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Composite manufacturing development for
wind turbine blades.

Dr Faye Smith April CEng, FIMMM, April 2010

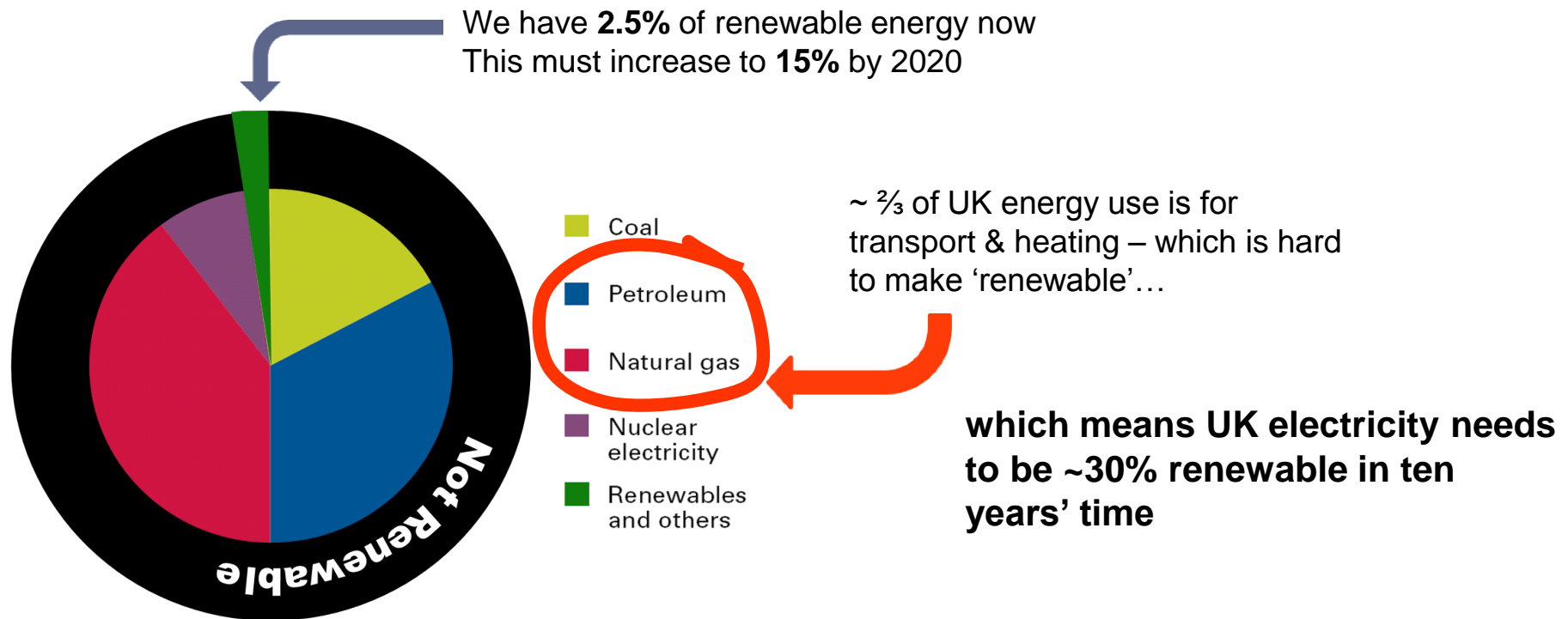


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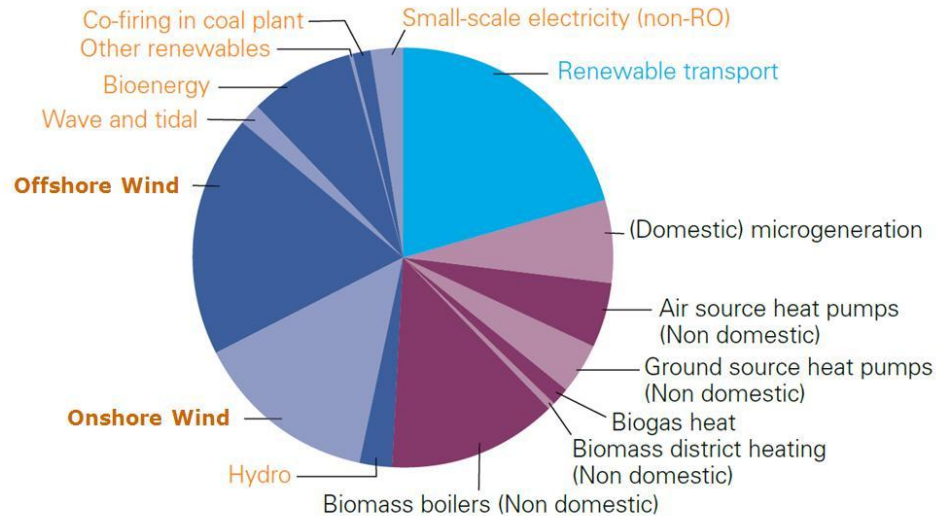
- ▶ Background
 - ▶ Policy
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 - ▶ Realising the UK's offshore potential
 - ▶ Innovation for industrial evolution
- ▶ Focus on blade technology and composites
 - ▶ Production method trends
 - ▶ UK Composites Strategy
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 - ▶ i-Composites projects
 - ▶ TSB funded project
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 - ▶ Other research areas
- ▶ Conclusions

Policy Context

- ▶ Climate Change Act requires 80% emissions cut by 2050
- ▶ EU requires UK to produce 15% of energy from renewable sources by 2020. This may mean 30% renewable electricity



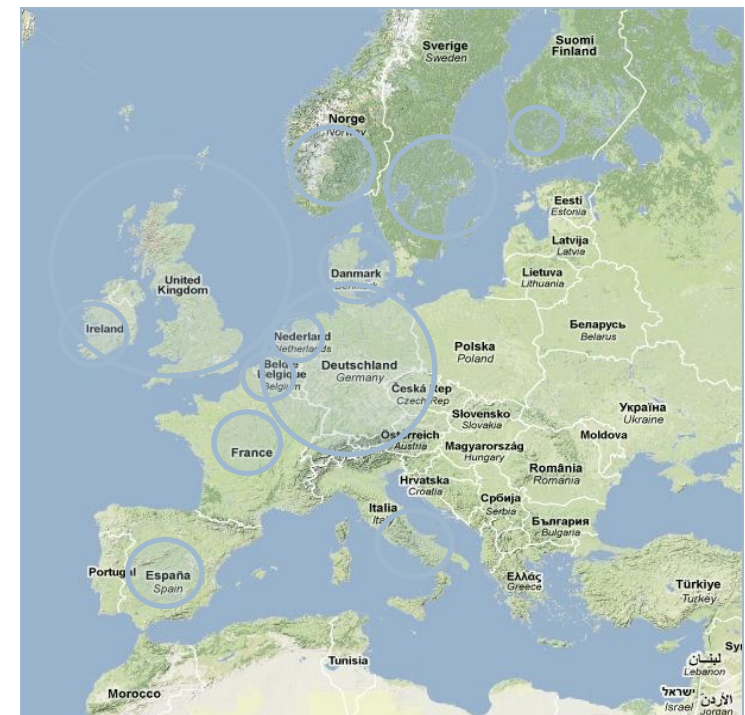
What Might 15% Renewables Look Like?



Illustrative mix of technologies that shows 30% of electricity from renewable energy is achievable.

| | Onshore | Offshore |
|--------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Benefits | Lower cost Well developed technology | Huge potential Reduced planning constraint |
| Installed capacity | ~ 3.6GW | > 1GW UK is the world leader |
| Potential | <ul style="list-style-type: none"> 4.4GW consented 7.6GW pre-consent | <ul style="list-style-type: none"> 4GW consented 2.3GW pre-consent Industry plan 47GW by 2020 |

- ▶ The UK has 40% of Europe's wind energy resource.
- ▶ Mainly due to exposed and Northerly seas and mountains.

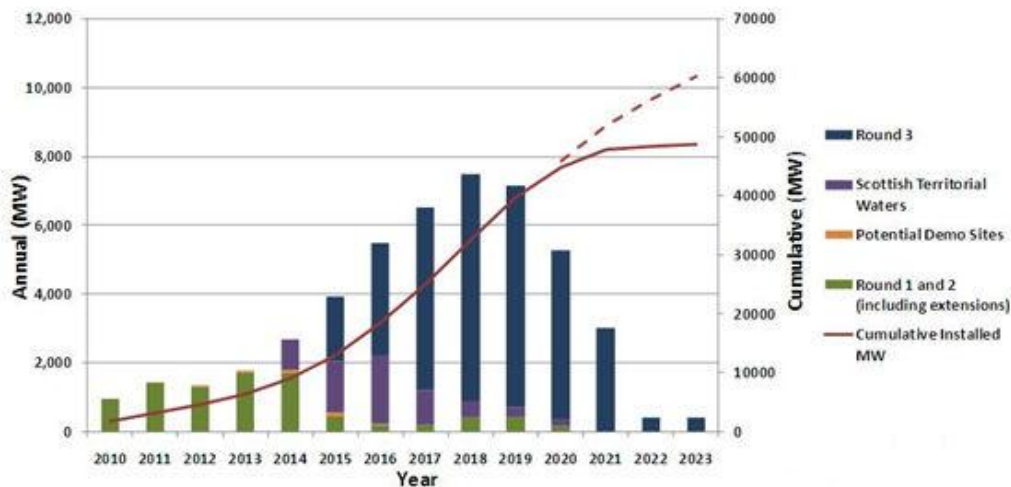


Average percentage contribution to offshore wind capacity based on EWEA and WWEA projections

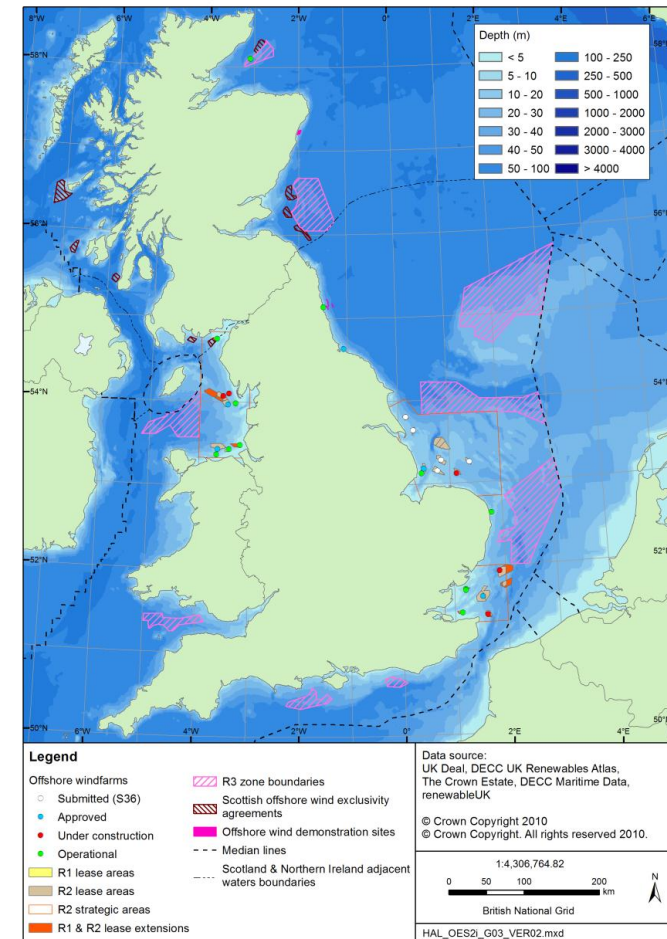


Realising the UK Offshore Wind Potential

| Round | Size (GW) | Status |
|--------------------|------------|-----------------------------------------------------------------|
| Round 1 | 1 | Majority generating (Autumn 2010) |
| Round 2 | 7 | 365MW generating, almost 1.7GW under construction (Autumn 2010) |
| Round 3 | Up to 32GW | Scoping stage Construction from 2015 |
| R1 & R2 Extensions | Up to 2GW | Confirmed |
| Demo sites | 14MW | Successful bidders notified |
| Scottish Waters | 6.4GW | Subject to Scottish SEA |



Information from Developers forward plans and projected capacity





Innovation for industrial evolution

- ▶ Until recently, offshore turbines were 'marinised' versions of onshore models.
- ▶ Increasingly, turbines are being designed specifically for offshore deployment with larger capacities (5MW and above, rather than about 3MW for onshore use).
- ▶ Reasons for technology diverging, which introduce significant scope for innovation:
 - ▶ Size of the offshore market justifies the development of specific technologies.
 - ▶ Offshore projects are free from many of the constraints that have shaped the onshore market, such noise and visual impacts, and transport.
 - ▶ Access to offshore turbines is constrained therefore greater emphasis on reliability.
 - ▶ While larger turbines are marginally more expensive per MW installed, they offer higher yields and reduced O&M costs.
- ▶ The UK market makes it a focus for new technology development and demonstration for offshore wind

2000-2009 Pioneering Phase

- Technology viability
- System knowledge
- Developing concepts
- Developing relationships



2009-2015 Industrialising offshore

- Stimulating competition
- Applying lessons
- R&D & demonstration
- Scale (sourcing & knowledge base)
- Cost efficiency (technology development, installation and O&M concepts & value chain engineering)
- Component reliability

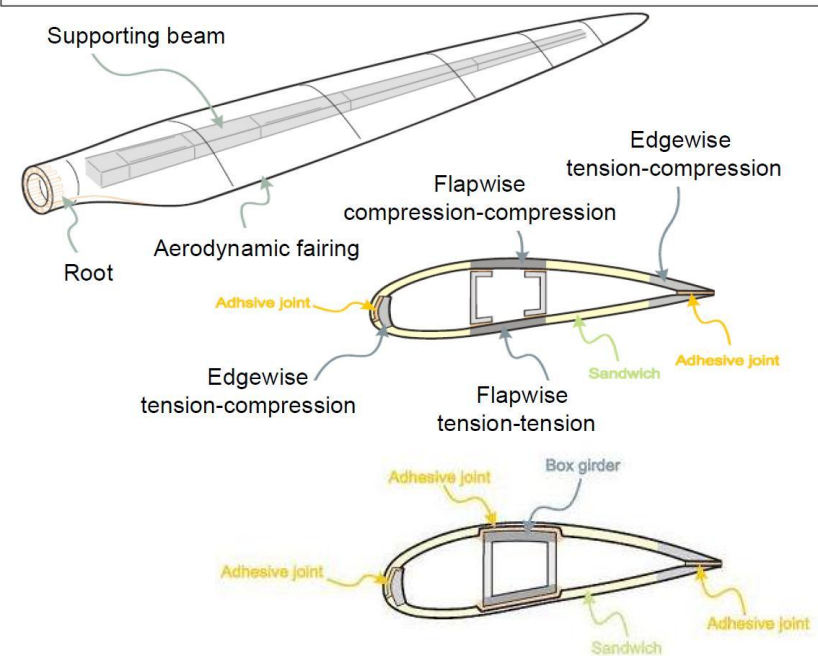
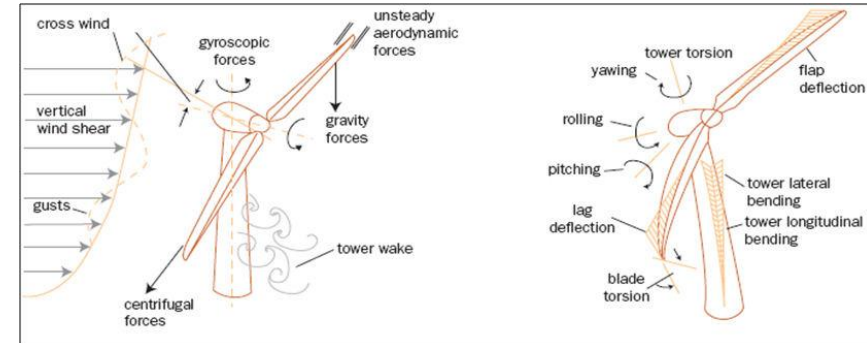


2015- Large scale GW offshore power plants

- Apply R&D & demonstration
 - New concepts
 - New materials
 - New technology

Focus on Blade Technology

- ▶ Approximately 25% of the cost of an offshore wind turbine goes on the rotor.
- ▶ Rotor blade design drivers include:
 - ▶ Tower clearance
 - ▶ Extreme aerodynamic loads
 - ▶ Mass loads
 - ▶ High fatigue loading
 - ▶ No maintenance
 - ▶ Environment
- ▶ Power output \propto blade length², but blade weight \propto blade length³. Heavier blades increase the loads on the rest of the machine and increase the costs of transport, installation etc.
- ▶ For offshore wind, where large blades are used to optimise power output, design and therefore material choice are driven by weight reduction while ensuring ability to cope with load and fatigue requirements.
- ▶ Schematics of two common designs are shown:
 - ▶ Load carrying laminates in the aeroshells and webs for preventing buckling
 - ▶ Load carrying box



Focus on Composites

Requirements:

- > Low weight and density
- > High stiffness/density ratio
- > High fatigue strength

Fibers :

- > Glass
- > Carbon
- > Wood
- > Mao bamboo

Matrix Resins :

- > Thermosets
- > Thermoplastics

Structural Materials :

- > UD Prepregs
- > Bi- & Multi-axial Fabrics
- > Preforms / Woven Fabrics
- > Hybrid Fabrics
- > Steel

Core Materials :

- > Wood
- > Foams
- > Honeycombs

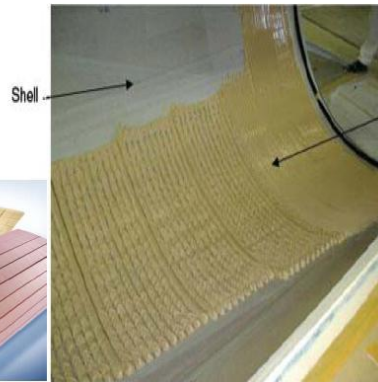
Priming / Finishing :

- > Gelcoats / primers
- > Sealants
- > UV epoxy coats
- > UV paints

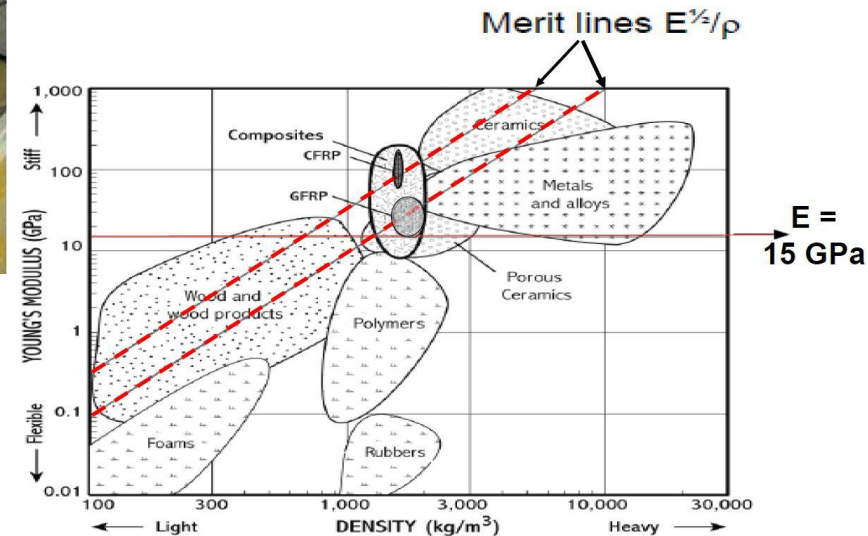
Adhesives :

- > Epoxy base
- > Polyurethane base

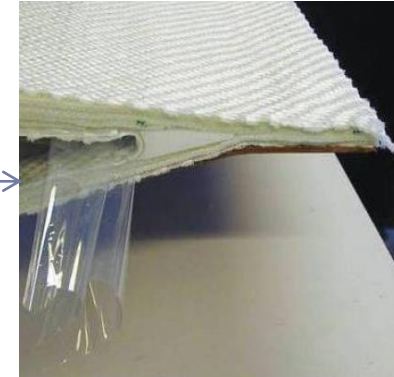
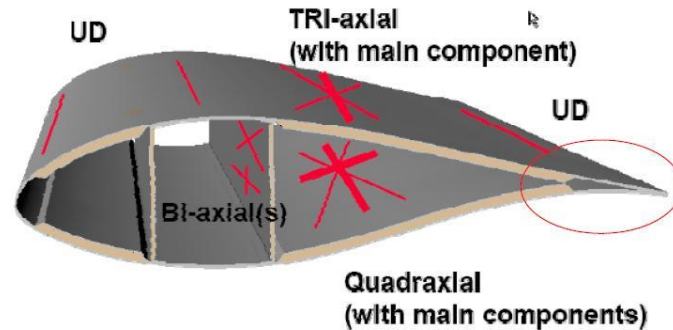
Given their excellent mechanical and environmental properties and light weight, composites have become the material of choice for turbine blades.



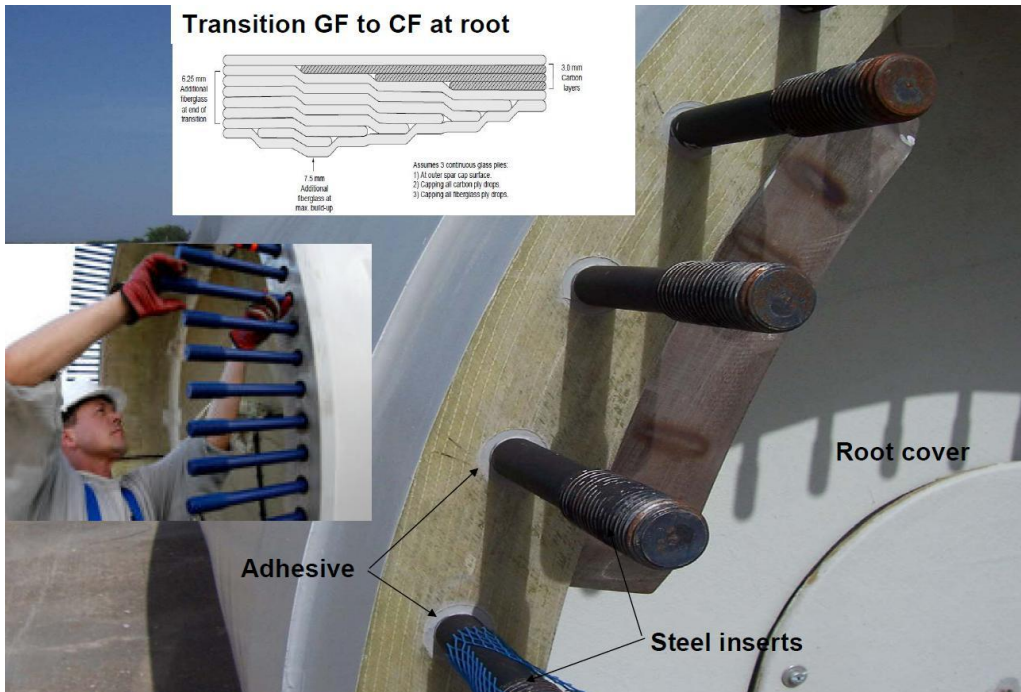
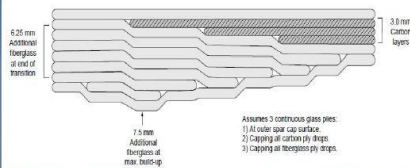
Adhesion



Focus on Composites



Transition GF to CF at root



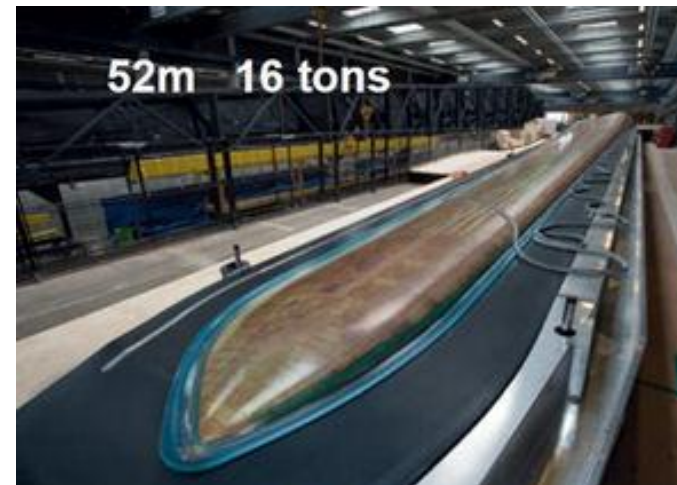
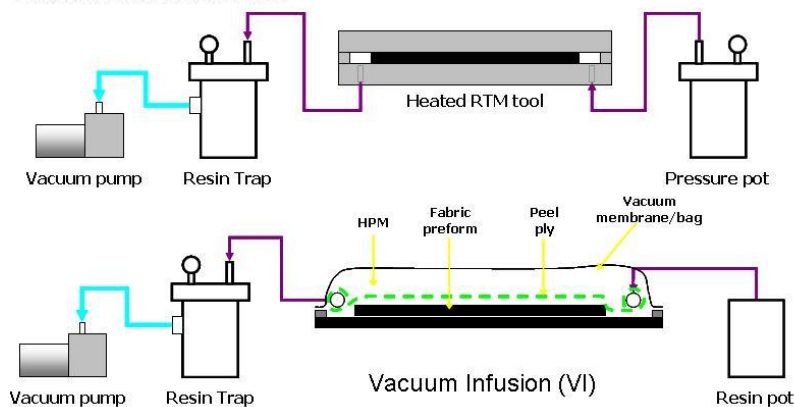
- ▶ Composite production techniques also allow properties of the part to be changed along the part.
- ▶ This can be achieved by using different fibres/orientations /thicknesses/cores at different parts of the part.

Production Method Trends



- ▶ Traditionally small turbine blade manufacture using composites shared a lot of common practises with the marine industry, using open mould hand lay-up of dry fabric and resin.
- ▶ Today, manufacture has improved in terms of environmental impact, quality and reproducibility and the methods used are:
 - ▶ Infusion (lay down of dry fabric on a mould, cover in a vacuum bag and using the vacuum to pull resin into the fabric. Resin is then cured.).
 - ▶ VARTM and RTM (as with infusion, but using a matched set of tooling)
 - ▶ Prepreg (strips of fabric preimpregnated with resin are laid up by hand onto a mould tool. The preform is encased in a vacuum bag and cured.

Photo courtesy of VienTek.





Production Method Trends

- ▶ BVG Associates estimates that by the end of the decade 1,300 turbines will be installed annually in Europe. This enormous market requirement is driving manufacturers to change production methods to increase blade production rates.
- ▶ The offshore market's requirement for larger blades is also forcing manufacturers to design larger blades which may require different materials and different production techniques.
- ▶ The requirement for no maintenance is also driving a requirement to improve quality and consistency through processes such as automation.
- ▶ The wind industry is therefore now looking to the same materials, manufacturing methods and QA practices for composite structures as the aerospace industry. Both industries need to increase materials deposition rate/reduce cycle time and improve quality/reduce manufacturing defects. In some areas (notably lay-down rate) challenges faced in wind exceed those of aerospace.
- ▶ Manufacturing methods being investigated include:
 - ▶ Automated Fibre Placement (AFP)
 - ▶ Automated Tape Laying (ATL)
 - ▶ Automated Dry Fabric Preforming
- ▶ The UK's expertise in composite aerospace structures means it is well placed to bring these two industries together to collaborate in further composite manufacturing development.

Production Method Trends

- ▶ **Examples of UK aerospace composites expertise:**
 - ▶ **BAE Systems Samlesbury** - The composites facility is one of the most up to-date anywhere in the world with continuous development for business including Eurofighter and JSF II production.
 - ▶ **GKN Aerospace IoW and Filton** - £14.8m new facility on IoW will develop & produce a new all-composite engine fan blade to reduce emissions. GKN took over Filton wing component and assemblies manufacturing unit and Filton-West is their new production plant making wing spars and trailing edge for A350.
- ▶ **Examples of companies investing in manufacturing R&D in the UK include:**
 - ▶ **Clipper Windpower** - In February, 2010 construction work began for the new Clipper Windpower facility in Newcastle. This will develop 72m turbine blades – the world’s largest – for Clipper’s 10MW ‘Britannia’ wind turbine.
 - ▶ **Vestas** – Vestas is investing more than £50m in R&D in the UK including a R&D Centre on the Isle of Wight to work on design and development of a next generation, multi mega watt offshore wind turbine blade.
- ▶ The following slides give a description of the UK composites strategy and examples of different types of research programmes in this area:
 - ▶ UK Composites Strategy, NCC and Grand Challenge (i-Composites)
 - ▶ Example of collaborative research funded by Technology Strategy Board
 - ▶ SuperGen Wind – University Consortium funded by EPSRC



UK Composites Strategy



Building
Britain's Future

- ▶ In order to enable the UK to be in a position to take full advantage of the significant, cross-sectoral commercial opportunities afforded by its composite capability, in November 2009, the Dept for Business, Innovation and Skills launched the UK Composites strategy.
- ▶ This included a £22m investment:
 - ▶ £16m into a National Composites Centre.
 - ▶ £6m into 'Grand Challenge' to develop new manufacturing techniques.

<http://avaloncsi.com/resources-2/reports/>

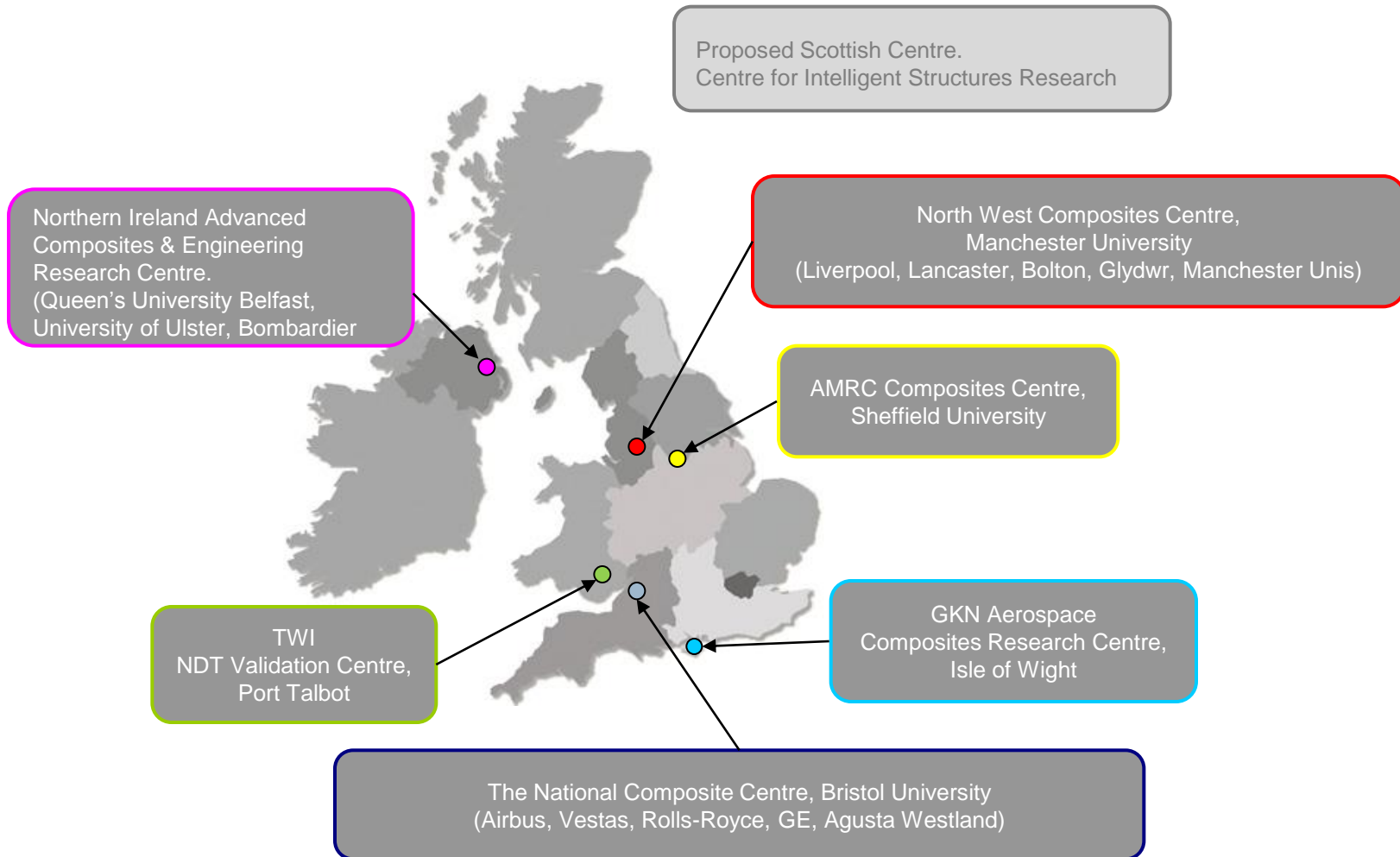
- ▶ Independent open-access *National* Centre delivering world-class innovation in the design & rapid manufacture of composites.
- ▶ Aims to facilitate cross-industry collaboration and enable industrial exploitation.
- ▶ An internationally leading hub linking activities across all sectors of the UK in research, education and training, technology transfer.
- ▶ £12M from Central Govt, £4M from SWRDA, additional £9M from ERDF.
- ▶ Purpose built 8500m² facility on SPark in Bristol with workshop, offices, meeting rooms, teaching facilities.
- ▶ Equipped to focus on optimised-design, analysis, rapid manufacture and testing.
- ▶ Two tier subscription membership, or 'pay as you go'.



- ▶ Founding tier 1 members currently include; Vestas, Rolls-Royce, GKN, Airbus, Agusta Westland.
- ▶ Coordinate Regional Composites Centres.
- ▶ The Centre will open in Summer 2011, but work amongst the members has already started.
- ▶ Part of High Value Manufacturing Catapult – long term funding.

<http://nccuk.com/>

UK Composite Centres



Composites Grand Challenge



- ▶ **i**-Composites is a unique £10M Technology Strategy Board research programme led by GKN Aerospace and 22 other cross-sector partners.
- ▶ The 1 year programme will develop innovative composite manufacturing techniques, processes and materials for high-performance, high-value products.
- ▶ Within technology themes, research partners from multiple industries are working together to strengthen UK capability in Advanced Materials.
- ▶ Themes:
 - Simulation
 - Energy reduction
 - Automation
 - Process time reduction
 - Materials
 - Sustainability

Leading UK industry in time, cost and energy reduction, *i*-Composites will enhance the performance of composite materials through sustainable design and manufacturing technology.

<http://www.axillium.com/i-composites/>



Simulation



Energy Reduction



Automation



Process Time Reduction



Materials



Sustainability

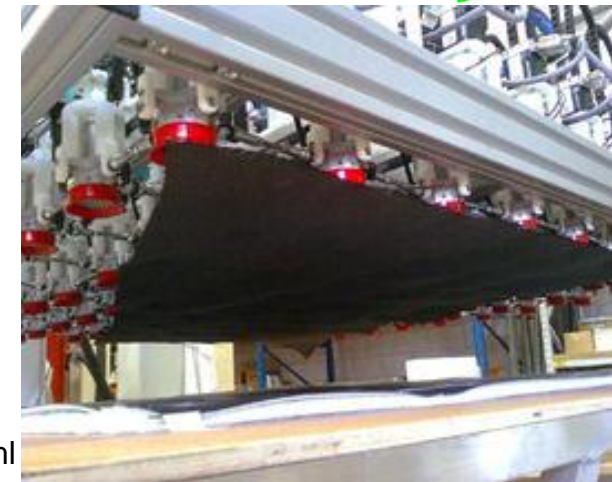
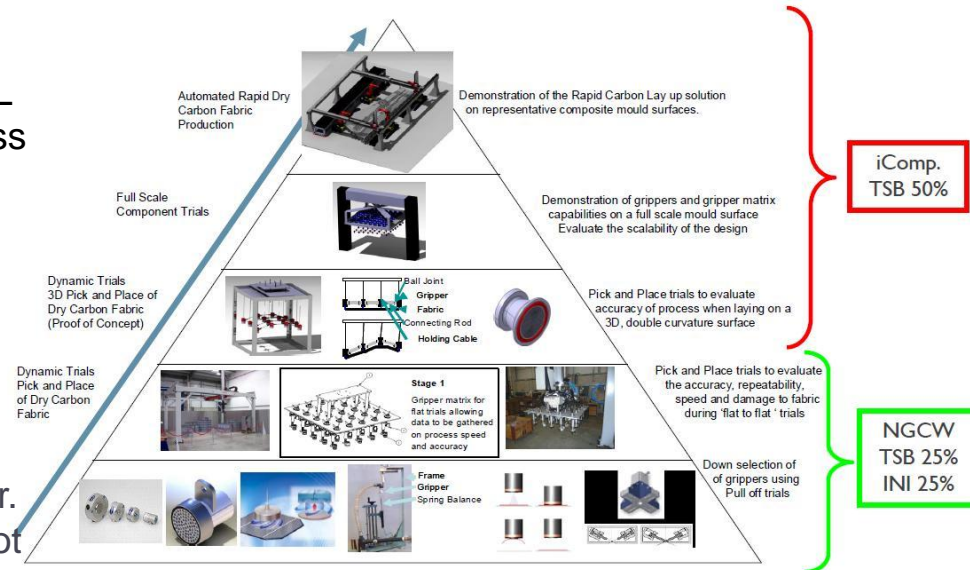
Pick and Place Project (i-Composites)



- ▶ Part of the Automation theme in i-Composites.
- ▶ Partners; Bombardier Aerospace, KUKA, GUDEL Lineartec UK Ltd, LOOP Technology Ltd, Princess Yachts International Plc .

Aims

- ▶ Cost reduction
 - ▶ 4 fold reduction in lay up time.
 - ▶ Fewer lay up tools required.
 - ▶ Less floor space required.
- ▶ Quality
 - ▶ Accuracy -Hand layup dependent on operator.
 - ▶ Repeatability -Stage 1 trials using gantry robot proved high degree of repeatability.
 - ▶ Quality control –Vision system will check and record fibre orientation of each ply.
 - ▶ Edge of part checked, adjusted and verified.
- ▶ Delivery
 - ▶ Flexibility - Adaptable to any mould shape/type.
 - ▶ Cycle time -Reduction in layup time will reduce overall time to market.



<http://www.axillium.com/i-composites/ic-themes/automation/picking-and-placing/index.html>

Complex AFP (i-Composites)

- ▶ Part of the Process Time Reduction theme in i-Composites programme.
<http://www.axillium.com/i-composites/ic-themes/process-time-reduction/auto-fibre-placement/index.html>
- ▶ Partners; Cobham, ACG and AMRC

Objective

- ▶ Design, develop and manufacture demonstrator component by AFP; equivalent component to be manufactured by hand layup to generate comparative test data and manufacturing metrics (cost, quality, time).

Key Deliverables

- ▶ Preliminary design of demonstrator component and identification of key features for process development
- ▶ Slit tape definition and development for AFP (MTM44-1 tack and impregnation optimised. Slitting facility optimised. 134gsm and 268gsm material produced)
- ▶ Tooling development for AFP
- ▶ Design optimisation for manufacturing process
(Path modelling used to provide design rules to avoid gaps and increase accuracy of placement)
- ▶ Manufacture of AFP demonstrator components
- ▶ Testing and comparison against hand-laid component





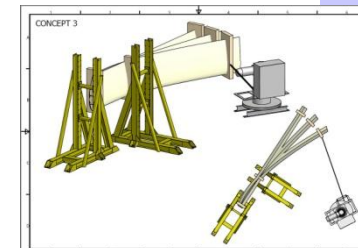
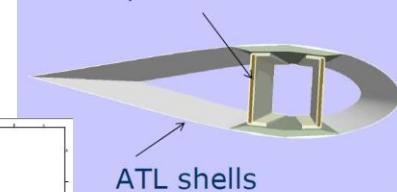
Airpower (TSB)

- Affordable Innovative Rapid Production of Off-shore Wind Energy Rotor-blades.
- £1.4m project funded by TSB over 3 years finished Sept 2010.
- Partners; Insensys, Hexcel, GE Aviation, Gamesa, NaREC, BAE Systems, Magnum Venus Plastech, Solent Composite Systems, Windsupply, Windturbine composites, Windforce, University of Nottingham.

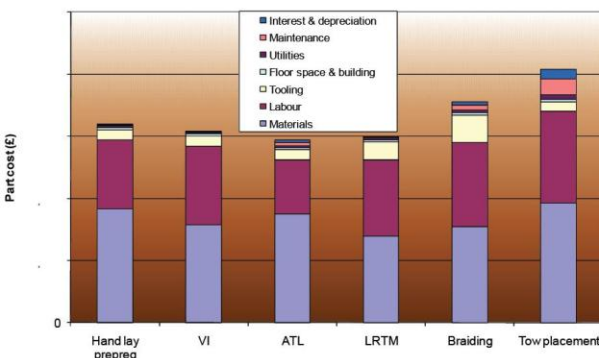
Objectives

- Develop cost effective, automated high deposition manufacturing of large scale rotor-blades (ATL and LRTM).
- Develop innovative low cost, high stiffness materials.
- Develop strain monitoring solutions using fibre optics (for cure process and in-service monitoring)
- Produce a demonstrator blade section (7m long).

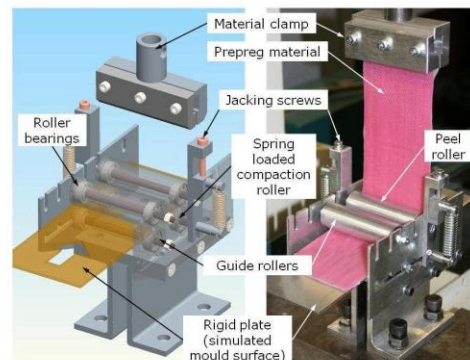
LRTM spar and core



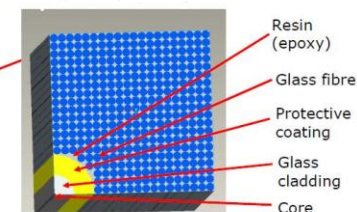
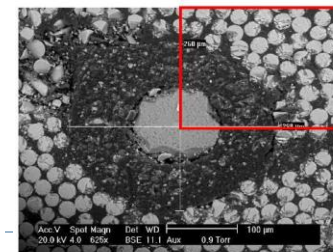
8% saving by utilising ATL over hand lay prepreg techniques



Peel tack test simulates ATL



Modelling FBG



SuperGen Wind (EPSRC)

- ▶ Established March 2006, renewed for 4 years, March 2010. Run under the Energy Programme of research councils UK, which is led by EPSRC.
- ▶ Led by Strathclyde and Durham Universities, also includes Manchester Uni, MMU, RAL, Surrey and Loughborough . The Consortium has the active support of 17 industrial partners.
- ▶ Three parallel themes in years 1 & 2:
 1. Research the physics and engineering of the offshore wind farm,
 2. Look more specifically at the wind turbine, building on Supergen Wind 1,
 3. Address technical barriers to wind farm connection and grid capacity issues.



Theme 1 The Farm

www.supergen-wind.org.uk

Theme 2 The Turbine

Theme 3 The Connection

Theme 4 The wind farm as a power station

- ▶ Theme 1: The Farm, Dr Simon Watson (Loughborough)
 - ▶ Offshore wind resource
 - ▶ Wakes and aerodynamics
 - ▶ Radar and the environment
 - ▶ Optimisation of farm performance
 - ▶ Multiple wake impacts on machines
- ▶ Theme 2: The Turbine, Dr Geoff Dutton (RAL)
 - ▶ Drive train dynamics
 - ▶ Rotor-wind field interaction
 - ▶ Turbine blade and tower materials
 - ▶ Fault detection for a greater range of future wind turbine drive train configurations
 - ▶ Subsea turbine foundation
- ▶ Theme 3: The Connection, Prof Peter Tavner (Durham)
 - ▶ New offshore nacelle and substation equipment arrangement
 - ▶ Offshore control schemes
 - ▶ Connection to shore
 - ▶ Integration of energy storage
- ▶ Theme 4: Wind Farm as a Power Station, Prof Bill Leithead (Strathclyde)
 - ▶ Array performance
 - ▶ Wind farm control
 - ▶ Operation as a power station
 - ▶ Integrated monitoring
 - ▶ Operation research for the farm
 - ▶ Integrated wind farm economics
 - ▶ Connection

SuperGen Wind Composite Research

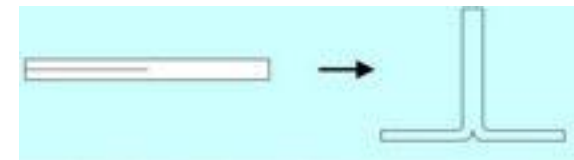
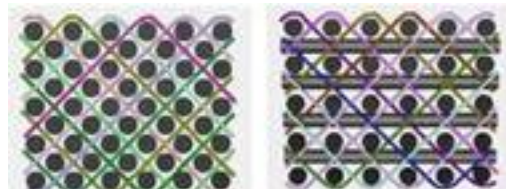
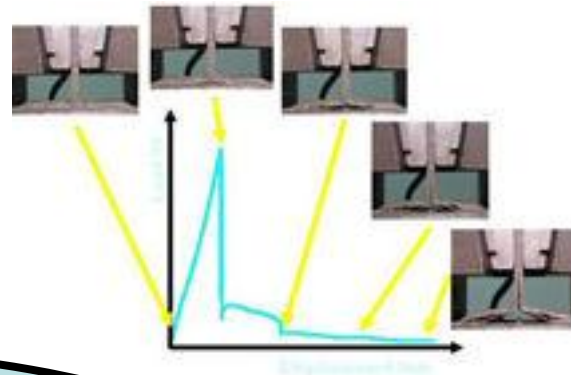
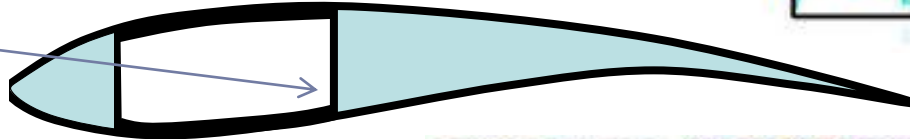
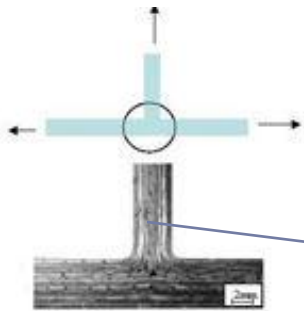


Identified key challenges:

- ▶ Reduce manufacturing defects
 - wrinkles, delaminations, dry-spots, under cure, misalignment, Sandwich core-skin debonds
- ▶ Increase rate of materials deposition
 - AFP/ATL, preforming
- ▶ Decrease cure cycle times
 - Use of pre-cured elements, single shot manufacture, Quickstep.

One area being researched is use of 3D Textiles

- Potential to increase deposition rate (thick fabrics) for preforming
- Z-direction reinforcement and clever design can prevent delaminations





Other Research Areas

- ▶ Just a few examples of research topics have been given. Other areas of research related to production technologies using AFP, ATL and dry fabric preforming include:
 - ▶ Investigation of the time and cost comparisons between dry and wet material lay-down in ATL/AFP.
 - ▶ Investigation of the trade-off between lay-down rate and design detail capability when comparing AFP and ATL - Learning lessons from GKN's spar production technology and comparing flat lay-up using ATL followed by a diaphragm forming with near net shape production using AFP.
 - ▶ Use of stitching technologies and/or binders to hold dry fabrics in place during lay-up.
 - ▶ Thermoplastic AFP/ATL.
- ▶ There are other topics related to the whole manufacturing process which have not been discussed here, but in which research is being performed. These include:
 - ▶ Production of functional structures (integrated lightening protection, morphing structures, sensing structures, self healing structures).
 - ▶ Through life-cycle analysis of a structure – design for recycling/sustainability.



Conclusions

- ▶ UK renewable obligations and the enormous potential offshore wind market make the UK a focus for new technology development and demonstration for offshore wind.
- ▶ Development trends in offshore wind turbines mean the wind industry is now looking to the same materials, manufacturing methods and QA practices for composite structures as the aerospace industry.
- ▶ The UK's expertise in composite aerospace structures means it is well placed to bring these two industries together to collaborate in further composite structure manufacturing development.
- ▶ The UK composites strategy ensures that there is a coordinated effort to facilitate collaborative composites manufacturing technology development to optimise technology and know-how transfer between different industry sectors.



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