UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Bachelor's Degree in Aerospace Technology Engineering

Bachelor Thesis

Project of designing and manufacturing a small wind turbine using fused deposition modeling technology

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Chapter 1

Aerodynamic design

1.1 Airfoil selection

In this section the polar curves obtained from XFLR5 will be presented. The data retrieved from each graph will also be shown.

Each value has been obtained using the following criteria:

1. Maximum efficiency E: The mean of the maximum efficiency for each Reynolds.
2. $\Delta\alpha = \alpha_s - \alpha_{opt}$: The mean of difference between optimal and stall angle of attack for each Reynolds.
3. $\frac{d\alpha_{opt}}{dRe}$: The mean of angle of attack variation from $Re = 1.2 \cdot 10^5$ to each other Reynolds.
4. $\frac{dE}{dRe}$: The mean of efficiency variation from $Re = 1.2 \cdot 10^5$ to each other Reynolds.
5. $\frac{dE}{d\alpha}(\alpha = \alpha_{opt})$: The mean of efficiency variation at $\alpha = \alpha_{opt} \pm 2$ for each Reynolds.
6. Thickness t/c: Maximum airfoil thickness.
7. Cl_{opt}: The mean of lift coefficient at maximum efficiency point for each Reynolds.

1.1.1 Airfoil data

Airfoil 1: SG6040

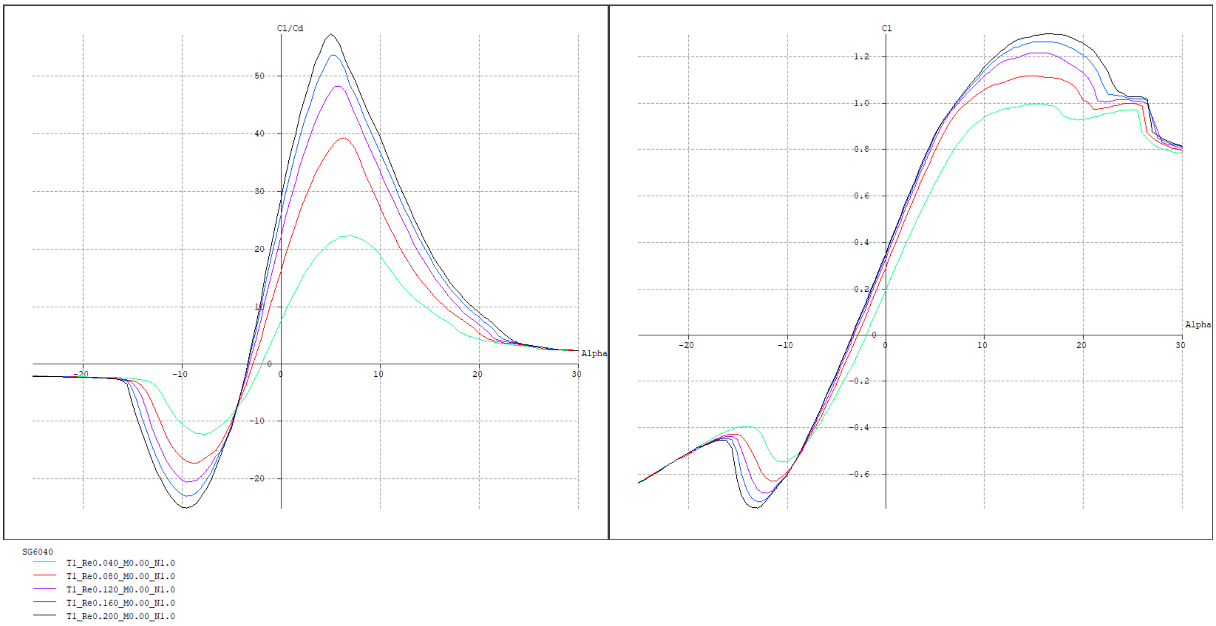

Figure 1: SG6040 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	44.11
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	10.81
3	$d\alpha_{opt}/dRe$	0.55
4	dE/dRe	9.86
5	$dE/d\alpha(\alpha = \alpha_{opt})$	4.66
6	Thickness t/c	16.00
7	Cl_{opt}	0.87

Table 1: SG6040 data.

Airfoil 2: SG6041

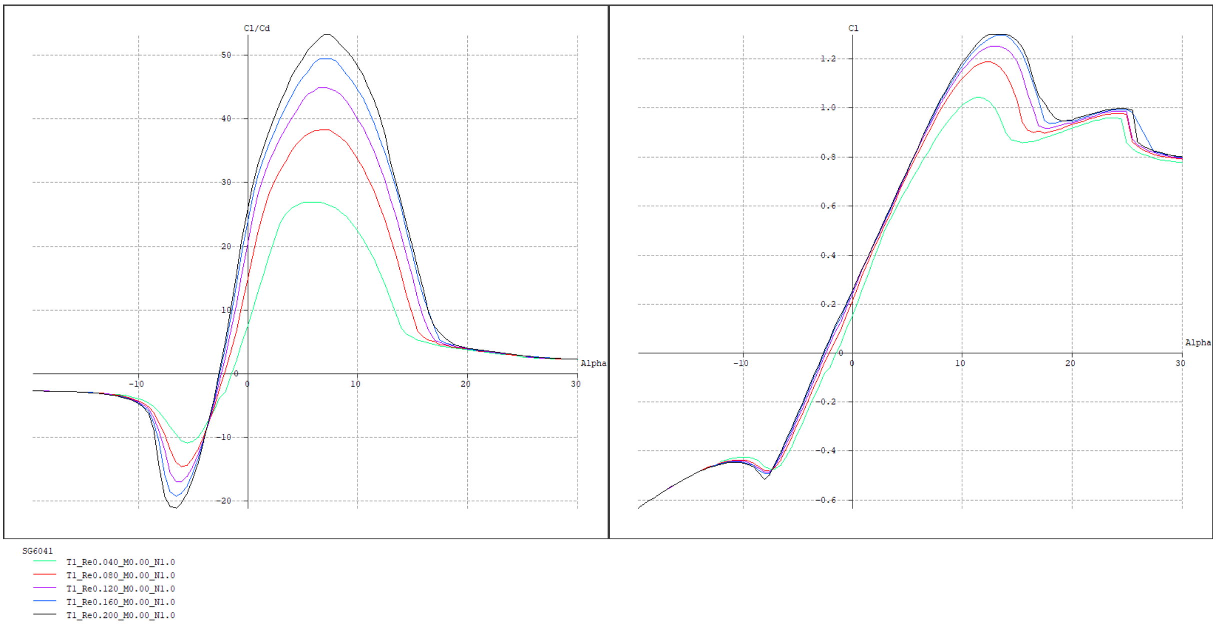

Figure 2: SG6041 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	42.46
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	6.02
3	$d\alpha_{opt}/dRe$	0.36
4	dE/dRe	7.50
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.14
6	Thickness t/c	10.00
7	Cl_{opt}	0.89

Table 2: SG6041 data.

Airfoil 3: SG6042

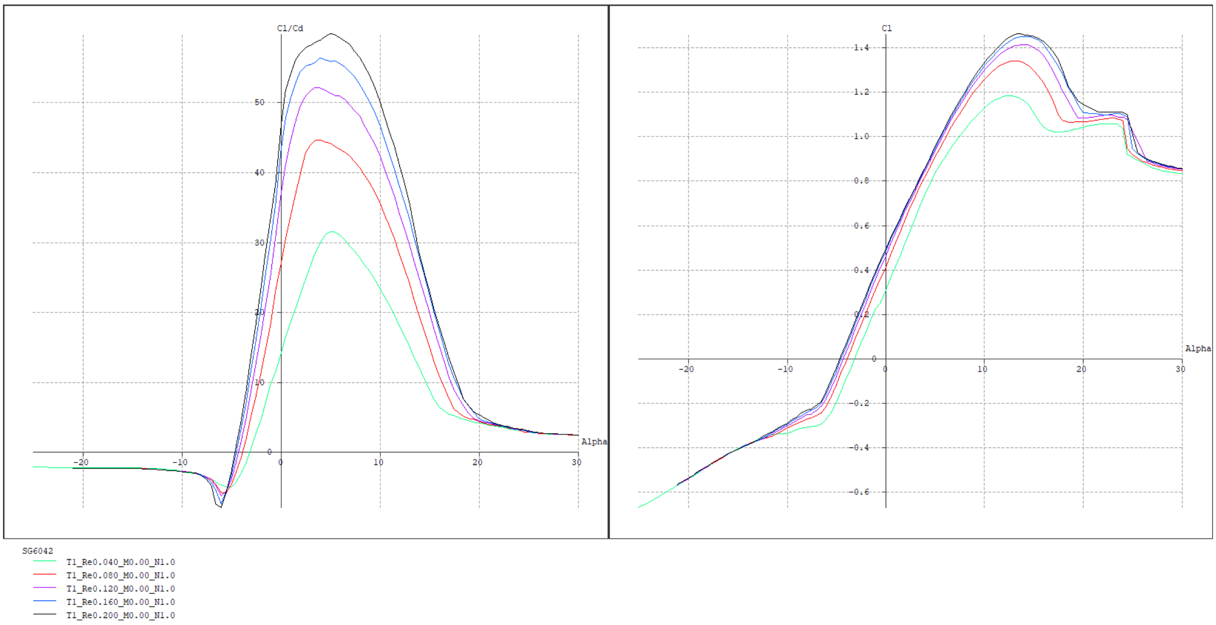

Figure 3: SG6042 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	48.89
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	9.24
3	$d\alpha_{opt}/dRe$	0.64
4	dE/dRe	8.01
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.57
6	Thickness t/c	10.00
7	Cl_{opt}	0.85

Table 3: SG6042 data.

Airfoil 4: SG6043

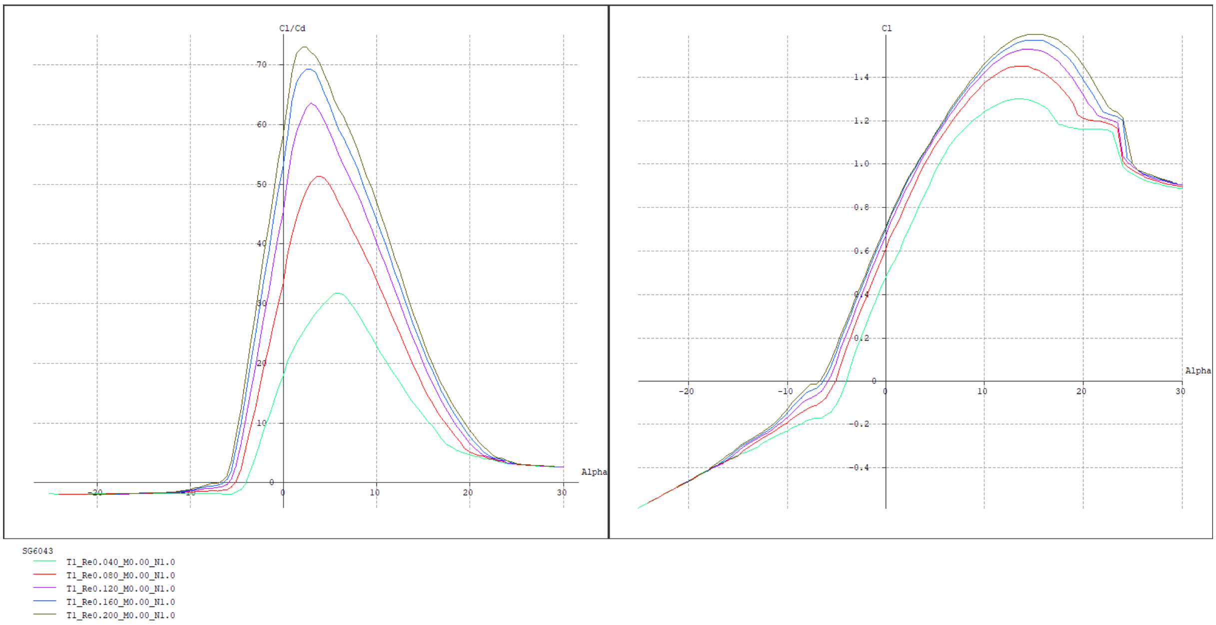

Figure 4: SG6043 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	57.73
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	10.96
3	$d\alpha_{opt}/dRe$	0.94
4	dE/dRe	11.87
5	$dE/d\alpha(\alpha = \alpha_{opt})$	5.59
6	Thickness t/c	10.00
7	Cl_{opt}	0.97

Table 4: SG6043 data.

Airfoil 5: S833

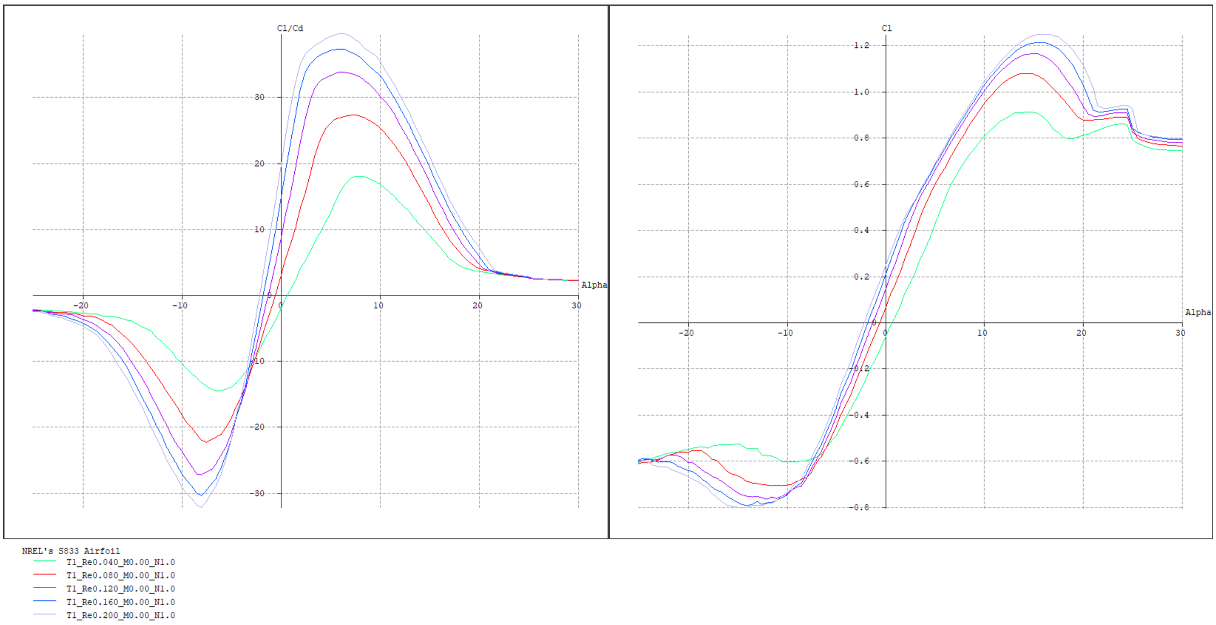

Figure 5: S833 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	31.13
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	8.59
3	$d\alpha_{opt}/dRe$	0.69
4	dE/dRe	6.32
5	$dE/d\alpha(\alpha = \alpha_{opt})$	1.32
6	Thickness t/c	18.00
7	Cl_{opt}	0.75

Table 5: S833 data.

Airfoil 6: S834

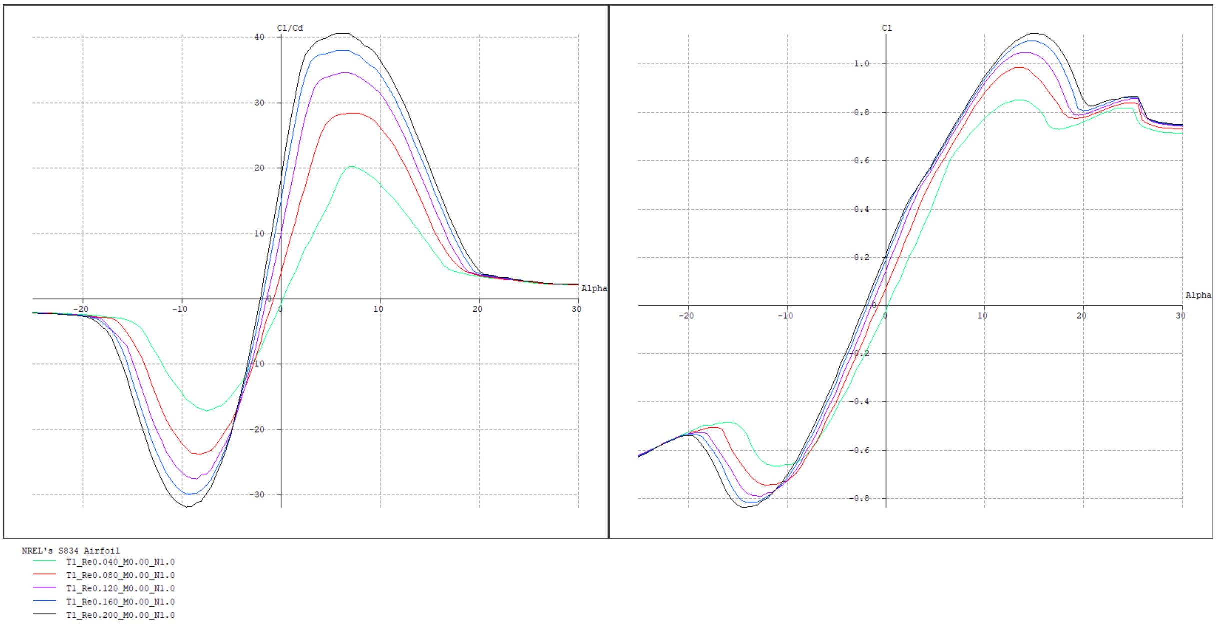

Figure 6: S834 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	32.30
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	7.62
3	$d\alpha_{opt}/dRe$	0.33
4	dE/dRe	5.96
5	$dE/d\alpha(\alpha = \alpha_{opt})$	1.32
6	Thickness t/c	18.00
7	Cl_{opt}	0.69

Table 6: S834 data.

Airfoil 7: S835

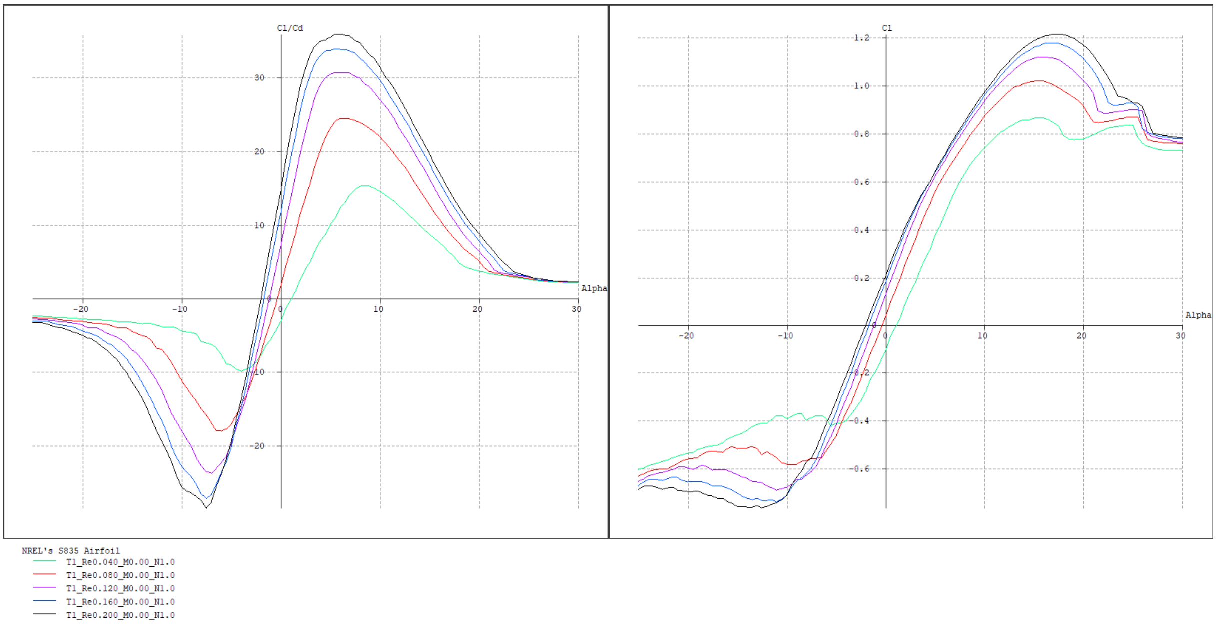

Figure 7: S835 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	27.96
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	10.03
3	$d\alpha_{opt}/dRe$	0.60
4	dE/dRe	6.00
5	$dE/d\alpha(\alpha = \alpha_{opt})$	1.97
6	Thickness t/c	21.00
7	Cl_{opt}	0.67

Table 7: S834 data.

Airfoil 8: S1210

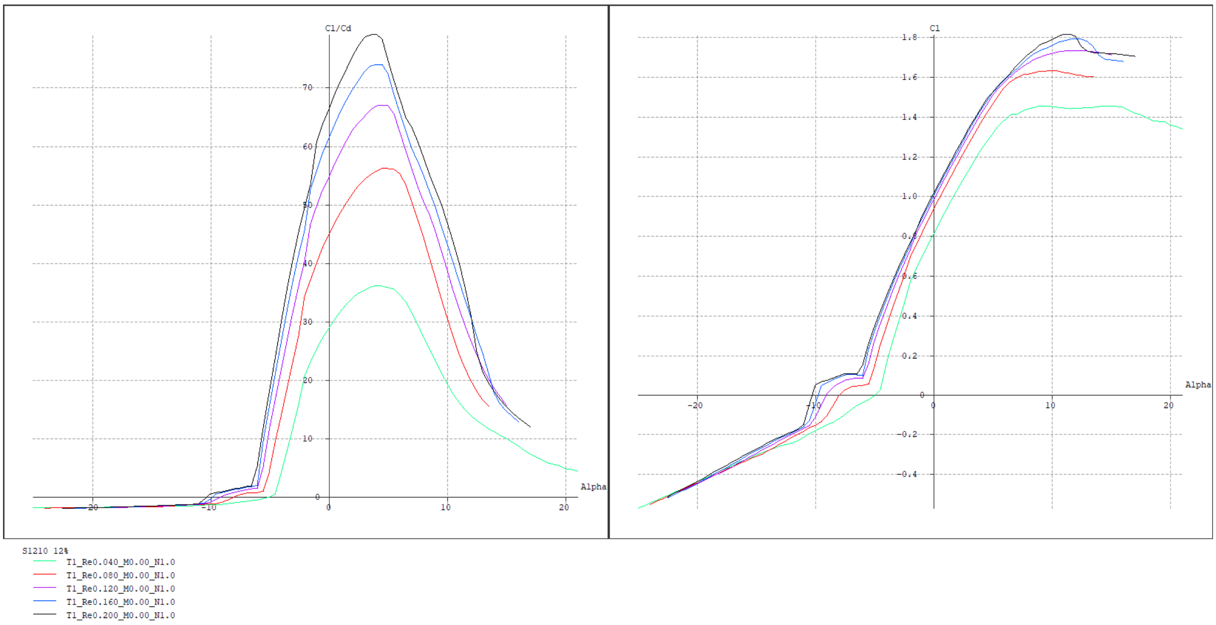

Figure 8: S1210 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	62.47
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	6.32
3	$d\alpha_{opt}/dRe$	0.31
4	dE/dRe	12.13
5	$dE/d\alpha(\alpha = \alpha_{opt})$	4.80
6	Thickness t/c	12.00
7	Cl_{opt}	1.40

Table 8: S1210 data.

Airfoil 9: S1223

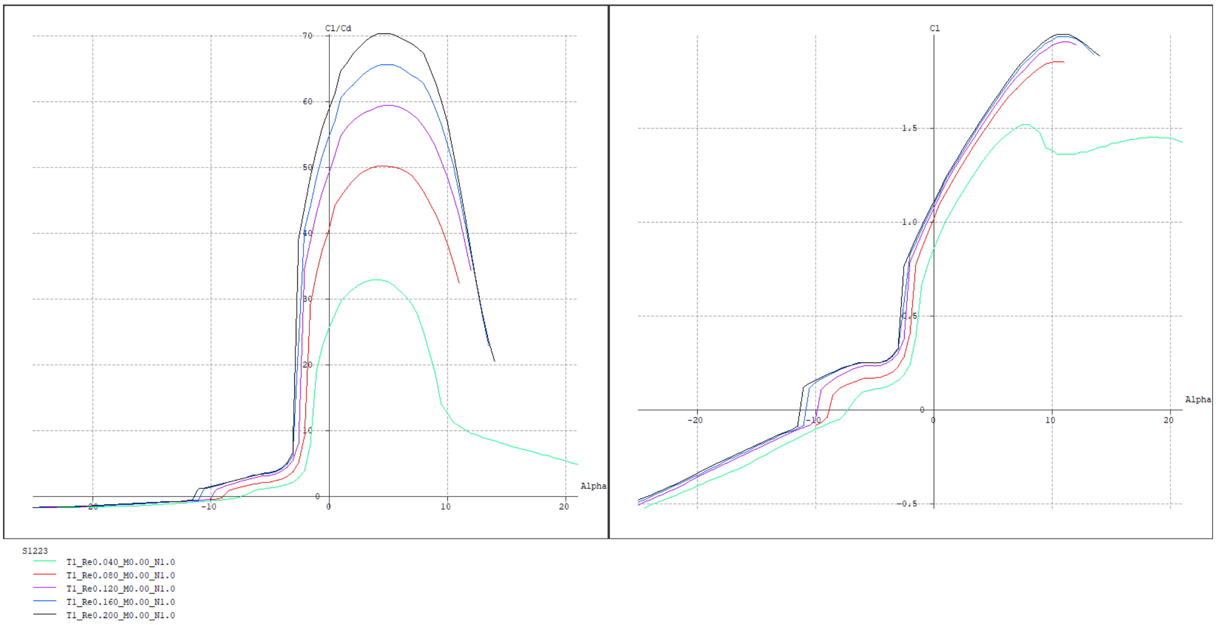

Figure 9: S1223 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	55.67
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	5.63
3	$d\alpha_{opt}/dRe$	0.37
4	dE/dRe	10.55
5	$dE/d\alpha(\alpha = \alpha_{opt})$	1.44
6	Thickness t/c	12.10
7	Cl_{opt}	1.52

Table 9: S1223 data.

Airfoil 10: S6063

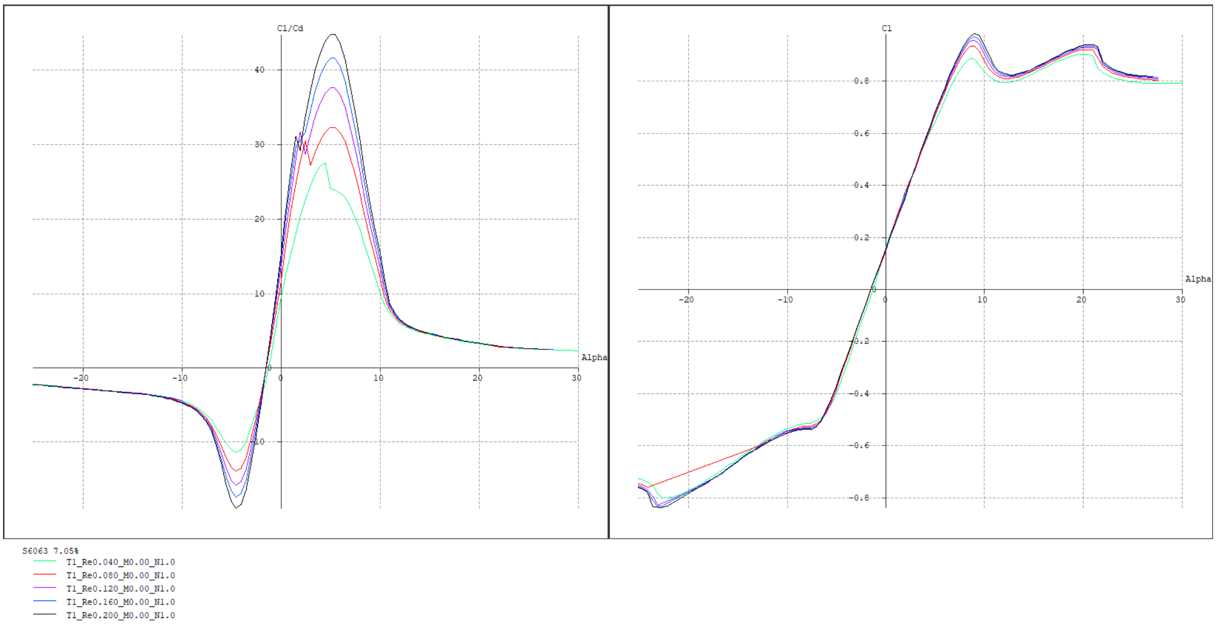

Figure 10: S6063 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	33.78
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	3.89
3	$d\alpha_{opt}/dRe$	0.18
4	dE/dRe	5.36
5	$dE/d\alpha(\alpha = \alpha_{opt})$	5.57
6	Thickness t/c	7.00
7	Cl_{opt}	0.67

Table 10: S6063 data.

Airfoil 11: S9037

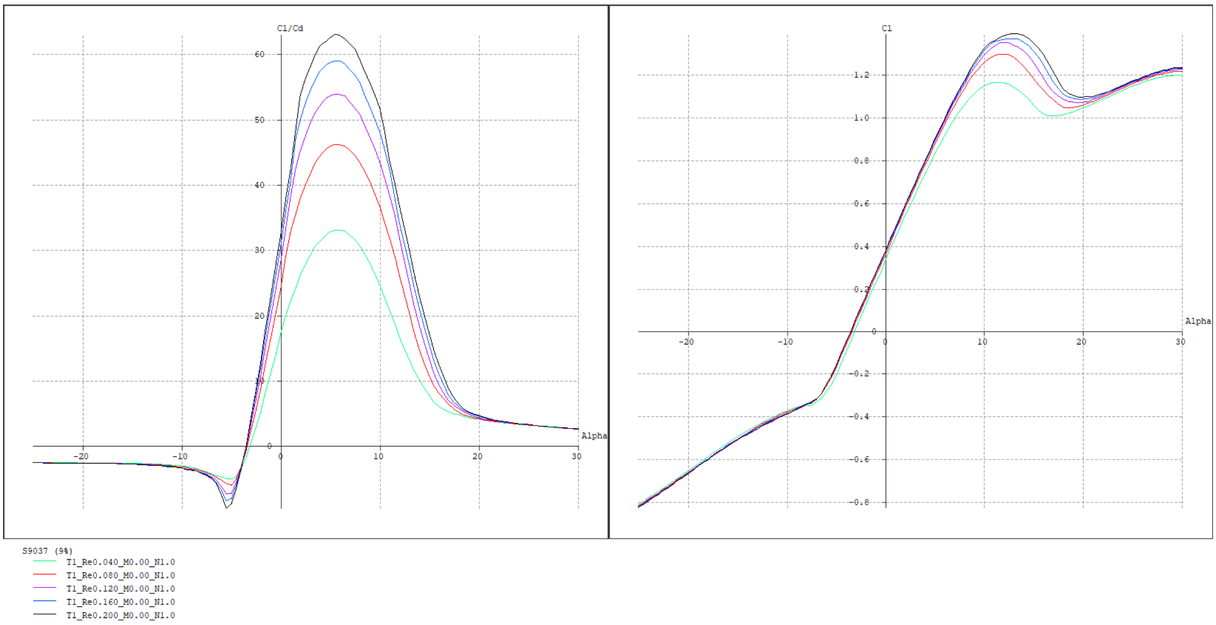

Figure 11: S9037 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	50.95
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	6.57
3	$d\alpha_{opt}/dRe$	0.09
4	dE/dRe	8.55
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.33
6	Thickness t/c	9.00
7	Cl_{opt}	0.93

Table 11: S9037 data.

Airfoil 12: S3010

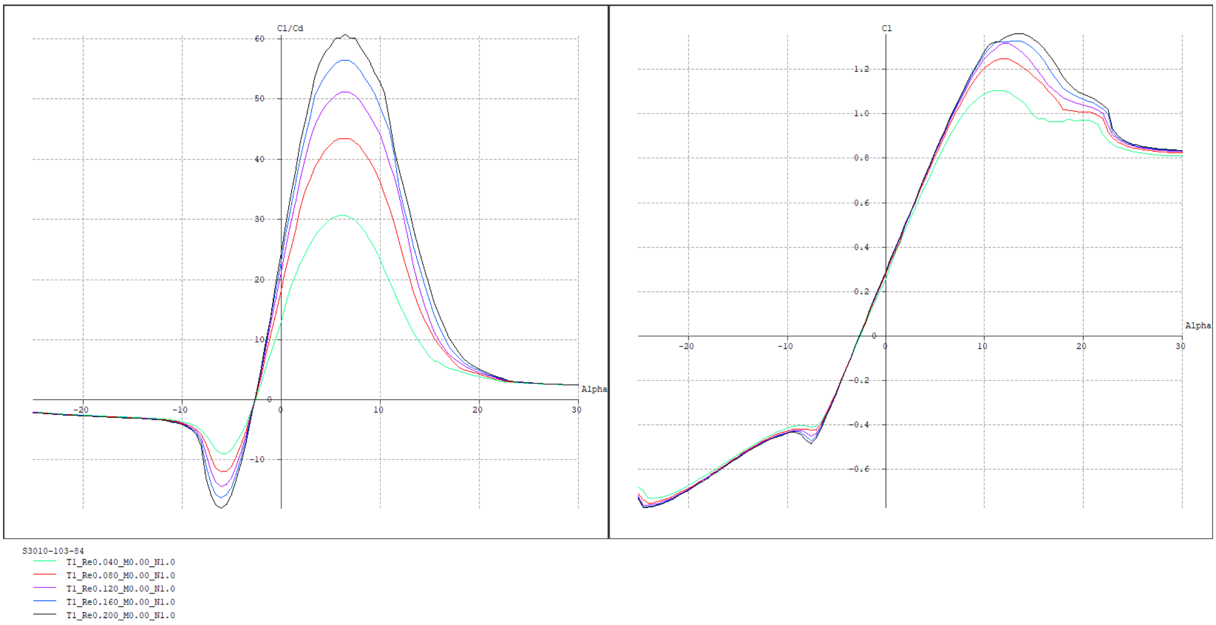

Figure 12: S3010 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	48.35
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	5.97
3	$d\alpha_{opt}/dRe$	0.07
4	dE/dRe	8.59
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.45
6	Thickness t/c	10.30
7	Cl_{opt}	0.94

Table 12: S3010 data.

Airfoil 13: SD8000

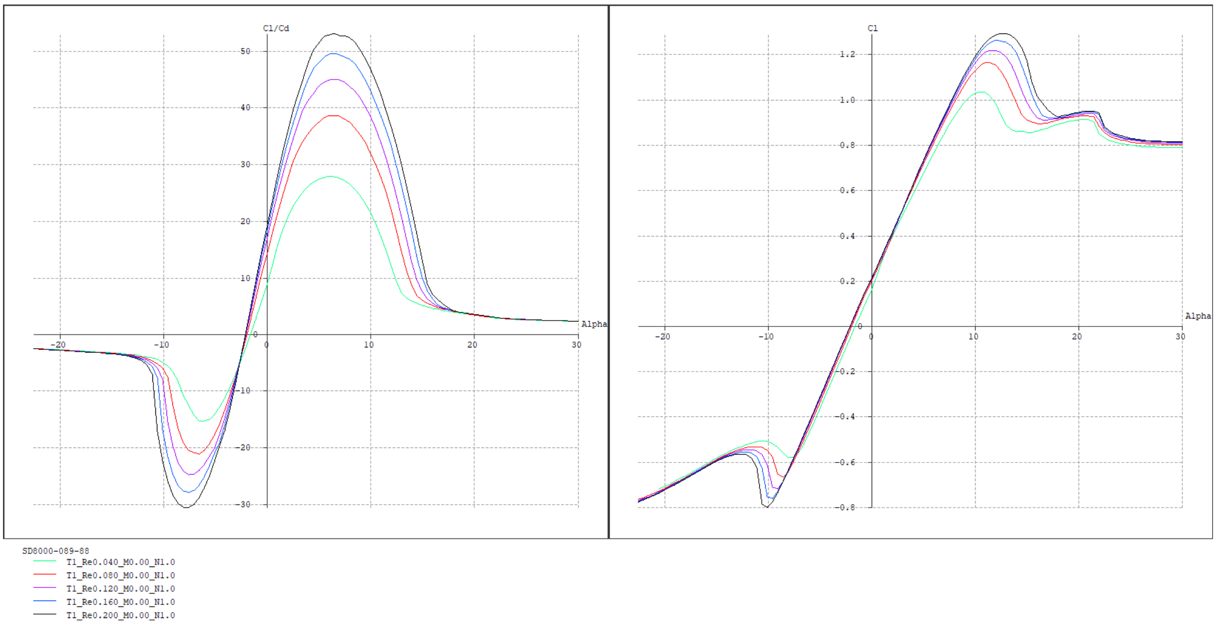

Figure 13: SD8000 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	42.76
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	5.35
3	$d\alpha_{opt}/dRe$	0.06
4	dE/dRe	7.24
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.15
6	Thickness t/c	8.90
7	Cl_{opt}	0.84

Table 13: SD8000 data.

Airfoil 14: BW3

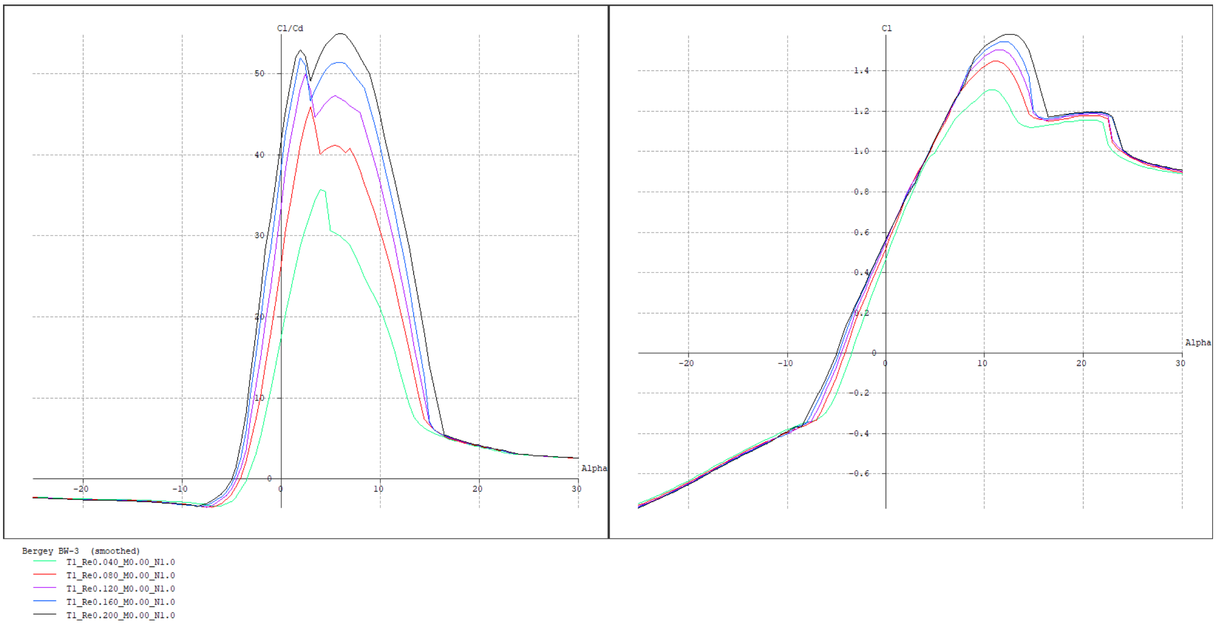

Figure 14: BW3 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	45.99
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	6.27
3	$d\alpha_{opt}/dRe$	0.49
4	dE/dRe	5.89
5	$dE/d\alpha(\alpha = \alpha_{opt})$	2.96
6	Thickness t/c	5.00
7	Cl_{opt}	1.08

Table 14: BW3 data.

Airfoil 15: E387

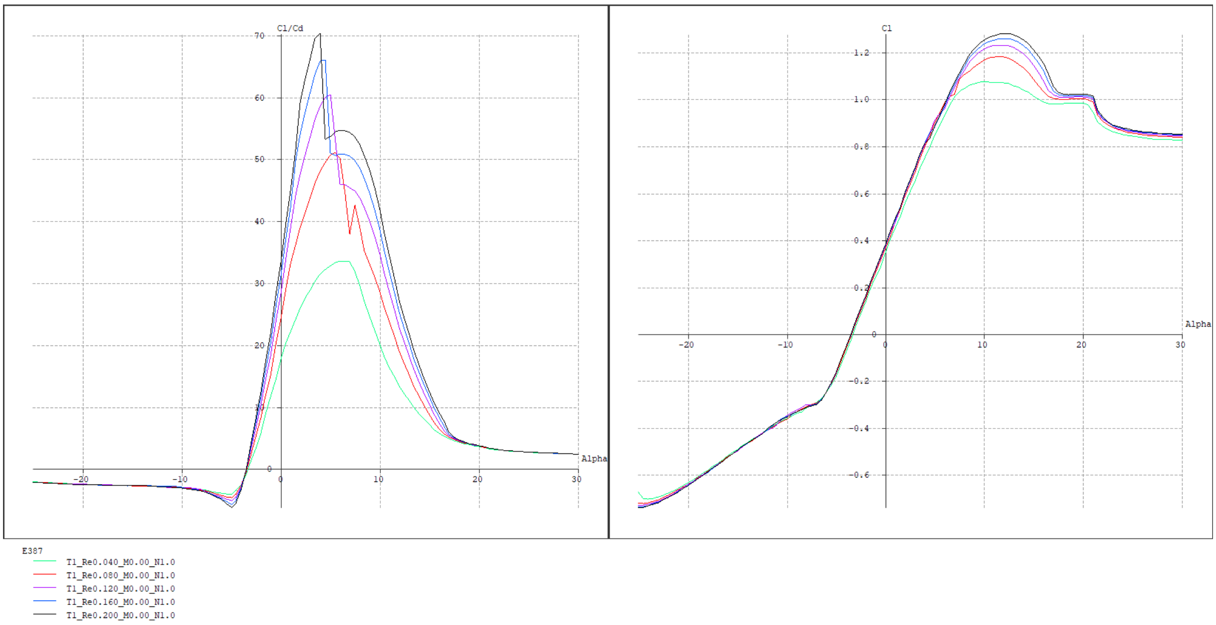

Figure 15: E387 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	56.17
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	6.85
3	$d\alpha_{opt}/dRe$	0.66
4	dE/dRe	10.42
5	$dE/d\alpha(\alpha = \alpha_{opt})$	9.22
6	Thickness t/c	9.10
7	Cl_{opt}	0.89

Table 15: E387 data.

Airfoil 16: E374

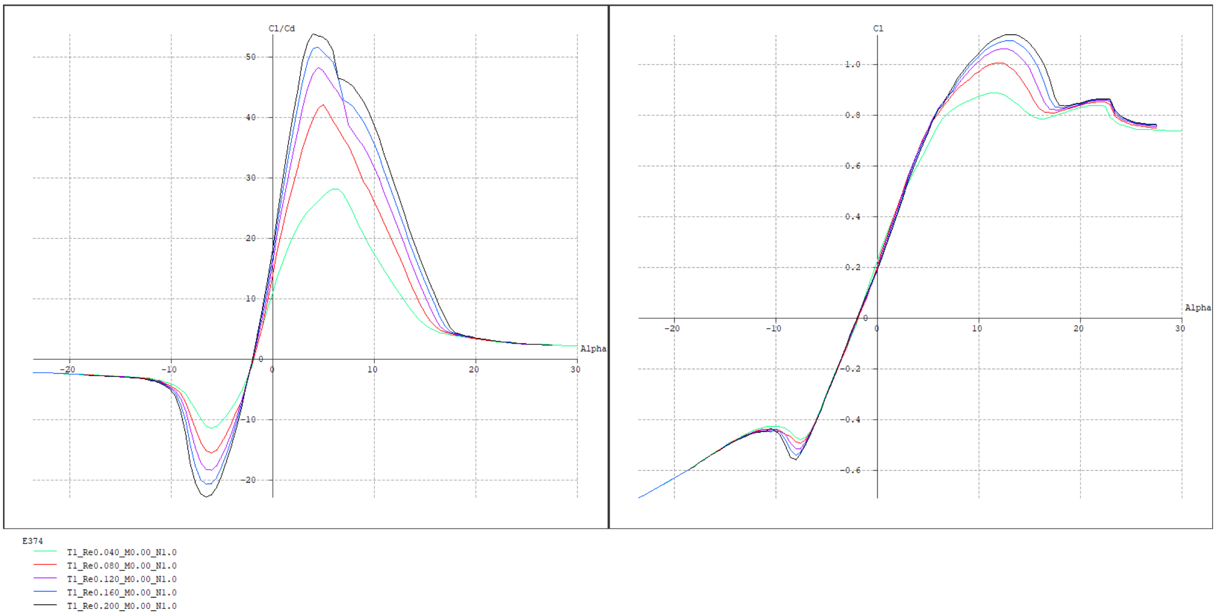

Figure 16: E374 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	44.81
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	7.98
3	$d\alpha_{opt}/dRe$	0.56
4	dE/dRe	7.04
5	$dE/d\alpha(\alpha = \alpha_{opt})$	6.69
6	Thickness t/c	10.90
7	Cl_{opt}	0.71

Table 16: E374 data.

Airfoil 17: E62

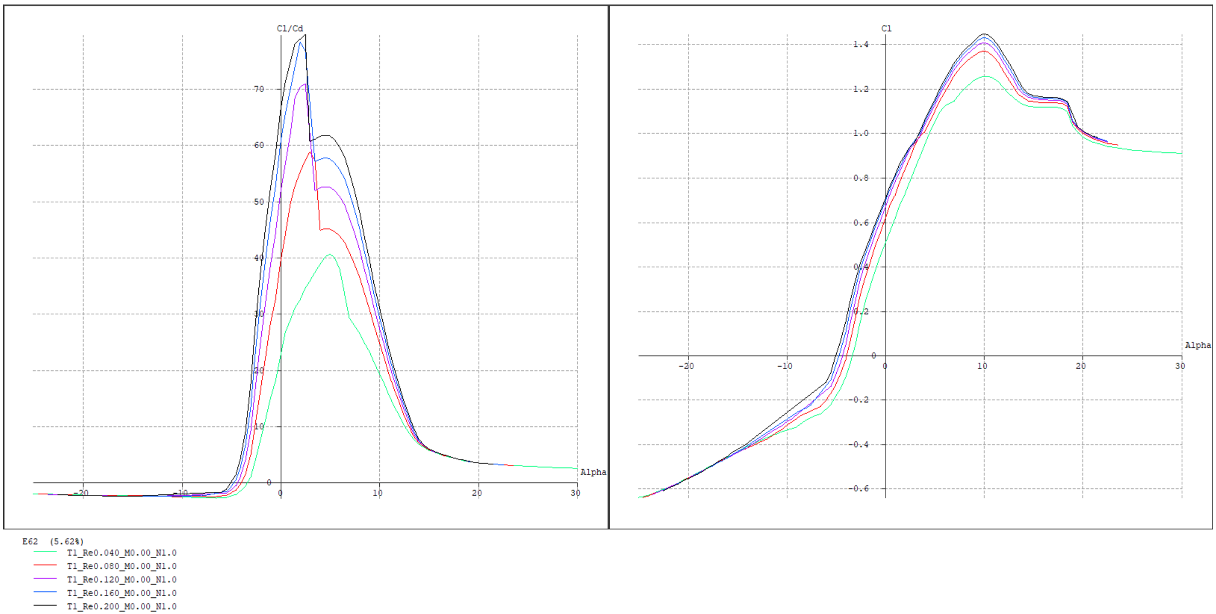

Figure 17: E62 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	65.55
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	7.02
3	$d\alpha_{opt}/dRe$	0.72
4	dE/dRe	11.70
5	$dE/d\alpha(\alpha = \alpha_{opt})$	13.64
6	Thickness t/c	5.60
7	Cl_{opt}	0.95

Table 17: E62 data.

Airfoil 18: RG15

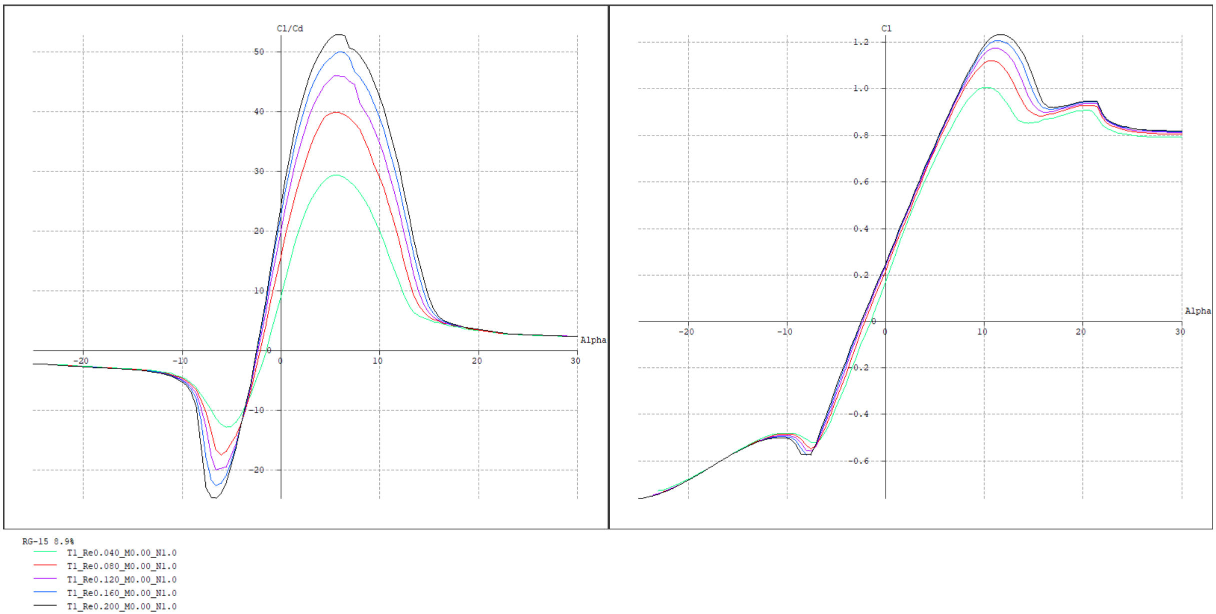

Figure 18: RG15 polar curves.

Code	Parameter	Value
1	Maximum efficiency E	43.48
2	$\Delta\alpha = \alpha_s - \alpha_{opt}$	5.41
3	$d\alpha_{opt}/dRe$	0.25
4	dE/dRe	6.74
5	$dE/d\alpha(\alpha = \alpha_{opt})$	4.66
6	Thickness t/c	8.90
7	Cl_{opt}	1.83

Table 18: RG15 data.

1.1.2 Decision procedure

Summary of the results obtained for each option:

Table 19: Airfoil selection results.

Nº	Airfoil	Parameters						
		1	2	3	4	5	6	7
		E_{max}	$\alpha_s - \alpha_{opt}$	$d\alpha_{opt}/dRe$	dE/dRe	$dE/d\alpha$	$(t/c)_{max}$	Cl_{opt}
1	SG6040	44.11	10.81	0.55	9.86	4.66	16.00	0.87
2	SG6041	42.46	6.02	0.36	7.50	2.14	10.00	0.89
3	SG6042	48.89	9.24	0.64	8.01	2.57	10.00	0.85
4	SG6043	57.73	10.96	0.94	11.87	5.59	10.00	0.97
5	S833	31.13	8.59	0.69	6.32	1.32	18.00	0.75
6	S834	32.30	7.62	0.33	5.96	1.32	15.00	0.69
7	S835	27.96	10.03	0.60	6.00	1.97	21.00	0.67
8	S1210	62.47	6.32	0.31	12.13	4.80	12.00	1.40
9	S1223	55.67	5.63	0.37	10.55	1.44	12.10	1.52
10	S6063	36.78	3.89	0.18	5.36	5.57	7.00	0.67
11	S9037	50.95	6.57	0.09	8.55	2.33	9.00	0.93
12	S3010	48.35	5.97	0.07	8.59	2.45	10.30	0.94
13	SD8000	42.76	5.35	0.06	7.24	2.15	8.90	0.84
14	BW3	45.99	6.27	0.49	5.89	2.96	5.00	1.08
15	E387	56.17	6.85	0.66	10.42	9.22	9.10	0.89
16	E374	44.81	7.98	0.56	7.04	6.69	10.90	0.71
17	E62	65.55	7.02	0.72	11.70	13.64	5.60	0.95
18	RG15	43.48	5.41	0.25	6.74	4.66	8.90	1.83

The results have been normalized using the following expressions. Equation applied to the parameters to be maximized (1, 2, 6, 7):

$$x_i^{norm} = \frac{x_i}{x_{max}} \tag{1}$$

Equation applied to the parameters to be minimized (3, 4, 5):

$$x_i^{norm} = \left(1 - \frac{x_i}{x_{max}}\right) \cdot \frac{1}{x_{max}^{norm}} \tag{2}$$

Table 20: Normalized results.

Parameter number		1	2	3	4	5	6	7	Final
Parameter weight		7	3	1	1	3	3	3	Score
1	SG6040	0.67	0.99	0.44	0.33	0.73	0.76	0.48	14.35
2	SG6041	0.65	0.55	0.66	0.68	0.93	0.48	0.49	13.22
3	SG6042	0.75	0.84	0.34	0.61	0.90	0.48	0.46	14.22
4	SG6043	0.88	1.00	0.00	0.04	0.65	0.48	0.53	14.19
5	S833	0.47	0.78	0.29	0.86	1.00	0.86	0.41	13.62
6	S834	0.49	0.69	0.69	0.91	1.00	0.71	0.38	13.41
7	S835	0.43	0.92	0.39	0.90	0.95	1.00	0.37	13.97
8	S1210	0.95	0.58	0.71	0.00	0.72	0.57	0.76	15.27
9	**S1223**	**0.85**	**0.51**	**0.64**	**0.23**	**0.99**	**0.58**	**0.83**	**15.56**
10	S6063	0.56	0.36	0.86	1.00	0.66	0.33	0.37	10.92
11	S9037	0.78	0.60	0.96	0.53	0.92	0.43	0.51	14.30
12	S3010	0.74	0.54	0.98	0.52	0.91	0.49	0.52	14.04
13	SD8000	0.65	0.49	1.00	0.72	0.93	0.42	0.46	13.21
14	BW3	0.70	0.57	0.51	0.92	0.87	0.24	0.59	13.14
15	E387	0.86	0.62	0.32	0.25	0.36	0.43	0.48	12.27
16	E374	0.68	0.73	0.43	0.75	0.56	0.52	0.39	12.57
17	E62	1.00	0.64	0.25	0.06	0.00	0.27	0.52	11.60
18	RG15	0.66	0.49	0.78	0.80	0.73	0.42	1.00	14.16

Where the score has simply obtained by multiplying the weight of the parameter by its normalized value.

Chapter 2

Structural design