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Wind Turbine Structural Path Stress & Fatigue Reductions Resulting from Active Aerodynamics

Dale Berg
Lead, Advanced Rotor Technology
Wind & Water Power Technologies
Sandia National Laboratories
deberg@sandia.gov
(+1) 505-844-1030

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NNSA National Nuclear Security Administration
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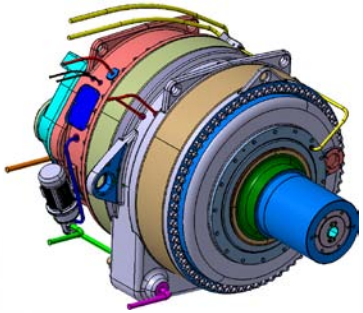
  - *Romax Technology Ltd., Boulder, CO*

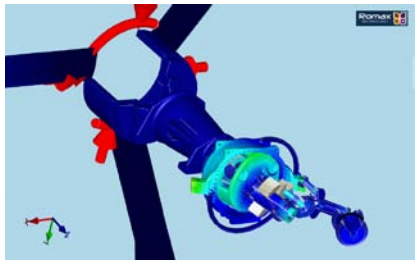
- **SMART Team Members**
  - *David Wilson, Jonathon Berg, Matt Barone, Josh Paquette, Wesley Johnson, Mark Rumsey, Jonathon White*

Romax Technology

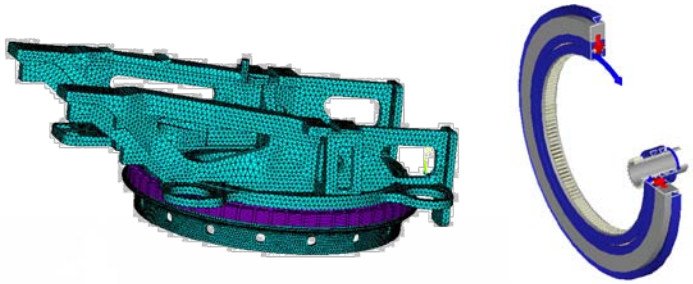
- Rotating machinery experts with 200 employees worldwide
- Boulder office dedicated to serving US customers for wind engineering



Gearbox Design



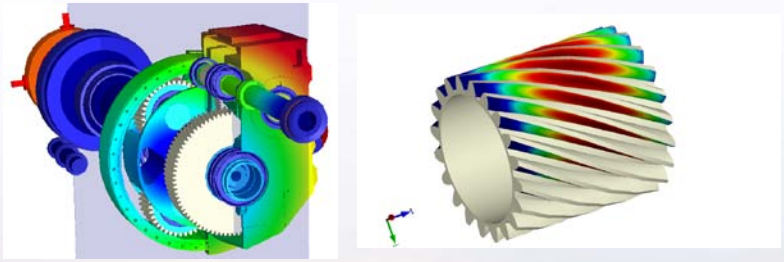
Drivetrain dynamics



Pitch and Yaw System Design and Analysis

Instrumentation

Drivetrain inspections



Gear and bearing durability and vibration

- Contact: Ashley Crowther, VP Engineering – Wind
  ashley.crowther@romaxtech.com, +1 303 562 6064

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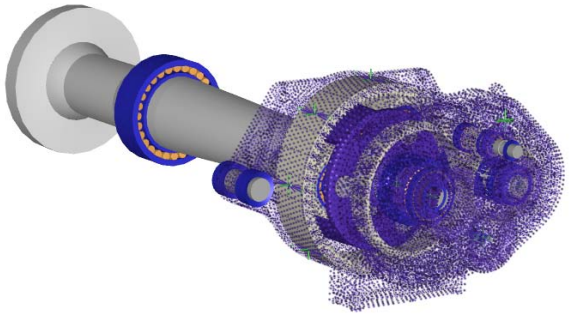
Outline

- **Review of GRC & Active Aerodynamic blade Load Control**
- **Conclusions & Future Work**

Motivation for Work

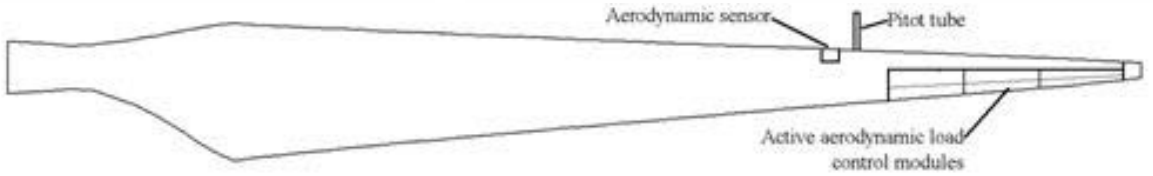
- **Industry has been plagued with numerous gearbox failures**
- **NREL established the Gearbox Reliability Collaborative to address this issue**
  - **heavily instrumented gearbox**
  - **extremely detailed gearbox model**
  - **model validated against experimental data**



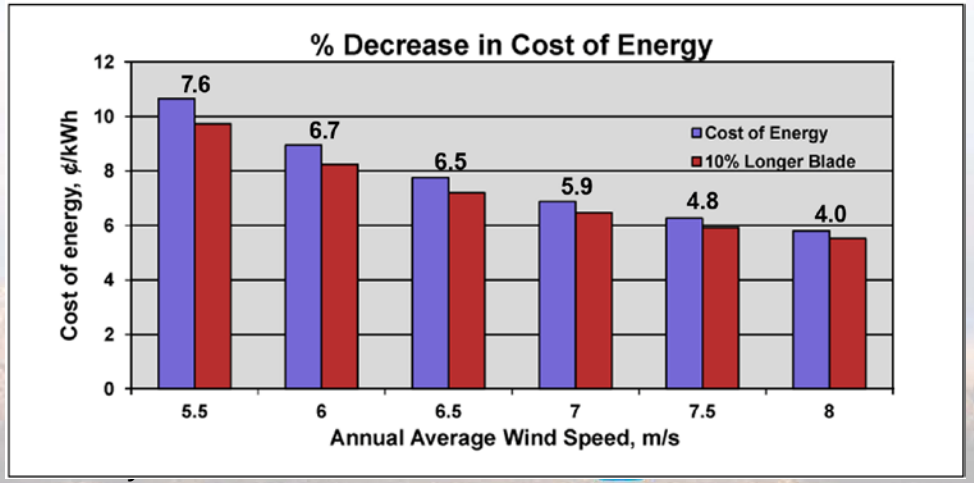
- **Simulations reveal bearing loads quite sensitive to non-torque loading**
  - **main shaft bending**
  - **out of rotor plane moments**
  - **non-uniform wind loading**

Impact of Active Load Control on COE

- **"20% by 2030" report: Decrease in blade fatigue loading will yield COE decrease**
- **Active Aerodynamic Load Control (AALC) investigated**
  - **sense local loads along blade**
  - **attenuate local loads with fast-acting distributed aero control surfaces**



- **Simulation results**
  - **controller designed to minimize blade-tip deflection**
  - **reduce blade fatigue loads**
  - **reduce turbine COE**

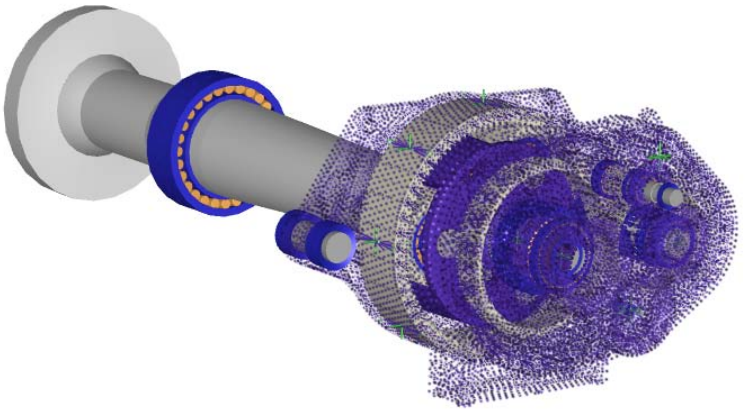


Preliminary work in 2010

- AALC also reduces non-torque loading on drivetrain (Resor)
- Romax performed limited analysis of impact on gearbox
  - small change in gear stresses due to off-axis loading
  - larger changes in carrier bearing off-axis moments
  - reduction in magnitude of stress cycles on bearings
  - suspicion:
    - may decrease fatigue damage
    - may increase fatigue life
- Conclusions:
  - AALC may mitigate gearbox damage
  - more complete analysis is needed

Gearbox Model

- Finite element representation of shafts
- Solid finite element representation
  - gearbox housing
  - gear blanks
  - planet carrier and torque arms
  - 6DOF spring connections for (elastomeric) trunnion mounts
- Semi-analytical formulations for gears and bearings
  - misalignment
  - area of contact under load
  - gear and bearing microgeometry
  - radial and axial clearances
  - preload and material properties

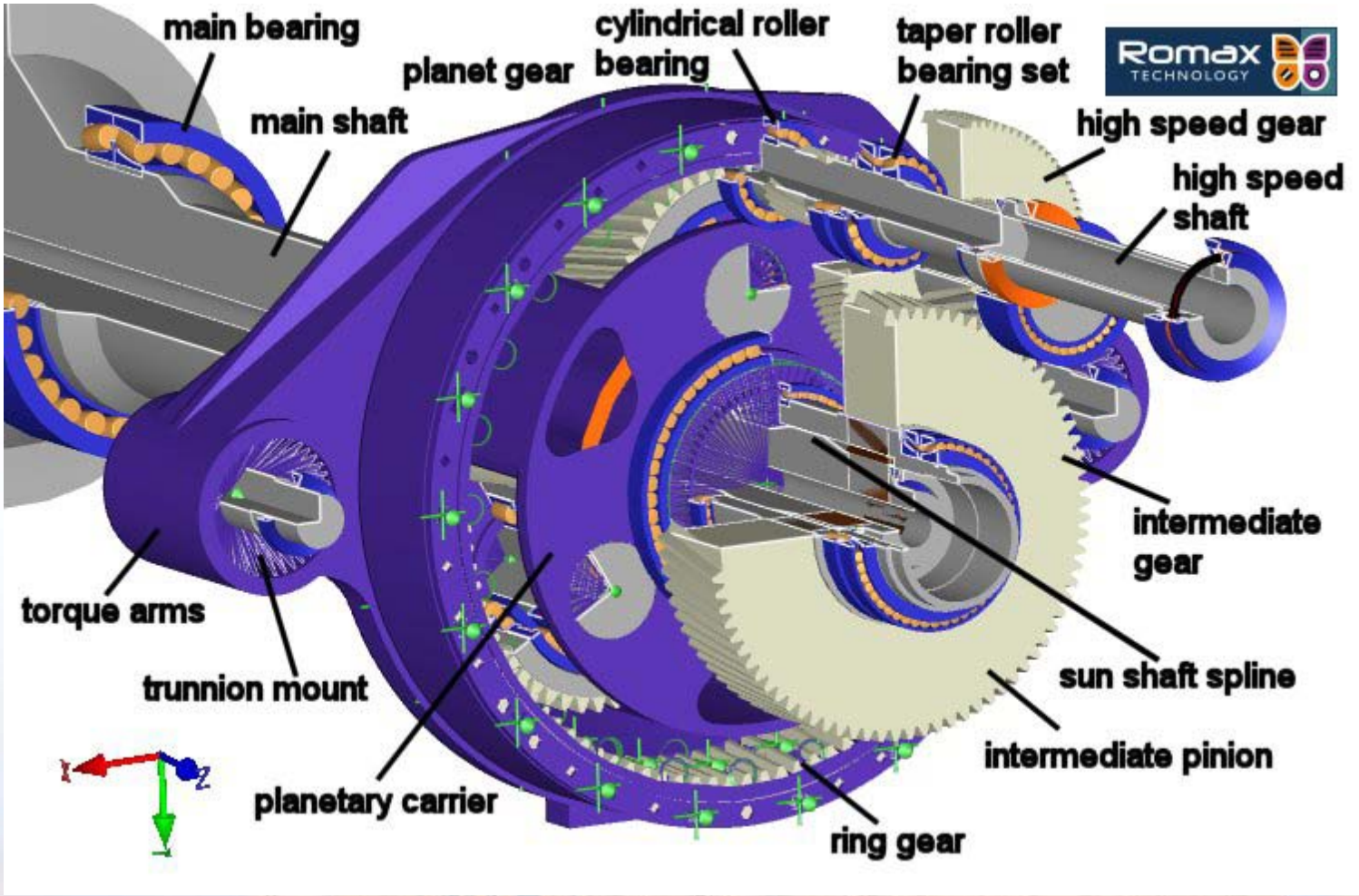


Gearbox model

Current Drive Train Analysis

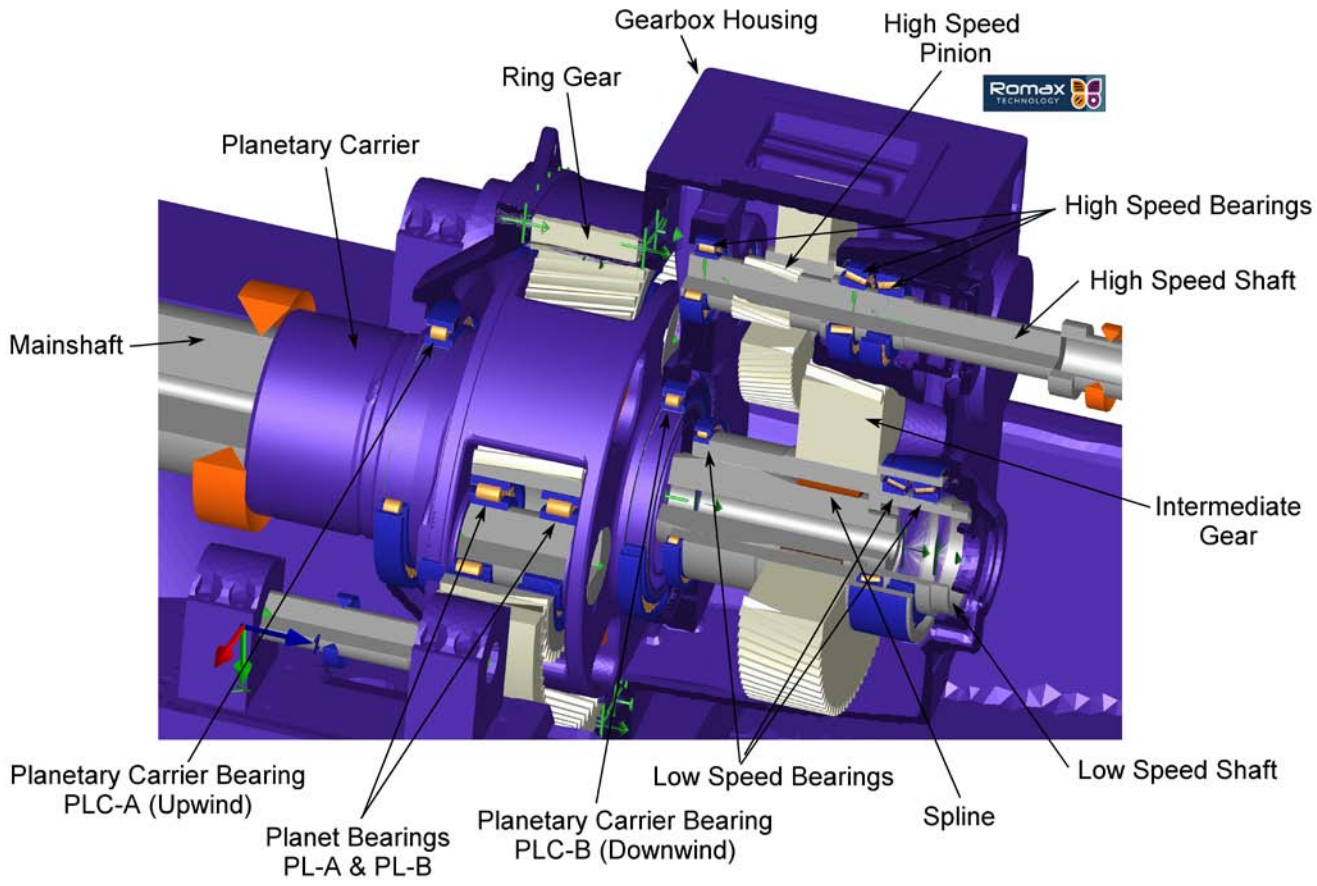
- GRC 750 Turbine
- Gearbox model validated against experimental loads data
- Extended to simulate drive train
  - bedplate
  - hub
  - blade pitch system
- Active pitch control system
- Detailed finite element modelling of all components
- AALC simulations on GRC 750 turbine model
  - reduce blade root flap fatigue loads
- Apply extreme and operating time-series loads to drivetrain
- Perform strength & fatigue analyses of components

GRC Gearbox Details

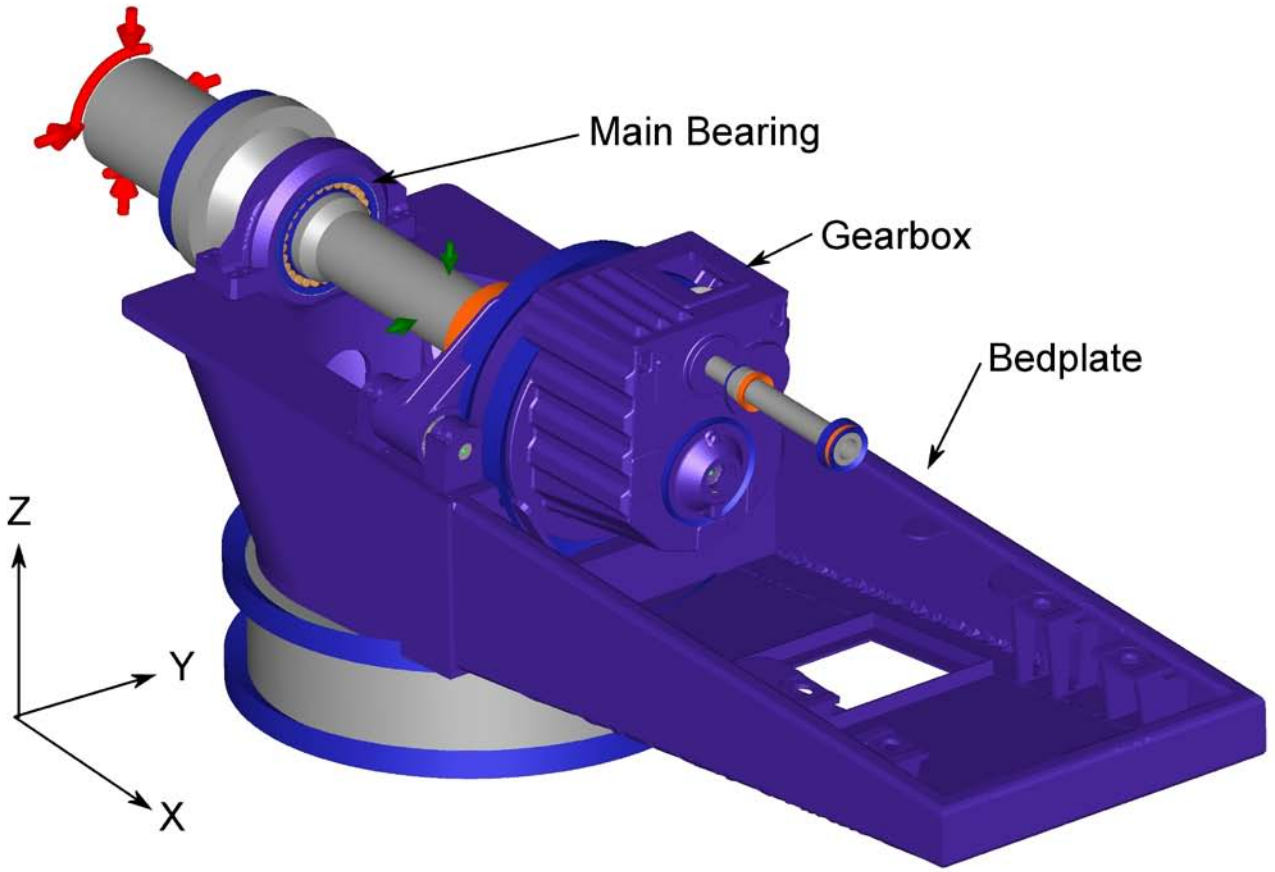


Model of GRC Gearbox

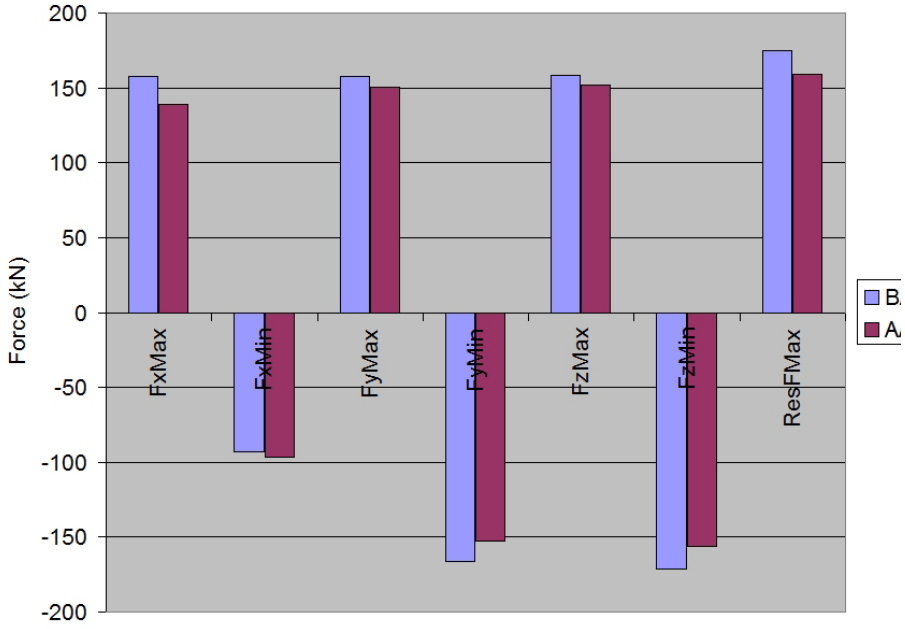
GRC Gearbox Details



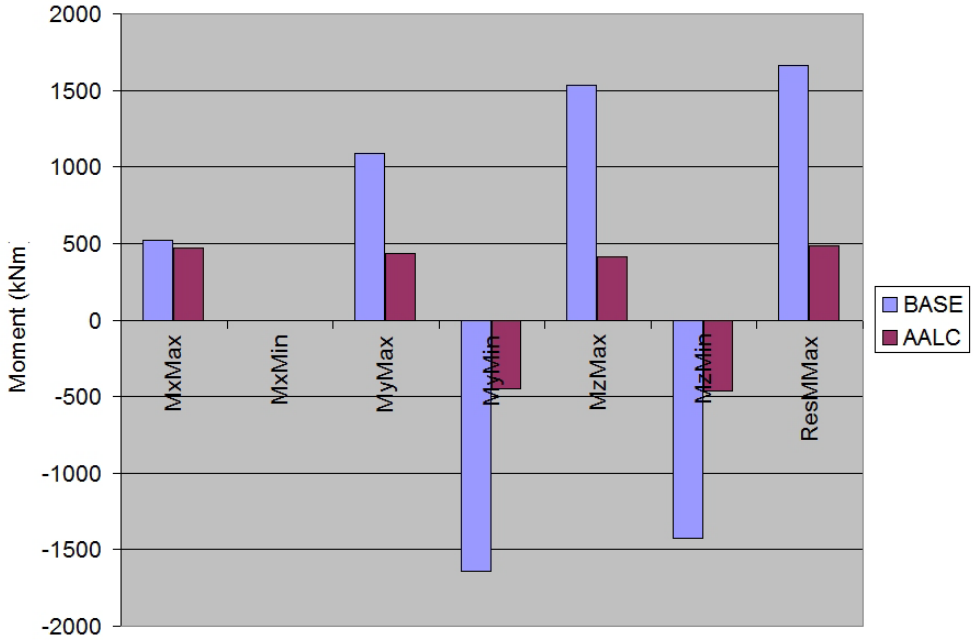
GRC Drivetrain Axis Definition



AALC Impact on Hub Loading



Hub Forces



Hub Moments

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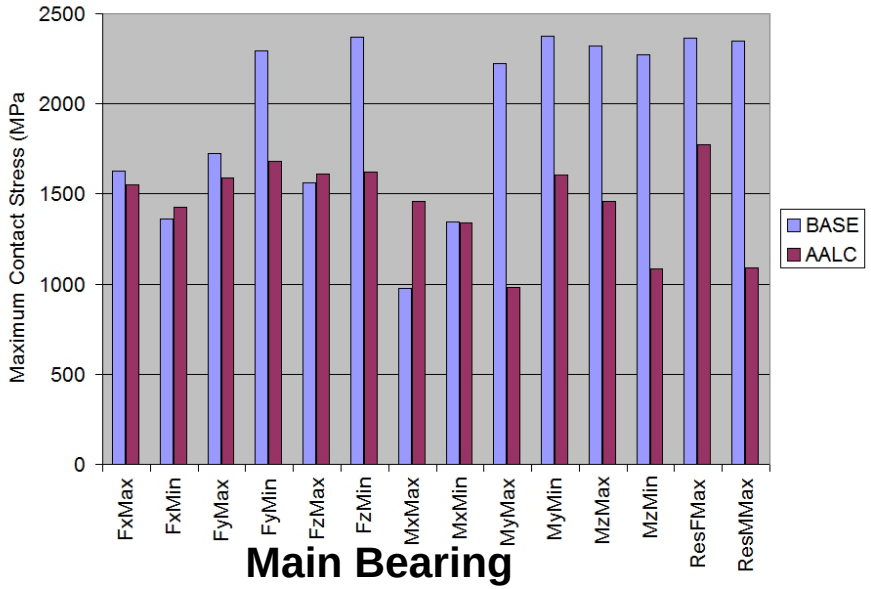
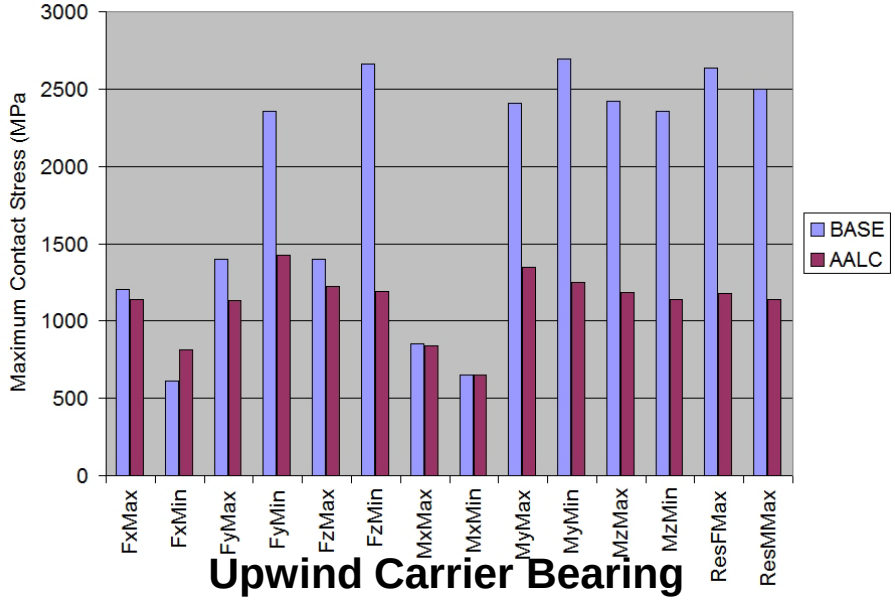
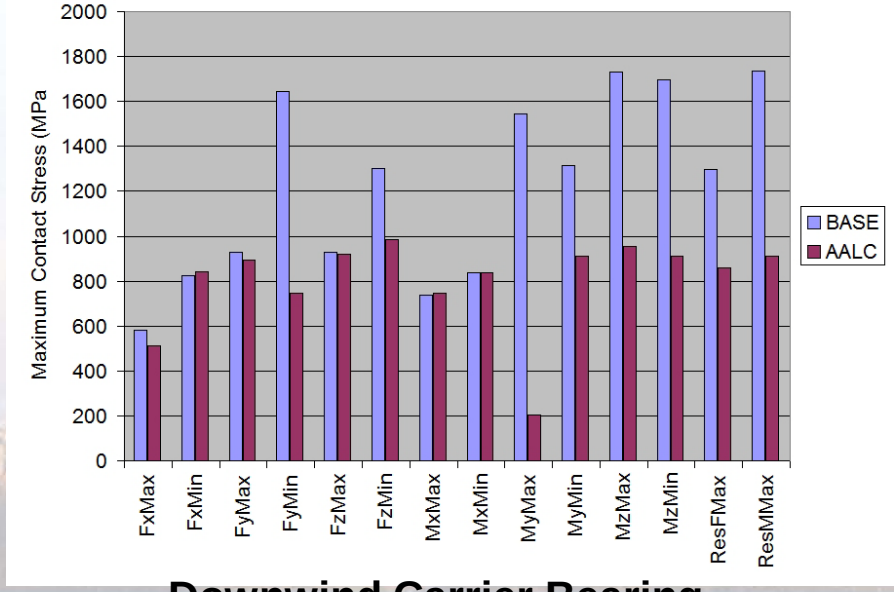
AALC Impact on Bearing Moments



Main Bearing



Upwind Carrier Bearing



Downwind Carrier Bearing

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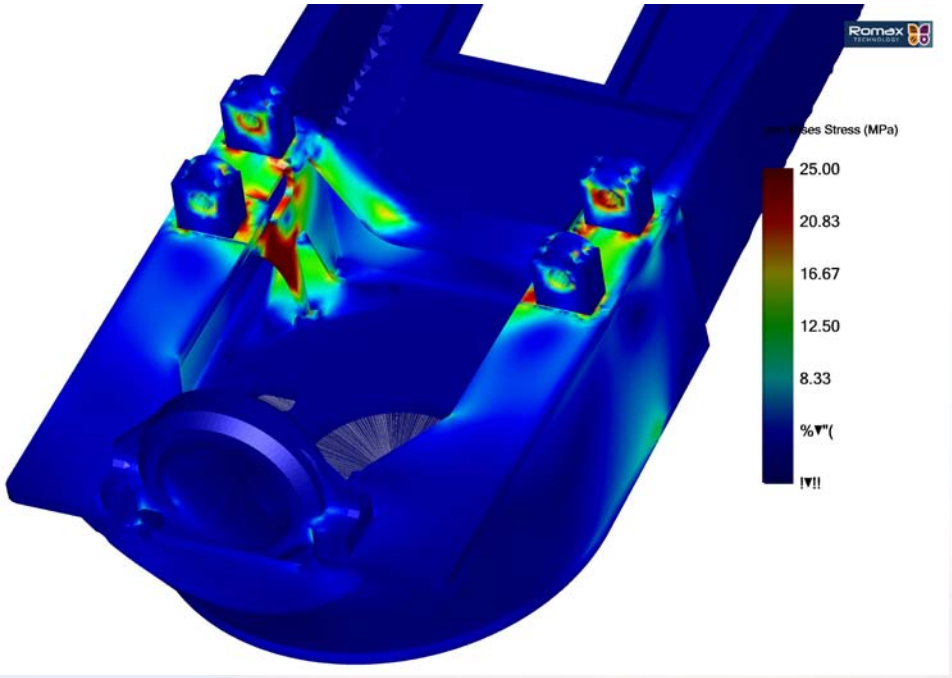
AALC Impact on Bearing Fatigue Damage

Bearing	Relative Change in Fatigue Damage due to AALC (ISO 281)
Main	-7%
Upwind Carrier	-32%
Downwind Carrier	-16%

AALC Impact on Extreme Bedplate Loads - M_{xMax}



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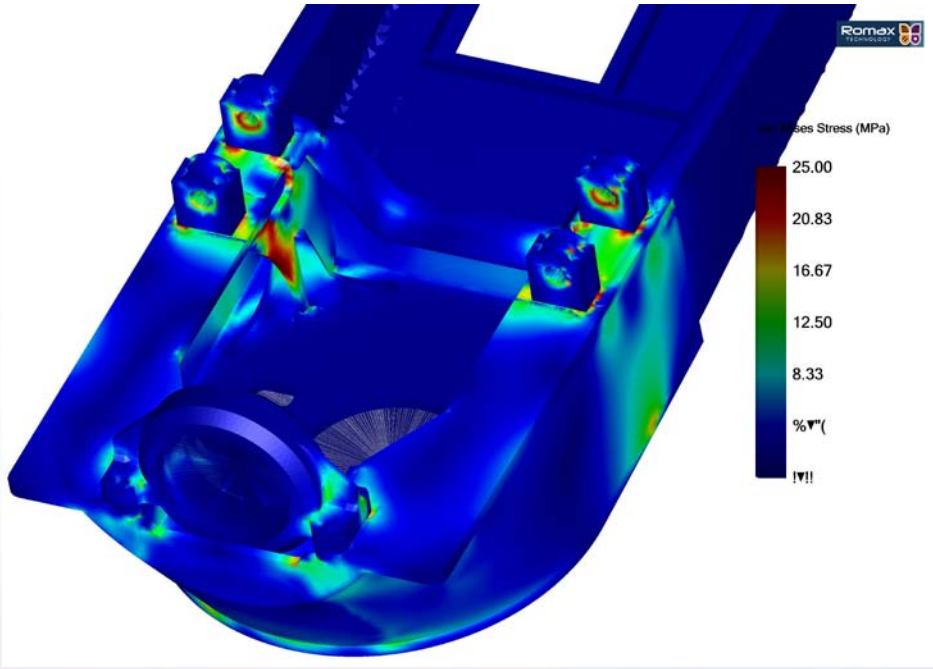
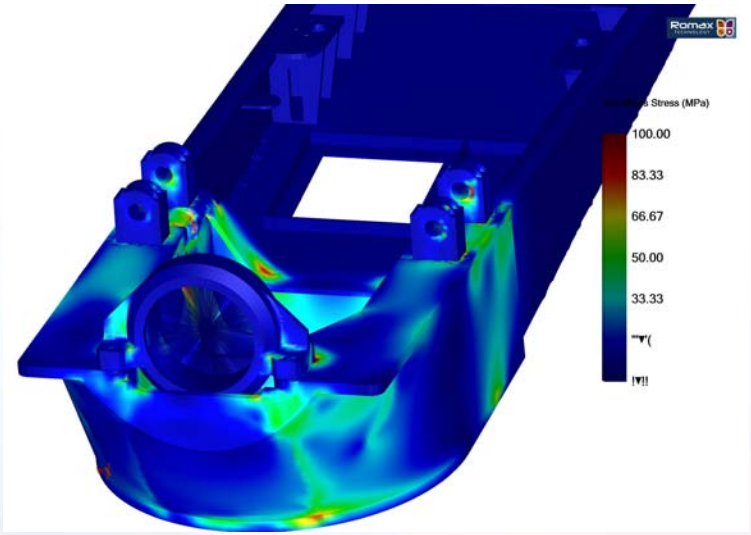


AALC

AALC Impact on Extreme Bedplate Loads - M_{yMax}



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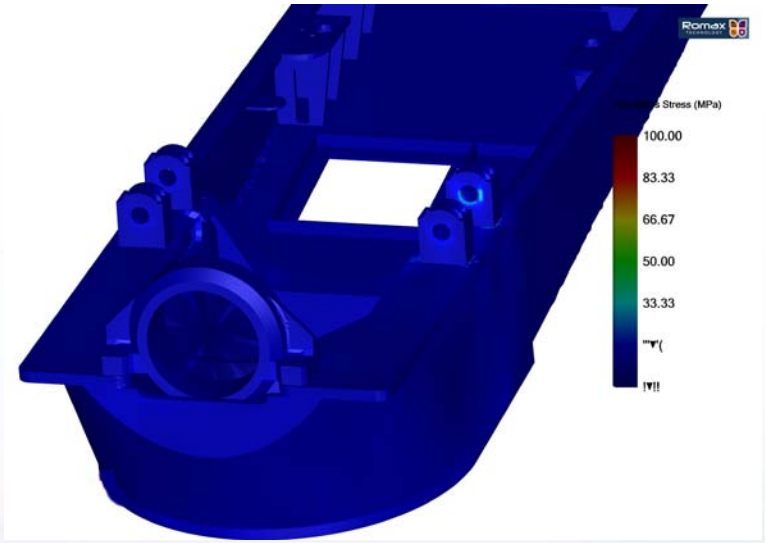

AALC

Summary

- Detailed computational model of drivetrain utilized to examine impact of AALC on drivetrain components.
- AALC significantly reduces the extreme loads on drivetrain components
  - bearing static stresses for limiting cases reduced by as much as 50%
  - fatigue damage reduced between 7 and 32% for the load carrying bearings
  - extreme load bedplate non-torque stresses reduced
- The greatest advantage for the turbine appears to be the reduction of the off-axis moments, which are often the design limiting loads for strength.

Conclusions & Future Work

- **Conclusions:**
  - **AALC reduces off-axis drivetrain moments, which are often the design limiting loads for strength**
  - **AALC has great potential to reduce ultimate and fatigue loads throughout the drivetrain of a turbine**

- **Future Work:**
  - **investigate impact on fatigue damage on other drivetrain components**
  - **investigate impact of drivetrain damage reduction on turbine cost of energy**
  - **investigate sensitivity of results to drivetrain details (different main shaft, gearbox and bedplate configurations) and turbine size**

Thank You

Questions?

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