Dedicated to innovation in aerospace

Literature Survey on Wind Turbine Blade Inspection Techniques

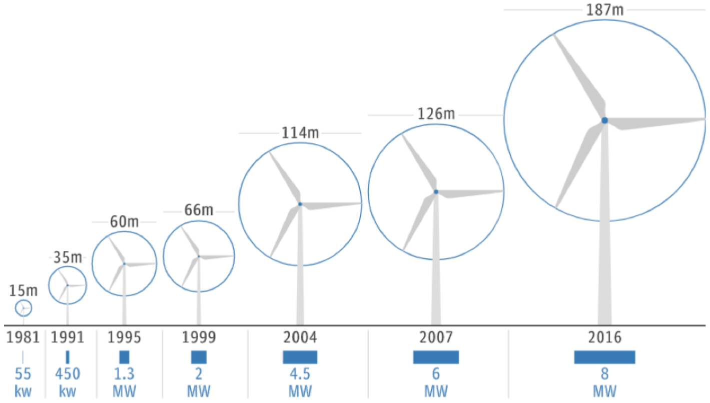
Jason Hwang | Blade Maintenance Workshop | 22 July 2021

Contents

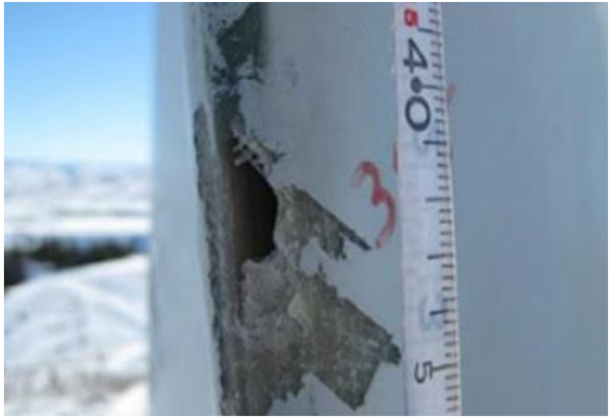
Dedicated to innovation in aerospace

AIRTuB Roadmap

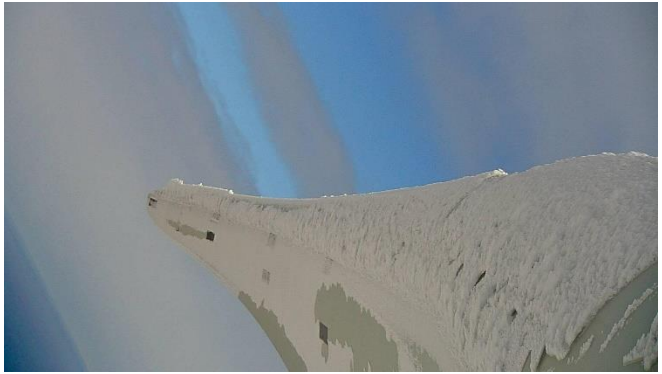
Challenge Ahead



Source: [1]



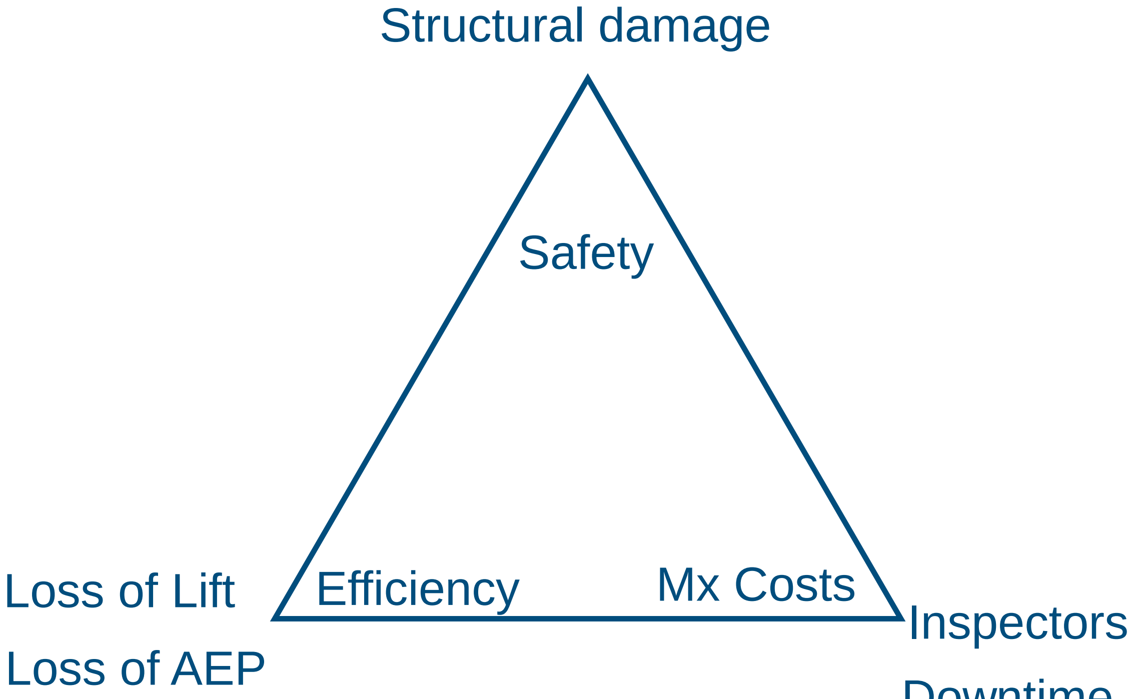
Source: [2]



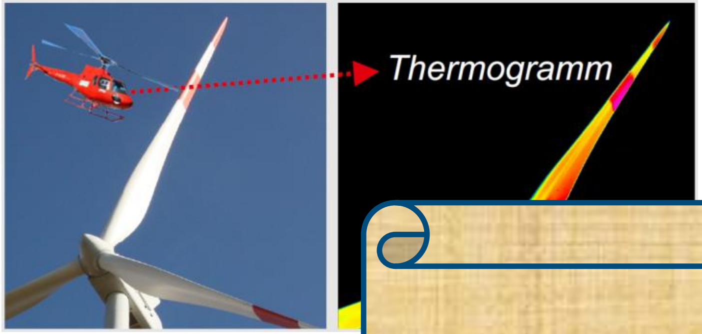
Source: [3]

Source: [4]

Balancing Between Safety, Efficiency and Mx Costs



Balancing



Source: [5]

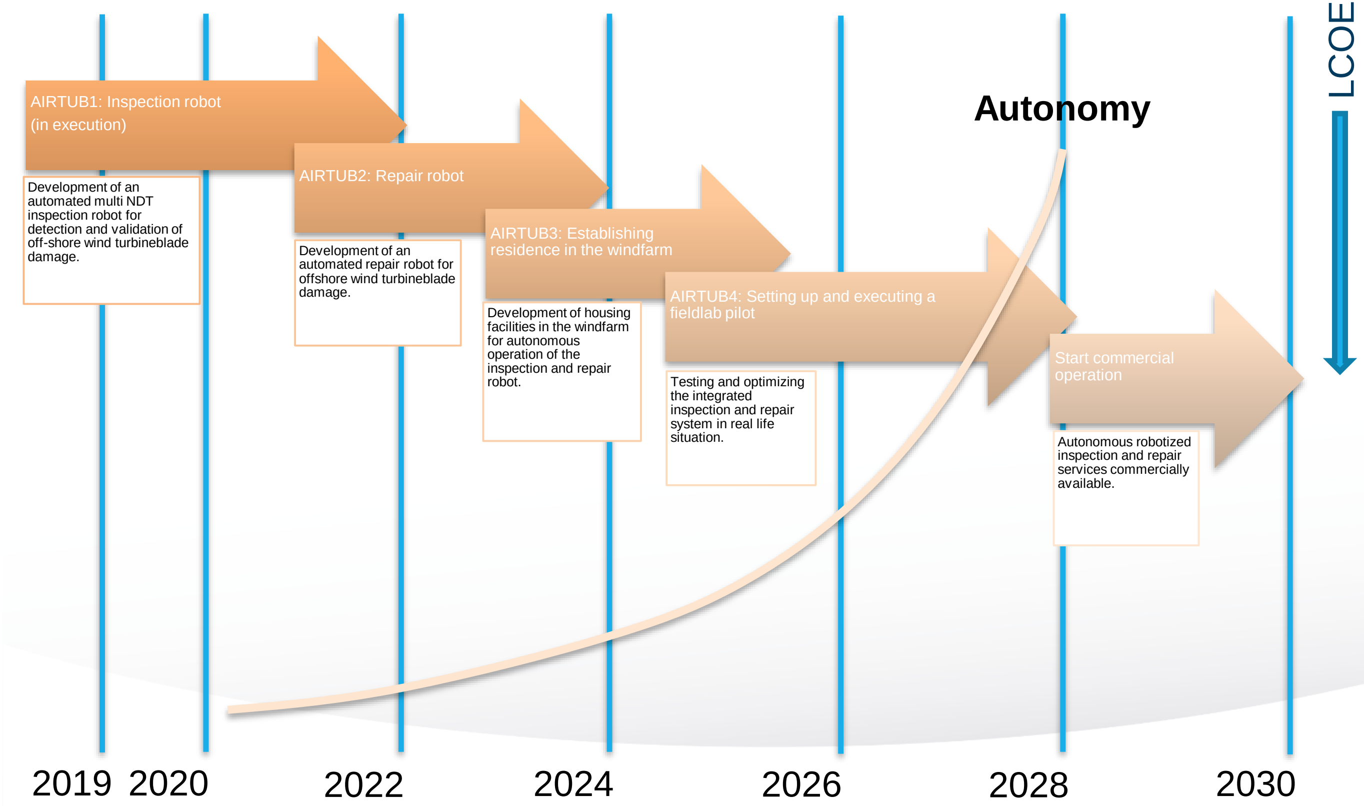
What brings AIRTuB?

Source: [6]

Source: [7]

AIRTuB *roadmap*

AUTOMATED INSPECTION AND REPAIR OF TURBINE BLADES



Call for Action / Business Driver = Need for LCOE reduction

- Lifetime extension
- AEP improvement
- Maintenance logistics reduction
- Elimination of human presence offshore
- Reduction of pollution in the marine environment (also erosion particles)

AIRTuB solution:
Fully autonomous robotized turbine blade maintenance by:

- Robotized inspection and repair system resident in windfarm
- Condition monitoring
- Frequent small high quality repair interventions

Business model:

- Owner Operator (OO) contracts AIRTuB as a Service from Service Provider (SP)
- SP operates on performance contract with OO
- OEM of AIRTuB Equipment rents Robots to SP

Involved partners:

WORLD CLASS MAINTENANCE

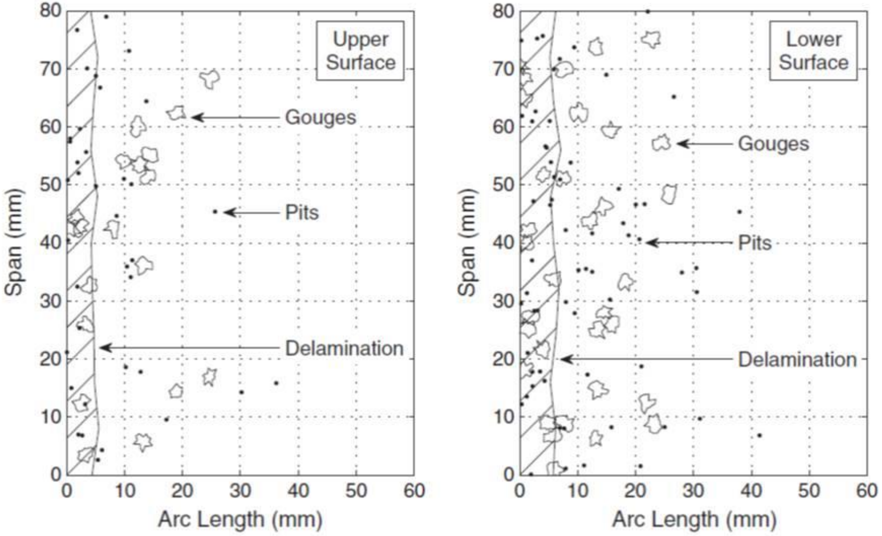
Fieldlab ZEPHYROS

Dedicated to innovation in aerospace

Typical Damage Modes in Wind Turbine Blades

Inspection of Wind Turbine Blade

External Damages



Source: [8]

(a) (b) (c)

Type of Damage	Erosion Depth (mm)	Erosion Diameter (mm)	Decrease in AEP expected	Number of features
Pit	0.3	2	3% - 5%	400 over a 2.5m span

Need for 3D profile

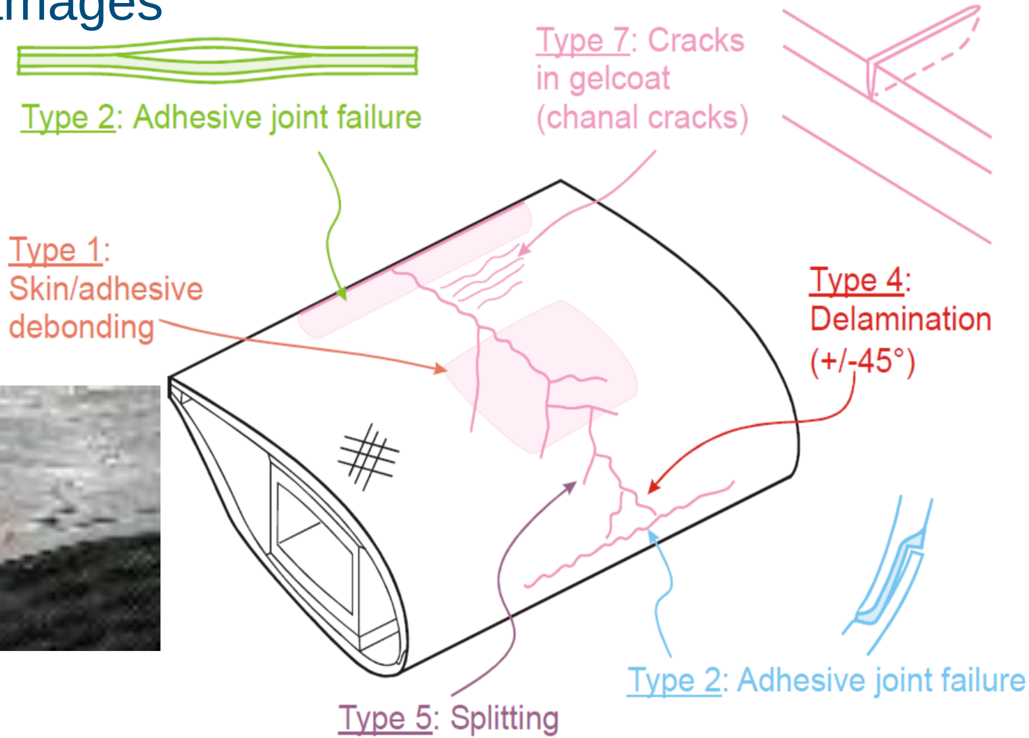
Source: [9]

Inspection of Wind Turbine Blade

Internal Damages

Type 3:
Skin/sandwich panel joint damage

Source: [11]



Source: [10]

Type 6:
Buckling of main spar and disbond as result

Source: [11]

Inspection of Wind Turbine Blade
Internal Damages

Type	Location	Depth (mm)	Length (mm)
Structural Gelcoat (type 7)	Trailing edge	0	Hairline, 100
delamination in root laminate (type 4)	20% inboard	75	100
delamination in outer skin-core bond of sandwich (type 3)	60% inboard, sandwich panels between spar caps and leading/trailing edge	2 – 5	100
bondline tunneling or disbond cracks (type 1 and 2)	web-spar cap, leading/trailing edge	0 - 30	hairline (tunneling) or 25 (disbond)

WORLD CLASS MAINTENANCE

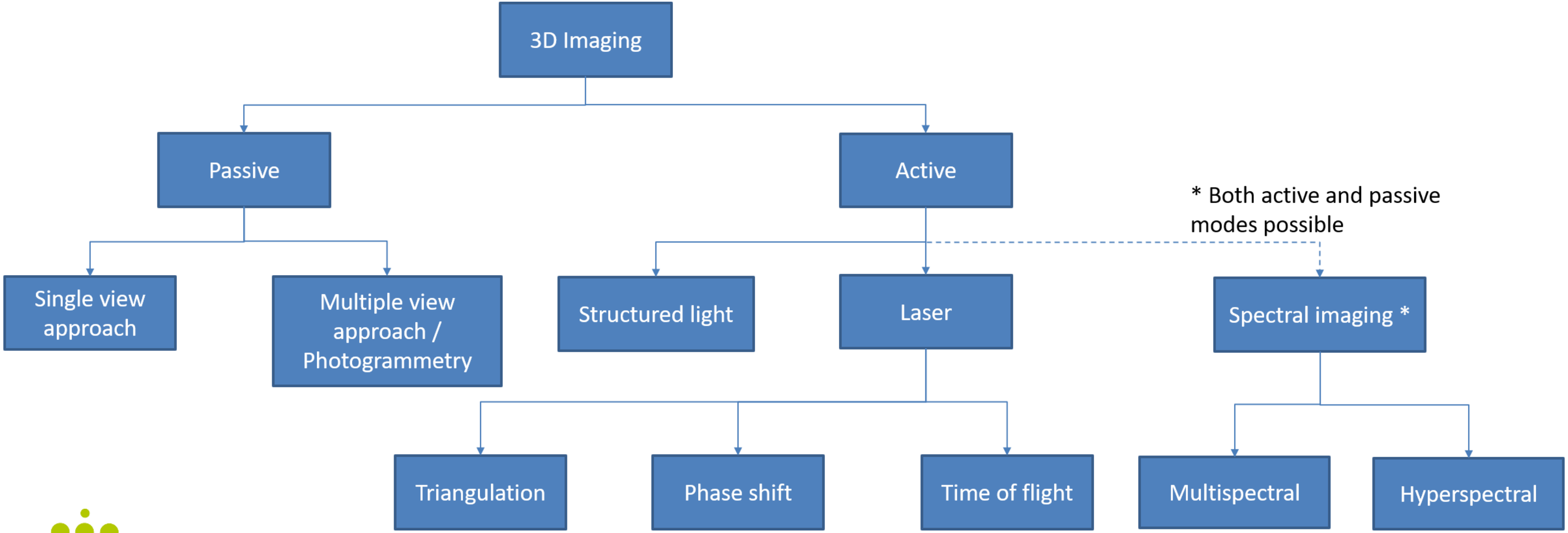
Source: [9]

Dedicated to innovation in aerospace

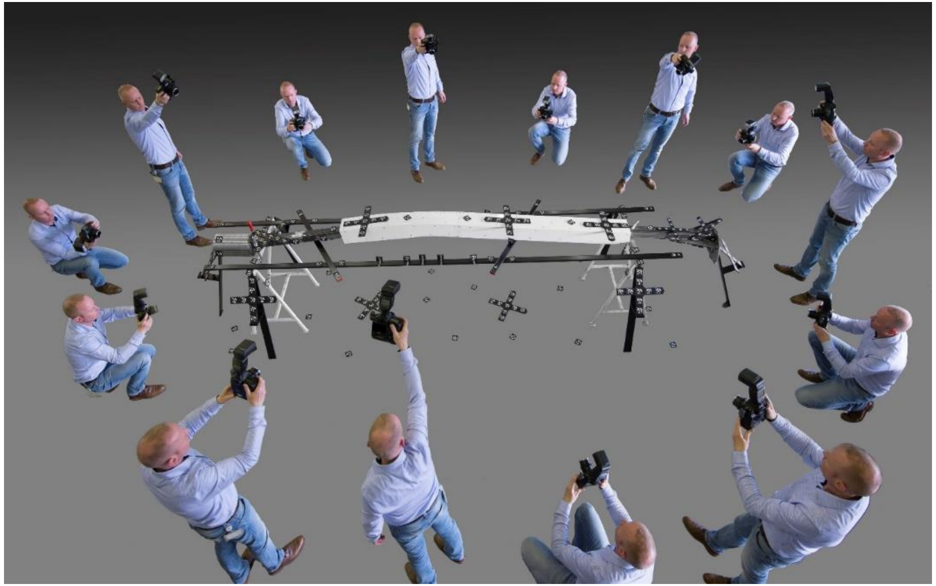
External Damage Inspection Methods

3D Imaging Techniques

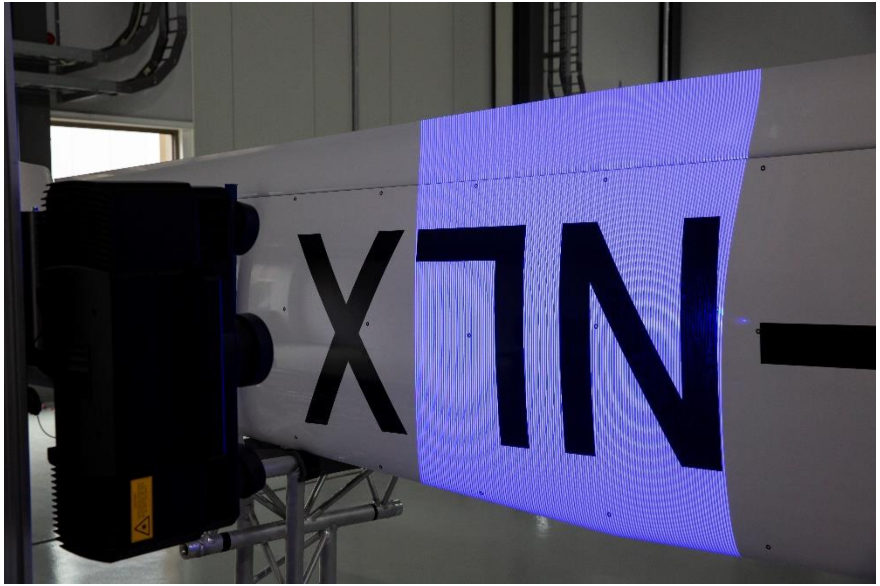
Overview of 3D Imaging Techniques



3D Imaging Techniques

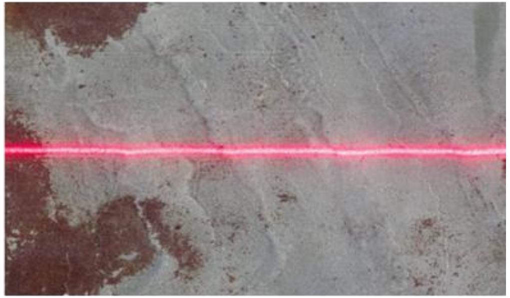


Photogrammetry



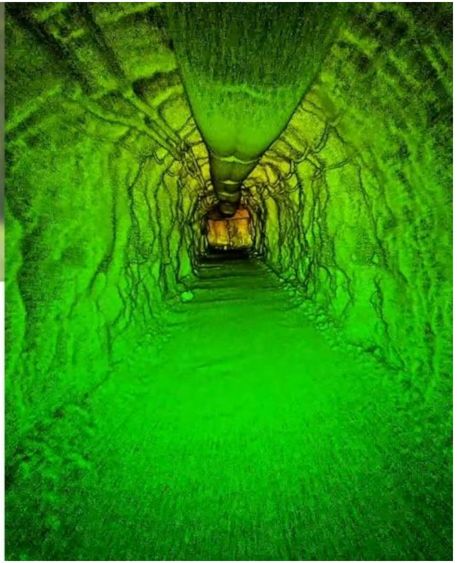
Structured Light

3D Imaging Techniques



Source: [12]

Laser Line Scanner



Source: [13]

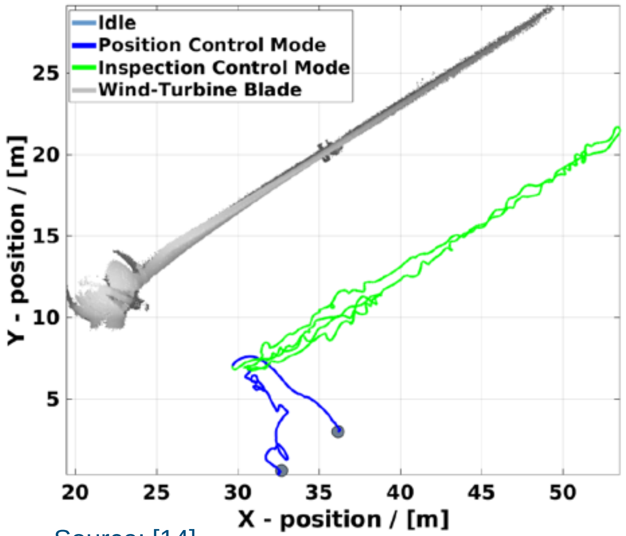
Laser Imaging Detection and Ranging (LIDAR)

3D Imaging Techniques
Strengths and Weaknesses

Imaging method	Strength	Weakness
Photogrammetry	• Miniaturization	• Visual characterization required • Depth resolution
Structured Light	• Accuracy from 10 µm	• Light condition • Sensitive to vibration
Laser Line Scanner	• Accuracy from 10 µm • Miniaturization	• Surface condition
LIDAR	• Robustness • Flexible measurement distance	• Accuracy

3D Imaging Techniques
Conclusions

- Triangulation laser has best potential to fulfill required erosion target for AIRTuB project
- There are three aspects to be dealt with
  – Effect of vibration
  – Effect of surface condition
  – Location of each measurements



Source: [14]

Dedicated to innovation in aerospace

Internal Damage Inspection Methods

Non-Destructive Inspection

Non-Destructive Inspection Methods

Overview

Inspection Characteristic		NDE technique: Visual	Tap Test Woodpecker	Bondmaster PC Swept/RF	Ultrasonic Inspection: Acoustocam	Ultrasonic Inspection: UT-PA	Ultrasonic Inspection: RapidScan	Thermography Lockin/Transient
Detection	Impact	+	+	0/+	+/++	++	++	+
Detection	Delamin.	-	0	0	++	++	++	-/0
Detection	Disbond	-	0	0	+	+/++	++	0/+
Defect sizing		-	0	0	+	++	++	+
Depth estimation		-	-	-	+	++	++	-
Portability		++	++	++	+	+	+	0
Field of view		~1 m2	Spot	Spot	25 mm2	68 mm	50-100 mm	~1 m2
Couplant required		No	No	No	Yes	Yes	Minimal	No
Inspection speed		++	0	0	+	+	+	++
Level of training		Low	Low	High	Medium	High	High	High
Equipm. costs [k€]		0	< 10	12-15	40-60	40-60	95-110	130-150

Source: [15]

Non-Destructive Inspection Methods
Overview

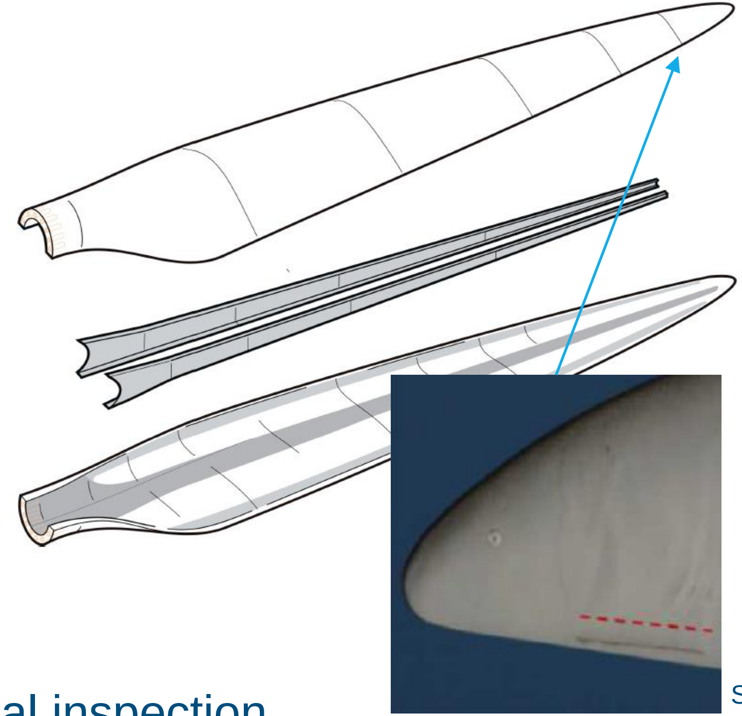
Suitable Inspection Areas for Inspecion Techniques							
Method	Spar Cap	Spar Cap to Shear Web Bond Line	Leading & Trailing Edge	Sandwich Structure	Deep Subsurface Flaws	Near Surface Flaws	Technology Readiness Level (TRL)
Microwave	Good	Satisfactory	Limited	Good	Good	Good	7-8
Shearography	Satisfactory	Poor	Limited	Excellent	Insufficient	Good	9
Terahertz Radiation	*	*	Excellent	Excellent	*	*	7
Oblique Incident Ultrasonics	Good	Good	*	*	*	*	8-9
Pulse Echo Ultrasonics	Excellent	Excellent	Satisfactory	Insufficient	Excellent	Good	9
Phased/Linear Array Ultrasonics	Excellent	Excellent	Satisfactory	Insufficient	Excellent	Good	9
Air Coupled Ultrasonics	Good	Good	Good	Good	Good	Good	7-8
Pulsed Thermography	Limited	Poor	Limited	Excellent	Insufficient	Good	9
Lock-In Thermography	Limited	Poor	Limited	Excellent	Insufficient	Good	7-8
Millimeter Wave	*	*	*	Good	*	*	5-6
* Determination cannot be made due to the lack of specimens inspected by this particular method							

Source: [16]

Non-Destructive Inspection Methods

Damage Types and NDI Methods

Type
Structural Gelcoat (type 7)
delamination in root laminate (type 4)
delamination in outer skin-core bond of sandwich (type 3)
bondline tunneling or disbond cracks (type 1 and 2)



Source: [17]

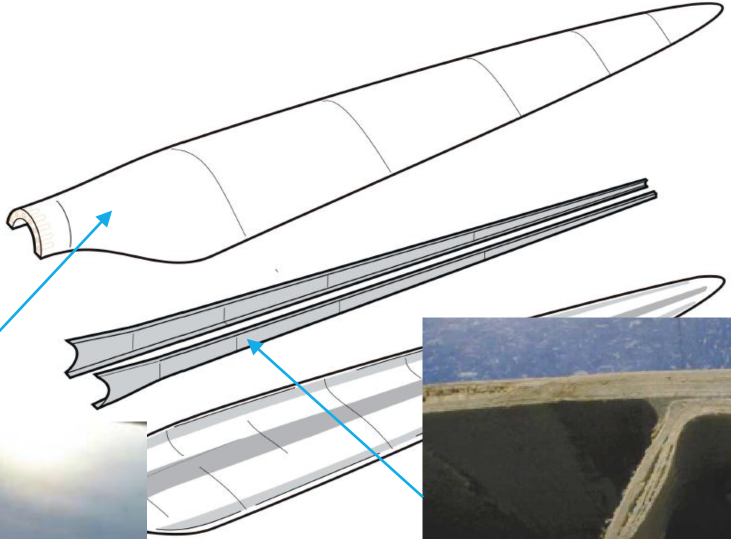
Source: [18]

Viable methods: Visual inspection

Non-Destructive Inspection Methods

Damage Types and NDI Methods

Type
Structural Gelcoat (type 7)
delamination in root laminate (type 4)
delamination in outer skin-core bond of sandwich (type 3)
bondline tunneling or disbond cracks (t



Source: [17]

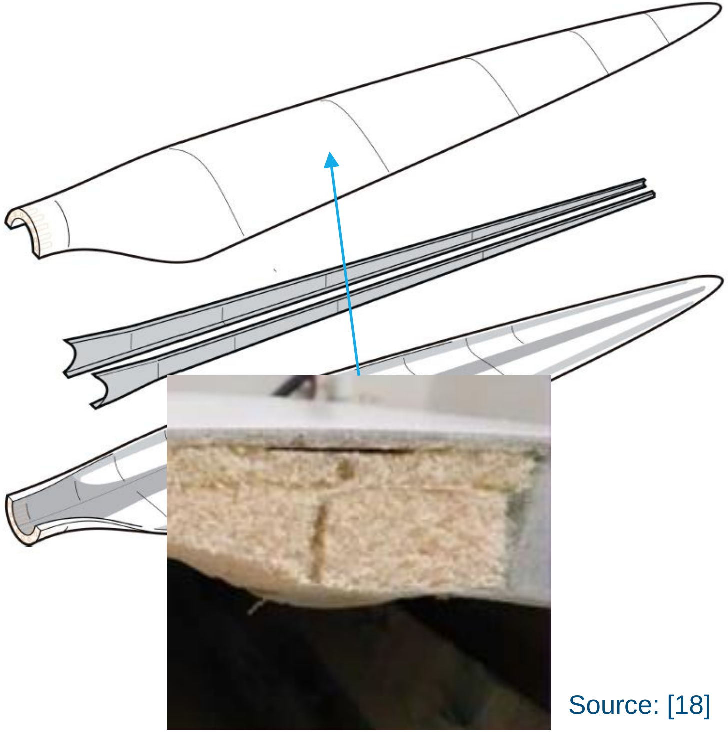
Source: [18]

Viable methods: ultrasonic inspection

Viable methods: none

Non-Destructive Inspection Methods
Damage Types and NDI Methods

Type
Structural Gelcoat (type 7)
delamination in root laminate (type 4)
delamination in outer skin-core bond of sandwich (type 3)
bondline tunneling or disbond cracks (type 1 and 2)



Source: [17]

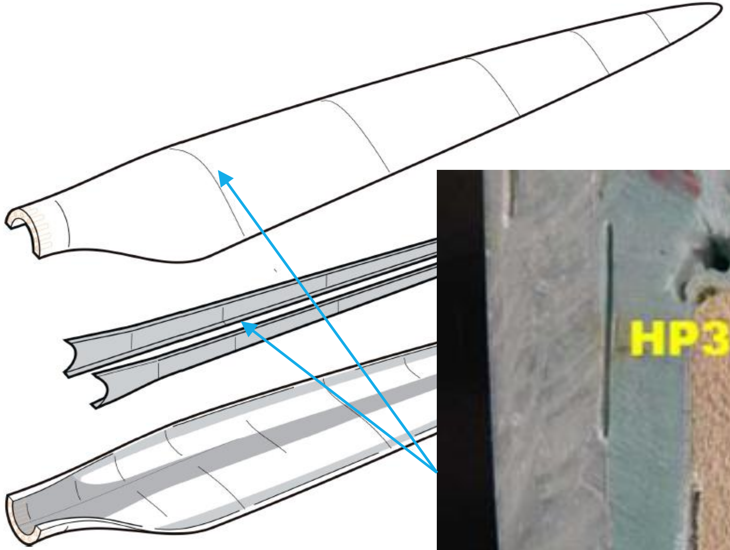
Source: [18]

Viable methods: thermography inspection

Non-Destructive Inspection Methods

Damage Types and NDI Methods

Type
Structural Gelcoat (type 7)
delamination in root laminate (type 4)
delamination in outer skin-core bond of sandwich (type 3)
bondline tunneling or disbond cracks (type 1 and 2)



Source: [17]

Source: [18]

Viable methods: ultrasonic inspection

Conclusions

Conclusions

- AIRTuB: Fully autonomous inspection, repair and maintenance of off-shore wind turbines
- External and internal damages relevant to AIRTuB established
- External inspection:
  - Laser scan has best potential to fulfill the requirement
  - Open questions remain
- Internal inspection:
  - No single-solution available, tailoring to the wind blade design

Credits

The project is executed with subsidy from Topsector Energy part of Ministry of Economic Affairs

Literature Study Report

Go to:

http://hdl.handle.net/10921/1559

References

[1] European Union (2016). "Future Energy Industry Trends", Interreg North Sea Region, northsearegion.eu/northsee/e-energy/future-energy-industry-trends,

[2] Sørensen, B.F., Toftegaard, H., McGugan, M., Pereira, G.F. and Branner, K. (2015). "Very Large Wind Turbine Rotor Blades Require Damage Tolerance and Damage Monitoring", Poster session presented at EWEA Offshore 2015 Conference, Copenhagen, Denmark

[3] Froese, M. and Rook, B. (2018). “The Cold, Hard Truth about Ice on Turbine Blades”, Windpower Engineering & Development, windpowerengineering.com/the-cold-hard-truth-about-ice-on-turbine-blades

[4] Sharpley, N., Tcherniak, D. and Hansen, J.J. (2015) “Algorithms Simplify and Predict Blade Maintenance”, Windpower Engineering & Development, windpowerengineering.com/algorithms-simplify-and-predict-blade-maintenance

[5] Krankenhagen, R. (2015). “Infrarot-Kameratechnologie zur beruhrungslosen Analyse von Rotorblattern unter Hoch-See-Bedingungen”, Poster presentation BAM, IKARUS Project

[6] Fauteux, L. and Jolin, N. (2018). “Drone Solution for Wind Turbine Inspections: Overview of Cutting-Edge Solution for Wind Farm O&M Industry”, NERGICA Renewable Energy Research and Innovation, December 2018

[7] Sandia National Laboratories (2019). “Don’t set it and forget it — scan it and fix it with tech that detects wind blade damage” Press release, 24 June 2019, newsreleases.sandia.gov/wind_robots

References

[8] Sareen, A., Sapre, C.A. and Selig, M.S. (2014). "Effects of Leading Edge Erosion on Wind Turbine Blade Performance", Wind Energy 2014; 17: 1531-1542

[9] Nijssen, R. and Manrique, E. “Literature Review of Structural and Non-Structural Wind Turbine Blade Damage”, TNO report, August 2020

[10] Sørensen, B.F., Jørgensen, E., Debel, C.P., Jensen, F.M., Jensen, H.M., Jacobsen, T.K. and Halling, K.M. (2004) "Improved Design of Large Wind Turbine Blade of Fibre Composites Based on Studies of Scale Effects" Phase 1 summary report, Risø-R-1390(EN), Risø National Laboratory, Denmark, September 2004

[11] Roach, D., Rice, T. and Paquette, J. (2017). "Probability of Detection Study to Assess the Performance of Nondestructive Inspection Methods for Wind Turbine Blades", Sandia National Laboratory report SAND2017-8032X, August 2017

[12] Micro-Epsilon (2020). “Applications for 2D/3D Laser Scanners”, https://www.micro-epsilon.com/2D_3D/laser-scanner/applications/ (accessed: 17-dec-20)

[13] Daly, S. (2019). “Australia’s Emesent launches Hovermap drone payload at International LiDAR Mapping Forum”, The C-Drone Review, 4-Feb-2019, c-drone-review.news/en/2019/02/04/australias-emesent-launches-hovermap-drone-payload-at-international-lidar-mapping-forum/ (accessed: 16-Dec-20)

References

[14] Car, M., Markovic, L., Ivanovic, A., Orsag, M. and Bogdan, S. (2020). “Autonomous Wind-Turbine Blade Inspection Using LiDAR-Equipped Unmanned Aerial Vehicle”, IEEE Access, 8, 131380-131387, doi: 10.1109/ACCESS.2020.3009738

[15] Heida J.H., Platenkamp D.J. (2010) “Evaluation of non-destructive inspection methods”, NLR-CR-2010-076

[16] Roach, D., Neidigk, S., Rice, T., Duvall, R. and Paquette, J. (2015). "Development and Assessment of Advanced Inspection Methods for Wind Turbine Blades Using a Focused WINDIE Experiment", Proceedings of 33rd Wind Energy ySmposium, 5-9 January 2015, Kissimmee, FL

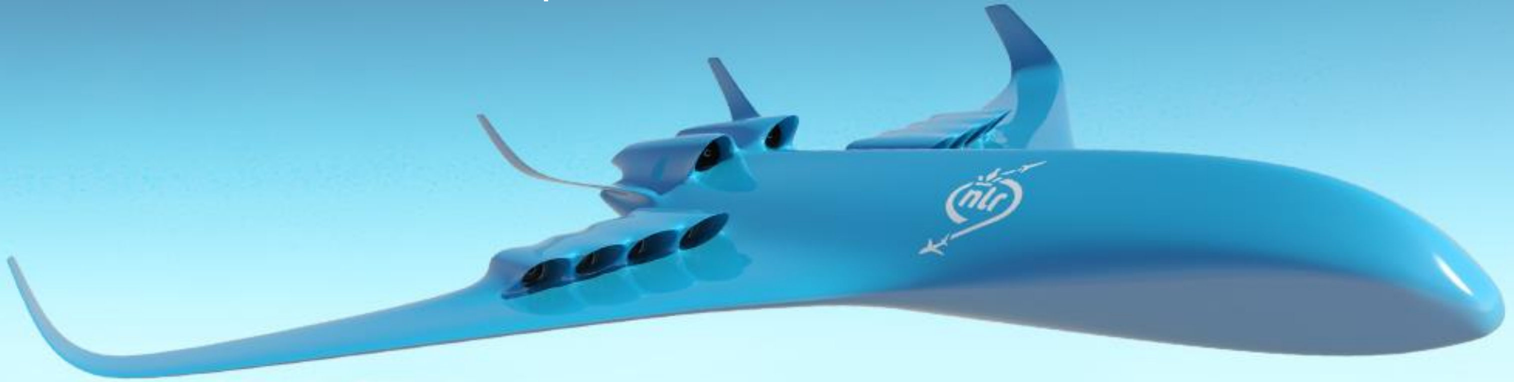
[17] Mishnaevsky, L., Branner, K., Petersen, H.N., Beauson, J., McGugan, M., and Sørensen, B.F. (2017). "Materials for Wind Turbine Blades: An Overview", Materials; 10(11)

[18] Ray Ely, G., Roach, D.P., Rice, T.M., Nelson, G.D. and Paquette, J. (2018). “Development and Evaluation of a Drone-Deployed Wind Turbine Blade Nondestructive Inspection System”, Sandia National Laboratories report, SAND2018-3116

Dedicated to innovation in aerospace

Fully engaged

NLR - Netherlands Aerospace Centre



Anthony Fokkerweg 2
1059 CM Amsterdam
The Netherlands

p) +31 88 511 31 13
e) info@nlr.nl i) www.nlr.org

Voorsterweg 31
8316 PR Marknesse
The Netherlands

p) +31 88 511 44 44
e) info@nlr.nl i) www.nlr.org