CALCULATION OF THE TURBINE BLADES PROFILE

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Abstract

The calculation of the blade profile has been made by determining the geometrical outline of the aerodynamic profile, defined analytically through the combination of two maths functions, the skeleton and the thickness functions. The model presented has been illustrated in seven calculation sections, which have configurated the final shape of the blade, taking into account the running of the aerodynamic profile which has been placed in air draught, based on a calculation algorithm.

Key words: wind turbine, blade, aerodynamic profiles, section calculations, calculation algorithm.

INTRODUCTION

The turbine variant which has been analyzed is addressed to a harness domain of 4-5 m/s, and the maximum revolution imposed by the electrical generator is n = 250 rpm, ω = 26,2 rad/s, u_R = 40 m/s (maximum – to minimize noise).

MATERIAL AND METHODS

The geometrical outline of the aerodynamic profile of the blade is made analytically, by combining two maths functions: the skeleton function and the thickness function. The aerodynamic profiles which have been chosen are those from the NACA series with four figures: NACA 4424 (at the hub) and 4415 (at the margin). The axis Oy falls perpendicularly on the chord in the board of attack, while the thickness function is given by the following expression:

$$\frac{y_d(x)}{l} = \frac{d_m}{l} \cdot \left[1{,}4845\sqrt{\frac{x}{l}} - 0{,}63\frac{x}{l} - 1{,}758\left(\frac{x}{l}\right)^2 + 1{,}4215\left(\frac{x}{l}\right)^3 - 0{,}5075\left(\frac{x}{l}\right)^4 \right]$$

The curvature radii of the boards of attack and run-off, which are both rounded, are determined using the relations: (A – attack, F – run-off)

$$\frac{r_A}{l} = 1{,}1019 \cdot \left(\frac{d_m}{l}\right)^2 \qquad \frac{r_F}{l} = 1{,}105 \cdot \left(\frac{d_m}{l}\right)^2$$

The skeleton function is defined using the relations below; the skeleton is made of two parabola arcs, which are connected in x_{f_m} / l.

$$\frac{y_f}{l} = \frac{f_m / l}{\left(x_{f_m} / l\right)^2}\left[2\frac{x_{f_m}}{l}\cdot\frac{x}{l} - \left(\frac{x}{l}\right)^2\right] \quad \text{for} \quad 0 \le \frac{x}{l} \le \frac{x_{f_m}}{l}$$

$$\frac{y_f}{l} = \frac{f_m / l}{\left(1 - x_{f_m} / l\right)^2}\left[\left(1 - 2\frac{x_{f_m}}{l}\right) + 2\frac{x_{f_m}}{l}\cdot\frac{x}{l} - \left(\frac{x}{l}\right)^2\right] \quad \text{for} \quad \frac{x_{f_m}}{l} \le \frac{x}{l} \le 1$$

The functioning of the aerodynamic profile, which is placed in a draught, primarily depends on the position of the profile against the draught speed, through the angle of incidence value. Based on it, we have represented the following drawings, regarding the geometrical outline of the blade.

The algorithm of calculation for the determination of the geometrical outlines implies the following steps:

- defining the calculation variants for each radius (r), correlated with the profile chord (l) and the relative thickness of profile (d/l)
- the profile chord has been divided into ten equal intervals, noted with $(0{,}1\ 0{,}2 \ldots 1) \cdot l$
- for each partition noted with x, we have determined the thickness function y_d / l (±), the curvature radius of the board of attack r_A /l, and of the board of run-off respectively, as well as the skeleton function y_f /l
- the front side and back side calculation of the profile has been determined according to the thickness and skeleton of the profile
- the calculation for each partition is illustrated in a grid where the relative values are presented (in relations to the profile chord – l) and another grid which has been turned into length units expressed in mm, in order to ease the performance of the profile drawings

CONCLUSIONS

These data will be utilized for the energy balances of the assembly H2500, which will be determined through a mathematical model used for the assessment of the system curves of energetic revaluation.

REFERENCES

1. Dubău C., 2007, Utilizarea microagregatelor eoliene în componența unor sisteme complexe, Editura Politehnicii din Timişoara, ISSN: 1842-4937, ISBN: 978-973-625-408-6, pag. 150-157;

Table 1

Variant 1.1. r = 0,3 ; l = 355 ; d/l = 0,282										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,1100	0,1348	0,1410	0,1364	0,1244	0,1072	0,0861	0,0616	0,0340	0,0030
$\frac{y_d}{l}$ (–)	-0,1100	-0,1348	-0,1410	-0,1364	-0,1244	-0,1072	-0,0861	-0,0616	-0,0340	-0,0030
r_a / l	0,0876									
r_f / l	0,0084									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,1275	0,1648	0,1785	0,1764	0,1633	0,1428	0,1161	0,0839	0,0462	0,0030
intrados	-0,0925	-0,1048	-0,1035	-0,0964	-0,0855	-0,0717	-0,0561	-0,0394	-0,0218	-0,0030

Table 2

Variant 1.1. r = 0,3 ; l = 355 ; d = 100										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	35,5	71	106,5	142	177,5	213	248,5	284	319,5	355
y_d (+)	39,07	47,87	50,07	48,41	44,17	38,07	30,57	21,88	12,08	1,05
y_d (–)	-39,07	-47,87	-50,07	-48,41	-44,17	-38,07	-30,57	-21,88	-12,08	-1,05
r_a	31,11									
r_f	2,96									
y_f	6,21	10,65	13,31	14,20	13,81	12,62	10,65	7,89	4,34	0,00
extrados	45,28	58,52	63,38	62,61	57,97	50,69	41,22	29,77	16,42	1,05
intrados	-32,85	-37,22	-36,76	-34,21	-30,36	-25,45	-19,92	-13,99	-7,74	-1,05

Graph of blade section at r = 0,3

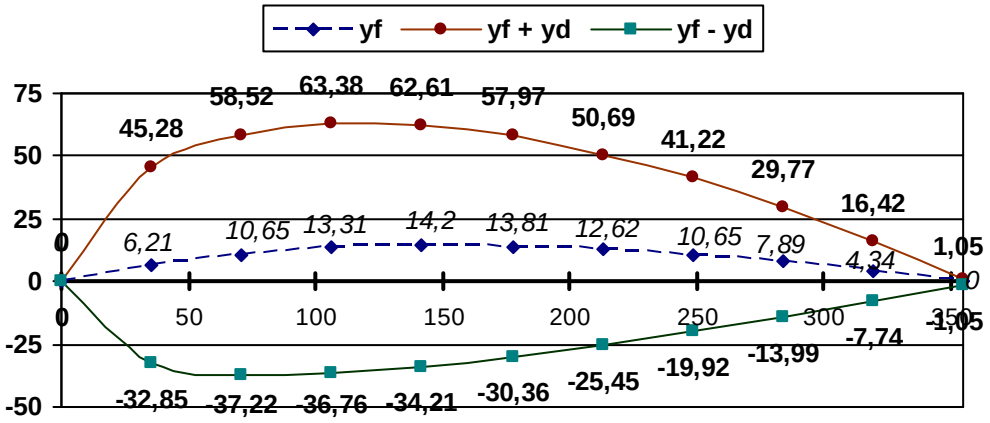


Table 3

Variant 1.2. r = 0,5 ; l = 338 ; d/l = 0,267										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,1042	0,1277	0,1335	0,1291	0,1178	0,1015	0,0815	0,0584	0,0322	0,0028
$\frac{y_d}{l}$ (–)	-0,1042	-0,1277	-0,1335	-0,1291	-0,1178	-0,1015	-0,0815	-0,0584	-0,0322	-0,0028
r_a / l	0,0786									
r_f / l	0,0075									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,1217	0,1577	0,1710	0,1691	0,1567	0,1371	0,1115	0,0806	0,0444	0,0028
intrados	-0,0867	-0,0977	-0,0960	-0,0891	-0,0789	-0,0660	-0,0515	-0,0361	-0,0200	-0,0028

Table 4

Variant 1.2. r = 0,5 ; l = 338 ; d = 90										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	33,8	67,6	101,4	135,2	169	202,8	236,6	270,4	304,2	338
y_d (+)	35,22	43,15	45,14	43,64	39,81	34,32	27,55	19,73	10,89	0,95
y_d (–)	-35,22	-43,15	-45,14	-43,64	-39,81	-34,32	-27,55	-19,73	-10,89	-0,95
r_a	26,55									
r_f	2,53									
y_f	5,92	10,14	12,68	13,52	13,14	12,02	10,14	7,51	4,13	0,00
extrados	41,13	53,29	57,81	57,16	52,96	46,34	37,69	27,24	15,02	0,95
intrados	-29,30	-33,01	-32,46	-30,12	-26,67	-22,30	-17,41	-12,22	-6,76	-0,95

Graph of blade section at r = 0,5

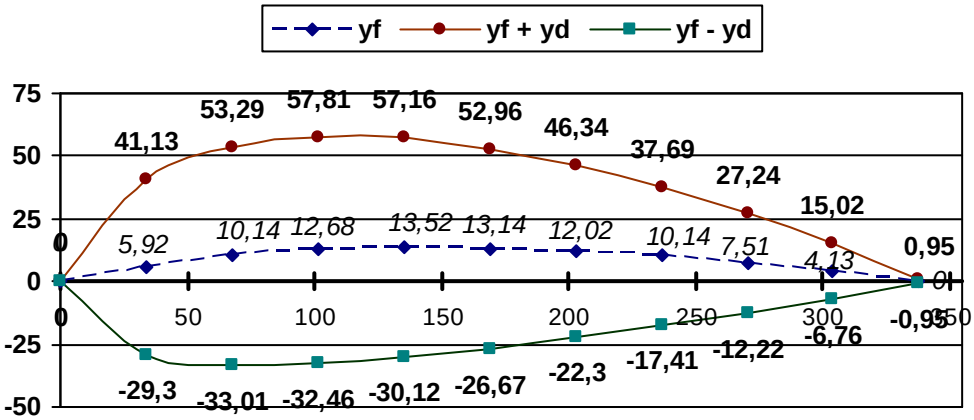


Table 5

Variant 1.3. r = 0,75 ; l = 316 ; d/l = 0,242										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,0944	0,1157	0,1210	0,1170	0,1068	0,0920	0,0739	0,0529	0,0292	0,0025
$\frac{y_d}{l}$ (–)	-0,0944	-0,1157	-0,1210	-0,1170	-0,1068	-0,0920	-0,0739	-0,0529	-0,0292	-0,0025
r_a / l	0,0645									
r_f / l	0,0061									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,1119	0,1457	0,1585	0,1570	0,1457	0,1276	0,1039	0,0751	0,0414	0,0025
intrados	-0,0769	-0,0857	-0,0835	-0,0770	-0,0679	-0,0565	-0,0439	-0,0307	-0,0170	-0,0025

Table 6

Variant 1.3. r = 0,75 ; l = 316 ; d = 77										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	31,6	63,2	94,8	126,4	158	189,6	221,2	252,8	284,4	316
y_d (+)	29,84	36,56	38,25	36,98	33,74	29,08	23,35	16,72	9,23	0,80
y_d (–)	-29,84	-36,56	-38,25	-36,98	-33,74	-29,08	-23,35	-16,72	-9,23	-0,80
r_a	20,39									
r_f	1,94									
y_f	5,53	9,48	11,85	12,64	12,29	11,24	9,48	7,02	3,86	0,00
extrados	35,37	46,04	50,10	49,62	46,03	40,32	32,83	23,74	13,09	0,80
intrados	-24,31	-27,08	-26,40	-24,34	-21,45	-17,85	-13,87	-9,69	-5,36	-0,80

Graph of blade section at r = 0,75

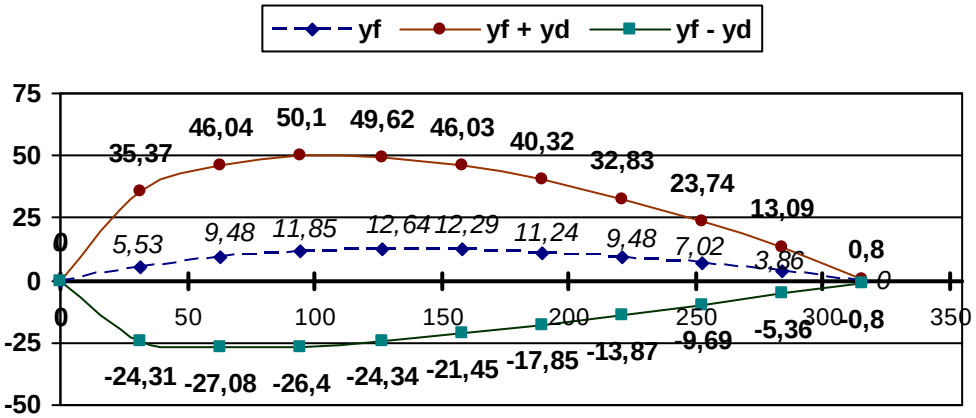


Table 7

Variant 1.4. r = 1 ; l = 295 ; d/l = 0,216										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,0843	0,1033	0,1080	0,1045	0,0953	0,0821	0,0660	0,0472	0,0261	0,0023
$\frac{y_d}{l}$ (–)	-0,0843	-0,1033	-0,1080	-0,1045	-0,0953	-0,0821	-0,0660	-0,0472	-0,0261	-0,0023
r_a / l	0,0514									
r_f / l	0,0049									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,1018	0,1333	0,1455	0,1445	0,1342	0,1177	0,0960	0,0694	0,0383	0,0023
intrados	-0,0668	-0,0733	-0,0705	-0,0645	-0,0564	-0,0466	-0,0360	-0,0250	-0,0138	-0,0023

Table 8

Variant 1.4. r = 1 ; l = 295 ; d = 64										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	29,5	59	88,5	118	147,5	177	206,5	236	265,5	295
y_d (+)	24,87	30,47	31,87	30,81	28,11	24,23	19,46	13,93	7,69	0,67
y_d (–)	-24,87	-30,47	-31,87	-30,81	-28,11	-24,23	-19,46	-13,93	-7,69	-0,67
r_a	15,17									
r_f	1,45									
y_f	5,16	8,85	11,06	11,80	11,47	10,49	8,85	6,56	3,61	0,00
extrados	30,03	39,32	42,93	42,61	39,58	34,72	28,31	20,48	11,29	0,67
intrados	-19,70	-21,62	-20,81	-19,01	-16,64	-13,74	-10,61	-7,37	-4,08	-0,67

Graph of blade section at r = 1

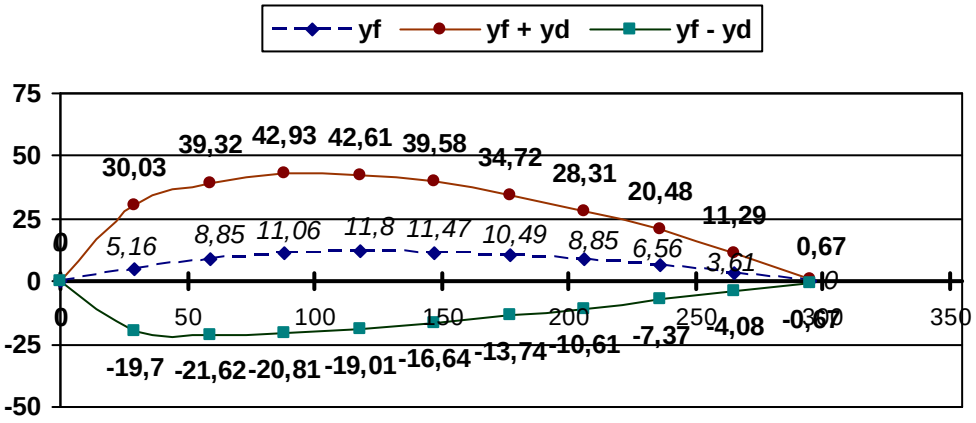


Table 9

Variant 1.5. r = 1,25 ; l = 274 ; d/l = 0,185										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,0722	0,0885	0,0925	0,0895	0,0816	0,0704	0,0565	0,0404	0,0223	0,0019
$\frac{y_d}{l}$ (–)	-0,0722	-0,0885	-0,0925	-0,0895	-0,0816	-0,0704	-0,0565	-0,0404	-0,0223	-0,0019
r_a / l	0,0377									
r_f / l	0,0036									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,0897	0,1185	0,1300	0,1295	0,1205	0,1059	0,0865	0,0627	0,0345	0,0019
intrados	-0,0547	-0,0585	-0,0550	-0,0495	-0,0427	-0,0348	-0,0265	-0,0182	-0,0101	-0,0019

Table 10

Variant 1.5. r = 1,25 ; l = 274 ; d = 50										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	27,4	54,8	82,2	109,6	137	164,4	191,8	219,2	246,6	274
y_d (+)	19,78	24,24	25,35	24,51	22,36	19,28	15,48	11,08	6,12	0,53
y_d (–)	-19,78	-24,24	-25,35	-24,51	-22,36	-19,28	-15,48	-11,08	-6,12	-0,53
r_a	10,33									
r_f	0,98									
y_f	4,80	8,22	10,28	10,96	10,66	9,74	8,22	6,09	3,35	0,00
extrados	24,58	32,46	35,63	35,47	33,02	29,02	23,70	17,17	9,46	0,53
intrados	-14,99	-16,02	-15,08	-13,55	-11,71	-9,53	-7,26	-4,99	-2,77	-0,53

Graph of blade section at r = 1,25

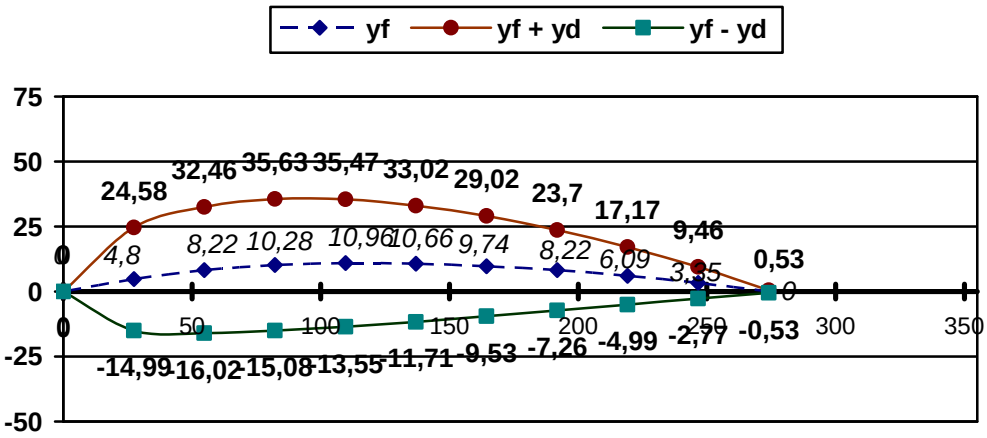


Table 11

Variant 1.6. r = 1,5 ; l = 252 ; d/l = 0,148										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,0578	0,0708	0,0740	0,0716	0,0653	0,0563	0,0452	0,0324	0,0179	0,0016
$\frac{y_d}{l}$ (–)	-0,0578	-0,0708	-0,0740	-0,0716	-0,0653	-0,0563	-0,0452	-0,0324	-0,0179	-0,0016
r_a / l	0,0241									
r_f / l	0,0023									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,0753	0,1008	0,1115	0,1116	0,1042	0,0918	0,0752	0,0546	0,0301	0,0016
intrados	-0,0403	-0,0408	-0,0365	-0,0316	-0,0264	-0,0207	-0,0152	-0,0101	-0,0056	-0,0016

Table 12

Variant 1.6. r = 1,5 ; l = 252 ; d = 37										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	25,2	50,4	75,6	100,8	126	151,2	176,4	201,6	226,8	252
y_d (+)	14,55	17,83	18,65	18,04	16,45	14,18	11,39	8,15	4,50	0,39
y_d (–)	-14,55	-17,83	-18,65	-18,04	-16,45	-14,18	-11,39	-8,15	-4,50	-0,39
r_a	6,08									
r_f	0,58									
y_f	4,41	7,56	9,45	10,08	9,80	8,96	7,56	5,60	3,08	0,00
extrados	18,96	25,39	28,10	28,12	26,25	23,14	18,95	13,75	7,58	0,39
intrados	-10,14	-10,27	-9,20	-7,96	-6,65	-5,22	-3,83	-2,55	-1,42	-0,39

Graph of blade section at r = 1,5

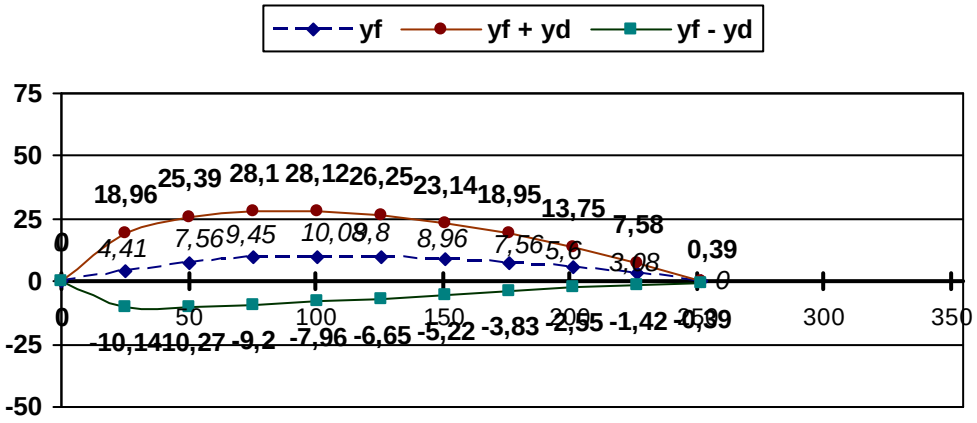
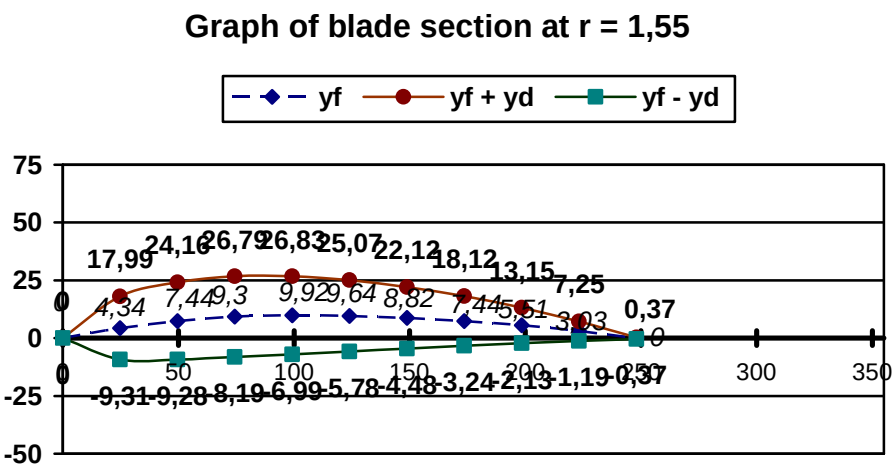


Table 13

Variant 1.7. r = 1,55 ; l = 248 ; d/l = 0,141										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,0550	0,0674	0,0705	0,0682	0,0622	0,0536	0,0431	0,0308	0,0170	0,0015
$\frac{y_d}{l}$ (–)	-0,0550	-0,0674	-0,0705	-0,0682	-0,0622	-0,0536	-0,0431	-0,0308	-0,0170	-0,0015
r_a / l	0,0219									
r_f / l	0,0021									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,0725	0,0974	0,1080	0,1082	0,1011	0,0892	0,0731	0,0530	0,0292	0,0015
intrados	-0,0375	-0,0374	-0,0330	-0,0282	-0,0233	-0,0181	-0,0131	-0,0086	-0,0048	-0,0015

Table 14

Variant 1.7. r = 1,55 ; l = 248 ; d = 35										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	24,8	49,6	74,4	99,2	124	148,8	173,6	198,4	223,2	248
y_d (+)	13,65	16,72	17,49	16,91	15,43	13,30	10,68	7,64	4,22	0,37
y_d (–)	-13,65	-16,72	-17,49	-16,91	-15,43	-13,30	-10,68	-7,64	-4,22	-0,37
r_a	5,43									
r_f	0,52									
y_f	4,34	7,44	9,30	9,92	9,64	8,82	7,44	5,51	3,03	0,00
extrados	17,99	24,16	26,79	26,83	25,07	22,12	18,12	13,15	7,25	0,37
intrados	-9,31	-9,28	-8,19	-6,99	-5,78	-4,48	-3,24	-2,13	-1,19	-0,37


Graph of blade section at r = 1,55
yf
yf + yd
yf - yd
75
50
25
0
-25
-50
0
50
100
150
200
250
300
350
17,99
24,16
26,79
26,83
25,07
22,12
18,12
13,15
7,25
0,37
4,34
7,44
9,3
9,92
9,64
8,82
7,44
5,51
3,03
0
-9,31
-9,28
-8,19
-6,99
-5,78
-4,48
-3,24
-2,13
-1,19
-0,37