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Input data for a comparison between uni-axial and bi-axial stresses

OB_TG2_R015 rev. 001

Confidential

OPTIMAT BLADES

TG 2

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ΚΑΠΕ CRES

Change record

Issue/revision	date	pages	Summary of changes
draft	16-06-04	Na	na
1	1-7-4	11, 13, 14 (Tabels)	Tail and Nose locations were mixed up in the description of the node position
		several	Small editorial changes

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1. INTRODUCTION

In order to realistically assess the impact of the type of analysis of the blade, results of a 1-dimensional (beam model) analysis performed with FOCUS is compared with results of a 2-dimensional analysis performed with MSC MARC.
Also included are strain gauge measurements on a blade test of the analysed blade.

1.1. Axis system and load cases

The X-axis is in flap-wise direction, with the positive side towards the compression direction.
The Y-axis is in edge-wise direction, with the positive side towards the tail.
The Z-axis is the radial position, running from 0 (centre of the hub) to 35m (tip).
See also Figure 1.

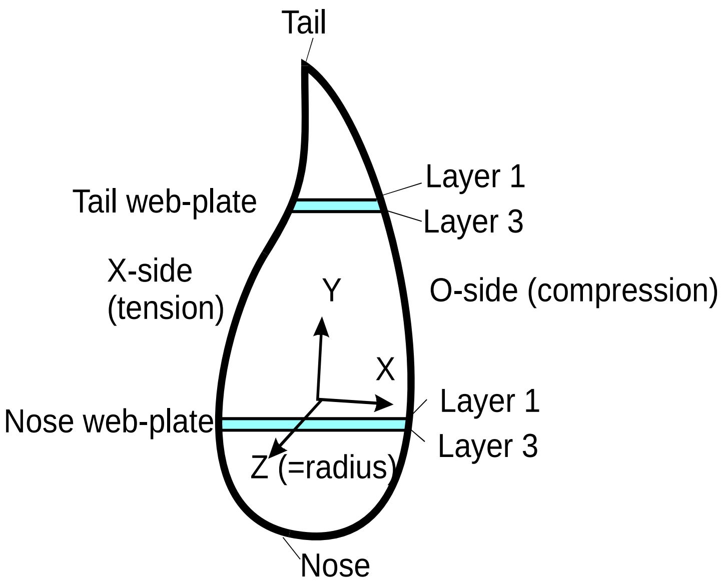


Figure 1 Co-ordinate system used

Two load cases were selected:

- The first load case consists of a load of 1 kN in positive X-direction
- The second load case consists of a load of 1 kN in positiveY-direction.

Each load is applied as two forces of 0.5 kN each on the nodes between main (nose) web plate and skin at a radius (Z-coordinate) of 22m.

1.2. Test Set-up

The test set-up is shown in Figure 2. The point R=0 denotes the centre of the hub.

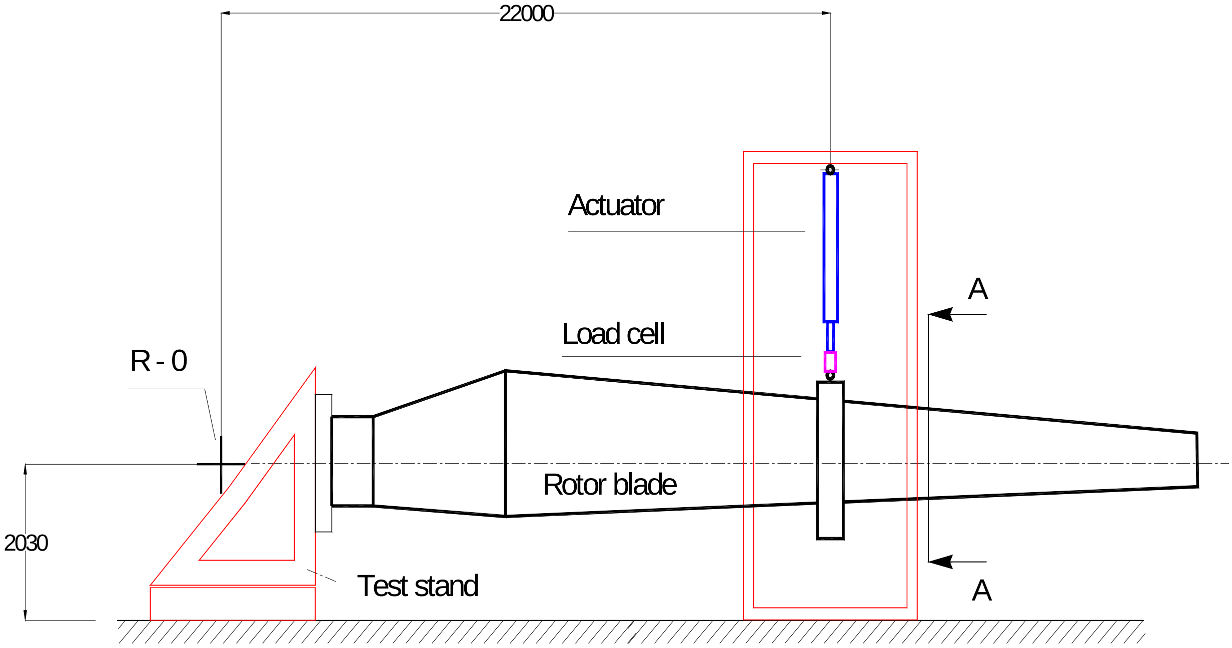


Figure 2 Test set-up

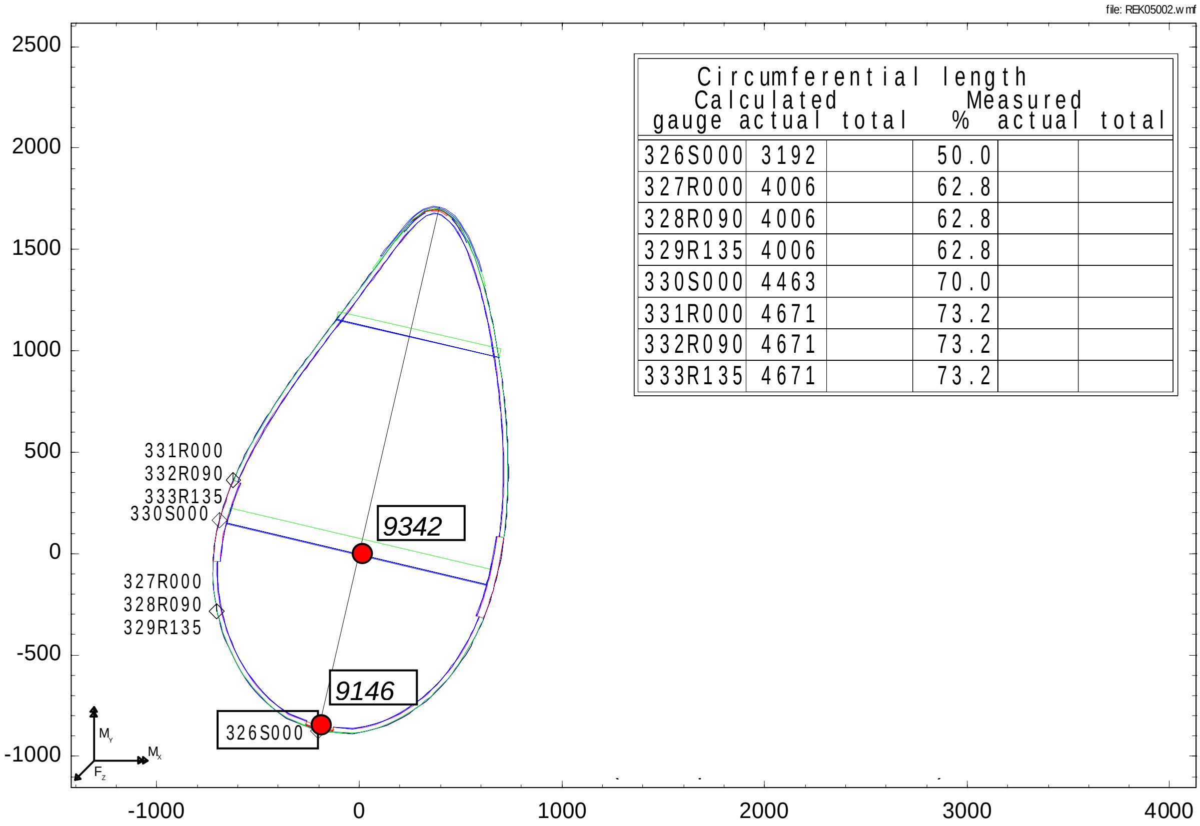
1.3. Cross sections

Three cross sections were selected for the comparison, so as to get an impression of the various stress states which occur on the blade. Care was taken to select cross sections for which measurement data exists as well.

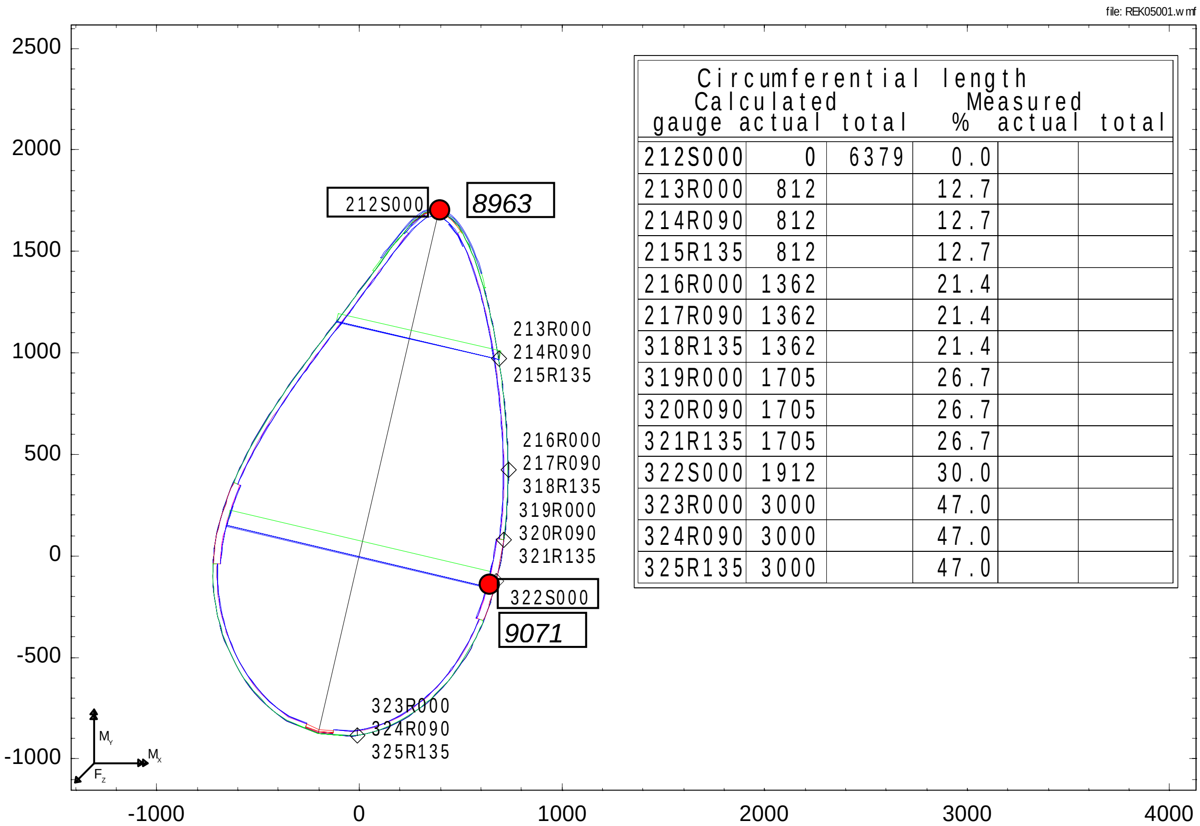
- The maximum chord has a radial position of R=7.00 m, so this section was selected.
- Further more one section in the transition area was selected at R=5.00 m
- One section after the maximum chord section at R=10.00 m.

The numbers and positions of the strain gauges at each cross section are shown, as well as the node numbers of the FE analysis.

2. STRAIN GAUGE POSITIONS AT SELECTED CROSS SECTIONS

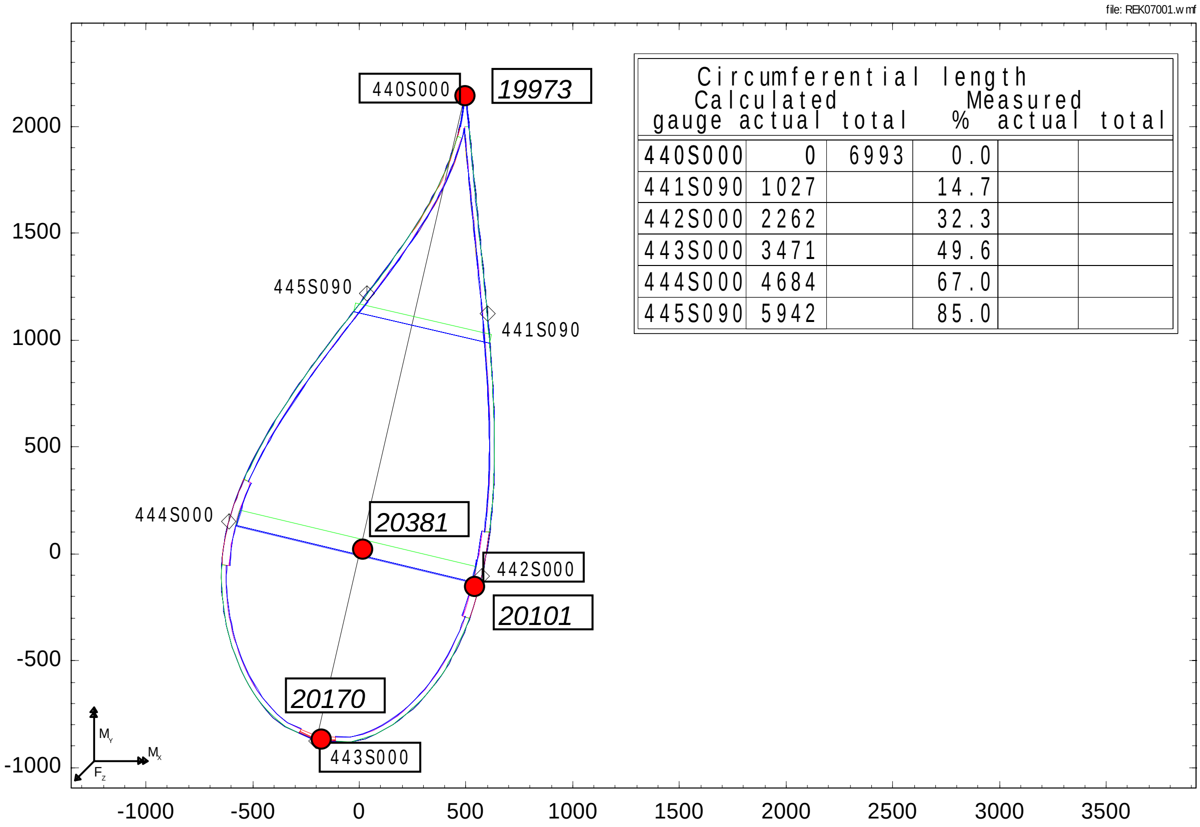


Circumferential length					
Calculated			Measured		
gauge	actual	total	%	actual	total
326S000	3192		50.0		
327R000	4006		62.8		
328R090	4006		62.8		
329R135	4006		62.8		
330S000	4463		70.0		
331R000	4671		73.2		
332R090	4671		73.2		
333R135	4671		73.2		



Circumferential length					
Calculated			Measured		
gauge	actual	total	%	actual	total
212S000	0	6379	0.0		
213R000	812		12.7		
214R090	812		12.7		
215R135	812		12.7		
216R000	1362		21.4		
217R090	1362		21.4		
318R135	1362		21.4		
319R000	1705		26.7		
320R090	1705		26.7		
321R135	1705		26.7		
322S000	1912		30.0		
323R000	3000		47.0		
324R090	3000		47.0		
325R135	3000		47.0		

Figure 3 Cross section at 5 m (left and right hand side)



Circumferential length					
	Calculated		Measured		
gauge	actual	total	%	actual	total
440S000	0	6993	0.0		
441S090	1027		14.7		
442S000	2262		32.3		
443S000	3471		49.6		
444S000	4684		67.0		
445S090	5942		85.0		

Figure 4 Cross section at 7 m

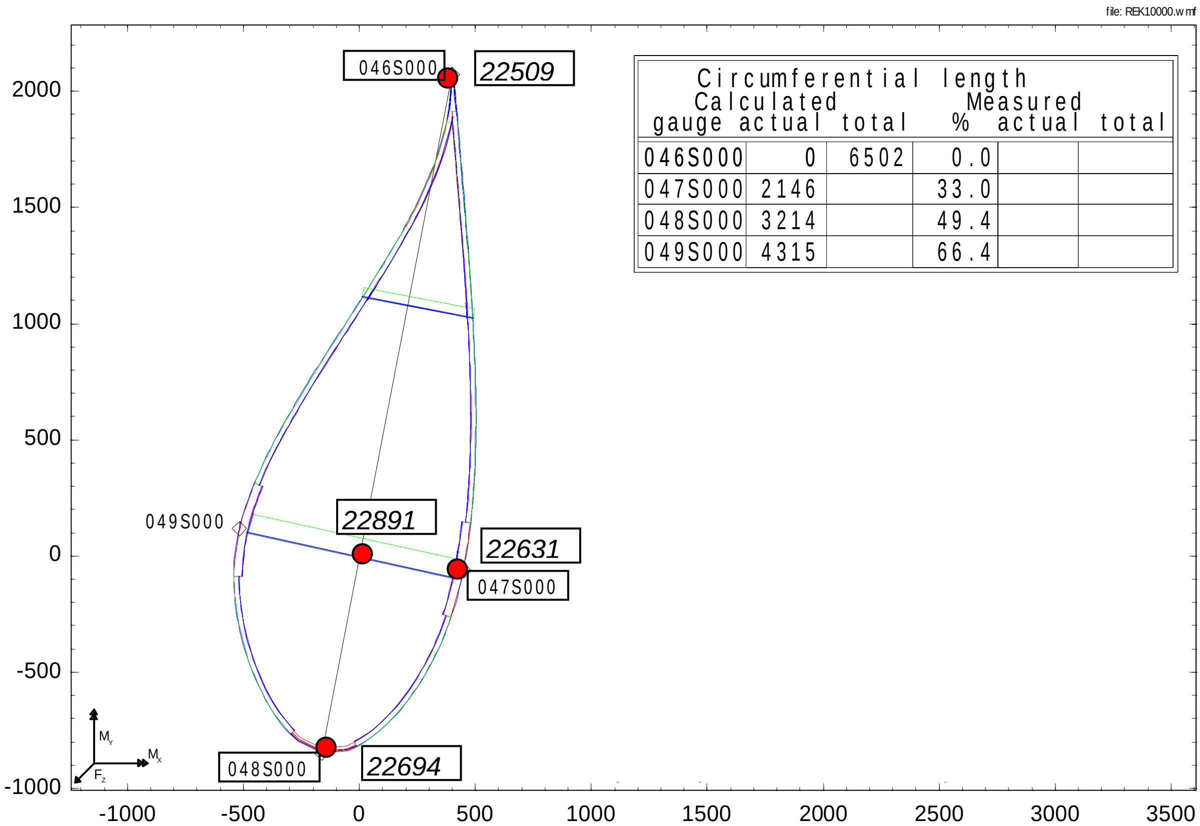


Figure 5 Cross section at 10 m

3. MATERIALS AND ELEMENTS USED

3.1. material overview and corrections

The nodes selected for the comparison are all defined by four surrounding elements. Each of those has it's own layer build-up. In general, the variations in element lay-up are small changes in thickness of the layers. However, at nodes 19973 and 20101 one or two layers are finished, changing the number of layers. Since it is unclear how MARC pairs this output, the material lay-up was changed to exclude the thin layers that were ending, by applying one material definition to all four elements, as denoted in the material# column.

Node	elements	Material#	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
8963	2940	1261	5	6	2	11	11	2	5
	3069	1323							
R=5	3075	1329							
Tail	3200	1391							
9071	2976	1279	2	8	2				
	2977	1279							
R=5	3111	1347							
Spar	3112	1347							
9146	3001	1291	5	2	2	5	6		
	3002	1293							
R=5	3136	1359							
Nose	3137	1361							
9342	3067	1325	9	10	9				
	3068	1325							
R=5	3203	1393							
Web	3204	1393							
19973	6666	~~2951~~	~~5~~	~~2~~	~~2~~	~~2~~			
	6799	~~3009~~							
R=7	6812	3015	2	2	2				
Tail	6945	~~3069~~							
20101	6708	~~2967~~	~~2~~	~~12~~	~~8~~	~~12~~	~~2~~		
	6709	2969	2	8	2				
R=7	6854	~~3029~~							
Spar	6855	~~3031~~							
20170	6731	2979	2	2	5	6			
	6732	2981							
R=7	6877	3041							
Nose	6878	3043							
20381	6802	3011	9	10	9				
	6803	3011							
R=7	6948	3071							
Web	6949	3071							
22509	7526	3291	2	2	2				
	7651	3339							
R=10	7664	3345							
Tail	7788	3393							
22631	7566	3303	2	8	2				
	7567	3303							
R=10	7704	3357							
Spar	7705	3357							
22694	7587	3313	2	2	5	6			
	7588	3315							
R=10	7725	3367							
Nose	7726	3369							
22891	7654	3341	9	10	9				
	7655	3341							
R=10	7791	3395							
Web	7792	3395							

3.2. Material properties

Note that material properties can either be given for FOCUS (beam model, only properties in one direction used and for FE modelling (properties can vary per direction).
Hence E-modulus next to E_11 (radial) and E-22 (circumferential).
Units are N, kg and mm.

3.2.1. material 1 (not used, but included as an example)

DEF MATERIAL STAAL

E-modulus	*210000.*
G-modulus	*80000.*
Density	*7800/10^9*
Poisson	*0.3*

3.2.2. material 2

E-modulus	13100.
G-modulus	10300.
Density	1787/10^9
Poisson	0.483

3.2.3. material 5

E-modulus	11300.
G-modulus	9300.
Density	1670/10^9
Poisson	0.496

3.2.4. material 6

Density	1700/10^9
E_11	31000
E_22	9700
G-modulus	4400
Poisson	0.205

3.2.5. material 8

Density	1860/10^9
E_11	39900
E_22	9850
G-modulus	4500
Poisson	0.26

3.2.6. material 9

E-modulus	11300.
G-modulus	9300.
Density	1670/10^9
Poisson	0.496

3.2.7. material 10

E-modulus	35.
G-modulus	22.
Density	55./10^9
Poisson	0.3

3.2.8. material 11

Density	1837/10^9
E_11	38800
E_22	9500
G-modulus	4830
Poisson	0.260

3.3. Element description

The element used for the analysis is MARC element type 72. Since this is a thin shell element, only 3 strain components are produced, namely:

- ε_{11} (strain in radial direction)
- ε_{22} (strain in circumferential direction)
- ε_{12} (in-plane shear).

4. RESULTS OF FE ANALYSIS/FOCUS AND TEST

For the load in Flap-wise direction, no direct test data was available, hence no comparison has been carried out.

Table 1 Comparison of strains for an flap-wise load of 1 kN at R=22m.

Node	test	FOCUS	FE /test	FOCUS /test	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
8963 ε_{11}					-2.95E-06	-3.01E-06	-3.06E-06	-3.08E-06	-3.10E-06	-3.12E-06	-3.15E-06
R=5 ε_{12}					-9.50E-07	-1.83E-06	-2.53E-06	-2.77E-06	-3.01E-06	-3.26E-06	-3.70E-06
Tail ε_{22}					1.01E-06	9.90E-07	9.73E-07	9.67E-07	9.62E-07	9.56E-07	9.45E-07
9071 ε_{11}					-1.05E-05	-1.02E-05	-9.94E-06	NA	NA	NA	NA
R=5 ε_{12}					-3.45E-07	-2.33E-06	-4.32E-06	NA	NA	NA	NA
Spar ε_{22}					-4.66E-06	2.68E-06	1.00E-05	NA	NA	NA	NA
9146 ε_{11}					3.03E-06	3.03E-06	3.04E-06	3.04E-06	3.06E-06	NA	NA
R=5 ε_{12}					-4.96E-07	-6.64E-07	-8.55E-07	-1.18E-06	-2.17E-06	NA	NA
Nose ε_{22}					-7.72E-07	-8.12E-07	-8.58E-07	-9.36E-07	-1.17E-06	NA	NA
9342 ε_{11}					2.03E-07	1.20E-07	3.66E-08	NA	NA	NA	NA
R=5 ε_{12}					-5.08E-06	-6.26E-06	-7.43E-06	NA	NA	NA	NA
Web ε_{22}					1.75E-06	5.74E-07	-5.99E-07	NA	NA	NA	NA
19973 ε_{11}					-8.08E-06	-7.99E-06	-7.81E-06	NA	NA	NA	NA
R=7 ε_{12}					-5.75E-06	-5.25E-06	-4.26E-06	NA	NA	NA	NA
Tail ε_{22}					-1.21E-06	1.05E-06	5.60E-06	NA	NA	NA	NA
20101 ε_{11}					-1.16E-05	-1.18E-05	-1.20E-05	NA	NA	NA	NA
R=7 ε_{12}					-1.73E-07	-5.60E-07	-9.46E-07	NA	NA	NA	NA
Spar ε_{22}					-8.03E-07	3.79E-06	8.39E-06	NA	NA	NA	NA
20170 ε_{11}					1.53E-06	1.53E-06	1.51E-06	1.47E-06	NA	NA	NA
R=7 ε_{12}					-1.48E-06	-1.55E-06	-1.67E-06	-2.03E-06	NA	NA	NA
Nose ε_{22}					-2.55E-07	-3.24E-07	-4.41E-07	-7.96E-07	NA	NA	NA
20381 ε_{11}					3.44E-07	5.51E-07	7.59E-07	NA	NA	NA	NA
R=7 ε_{12}					-3.55E-06	-4.58E-06	-5.61E-06	NA	NA	NA	NA
Web ε_{22}					-8.39E-07	-7.88E-07	-7.36E-07	NA	NA	NA	NA
22509 ε_{11}					-3.80E-06	-3.50E-06	-2.88E-06	NA	NA	NA	NA
R=10 ε_{12}					-3.85E-06	-4.78E-06	-6.63E-06	NA	NA	NA	NA
Tail ε_{22}					3.03E-06	2.14E-06	3.53E-07	NA	NA	NA	NA
22631 ε_{11}					-1.50E-05	-1.47E-05	-1.43E-05	NA	NA	NA	NA
R=10 ε_{12}					-6.75E-07	-1.80E-06	-2.93E-06	NA	NA	NA	NA
Spar ε_{22}					2.12E-06	4.43E-06	6.74E-06	NA	NA	NA	NA
22694 ε_{11}					7.44E-07	7.48E-07	7.56E-07	7.75E-07	NA	NA	NA
R=10 ε_{12}					-1.90E-06	-2.02E-06	-2.22E-06	-2.74E-06	NA	NA	NA
Nose ε_{22}					-7.10E-07	-5.99E-07	-4.10E-07	6.46E-08	NA	NA	NA
22891 ε_{11}					8.41E-07	9.72E-07	1.10E-06	NA	NA	NA	NA
R=10 ε_{12}					-6.97E-06	-8.64E-06	-1.03E-05	NA	NA	NA	NA
Web ε_{22}					-1.10E-06	-7.80E-07	-4.61E-07	NA	NA	NA	NA

For the load in edge-direction, FE, FOCUS and measurement data can be directly compared. The results of FOCUS have also been included.

Table 2 Comparison of strains for an edge-wise load of 1 kN at R=22m.

Node		test	FOCUS	FE /test	FOCUS /test	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
8963	ε_{11}	-1.69E-05	-2.48E-05	1.12	1.46	-1.89E-05	-1.92E-05	-1.94E-05	-1.95E-05	-1.95E-05	-1.96E-05	-1.98E-05
R=5	ε_{12}					-1.56E-06	-9.02E-07	-3.88E-07	-2.03E-07	-2.89E-08	1.56E-07	4.89E-07
Tail	ε_{22}					-4.17E-06	3.06E-06	8.72E-06	1.08E-05	1.27E-05	1.47E-05	1.84E-05
9071	ε_{11}	7.91E-06	9.55E-06	0.85	1.21	6.70E-06	6.43E-06	6.17E-06	NA	NA	NA	NA
R=5	ε_{12}					-1.85E-06	-3.32E-06	-4.80E-06	NA	NA	NA	NA
Spar	ε_{22}					2.80E-06	-9.43E-07	-4.69E-06	NA	NA	NA	NA
9146	ε_{11}	2.70E-05	2.09E-05	1.12	0.77	3.02E-05	3.03E-05	3.04E-05	3.06E-05	3.11E-05	NA	NA
R=5	ε_{12}					-8.05E-08	-6.26E-08	-4.22E-08	-7.39E-09	9.84E-08	NA	NA
Nose	ε_{22}					-1.18E-05	-1.16E-05	-1.12E-05	-1.07E-05	-9.07E-06	NA	NA
9342	ε_{11}					1.05E-06	2.61E-06	4.17E-06	NA	NA	NA	NA
R=5	ε_{12}					2.74E-06	2.71E-06	2.68E-06	NA	NA	NA	NA
Web	ε_{22}					-7.94E-07	-3.08E-06	-5.36E-06	NA	NA	NA	NA
19973	ε_{11}	-4.50E-05	-3.05E-05	1.01	0.68	-4.53E-05	-4.51E-05	-4.47E-05	NA	NA	NA	NA
R=7	ε_{12}					4.97E-07	1.44E-07	-5.64E-07	NA	NA	NA	NA
Tail	ε_{22}					1.01E-05	1.50E-05	2.49E-05	NA	NA	NA	NA
20101	ε_{11}	8.28E-06	8.89E-06	0.89	1.07	7.41E-06	7.69E-06	7.98E-06	NA	NA	NA	NA
R=7	ε_{12}					-2.81E-06	-2.18E-06	-1.55E-06	NA	NA	NA	NA
Spar	ε_{22}					4.18E-06	-1.75E-06	-7.68E-06	NA	NA	NA	NA
20170	ε_{11}	1.91E-05	1.85E-05	1.17	0.97	2.23E-05	2.22E-05	2.21E-05	2.18E-05	NA	NA	NA
R=7	ε_{12}					-5.77E-07	-5.55E-07	-5.18E-07	-4.04E-07	NA	NA	NA
Nose	ε_{22}					-9.31E-06	-8.97E-06	-8.38E-06	-6.59E-06	NA	NA	NA
20381	ε_{11}					3.81E-06	4.79E-06	5.76E-06	NA	NA	NA	NA
R=7	ε_{12}					-2.15E-07	-7.73E-08	6.06E-08	NA	NA	NA	NA
Web	ε_{22}					-5.91E-06	-4.80E-06	-3.70E-06	NA	NA	NA	NA
22509	ε_{11}	-2.91E-05	-2.87E-05	1.05	0.99	-3.07E-05	-3.06E-05	-3.04E-05	NA	NA	NA	NA
R=10	ε_{12}					-2.33E-06	-1.50E-06	1.75E-07	NA	NA	NA	NA
Tail	ε_{22}					1.32E-05	1.39E-05	1.55E-05	NA	NA	NA	NA
22631	ε_{11}	9.18E-06	7.30E-06	0.84	0.80	7.70E-06	7.65E-06	7.61E-06	NA	NA	NA	NA
R=10	ε_{12}					-8.08E-07	-8.11E-07	-8.14E-07	NA	NA	NA	NA
Spar	ε_{22}					-1.64E-06	-2.21E-06	-2.78E-06	NA	NA	NA	NA
22694	ε_{11}	1.66E-05	1.64E-05	1.08	0.99	1.79E-05	1.79E-05	1.80E-05	1.81E-05	NA	NA	NA
R=10	ε_{12}					-5.56E-07	-5.58E-07	-5.61E-07	-5.70E-07	NA	NA	NA
Nose	ε_{22}					-8.86E-06	-8.31E-06	-7.38E-06	-4.99E-06	NA	NA	NA
22891	ε_{11}					3.21E-06	3.86E-06	4.51E-06	NA	NA	NA	NA
R=10	ε_{12}					-6.76E-07	-7.19E-07	-7.61E-07	NA	NA	NA	NA
Web	ε_{22}					-1.70E-06	-1.75E-06	-1.81E-06	NA	NA	NA	NA

5. SHORT DISCUSSION

The data in this report is just meant as input for comparison between uni- and biaxial stress analysis and as no conclusions will be drawn at this stage.

However, a few observations can be made. From table 2, it can be observed that:

1. The stress component in circumferential direction are often of the same magnitude as those in radial direction. A clear biaxial situation exists in most of the blade.
2. A comparison of results between FE results and measured strains in the test, shows a good agreement, typically within 15% (mostly due to discrepancies between the modelled and the actual blade).
3. A comparison between FOCUS and the measured strains show results to be within 20% in most cases, with a few noticeable exceptions.