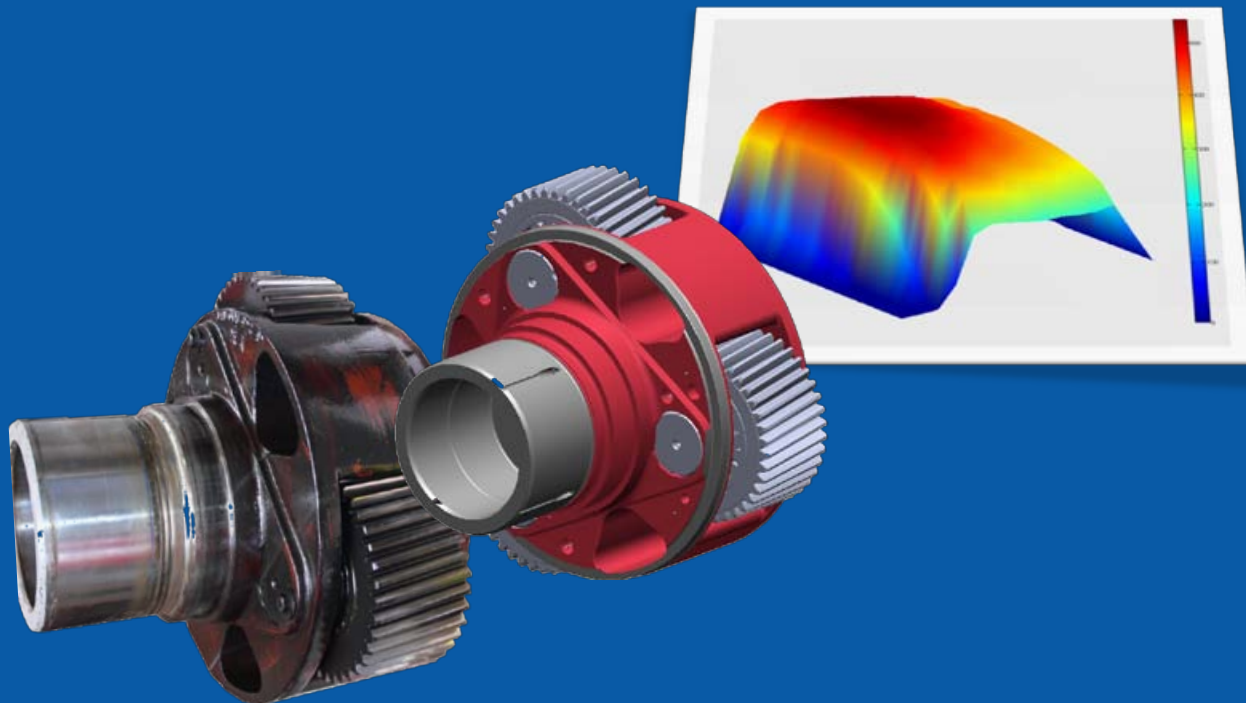


Gearbox Reliability Collaborative Experimental Data Overview & Analysis



Presenter
Francisco Oyague

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Dallas, Texas

NREL/PR-500-48176

Drivetrain and the Cost of Energy

Wind turbine gearboxes fail to meet 20-year design life

- Premature failure of gearboxes increases cost of energy
 - Turbine downtime
 - Unplanned maintenance
 - Gearbox replacement and rebuild
 - Increased warranty reserves
- The problem:
 - Widespread
 - Affecting many OEMs
 - Not caused by manufacturing practices



Gearbox Reliability Collaborative (GRC)

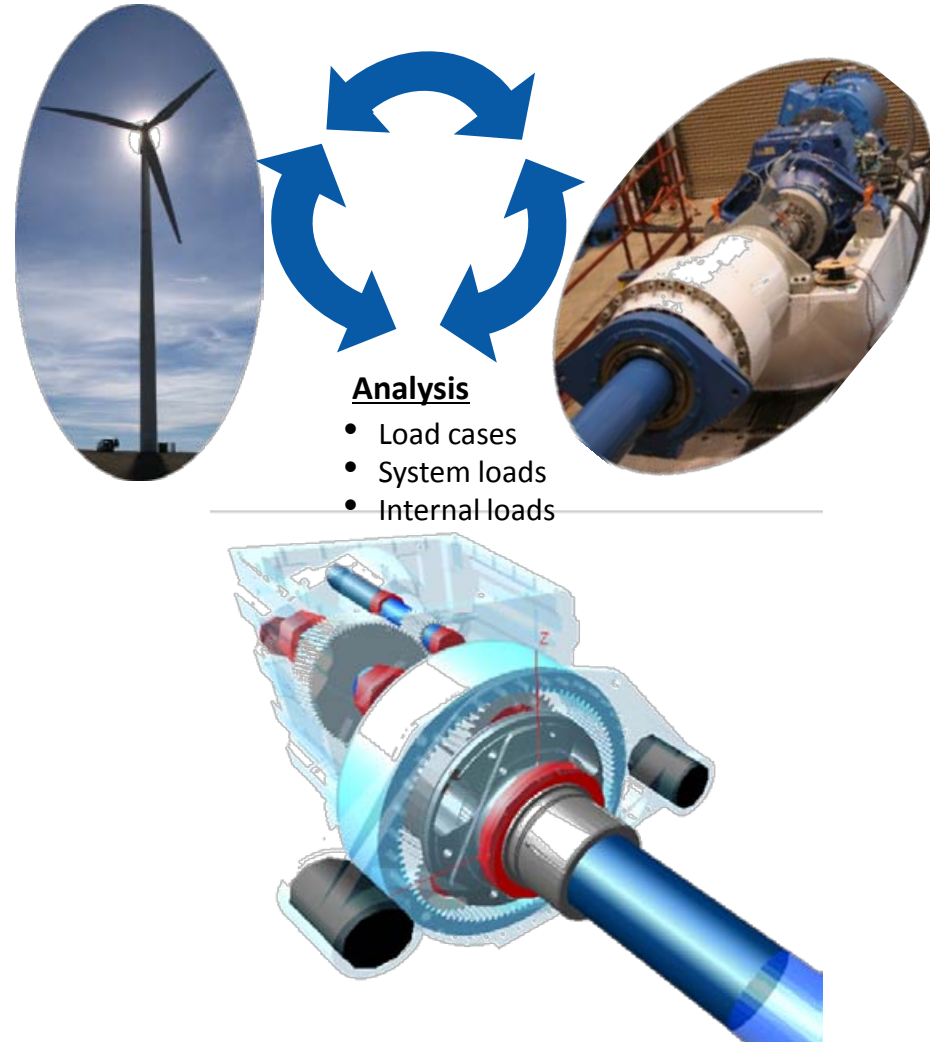
- Facilitate dialog among all parties
 - Designers and consultants
 - Suppliers and rebuilders
 - Operations and maintenance organizations
- Understand gearbox response to specific loading
 - Pure torque, bending, thrust (dynamometer)
 - Turbulence (field)
- Understand physics of premature failure of wind turbine gearboxes
- Identify gaps in design process
- Suggest improvements in design practices and analytical tools

Field Test

- Test plan
- Test turbine
- Test setup & execution

Dynamometer Test

- Test plan
- Test turbine
- Test setup & execution



Gearbox Reliability Collaborative (GRC)

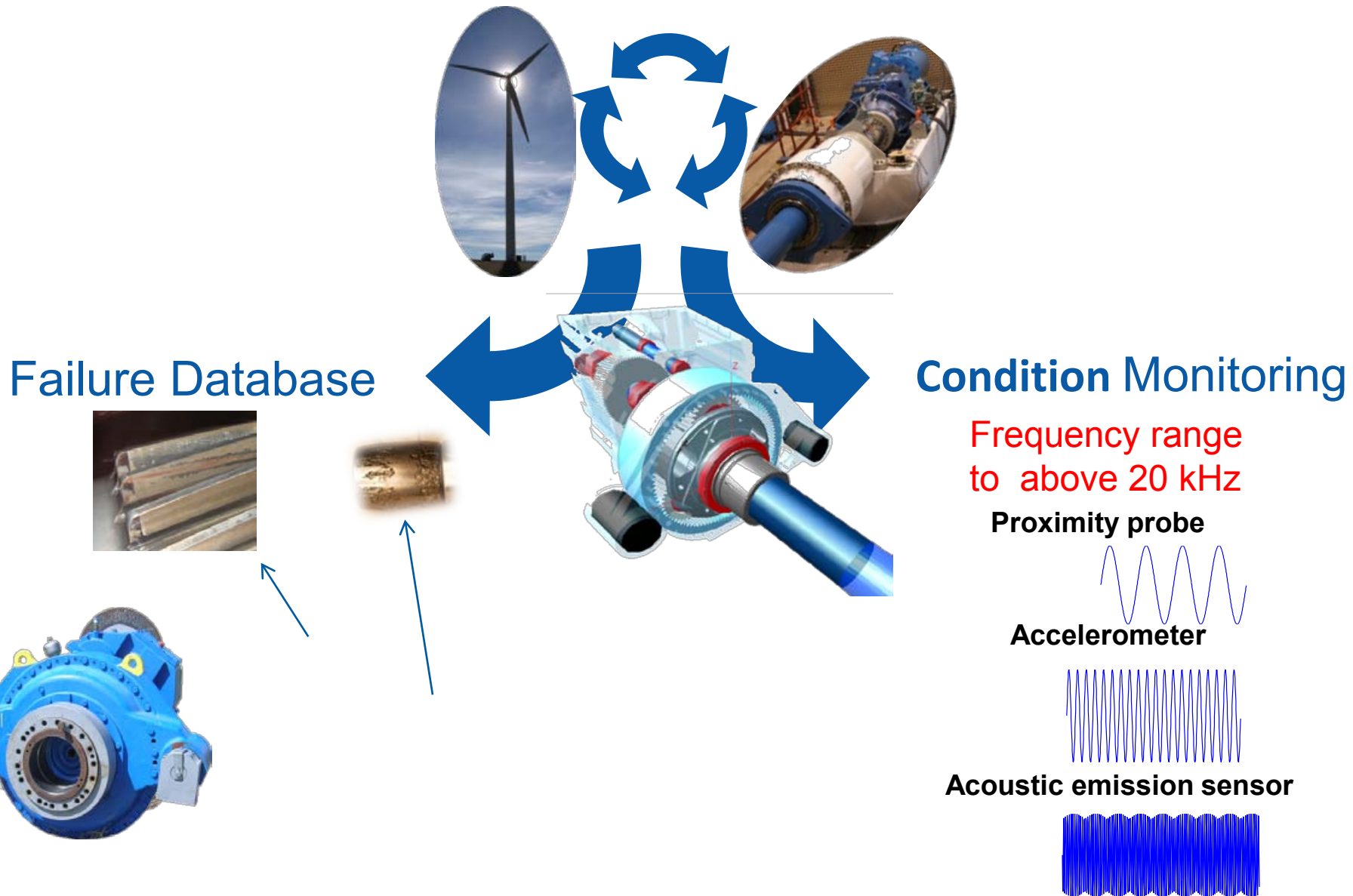
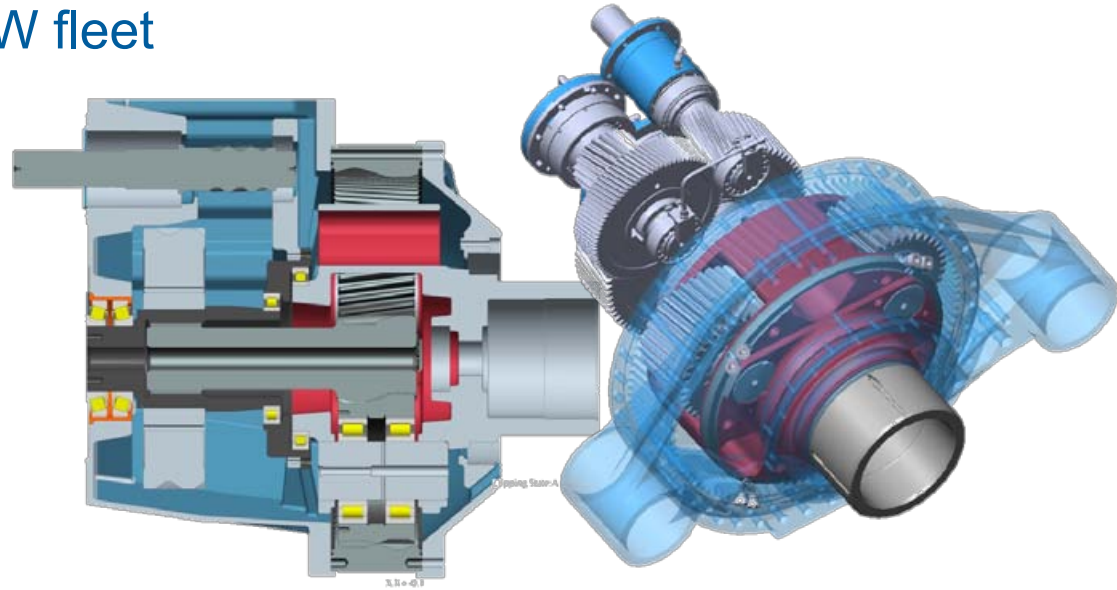


Photo Sources: ProvibTech, Machine Condition Monitoring Ltd, Physical Acoustics Corporation

Gearbox Redesign

Gearbox redesign to reflect MW fleet

- Floating sun
- Bearing arrangement
- Lubrication
- Gearing micro geometry



DOE-owned GRC gearbox design distribution

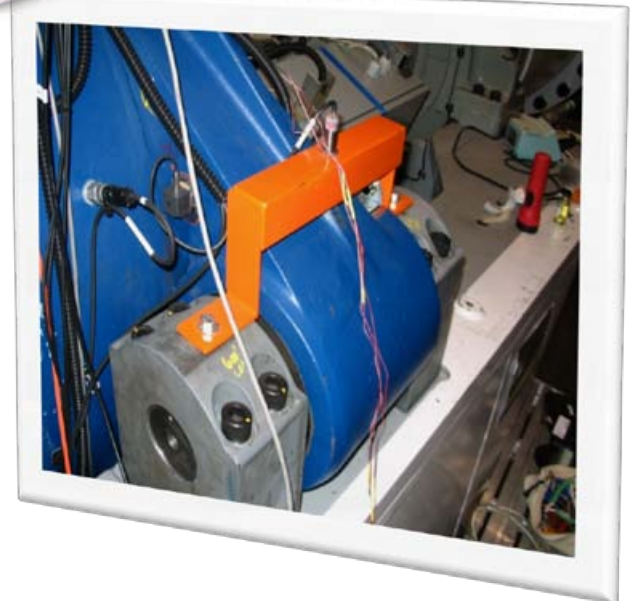
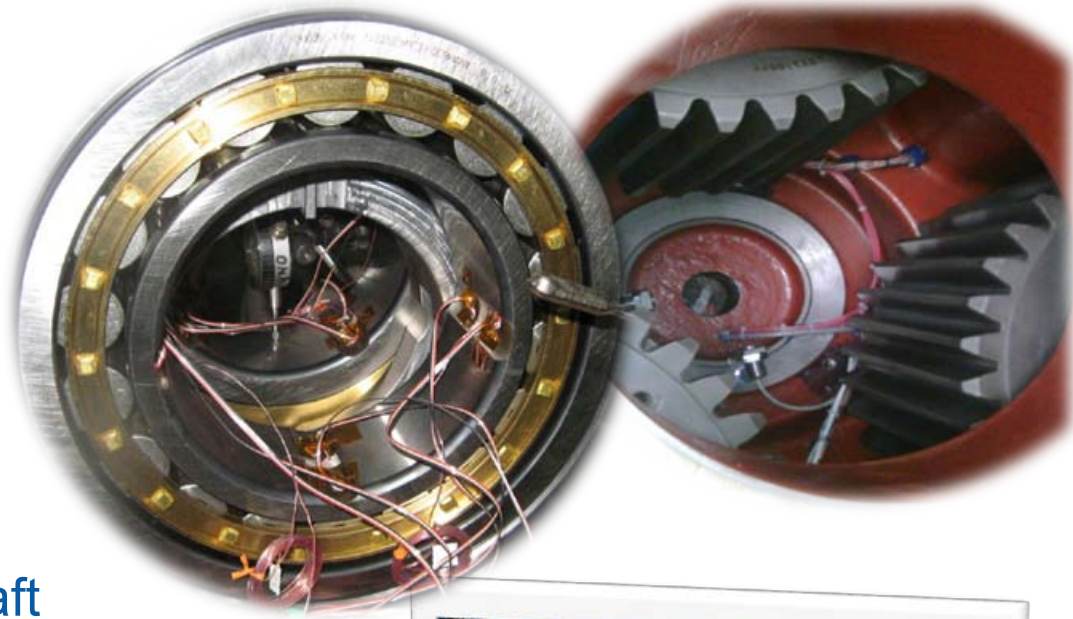
- Detailed technical specifications
- Drawings and solid models
- Material

Round Robin Analysis

- Standardized analytical approaches
- Results from many commercial and in-house codes

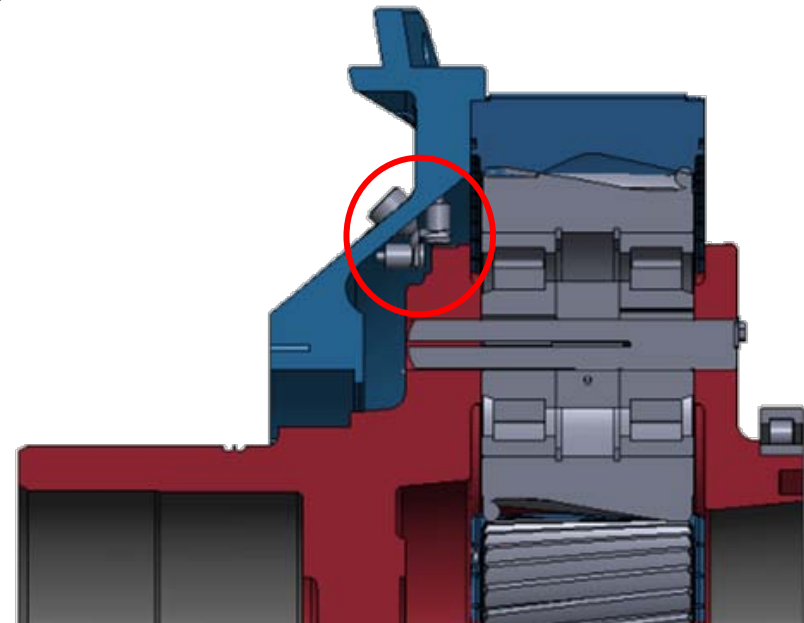
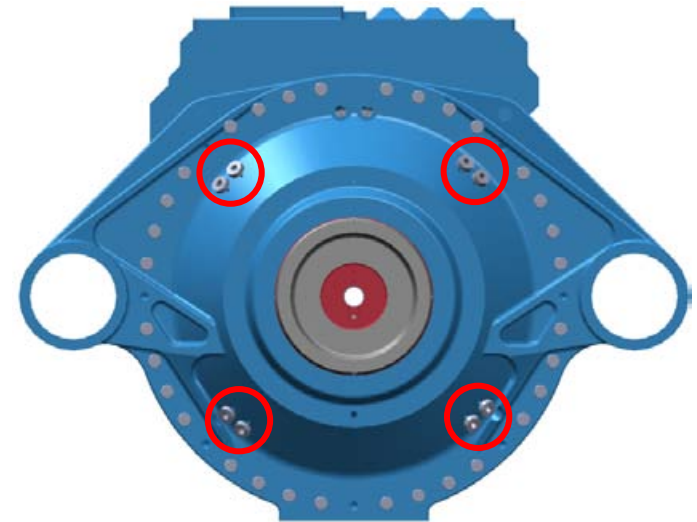
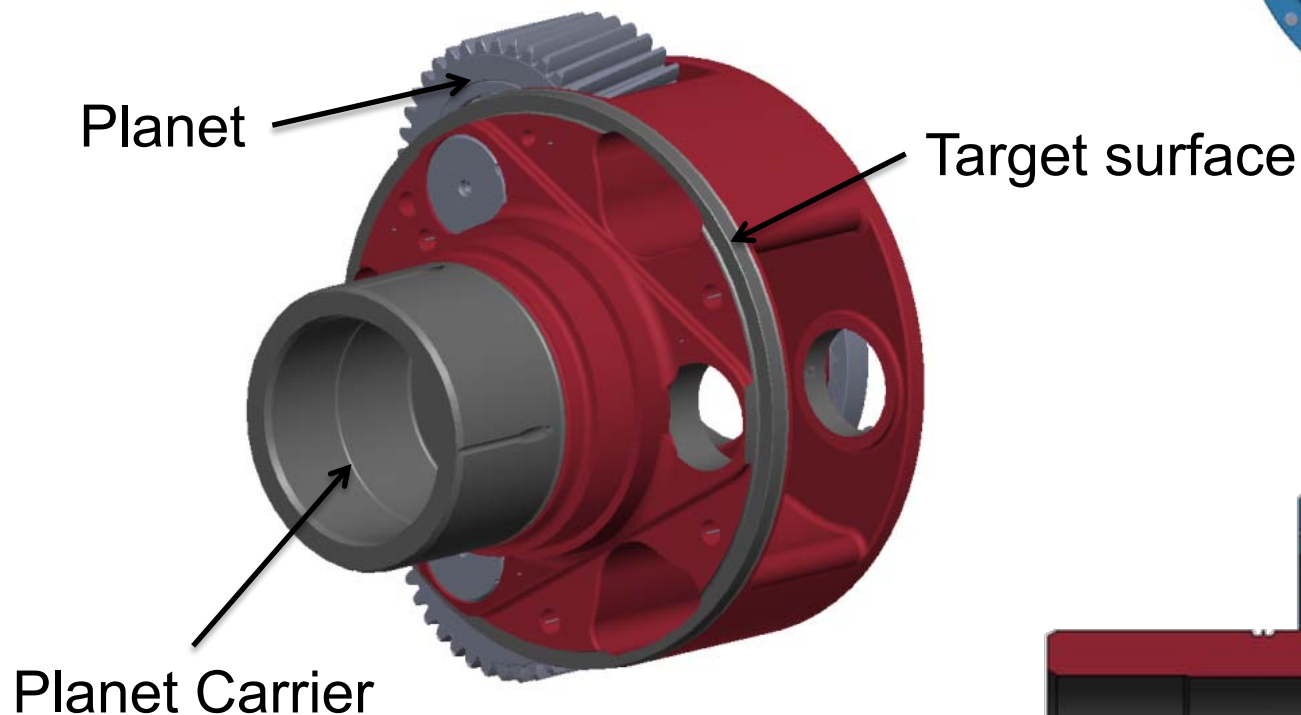
Instrumentation

- Relative motion
 - Planet carrier
 - Sun
 - Planet
 - Housing
- Forces, moments on main shaft
- Tooth load sharing between planet gears
- Bearing roller load distribution
- Temperature gradients of bearings
- Planet bearing collective roller slip



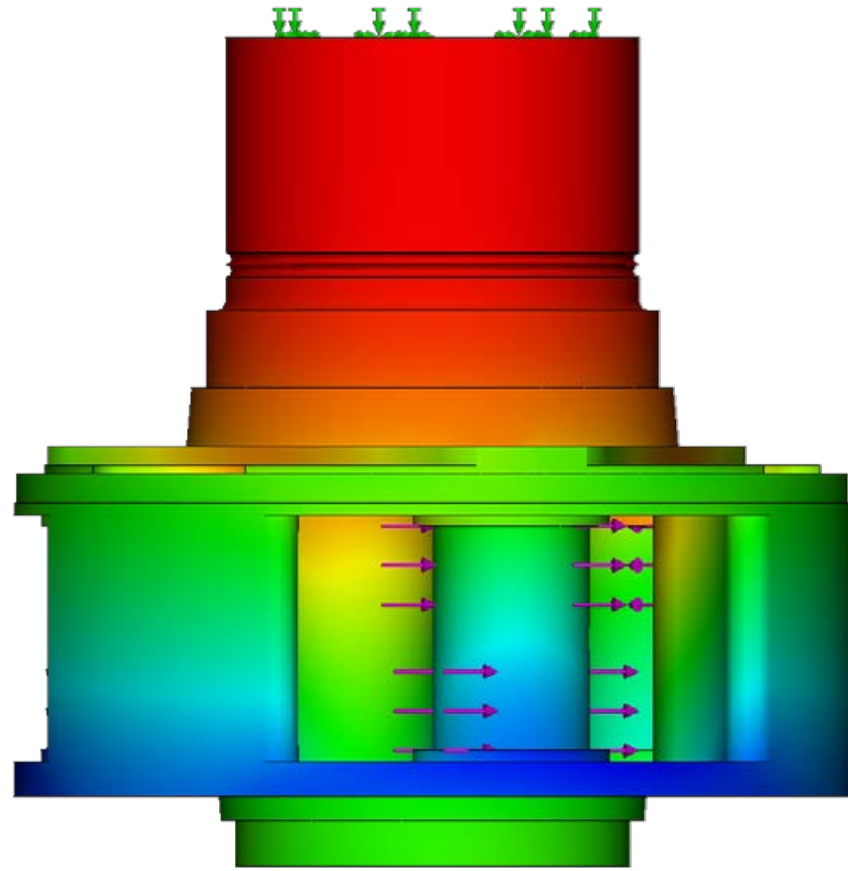
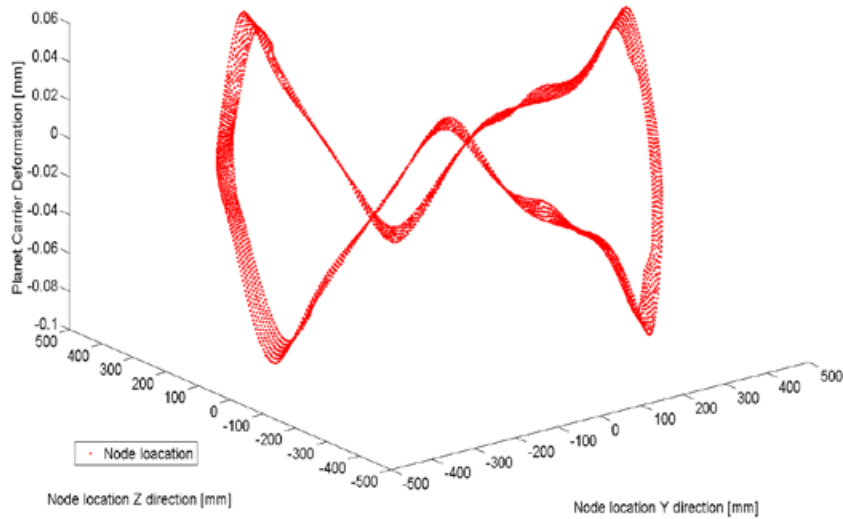
Planet Carrier Motion

- Implemented 4 sets of proximity sensor
- Machined Target surface
- Monitor of axis motions and angular motion



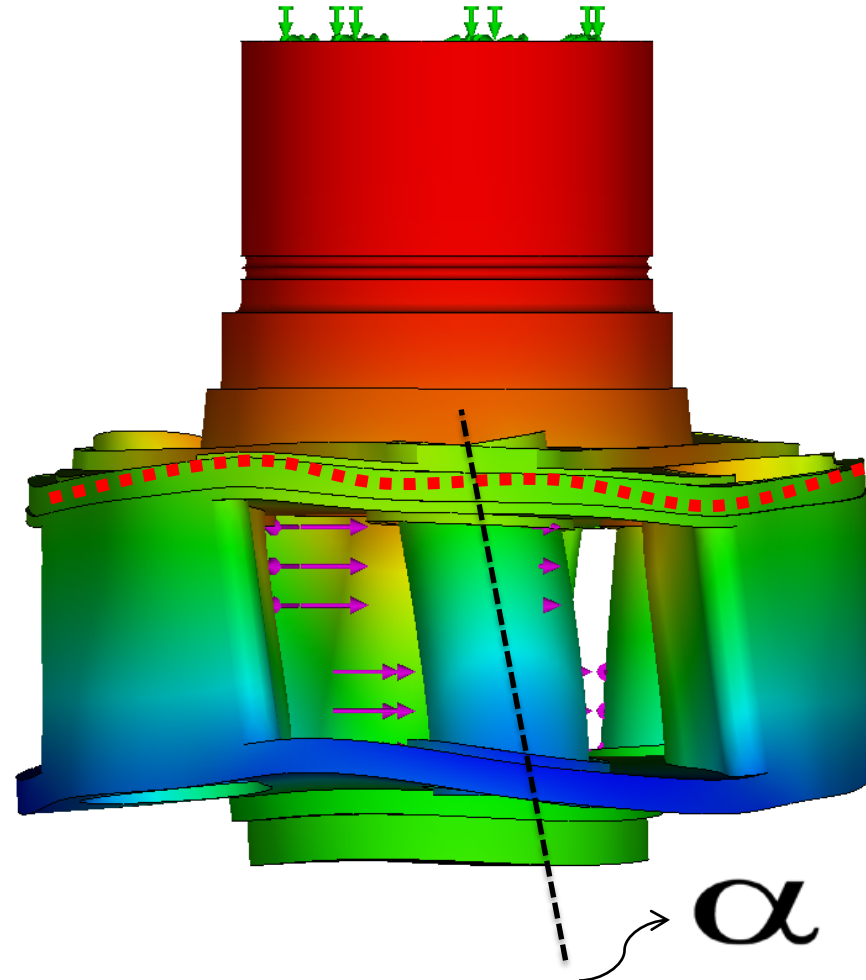
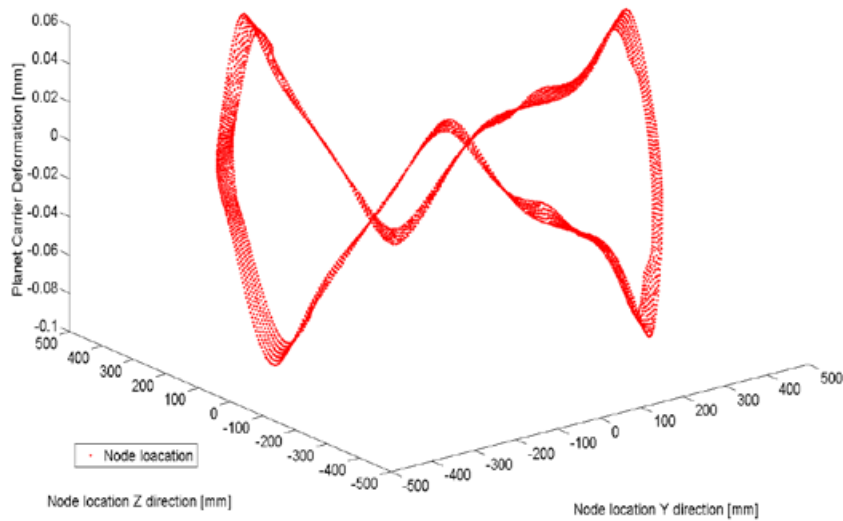
Planet Carrier Deformation

- Target surface deformation captured by the proximity sensors
- Deformation of planet carrier body correlated to planet pin misalignment



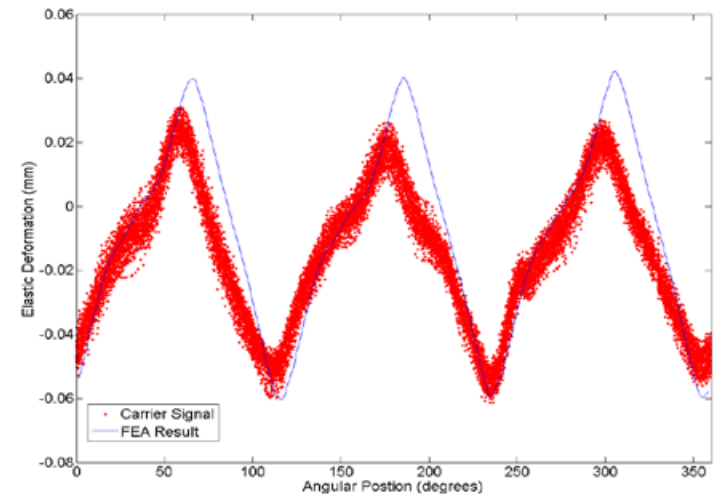
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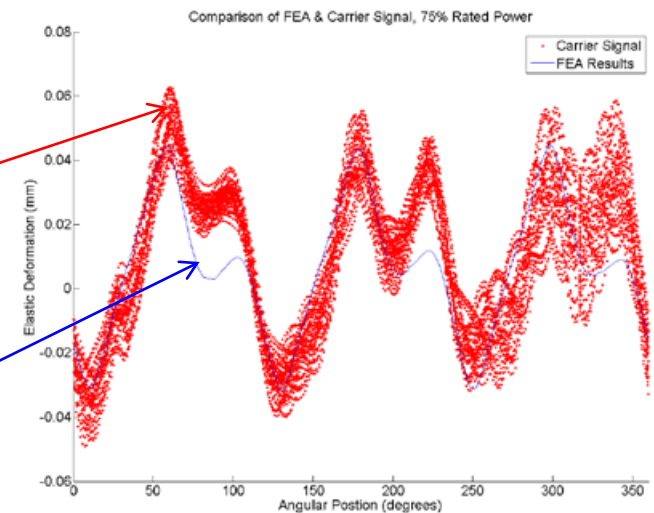
Analysis Versus Experimental Data

- Finite element model validation using 75% rated power
- Two gearboxes produced slightly different behavior
- Boundary conditions are adjusted to account for the differences

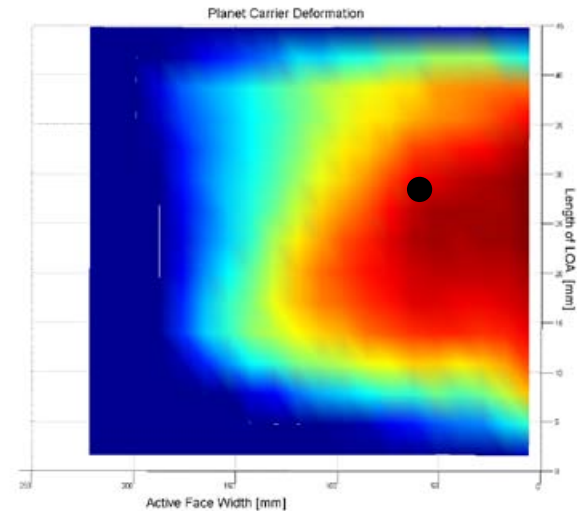
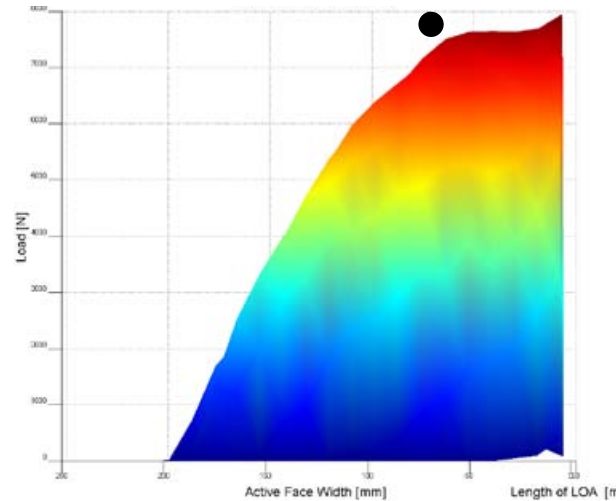
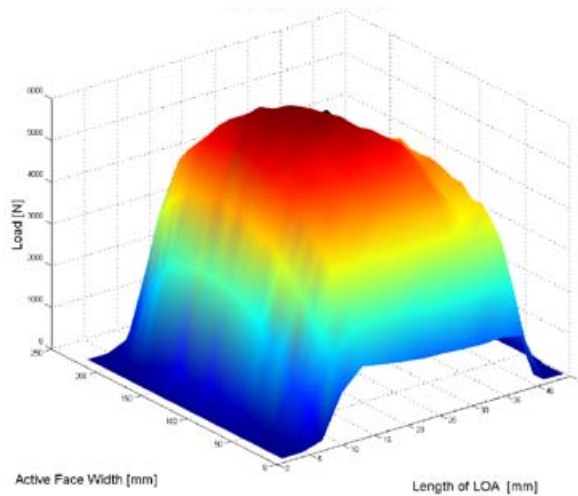
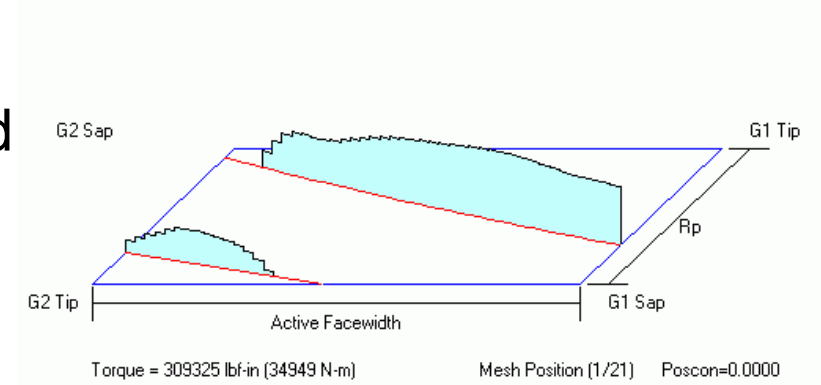
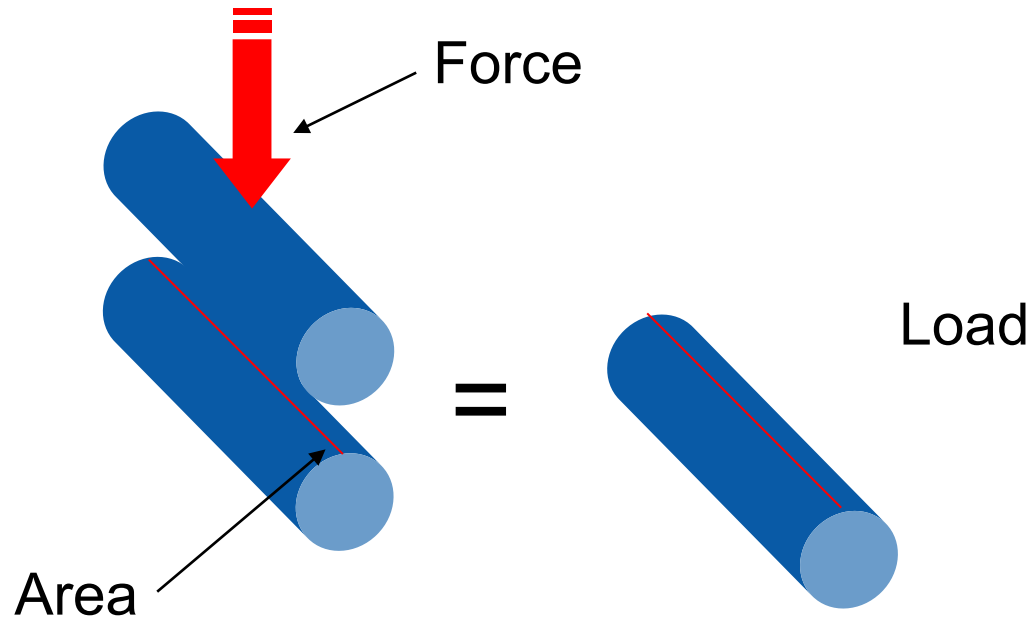


Experimental data

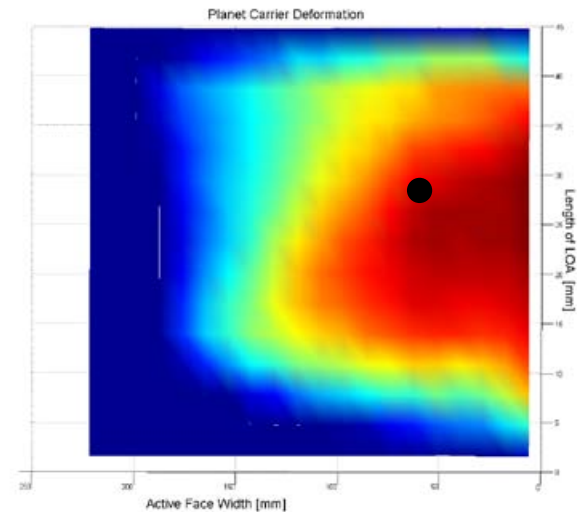
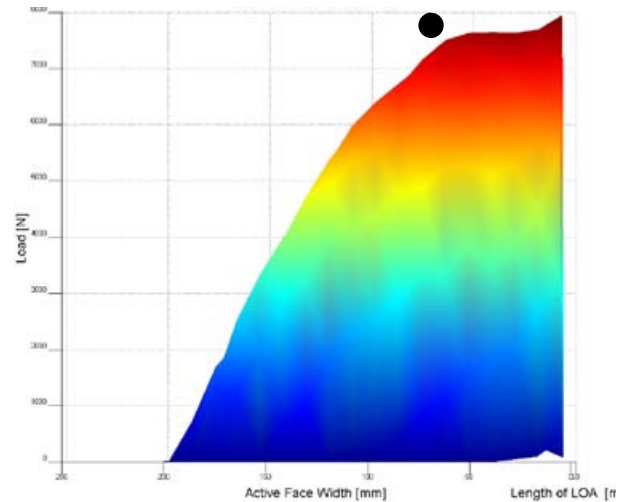
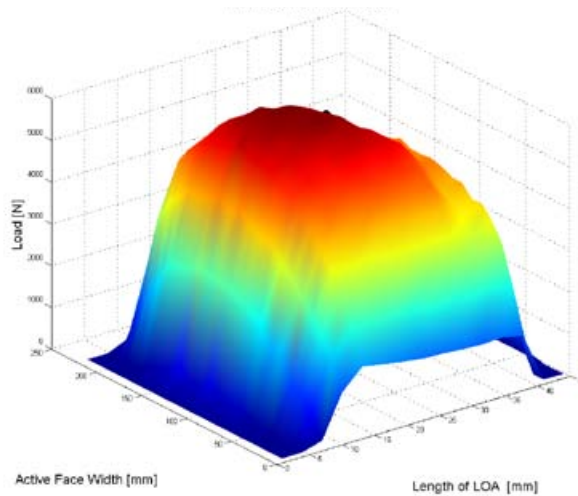
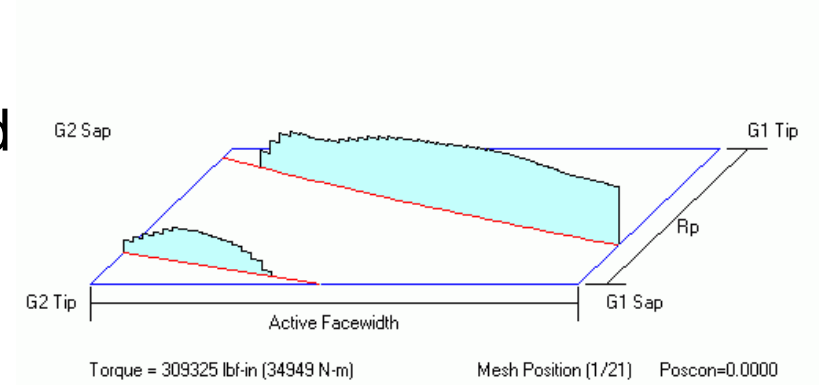
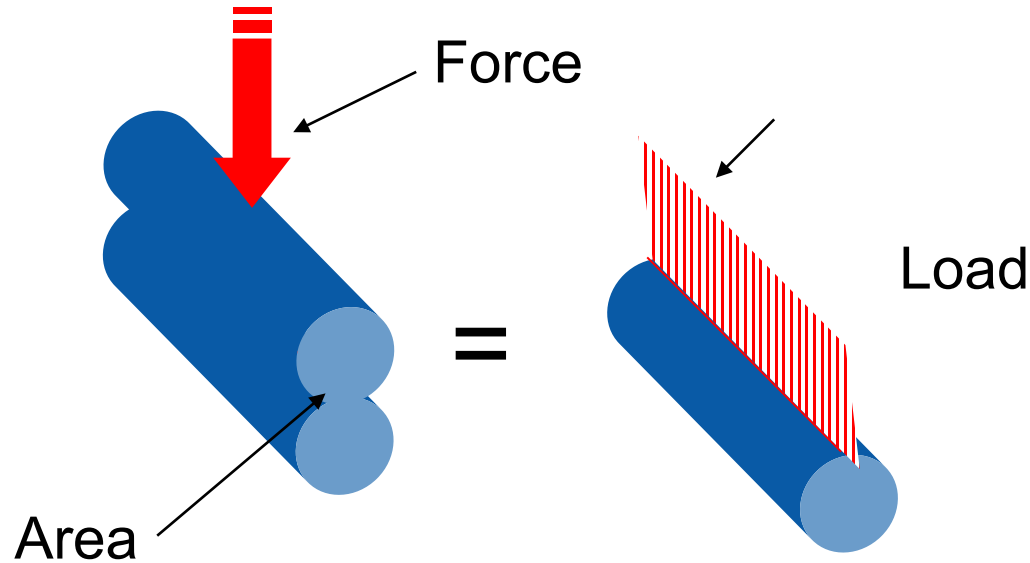
Simulated results



Gear Tooth Contact Stress

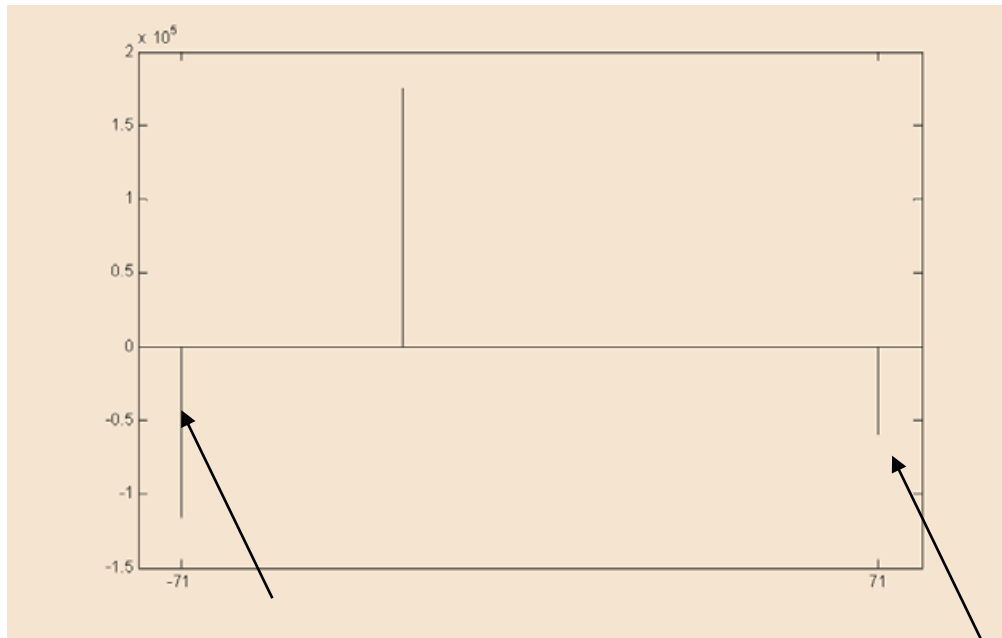


Gear Tooth Contact Stress



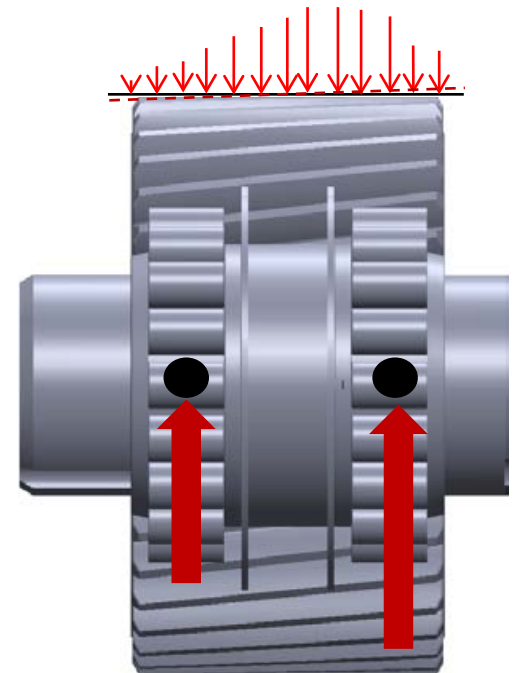
Bearing Load

- Equivalent load location => Bearing load distribution
- Life reduction of 8% due to gearbox manufacturing variability (planet pin misalignment only)



Up-wind BNG

Down-wind BNG



GRC Current and Future Work

- Facilitation and communication between the various parties involved in the design process
- Multi-fidelity analysis validation through a round robin approach
- Acquisition of field and dynamometer test data for post-processing analysis
- Evaluation of analytical assumptions and other assumptions imbedded in the design process
- Implementation and population of database in order to truly understand the problem

GRC Current and Future Work

- Long term
 - Produce multiple topical reports
 - Provide reference data set for future testing of analytical tools and analysis approaches
 - Provide support for standards updates
- Redirect research and narrow focus by using the database statistics
- Expand project to include full drivetrain study
- Expand project to other drivetrain configurations