Task 46 Erosion of Wind Turbine Blades Work Package #3: Wind turbine operation with erosion

# **Operation with Erosion, Aerodynamic Benchmarking Updates** and Next Steps

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Technology Collaboration Programme

# WP 3 : Wind turbine operation with erosion

This work package has three key overarching objectives:

- 1. Promote collaborative research to mitigate erosion by means of wind turbine control, assessing the viability of erosion safe mode.
- 2. Improve the understanding of droplet impingement in the context of erosion.
- 3. Improve the understanding of wind turbine performance in the context of erosion, specifically the effect of LEE surface roughness on aerodynamics.

Please reach out	if
interested in	
collaborating!	

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Activity	WP code
Model to predict annual energy production loss on blade erosion class	WP3.1
Report on standardization of damage reports based on erosion observations	WP3.2
Droplet impingement model for use in fatigue analysis	WP3.3
Potential for erosion safe-mode operation	WP3.4
Accuracy of LEE performance loss model based on field observations (validation)	WP3.5

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# WP 3: Wind Turbine Operation with Erosion

### WP3.1: Model to predict annual energy production loss on blade erosion class

• Common model of performance loss due to leading edge roughness and erosion standardized classes.

## WP3.2: Report on standardization of damage reports based on erosion observations

• Erosion classification report released February 2023 (https://iea-wind.org/task46/t46-results/)

## WP3.3: Droplet impingement model for use in fatigue analysis

• Develop a standard model for droplet impingement, validated with wind tunnel experimental data.

### WP3.4: Potential for erosion safe-mode operation

• Report describing potential for leading edge erosion safe mode operation.

## WP3.5: Accuracy of LEE performance loss model based on field observations (validation)

• Iterative aerodynamic loss benchmarks. Validation of complete performance loss model using probabilistic analysis of field observations.

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## Accomplishments in Work Package 3: Erosion Classification System

## **Visual Condition**

IEA Wind TCP Task 46 Technical Report

Level 4 - "Erosion of topcoat with immediate layer underneath visible and exposed"

Damage threshold: erosion of topcoat ≥10cm<sup>2</sup>; erosion of laminate ≤1cm<sup>2</sup>

- Erosion has worn away to the laminate such that the filler layer or immediate laminate is observable over an area greater than 10cm<sup>2</sup>
- Damage to the substrate is either not entirely obvious or sufficiently small/minor.





Report contains many visual examples of categories of blade and LEP damage. Mass Loss



Mass loss model has the potential to improve its prediction of future erosion level progression through its incorporation of inspection data.

## Aerodynamic Performance Categorization



Power loss is defined in Region 2 of the power curve.

Structural Integrity



Detailed description of severity level definitions and thresholds.



## Accomplishments in Work Package 3: Erosion Classification System

• Deliverable 3.2 was completed with the erosion classification report, published on the website for Task 46

				Severity Level		
Evaluation Criteria	0	1	2	3	4	5
Visual Condition (LEP)		Lightly worn external coating/LEP Instances of reduced LEP adhesion	Notable areas of localized damage on external coating/LEP Individual Instances of LEP adhesive failure.	LEP is largely compromised over a large area and no longer providing protection to underlying layers	Delamination of topcoat with immediate layer underneath clearly visible and exposed	Notable damage to substrate
Visual Condition (No LEP)	Initial	Erosion barely visible or pinholes	Localized pitting	Widespread or coherent pits, some gouges		
Mass-loss	condition	Coating <10% Laminate 0%	Coating 10-50%, Laminate 0%	Coating 50-100%, Laminate <10%	Coating 100% Laminate 10-100%	Coating 100%, Laminate 100%
Aerodynamic Performance		Normal surface roughness Region 2 Power loss 0 -1%	Region 2 Power loss 1%-2%	Region 2 Power loss 2%-3%	Region 2 Power loss 3-4%	Region 2 Power loss >4%
Blade Integrity		Initial erosion of topcoat	Erosion through topcoat	Initial exposure of immediate laminate layers	Erosion through immediate laminate layers	Exposure of structural laminate layers

## Erosion Classification System Example



Observation Category	Erosion Class
Visual data definition	3
Mass-loss or Depth	3
Aerodynamics/Perf.	3
Structural	3



# 🗔 Aerodynamic Benchmark

- Aerodynamic benchmark kicked off in Fall 2022, coordinated by Beatriz Mendez at CENER.
  - Focused on NACA  $63_3\mathchar`-418$  and S814 airfoils
- Results from six participants; includes national labs, academia, and OEMs.
- There is a wide spread in the results for some cases, so comparing model parameters
- Also comparing coordinates of the airfoils for the different wind tunnel tests





# **S814 Airfoil Preliminary Results**

2% suction side & 13% pressure side Re 3.2e6

Roughness 200 um

Experiments: https://a2e.energy.gov/data/lees/report.z01.00





**1st Iteration** 

#### S814 Clean









#### **S814 Clean ITERATION 1 VS ITERATION 2**



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iea wind

#### S814 Rough ITERATION 1 VS ITERATION 2



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# **Reference Turbine Models for LEE**

- Plan to develop detailed turbine models for performance loss
  - Requires airfoil polars with range of loss, mapping of blade erosion category to local erosion level (and airfoil loss polar), turbine controllers,
  - Need modified polars for outer ~30% of rotor; 1-2 airfoils with categories 0-4 (or 5) eroded polars
  - Detailed turbine models can be used to improve the simpler models or at least assess their useful range.

Proposed reference turbine models:

- Offshore older: NREL 5MW
  - Lancaster Univ. (Sergio). Model complete and available.
- Onshore older: Wind Pact 1.5 (or 2000's era 1.5MW turbine)
  - Sandia started on this, but got stuck in controller stability issues
- Onshore newer: BAR 3MW
  - Sandia has started on this based on the <u>IEA 3.4-130-RWT</u>
- Offshore newer: 15MW Reference
  - <u>IEA 15-240-RWT</u>
  - (22MW available next year)



# Next Steps in Work Package 3

- Aerodynamic benchmarks, publication of phase 1 results and phase 2 to commence in spring 2024
- 3.1 AEP loss model. Work will progress through the aero. benchmarking group for detailed modeling.
  - Will also pursue simpler model, likely based on DTU or SNL simple performance models
  - $\circ$  Turbine reference models will be developed
- 3.3 Impingement model: via aerodynamic benchmark group
  - WP3: Model the aero. impact of the geom. Change (lwift/drag curves, then used for power and AEP change). WP5: Damage progression modeling of the eroded shape, quantify damage evolution
- 3.4 Erosion Safe Mode: demonstrated by able participants on the reference turbine model(s)
- 3.5 Validation with field data: ongoing work by multiple participants
  - Goal is to align with reference turbine models

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# Thank you!!!

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IEA TEM on LEE

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