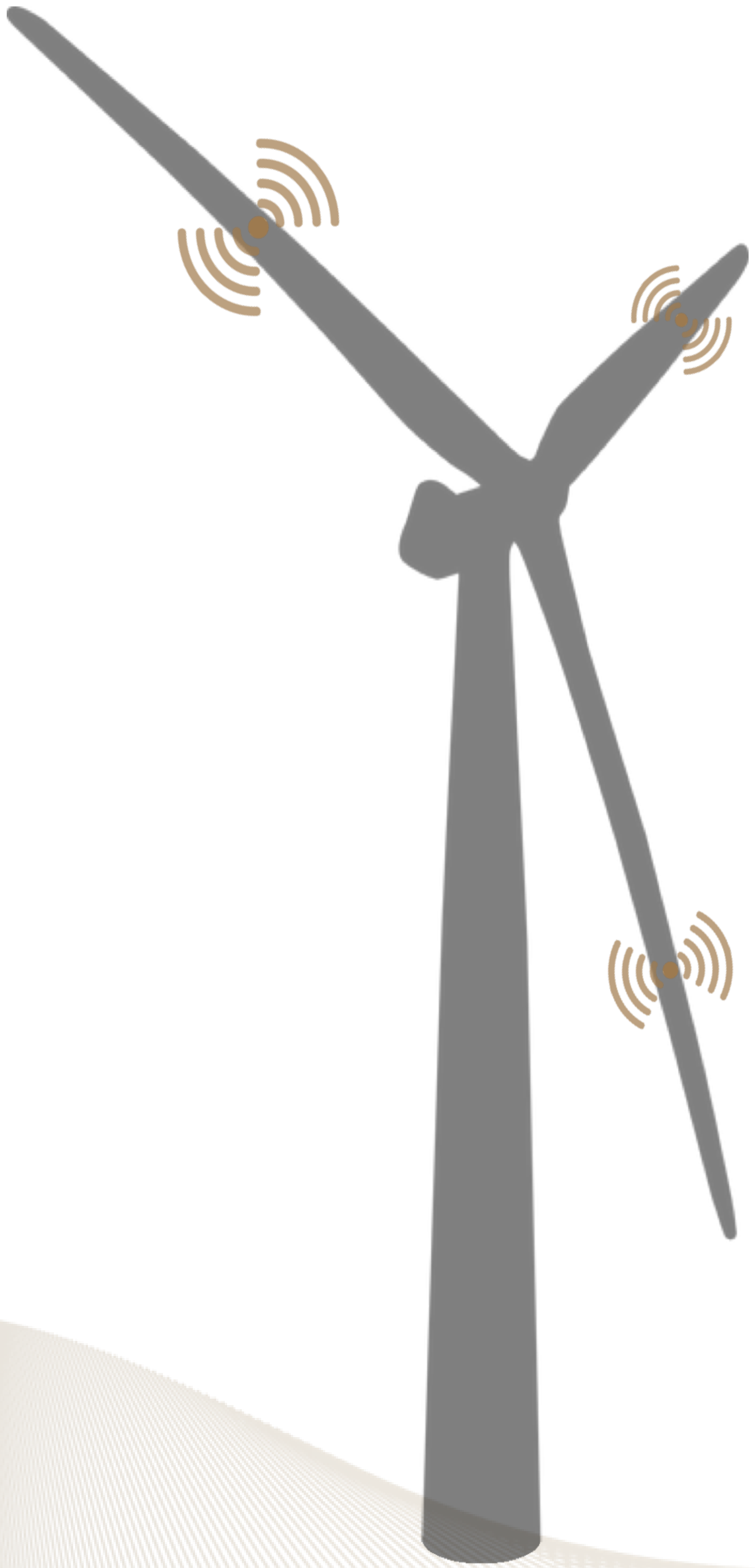
marinvent AERAS



EAPM

Real-time aerodynamic performance sensing
for aerodynamic assets

Outline

1. EAPM introduction
2. How EAPM works
3. EAPM test history
4. Preliminary test results
5. The way ahead

EAPM Introduction

EAPM is an aerodynamic sensor that measures the state of the airflow wherever its sensors are located

- EAPM is not an icing detector, yet it can quantify the performance impact and stall-margins in icing in ways that ice detectors cannot
- EAPM is not a salt or insect detector, but it detects and quantifies their effects on efficiency in real-time
- EAPM is not an inspection system, but it enables targeted on-condition inspections to an individual compromised segment of a single blade on a wind turbine
- EAPM is not a structural monitor, but it can detect structural degradations (delamination, leading-edge erosion) before they manifest on the power curve

Aerodynamic impacts from environmental factors

"In cold climates, the performance of wind turbines may be significantly reduced by ice accretion on the turbine blades. The magnitude of production loss can reach over 50% during winter months, and exceed 10% on an annual basis."

DNV (2020)

"Operators have no quantitative sense of production loss due to roughness."

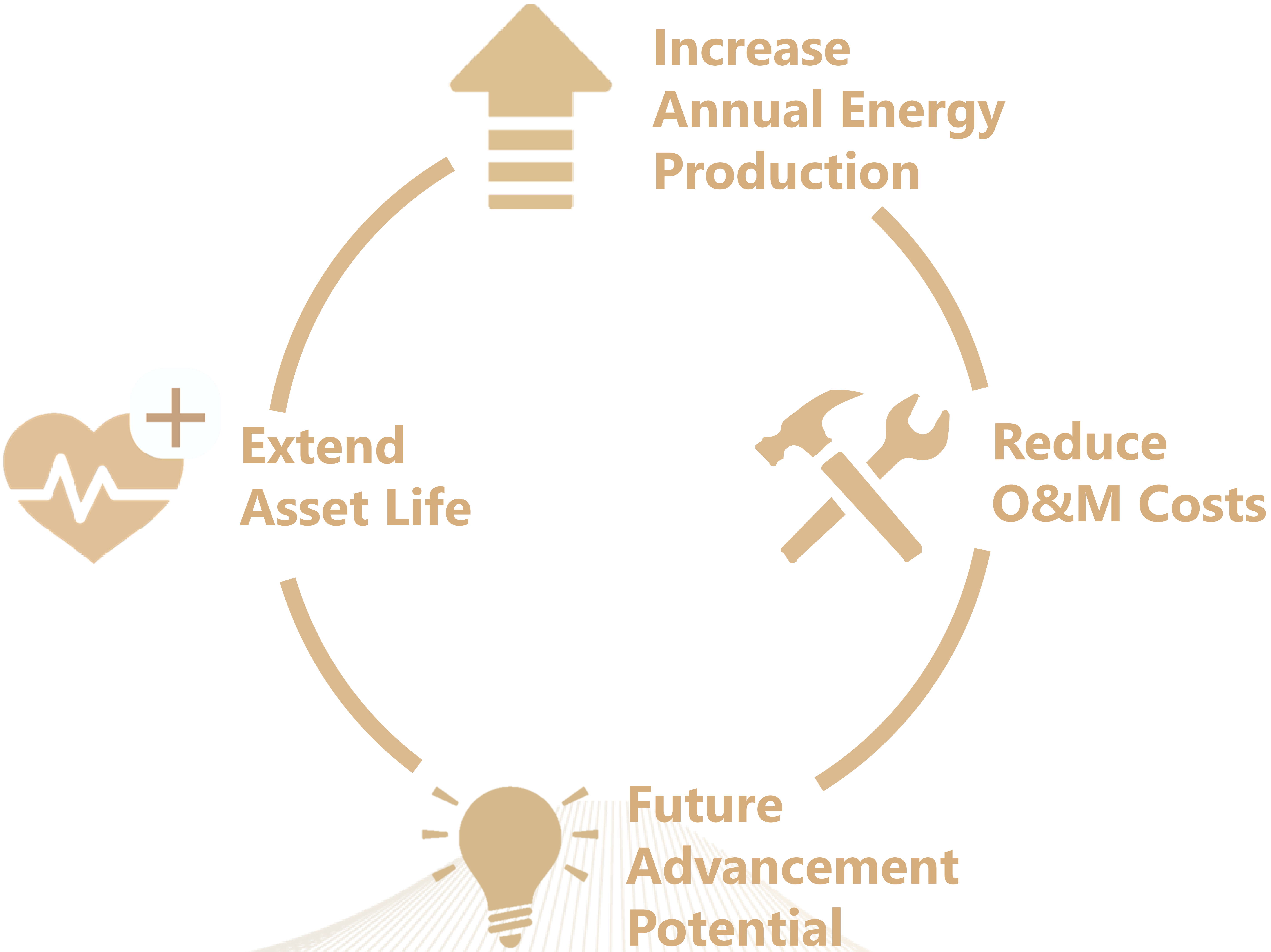
"Insect roughness was observed to cause a 25% decrease in energy production."

"...erosion has been observed to result in 20% or greater loss in energy capture and can affect blades that have been operating for as little as two-to-three years."

Sandia National Labs (2017)

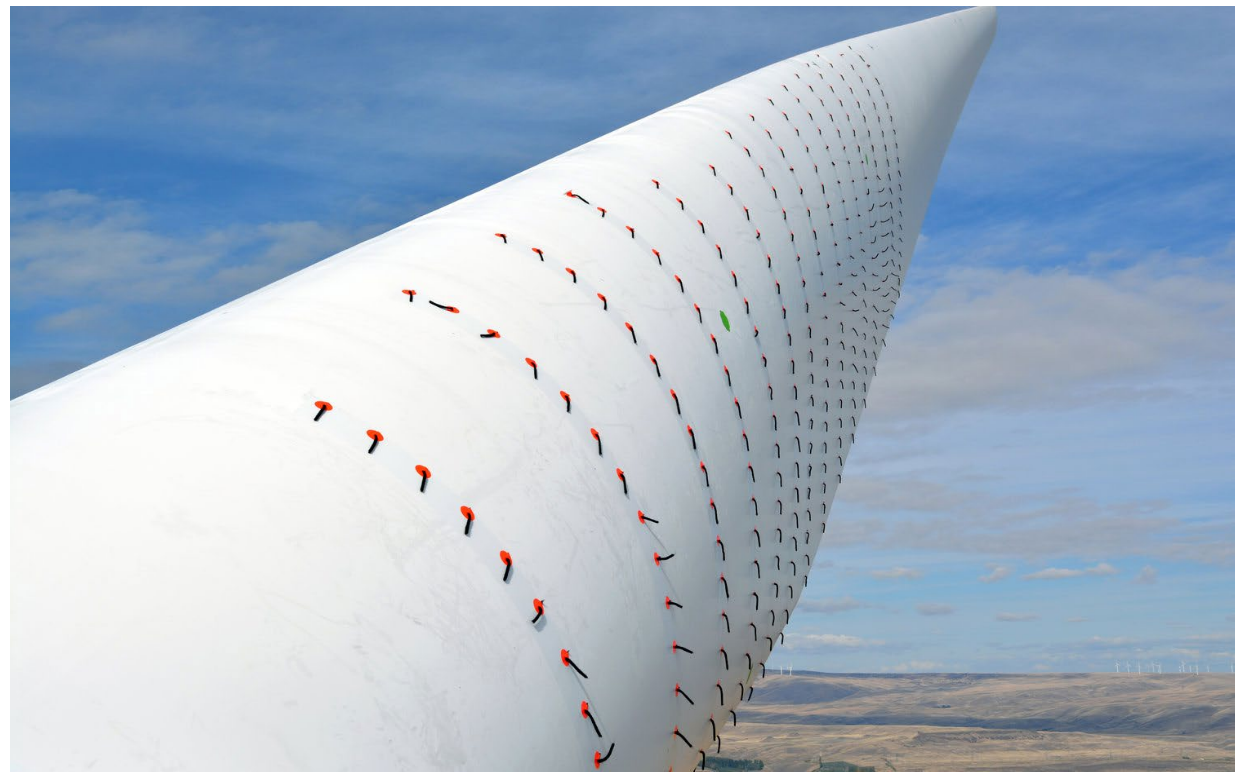
If real-time blade aerodynamic performance is available, these impacts can be substantially reduced by optimizing W-T operation and improving maintenance planning

What if we quantified **real-time aerodynamic performance**?



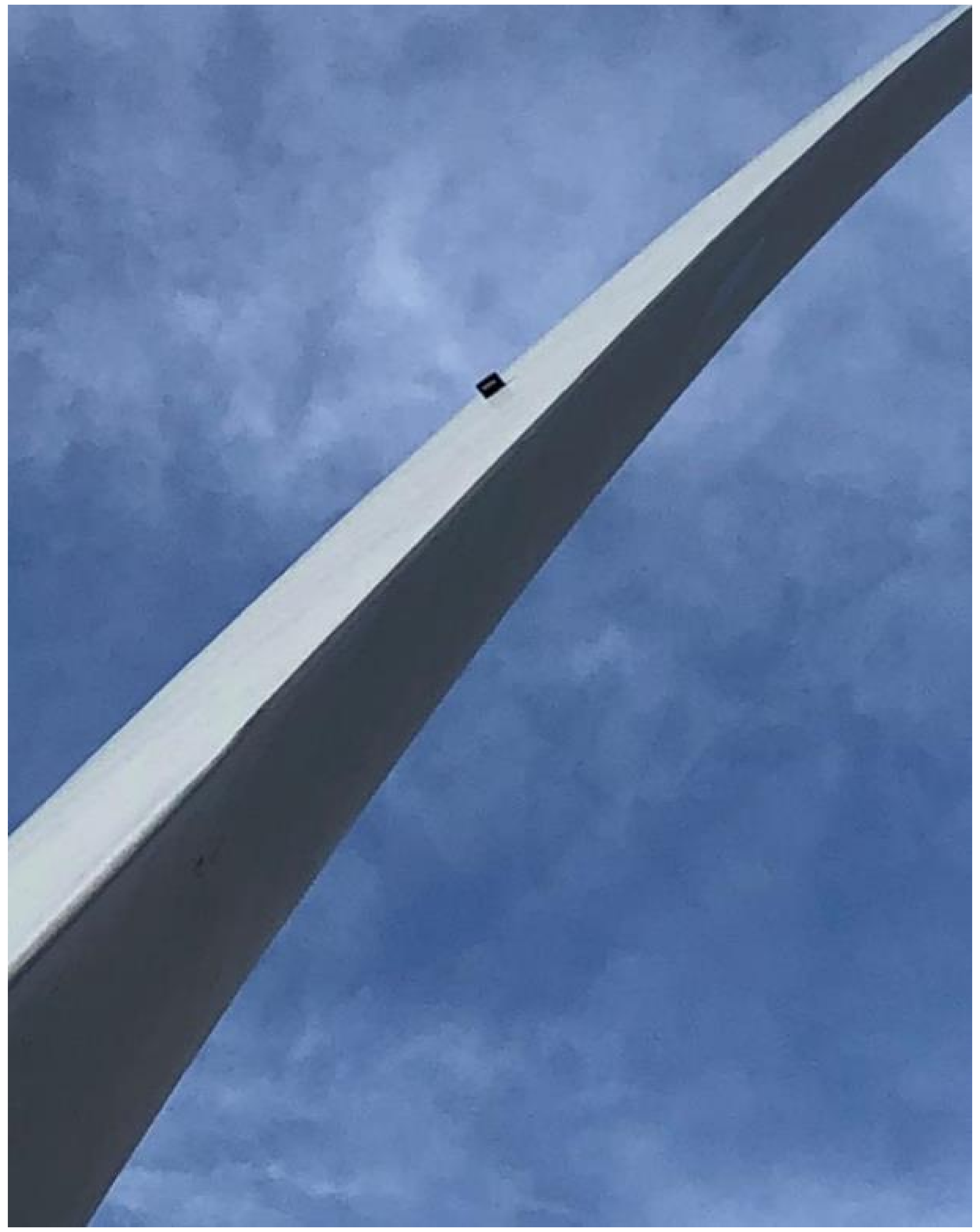
Detecting Turbulence is the key!

String Tufts ("tell-tales")
1. *Limited quantitative data*
2. *Rarely permanently installed*
3. *Unsuited to harsh conditions, including icing*



Source: Smart Blade GMBH

Wind Tufts on a Turbine Blade



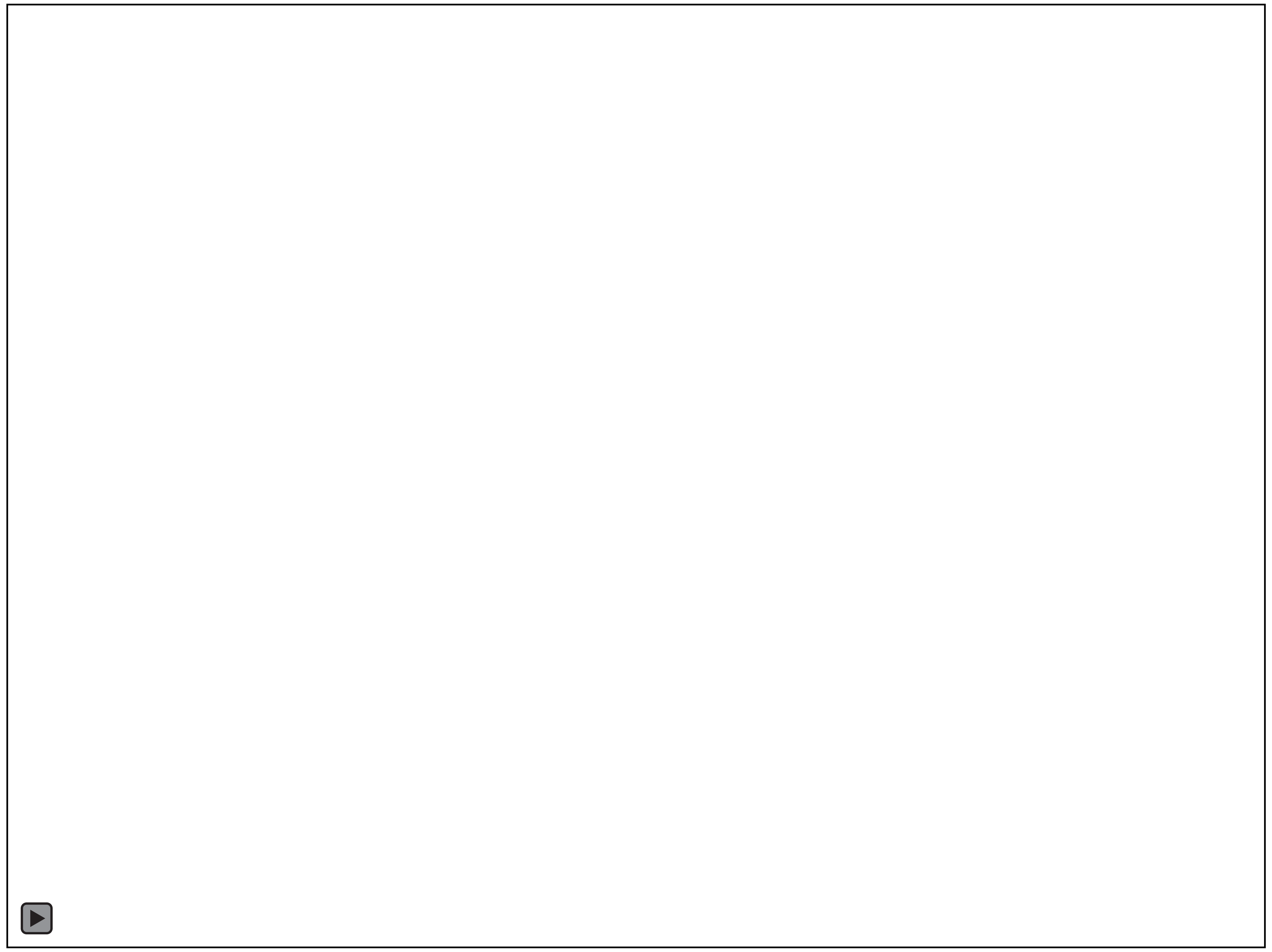
Source: Practical Boat Owner, UK

"Tell-tales" on a Sail

EAPM: A permanently-installed electronic wind tuft that produces quantified aerodynamic performance data

The R value: quantifying aerodynamic performance

- EAPM measures the non-dimensional turbulence intensity ratio ("R") of the airflow
- R correlates very strongly with the *actual* lift curve slope – regardless of contamination (icing, salt, insects), or airfoil surface degradation (erosion, delamination)
- R indicates proximity to the stall and quantifies the remaining performance margin available from the blade



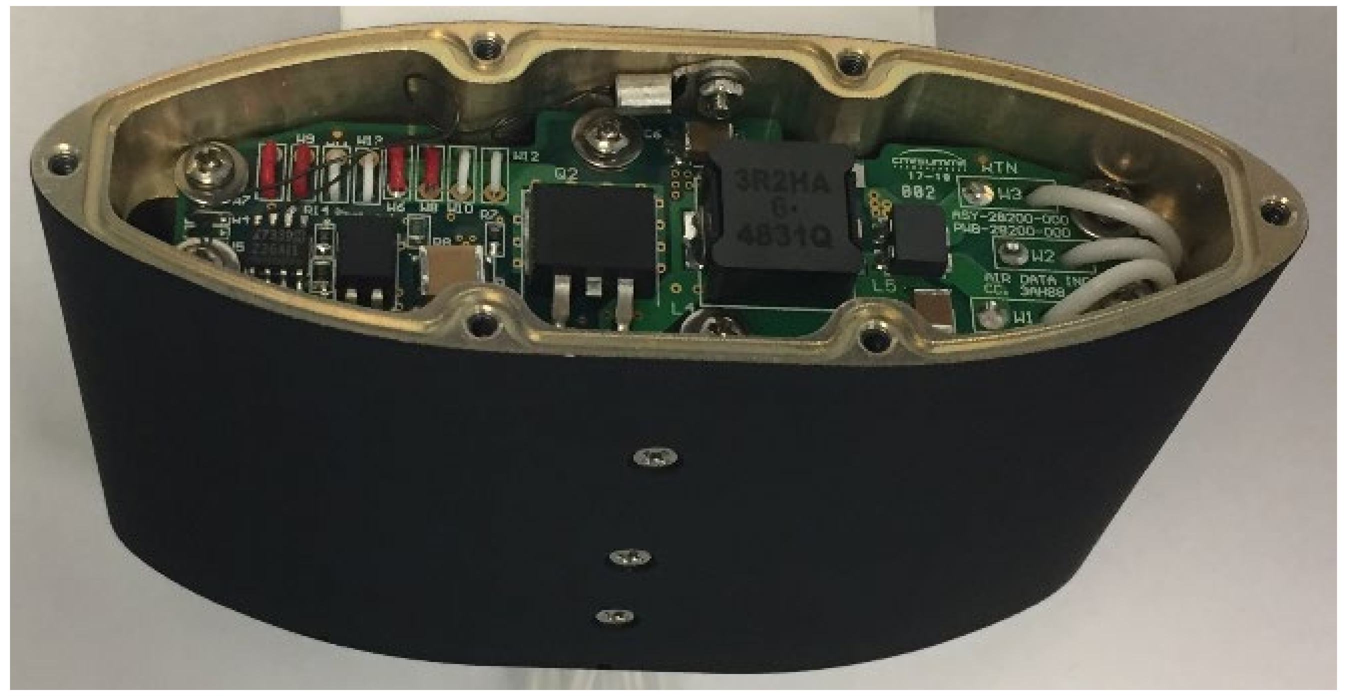
Source: Cambridge University, College of Engineering

Enhanced Airfoil Performance Monitor (EAPM)

Patented technology with a very strong aerospace pedigree (APM)

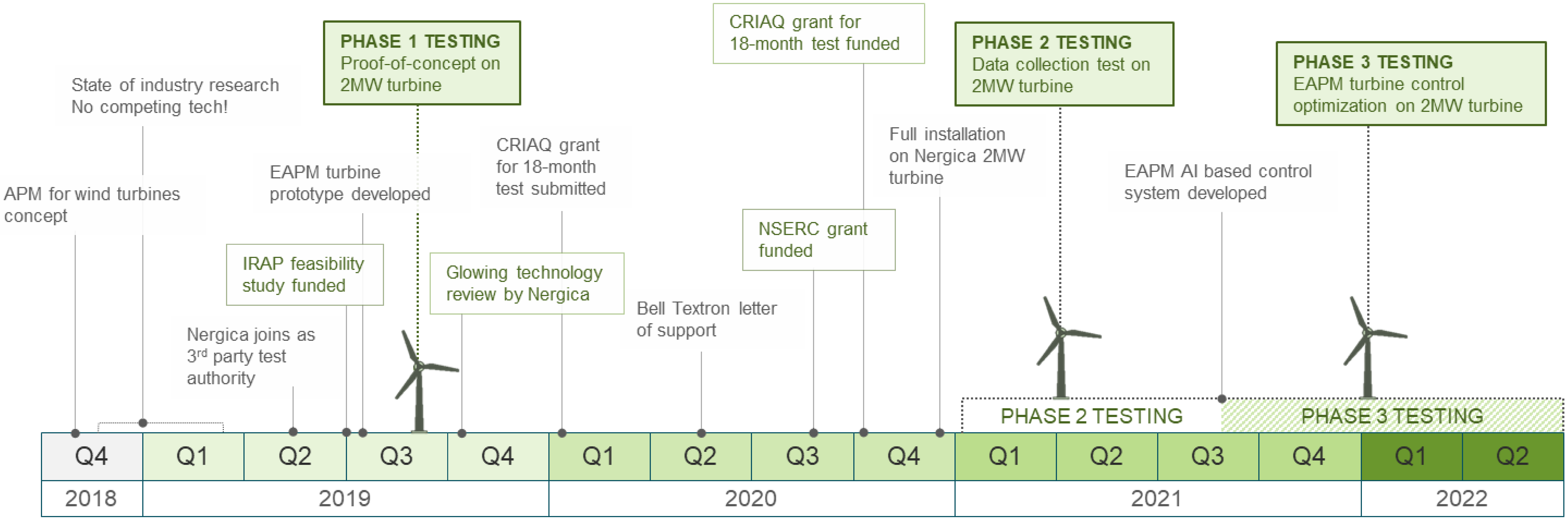
EAPM is the enhanced version tailored for the wind industry

- Developed to capture and quantify the turbulence intensity ratio and report the R value
- Allows real-time, actionable control decisions to optimize turbine operation



EAPM TEST HISTORY

EAPM **Development Timeline**



Tested and proven technology

Tunnel Testing	Aircraft Testing	Turbine Testing
		
Rail-Tec Arsenal Icing Tunnel (Vienna)	**Twin-Otter Flight Testing (Canada)**	**Nergica 2MW Turbine Testing (Canada)**
• 9 successful tunnel tests, 4 test facilities	• Multiple successful drone and passenger aircraft tests	• 2019 successful Phase 1 turbine testing • 2021 Phase 2 testing in progress NERGICA

Nergica (Quebec) EAPM Test Facility

Photo of a Senvion MM92 CCV at the Nergica test facility

NERGICA

Testing partner:	Nergica
Turbine:	Senvion MM92 CCV (Cold Climate Version)
Rated power:	2.05 MW
Rotor diameter:	92.5 m
Hub height:	80 m
EAPM masts:	3
EAPM Mast 1:	18.8 m radius 65% chord (blade 1)
EAPM Mast 2:	18.8 m radius 70% chord (blade 2)
EAPM Mast 3:	18.8 m radius 75% chord (blade 3)

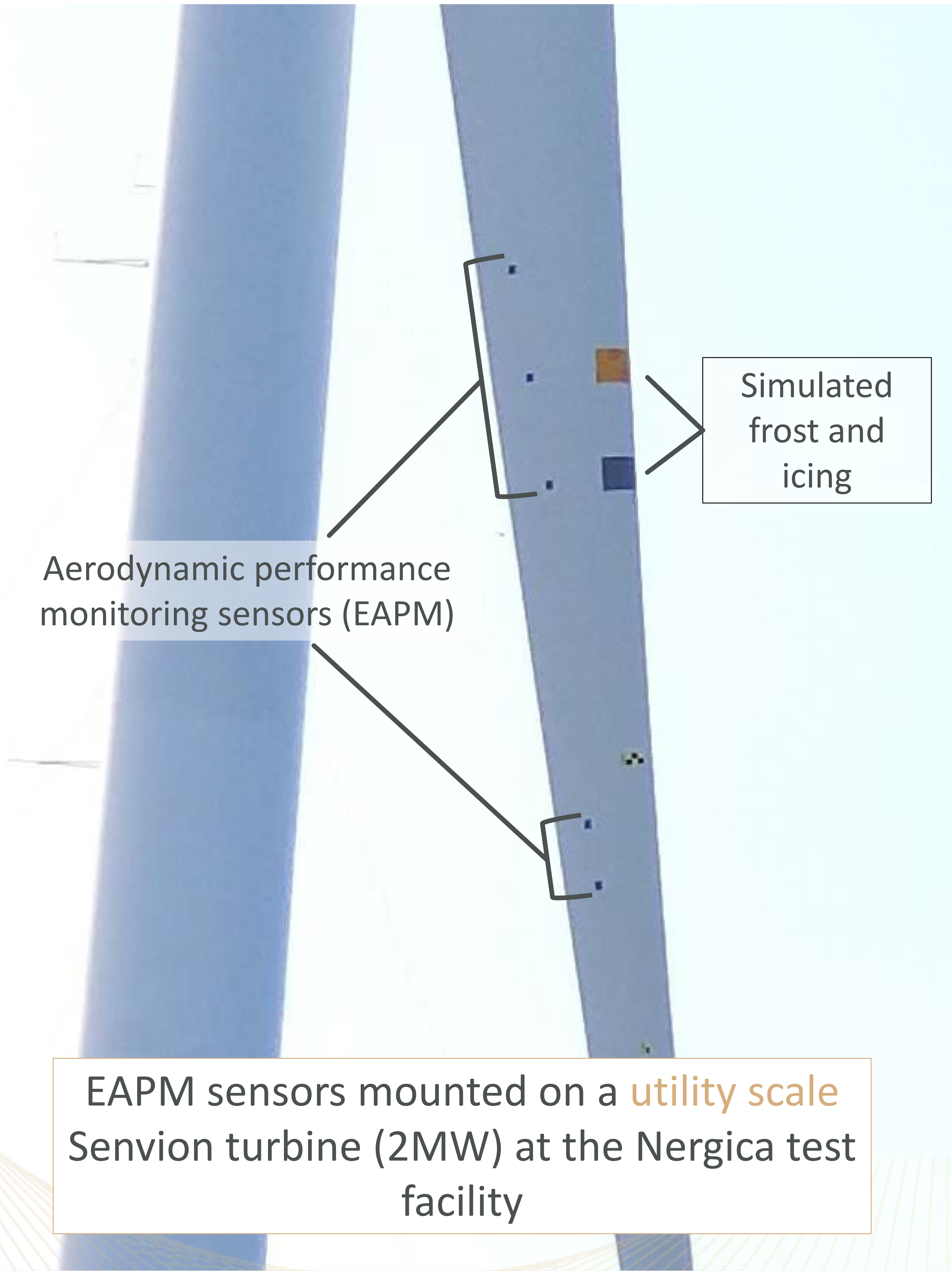
Main observed test parameters

- EAPM R-values
- Turbine RPM
- Turbine power output
- Nacelle direction
- Blade pitch angles
- Wind speed and direction
- Icing information from multiple sensors

Phase 1 testing: **Exceptional results**

"Given the results of this test, the **potential** for deploying EAPM sensors in the wind energy industry is **undeniable**." "…this sensor could be used and contribute to significant applications, including ice detection, turbine control in icing, leading-edge erosion detection and individual pitch control."

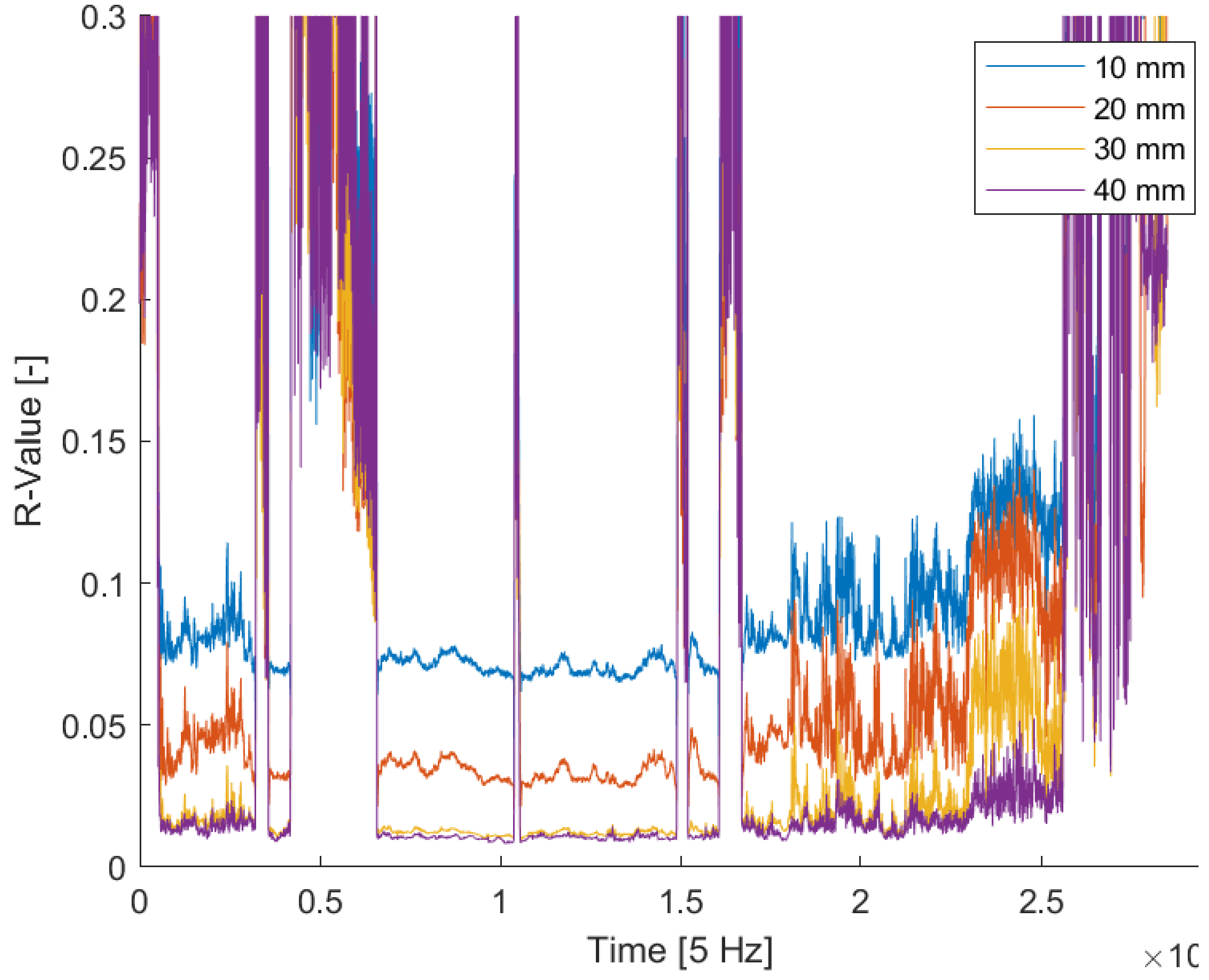
NERGICA
(3rd party testing partner)



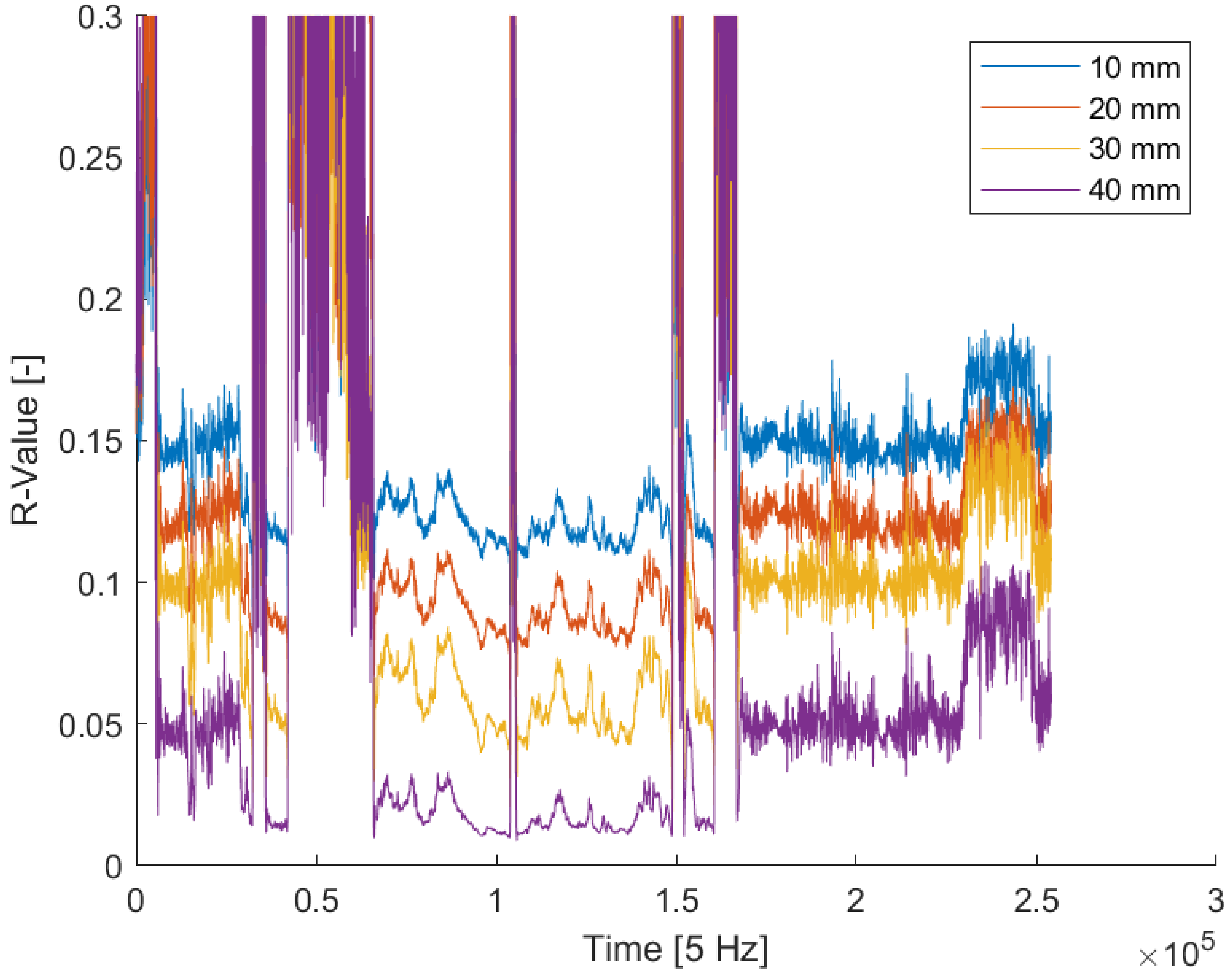
EAPM sensors mounted on a utility scale Senvion turbine (2MW) at the Nergica test facility

Nergica Phase 1 **Test Results**

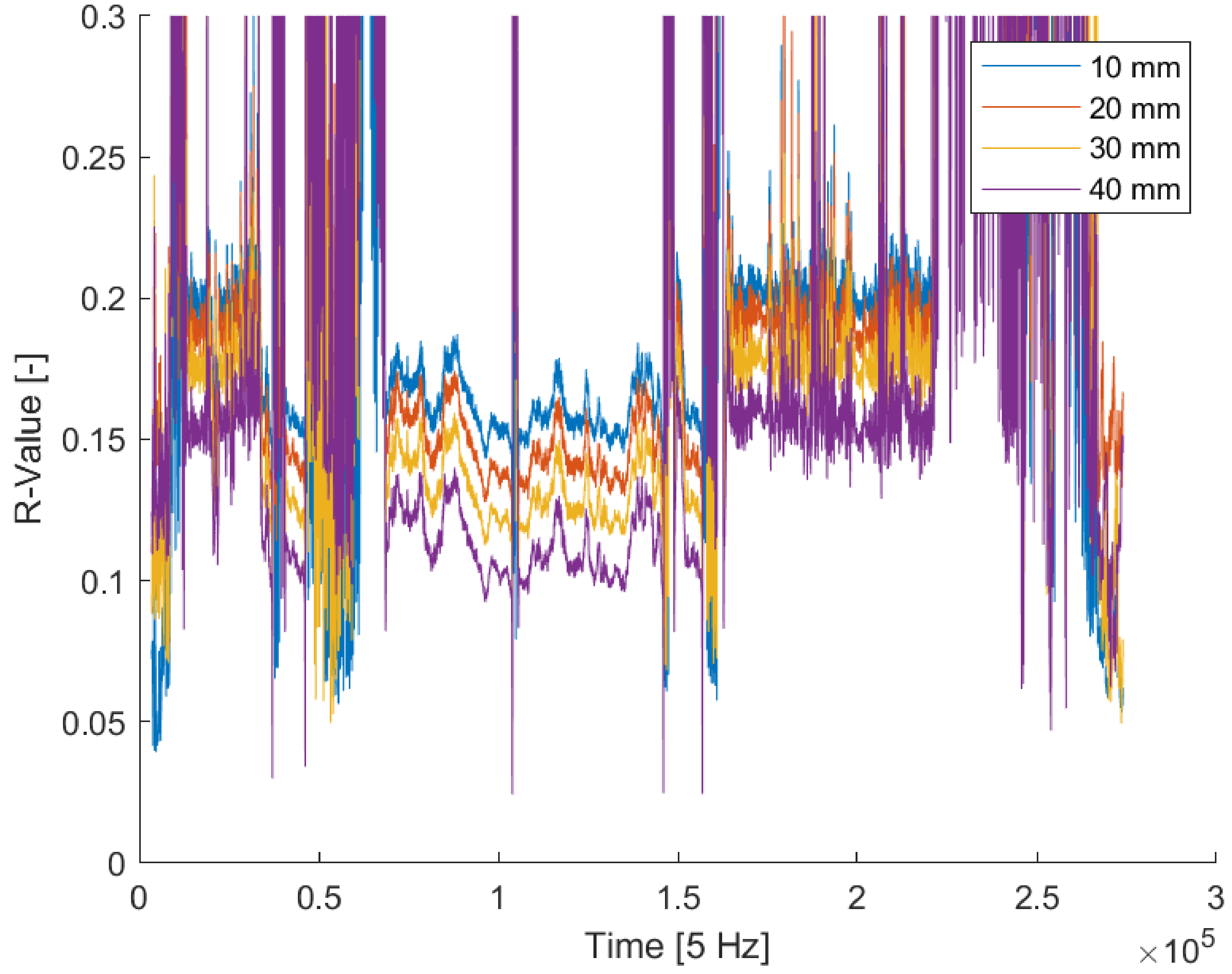
EAPM traces showing the aerodynamic stress caused by simulated frost and moderate icing on the Senvion MM92 CCV wind turbine



Clean



Simulated Frost



Simulated Ice

Phase 2/3 extended duration testing

Phase 2: Data collection / analysis

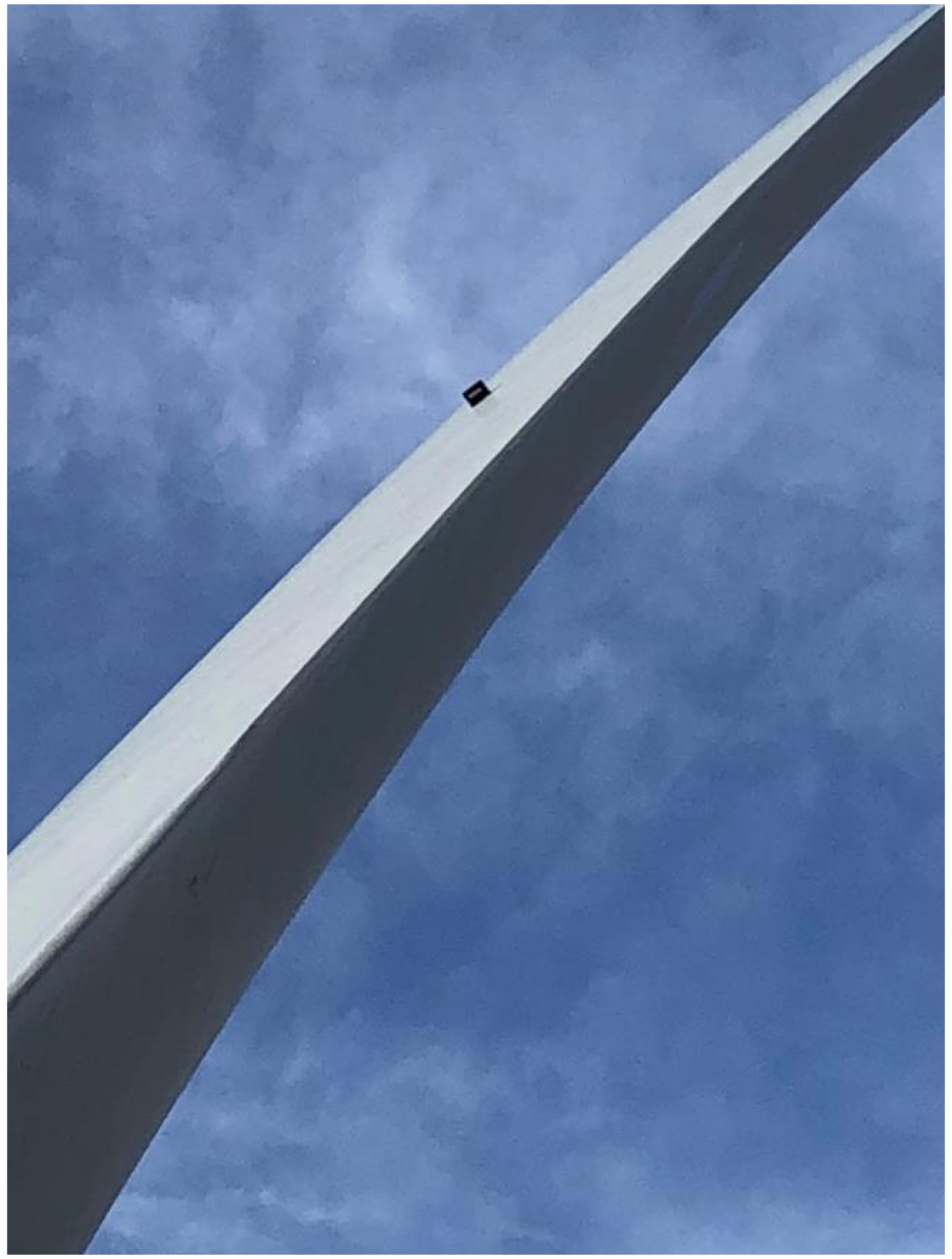
- Characterize performance in all conditions
- AI / machine learning data insights

Phase 3: Control optimization

- Integrate with SCADA
- Optimize with AI insights
- Quantify AEP improvement, O&M savings, other AI insights ($$$)

Phase 2 testing is **underway now!**

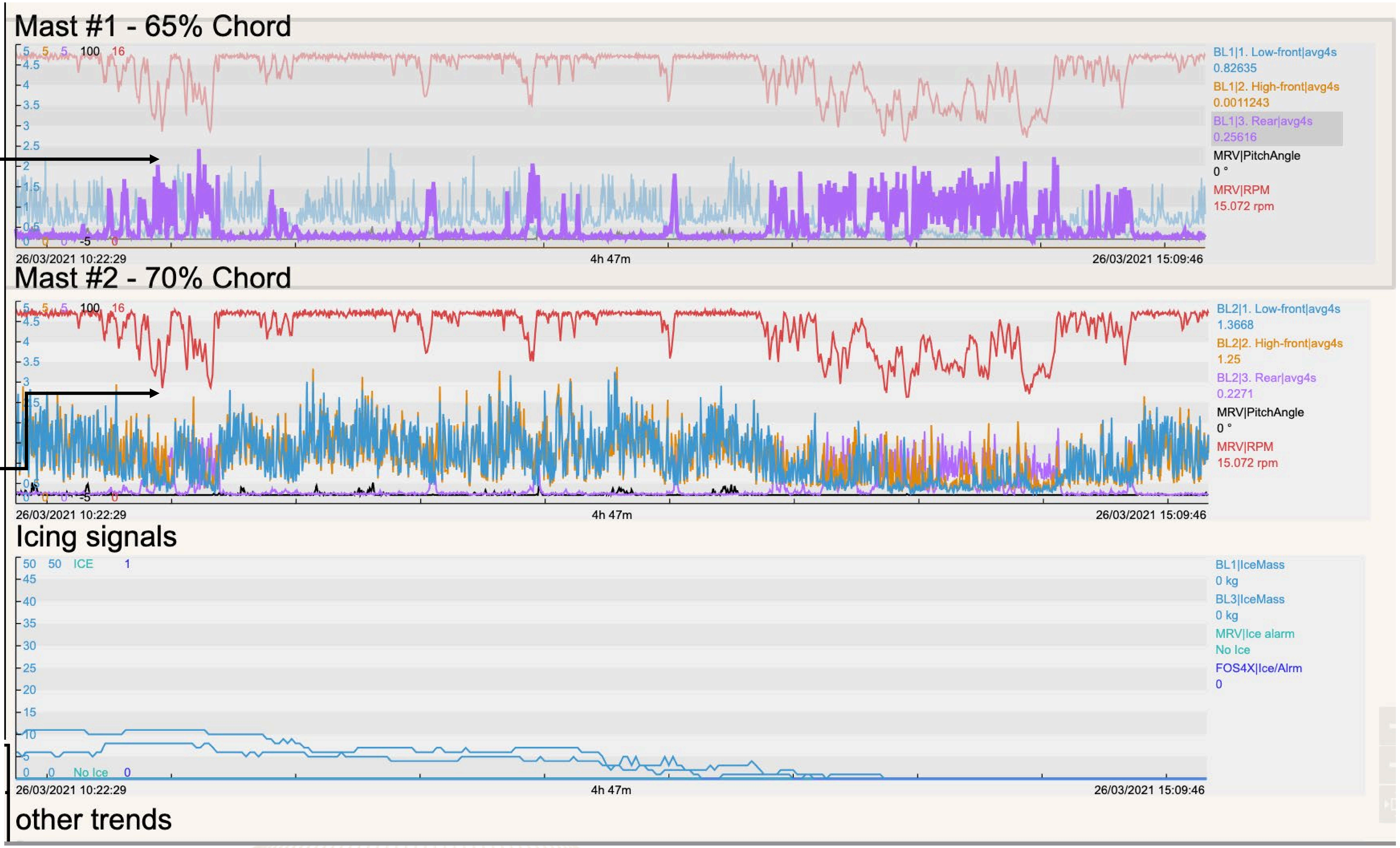
- 18 months of testing through **two winter periods**
- **Fully funded** by Canadian Government
- Test team includes:
  - **Marinvent** – technology inventor and aerodynamics experts
  - **Nergica** – industry and cold climate experts
  - **AI data analytics** company
  - In discussion to involve an **operator** and turbine **manufacturer**
- Comprehensive real-time high-frequency EAPM data **streaming via VPN today!**



EAPM mast installed on one of Nergica Senvion MM92 CCV

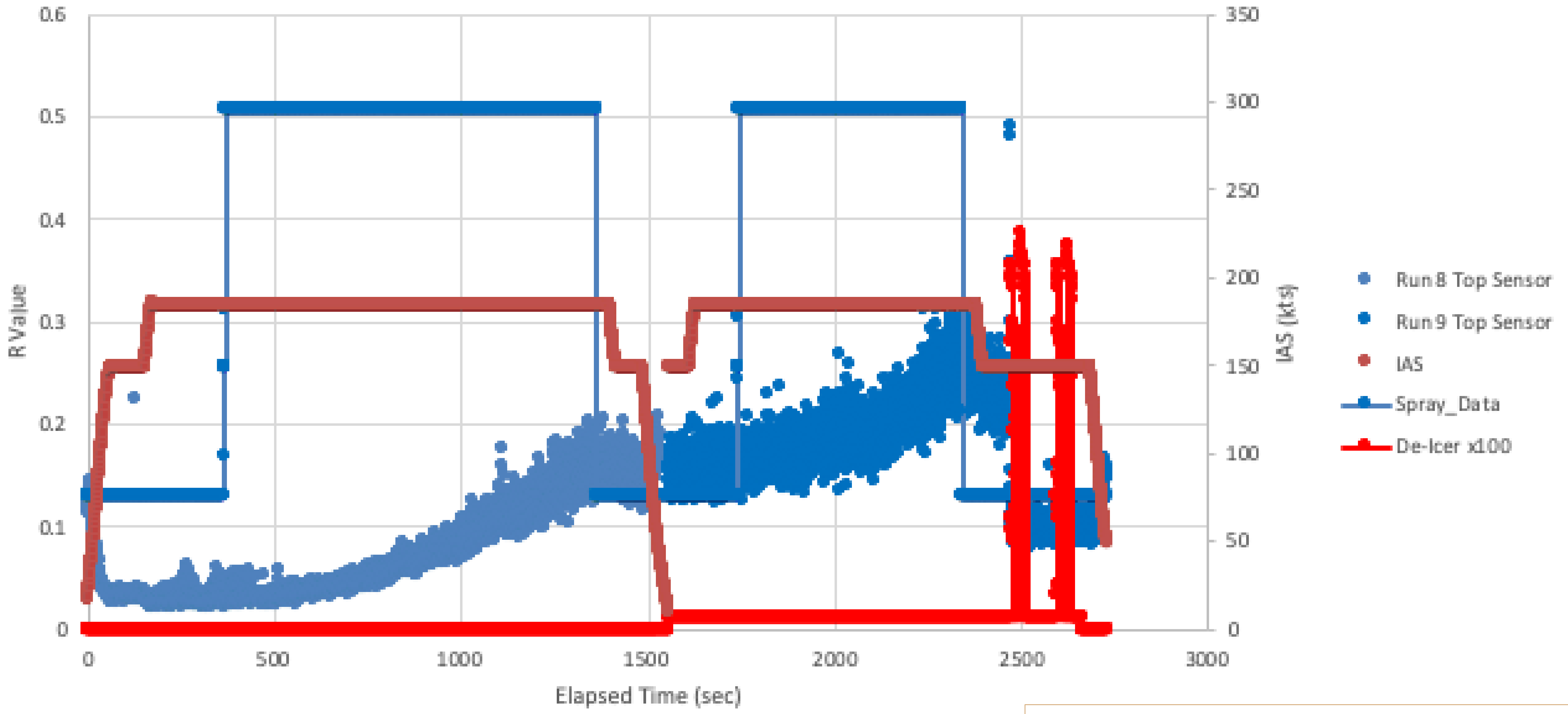
EAPM in action

Examples of EAPM signalling multiple local blade “distress” periods when RPM sags



EAPM "seeing" icing degradation

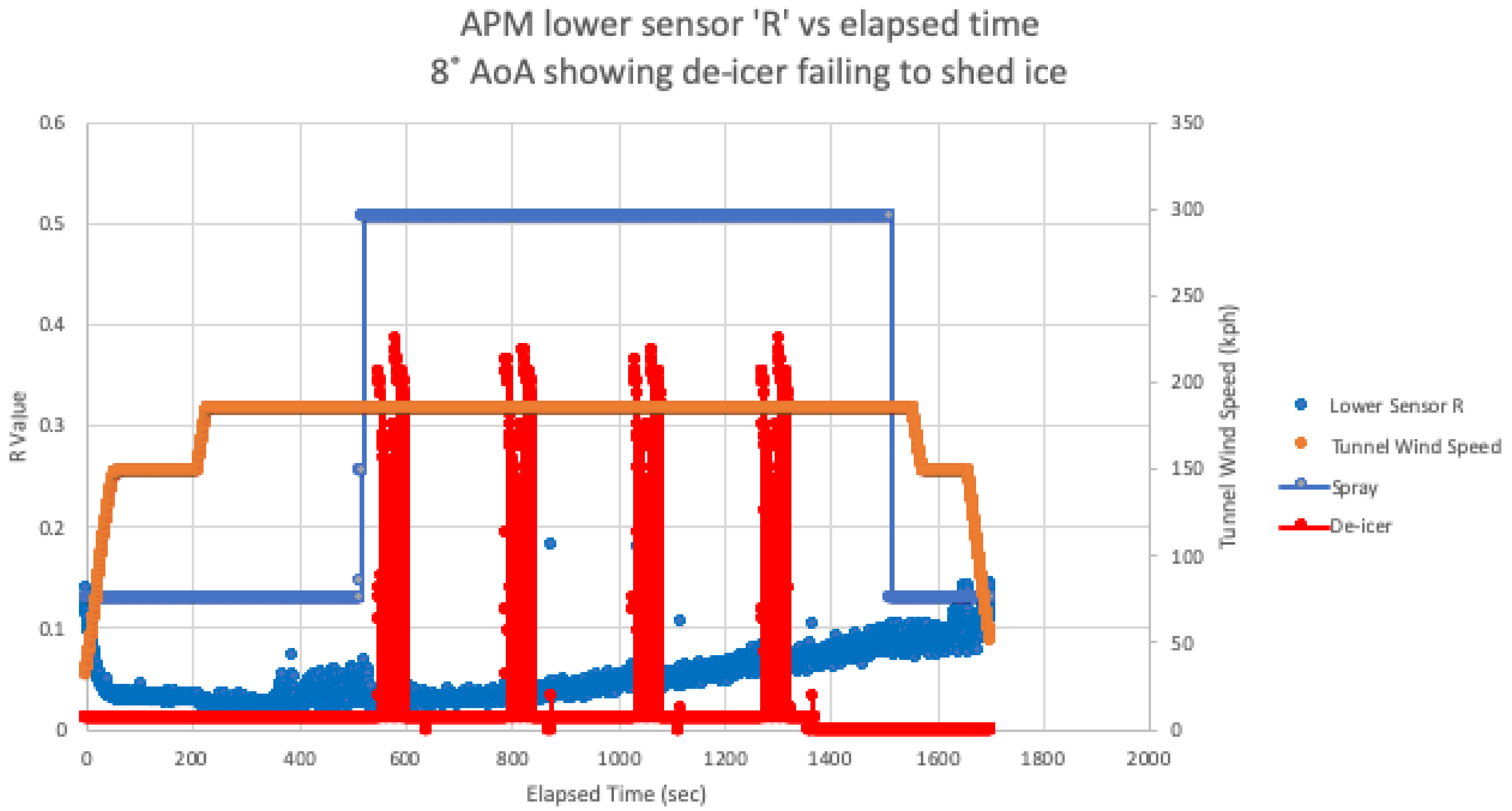
Example of EAPM signalling increasing blade distress (blue slanted line) as ice accumulates with time



Red spikes show de-ice system activation and reduction of blade distress

EAPM “seeing” deicing system failing

EAPM signalling increasing blade distress (blue slanted line) as ice accumulates with time



Red spikes show de-ice system activation with *no* reduction of blade distress

Let’s take a look at **EAPM in real-time**

Real time EAPM display

EAPM potential

Increase AEP

- More predictable AEP (lower project risk)
- Better AEP through closed-loop control of blade pitch based on real-time aerodynamic performance
- Optimized blade angle-of-attack (AoA) and stall margins in *all* conditions

2% increase in AEP translated to $5,700/MW – WindESCo (2020)

"A 1% annual production increase at a typical wind farm with 100 two megawatt turbines can boost revenue by $250,000–$500,000." – EPRI Journal

Reduce O&M

- Detect and react to abnormal or degraded aerodynamics in real-time
- Enable optimized on-condition maintenance and inspections based on highly-specific real-time monitoring

"Within the next couple of years… operating expenses (OPEX) will eclipse capital expenditures (CAPEX) – Wind Power Engineering and IHS Markit (2019)

Extend Asset Life

- Very precise health trend-monitoring data, for a single wind turbine or an entire installation
- Optimized maintenance interventions
- Reduced chance of black swan events

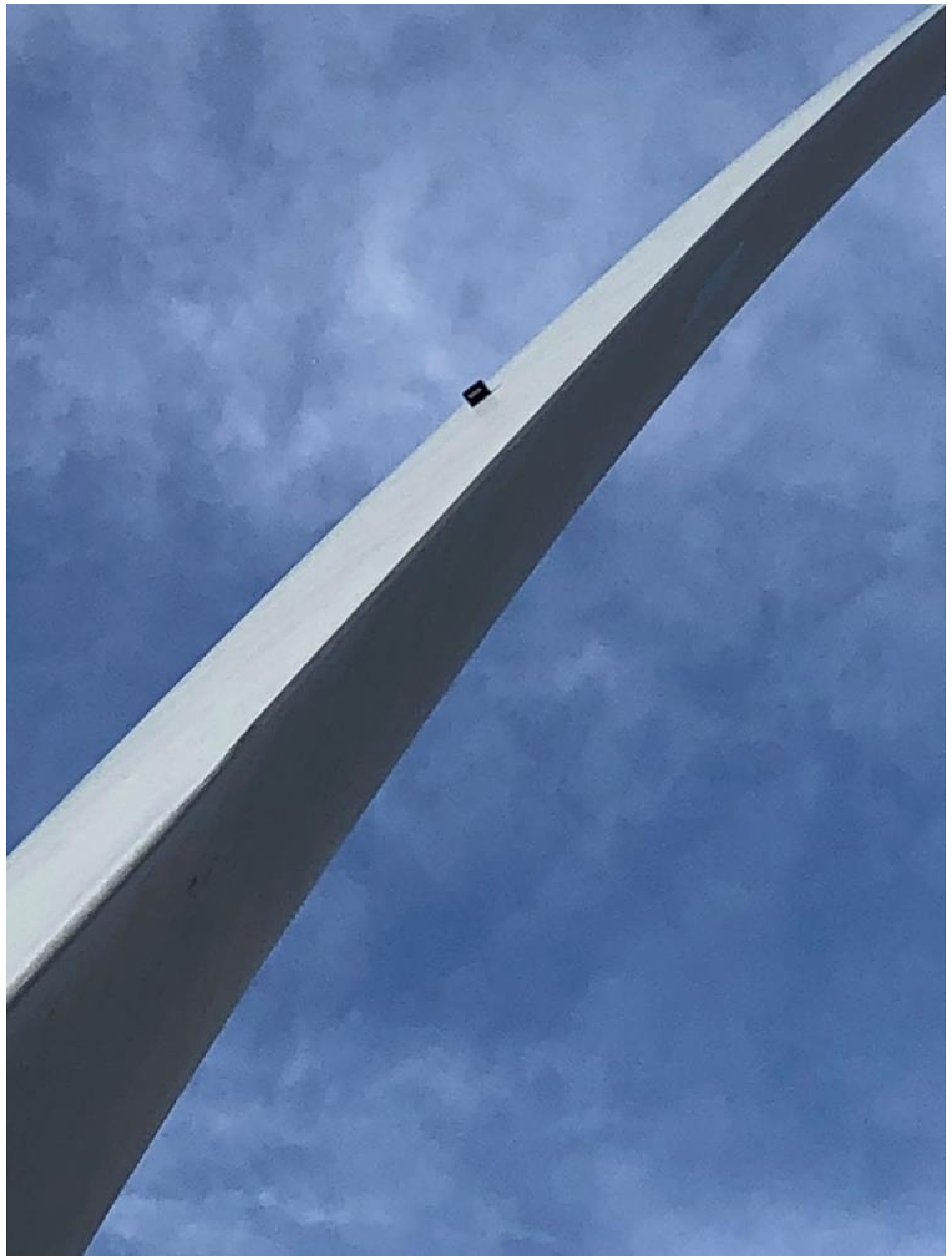
"The wind industry needs to prepare for upcoming challenges, such as maintenance of aging assets, assessment of structural integrity, lifetime extension decision making, and decommissioning of turbines" – Renewable & Sustainable Energy Review

Future Advancements

- Detailed quantified metrics for performance Δs from future aerodynamic optimizations (vortex generators, saw-teeth, etc.)
- Optimized individual (cyclic) blade pitch control
- Closed-loop feedback for AI wind-farm optimizations

Thank you!

A special thank you to our colleagues at Nergica and to the Canadian government for co-funding the intense development effort that allowed us to introduce this disruptive technology to the wind industry!



Questions?

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