INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

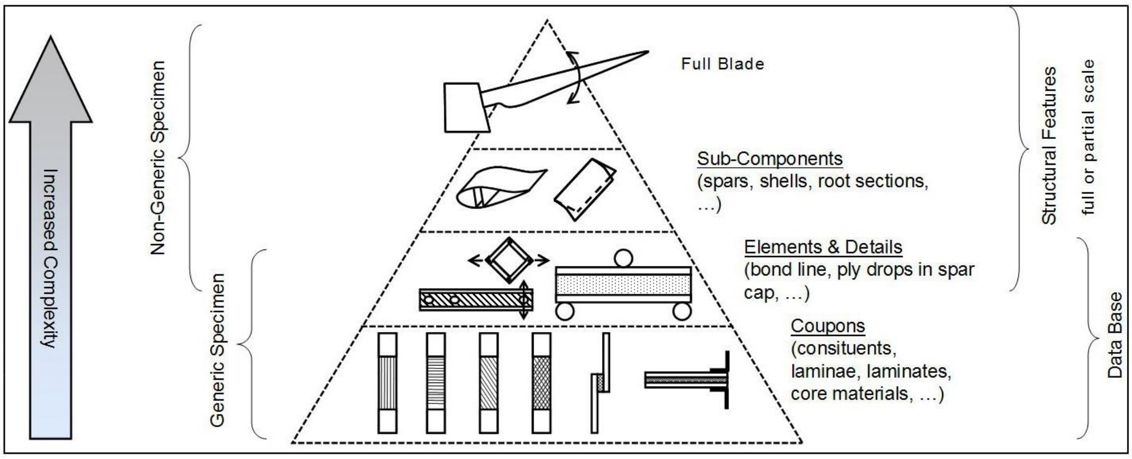
Topical Expert Meeting #91 on

Durability and Damage Tolerant Design of Wind Turbine Blades

IEA Wind Task 11- Topical expert meeting

June 12-14, 2018

Montana State University, Bozeman, MT, USA



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International Energy Agency
Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, Denmark, the European Commission, EWEA, France, Finland, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of China, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Two Subtasks

The task includes two subtasks.

The objective of the first subtask is to develop recommended practices (RP). Recent developed RPs were on "Wind Farm Data Collection and Reliability Assessment for O&M Optimization (Task 33)" (RP#17) and "Floating Lidar Systems (Task 32 in coordination with the Offshore Wind Accelerator initiative)" (RP#18).

The objective of the second subtask is to conduct topical expert meetings in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, Topical Expert Meetings are arranged four times a year.

Documentation

Since these activities were initiated in 1978, more than 70 volumes of proceedings have been published. In the series of Recommended Practices 18 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task.

Operating Agent

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COUNTRIES PRESENTLY PARTICIPATING IN THE TASK 11	
COUNTRY	**INSTITUTION**
Denmark	Danish Technical University (DTU) - Riso National Laboratory
Finland	Technical Research Centre of Finland - VTT Energy
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Ireland	Sustainable Energy Ireland - SEI
Italy	Ricerca sul sistema energetico, (RSE S.p.A.)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Mexico	Instituto de Investigaciones Electricas - IEE
Netherlands	Rijksdient voor Ondernemend Nederland (RVO)
Norway	The Norwegian Water Resources and Energy Directorate - NVE
Republic of China	Chinese Wind Energy Association (CWEA)
Spain	Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas CIEMAT
Sweden	Energimyndigheten - Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy - SFOE
United Kingdom	CATAPULT Offshore Renewable Energy
United States	The U.S Department of Energy -DOE

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1. INTRODUCTORY NOTE

Josh Paquette - Sandia National Laboratories (SNL)
Doug Cairns - Montana State University (MSU)

BACKGROUND

Wind turbine components are currently designed for a 20-year service or "safe" life based on assumptions about the strength of materials, the quality of the manufacturing process, and the environment where the components will operate. In practice, this design life is too often not achieved, with blades requiring repair or in some cases being disposed of completely due to environmental degradation and structural failure. An obvious solution to this problem is to build higher quality, more resilient blades. However, there is a penalty for this, both in terms of cost and weight of the blades. An alternative is to adopt the design methodology of durability and damage tolerant design (DADT), which is used in other industries, including civilian aerospace. Damage tolerance is the ability of a structure to sustain damage, without catastrophic failure, until such time that the component can be repaired or replaced. This leads to a maximum permissible flaw size which is then detected, using nondestructive inspection methods, before it reaches a critical size.With a DADT design philosophy, effects of defects and damage, inspection capability, repair techniques, and operating environments are known and tightly coupled, such that the current state of the component is continually evaluated and adjusted, if necessary. This process requires greater understanding of defect and damage growth through the development of models validated at all scales, coupon through full structure. Test methods at intermediate scales require development and acceptance.

Figure 1. Damage Tolerant Design

The current state-of-art in wind blade inspection and repair, as well as the effect of defects and damage on blade structures lags behind aerospace in many regards. Much of this is attributable to differences in delivered cost, testing budgets, manufacturing methods, materials, scale, and inspection locations/intervals. In addition, many wind farms have limited technical capabilities associated with their on-site personnel and this can be combined with a resistance to take turbines out of service for inspection and repair. However, there is a growing overlap between aerospace and wind blades in terms of scale and manufacturing processes, to the extent where information exchange is becoming beneficial to both industries

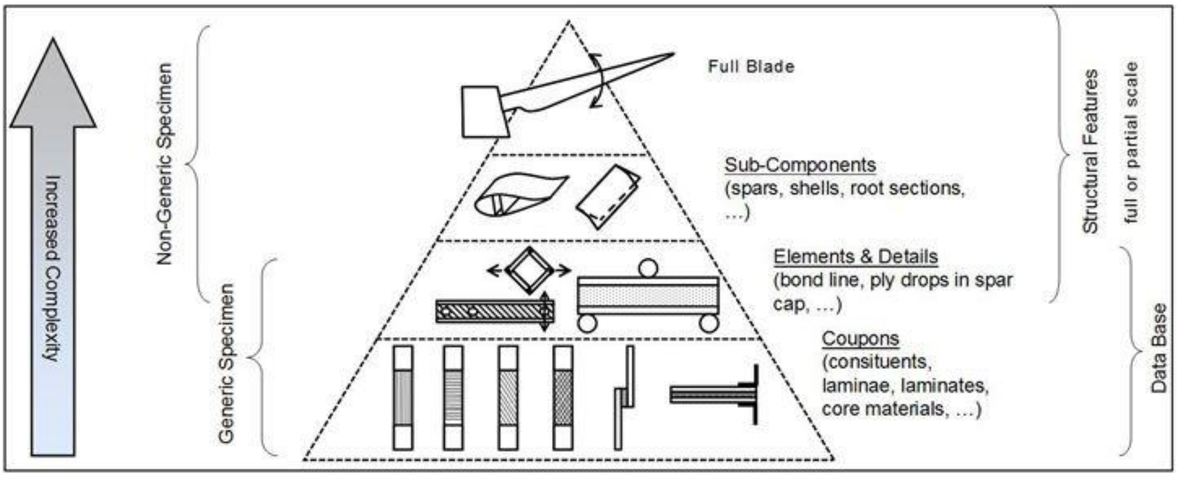

Figure 2. Building Block Approach to Structural testing and Model Validation

Adoption of the DADT design philosophy requires the close coupling of the effects of defects analysis and associated NDI methods to detect damage/defects before they can grow to critical sizes. Moving from safe-life to DADT in wind has the potential to lower cost and cost uncertainty by focusing maintenance effort where and when it is needed, while avoiding large-scale failures, as it has in commercial aerospace. Additionally, the wind industry will soon be facing a large life-extension problem as plants near their original design life. This problem is similar to what commercial aviation faced several decades ago and will likely need this new philosophy to operate turbines reliably and safely for 10 or more additional years.

OBJECTIVES

Sandia National Laboratories and VTT Technical Research Centre of Finland have proposed an IEA Wind Task 11 Topical Expert Meeting (TEM) on Durability and Damage Tolerant Design of Wind Turbine Blades. At this meeting, the participants will exchange information and ideas on what a durability and damage design process would look like for wind blades. The specific topics to be discussed include:

- Current design standards, lessons from other industries, and opportunities for improvement
- Computational methods for modeling damage growth in composites
- Test methods for manufacturing flaws and blade erosion
- Nondestructive inspection capabilities for detecting defects and damage
- Structural health monitoring options for blades
- Repair methods and efficacy

TENTATIVE PROGRAM
The TEM will be hosted at Montana State University in Bozeman, MT on June 12-14, 2018. The program will include:

- Introduction by hosts (SNL, MSU and VTT)
- Recognition of participants
- Presentations from participants covering the topics listed above
- Break-out sessions in the areas of computational modeling, inspection and health monitoring, repairs, and test methods
- Summarizing the results of the breakout sessions
- Formation of recommendations for next steps

INTENDED PARTICIPATION
Participation is expected from academia, research labs, OEM’s, wind plant owner/operators, certifiers, and blade service providers. In addition, experts from the aerospace industry will be invited to provide their experience. All attendees will be asked to present their experience in one of the listed topic areas.

EXPECTED OUTCOMES
The outcome of this meeting will be a document summarizing

- Presentations from the participants
- A framework for the DADT process for wind blades
- Recommendations for changes to blade standard
- Needed research activities to support standards updates
- Formulation of inputs for the IEA Wind Strategic Plan's update

2. AGENDA

Note: The agenda includes the links to the presentations uploaded on the IEA Wind platform

Tuesday, June 12th (JABS 405)

12:00 PM Check-in and Badging

1:00 PM Introductions

Doug Cairns, *Montana State University*

Josh Paquette, *Sandia National Laboratories*

1:30 PM IEA Wind TCP and Task 11: Nadine Mounir, *IEA Wind*

1:45 PM Durability and Airworthiness Requirements of Civil Aerospace Products: Carey O'Kelley, *Delta*

2:30 PM Aerospace Experience in Durability and Damage Tolerant Design: Doug Graesser, *NSE Composites*

3:15 PM Break

3:30 PM Current (New) International Standard for Wind Blade Design and Manufacturing: IEC 61400-5 (PT5): Derek Berry, *NREL*

4:15 PM Day 1 Wrap-Up

6:00 PM No-Host Social Event

Wednesday, June 13th (JABS 405)

7:30 AM Breakfast

8:30 AM Manufacturing Process and Flaws: Steve Nolet, *TPI Composites*

9:30 AM The Importance of Damage Tolerance Analysis in Establishing Proper Inspection Oversight of Wind Turbine Blades: Dennis Roach, *Sandia National Laboratories*

10:30 AM Break

10:45 AM Manufacturing/Inspection Breakout Sessions (Led by Steve Nolet and Dennis Roach)

12:15 PM Lunch

1:15 PM Continuum and Discrete Damage Modeling Techniques of the Effects of Manufacturing Defects to Composite Structures: Doug Cairns, *Montana State University*

2:15 PM Multi-Scale Testing: Henrik Stang, *Danish Technical University*

3:15 PM Break

3:30 PM Multi-Scale Modeling/Testing Breakout Sessions (Led by Doug Cairns and Henrik Stang)

5:00 PM Day 2 Wrap-Up

6:00 PM No-Host Social Event

Thursday, June 14th (JABS 405)

7:30 AM	Breakfast
8:30 AM	Blade Rain Erosion: Raul Prieto, *VTT*
9:00 AM	Wind Blade Repair Methods and Standards: Dayton Griffin, *DNV-GL*
9:30 AM	Structural Health Monitoring and Operational Modifications: Josh Paquette, *Sandia National Labs*
10:00 AM	Break
10:15 AM	Operations Breakout Sessions (Led by Raul Prieto, Dayton Griffin, and TBD)
11:45 AM	Day 3 Wrap-Up and Next Steps
12:00 PM	Adjourn

3. LIST OF PARTICIPANTS

The meeting was attended by 21 participants from 6 countries. Following is the list of participants and their affiliations.

Name	Country	Company/Organization
Alejandro Gonzalez	Mexico	CIATEQ
Alex Quinlan	Denmark	DTU
Ariel Lusty	United States	MSU, PhD Candidate
Carey O'Kelley	United States	Delta Airlines
Dayton Griffin	United States	DNV-GL
Dennis Roach	United States	SNL
Derek Berry	United States	NREL
Doug Graesser	United States	NSE Composite
Douglas Cairns	United States	Montana State University
Florian Sayer	Germany	Fraunhofer IWES
Henrik Stang	Denmark	DTU
Josh Crayton	United States	Rope Partners
Joshua Paquette	United States	SNL
Justin Mullings	United States	Envision
Matt Meyers	United States	NSE Composite
Nadine Mounir	Switzerland	IEA Wind
Raul Prieto	Finland	VTT
Ray Ely	United States	SNL
Steve Nolet	United States	TPI Composites
Wibke Exner	Germany	DLR
William B. Avery	United States	Boeing Commercial Airplane Group

4. SUMMARY

Introduction

Wind turbine components are currently designed for a 20-year service or "safe" life based on assumptions about the strength of materials, the quality of the manufacturing process, and the environment where the components will operate. In practice, this design life is too often not achieved, with blades requiring repair or in some cases being disposed of completely due to environmental degradation and structural failure. An obvious solution to this problem is to build higher quality, more resilient blades. However, there is a penalty for this, both in terms of cost and weight of the blades. An alternative is to adopt the design methodology of durability and damage tolerant design (DADT), which is used in other industries, including civilian aerospace. Damage tolerance is the ability of a structure to sustain damage, without catastrophic failure, until such time that the component can be repaired or replaced. This leads to a maximum permissible flaw size which is then detected, using nondestructive inspection methods, before it reaches a critical size. With a DADT design philosophy, effects of defects and damage, inspection capability, repair techniques, and operating environments are known and tightly coupled, such that the current state of the component is continually evaluated and adjusted, if necessary. This process requires greater understanding of defect and damage growth through the development of models validated at all scales, coupon through full structure. Test methods at intermediate scales require development and acceptance.

The current state-of-art in wind blade inspection and repair, as well as the effect of defects and damage on blade structures lags behind aerospace in many regards. Much of this is attributable to differences in delivered cost, testing budgets, manufacturing methods, materials, scale, and inspection locations/intervals. In addition, many wind farms have limited technical capabilities associated with their on-site personnel and this can be combined with a resistance to take turbines out of service for inspection and repair. However, there is a growing overlap between aerospace and wind blades in terms of scale and manufacturing processes, to the extent where information exchange is becoming beneficial to both industries.

Adoption of the DADT design philosophy requires the close coupling of the effects of defects analysis and associated NDI methods to detect damage/defects before they can grow to critical sizes. Moving from safe-life to DADT in wind has the potential to lower cost and cost uncertainty by focusing maintenance effort where and when it is needed, while avoiding large-scale failures, as it has in commercial aerospace. Additionally, the wind industry will soon be facing a large life-extension problem as plants near their original design life. This problem is similar to what commercial aviation faced several decades ago and will likely need this new philosophy to operate turbines reliably and safely for 10 or more additional years.

To begin a path forward towards this change in design, a technical experts meeting was held on June 12th-14th on the campus of Montana State University in Bozeman, Montana, United States. The meeting was organized by Montana State University and Sandia National Laboratories. Over 20 participants from around the world discussed the current state of wind blade design, established practices in aerospace, and several detailed sub-topics related to the design, manufacture and operation of wind blades. The meeting was organized to have two-three presentations on a sub-topic, followed by the participants dividing into breakout groups to discuss what is needed going forward to improve those topics areas to implement DADT in wind blades. The participants then reconvened to summarize the discussions to the broader group.

Sub-Topics and Presenters

Design Methodologies in Wind Blades and Aerospace

Carey O'Kelley from Delta Airlines and Doug Graesser of NSE composites gave presentations about their experience with DADT in the aerospace industry, where this topic has been well-established for several decades.

Derek Berry of the National Renewable Energy Laboratory in the United States presented on the newly-drafted IEC61400-5 design standard for wind blades.

Manufacturing and Inspection

Steve Nolet of TPI Composites gave an overview of the wind blade manufacturing process, focusing on challenges that are experienced by blade manufactures now and expected in the future.

Dennis Roach from Sandia National Laboratories in the United States spoke about several years of research into wind blade plant inspection methods and their effectiveness.

Multi-Scale Modeling and Testing

Doug Cairns from Montana State University in the United States presented on his industrial and research experience in aerospace and wind on modeling and testing composite laminates and substructures.

Henrik Strang from the Danish Technical University presented on research that his institution has performed in the area of coupon and sub-structure testing.

Operations

Raul Prieto of VVT in Finland gave a presentation on wind blade leading edge erosion based on a recent offshore project.

Dayton Griffin from DNV-GL spoke about the development of a joint industry project that his organization is forming to share information and develop best practices in wind blade repairs.

Josh Paquette of Sandia National Laboratories presented on previous research projects at his organization that looked at the ability of structural health monitoring systems to identify damage growth in wind blades.

Outcomes

The outcomes of the meeting discussions are summarized below. These represent the participants thoughts on actions that will be required to implement DADT design philosophy in wind blades.

Design Methodologies in Wind Blades and Aerospace

- The Aerospace Industry is the "gold standard" for DADT. It has dominated design, certification, and maintenance of commercial transport aircraft since the Aloha Airlines Flight 243 failure in 1988. Durability and Damage Tolerance requires three elements; an inspection plan, a damage growth analysis (to establish inspection intervals), and a knowledge of residual strength with damage. Implementation of these elements has dramatically increased the safety and reliability of commercial transport aircraft since implementation of DADT.

Manufacturing and Inspection

- Flaws must be considered during the design process if they cannot be shown to not exist in a certain manufacturing process, or found with inspection and adequately repaired.
- Wind plant owners should receive manufacturing reports on every blade that include the results of inspections and repairs that are performed in the factory.
- Damage tolerance includes designing and manufacturing for the possibility of damage caused by lightning and erosion.
- Non-destructive inspection methods for wind blades will need to be faster, easier, and cheaper than what exists in the aerospace industry.
- Owner operators win need to improve their technology base to more fully understand wind blade design and composite structures.
- Formation of an operator group devoted specifically to wind blade damage, inspection techniques, and repair methods.
- A comprehensive maintenance approach should be developed which engages OEM's and owner/operators in a collaborative relationship to share information.
- This use of digital twins should be explored as a method of prognostics for both
- Actionable findings should be defined by turbine OEM's so that damage can be classified and dispositioned.
- Updates like airworthiness directives should be issues so that owner/operators can direct inspections.
- Wind blades should have more frequent inspections early in operation to detect premature failures and less frequent thereafter.
- Improve standards to drive industry.

Multi-Scale Modeling and Testing

- More detailed sub-structure test methods should be developed to add to or possibly replace full-scale structural blade tests.
- Certification by analysis should be explored after design methods are validated for blades that are similar to previous designs. This would include the allowance for adjustments to already certified designs.
- Blade that have been removed from service should be subsequently inspected and tested to validate damage growth models.
- Develop a model of leading edge erosion that includes the effects of both rain and environmental exposure.
- Repairs should be based on analysis or pre-approved and defined methods from the OEM.
- Include the effects of manufacturing variances in tests and models of blades.
- Further develop damage progression models and utilize high-performance computing for probabilistic analysis of operational failure.
- Focus on known problematic areas in developing test methods such as spar-web interface, trailing edge bonds, and sandwich panels.
- Investigate damage tolerant materials, material forms, and structural designs that optimize mass and reliability.

Operations

- Develop repair methods standards or recommended best practices specific to wind blades which consider both the original design standards requirements and applicability to field installation.
- Establish training requirements for wind blade inspectors and repair technicians.
- Develop inspection procedures for repairs and recommended re-inspect schedules to verify quality.
- Investigate other methods besides scarf repairs, such as the use of doublers.
- Develop test methods for determining allowables for erosion protection and other repairs.
- Understand other environmental effects like icing, hail, and dust.
- Improve standards to require evaluation of and design for erosion effects.
- Define erosion classes based on rain occurrence, droplet size, UV exposure, temperature extremes, and other important operational and environmental metrics.
- Modify standards to allow designers to take advantage of inspection and repair in the operational life of a blade.
- Preform load accumulation monitoring through the use of existing turbine sensors to understand differences between turbines in a plant, inform inspections, and possibly modify operation.
- Define allowable damage size based on testing of coupons, details, and substructures with simulated damage.

Future Activities

As this meeting served as a basis to identify the current state of wind blade design and what is needed to achieve a change in design methodology for wind blades, several activates should be initiated to accomplish these goals.

- A formal IEA Task should be developed that focuses specifically on the development of durability and damage tolerant design for wind blades.
- Research should be conducted into the development of test methods for wind blade laminates and sub-structures with simulated damage, along with accompanying validated models.
- Further development of filed inspection technology to be able to perform higher-quality inspections that conform to the economics of wind plants, and which are informed by improved monitoring of turbine loads.
- Future editions of IEC 61400-5 should include language on durability and damage tolerant design.
- A working group should be formed to develop a leading edge erosion standard for wind blade design that would include appropriate test methods and define erosion classes.
- Repair standards for wind blades should be developed to ensure uniformity and quality.
- The Aerospace participants expressed an interest in mapping the knowledge and experience base for each industry to determine how each industry can benefit from the other's practices.