Leading edge - length: 146 mm; thickness: 0.68 mm (root), 0.48 mm (tip)

Trailing edge - length: 156 mm; thickness: 0.37 mm (root), 0.22 mm (tip)

Tip length: 73.7 mm

Root - cord length: 81.0 mm

Root thickness (centre): 7.1 mm

Tip thickness (centre): 1.3 mm

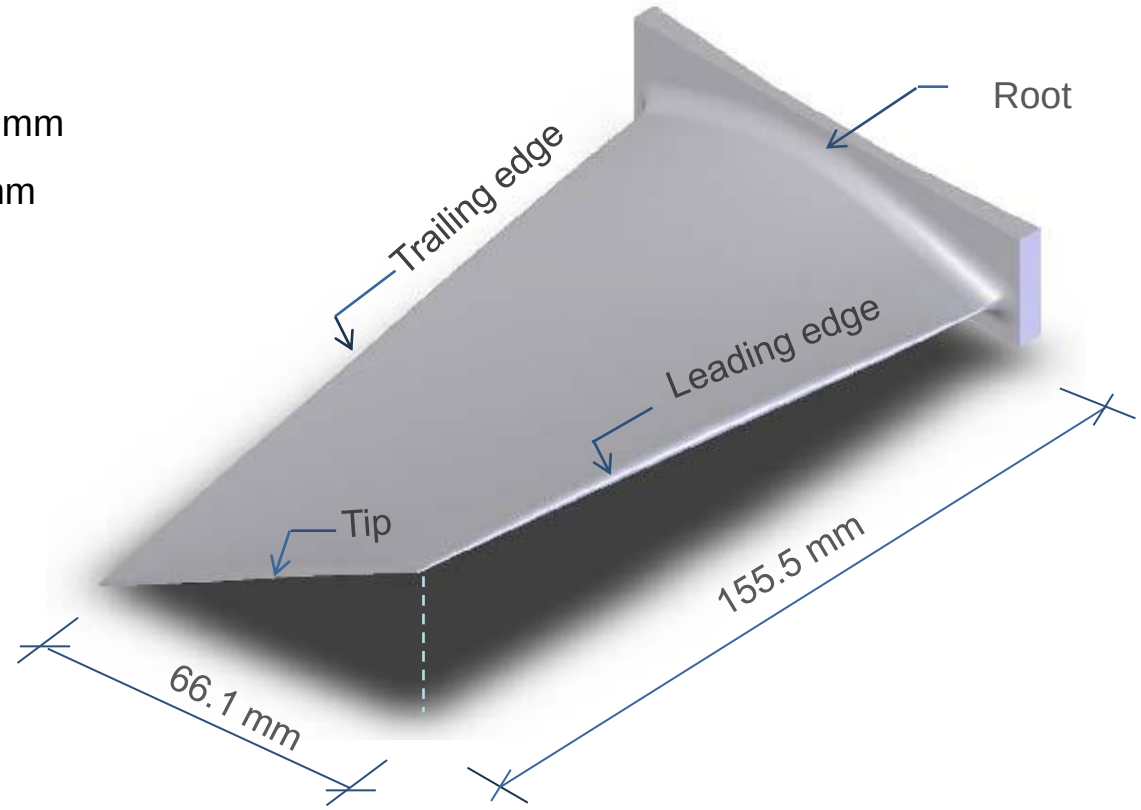


Fig. 1 Geometry of the ‘control’ blade

(a)

Min. Surf. 1
Boundary edges as in the Control Blade

Min. Surf. 2
Tip thicker in the centre by 1mm

Min. Surf. 3
Root thicker in the centre by 1mm

Min. Surf. 4
Root and tip 1mm thicker in the centre

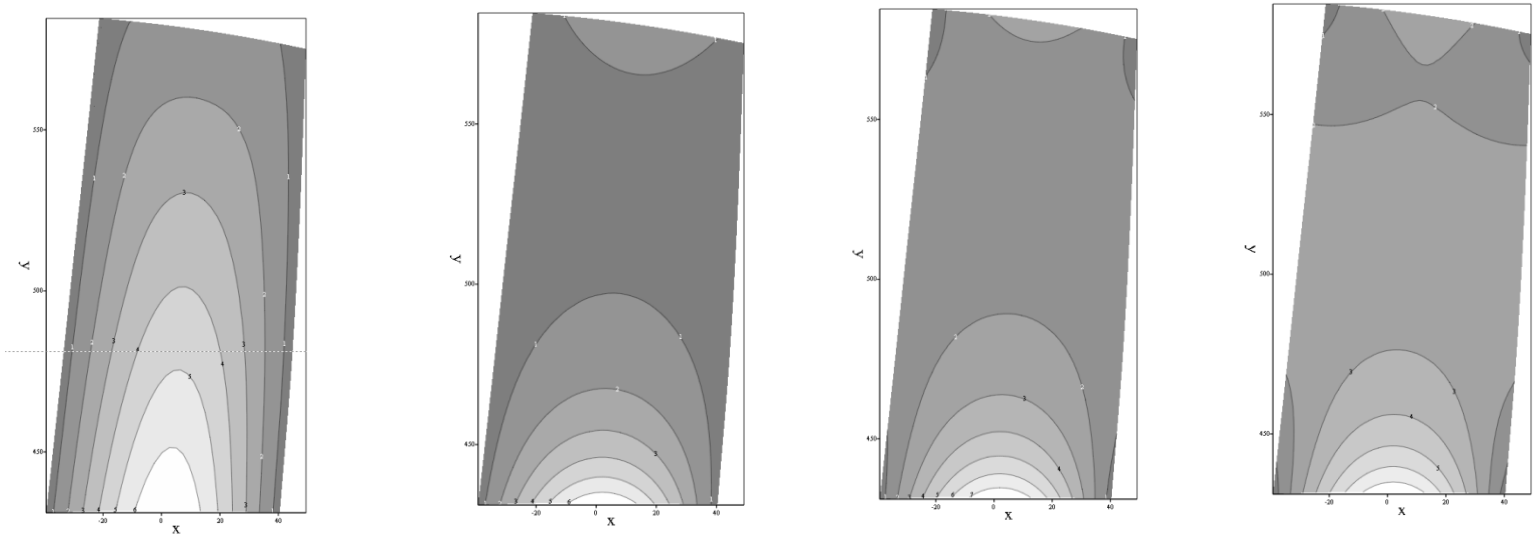
Min. Surf. 5
Both edges thicker in the centre by 1 mm

Min. Surf. 6
Root, tip and edges 1 mm thicker in the centre

Min. Surf. 7
Root and tip 1 mm, and edges 2 mm thicker in the centre

Min. Surf. 8
As Min Surf 6, but with thickening of edges 1/3 way from the root

(b)



'Control' *blade* ***Min. Surf. 1*** ***Min. Surf. 6*** ***Min. Surf. 7***

Fig.2. (a) Description of the 'minimal' blade family (b) Shape contours of selected 'minimal' blades versus the 'control'

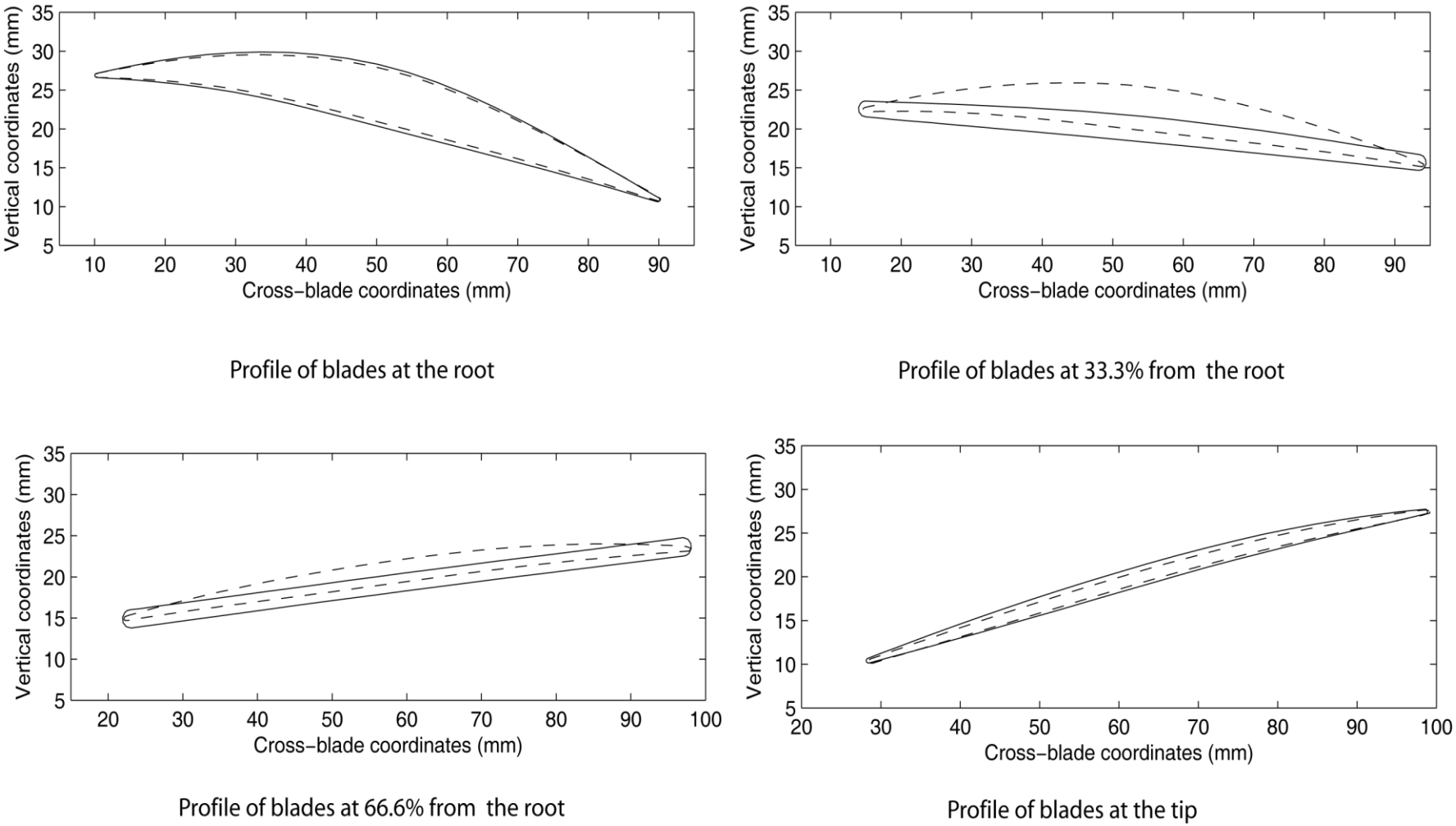


Fig.3. ‘Minimal’ blade 7. Cross-sectional profiles (solid line), relative to the ‘control’ (dotted)

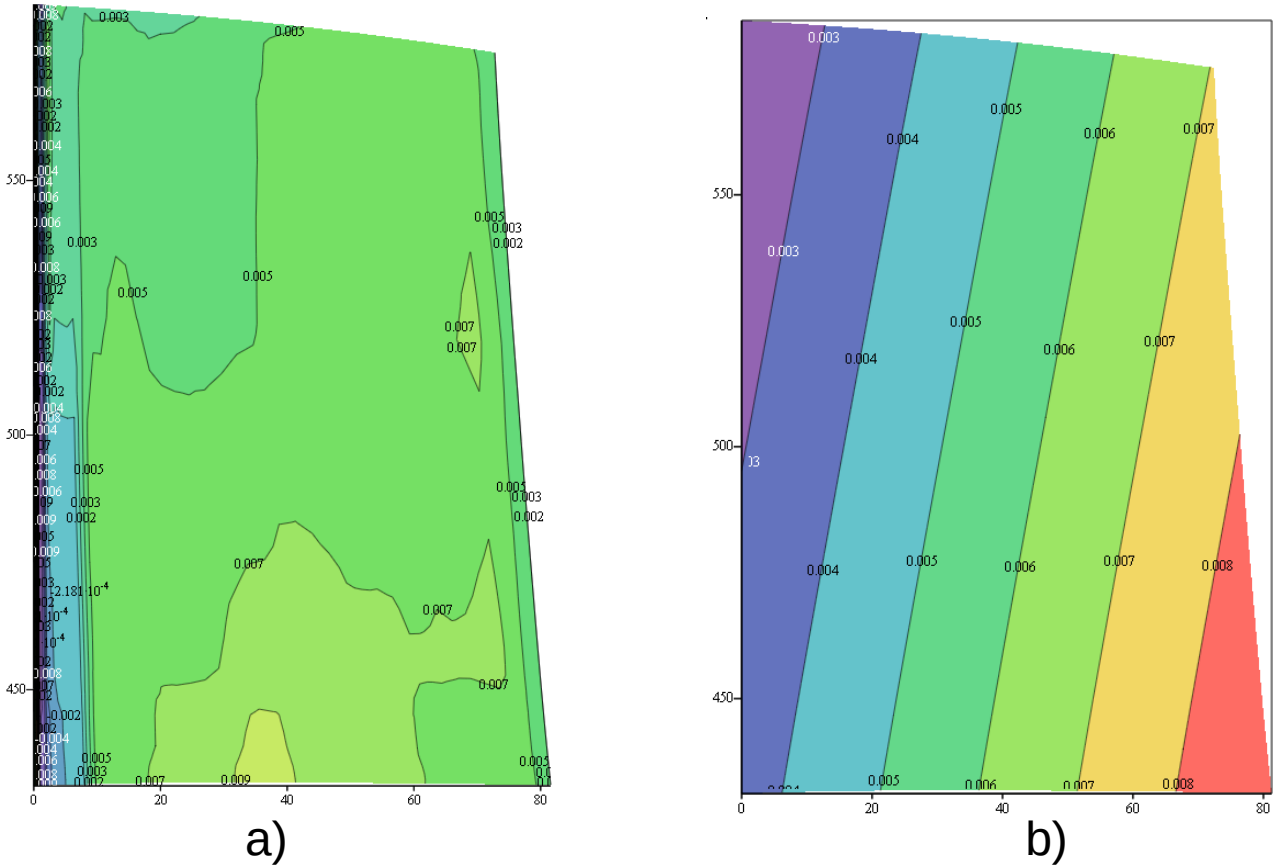
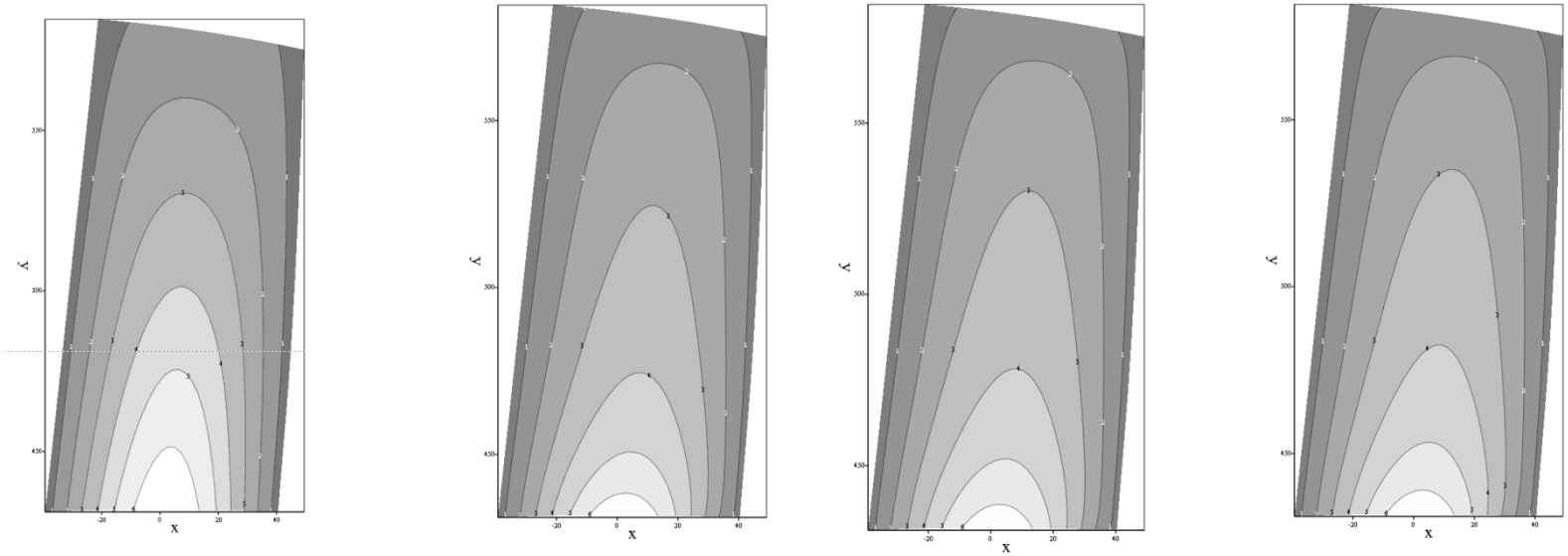


Fig. 4. Pressure data - untwisted blade (a) Nett pressure, (b) Fitted nett pressure



'Control' blade

'Pressure' Surf. 9
Pressure parameters:
k=0.7328
Blade volume 93% off 'control' blade.

'Pressure' Surf. 10
Pressure parameters:
k=0.7431
Blade volume 95% off 'control' blade.

'Pressure' Surf. 11
Pressure parameters:
k=0.7534
Blade volume 97% off 'control' blade.

Fig.5. Shape contours of the 'pressure' blades versus the 'control'

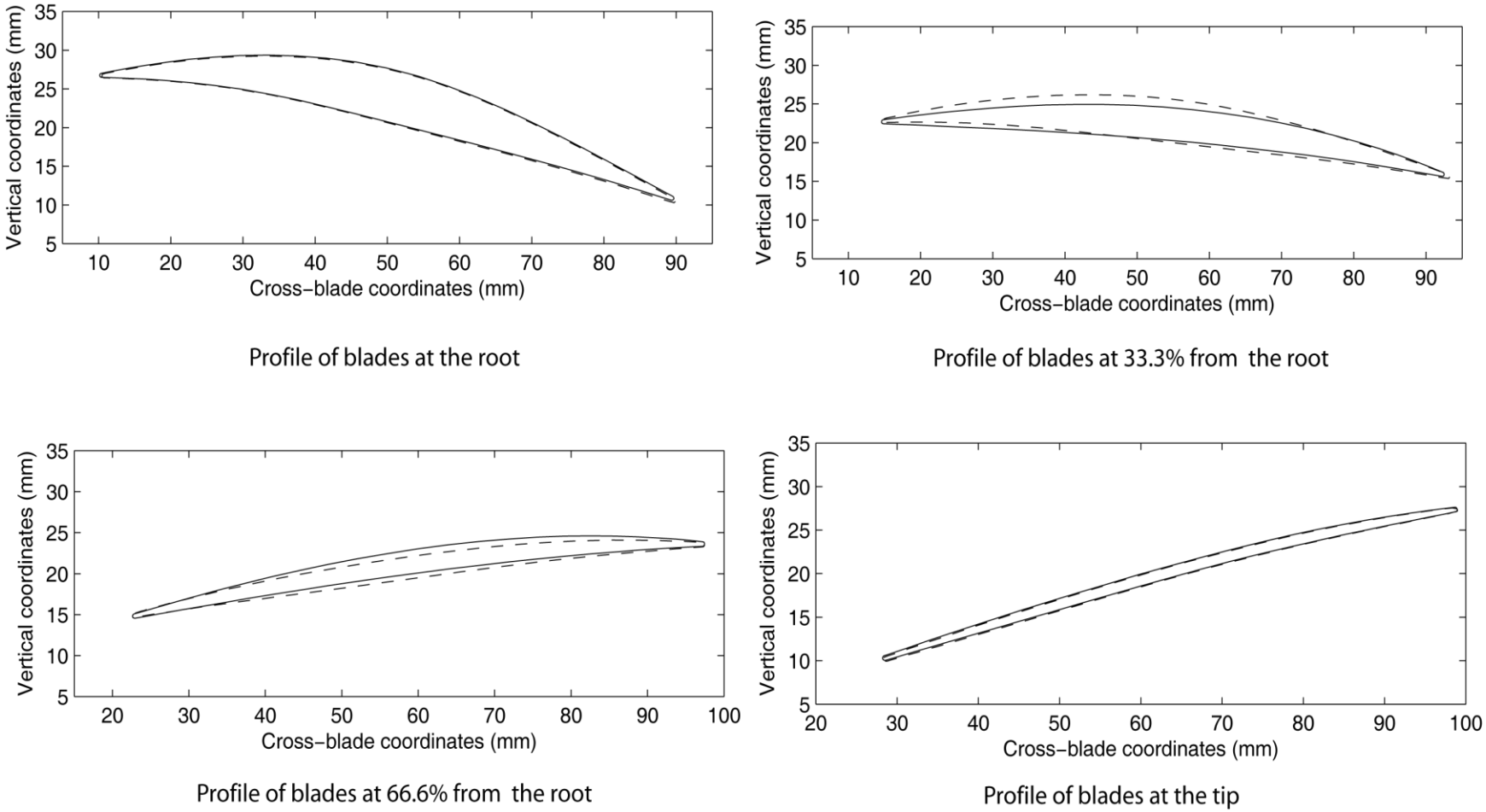


Fig.6. ‘Pressure’ blade 10. Cross-sectional blade profiles (solid line), relative to the ‘control’ (dotted)

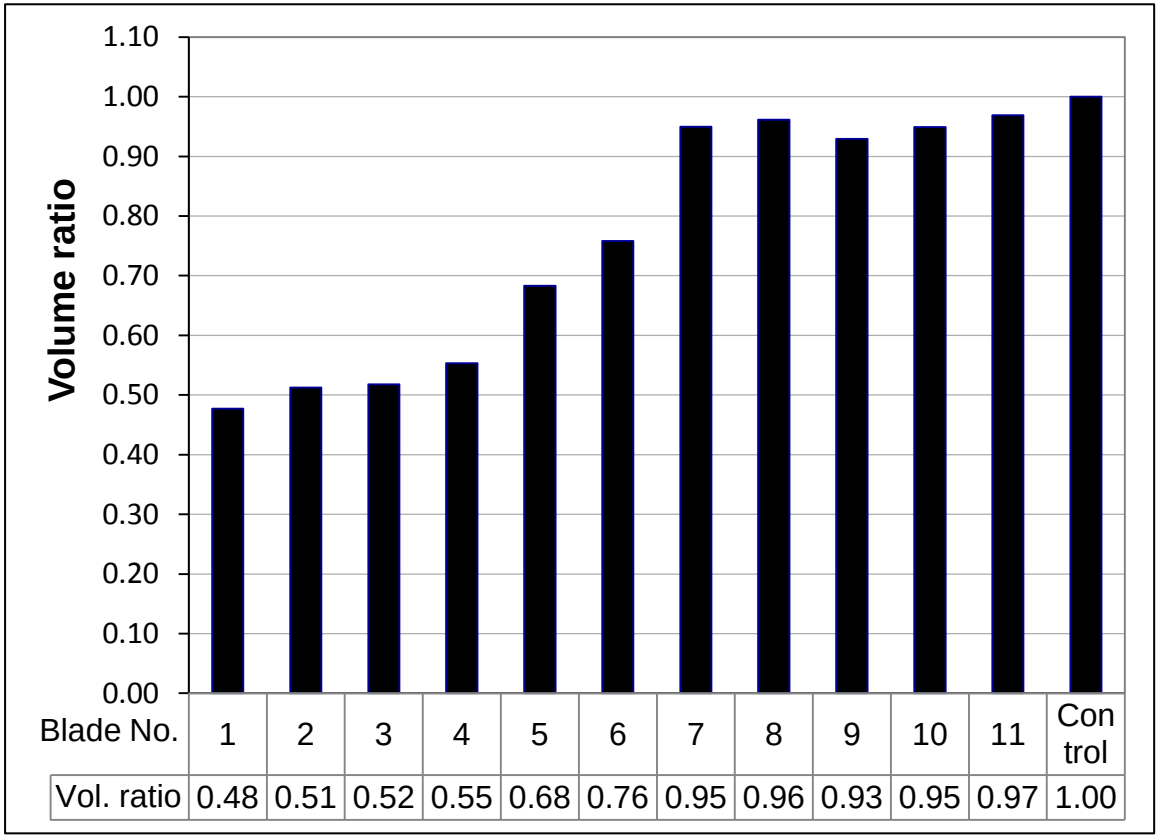


Fig.7 Variations in volume of material in form-found blades relative to the ‘control’ blade volume of 30898.71 mm^3

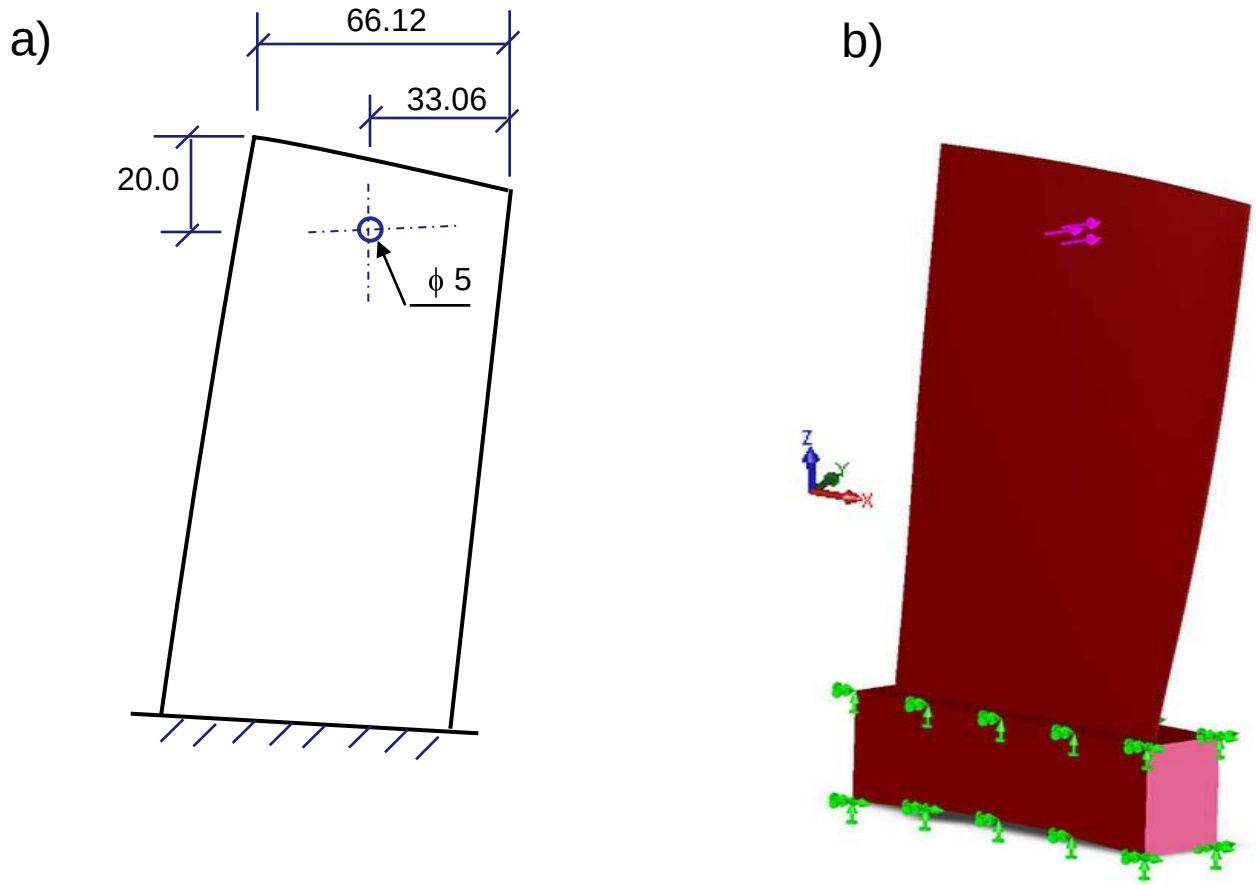


Fig. 8. Finite element modelling in *Cosmosworks*. (a) Static loading position (b) Loading direction and restraints. (Dimensions in mm)

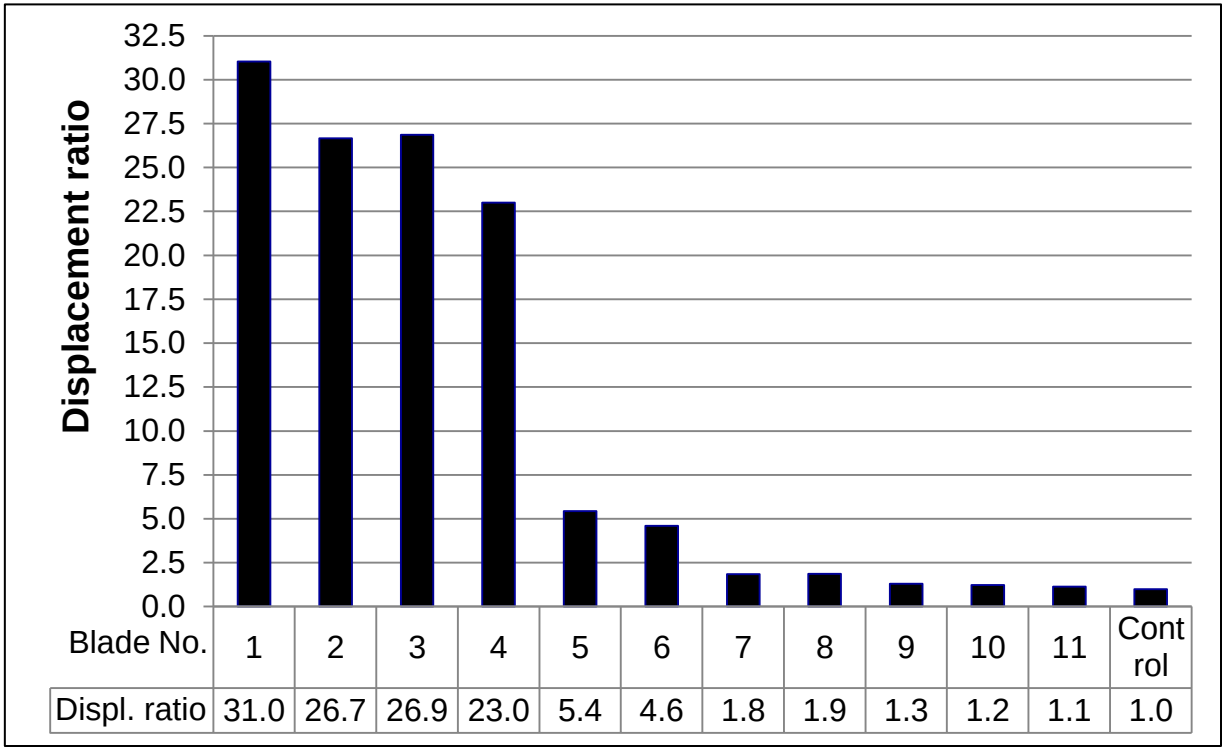
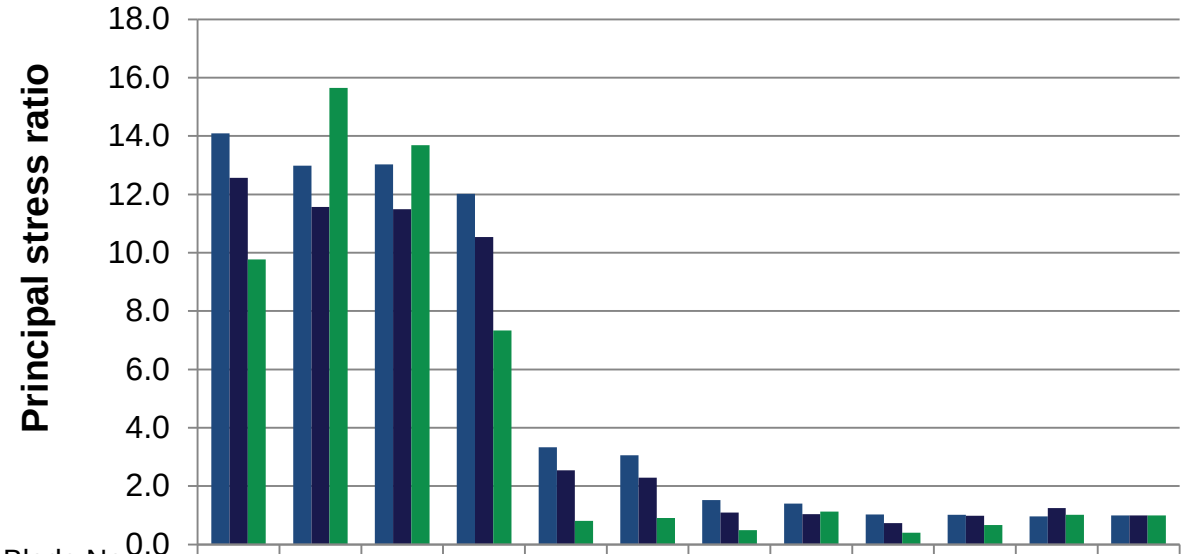


Fig. 9. Case 1. Displacement of form-found blades relative to the ‘control’ blade displacement of 0.74 mm



Blade No.	1	2	3	4	5	6	7	8	9	10	11	Control
Max. P1 ratio	14.10	12.98	13.03	12.02	3.34	3.06	1.52	1.40	1.03	1.02	0.96	1.00
Max. P2 ratio	12.57	11.57	11.49	10.54	2.54	2.28	1.09	1.04	0.73	0.99	1.25	1.00
Max. P3 ratio	9.77	15.64	13.68	7.34	0.81	0.90	0.49	1.13	0.40	0.66	1.01	1.00

Fig. 10. Case 1. Maximum values of principal stresses, P1, P2 and P3, for form-found blades, relative to the ‘control’ blade with the corresponding stress values of: 1.88×10^{7} N/mm^2, 6.7×10^{6} N/mm^2, and 3.42×10^{6} N/mm^2 respectively

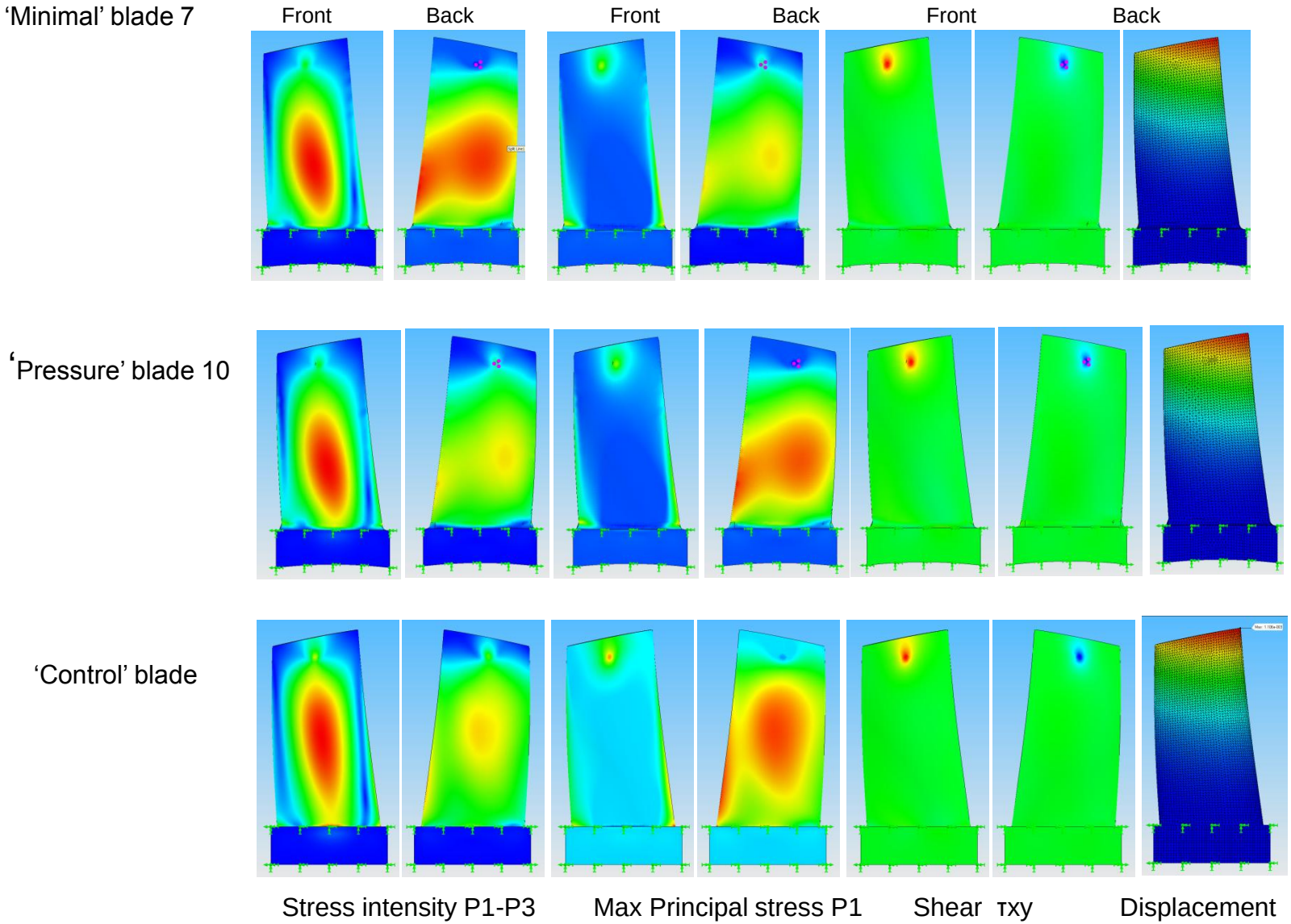


Fig. 11. Case1. Distribution of stresses and displacements in selected 'minimal' and 'pressure' blades versus the 'control'

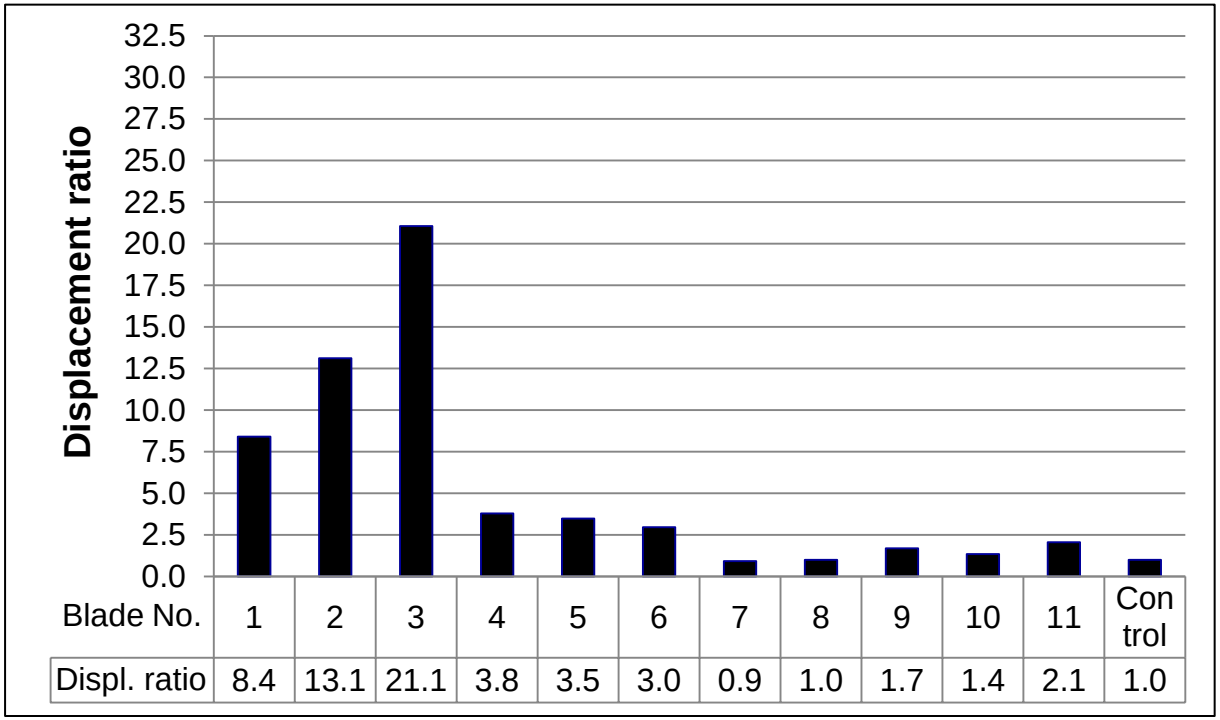
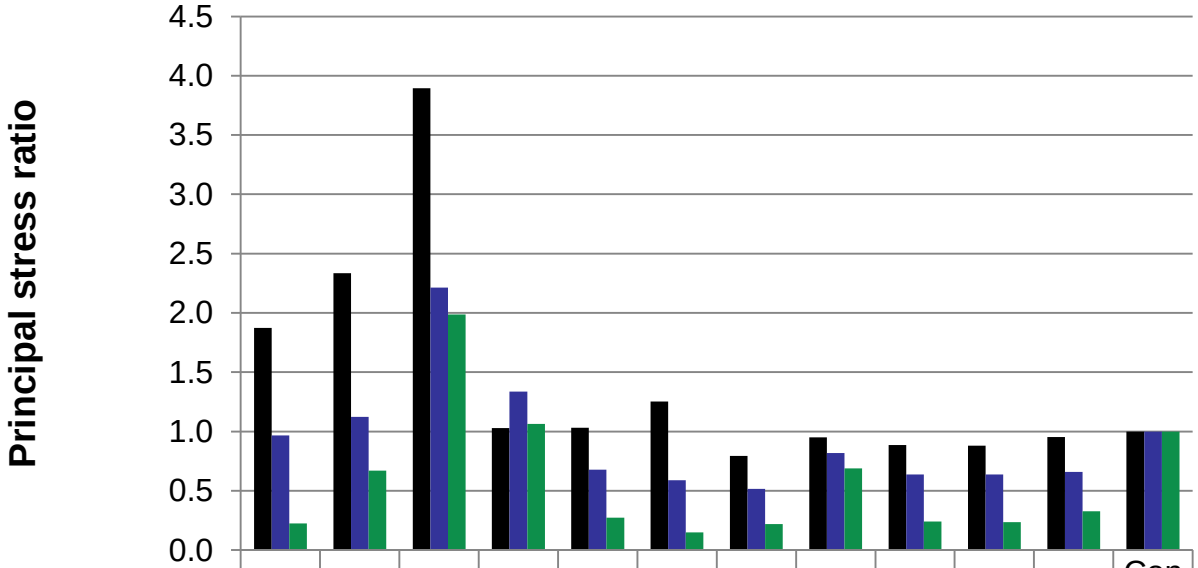


Fig. 12. Case 2. Displacement of form-found blades relative to the ‘control’ blade displacement of 4.71 mm



Blade No.	1	2	3	4	5	6	7	8	9	10	11	Control
Max. P1 ratio	1.87	2.33	3.89	1.03	1.03	1.25	0.79	0.95	0.89	0.88	0.95	1.00
Max. P2 ratio	0.97	1.12	2.21	1.34	0.68	0.59	0.51	0.82	0.64	0.64	0.66	1.00
Max. P3 ratio	0.22	0.67	1.99	1.06	0.27	0.15	0.22	0.69	0.24	0.23	0.33	1.00

Fig. 13. Case 2. Maximum values of principal stresses, P1, P2 and P3, for form-found blades, relative to the 'control' blade with the corresponding stress values of: 3.93×10^{8} N/mm^{2}, 1.87×10^{8} N/mm^{2}, and 1.57×10^{8} N/mm^{2} respectively

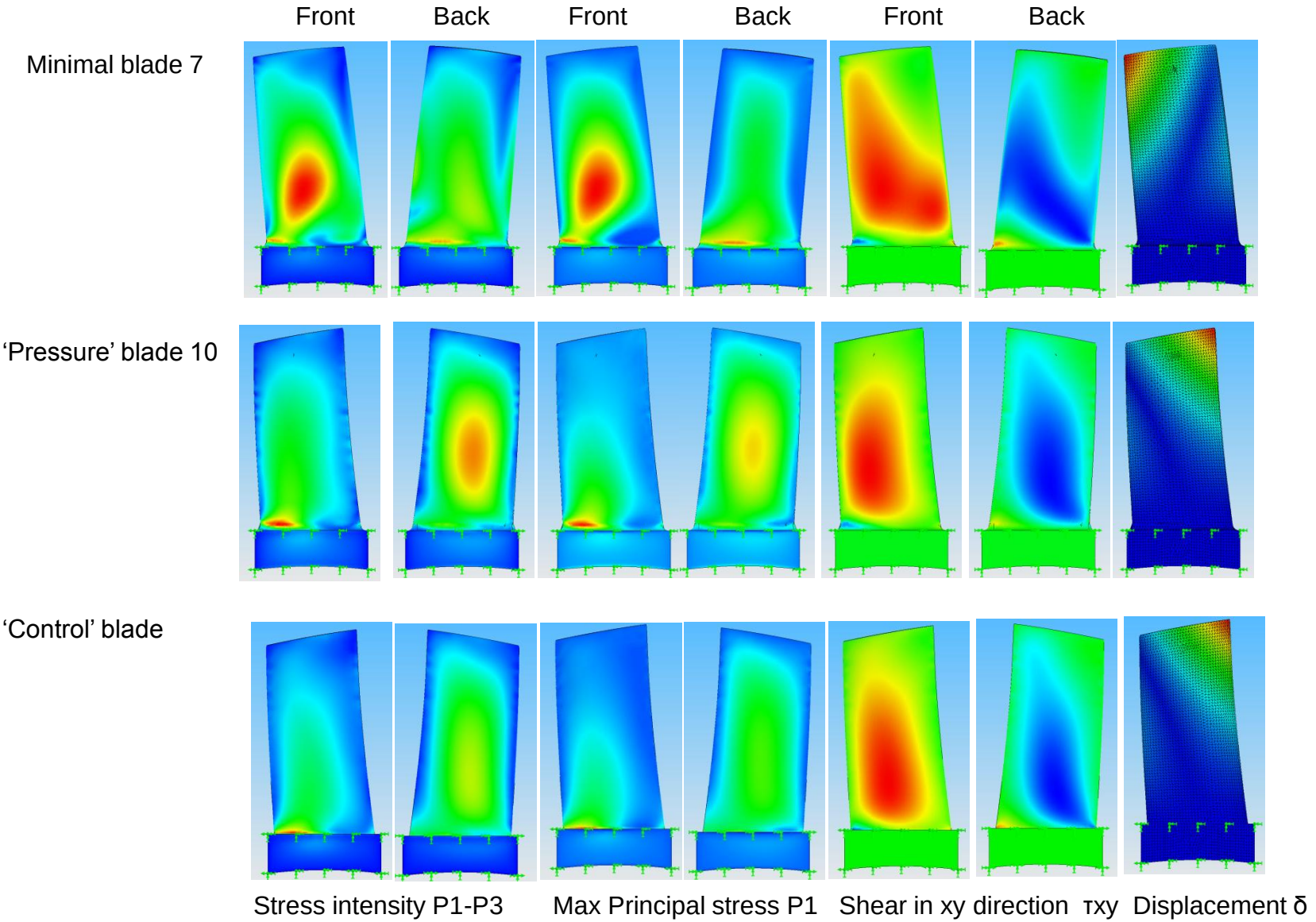


Fig. 14. Case 2. Distribution of stresses and displacements in selected 'minimal' and 'pressure' blades versus the 'control'

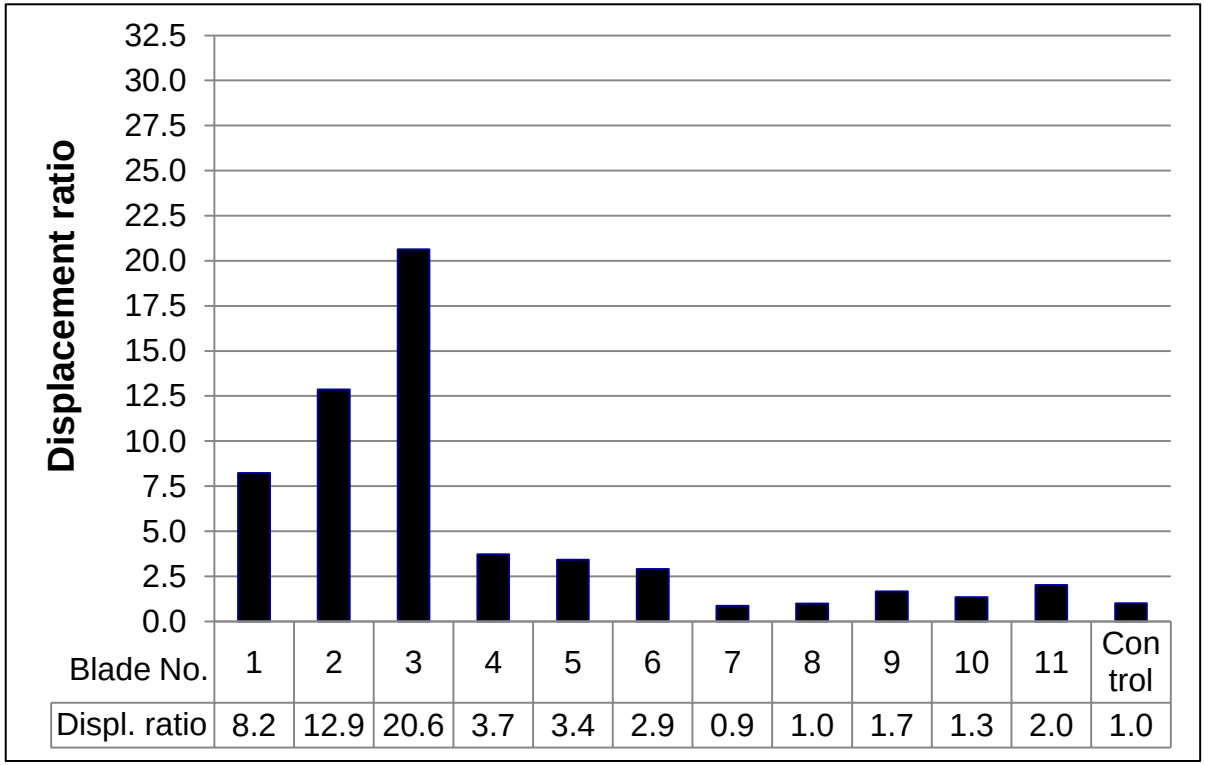
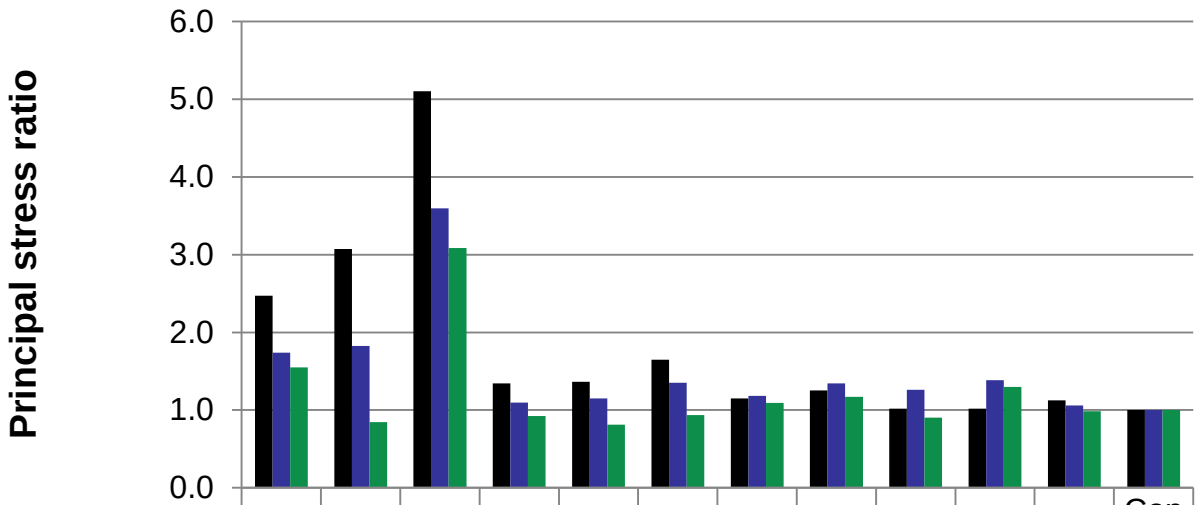


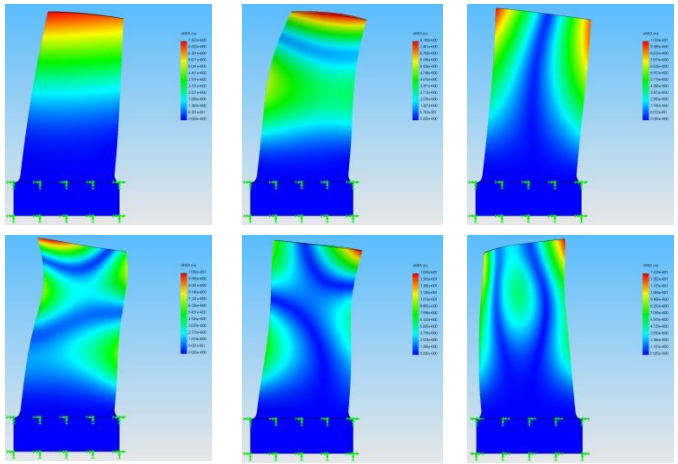
Fig. 15. Case 3. Displacement of form-found blades relative to the ‘control’ blade displacement of 4.81 mm



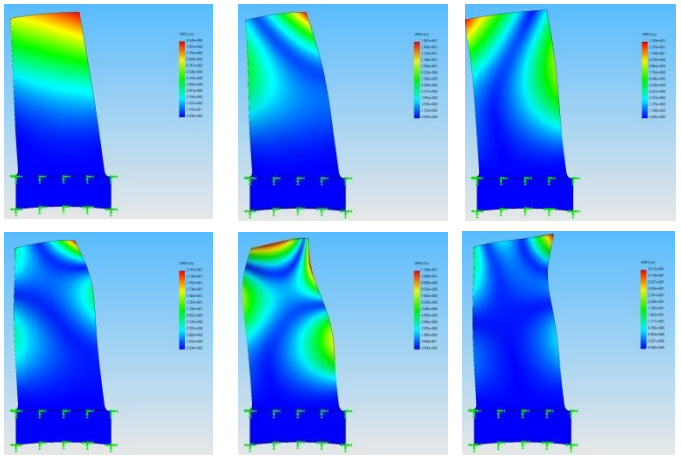
Blade No.	1	2	3	4	5	6	7	8	9	10	11	Control
Max. P1 ratio	2.47	3.07	5.10	1.34	1.36	1.65	1.15	1.26	1.02	1.02	1.13	1.00
Max. P2 ratio	1.74	1.82	3.60	1.10	1.15	1.35	1.18	1.34	1.26	1.39	1.06	1.00
Max. P3 ratio	1.55	0.85	3.08	0.92	0.81	0.94	1.09	1.17	0.90	1.30	0.99	1.00

Fig. 16. Case 3. Maximum values of principal stresses P1, P2 and P3, for form-found blades, relative to the 'control' blade with the corresponding stress values of: 2.98×10^{8} N/mm^2, 1.14×10^{8} N/mm^2, and 9.24×10^{7} N/mm^2 respectively

a)



b)



c)

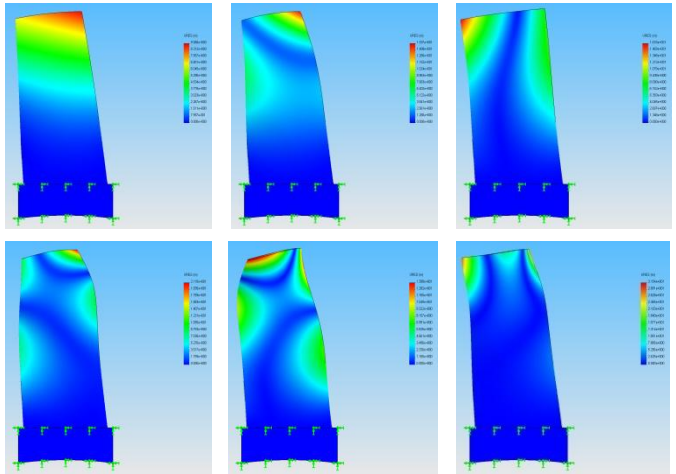
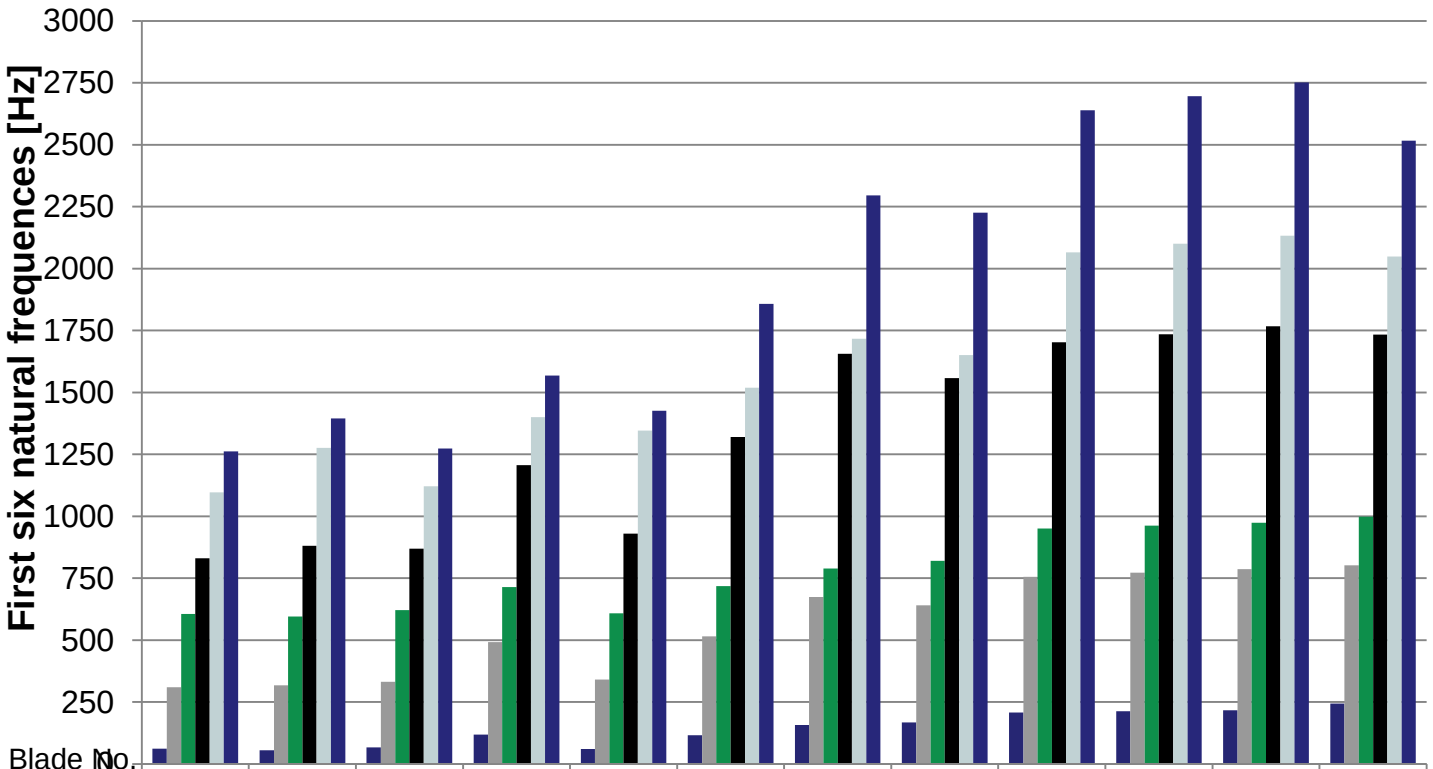


Fig. 17. Modal shapes corresponding to the first six natural frequencies for:
(a) ‘Minimal’ blade 7, (b) ‘Pressure’ blade 10, and (c) ‘Control’ blade



Blade No.	1	2	3	4	5	6	7	8	9	10	11	Control
Mode 1	62.0	56.0	67.0	118.6	60.7	116.0	157.9	168.2	208.6	212.8	216.4	244.6
Mode 2	310.3	318.1	331.7	492.3	341.6	515.5	674.4	640.5	755.4	772.5	787.0	802.2
Mode 3	605.3	595.0	620.9	714.4	608.7	718.5	788.8	820.6	950.6	963.0	974.5	998.8
Mode 4	830.2	880.8	868.8	1206.2	930.7	1319.7	1655.4	1557.2	1702.0	1735.2	1767.7	1733.1
Mode 5	1096.3	1275.7	1120.9	1400.7	1346.5	1518.9	1716.2	1650.2	2065.0	2100.3	2132.8	2049.1
Mode 6	1262.0	1395.6	1273.7	1568.3	1425.6	1857.9	2295.8	2225.4	2638.8	2695.3	2751.3	2516.9

Fig. 18 First six natural frequencies for form-found blades versus the ‘control’