e.on Engineering

Offshore Wind/Marine

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Setting the Scene

Renewable Energy: Integral to the UK Government’s Strategy for tackling climate change

• Target of 20% of UK Energy from Renewable sources by 2020 (Ref DTI Energy Review Report July 2006)

• BERR UK Renewable Energy Strategy Consultation, June 2008

£100 Billion investment in next 12 years; Large increase in Wind Power

Technology Development and Innovation; key to meeting the challenge
Agenda

• An End Users Approach

• Wind Power – Blade Composites
  Manufacturing
  Experimental testing, Structural Health Monitoring, Material Durability
  Computational Modelling
  Non-Destructive Testing

• Marine Devices

• Summary
**End Users Approach**

Operation and Maintenance: **Need to adapt** from trusted approach used on Conventional Plant. Cornerstones such as.....

<table>
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<tr>
<th>Informed Owner and Operator</th>
<th>Service data, Broad and Holistic Eng/Science support, Focussed R&amp;D.</th>
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<tr>
<td>Inspection and Maintenance Plan</td>
<td><strong>Wide fleet knowledge</strong>, Consistent plan, Component and/or System specific.</td>
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<tr>
<td>Condition Assessment</td>
<td>Predominantly Inspection based assessments, Plant on outage, Repair, <strong>Limited on-load monitoring.</strong></td>
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<td>Handling unexpected failures/events</td>
<td>Failure analysis, Safety case, Additional testing, Feedback learning outcomes.</td>
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Offshore Wind Power – Turbine Blade Composites

Horizontal Axis Offshore Turbines

Offshore vs Onshore

- Same turbine concepts
- Offshore: Larger areas for farm development
- Offshore: Higher wind exposure levels
- Offshore: More limited local environmental impact

Additional Offshore Challenges

- Effects of Marine Environment on the Structure
- Implementation of Cost-effective and Safe Operation and Maintenance Procedures; supported by sound science – More arduous environment
Material Behaviour and Ultimate Performance is Dependent on Knowledge of:

- Structural Design Details
- Manufacturing Process
- As manufactured condition on entering service (All blades pass certification tests, so why be concerned?)
- Service conditions (Load, Environment, etc)
- Inspection (How, Which Location, What are we looking for, If we find something is it important?) and Maintenance Feedback
- Computational Modelling (Improve planning, Data required? Capability?)
- Effective refurbishments (Procedures, Durability?)

Now some current research being undertaken to illustrate the above
Blade Characteristics

- Hollow Profile
- Mix of Laminates/Sandwich Panels
- Different loading types
- Flap-wise loading – flexure
- Flexure loading – additional crushing load – Brazier effect
- Internal beams/webs add stiffness
- Fibre-reinforced polymers, wood etc
- Thermosetting Resins; polyester, vinylester, epoxy
- Blade components are adhesively bonded
- IEC 61400-1 (Design loading)
As Manufactured Imperfections or Features

- Resin infusion, with vacuum assist
- Some resin preimpregnated fabrics – laid up
- Cured
- Components adhesively bonded

Imperfections

- Delaminations
- Poor curing – local zones
- Wrinkles, Fibre defects
- Voids/Dry-Zones
- Misalignment of fibres
- Sandwich structures (Core/skin debonds; Core imperfections)
- Bonded joints, voids – partial filling, lack of adhesion - contamination
Modes of Failure - Fracture

Ref: Sorensen et al, “Improved design of large wind turbine blade of fibre composites based on studies of large scale effects”, Riso-R-1390(EN), 2004
Perspective

Modelling/Prediction of damage evolution and assessment of its significance requires:

- Multiscale modelling → Global to Local damage models
- Failure Mechanisms, Significance? Evolution? Scaling – from test to production blades
- Understanding failure under service conditions
  - Repair durability
  - Use of Structural Health Monitoring

Some Details on Current E.ON Research......Full scale to small specimen
**Full Scale Testing**

- Girder Preparation: Failure modes
- Pre Test Inspections: Laser Shearography
- Displacement transducers
- Resistance strain gauges
- Acoustic Emission
- 3D Deflection measurement - ARAMIS
- Post Test Inspections: Laser Shearography + Sectioning

Finite Element Modelling vs Experimental Test

• Ultimate test blade failure; initiated by de-bonding failure in sandwich webs
• Non-linear FE global model; reasonable at tracking global strains
• Need to know detail design features

Ref: Branner, Morris et al “Effect of Sandwich core properties on ultimate strength of a wind turbine blade”, 8th International Conf on Sandwich Structures, ICSS 8, 2008
Shear debonding (or wrinkling) of the outer skin leads to ultimate failure

- Laminate Flange Panel bending
- Sandwich Panel bending and buckling
- Future proposed tests
Box-Beam Overview

Lightweight materials:
- Glass-fibre with epoxy resin
- PVC foam
- Unidirectional fibres for flange - built up in layers
- $\pm 45^\circ$ biaxial outer layers of flanges
- $\pm 45^\circ$ biaxial layers for webs – foam centre creates sandwich
- Dimensions vary along blade length
Flange Testing

Ref: Dear, Morris et al "Digital Image Correlation Based Failure Examination of Sandwich Structures for Wind Turbine Blades", 8th International Conf on Sandwich Structures, ICSS 8, 2008
Bending strain (horizontal) plots

3 Point

4 Point

Initial inter-laminar failure

Experimental Test

Interlaminar cracks initiate at 4-8mm cap deflection

Full scale test

Cap deflections up to 6mm
Sandwich Panel (Web) Testing

**Type 1**
- 2 mm faces
- 13 mm

**Type 2**
- 1 mm faces
- 21 mm

**Type 3**
- 2 mm faces
- 34 mm

Build up of shear in adhesive identified followed by debonding of skin/core and core shear failure (Type 1 Specimen)
Proposed 2009.....

Instrumented sub component

- DIC
- Conventional metrology
- Acoustic Emission (benchmarked off small scale testing)
- Modelling!

• Aim: Define Effective Structural Health Monitoring Strategies
Non-Destructive Testing

To detect, size and characterise defects that might impact on reliability

- Ultrasonic
- Transient thermography
- Laser shearography
- Radiography

- Each has strengths and weaknesses and needs further development before a practical system can be implemented
Marine

Similar philosophy/challenges apply

- Wave loading
- Survivability in harsh environment
- Structural Dynamics in marine environment
- Materials behaviour
- Need for condition monitoring

Computational methods developing to become faster, cheaper and better. Experimental techniques are developing less quickly – how do we reconcile/adapt experimental techniques to keep pace?
Summary

• Integrated approach to understanding material behaviour; under service conditions
  - Experimental methods, Damage initiation and evolution
  - Consideration of manufacturing and design features
  - Environmental effects
  - Modelling
• Broad based and informed Structural Health Monitoring Strategy
• Development of NDE techniques
• Utilisation of UK testing facilities; small scale to full scale
• Underpinning/Enhancing certification procedures
• Durability of repairs
Thank You For Your Attention