Blade Inspection and Repair

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MSc, Mechanical & Aeronautical Engineer, CompBlades founder

Content

- Blade Visual Inspections
- Blade damage types and severity categories
- Damage assessment using NDT
- Repair strategy / R&D background work
- Environmental, health and safety plan
- Training courses matrix for technicians
- Case study of a repair

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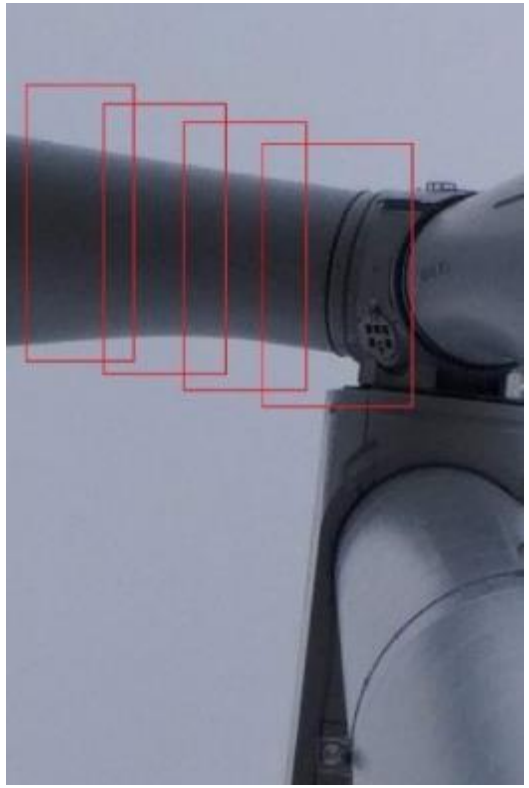
Blade Visual Inspections / External

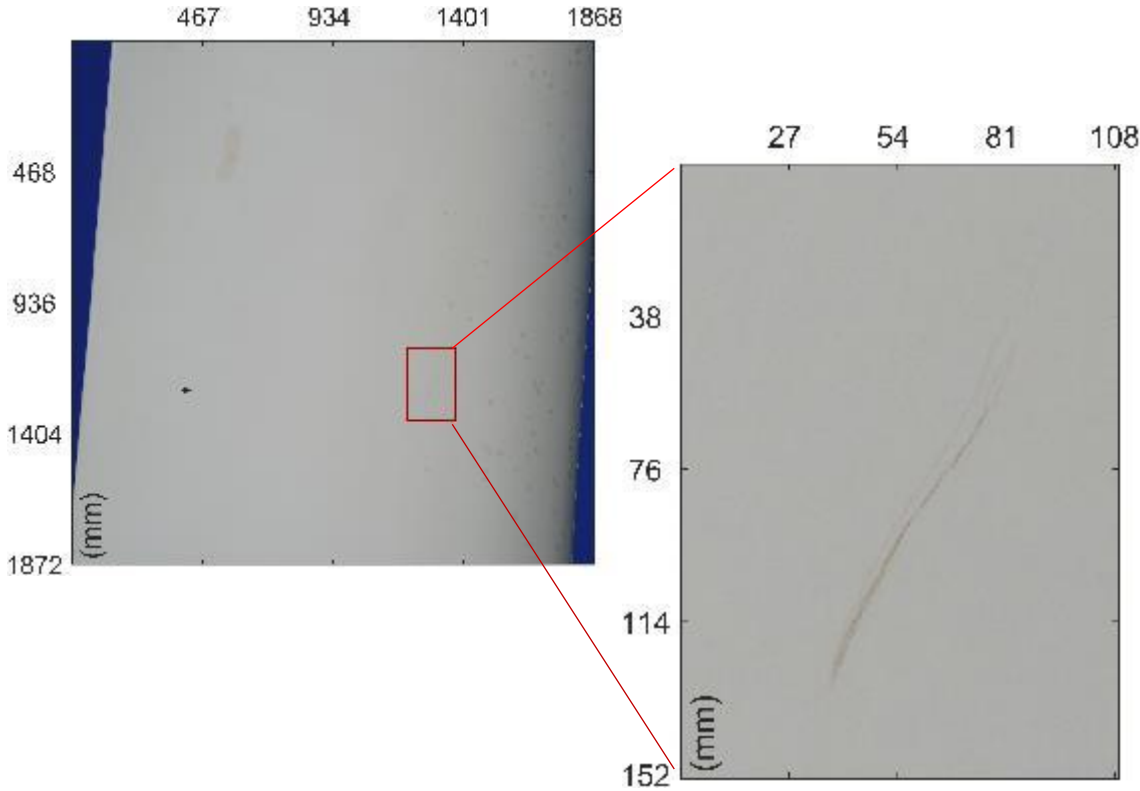
Can be performed:

- From the ground using multi megapixel cameras and super telephoto lens and even the use of a servomechanism for automatic image capturing
- Using a drone and an automatic flight path
- Using a working platform
- Via rope access

Blade Visual Inspections / External

- From the ground using multi megapixel cameras and super telephoto lens and even the use of a servomechanism for automatic image capturing





Blade Visual Inspections / External

- Using a drone and an automatic flight path

Source: https://renews.biz/75706/swiss-firm-launches-blade-inspection-drone-technology

Blade Visual Inspections / External

- Via a working platform

Blade Visual Inspections / External

- Via rope access

Blade Visual Inspections / Internal

Can be performed:

- By drilling a hole of few millimeters and by penetrating an endoscope

- Using a robotic system

Blade Visual Inspections / Internal

- By drilling a hole of few millimeters and penetrating an endoscope

Internal inspection via Endoscope – Broken conductor rod (cable) of Lightning Protection System (LPS of the blade)

Blade Visual Inspections / Internal

- Using a robotic system

Source: https://skyspecs.com/rover-support

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Blade damage types and severity categories

1. **Coating system** →
   - 1.1 Damage, Erosion, Cracks, burnt due to lightning
   - 1.2 Pinholes (exposed laminate), lightning spot
   - 1.3 Contamination (oil, grease, lubricant)
   - 1.4 Blistering, Runs, Overspray, Intended/unintended surface marks
2. **Laminate** →
   - 2.1 Break in laminate, lightning spot, burnt laminate
   - 2.2 Hole in laminate
   - 2.3 Cracks in laminate
   - 2.4 Delamination
3. **Bonding** →
   - 3.1 Cracks in the adhesive-bonding line
4. **Lightning protection system** →
   - 4.1 Lightning on tip/side receptor, possible reduction of conductivity of lightning protection system
   - 4.2 Side receptor placement
   - 4.3 Tip drain receptor placement
5. **Dimensional/Features** →
   - 5.1 Alpha angle out of tolerance
   - 5.2 Trailing edge thickness out of tolerance
   - 5.3 Blade shell offsets, inspection box cover offset, airbrake blade tip offset
   - 5.4 VGs destroyed, lightning strips destroyed
   - 5.5 Erosion foil or Leading edge protection system
   - 5.6 Drain receptor/Drilled drain holes is blocked by debris
   - 5.7 General blade waviness/bumps (Leading edge, Trailing edge, Blade surface)
6. **Old repairs** →
   (Shown indicatively more serious old repairs which have been carried out by third parties).
7. **Further investigation** →
   A visit to the wind park should follow according to the recommended repair or action time for targeted inspection. An additional report will follow
8. **Other** →

CATEGORY	STOP THE WT?	RECOMMENDED REPAIR or ACTION TIME
CAT1	NO	No repair is needed
CAT2	NO	Repair within 1.5 years if other damage/defects above CAT2 are detected in the blade or rotor. For repair extension, inspect after 1.5 year
CAT3	NO	Repair within 6 months. For repair extension, inspect after the 5th month
CAT4	NO	Repair within 3 months. For repair extension, inspect after two months
CAT5	YES	As Soon As Possible

Blade damage types and severity categories

- Various Damage cases and Repairs

Shear webs were debonded (16m) along the blade skins. Blade was repaired and was in service from 2005 till 2010 (repower).

Burnt shear web from lightning and plastic tubular steel-rope container. Shear web was repaired, and plastic tube was replaced

LM 19.1: Broken tube of the blade tip mechanism. A hole is opened on the spar cap to fix the spring end and reconnect the tube for the wire

Blade damage types and severity categories

- Various Damage cases and Repairs

Repair 45m blade length at R25, Skins buckling (2015)

Suction side, 2m x 1m destroyed skin

Pressure side, 1.5m x 1m destroyed skin

Destroyed core material

Repair using crane

Pressure side after repair

Suction side after repair

Blade damage types and severity categories

- Various Damage cases and Repairs

Carbon spar cap repair at 45m blade length (2014)

Lightning at spar cap

Damaged spar cap

Repaired spar cap

Blade damage types and severity categories

- Various Damage cases and Repairs

Repair 43,8m prebending blade in the winter (2016)



Blade repair at N90-2,5 MW. Destroyed 3,5m pressure side and 1,5m skin suction side and 5,9m debonding between shear webs and skins. Skin Reconstruction



NDT inspection for deboning

Blade after repair

Blade damage types and severity categories

- Various Damage cases and Repairs

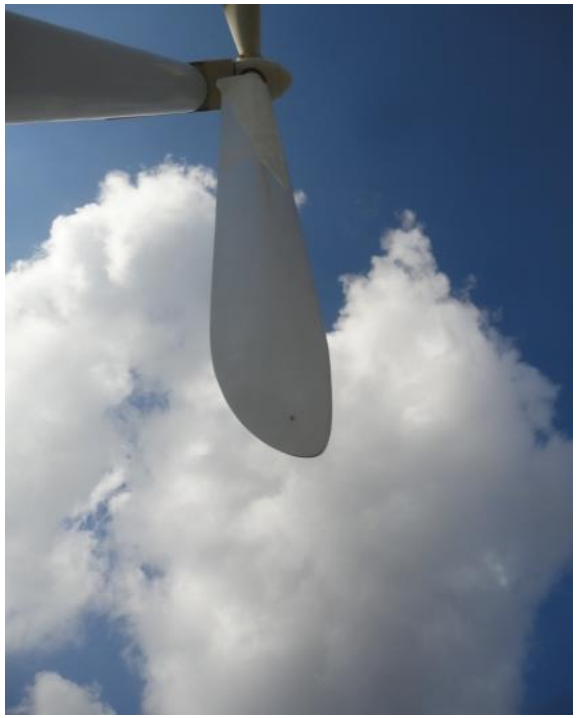
Repair 40m blade (2009)

5m skin replacement in 40m blade without moving or turning the blade

Blade damage types and severity categories

- Various Damage cases and Repairs

17m blade shell repair and replace without dismantling the blade and without affecting the balancing of the Rotor (2016)



Blade damage types and severity categories

- Various Damage cases and Repairs

10m repair on 23m blade keeping the balancing of the Reference rotor (2008)

Before

Before

After

Blade damage types and severity categories

- Various Damage cases and Repairs

Blade Spar cap Reconnected and Reconstructed, In operation since 2006 without problems

Blade reconstruction: Restoration of the blade in a 7m length.

Skin reconstruction over 8m length

After

Blade damage types and severity categories

- Various Damage cases and Repairs

Blade Spar cap Reconnected and Reconstructed, In operation since 2006 without problems

Burnt blade tip

Destroyed blade tip

After

Blade damage types and severity categories

- Various Damage cases and Repairs

Blade Reconstruction. In operation since 2010 without problems

Destroyed blade

Skins and Spar box repair

After

Blade damage types and severity categories

- Various Damage cases and Repairs

Reconstruction of Trip Strips, recovering the aerodynamic performance of leading edge (2012)

Eroded Blade tip leading edge and destroyed trip strips

Repaired leading edge new trip strips

Blade damage types and severity categories

- Various Damage cases and Repairs

3M Vortex Generators installation at Turkey on 2.5MW (2017), Compblades is VG's certified installer

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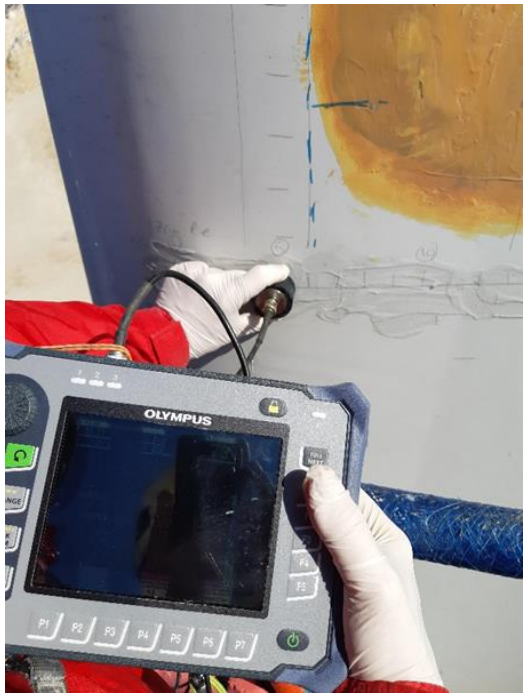
Damage assessment

- Ultrasonic (UT) equipment can be used if further inspection of a damage is needed

  Using the method is achieved, i) Damage dimensioning, ii) Definition of number and type of defected layers, iii) Possible debonding of the load carrying internal structure with the shells

Ultrasonic on the ground



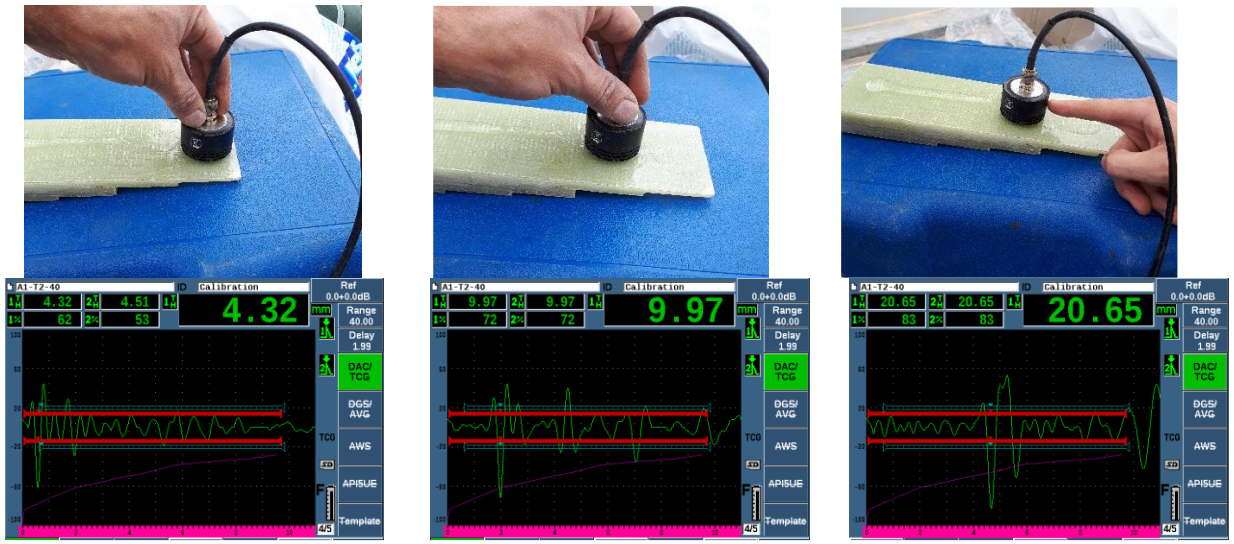
Ultrasonic via crane

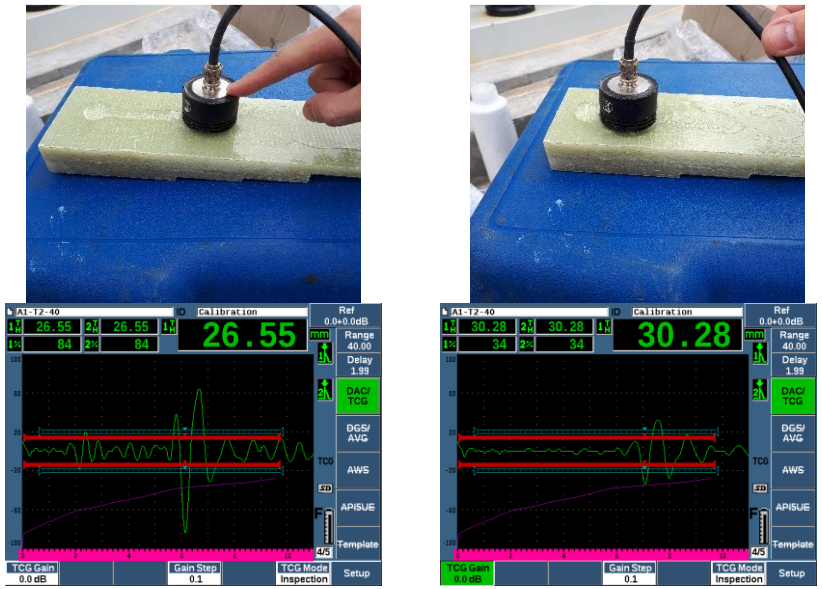
Ultrasonic via rope access

Damage assessment / UT calibration

Calibration procedure with one out of multiple calibration blocks

To calibrate the UT system for a certain campaign a stepwise calibration specimen was used. This specimen has 5 steps with 5 different thicknesses (4mm, 10mm, 20mm, 26mm, 30mm) covering the expected measuring thickness of this blade at specific blade radial distances. All the necessary calibration parameters were computed and given as input to the OLYMPUS EPOCH 650 software to ensure the accuracy of the data.





Calibration positions and output signals from Epoch 650 system.

There are several calibrations blocks available which cover several cases of delamination, debonding in different posit of the blade and for different types of blades taking into account the different production processes as well as different types of materials (resins, fibers). Below is shown the position of sensor and output signal for the distinguished positions.

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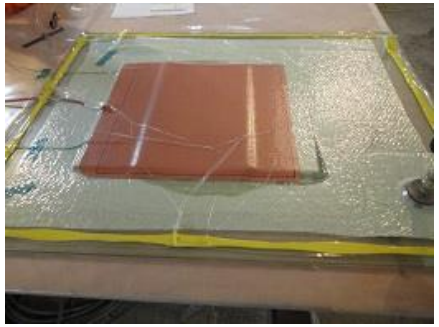
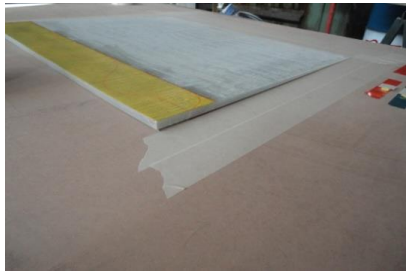
Repair strategy / R&D work

Repair Techniques and Configurations

Several repair parameters were investigated and evaluated as to % of recovered strength: 6 OVERLAPPING LENGTHS, COMPATIBILITY OF DIFFERENT MATRICES, REPAIR TECHNOLOGIES (WET HAND LAY-UP, VACUUM AND INFUSION), REPAIR CONFIGURATIONS (Jooggle lap, single-double strap, step, marine-aviation scarf, CURING PROGRAMS, SLOPES, LAY-UP). 633 static tests were performed in total. Urgent repair solutions were also established.

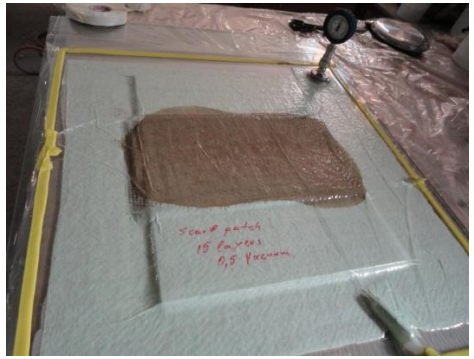


Different curing programs



Different scarf slopes

Repaired specimens



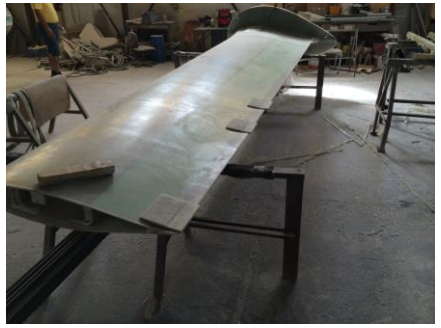
Investigating technological repair parameters

Repair strategy / R&D work

Different repair configurations specimens

Various specimens

Molds for structural parts



19.1 blade part

Hole at 19.1 blade spar cap

Spar cap repair and testing - 100% recover

Repair strategy / R&D work

Destroyed leading edge

Repaired leading edge

Measuring aerodynamic performance (wind tunnel at NTUA) after leading edge repair - 100% Recover

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Environmental, health and safety plan

- *An Environmental, Health and Safety study is a PREREQUISITE for any blade inspection and repair activity, which covers the following issues:*

- Type - Job description
- Occupational risks – Occupational accidents
- Workplace organization
- Disposal of waste
- Traffic rules and safety
- Machinery and equipment
- Portable ladders
- Marking
- Personal Protective Equipment (PPE)
- Fire and Electricity safety
- Toxic, Chemical flammable materials
- Manual cargo handling – Safe work methods
- Heat stress & weather conditions
- Work at height
- Work in confined spaces
- Diseases – Injuries
- Organization (Duties and responsibilities, project manager, safety technician, etc.)
- Communication network and alarm signaling
- Evacuation plan and transport of wounded people
- Occupational Risk Assessment study
- Height Rescue plan, Rope Rescue procedures etc.

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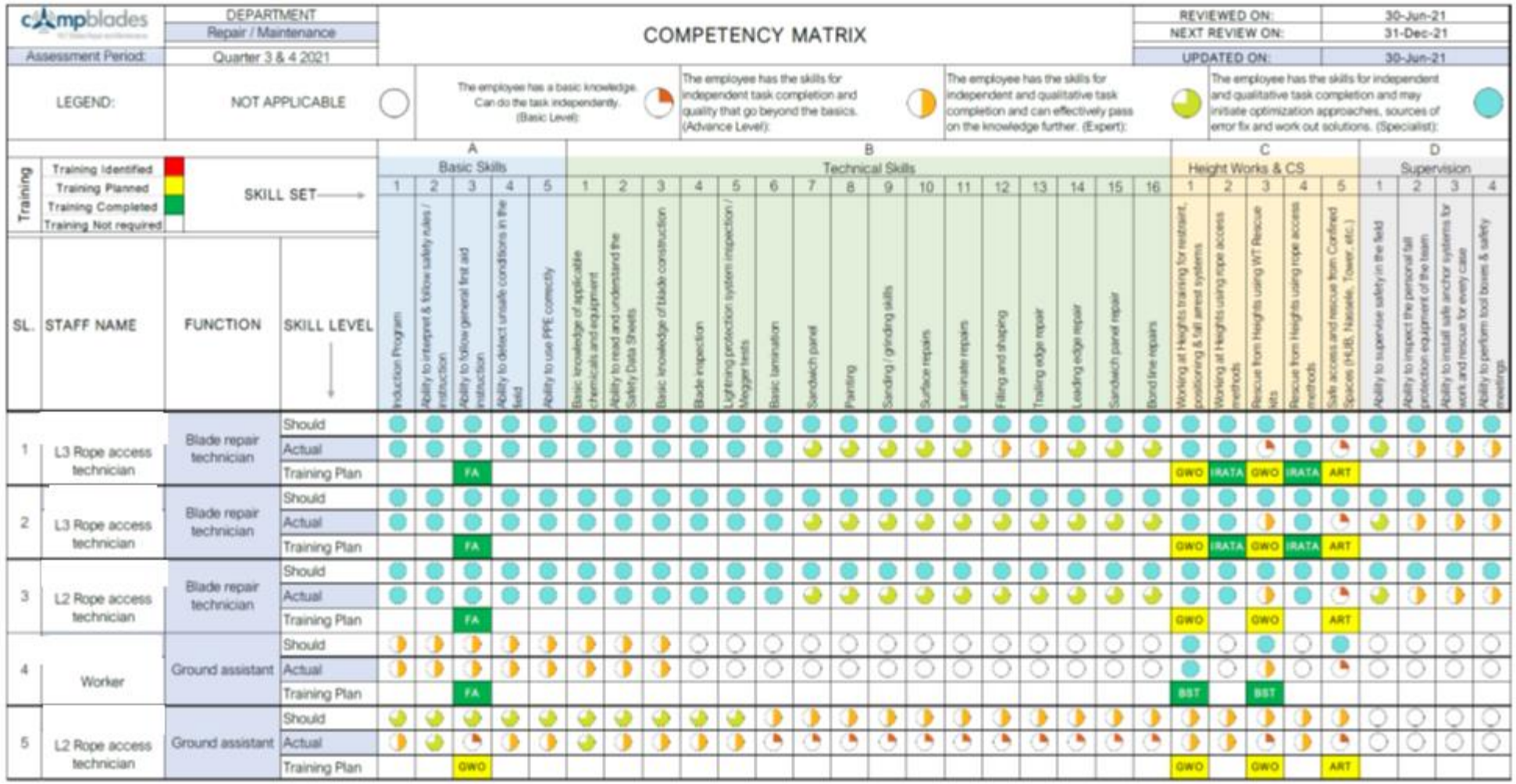
Training courses matrix for technicians

EHS & Risk Assessment Training Requirements Matrix

Course Title	Compblades Training Learning Codes	Frequency(years)	Method	Job			Task			
			Classroom-In person	Ground Technician	Rope Access Technician	Office engineer	Work at Heights(repair-inspection) Worker	Work on the ground(repair-	Work at Heights(repair-inspection) Supervisor	Work on Platform(repair)-Worker
Automatic External Defibrillator	High-Access_Emergency first aid	3	X	X	X		X	X	X	X
Crisis Management & Security	Comp_EHS	1	X	X	X	X				
EHS Awareness Overview	Comp_EHS	1	X			X				
EHS Awareness for Field Service	Comp_EHS	1	X	X	X	X	X	X	X	X
Electrical Safety Awareness	Comp_EHS	1	X	X	X		X	X	X	X
Extreme Temperature Awareness	Comp_EHS	1	X	X	X		X	X	X	X
Fall Protection Competent Person	Hight Access_Work at height	3	X		X				X	
Fall Protection Awareness	Hight Access_Work at height	2	X		X		X	X	X	X
Fire Awareness	Safety Technician_Fire	2	X	X	X	X	X	X	X	X
First Aid	High-Access_Basic first aid at	2	X	X	X	X	X	X	X	X
Hand and Power Tools	Safety Technician_Manual	2	X	X	X		X	X	X	X
Hazard Recognition	Comp_EHS	1	X	X	X	X	X	X	X	X
Hazardous Material Transportation & Security Awareness	Comp_EHS	1	X	X	X	X	X	X	X	X
Hazardous Waste Awareness	Comp_EHS	1	X	X	X	X	X	X	X	X
Occupational Noise Exposure Awareness	Comp_EHS	1	X	X	X		X	X	X	X
Pandemic Preparedness and Business Continuity Plan	Comp_EHS	1	X	X	X	X	X	X	X	X
Covid-19 Awareness	High Access_Covid-19 awareness	once	X	X	X		X	X	X	X
Portable Fire Extinguishers	Comp_EHS	1	X	X	X	X	X	X	X	X
Preventing Violence in the Workplace	Comp_Workers Welfare Policy	once	X	X	X	X	X	X	X	X
Safety Risk Assessment	Comp_EHS	1	X	X	X	X	X	X	X	X
Travel Health, Safety & Security	Comp_EHS	1	X	X	X	X	X	X	X	X
Respiratory Protection Awareness	Comp_EHS	1	X	X	X		X	X	X	X

Training courses matrix for technicians



campblades	DEPARTMENT: Repair / Maintenance	COMPETENCY MATRIX	REVIEWED ON: 30-Jun-21
	Assessment Period: Quarter 3 & 4 2021		NEXT REVIEW ON: 31-Dec-21
			UPDATED ON: 30-Jun-21

LEGEND: NOT APPLICABLE ○ — The employee has a basic knowledge. Can do the task independantly. (Basic Level): ◔ — The employee has the skills for independent task completion and quality that go beyond the basics. (Advance Level): ◑ — The employee has the skills for independent and qualitative task completion and can effectively pass on the knowledge further. (Expert): ◕ — The employee has the skills for independent and qualitative task completion and may initiate optimization approaches, sources of error fix and work out solutions. (Specialist): ●

Training: Training Identified / Training Planned / Training Completed / Training Not required

SKILL SET ⟶

				A – Basic Skills					B – Technical Skills														C – Height Works & CS					D – Supervision			
SL.	STAFF NAME	FUNCTION	SKILL LEVEL	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	1	2	3	4
				Induction Program	Ability to interpret & follow safety rules / instruction	Ability to follow general first aid instruction	Ability to detect unsafe conditions in the field	Ability to use PPE correctly	Basic knowledge of applicable chemicals and equipment	Ability to read and understand the Safety Data Sheets	Basic knowledge of blade construction	Blade inspection	Lightning protection system inspection / Megger tests	Basic lamination	Sandwich panel	Painting	Sanding / grinding skills	Surface repairs	Laminate repairs	Filling and shaping	Trailing edge repair	Leading edge repair	Sandwich panel repair	Bond line repairs	Working at Heights training for restraint, positioning & fall arrest systems	Working at Heights using rope access methods	Rescue from Heights using WT Rescue kits	Rescue from Heights using rope access methods	Safe access and rescue from Confined Spaces (HUB, Nacelle, Tower, etc.)	Ability to supervise safety in the field	Ability to inspect the personal fall protection equipment of the team	Ability to install safe anchor systems for work and rescue for every case	Ability to perform tool boxes & safety meetings
1	L3 Rope access technician	Blade repair technician	Should	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
			Actual	●	●	●	●	●	●	●	●	●	●	●	◕	◕	◕	◕	◕	◑	◑	◕	◕	◕	●	●	◔	●	◕	◕	◑	◑	◑	◑
			Training Plan			FA																			GWO	IRATA	GWO	IRATA	ART				
2	L3 Rope access technician	Blade repair technician	Should	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
			Actual	●	●	●	●	●	●	●	●	●	●	●	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	●	●	◑	●	◕	◕	◑	◑	◑	◑
			Training Plan			FA																			GWO	IRATA	GWO	IRATA	ART				
3	L2 Rope access technician	Blade repair technician	Should	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
			Actual	●	●	●	●	●	●	●	●	●	●	●	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	●	●	◑	●	◕	◕	◑	◑	◑	◑
			Training Plan			FA																			GWO		GWO		ART				
4	Worker	Ground assistant	Should	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	●	○	●	○	○	○	○
			Actual	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	◑	○	◔	○	○	○	○	○
			Training Plan			FA																			BST		BST						
5	L2 Rope access technician	Ground assistant	Should	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○	○
			Actual	◑	◕	◔	◑	◑	◕	◑	◑	◑	◑	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◑	◑	◔	◑	◔	○	○	○	○
			Training Plan			GWO																			GWO		GWO		ART				

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Case study of a complex repair

- Blade 48.5m long (year 2015)
- Winter time (low temperature, High humidity)
- Only the damaged blade on the ground
- The damaged blade was the heaviest of the rotor

Case study of a complex repair

Repair place - Environment

Work place organization in order to start the repair procedure

Case study of a complex repair

Destroyed blade tip

Destroyed blade on the ground

Blade tip geometry replica

Case study of a complex repair

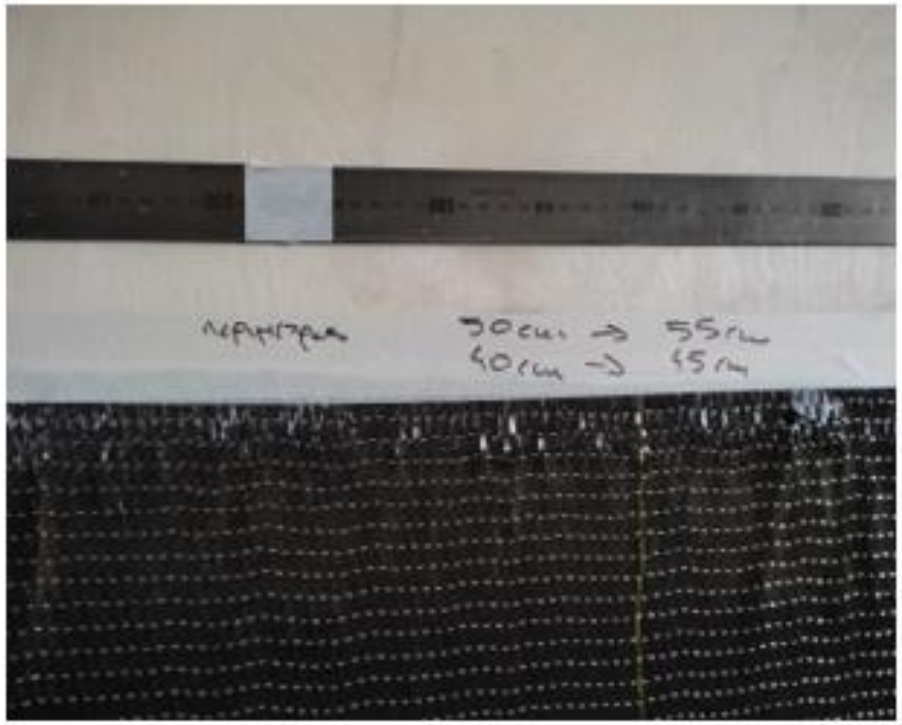
Geometry of damaged blade is recovered

4m mold for the construction of replacement parts

Carbon fibers - roll

Materials preparation

Case study of a complex repair



Unidirectional carbon fibers

Glass fibers ready for lamination

Case study of a complex repair

Measure of environmental Temperature and Humidity

Blade surface temperature

Case study of a complex repair

Data logger for curing program via thermocouples and vacuum pressure

Lightning protection system (LPS), measurement of electrical resistance (mΩs)

Case study of a complex repair

Replacement parts construction via vacuum bagging

Assembly of pressure skin

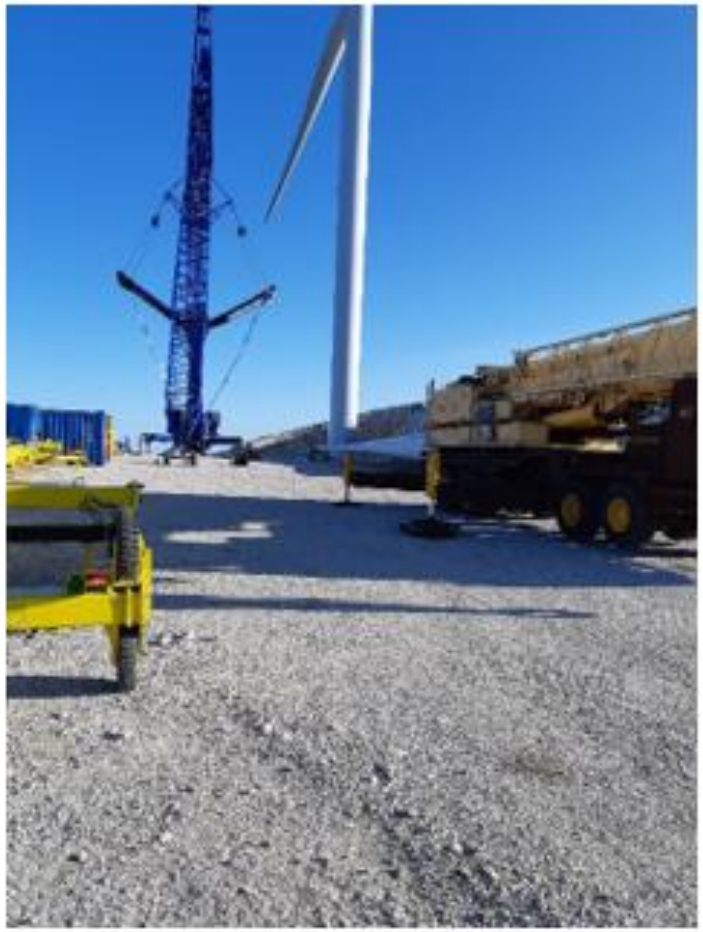
Case study of a complex repair

Assembly of suction skin

Overlapping stage

After repair

Case study of a complex repair



Difficult weather conditions for blade de-assembly

THANK YOU FOR YOUR ATTENTION

Theodore Kossivas on behalf of

compblades
W/T Blades Repair and Maintenance