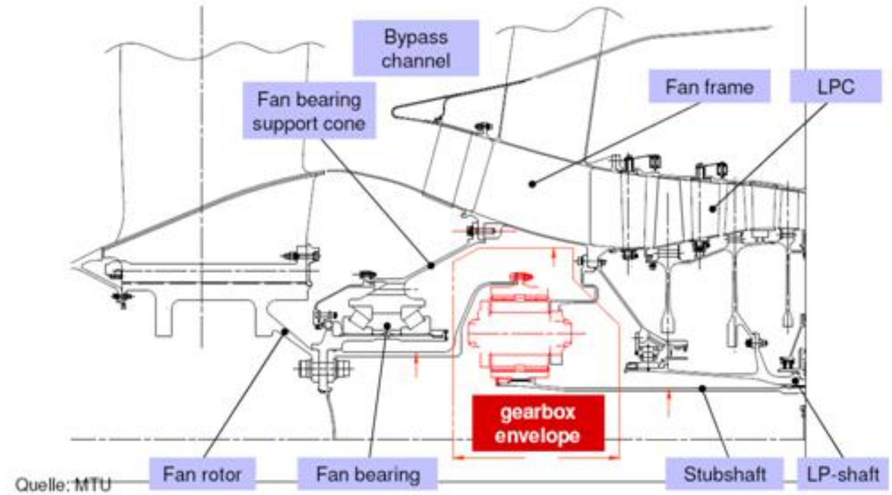
Task for the Institute of Machine Elements and Machine Design:

➢ The hydrodynamic journal bearings, on which the planetary wheels are mounted, have to be designed

* C. Riegler, C. Bichlmaier, THE GEARED TURBOFAN TECHNOLOGY

Some specifications:

- Mounting of the gear wheels on hydrodynamic bearings
- Planetary Gear with a fixed carrier
- Rotational speed up to ~10.000 rpm



Project goals:

- Verification of operation
- Displacement of planetary gearwheel for high tooth accuracy
- Optimum of bearing dimensioning regarding reliability and efficiency

Problems:

- **High Load** at **high circumferential speed** and **high temperature**
- Elastic deformation of the surrounding structure
- Little know-how for dimensioning at these conditions available

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Reliability of bearing design:

- Durability of the bearing material ↔ Pressure Distribution
- Temperature safety ↔ Temperature Distribution
- Protection against wear ↔ Minimum oil film thickness

Dimensioning tools:

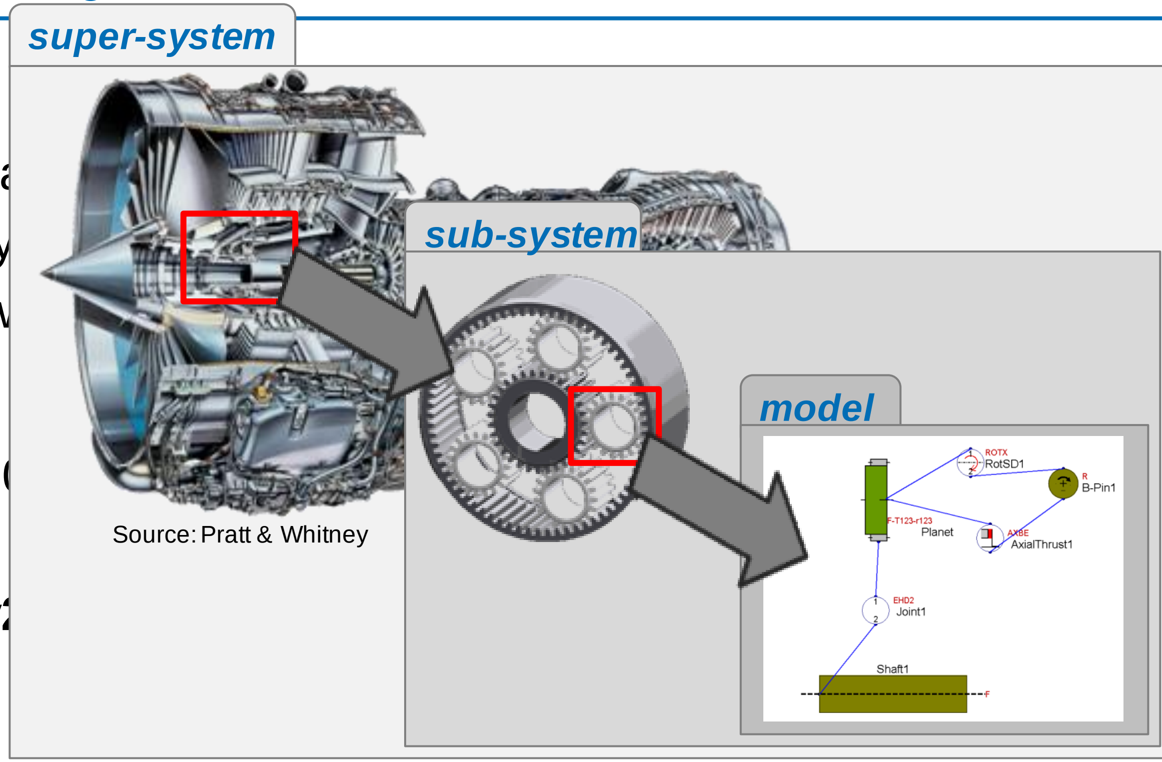
- DIN 31652, VDI 2204
- ALP3T

} **No elastic deformation considered!**

- **AVL EXCITE PU v2010**

Approach

Reliability / Dimensioning tools



Source: Pratt & Whitney

Reliability of bearing

- Durability of the bea
- Temperature safety
- Protection against w

Dimensioning tools:

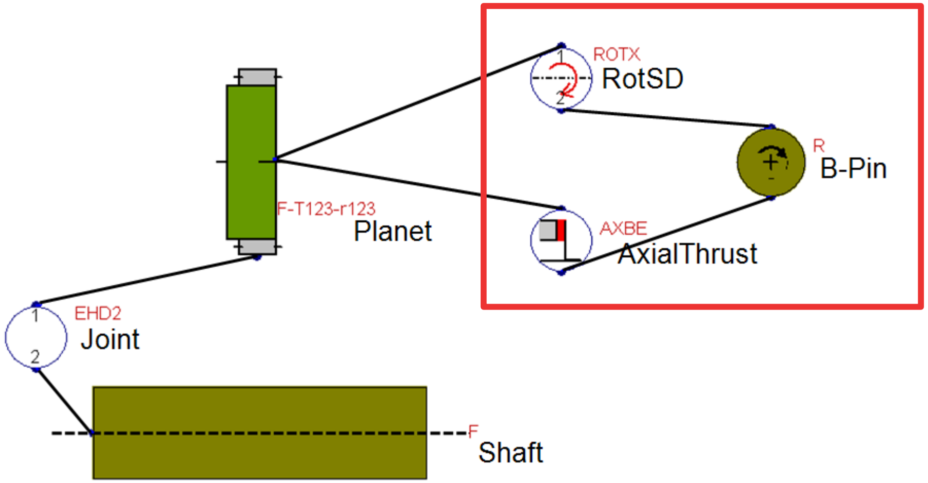
- DIN 31652, VDI 22
- ALP3T
- ➢ **AVL EXCITE PU v2**

Stepwise approach:

- Basic analyses of the journal bearing extracted from the surrounding structure
  - Verification of functioning under optimal conditions
  - Short calculating time
  - Rigid bodies ↔ flexible bodies
  - Central force application ↔ force application at teeth
- Enlargement of the system with ambient structure

Elements:

- B-Pin, ROTX, AXBE
- Planetary wheel
- Wheel shaft
- ElastoHydroDynamic bearing



- Constant rotation is given by B-Pin with rotational (ROTX) joint to planetary wheel
- Additional axial (AXBE) joint adjust numerical inaccuracies

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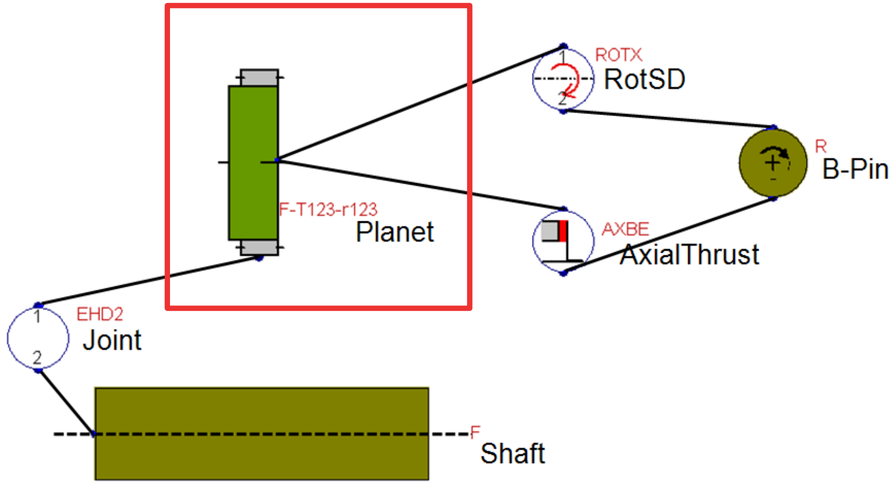
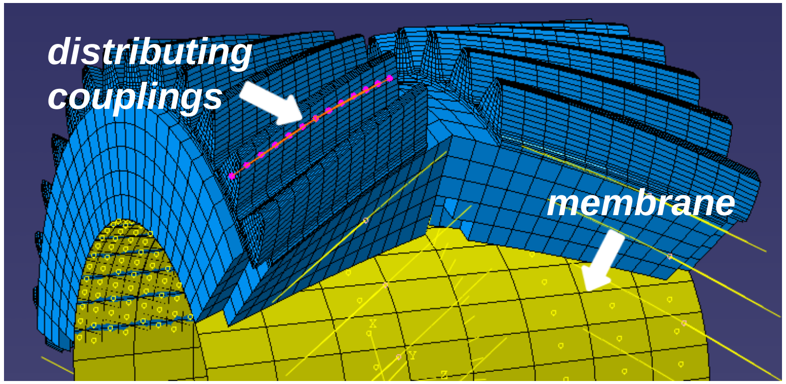


- Gearwheel with linear hexahedra (C3D8I) and 9x36 Nodes Membrane (M3D4) in the inner contour
- Gear forces are applied to reference points in the middle of the tooth with distributed couplings across tooth width



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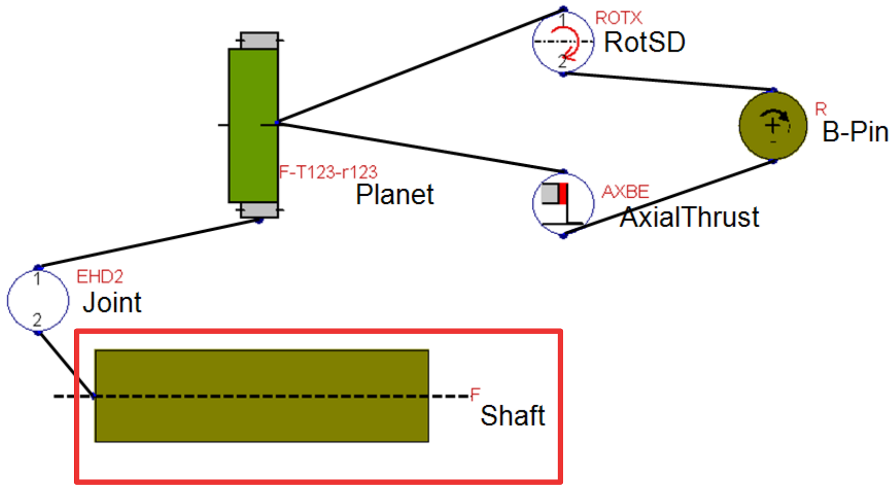
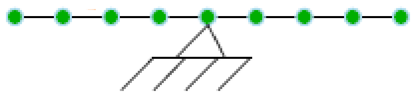


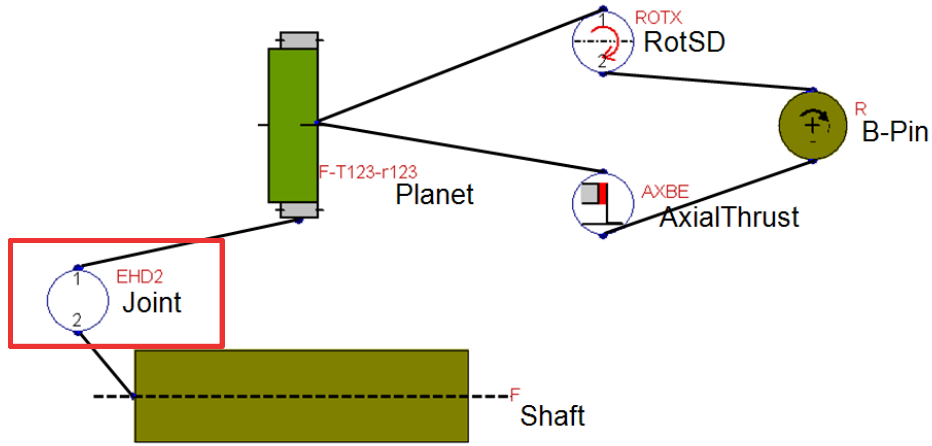
- Shaft is modeled – due to the complex geometry – with linear tetrahedra (C3D4) and a bush with linear hexahedra (C3D8I), tied on the inner structure
- Shaft is restraint at on central node



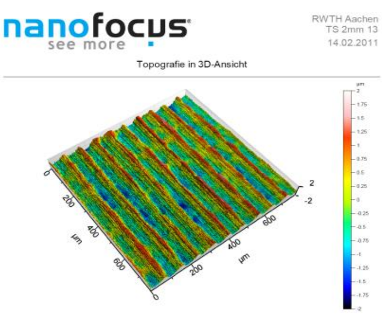
- Combined static dynamic reduction decrease number of degree of freedom (DOF) from 2,000,000 to 700
- 10 Eigenmodes show an appropriate accuracy

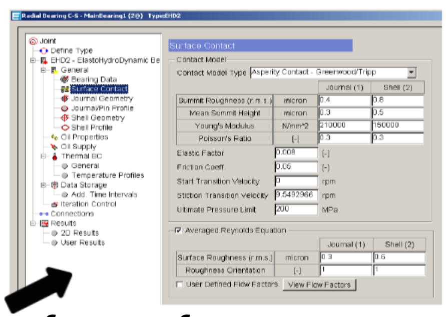
Elements:

- B-Pin, ROTX, AXBE
- Planetary wheel
- Wheel shaft
- ElastoHydroDynamic bearing

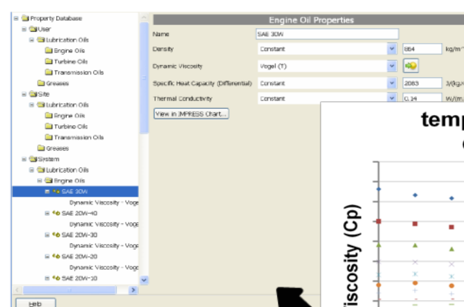


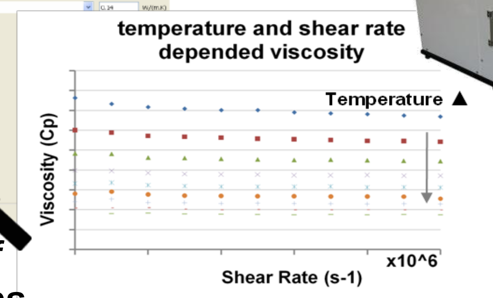
- Planetary wheel and shaft are coupled via EHD2 joint
  - Definition of surface profile and viscosity of the used oil





factors for AVERAGED REYNOLDS EQUATION





definition of oil properties

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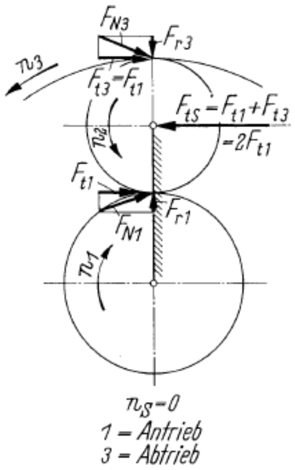
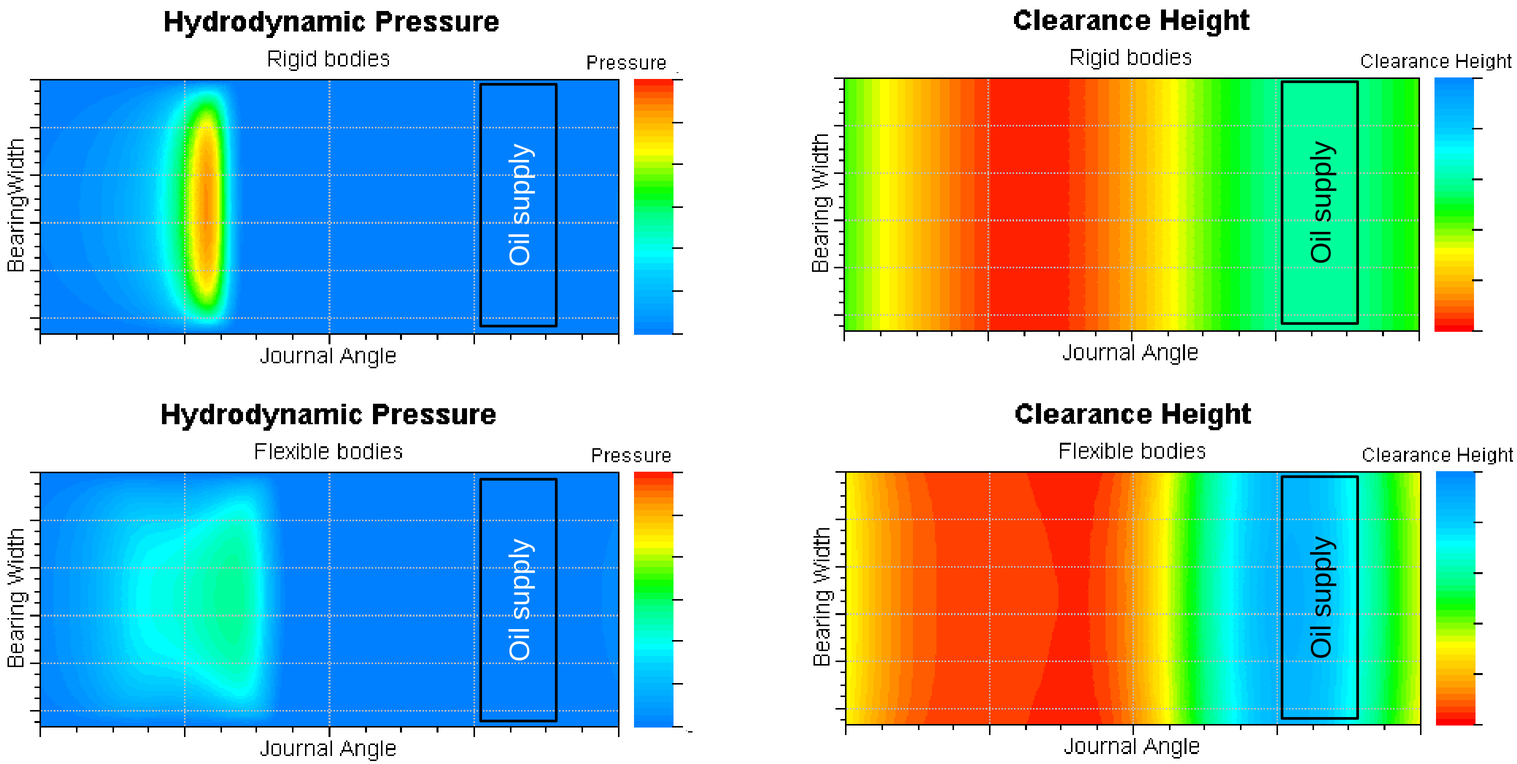


Source: Haberhauer

Force application in center of planetary wheel:

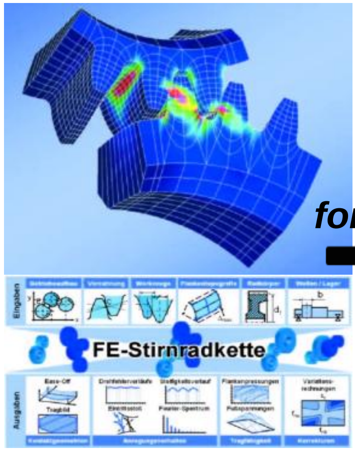
- Rigid bodies vs. flexible bodies



- Results of rigid bodies match the results of ALP3T
- Enlargement of pressure area and decrease of pressure maxima with flexible bodies

Approach

Central force application ↔ force application on teeth

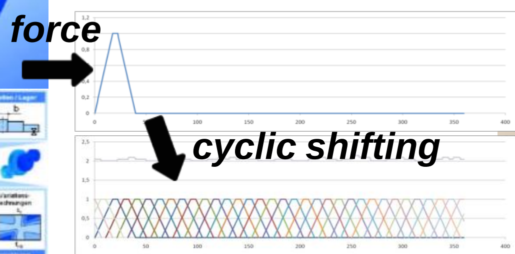


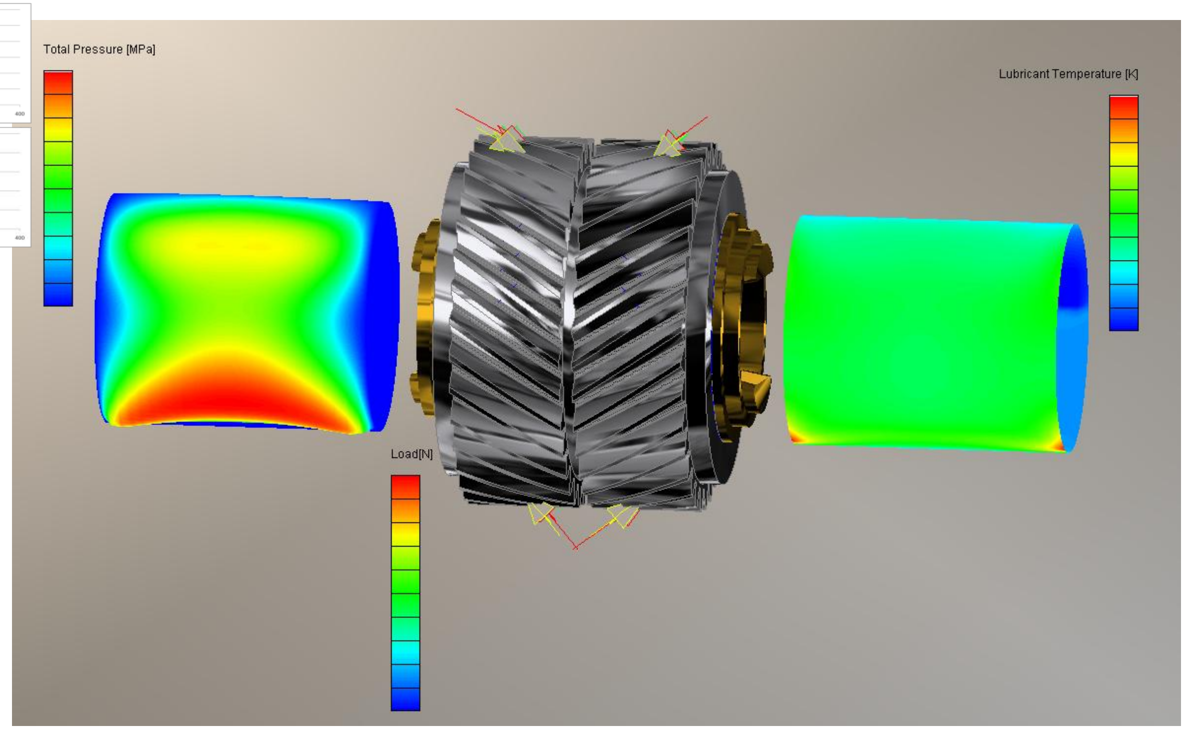
Source: WZL

- Meshing forces out of FE-Stirnradkette (STIRAK)
- Application on Tooth-center
- No axial forces due to double helical gearwheel

Flexible bodies:

- Central force application vs. force application on tooth-center





- ➢ Toothing forces lead to an elastic ovalisation of the planetary wheel
- ➢ Pressure build-up is disturbed by a diverging gap

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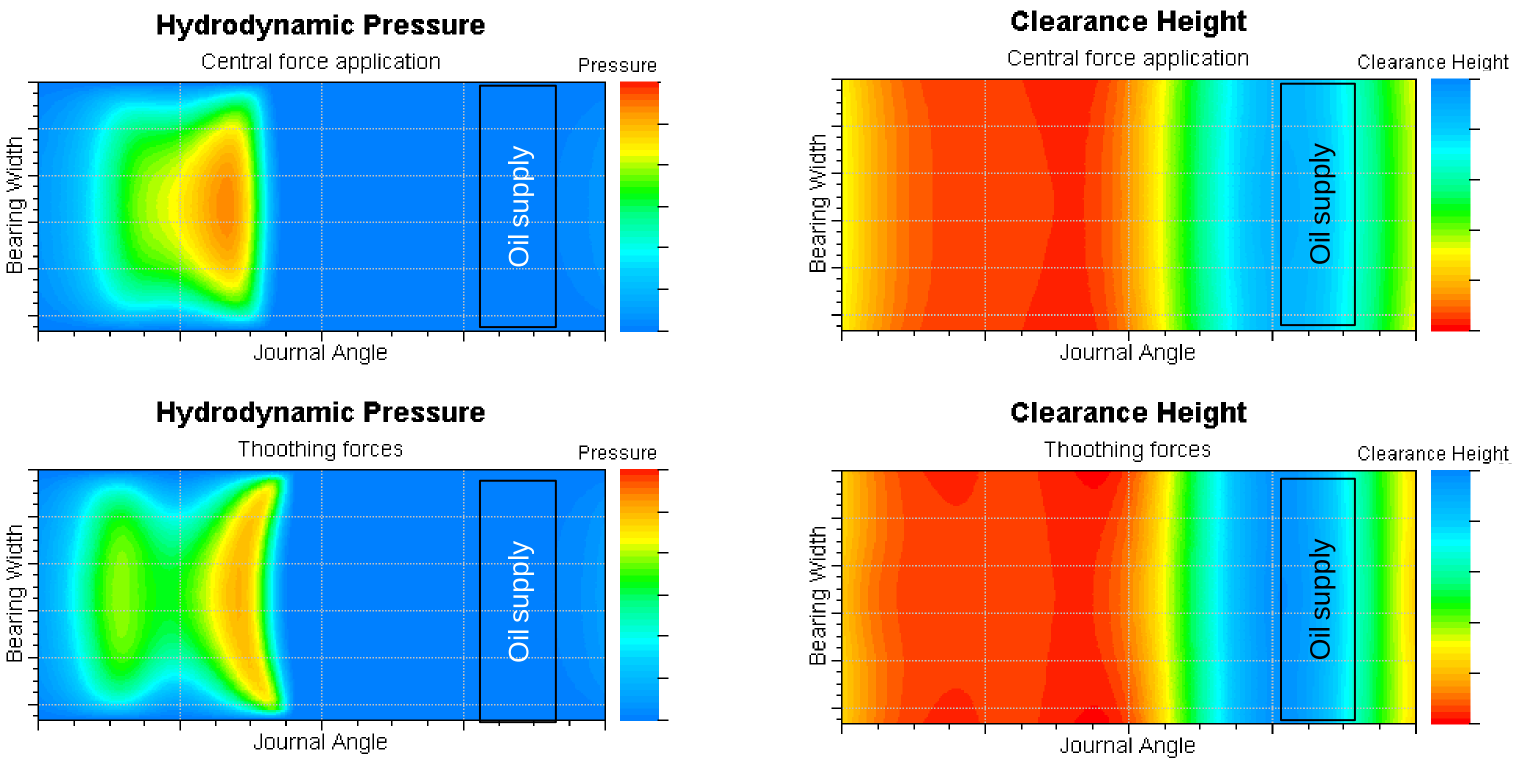

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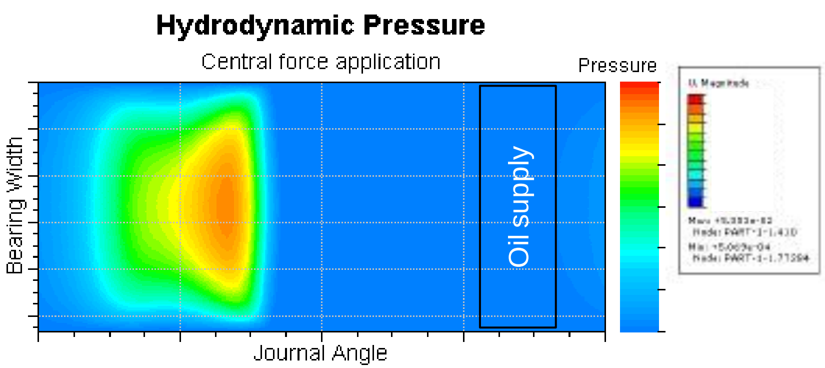

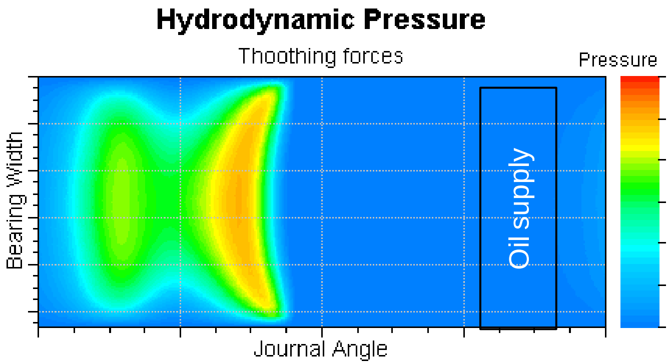

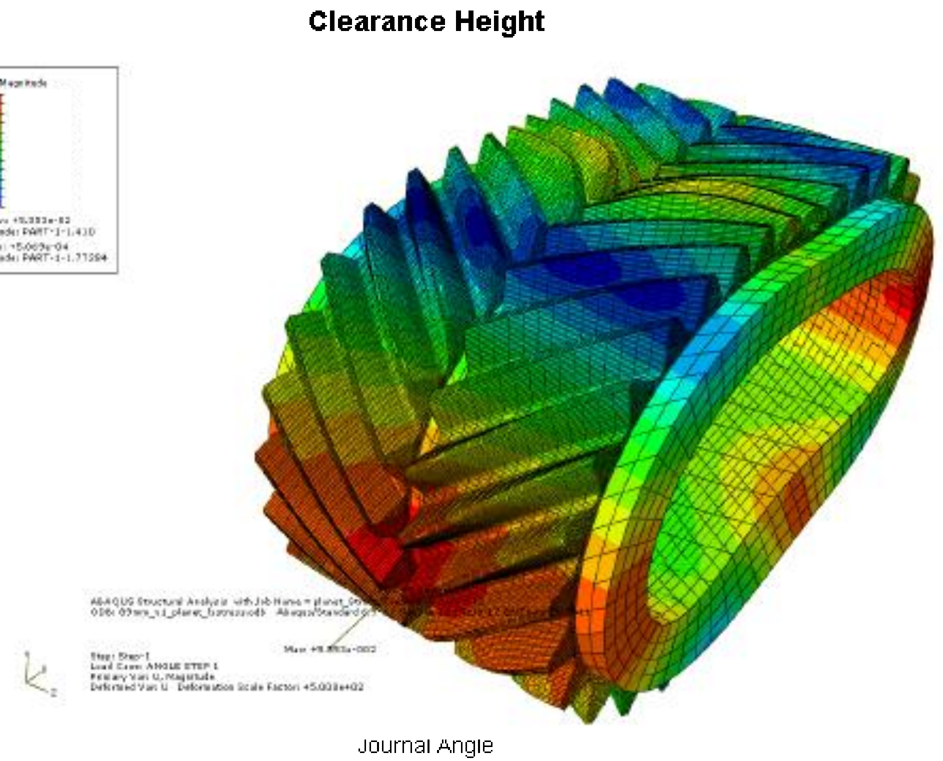

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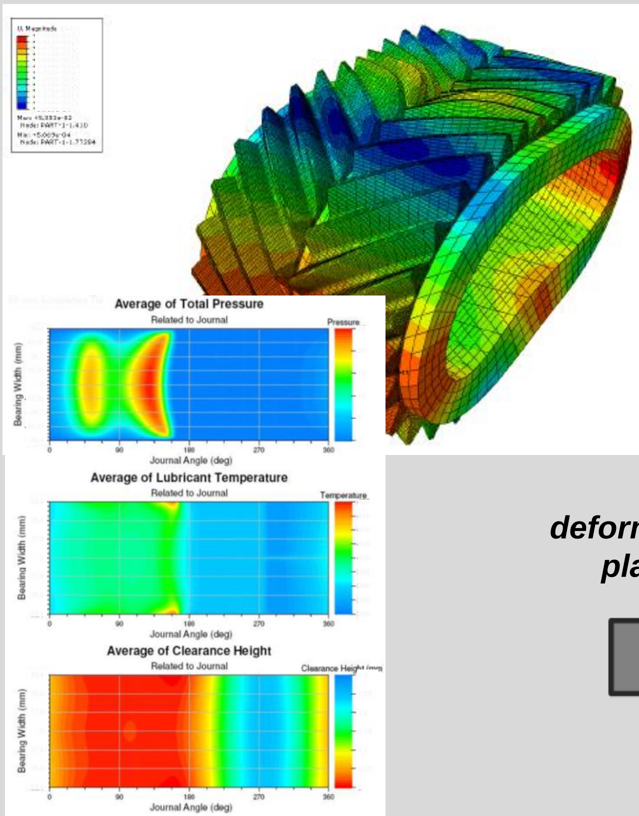
Iterative optimization process

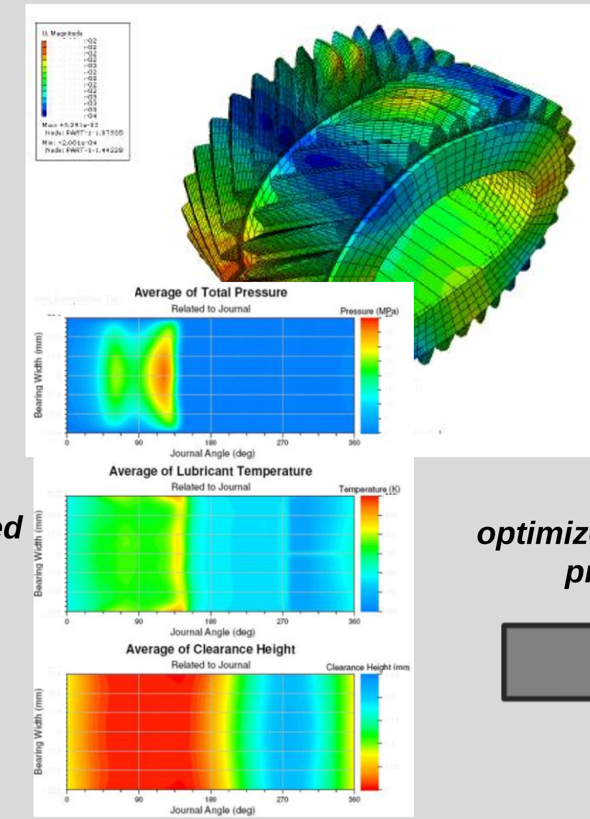
iterative optimization

basic design



deformation optimized planetary wheel

first iteration



optimized bearing profile

2nd *3rd*

- Reduced inner diameter increases stiffness of planet an results in greater gap height

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Summary and Conclusion

- Results of pressure distribution, temperature distribution and minimal oil film thickness are essential for bearing design
- Elastic deformation of planetary gearwheel and carrier shaft has a great effect of the hydrodynamic pressure distribution and has to be considered
- ➢ **Flexible EHD2 contact is necessary for adequate simulation of the planetary wheel bearing**

- Results show that bearing diameter has to be reduced to gain higher stiffness of the planetary wheel
- Fine tuning via contourisation of the bush surface
- ➢ **Several loops to achieve optimum geometry necessary**

- Next step is the enlargement of the system with ambient structure and the remaining planets

Thank you for your attention!

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Citation

- Slide 1: Wikipedia: http://en.wikipedia.org/wiki/Geared_turbofan (05/28/2011)
- Slide 7: Pratt & Whitney: http://www.pw.utc.com/media_center/images_library/images_ce_library.asp (05/28/2011)
- Slide 13: Haberhauer: H. Haberhauer, F. Bodenstein, Maschinenelemente - Gestaltung, Berechnung, Anwendung, 15. Auflage, Springer-Verlag Berlin Heidelberg, 2009
- Slide 14: WZL, RWTH Aachen: http://www.institut-wv.de/2819.html (05/28/2011)