The Gö 711 airfoil modified as the Gö 711-12% airfoil and the Gö 711-10% airfoil for use in windmill rotor blades

ing. A. Kragten

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Engineering office Kragten Design
Populierenlaan 51
5492 SG Sint-Oedenrode
telephone: +31 413 475770
e-mail: info@kdwindturbines.nl
website: www.kdwindturbines.nl

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1 Introduction

In report R443D (ref. 1) of the former Wind Energy Group of the University of Technology Eindhoven, about eighty airfoils are assembled which have been measured for low Reynolds numbers. A problem with this report is that it is probably no longer available and that most of the given airfoil graphs are too small for use in rotor blade calculations. Fortunately the original measuring points are given for almost all airfoils and using these points, new accurate graphs can be made.

Airfoils with a flat lower side are of interest for windmill rotor blades, especially if they are manufactured from massive wood. The Gö 623 airfoil which has a maximum thickness of 12 % of the chord is used in all my present VIRYA-windmills with wooden blades. The characteristics and geometry of this airfoil are given in my report KD 35 (ref. 2).

For the Gö 623 and a lot of other airfoils, the flat lower side starts at 30 % of the chord. This means that the whole upper side and the front part of the lower side is curved. If the blade is made using a rotating cutter it means that one needs a cutter for the upper side and a cutter for the lower side of the airfoil.

For the Gö 711 airfoil, the flat lower side starts at 2.5 % of the chord. This means that no rotating cutter is required for the lower side of the airfoil because the little rounding off can be easily done by hand. The Gö 711 airfoil is rather thick (the maximum thickness is 14.85 % of the chord) and the lift coefficient at a certain angle of attack α is therefore a lot higher than for the Gö 623 airfoil. The maximum lift coefficient ($C_{l\ max}$ = 1.5) is even higher than for the Gö 624 airfoil which has a maximum thickness of 16 % of the chord. The minimum C_d/C_l ratio is very low for the given Reynolds number which means that a rotor with a high maximum C_p value can be realised. The minimum C_d/C_l ratio is about 0.015 for C_l = 0.97 corresponding with α = 3.7°.

A disadvantage is that the Gö 711 airfoil has only been measured for a rather high Reynolds number of $4 * 10^5$. Therefore it is advised not to use it for rotor blades with small chords for which the critical Reynolds values at low wind speeds are lower than about $3 * 10^5$.

The Gö 711 airfoil is not very well known probably because it has only been published by F. W. Riegels in Aerodynamische Profile (ref. 3). Probably it is never used for windmill rotor blades. The Gö 711 airfoil is described in my report KD 285 (ref. 4).

At this moment I am designing a rotor with blades which are made out of aluminium strip. For the available strip sizes it would be nice to use an airfoil with a maximum thickness which is 12 % or 10 % of the chord. For manufacture it is very attractive to use an airfoil like the Gö 711 which has a flat lower side over almost the whole chord. However, the Gö 711 is the only airfoil of its kind and not a member of a range of similar airfoils with varying maximum thickness. So it is decided to modify the Gö 711 airfoil.

2 The Gö 711-12% and the Gö 711-10% airfoil geometry

For the original Gö 711 airfoil, the maximum thickness is 14.85 % of the chord and for the modified Gö 711 airfoil it is 12 % or 10 %. The 12 % modified Gö 711 airfoil is called the Gö 711-12% airfoil and the 10 % modified Gö 711 airfoil is called the Gö 711-10% airfoil. It is decided to multiply all y-values with a factor 12 / 14.85 = 0.8081 for the Gö 711-12% and to multiply all y-values with a factor 10 / 14.85 = 0.6734 for the Gö 711-12%. In table 1 the airfoil geometry of the original Gö 711 is given for a chord of c = 100 mm, copied from page 3-76 of report R 443 D. The distance x is the value from the airfoil nose. The distance y_u is the corresponding value for the upper part of the airfoil. The distance y_l is the corresponding value for the lower part of the airfoil. The calculated values of y_u and y_l for the Gö 711-12% and the Gö 711-10% airfoils are also given in table 1. The airfoil geometry for the Gö 711-12% airfoil, derived from table 1 is given in figure 1. The airfoil geometry for the Gö 711-10% airfoil, derived from table 1 is given in figure 2.

	Gö 711		Gö 711-12%		Gö 711-10%	
x (mm)	y_u (mm)	y_l (mm)	y_u (mm)	y_l (mm)	y_u (mm)	y_l (mm)
0	1.30	1.30	1.051	1.051	0.875	0.875
1.25	4.0	0.02	3.232	0.016	2.694	0.013
2.5	5.45	0	4.404	0	3.670	0
5.0	7.75	0	6.263	0	5.219	0
7.5	9.55	0	7.717	0	6.431	0
10	10.95	0	8.848	0	7.374	0
15	12.90	0	10.424	0	8.687	0
20	14.02	0	11.329	0	9.441	0
30	14.85	0	12.000	0	10.000	0
40	14.6	0	11.798	0	9.832	0
50	13.70	0	11.071	0	9.226	0
60	12.25	0	9.899	0	8.249	0
70	10.4	0	8.404	0	7.003	0
80	8.05	0	6.505	0	5.421	0
90	5.05	0	4.081	0	3.401	0
95	3.24	0	2.618	0	2.182	0
100	1.4	0	1.131	0	0.943	0

table 1 Geometry of the Gö 711 airfoil, the Gö-711-12% and the Gö 711-10% airfoil for a chord c = 100 mm

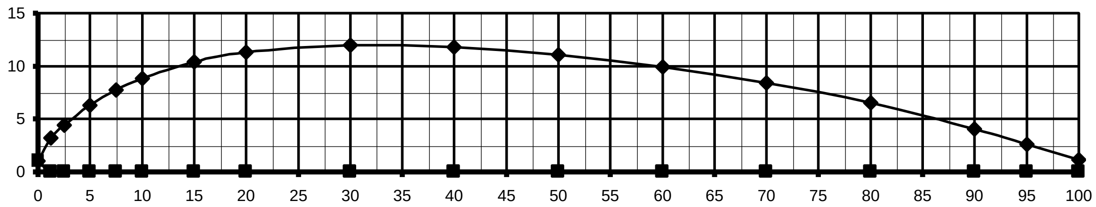

fig. 1 Gö 711-12% airfoil for c = 100 mm

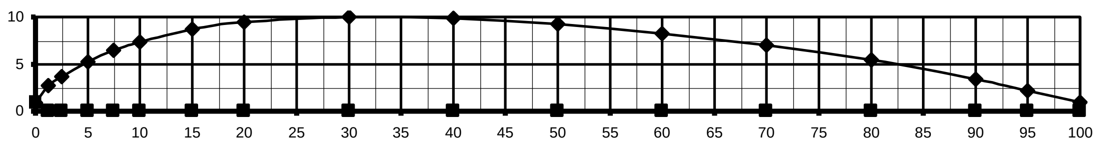

fig. 2 Gö 711-10% airfoil for c = 100 mm

If the real blade chord c is a factor i larger than 100 mm, all the x-values, y-values and corrected y-values of figure 4 have to be multiplied by the same factor i.

3 The Gö 711-12% and the Gö 711-10% airfoil characteristics

The Gö 711-12% and the Gö 711-10% airfoil characteristics have not been measured so they have to be estimated. To see how a different maximum thickness is influencing the characteristics, an airfoil family is selected which is measured for different maximum thickness' and which has a geometry which is as closest as possible similar to the Gö 711. It is chosen for the airfoil family Gö 795, Gö 796, Gö 797 and Gö 798 which have a maximum thickness of respectively 8 %, 12 %, 16 % and 20 %. For this airfoil family, the lower side is flat for 85 % of the chord. All four airfoils have only been measured for $Re = 3.8 * 10^5$. As we are interested in rather thin airfoils, the Gö 798 is not taken into account. The C_l-α curves are given in figure 3. The C_l-C_d curves are given in figure 4. The C_m-α curves are given in figure 5. α is the angle of attack. C_l is the lift coefficient. C_d is the drag coefficient. C_m is the moment coefficient.

The moment coefficient is defined around the quart chord point which is laying on the flat lower side at ¼ of the chord from the nose. The right hand direction is defined positive if the airfoil nose is pointing to the left. So the direction of C_m is such that it is increasing the angle of attack α. However, the moment coefficient is negative which means that in reality, the moment has a tendency to decrease the angle of attack.

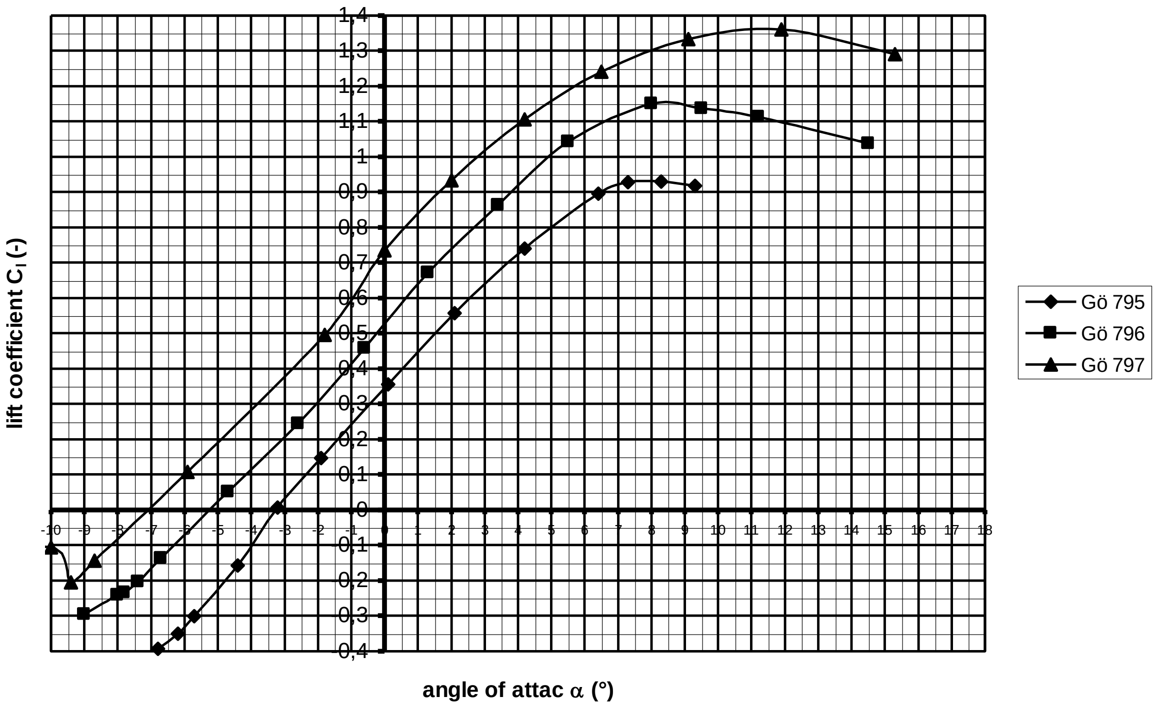

fig. 3 C_l-α curves for the Gö 795, Gö 796 and Gö 797 airfoils for $Re = 3.8 * 10^5$.

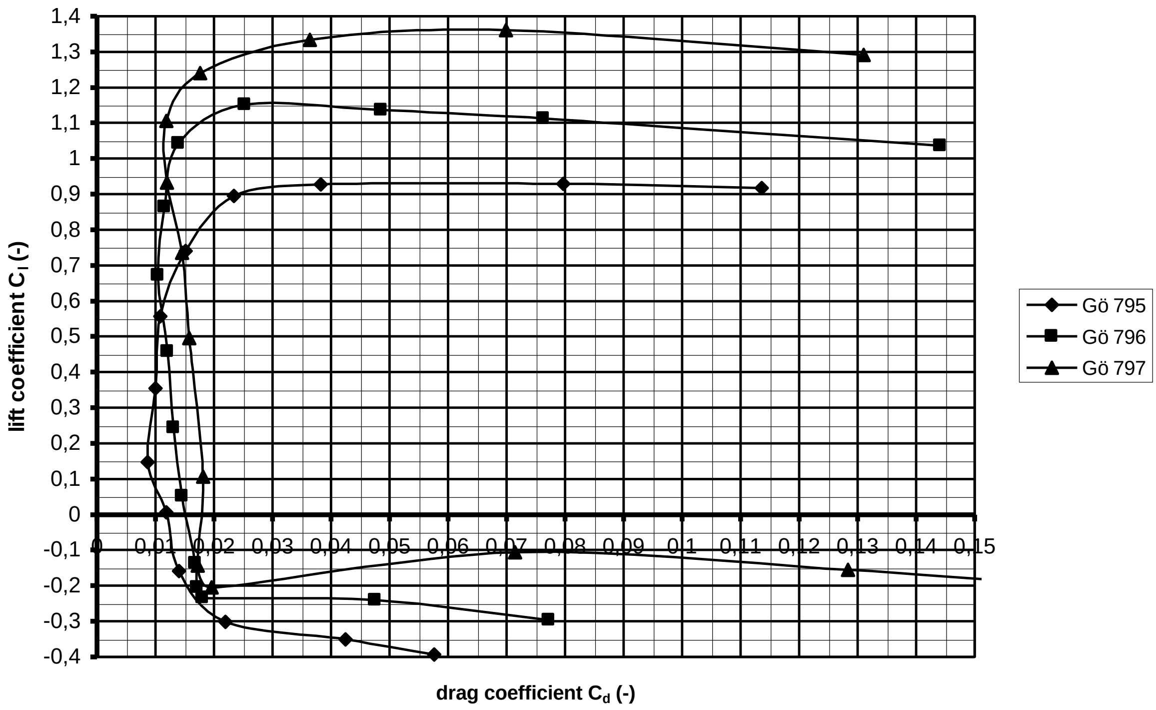

fig. 4 C_l-C_d curves for the Gö 795, Gö 796 and Gö 797 airfoils for Re = 3.8 * 10^5

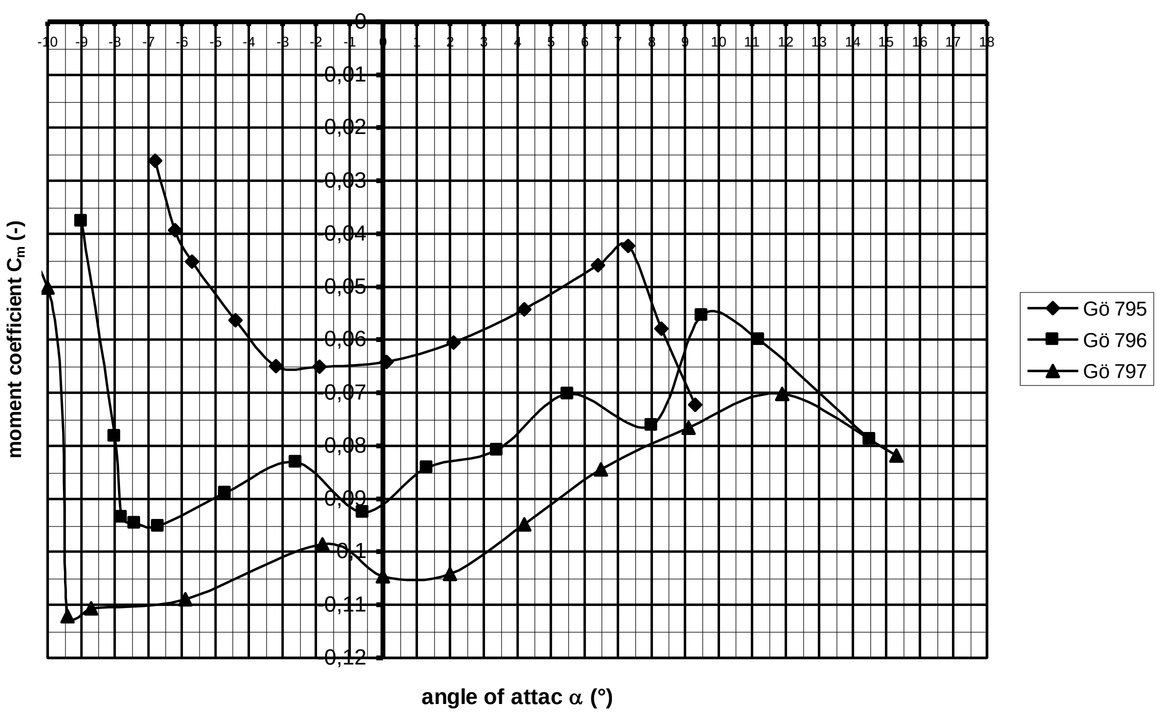

fig. 5 C_m-α curves for the Gö 795, Gö 796 and Gö 797 airfoils for Re = 3.8 * 10^5.

In figure 3 it can be seen that the three C_l-α curves are about parallel for $-7° < \alpha < 7°$. Decrease of the airfoil thickness from 16 % to 12 % results in decrease of the lift coefficient by about 0.18. Decrease of the airfoils thickness from 12 % to 8 % results also in a decrease of lift coefficient by about 0.18. So 1 % reduction of the thickness will result in a decrease of lift coefficient of about 0.045.

The reduction of the thickness of the Gö 711 to the Gö 711-12% is 2.85 % and to the Gö 711-10% is 4.85 %. It is estimated that this results in a decrease of lift coefficient of 2.85 * 0.045 = 0.13 for the Gö 711-12% and of 4.85 * 0.045 = 0.22 for the Gö 711-10%. So the C_l-α curve of the Gö 711-12% is lying 0.13 lower than the C_l-α curve of the Gö 711 and the C_l-α curve of the Gö 711-10% is lying 0.22 lower than the C_l-α curve of the Gö 711.

In figure 4 it can be seen that transformation of one C_l-C_d curve into another is more difficult than for the C_l-α curves because the curves are not similar. The lowest C_d value is obtained for the thinnest airfoil. The 8 % Gö 795 has a minimum C_d value of $C_d = 0.0087$ for $C_l = 0.147$. The 12 % Gö 796 has a minimum C_d value of $C_d = 0.0104$ for $C_l = 0.672$. The 16 % Gö 797 has a minimum C_d value of $C_d = 0.0119$ for $C_l = 1.106$. So for a thin airfoil, the minimum C_d value is gained for a much lower C_l value than for a thick airfoil.

It may be expected that the same minimum value of $C_d = 0.0104$ for $C_l = 0.672$ as measured for the 12 % Gö 796 is valid for the Gö 711-12%. It may be expected that for a 10 % airfoil a minimum C_d value of about 0.0095 would have been measured for a C_l value of about 0.4. It is assumed that these values are also about realised for the Gö 711-10% airfoil.

To transform the C_l-C_d curves of the Gö 771 into the C_l-C_d curves of the Gö 711-12%, all C_l values are first reduced by 0.13. Next the curve is modified such that the minimum C_d value = 0.0104 and that it is lying at a about a C_l value of 0.672. To transform the C_l-C_d curves of the Gö 771 into the C_l-C_d curves of the Gö 711-10%, all C_l values are first reduced by 0.22. Next the curve is modified such that the minimum C_d value = 0.0095 and that it is laying at a about a C_l value of 0.4.

In figure 5 it can be seen that the moment coefficient for thinner airfoils is lying higher than for thicker airfoils. But the curves are not horizontal lines like it is the case for many other airfoils. The Gö 711-12% and Gö-10% airfoils will be used at an average angle of attack of about 3°. So lets look at the C_m-α curves for $\alpha = 3°$. For the 8 % Gö 795, $C_m = -0.058$ for $\alpha = 3°$. For the 16 % Gö 797, $C_m = -0.101$ for $\alpha = 3°$. So the difference in C_m is 0.043 for a difference in thickness of 8 %. So 1 % difference in thickness roughly gives a difference in C_m of 0.043 / 8 = 0.0054.

The Gö 711 and the Gö 711-12% have a difference in thickness of 2.85 %. The difference in C_m will therefore be about 2.85 * 0.0054 = 0.015. So the C_m-α curve of the Gö 711-12% will lie about 0.015 higher than the C_m-α curve of the Gö 711. The Gö 711 and the Gö 711-10% have a difference in thickness of 4.85 %. The difference in C_m will therefore be about 4.85 * 0.0054 = 0.026. So the C_m-α curve of the Gö 711-10% will lie about 0.026 higher than the C_m-α curve of the Gö 711.

In table 2, the original measuring points of the Gö 711 airfoil characteristics for C_l, C_d and C_m are given which were copied from page 3-74 of report R 443 D. The angle of attack is α (°). The lift coefficient is C_l (-). The drag coefficient is C_d (-). The moment coefficient is C_m (-). The estimated C_l, C_d and C_m values for the Gö 711-12% and Gö 711-10% airfoils are also given in table 2.

	Gö 711			Gö 711-12%			Gö 711-10%		
α (°)	C_l (-)	C_d (-)	C_m (-)	C_l (-)	C_d (-)	C_m (-)	C_l (-)	C_d (-)	C_m (-)
-14.1	-0.173	0.1640	-0.0174	-0.303	0.1640	-0.0024	-0.393	0.1640	0.0086
-11.6	-0.083	0.1275	-0.0350	-0.213	0.1275	-0.0200	-0.303	0.1275	-0.0090
-9.0	0.009	0.0928	-0.0554	-0.121	0.0928	-0.0404	-0.211	0.0928	-0.0294
-6.2	0.070	0.0587	-0.0912	-0.060	0.0587	-0.0762	-0.150	0.0587	-0.0652
-4.2	0.284	0.0299	-0.1236	0.154	0.025	-0.1086	0.064	0.020	-0.0976
-2.2	0.483	0.0165	-0.1174	0.353	0.013	-0.1024	0.263	0.012	-0.0914
0.0	0.665	0.0142	-0.1145	0.535	0.011	-0.0995	0.445	0.0095	-0.0885
2.1	0.843	0.0134	-0.1089	0.713	0.0104	-0.0939	0.623	0.011	-0.0829
4.3	1.019	0.0153	-0.1070	0.889	0.013	-0.0920	0.799	0.014	-0.0810
6.6	1.190	0.0235	-0.1060	1.060	0.020	-0.0910	0.970	0.020	-0.0800
8.8	1.361	0.0297	-0.1061	1.231	0.0297	-0.0911	1.141	0.0297	-0.0801
11.3	1.479	0.0476	-0.1110	1.349	0.0476	-0.0960	1.259	0.0476	-0.0850
14.3	1.478	0.1078	-0.1270	1.348	0.1078	-0.1120	1.258	0.1078	-0.1010
17.8	1.354	0.2090	-0.1460	1.224	0.2090	-0.1310	1.134	0.2090	-0.1200

table 2 C_l, C_d and C_m as a function of α for Gö 711, Gö 711-12% and Gö 711-10% for Re = 4 * 10^5

The measured C_l-α, C_l-C_d and C_m-α curves for the Gö 711 airfoil and the estimated C_l-α, C_l-C_d and C_m-α curves for the Gö 711-12% and Gö-711-10% airfoils are given in figure 6, 7 and 8.

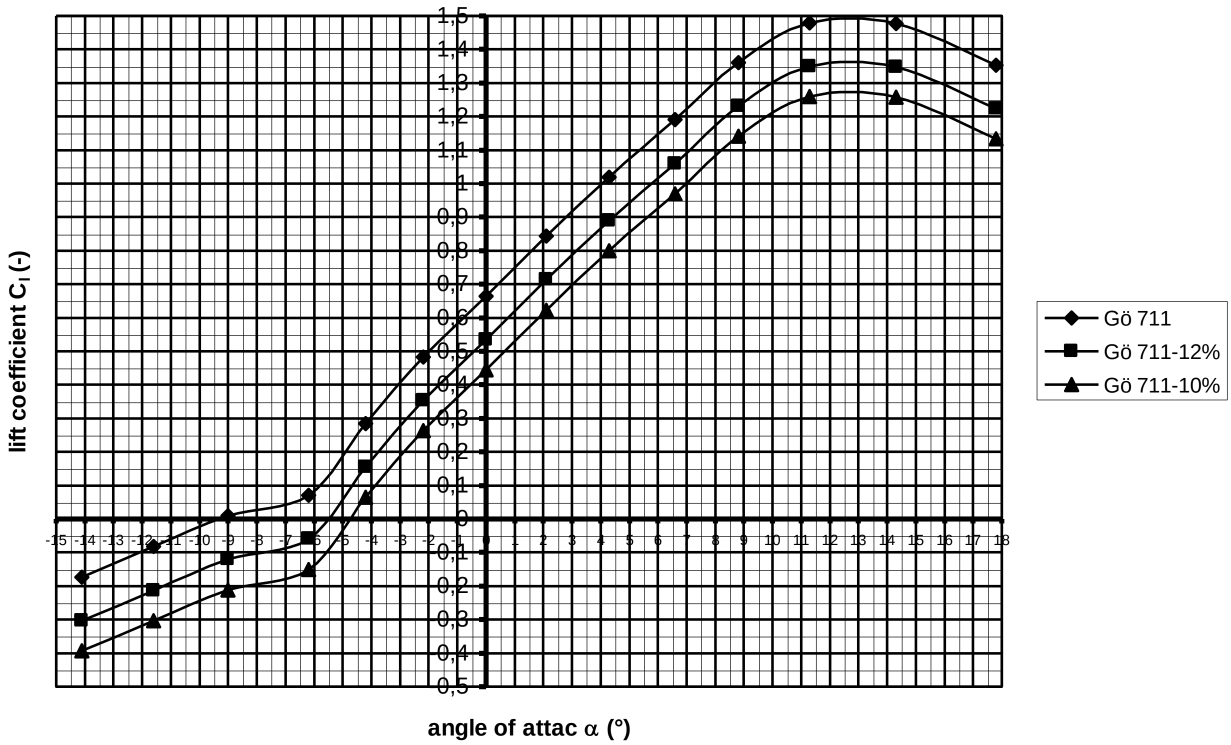

fig. 6 Measured C_l-α curve for the Gö 711 airfoil and estimated C_l-α curve for the Gö 711-12% and Gö 711-10% airfoils for Re = 4 * 10^5

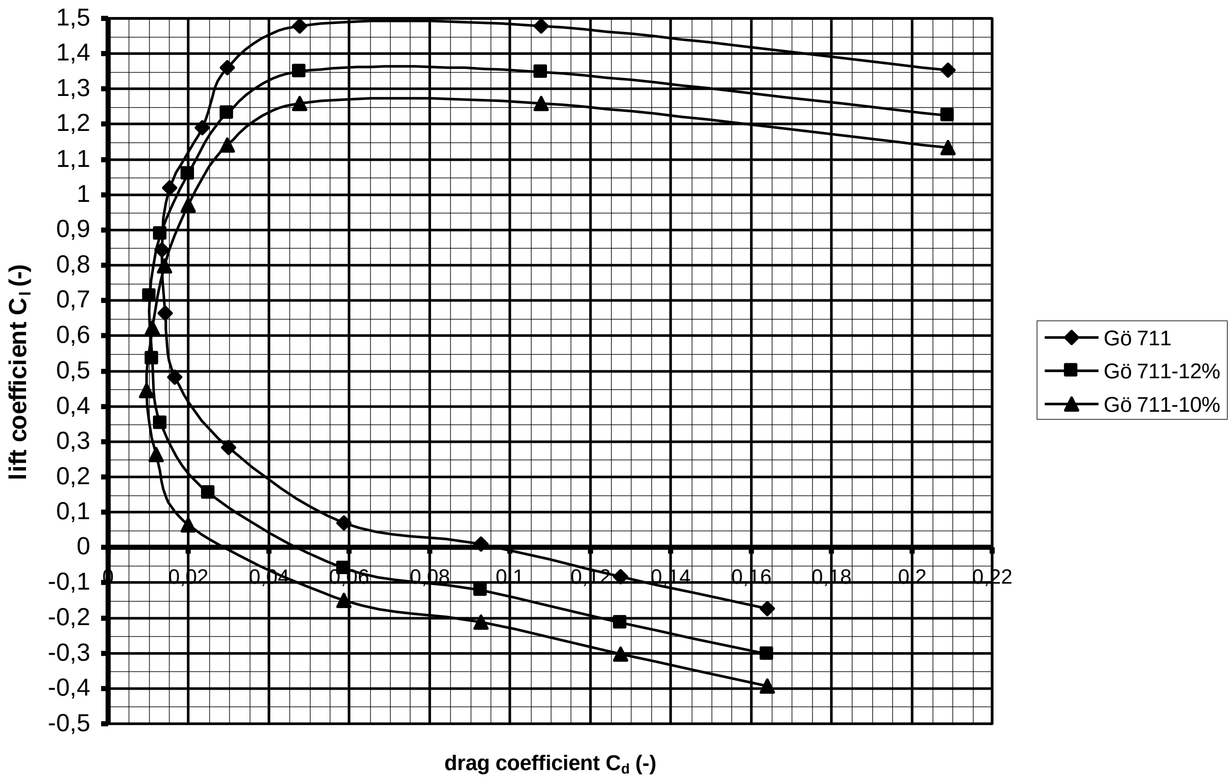

fig. 7 Measured C_l-C_d curve for the Gö 711 airfoil and estimated C_l-C_d curve for the Gö 711-12% and Gö 711-10% airfoils for Re = 4 * 10^5

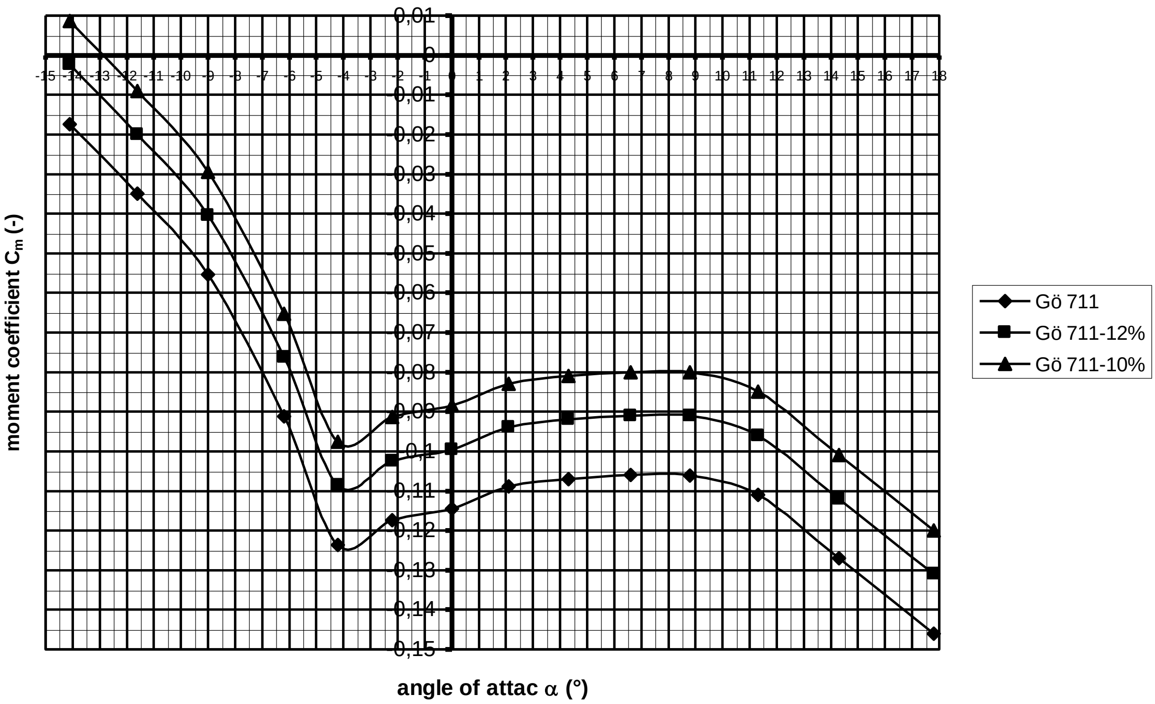

fig. 8 Measured C_l-α curve for the Gö 711 airfoil and estimated C_l-α curve for the Gö 711-12% and Gö 711-10% airfoils for Re = 4 * 10^5

4 Comparing of the Gö 711-12% and the Gö 623

The Gö 711-12% and the Gö 623 have both a maximum thickness of 12 % of the chord. The Gö 623 is used in the present VIRYA windmills with wooden blades. It will now be investigated how much the C_l-α curves of both airfoils differ and if it might be possible to replace the Gö 623 by the Gö 711-12%. The C_l-α curve of the Gö 711-12% and the Gö 623 for Re = 4.2 * 10^5 are both given in figure 9.

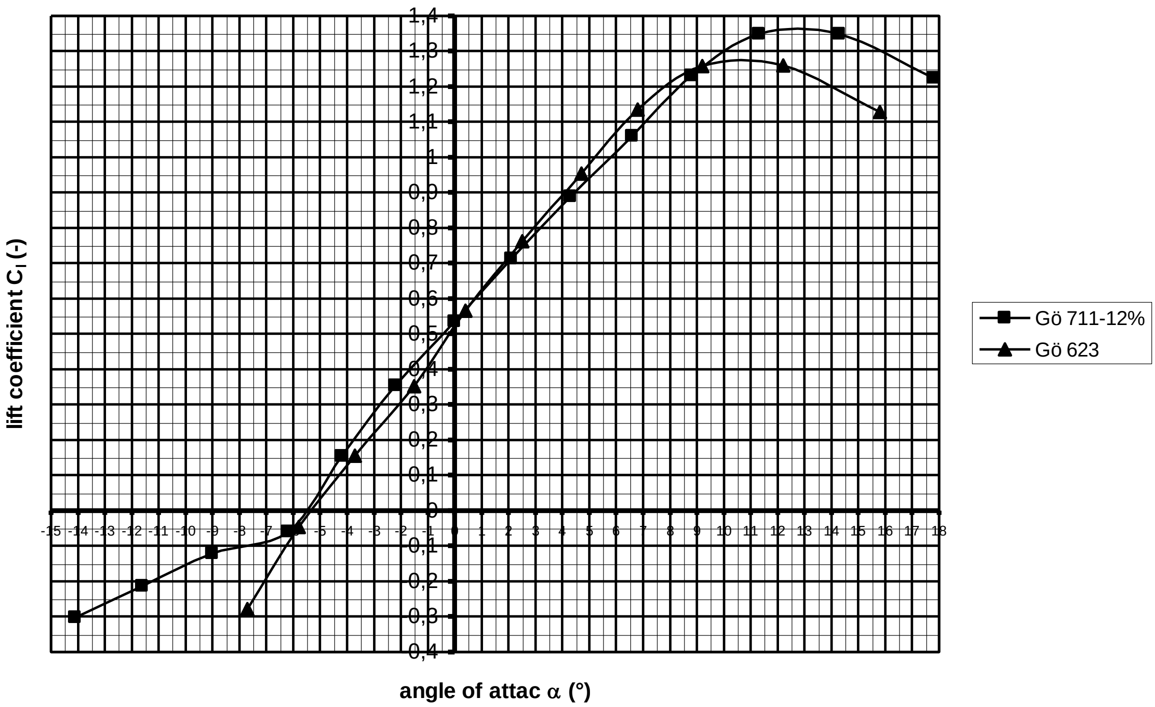

fig. 9 Estimated C_l-α curve for the Gö 711-12% for Re = 4 * 10^5 and measured C_l-α curve for the Gö 623 for Re = 4.2 * 10^5

In figure 9 it can be seen that the C_l-α curves of both airfoils are lying close to each other for angles α in between –6° and 10° which is the region for which the airfoil is normally used. This is an indication that the transferring procedure from the Gö 711 to the Gö 711-12% is correct. The maximum C_l value for the Gö 711 is higher than for the Gö 623 and the maximum value is realised for a higher value of α (about 12.5° in stead of 10.5°). This may be caused by the sharper leading edge of the Gö 711-12% airfoil. So it seems to be acceptable to replace the Gö 623 by the Gö 711-12% without changing of the blade angle β. Using of the Gö 711-12% has as advantage that the lower side of the airfoil needs almost no machining.

5 References

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