Wind Turbine Drivetrain Development

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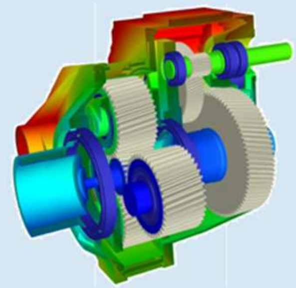
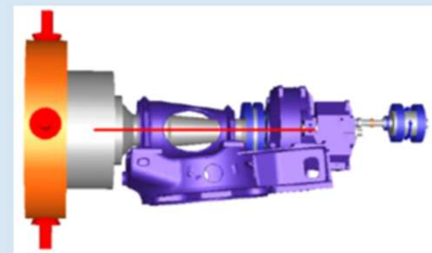
Romax Technology Inc.

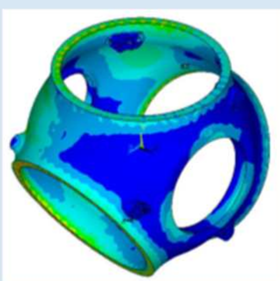
Drivetrain and gearbox design, worldwide no. 1 independent wind turbine gearbox designer; 25 certified gearbox designs and 1.4 GW of gearboxes shipped

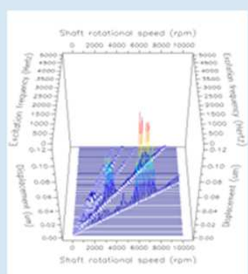
Drivetrain simulation software RomaxWIND, virtual product development environment; dynamic analysis and bearing simulation



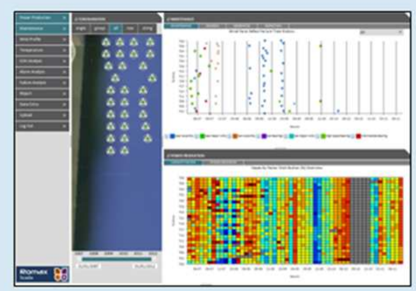


Engineering Consultancy, analysis, certification support and failure investigation





O&M Strategy and Wind Farm Monitoring, Romax InSight software, hardware and services for optimising O&M



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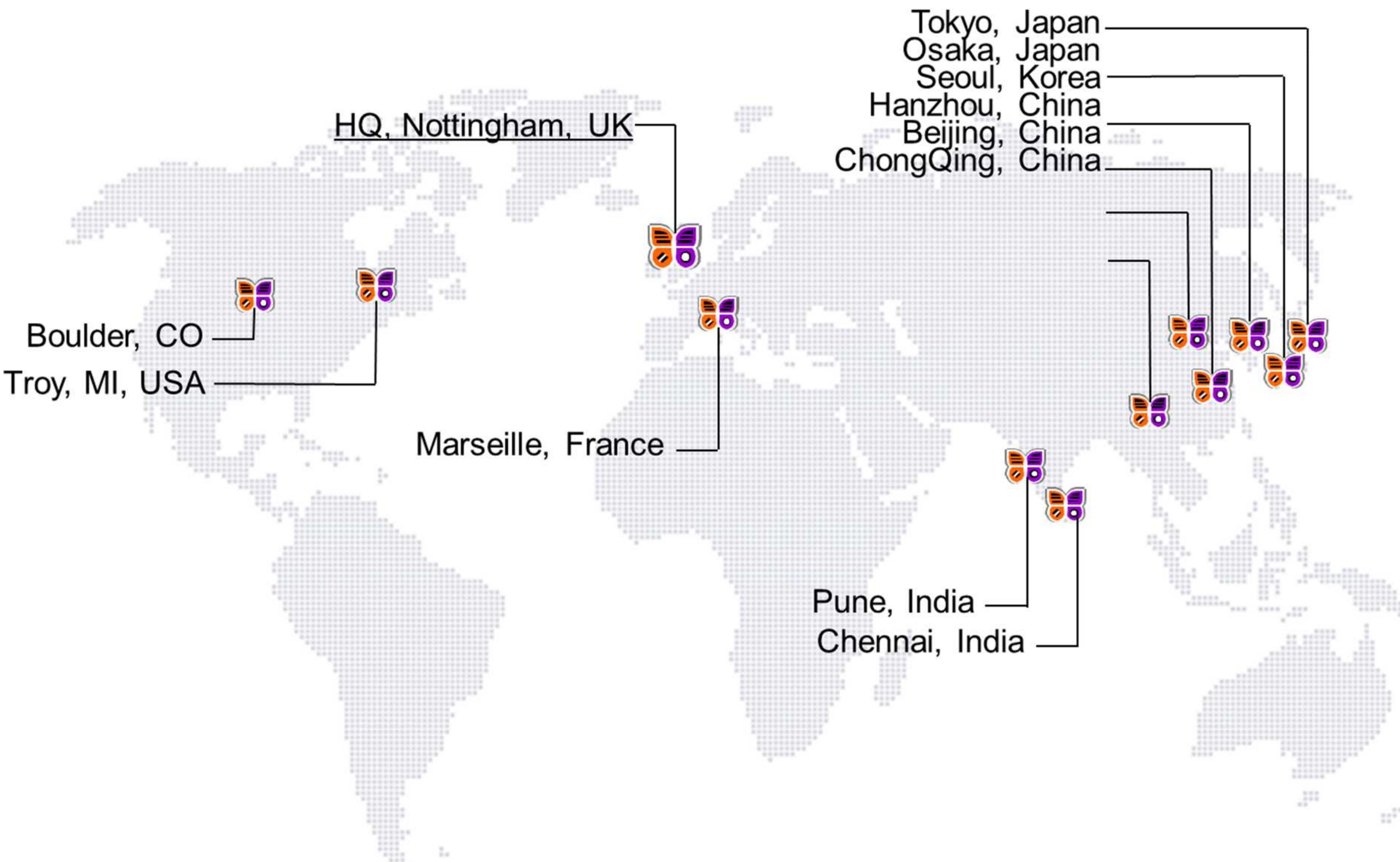


Systems Engineering for Wind Turbine Drivetrains

The Challenge

"Britain's offshore windpower costs **twice as much** as coal and gas generated electricity"

The Daily Telegraph

16th September 2012

The Aim

"Offshore wind power cost could fall **one-third** by 2020"

theguardian

13th June 2012

What the drivetrain designer can do

"**Collaboration** through the supply chain, to deliver more **cost-optimised** integrated design approaches to the turbine system (turbine, tower, foundation, electrics)"

Department of Energy & Climate Change

Office for Renewable Energy Deployment

Systems Engineering for Wind Turbine Drivetrains

- Lifecycle costing
- Supply chain flexibility
- Reliability focus in concept selection
- System interactions – aero/ electrical/ dynamic

- “Over the wall” component design does not result in an optimum drivetrain
- Better systems engineering can help achieve a lower cost of energy

- Demonstrated in the development of our Romax Butterfly™ platform

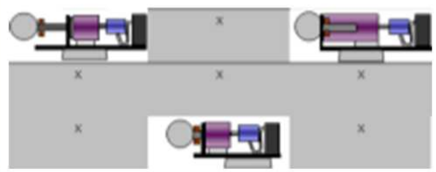
Cost of Energy Analysis – Lifecycle Costing

- Rotating machinery lifecycle cost model - based on
  - CAPEX (capital expenditure) of drivetrain components
    - Generated from our work developing 25 GL-certified gearboxes for a variety of size wind turbine drivetrains
    - $/kg for gearbox shafts, housing, gearing, bearing - estimated based on known purchase cost for various gearbox sizes and types
  - OPEX (operations & maintenance) for drivetrain components
    - Based on experience with wind farm operators
    - Includes realistic failure rates of bearings/gear stages/generator
    - Increased expense of offshore O&M is included
    - Variations with size (kNm) are included
- Cost model is used early – in concept selection

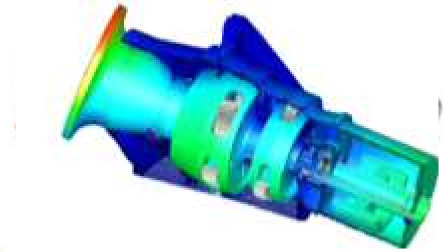
Cost of Energy Model in Concept Design

Fundamental Architecture Selection

Layout Generation



Layout Selection



Step 1: Comparison of Direct Drive vs. High Speed vs. Medium Speed

Step 2: Select fundamental architecture

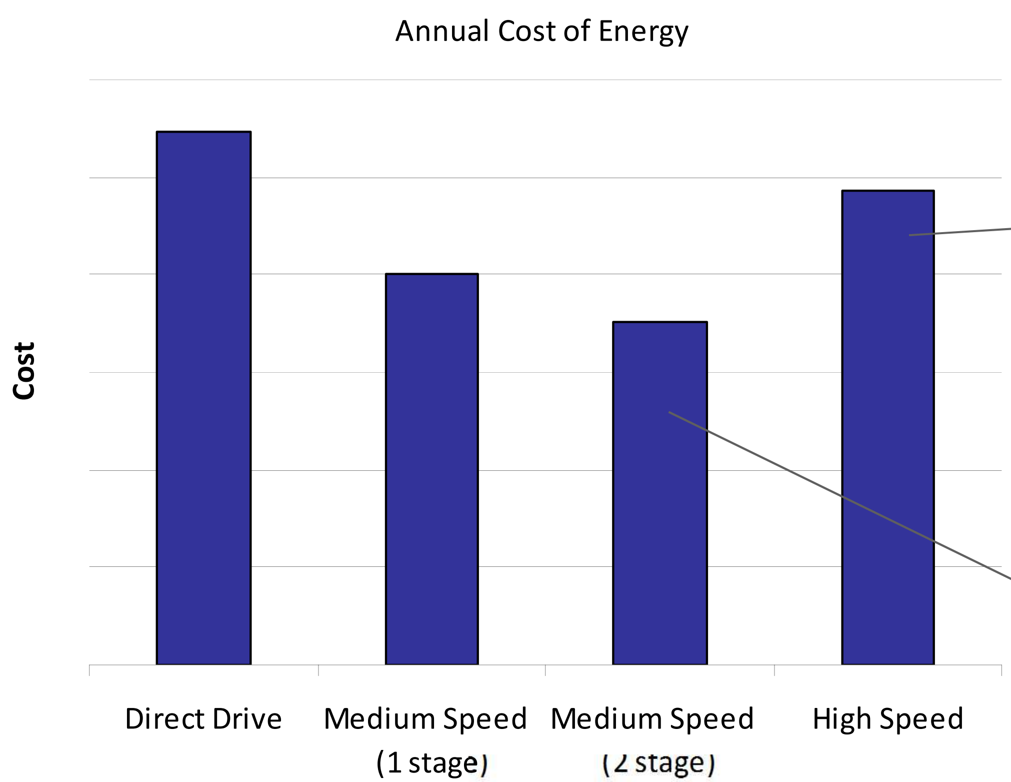
Step 3: Generate possible layouts

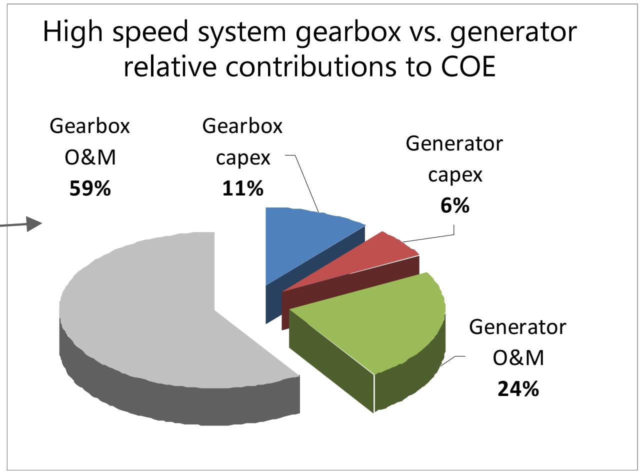
Step 4: Cost of energy calculation of all feasible layouts

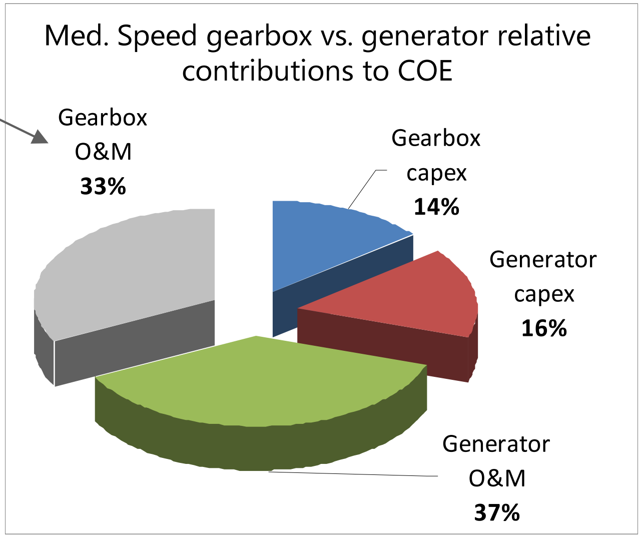
Step 5: Detail subcomponent analysis. Qualitative & quantitative down selection

Increased Reliability: Our Approach

6.xMW Drivetrain Cost Model Off-shore Results



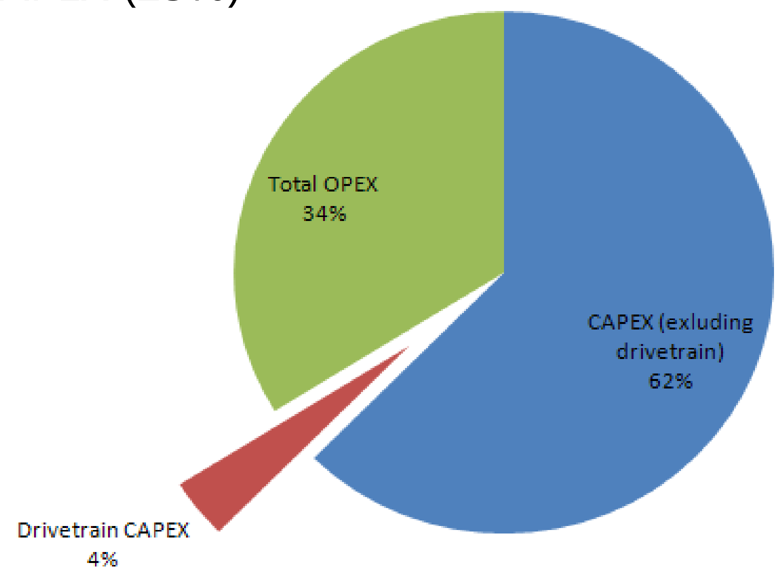




Reducing Cost of Energy

- To reduce Cost of Energy by 1%, we need
  - A moderate reduction in drivetrain O&M cost (7%)
  - A massive reduction in drivetrain CAPEX (25%)

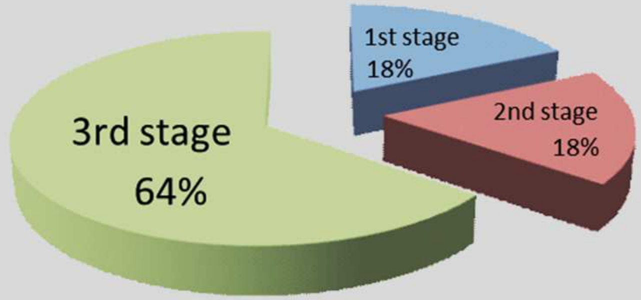
Investing in reliable drivetrains has a major impact on COE



6MW Wind Turbine Cost of Energy

Concept Design Findings

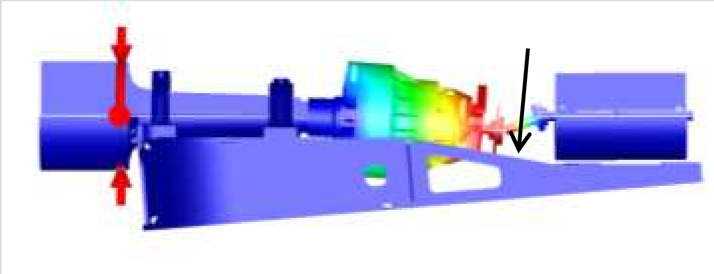
- **High speed gear stage issues**
  - Failure data indicates 64% of gearbox failures are due to high speed shaft gear & bearing failure
  - Pitch line velocities are such that heat generated is significant – issues arise: gear scuffing, controlling bearing preload etc.



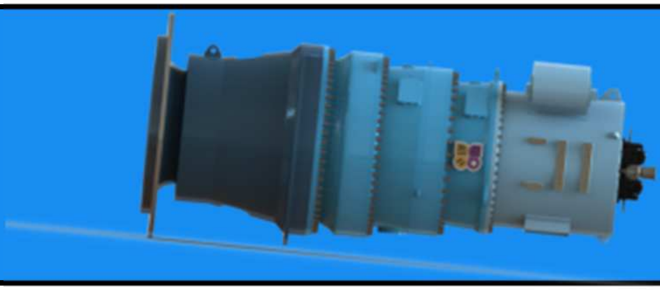
Failure rate of 3MW PL-PL-PA gearbox (failures/turbine/year)

- **Gearbox/Generator alignment**
  - Mounting and bedplate flexibility can cause high misalignment between the gearbox & generator
  - Generator can be incorrectly positioned or sink over time as the rubber mounts degrade + it also moves due to dynamic loading

Potential for high misalignment

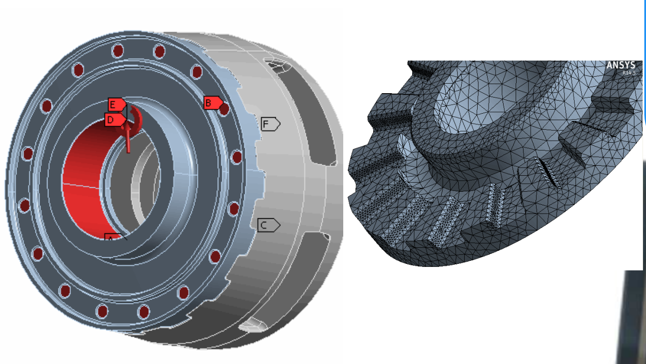


- **Butterfly™ drivetrain**
  - 3 modules aligned using housing connections
  - No high speed stage

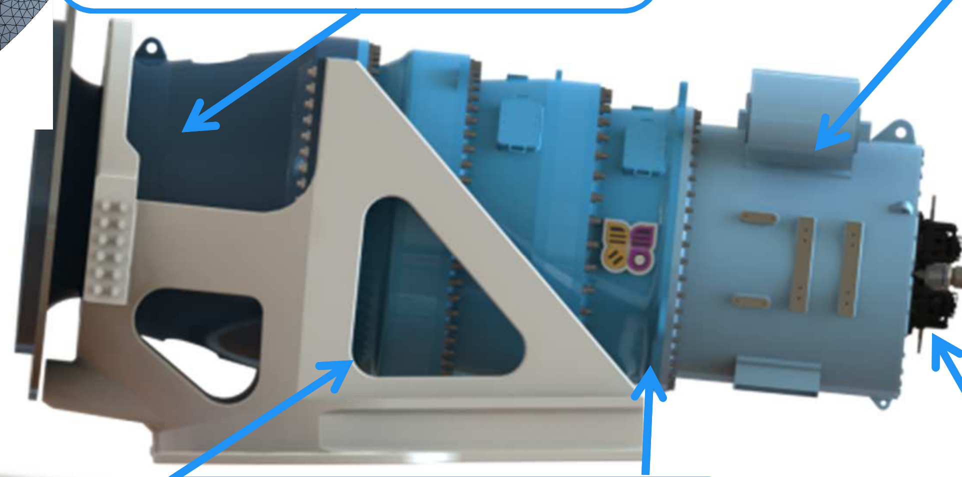


Engineering the System for Flexible O&M

- Service items are easy to replace with nacelle hoist
- Gearbox & generator modules are designed for fast replacement



Patented rotor shaft to gearbox face spline connection



Rotor module can be replaced complete with bearings. Bearing pre-load is therefore set in the factory and not in the tower

Generator can be quickly removed and replaced as sealed and tested item

Generator driven from down wind end

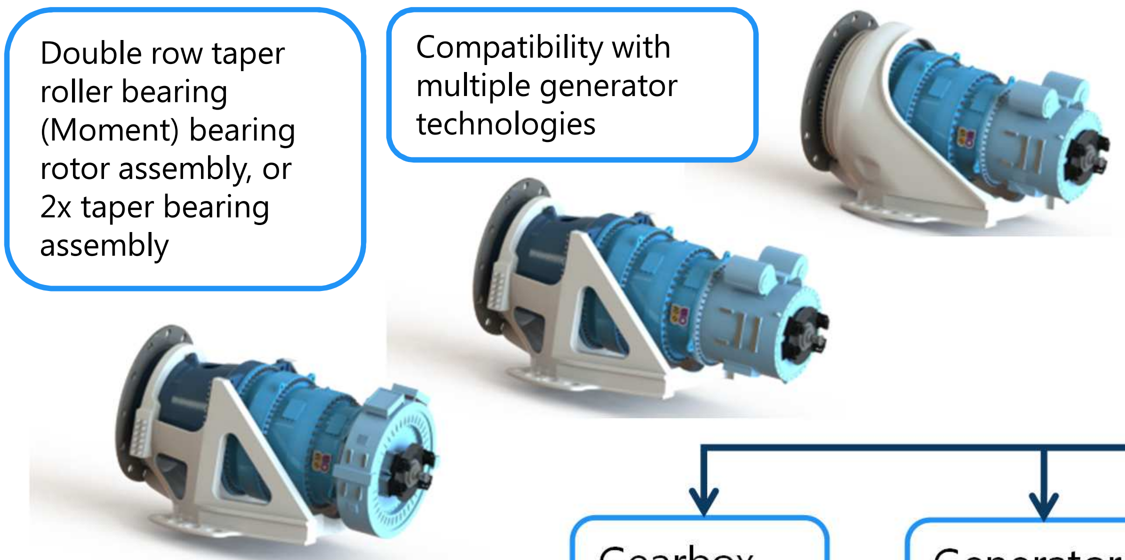
Gearbox can be quickly separated from the rotor module for fast replacement as a sealed and tested item

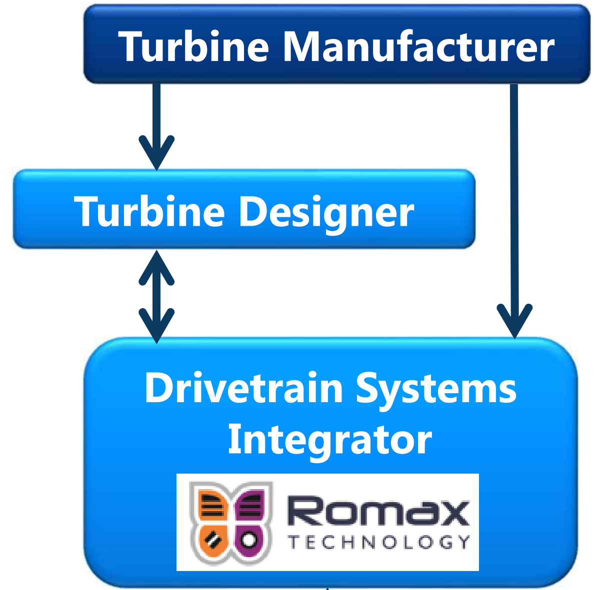
Gearbox and generator can be removed together or the generator can remain in the nacelle and only the gear stages are replaced

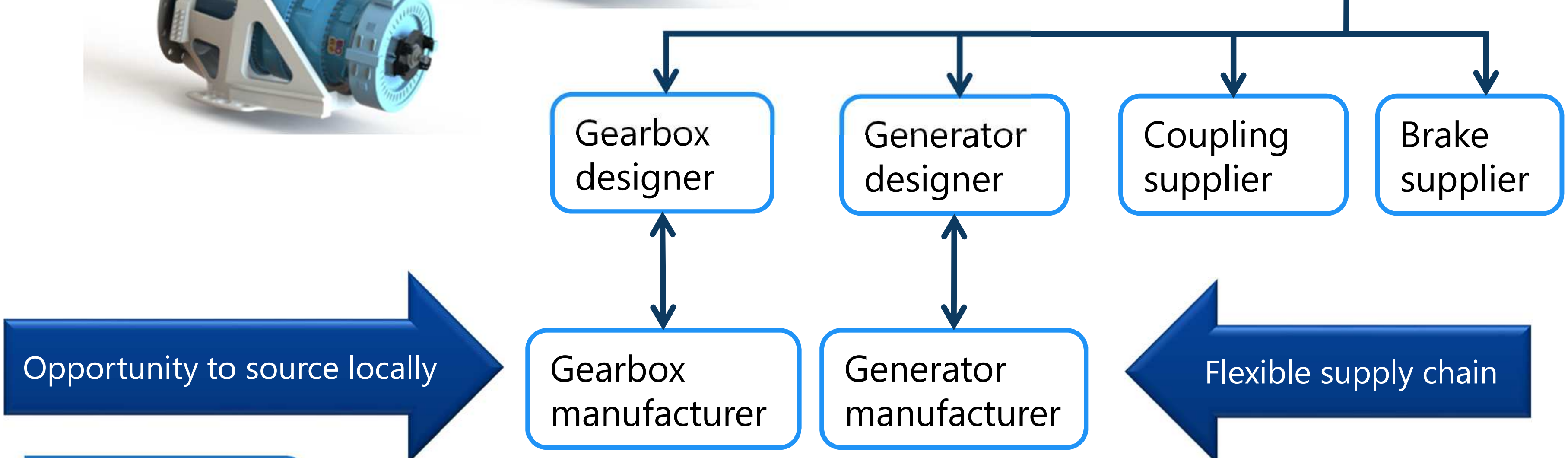
Slip rings, brakes & coupling placed at rear for easy replacement without removing generator

Engineering the System for Supply Chain Flexibility

- Lifecycle costs after prototyping are key
- Flexible supply chain will help keep future costs down

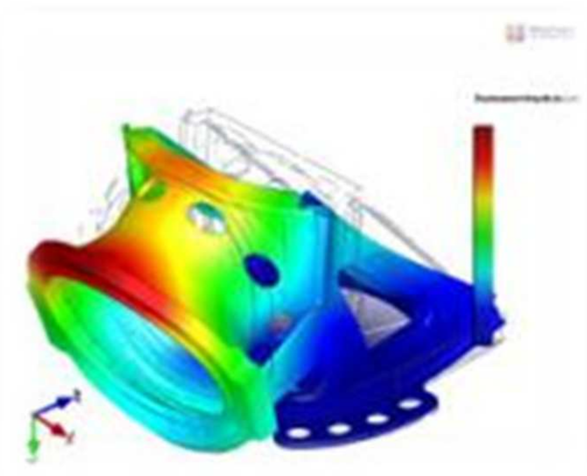






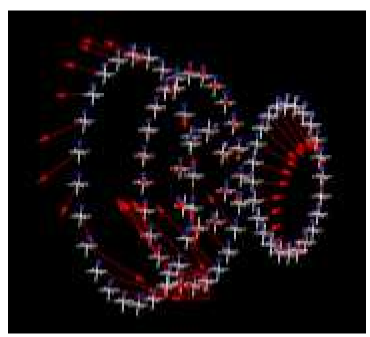
Drivetrain Interaction with Aerodynamic Loads

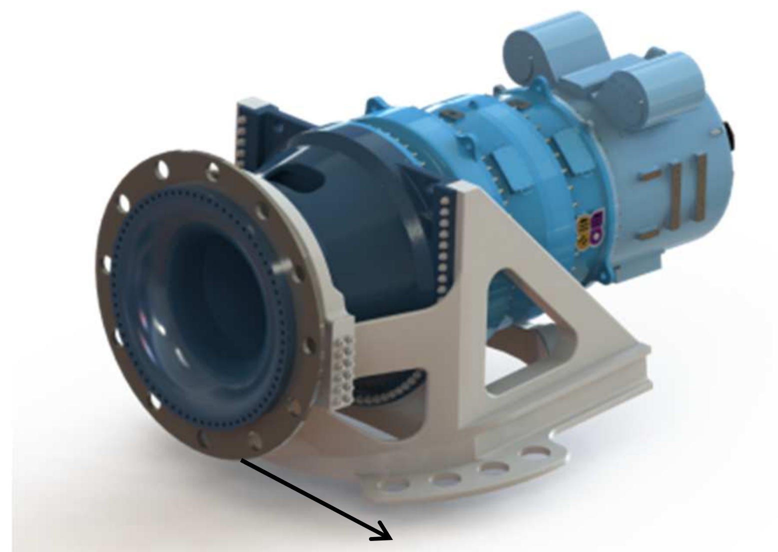
- Nacelle mainframe, main bearings and main shafts are integral parts of the drivetrain system and react the aerodynamic loading
- Even with two large main bearings, some system deflections and forces may be transferred into the gearbox



Structural deflection of the rotor bearing support structure can cause uneven loading of the rotor bearings & premature failure

Understanding of the interaction between bearing forces and system deflections is key for mainframe design

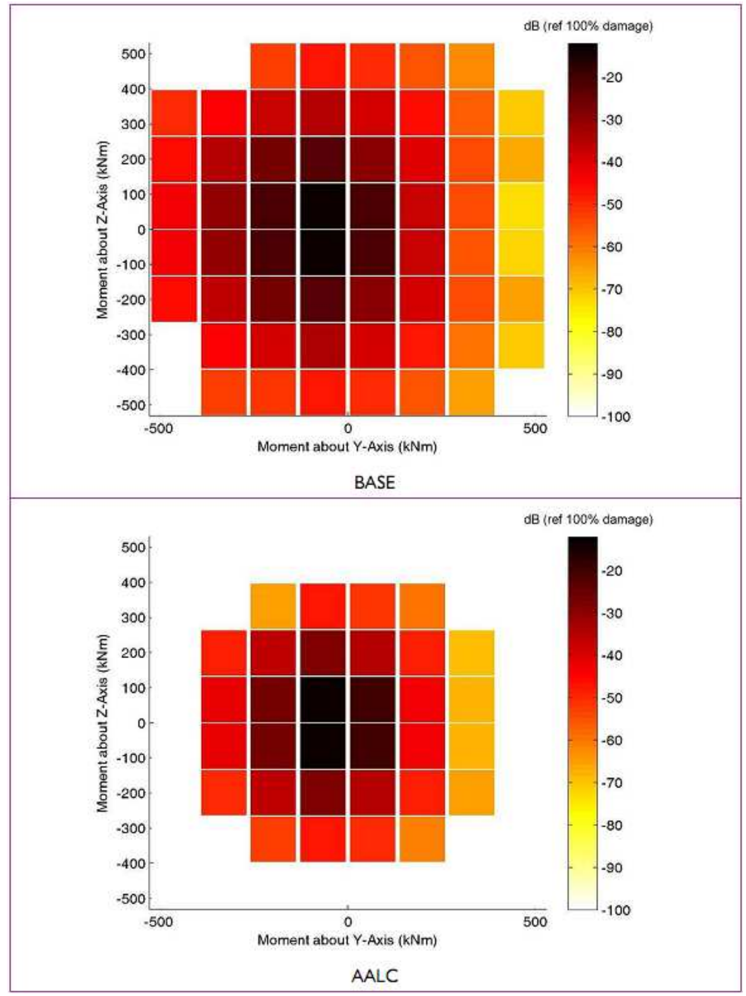




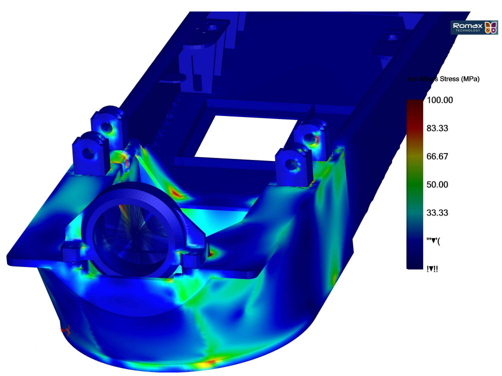
Butterfly™ - Unique Romax designed rotor shaft to gearbox 'flexi-shaft' connection to minimise the bending load transferred from the rotor shaft into the gearbox (patent pending)

Drivetrain Interaction with Control System

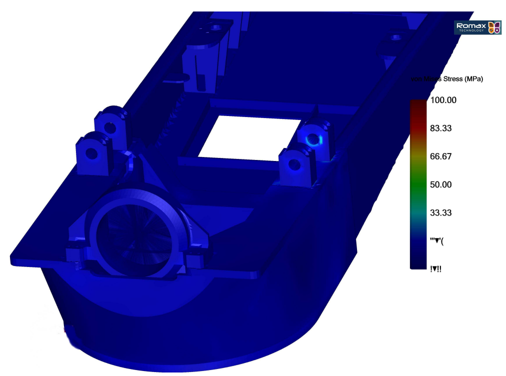
- **Active blade** control systems can reduce bending moments on drivetrain, hence reduce stress, and increase life of components
- **Existing** control systems may be “tuned” to reduce bending moments



Example baseplate stress w & w/o Active Blade control



Base

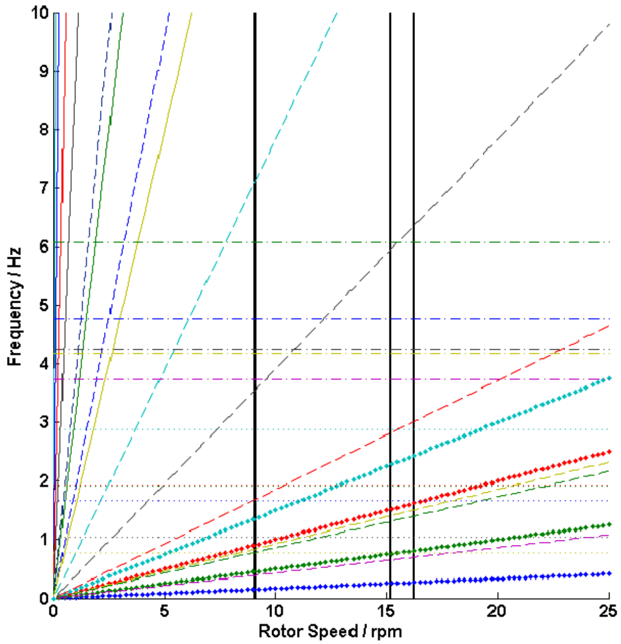


AALC

(from work presented by Dale Berg, Sandia Labs, Wind Turbine Structural Path Stress & Fatigue Reductions Resulting from Active Aerodynamics, AWEA Windpower 2011)

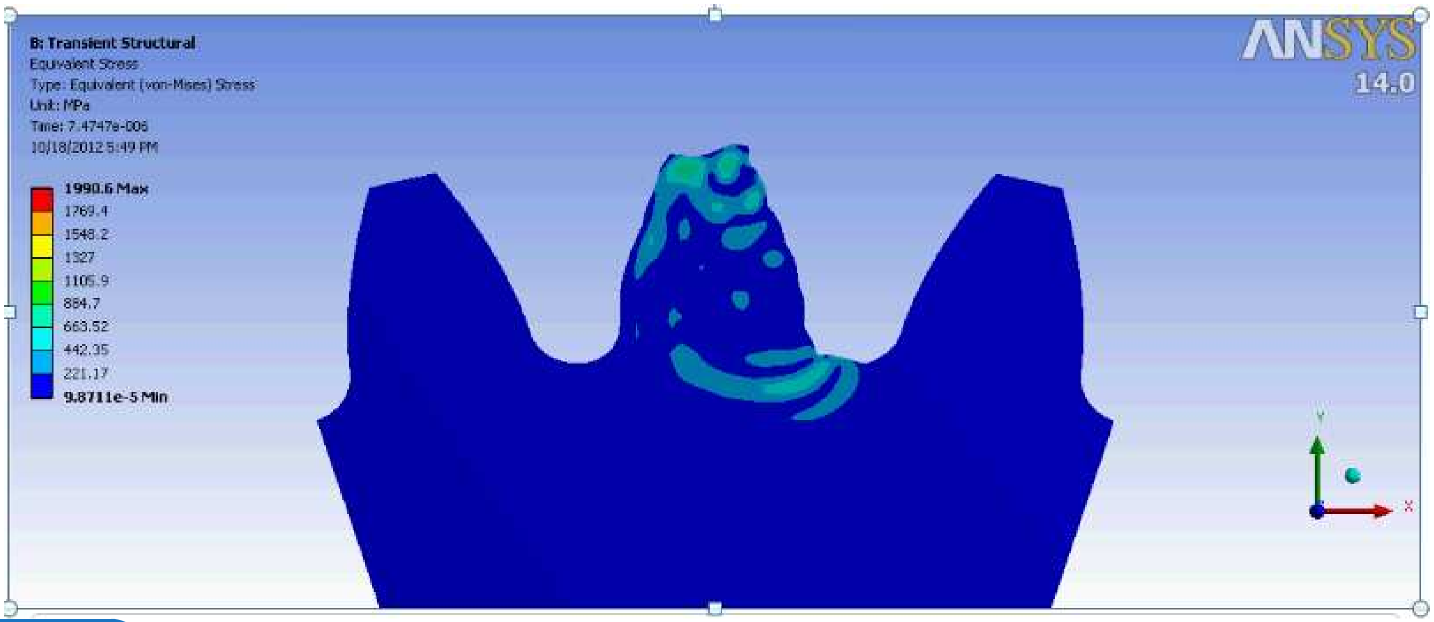
Drivetrain Interaction with Dynamic System

- AGMA, ISO and GL Guidelines require a drivetrain dynamics assessment
- Wind turbine aero-elastic loads models (e.g. FAST, GH Bladed) has only a few lumped inertias for the drivetrain
- Interactions between the lower frequency modes of the drivetrain and blade modes may be missed
- Therefore an additional model is required including more detail of the drivetrain with a simple blade model to check for resonances



Drivetrain Response to Grid and Electrical Loads

- Effect of electrical phenomena on mechanical components
  - Shock loading effect on component durability
    - Standard life calculations assume steady operation
    - Romax are developing an analytical method for capturing fatigue cycles in components after impact.
- Romax are working with NREL/DoE on a new medium speed drivetrain where we will use NREL's new grid-simulator to investigate this further
- Further research is underway on the effect of drivetrain deflection on generator air-gap and combined generator/gearbox noise and vibration transfer



Systems Engineering Applied

Increased reliability

Supply chain flexibility

Reduced time to market

Flexible O&M strategy

Complete drivetrain 'tube' can be lifted into position as one assembly

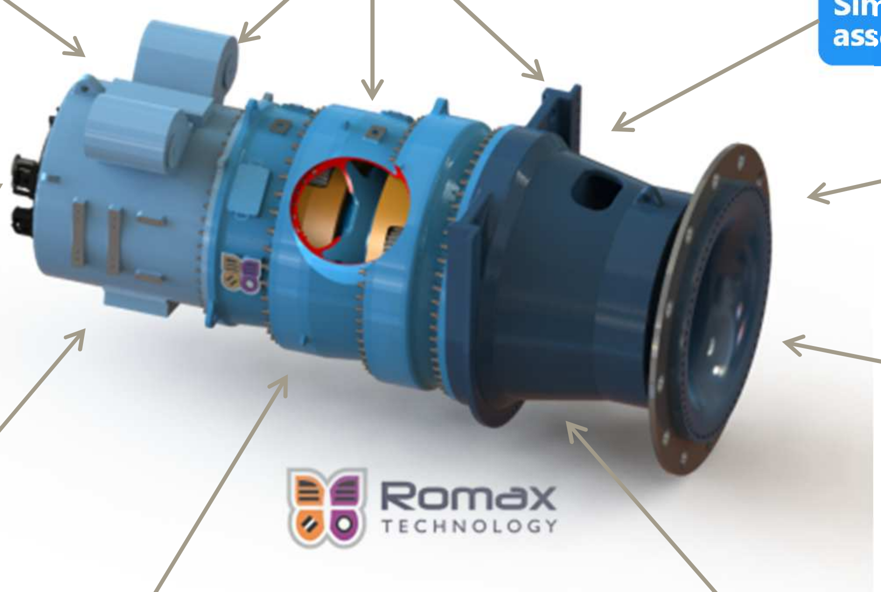
3 self contained 'modules' for ease of assembly & replacement

Multiple suppliers available for all components & sub systems

Simple drivetrain assembly & alignment

Designed for Romax InSight integrated health management system

Design scalable to 10MW



Fast replacement of all serviceable items

Analysis of drivetrain dynamics and system-level behaviour

Advanced Romax gearbox design with patented technology

Innovative lubrication system

Wind Turbine Drivetrain Development

Please visit our website for further information or use the contact details below:

www.romaxtech.com

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