ADAMANT COMPOSITES Ltd. (ADC)

CA3Viar project: Dissemination event

Date: 05/09/22-06/09/22, Hannover, Germany

Presenter: Dr-Ing Dimitrios E. Mazarakos,
Principal Engineer

Contents

- ADC company (facilities and infrastructure)
- ADC responsibilities in CA3VIAR Project.
- Material selection for blade structure. Mechanical Tests campaign
- Mould development for the CFRP blades' production
- Strain Gauge installation and routing: Trade-off study
- Metallic parts production: Stator vane
- DIC speckle pattern: Trial tests for method selection.
- Single blade ping test
- Static balance test

ADC facilities

Operational Production Facilities with:
Hall 1 – 800m^2 Industrial space + 150m2 Office space
Hall 2 – 300m^2 Industrial space

For Materials & Processes and Space Systems Assembly & Integration

ADC Infrastructure

MATERIALS & PROCESSES

✓ Monitored Materials Storage Unit
✓ Composite Materials Processing Unit
✓ Composite Materials Curing Area
✓ Quality Control Room

General View of Hall I

Freezers with monitoring system

Chemical Lab

Leica AT402 Laser Tracker

- **Monitored Materials Storage Unit**
  - 5x Industrial Freezers (T < -18°C) for prepregs and film adhesives
  - Monitoring, Logging and On-line Alarm system
- **Composite Materials Processing Unit**
  - 15m² Room with controlled environment (RT=20-25°C, RH=40%-60%)
  - Chemical Lab for processing liquid resin systems and lamination
  - 4x Pre-preg Lamination movable stations
  - FRP Monocoque parts and Face-sheet Lamination
  - CFRP Sandwich Panel Manufacturing & Assembly
  - CFRP Strut Rolling, Assembly & Integration
  - Pre-preg Nano-enabling Pilot Line
  - Trimming and Rough cutting stations
- **Composite Materials Curing Area**
  - Autoclave: Dia 1000 x Length 2000 mm for Aerospace FRP structures
  - Curing Oven: 600x800x450 mm, max temp 300°C
  - Various Molds, Utilities and Tools
- **Quality Control Room**
  - 15m² Room with controlled environment
  - Calibrated measurement of physical properties: Length, Thickness, Weight
  - Stereo-Microscope
- **Industrial Metrology System:** LEICA AT402 Absolute & Interferometric Laser Tracker
- Access to:
  - Ultrasonic Testing for NDT of CFRP
  - Mechanical Testing facilities (coupon, sub-component, component & structure)
  - Material Characterization: DSC, DMA, TGA, TMA, SEM, …

Autoclave

Prepreg Nano-enabling Pilot Line

QC Room

ADC responsibilities in CA3VIAR Project.

1) Manufacturing of Composite fan Blades including the mold manufacturing : Number of parts=up to 22 , including the strain gauge instrumentation and the speckle pattern for aero acoustics measurements.
2) Design and manufacturing of the metallic mold for the CFRP blades production.
3) Manufacturing of metallic parts:

a) 1 spinner
b) 1 hub/ adapter/ O-ring
c) 42 stator vanes
d) Foot and wedge parts for the CFRP blade.

3) Instrumentation

The fan blades are instrumented with 3 SG on the suction side.

4) Inspection: Surface quality and roughness, dimensional checking of the parts.

5) Testing: Single blade ping test, static tests MGSE and static balance check.

6) Assembly to test rig and test execution.

ADC support: From Design to Manufacturing process

1) CFRP prepreg selection as Blade material. Material characterization performing Mechanical Tests Campaign for properties investigation (density, ply thickness, tensile strength, elasticity modulus etc)
2) Design, analysis and CNC manufacturing of the metallic mold for the CFRP blades production.
3) Strain gauge application method: Trade-off Study.
4) Speckle Pattern for DIC measurements: Application method
5) Metallic parts: Stator vane
6) Mechanical Tests : Ping Test and structural static test
7) Static Balance test

Material selection for blade structure. Mechanical Tests campaign

ADAMANT COMPOSITES

Supplier's datasheet
Production: Roll material, Length: 100m, width 300 mm

MTC510
Epoxy Component Prepreg

Mechanical Properties

Material: MTC510-UD300-HS-33%RW (SHD0373-300P)
Initial cure: 2 hrs @ 110°C, 2°C/min ramp (solid release, caul-plated, 6 bar)
Testing: Performed at room temperature conditions (J15)

Test	Results			*Standard*
Fibre volume fraction (VF)	Measured	60.20	%	*N/A**
	Theoretical	57.71	%	
Cured Ply Thickness (CPT)	Measured	0.286	mm	*N/A**
	Theoretical	0.289	mm	
Tension 0°	Tensile strength	2282	MPa	*BS EN ISO 527-5*
	Tensile modulus	119.3	GPa	
	Poisson's Ratio	0.34		
Tension 90°	Tensile strength	54	MPa	
	Tensile modulus	8.2	GPa	
	Poisson's Ratio	0.01		
Compression 0°	Compressive strength	1067	MPa	*EN 2850 Type B*
	Compressive modulus	113.6	GPa	
Compression 90°	Compressive strength	200	MPa	
	Compressive modulus	9.3	GPa	
In-Plane Shear ±45°	In-Plane shear strength	99	MPa	*ASTM D3518*
	In-Plane shear modulus	3.60	GPa	
Interlaminar Shear Strength 0°	Interlaminar shear strength	84.8	MPa	*BS EN ISO 14130*
DMA	Tg Onset	123	°C	*Modified ASTM D7028**
	Peak Tan Delta	133	°C	*(Single Cantilever)*

*All tests marked * were completed at SHD Composites laboratories on non-condition specimens. Complete test reports can be supplied independently upon request.*

<u>ASTM D3039 (Ambient Temperature)</u>

A) Tensile strength 0° and 90° (MPA)
B) Tensile modulus of Elasticity 0° and 90° (MPA)
C) Poisson ratio
D) Tensile strain 0° and 90° (%)
E) density (kg/m³)

Closed mold/oven vacuum manufacturing method

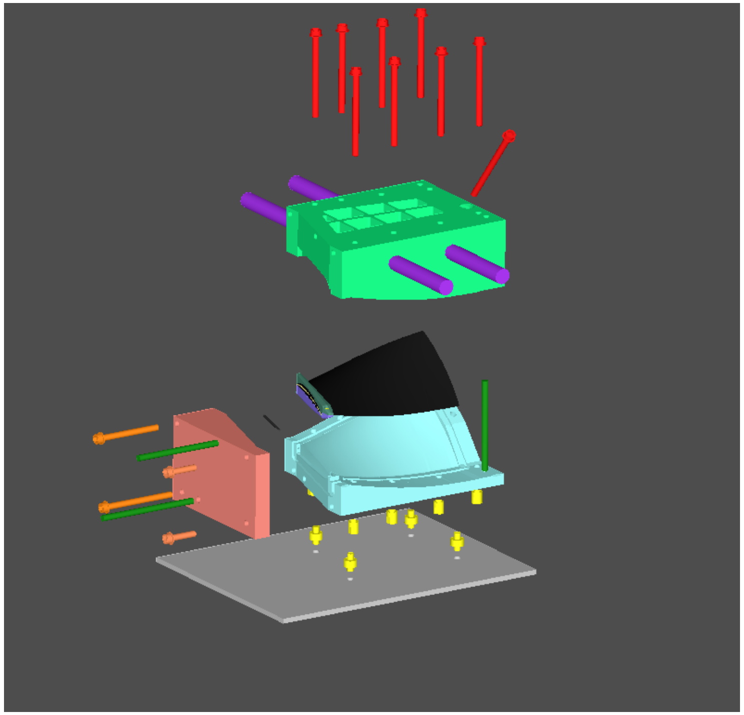
ASTM D3039/D3039M-17

Legende	Nr	Specimen	h mm	w mm	L mm	P^{max} N	E^{chord} MPa	F^{tu} MPa	ε^{tu} %	ν
	max			25,20	226					
	min			24,80	---					
	1	P50-CM-004-1_1	2,24	25,07	225	1935	6992	34,48	0,4788	0,022
	2	P50-CM-004-1_2	2,29	25,01	225	1688	6727	29,5	0,4216	0,022
	3	P50-CM-004-1_3	2,32	24,91	225	1489	6655	25,8	0,3699	0,026
	4	P50-CM-004-1_4	2,31	25,02	225	1684	6594	29,08	0,4224	0,021
	5	P50-CM-004-1_5	2,29	25,03	225	1852	6777	32,32	0,4647	0,022

<u>Key point:</u> σ22 was meausured 30 MPa . Further updates on structural FEM analysis .

Serie n = 5	h mm	w mm	P^{max} N	E^{chord} MPa	F^{tu} MPa	ε^{tu} %	ν
x	2,29	25,01	1730	6749	30,24	0,4315	0,023
min	2,24	24,91	1489	6594	25,8	0,3699	0,021
max	2,32	25,07	1935	6992	34,48	0,4788	0,026
R	0,08	0,16	446	398	8,685	0,1089	0,005
s	0,03	0,06	172,4	152,7	3,315	0,04276	0,002
ν [%]	1,39	0,24	9,97	2,26	10,96	9,91	8,67

Design and Analysis of Mold for Blades production

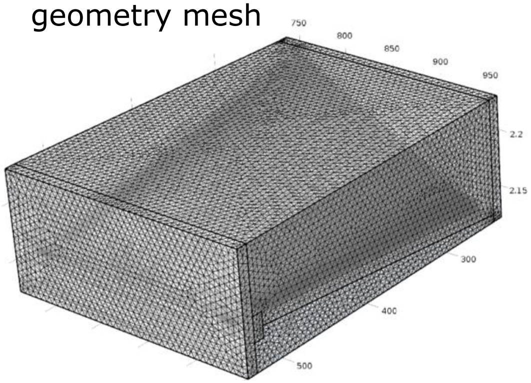


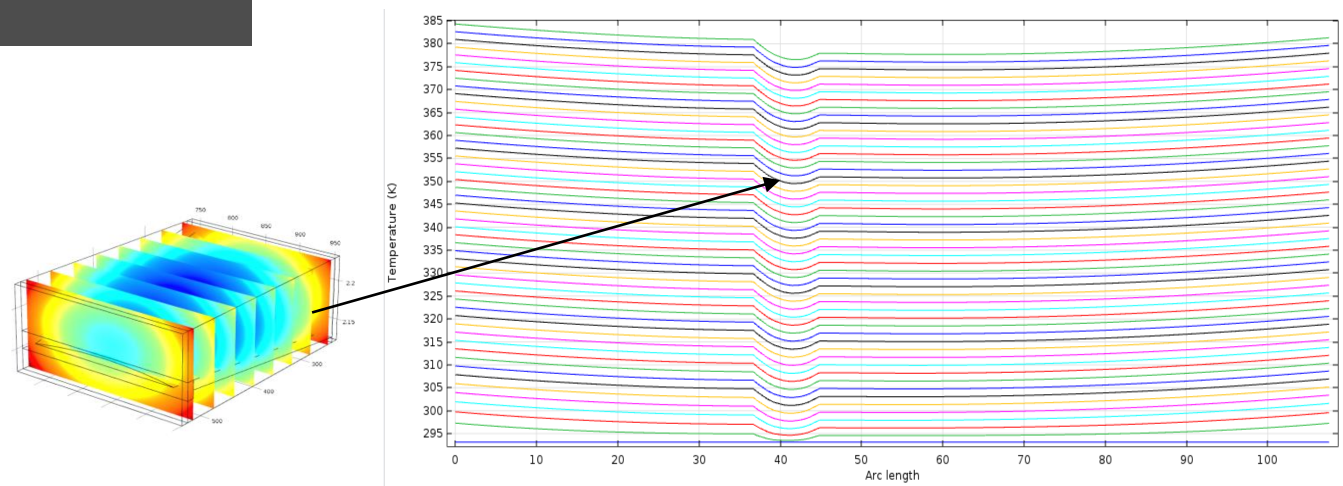
-Parametric thermoelastic analysis for developmental cost evaluation.

1) Material type: RAMAX steel and Invar 36
2) Temperature distribution around the blade during curing process.
3) Global Mould deformations.

<u>Key point: </u>Avoid any imposed deformations on CFRP blade by local deformations of mold’s material during curing process.

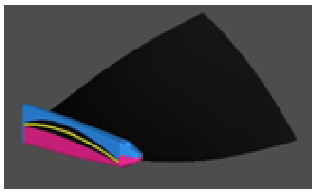
Upper and lower geometry mesh



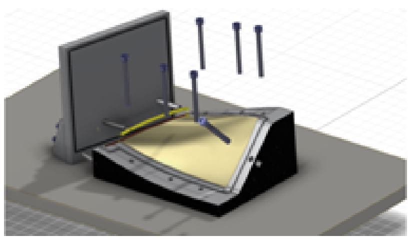


Design and Analysis of Mold for Blades production

Blade assembly geometry



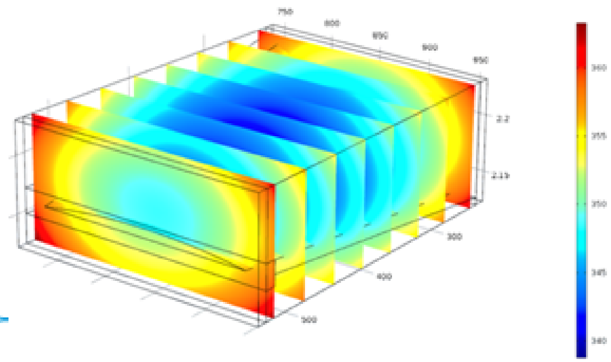
Mold geometry definition

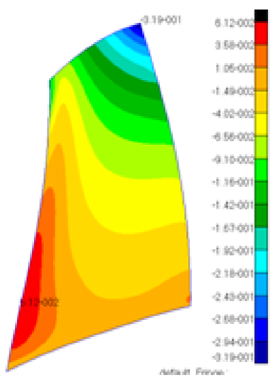


Curing cycle:

Heat-up Rate: **0.5°C/min,**
Steady: 120 min @ 110°C
Cool-down Rate: **3°C/min,**

1-way thermostructural mold (m) FEM analysis (COMSOL)





Blade (b) FEM structural analysis: Behavior under thermal load for Heat up and cool-down rate phases, including overshoot (+20oC)

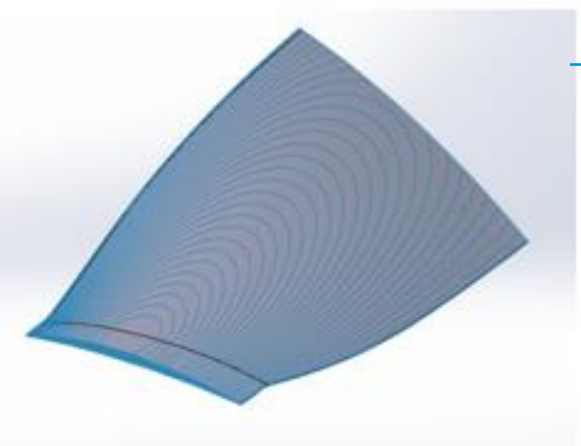
If $u_m(xi, yi,zi)-u_b(xi,yi,zi)>0$ and $\theta_m(xi, yi,zi)-\theta_b(xi,yi,zi)>0$

"Mold imposes deflections to the blade"

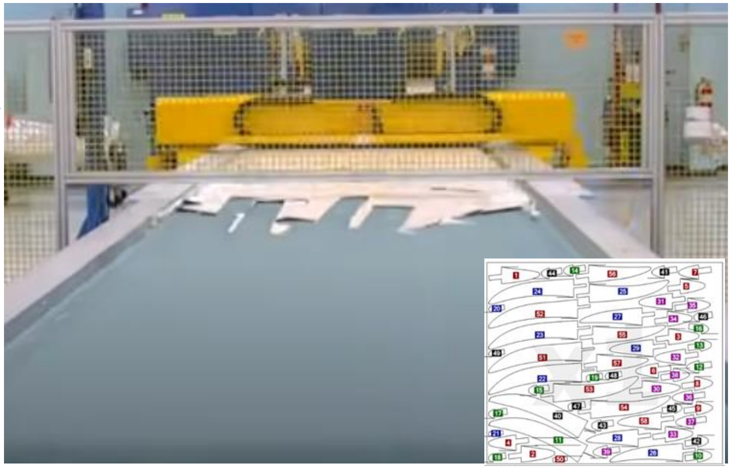
Else "Blade self distortion deformations during curing process

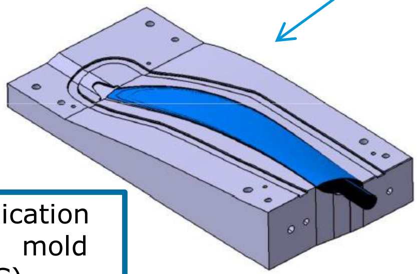
CFRP blade manufacturing activities

3D ply book and 2D plies layout with stacking sequence (IBK)



Kit cutting operations (ADC)



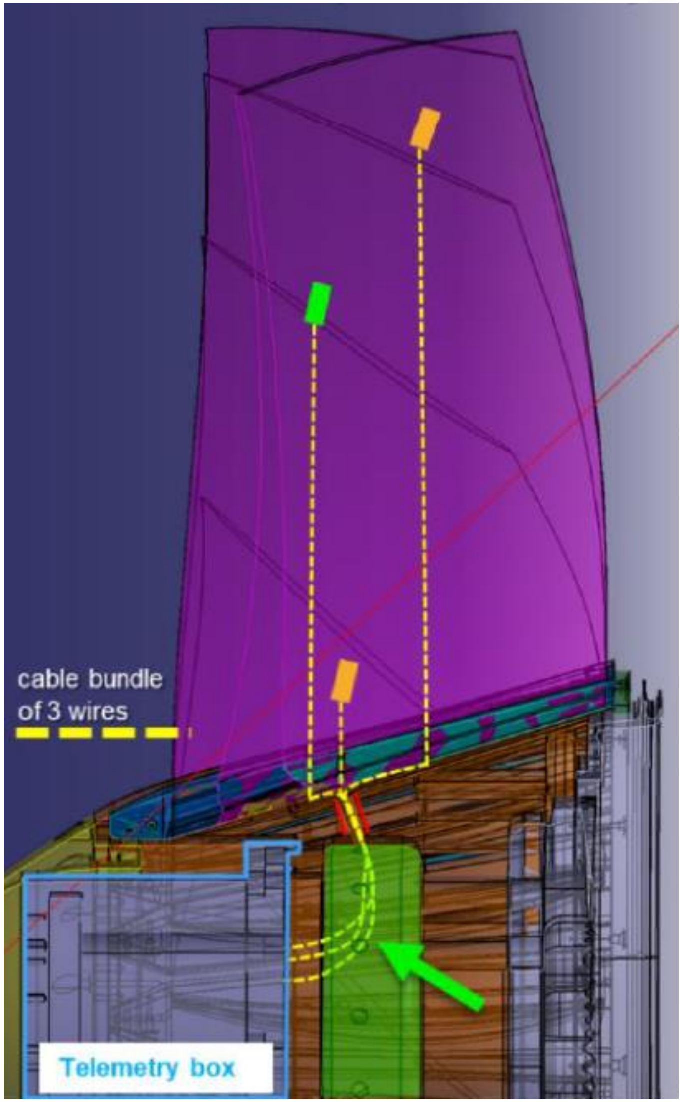


Plies application on closed mold (ADC)

Autoclave curing (ADC)

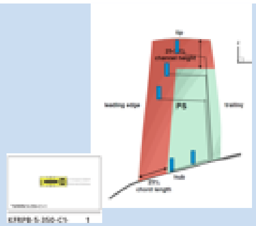
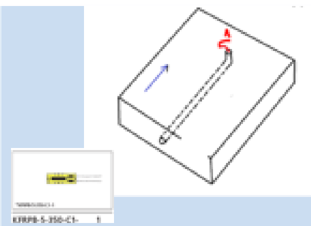
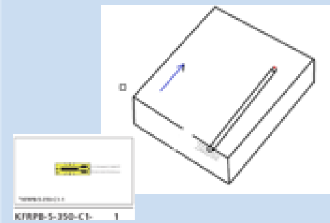
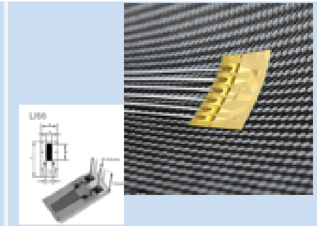
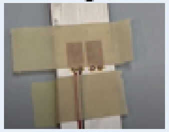
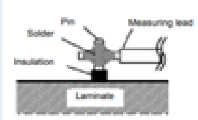
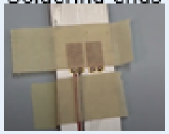
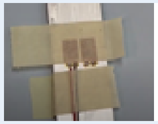
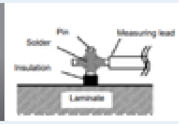
Strain Gauge positioning on Blade

Data provided by IBK

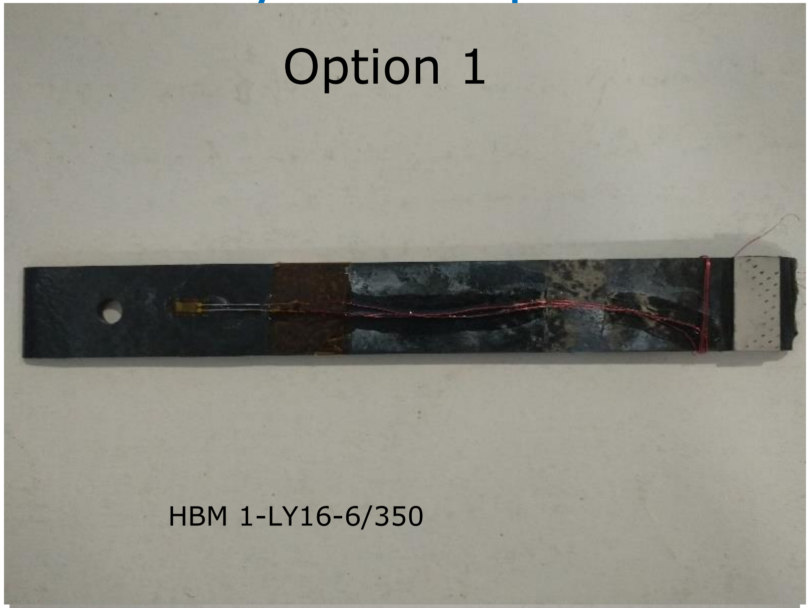


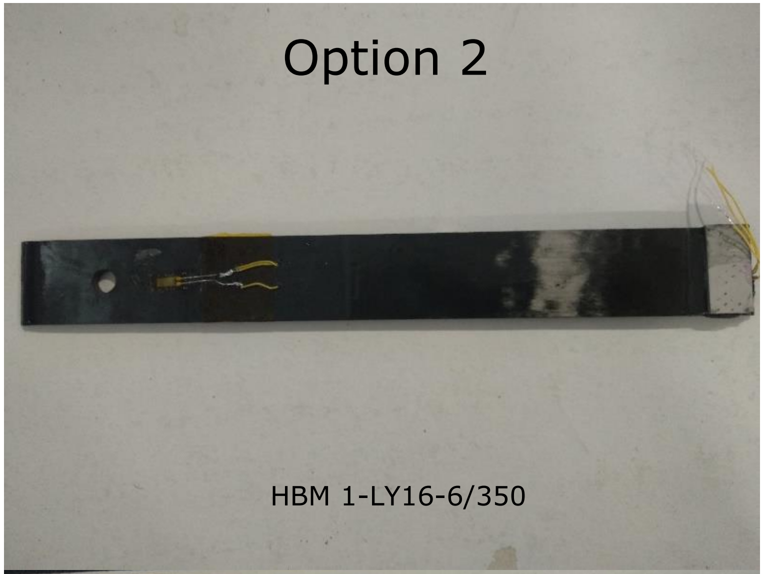
-Embedded or Semi-embedded Lead wires channeling in the CFRP blade?? Less aerodynamic interference?? Less complexity during assembly process??
-Embedded Strain Gauges installation in the blade??? Less time consuming process than the surface installation??? Save installation time??

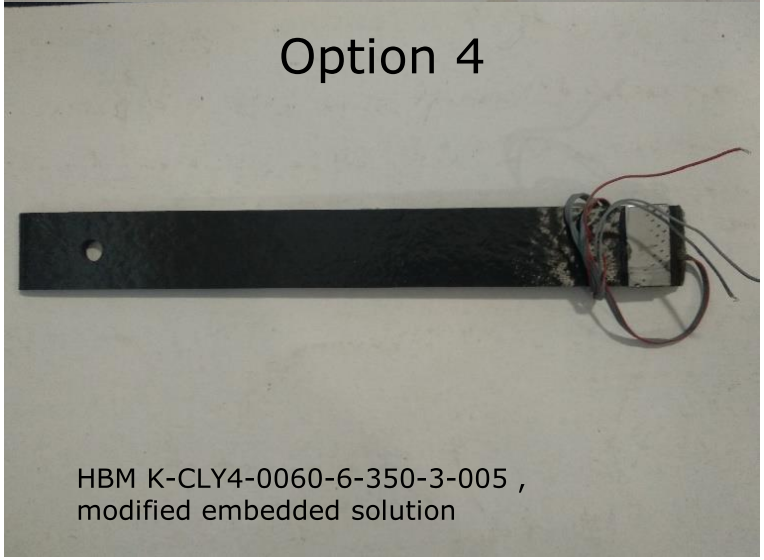
SG installation options

Characteristic	Option 1:Surface SG/surface lead wire	Option 2: Surface SG/embedded lead wire	Option 3: Surface SG/semi-surface lead wire	Option 4: embedded SG/embedded lead wire
Option Figure				
Strain gauge type	Resistance : basic (350 Ω) CTE: 1.0E-06/K Voltage Excitation: 5-10 V	Resistance : basic (350 Ω) CTE: 1.0E-06/K Voltage Excitation: 5-10 V	Resistance : basic (350 Ω) CTE: 1.0E-06/K Voltage Excitation: 5-10 V	Resistance : basic (350 Ω) CTE: 0.5 E-06/K Voltage Excitation: Max 2.5 V
Wiring/Rooting	3 Wires Φ0.2 polyester lead wire (-196 deg Celc< T< +200 deg) 1.5Ω/m Max strain value: 50000 μm/m	3 Wires Φ0.2 polyester lead wire (-196 deg Celc< T< +200 deg) 1.5Ω/m Max strain value: 50000 μm/m	3 Wires Φ0.2 polyester lead wire (-196 deg Celc< T< +200 deg) 1.5Ω/m Max strain value: 50000 μm/m	3 Wires Φ0.2 polyester lead wire (-196 deg Celc< T< +200 deg) 1.5Ω/m Max strain value: 50000 μm/m
Adhesive	Z70 is recommended	Z70 is recommended for SG Wiring is consolidated with CFRP plies	Z70 is recommended for SG Wiring is consolidated with CFRP plies	Z70 is recommended for SG Wiring is consolidated with CFRP plies
Coating	SG250 for general mechanical protection	SG250 for general mechanical protection	SG250 for general mechanical protection	SG250 for general mechanical protection
Connection-SG/ wiring	Soldering ends 	Through soldering pin 	Soldering ends 	Combined  

Basic layout of specimen

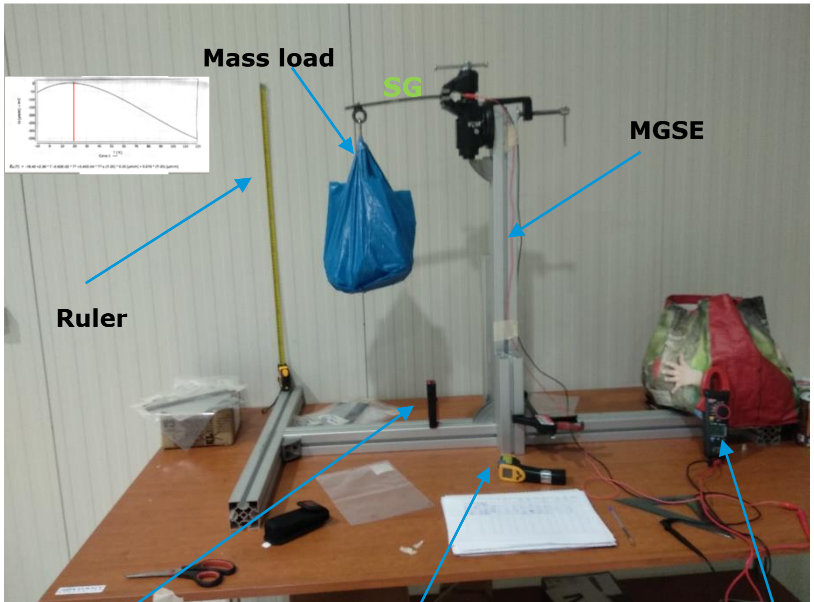




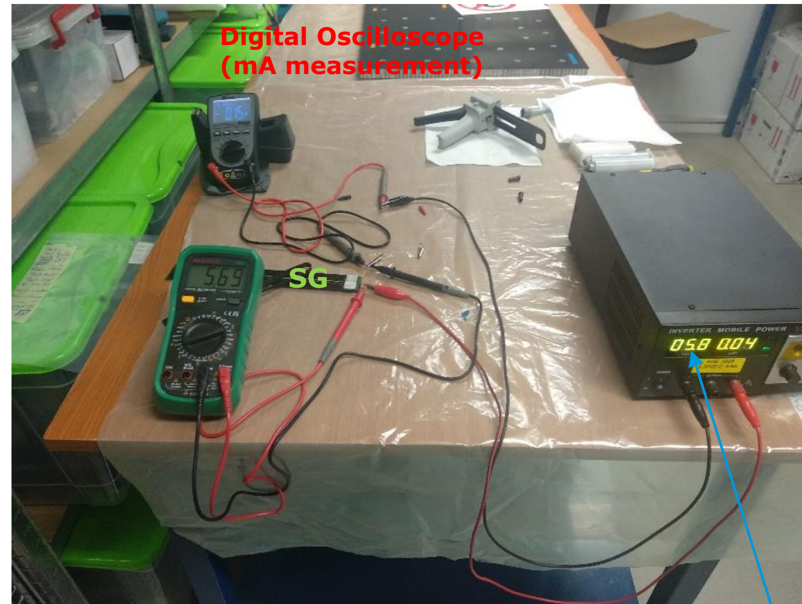


SG options: Functional Testing

Resistance change check under static load



Electric current check (no static load)



Laser distance meter

Laser beam (Temperature measurement)

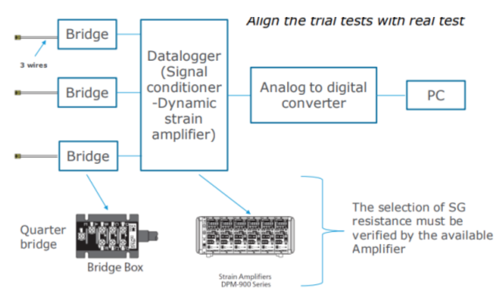
Multimeter (Resistance measurement)

Multimeter (Voltage measurement)

Power supply , DC up to 6.6. V

Keypoint : Load selection following the Strain field of the Blade (FEM analysis)

Similarity with

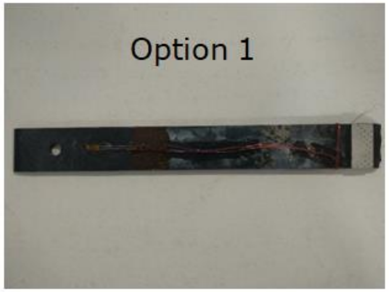


SG options: Trade-off Criteria

Criteria	Weight Factor
1-Market research and delivery time	20
2-Surface quality/interaction with air flow	25
3-SG integration-extrapolated to blade application	10
4-Integration time	5
5-Functionality tests: Load application and Electric conductivity	20
6-Correcting after-installation malfunctions	10
7-Interaction with DIC paint/varnish method	10
TOTAL	100

	Option 1	Option 2	Option 3	Option 4
Criterion 1	80.0	80.0	80.0	2.0
Criterion 2	100.0	75.0	125.0	125.0
Criterion 3	30.0	10.0	45.0	50.0
Criterion4	12.5	10.0	25.0	25.0
Criterion 5	100.0	100.0	100.0	20.0
Criterion 6	50.0	20.0	40.0	0.0
Criterion 7	50.0	20.0	20.0	50.0
TOTAL SCORE	422.5	315.0	435.0	272.0

Key point: (Risk) :The penalty factor is referred to further CFRP blade structural behavior investigation due to V-groove modification on CFRP installation. Risk consideration for eigenfrequency shift and local "damage" of CFRP plies (installation with applied pressure) that affect the structural integrity.



DIC speckle pattern: Trial tests for method selection.

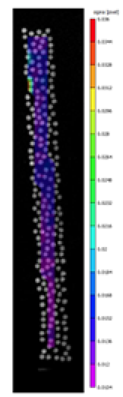
Developing DIC speckle pattern specimen series:

1) Parameters: a) dot size sensitivity/stencil cutting method, b) spraying distance, c) polish/varnish option, d) prior or after autoclave application.
2) Evaluation methods:

- Surface reflectivity via laser illumination by LUH.
- Surface quality after DIC application. (p.e. roughness). Performed by LUH and TUBS

Collaboration with LUH

Probe:	Laser Mode:	Mean Projection Error:	Comment
P50-CM010-1A	Alignment Mode	0.0157	
P50-CM010-2A	Alignment Mode	0.0147	
P50-CM010-4A	Alignment Mode	0.018	no benefit of white background
P50-CM011-1B	Alignment Mode	0.04	
P50-CM011-2B	Alignment Mode	0.035	
P50-CM011-3B	Alignment Mode	0.0137	best result regarding DIC application
P50-CM012-1C	Alignment Mode	0.041	
P50-CM013-1D	Alignment Mode	0.04	Dark image with filter, No fluoresonet effect
P50-CM014-1E	Alignment Mode	0.04	
P50-CM015-1F	Alignment Mode	-	no correlation possible



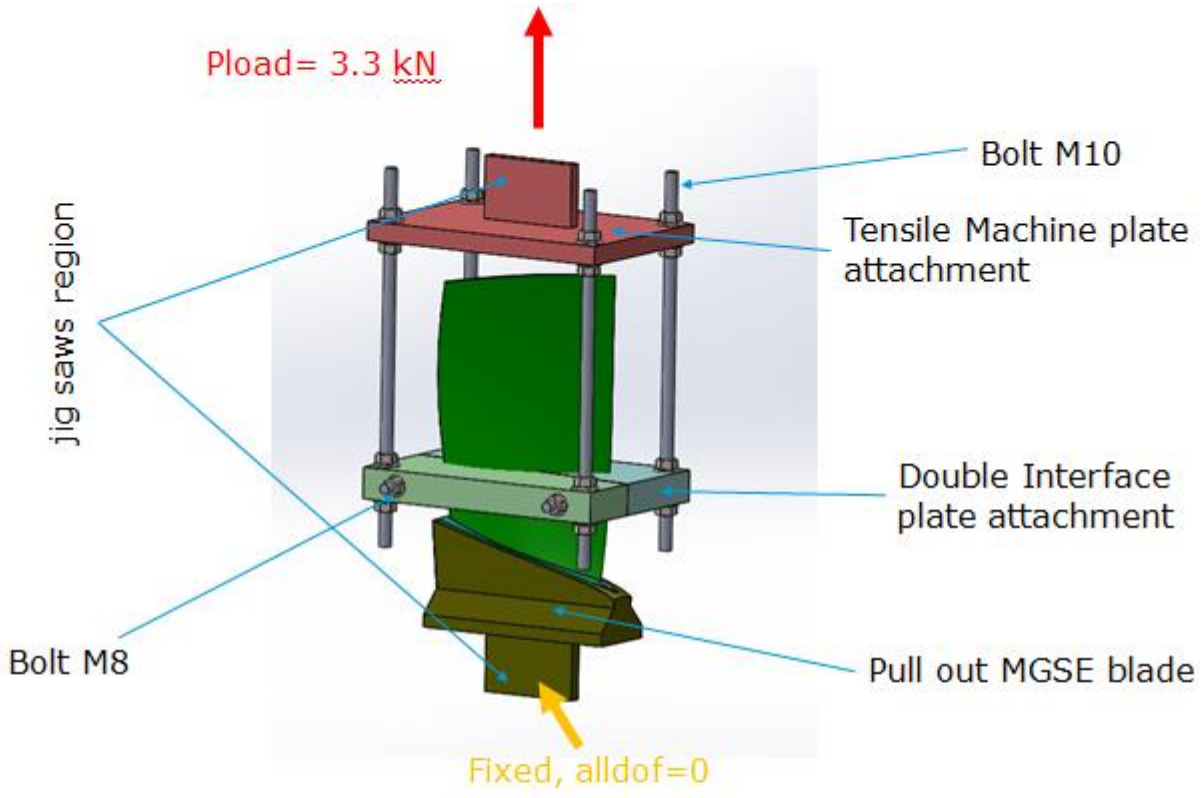
Mean pixel projection error
$\sigma = 0.0137$

Filter eliminates background reflection perfectly
Elimination of green laser light reflections on wind tunnel

Ideal solution for DIC-application!

- Achieving MEAN pixel projection error close to 0.01
- Best DIC quality specimen (green): after autoclave application, knife-cut profiles, fluorescent paint (max TEMP 50oC)

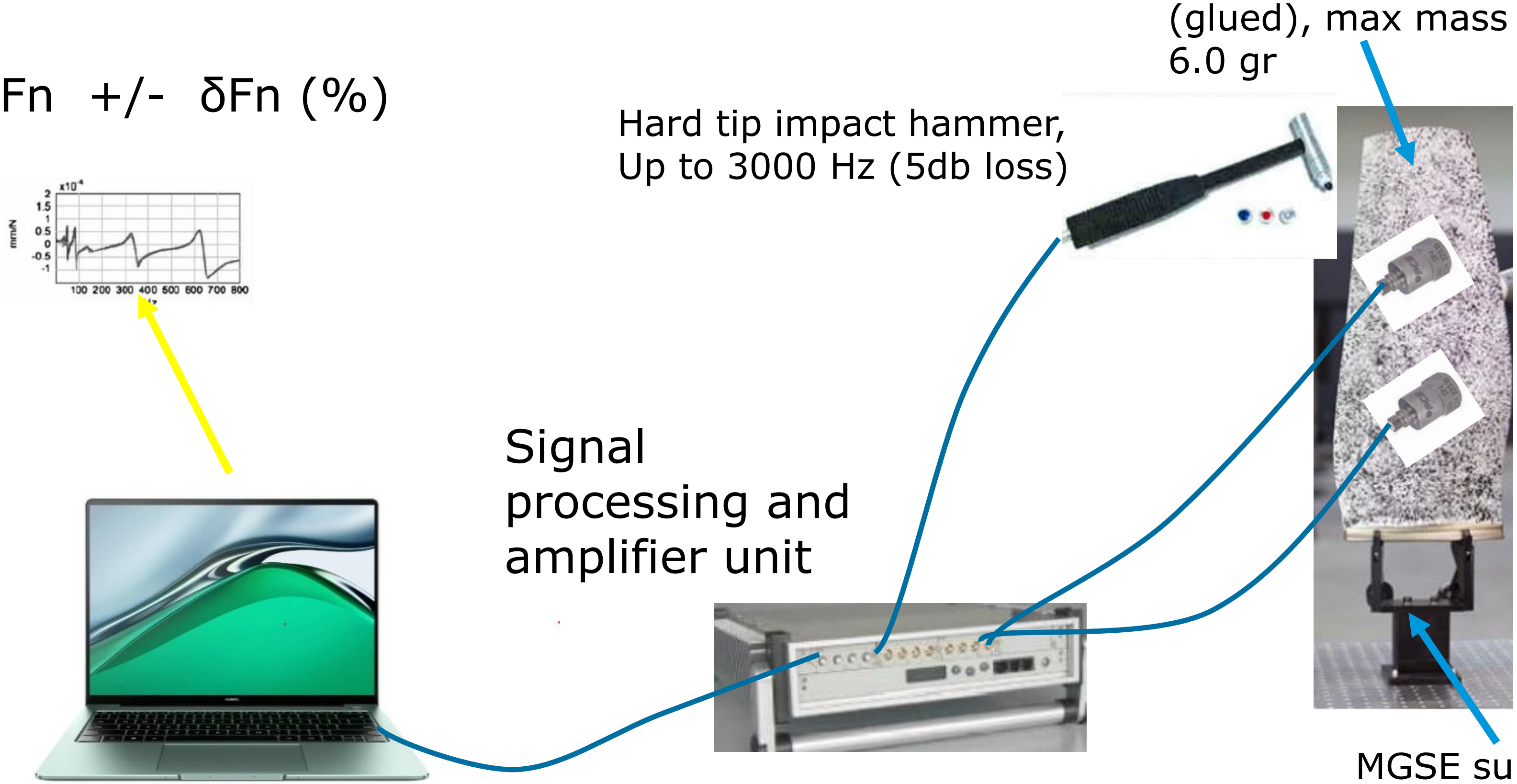
Pull-out static test



__Key point: Maximum pullout load definition for the blade root__

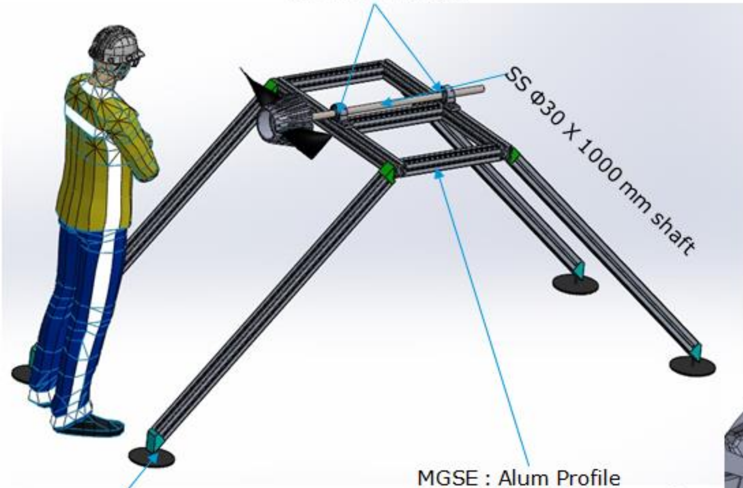
Single blade ping test set up

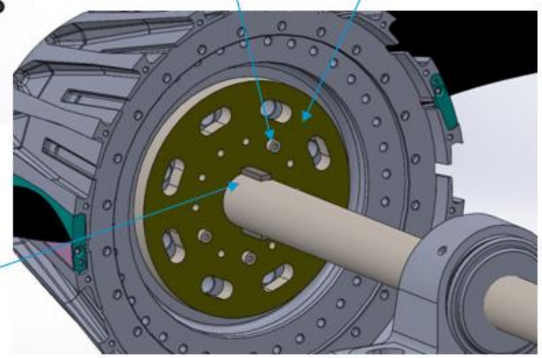
Tips: - Blade cold shape
- MGSE Design: To suceed the BC that assumed on FEA models

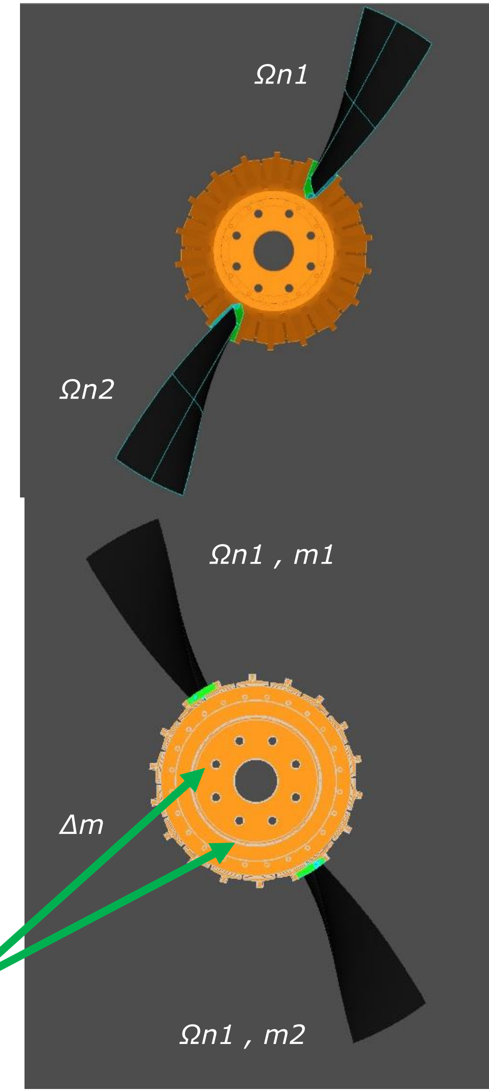


<u>Key point:</u> Creating a list with numbered parts with data meausurements: mass (kg), 1st Eigenfreq (Hz), approved-low % error

Static balance test set up







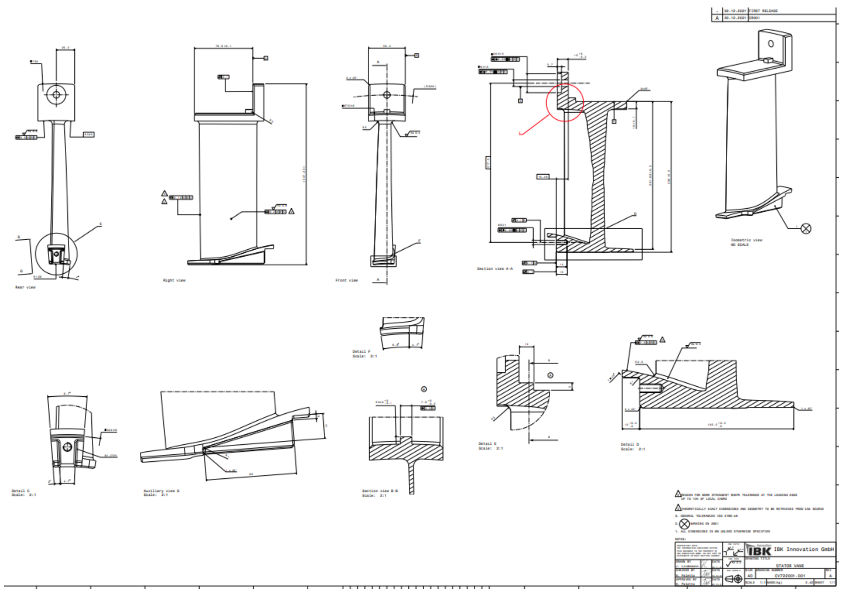
<u>Key point:</u>
-Selecting pair of blades following ping test measurements.ΔΩn= minimum
- Algorithm for balance masses calculations (counterweight selection), Δm

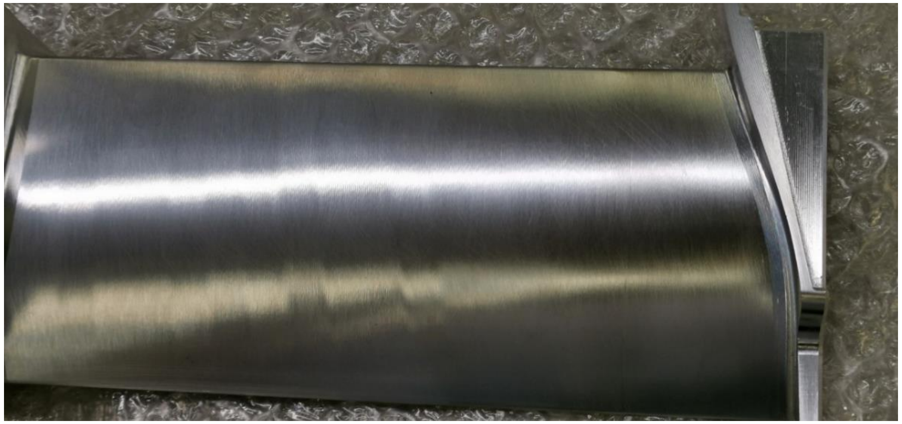
Holes for balance masses, Δm

Metallic parts: Stator vane

CV 722001-001A

No :   42 parts





Thank you!!!!

Questions ????

Dr-Ing. Dimitrios E. Mazarakos
e-mail: mazarakos@adamant-composites.com
tel: +30 2610 931730
cell phone: +30 6974603960