The Gö 711 airfoil for use in windmill rotor blades

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June 2006
reviewed September 2022

KD 285

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1 Introduction

In report R443 (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 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 $\alpha = 3.7°$. The moment of resistance W (mm^3) of a blade with a certain chord with a Gö 711 airfoil is more than a factor 1.5 larger than for a blade with a Gö 623 airfoil.

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. But I think it is worth wile to describe and test it because of its special shape and because of its very good aerodynamic characteristics. In report KD 614 (ref. 4) a 2-bladed rotor with wooden blades for the VIRYA-5 windmill is described in which the Gö 711 airfoil is used. However, a rotor blade with the Gö 711 airfoil has not yet been tested by me.

2 The Gö 711 airfoil geometry

In table 1 the airfoil geometry 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 airfoil geometry derived from table 1 (for $y_{u\ corr.}$) is given on scale in figure 1 and not on scale in figure 2.

x (mm)	y_u (mm)	y_l (mm)	$y_{u\ corr.}$ (mm)
0	1.30	1.30	
1.25	4.0	0.02	
2.5	5.45	0	
5.0	7.75	0	
7.5	9.55	0	
10	10.95	0	
15	12.90	0	
20	14.02	0	
30	14.85	0	
40	14.6	0	
50	13.70	0	
60	12.25	0	12.25
70	10.4	0	10.2
80	8.05	0	7.7
90	5.05	0	4.7
95	3.24	0	2.9
100	1.4	0	1.0

table 1 Geometry of the Gö 711 airfoil for a chord c = 100 mm

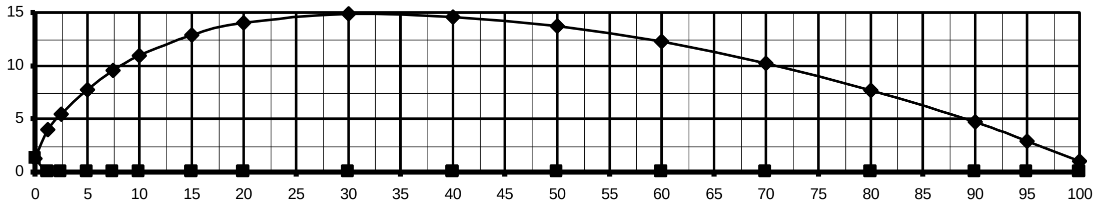

fig. 1 Gö 711 airfoil for c = 100 mm (same scale for x-axis and y-axis)

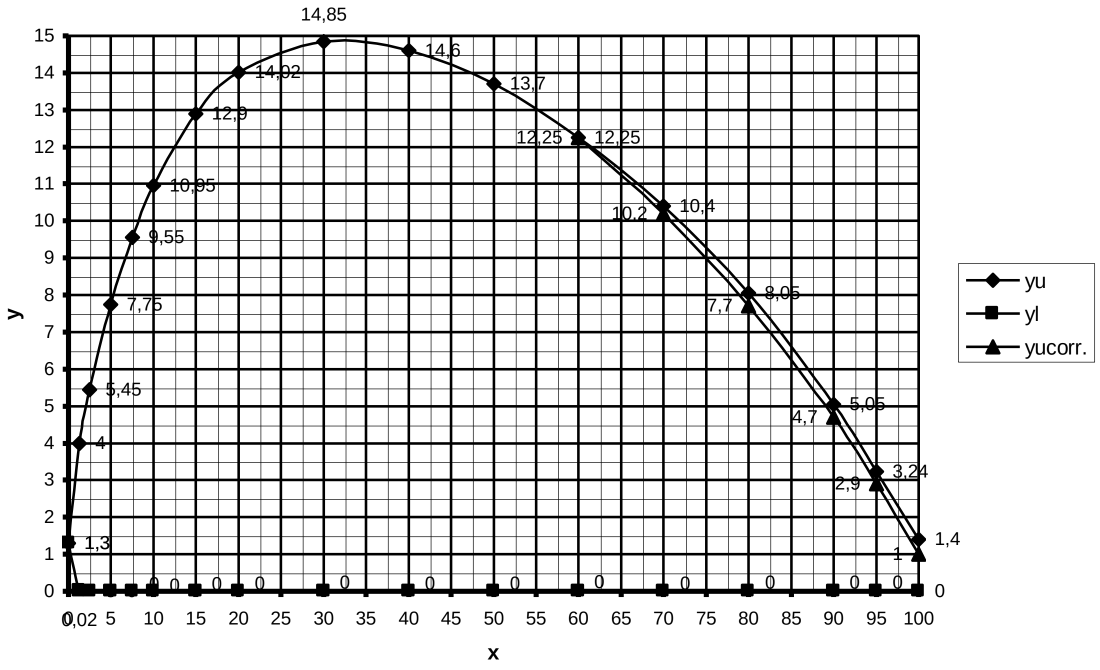

fig. 2 Geometry of the Gö 711 airfoil for c = 100 mm (different scale for x-axis and y-axis)

The airfoil in figure 2 looks extremely thick but this is because of the different scale between the x-axis and the y-axis. This is done to create enough space to place the y-co-ordinates. Figure 1 gives the real shape (for the corrected values of y_u).

The airfoil thickness y_u at x = 100 mm is 1.4 mm. This is much more than for the Gö 623 airfoil where y_u = 0.3 mm or for the Gö 624 airfoil where y_u = 0.5 mm. A large value of y_u for x = 100 mm may result in extra noise production. A certain thickness of the trailing edge is required to prevent damage of the airfoil during manufacture or transport but I expect that y_u = 1 mm is enough. So the airfoil has to be corrected a little near the trailing edge. The corrected values $y_{u\ corr.}$ are also given in figure 2 and table 1. It is expected that this correction has no influence on the characteristics.

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 airfoil characteristics

In table 2, the original measuring points of the Gö 711 airfoil characteristics 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 around the quart chord point is $C_{m0.25}$ (-). The quart chord point is lying at the flat lower side at a distance x = 25 mm from the nose. The direction of moment coefficient is defined clock wise if the nose points to the left side (see figure 7). Because the moment coefficient is negative, it means that the aerodynamic moment is working anti clock wise and therefore it has a tendency to decrease the angle of attack α.

The C_l-α curve, derived from table 2, is given in figure 3. The C_l value for α = -6.2° is very low but it is copied well from the table in report R 443 D. The C_l/C_d curve derived from table 2 is given in figure 4. The C_d-α curve is given in figure 5. The $C_{m0.25}$-α curve is given in figure 6.

α (°)	C_l (-)	C_d (-)	$C_{m0.25}$ (-)
-14.1	-0.173	0.1640	-0.0174
-11.6	-0.083	0.1275	-0.0350
-9.0	0.009	0.0928	-0.0554
-6.2	0.070	0.0587	-0.0912
-4.2	0.284	0.0299	-0.1236
-2.2	0.483	0.0165	-0.1174
0.0	0.665	0.0142	-0.1145
2.1	0.843	0.0134	-0.1089
4.3	1.019	0.0153	-0.1070
6.6	1.190	0.0235	-0.1060
8.8	1.361	0.0297	-0.1061
11.3	1.479	0.0476	-0.1110
14.3	1.478	0.1078	-0.1270
17.8	1.354	0.2090	-0.1460

table 2 C_l, C_d and C_m as a function of α for Re = $4 * 10^5$

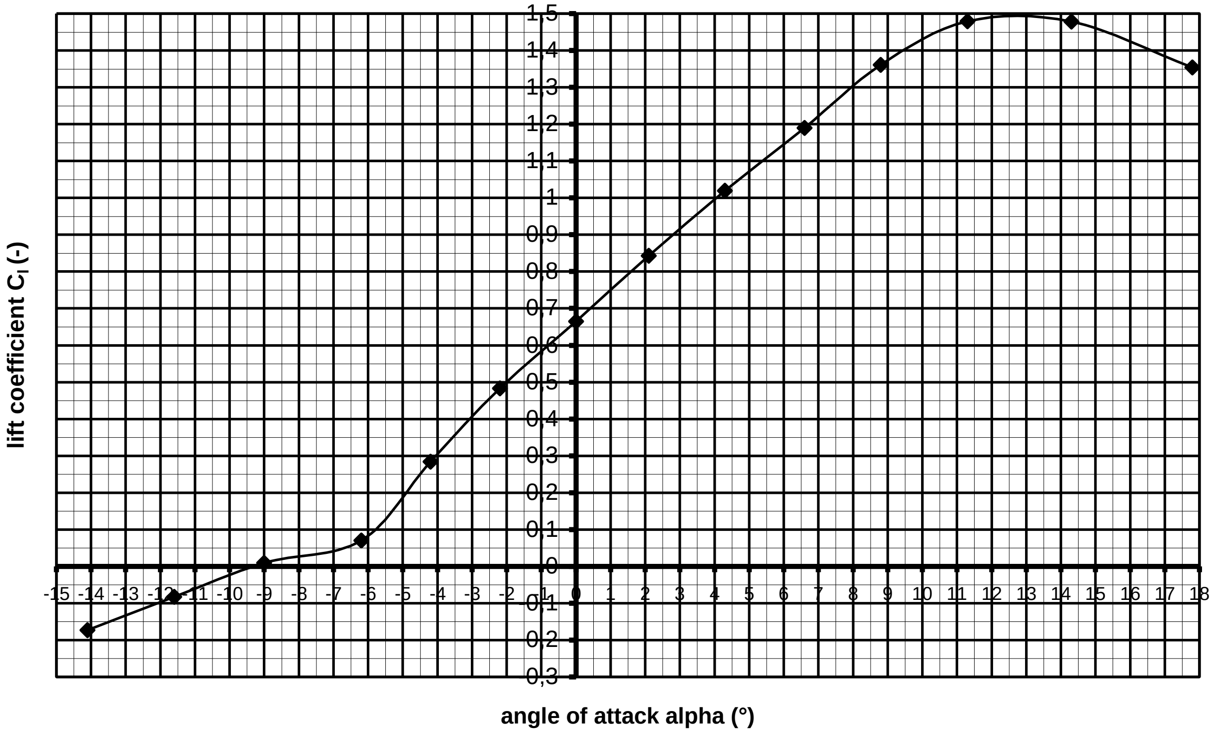

fig. 3 C_l-α curve for Gö 711 airfoil for Re = 4 * 10^5.

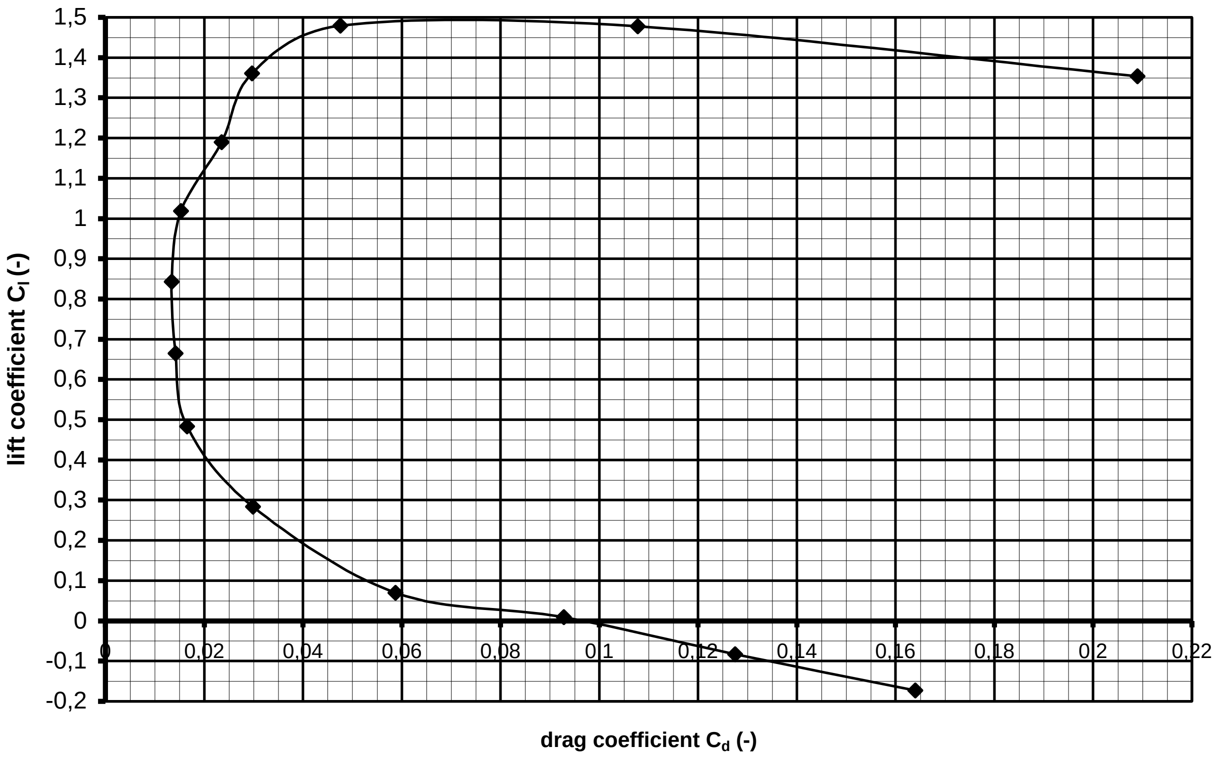

fig. 4 C_l-C_d curve for the Gö 711 airfoil for Re = 4 * 10^5.

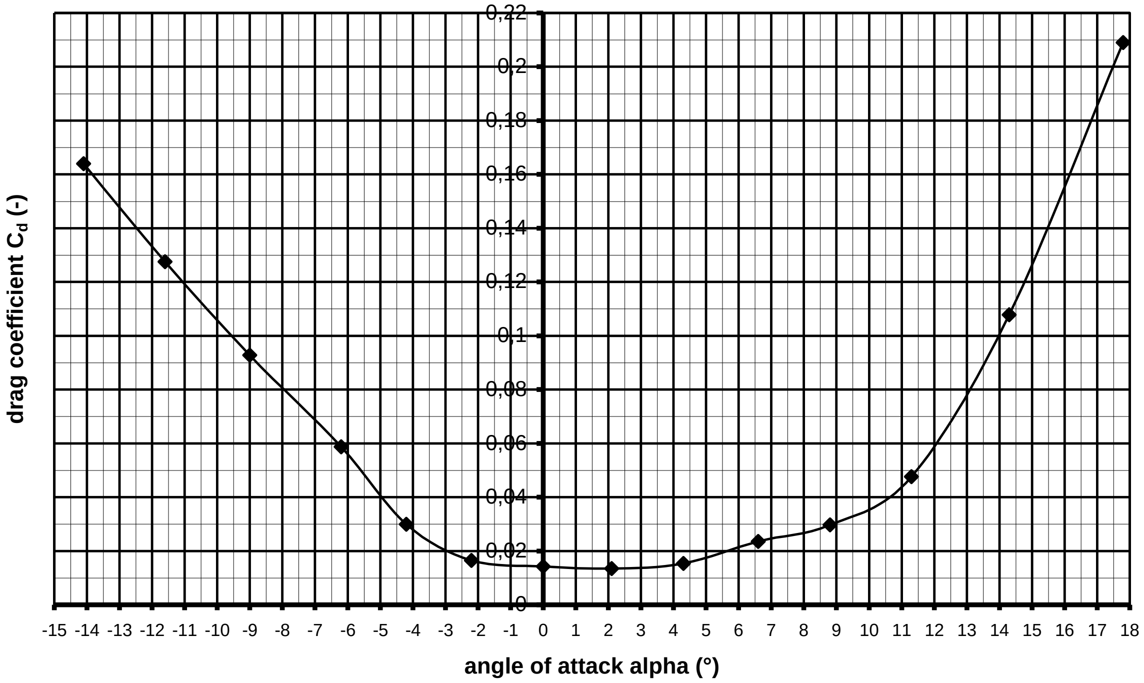

fig. 5 C_d-α curve for Gö 711 airfoil for Re = $4 * 10^5$.

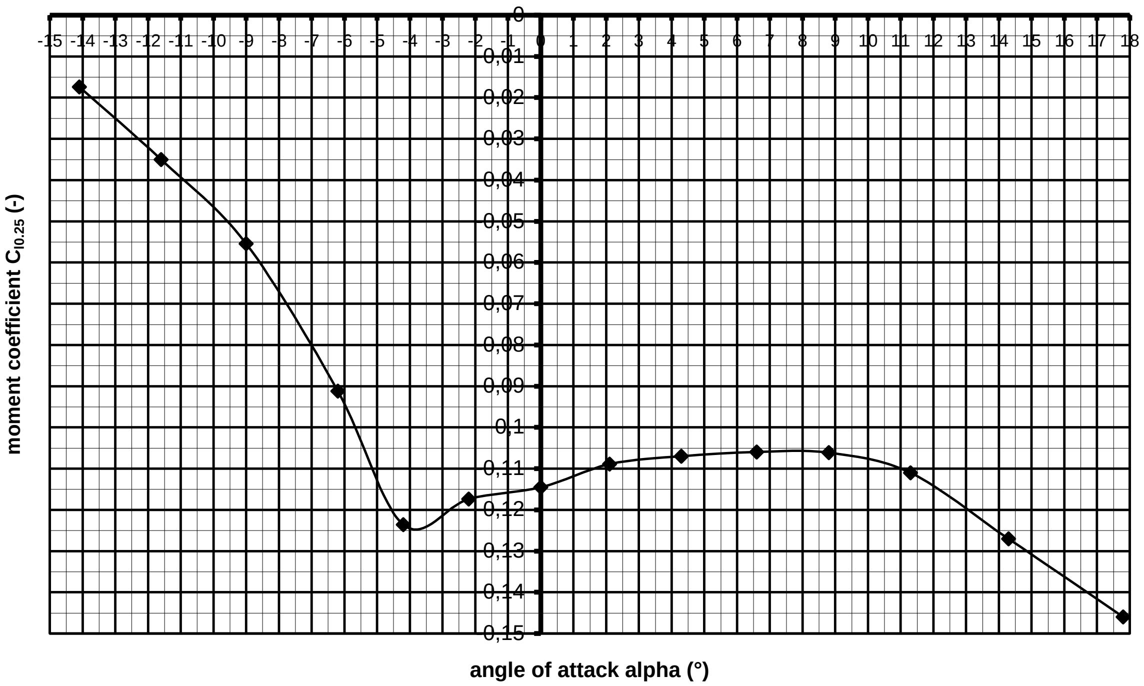

fig. 6 $C_{m0.25}$-α curve for Gö 711 airfoil for Re = $4 * 10^5$

4 The moment coefficient around a point H

For pitch control systems, one often wants to know the moment coefficient around another point H than the quart cord point. Point H is lying at a distance p from the quart chord point and the line through the quart chord point and point H makes a right hand angle γ with the flat lower side of the airfoil (see figure 7). The quart chord point is lying at the flat lower side.

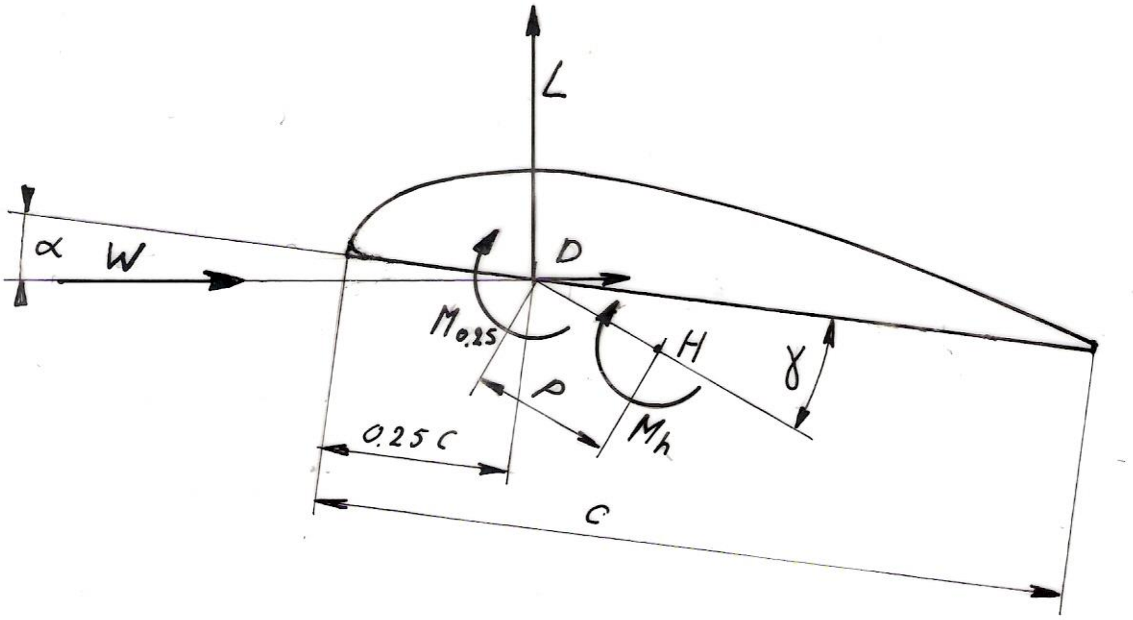

fig. 7 L, D, $M_{0.25}$ and M_h around point H at a distance p from the quart chord point

It can be proven that the moment coefficient around point H, C_{mh} is given by:

$$C_{mh} = C_{m0.25} + p/c \, \{C_l \cos(\alpha + \gamma) + C_d \sin(\alpha + \gamma)\} \qquad (-) \qquad (1)$$

A pitch control system needs a shaft around which the blade can rotate. A logic place for the shaft axis is at the thickest part of the blade and just half way the blade thickness. Assume that this point is taken as point H.

The thickest part of the blade lies at a distance 0.3 * c from the nose (see table 1 and figure 1). So H lies at an x-distance 0.05 * c at the right side of the quart chord point. The blade has a maximum thickness of 0.1485 * c (see table 1). So point H lies at an y-distance of 0.5 * 0.1485 * c = 0.07425 * c above the flat lower side. Point H is given in figure 8.

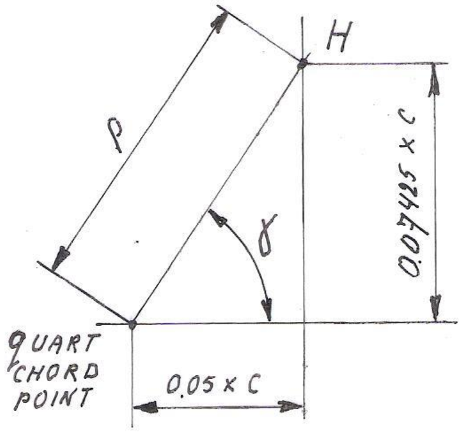

figure 8 Point H lying at 0.05 * c right and at 0.07425 * c above the quart chord point

Using figure 8, it can be calculated that $p = 0.0895 * c$ and that $\gamma = -56°$. γ is negative as the right hand direction of γ with respect to the flat lower side is defined positive. So $p/c = 0.0895$. The moment coefficient around this point is called $C_{mh0.3}$. Substitution of $p/c = 0.0895$, $\gamma = -56°$ and $C_{mh} = C_{mh0.3}$ in formula 1 gives:

$$C_{mh0.3} = C_{m0.25} + 0.0895 \{C_l \cos(\alpha - 56°) + C_d \sin(\alpha - 56°)\} \quad (-) \qquad (2)$$

Another logic place for the shaft axis is at an x-distance of 0.35 * c from the nose just half way the maximum thickness of the blade. So the y-distance is also 0.07425 * c. The values of p and γ can now be determined in the same way but now the x-distance in between the quart chord point and point H is 0.1 * c. This gives $p = 0.1246 * c$ and $\gamma = -36.6°$. So $p/c = 0.1246$. The moment coefficient around this point is called $C_{mh0.35}$. Substitution of $p/c = 0.1246$, $\gamma = -36.6°$ and $C_{mh} = C_{mh0.35}$ in formula 1 gives:

$$C_{mh0.35} = C_{m0.25} + 0.1246 \{C_l \cos(\alpha - 36.6°) + C_d \sin(\alpha - 36.6°)\} \quad (-) \qquad (3)$$

Table 2 is now copied as table 3 but columns for the calculated values of α - 56°, α - 36.6°, $\{C_l \cos(\alpha - 56°) + C_d \sin(\alpha - 56°)\}$, $\{C_l \cos(\alpha - 36.6°) + C_d \sin(\alpha - 36.6°)\}$, $C_{mh0.3}$ and $C_{mh0.35}$ are added for the chosen two points of H.

α (°)	C_l (-)	C_d (-)	$C_{m0.25}$ (-)	(α – 56°)	(α – 36.6°)	$\{C_l \cos(\alpha - 56°) + C_d \sin(\alpha - 56°)\}$	$\{C_l \cos(\alpha - 36.6°) + C_d \sin(\alpha - 36.6°)\}$	$C_{mh0.3}$ (-)	$C_{mh0.35}$ (-)
-14.1	-0.173	0.1640	-0.0174	-70.1	-50.7	-0.2131	-0.2365	-0.0365	-0.0469
-11.6	-0.083	0.1275	-0.0350	-67.6	-48.2	-0.1495	-0.1490	-0.0484	-0.0536
-9.0	0.009	0.0928	-0.0554	-65.0	-45.6	-0.0803	-0.0600	-0.0626	-0.0629
-6.2	0.070	0.0587	-0.0912	-62.2	-42.8	-0.0193	0.0115	-0.0929	-0.0898
-4.2	0.284	0.0299	-0.1236	-60.2	-40.8	0.1152	0.1954	-0.1133	-0.0992
-2.2	0.483	0.0165	-0.1174	-58.2	-38.8	0.2405	0.3661	-0.0959	-0.0718
0.0	0.665	0.0142	-0.1145	-56	-36.6	0.3601	0.5254	-0.0823	-0.0490
2.1	0.843	0.0134	-0.1089	-53.9	-34.5	0.4859	0.6871	-0.0654	-0.0233
4.3	1.019	0.0153	-0.1070	-51.7	-32.3	0.6195	0.8531	-0.0516	-0.0007
6.6	1.190	0.0235	-0.1060	-49.4	-30.0	0.7566	1.0188	-0.0383	0.0209
8.8	1.361	0.0297	-0.1061	-47.2	-27.8	0.9029	1.1901	-0.0253	0.0422
11.3	1.479	0.0476	-0.1110	-44.7	-25.3	1.0178	1.3168	-0.0199	0.0531
14.3	1.478	0.1078	-0.1270	-41.7	-22.3	1.0318	1.3266	-0.0347	0.0383
17.8	1.354	0.2090	-0.1460	-38.2	-18.8	0.9348	1.2144	-0.0623	0.0053

table 3 C_l, C_d and $C_{m0.25}$ as a function of α for $Re = 4 * 10^5$. Calculated values of α - 56°, α - 36.6°, $\{C_l \cos(\alpha - 56°) + C_d \sin(\alpha - 56°)\}$, $\{C_l \cos(\alpha - 36.6°) + C_d \sin(\alpha - 36.6°)\}$, $C_{mh0.3}$, and $C_{mh0.35}$ for point H according to figure 8

The calculated values of $C_{mh0.3}$ and $C_{mh0.35}$ as a function of α are given in figure 9.

Another logic place for the shaft axis is at an x-distance of 0.25 * c from the nose just half way the maximum thickness of the blade. So the y-distance is also 0.07425 * c. The values of p and γ can now be determined in the same way but now the x-distance in between the quart chord point and point H is zero. This gives $p = 0.07425 * c$ and $\gamma = -90°$. So $p/c = 0.07425$. The moment coefficient around this point is called $C_{mh0.25}$. Substitution of $p/c = 0.07425$, $\gamma = -90°$ and $C_{mh} = C_{mh0.25}$ in formula 1 gives:

$$C_{mh0.25} = C_{m0.25} + 0.07425 \{C_l \cos(\alpha - 90°) + C_d \sin(\alpha - 90°)\} \quad (-) \qquad (4)$$

Another logic place for the shaft axis is lying at an x-distance of 0.23 * c from the nose just half way the maximum thickness of the blade. So the y-distance is also 0.07425 * c. The values of p and γ can now be determined in the same way but now the x-distance in between the quart chord point and point H is -0.02 * c. This gives p = 0.07690 * c and $\gamma = -105.1°$. So p/c = 0.07690. The moment coefficient around this point is called $C_{mh0.23}$. Substitution of p/c = 0.07690, $\gamma = -105.1°$ and $C_{mh} = C_{mh0.23}$ in formula 1 gives:

$$C_{mh0.23} = C_{m0.25} + 0.07690 \{C_l \cos(\alpha - 105.1°) + C_d \sin(\alpha - 105.1°)\} \qquad (-) \qquad (5)$$

Table 2 is now copied as table 4 but columns for the calculated values of α - 90°, α - 105.1°, $\{C_l \cos(\alpha - 96°) + C_d \sin(\alpha - 90°)\}$, $\{C_l \cos(\alpha - 105.1°) + C_d \sin(\alpha - 105.1)\}$, $C_{mh0.25}$, and $C_{mh0.23}$ are added for the chosen two points of H.

α (°)	C_l (-)	C_d (-)	$C_{m0.25}$ (-)	(α – 90°)	(α – 105.1°)	$\{C_l \cos(\alpha - 90°) + C_d \sin(\alpha - 90°)\}$	$\{C_l \cos(\alpha - 105.1°) + C_d \sin(\alpha - 105.1°)\}$	$C_{mh0.25}$ (-)	$C_{mh0.23}$ (-)
-14.1	-0.173	0.1640	-0.0174	-104.1	-119.2	-0.2131	-0.2365	-0.0261	-0.0219
-11.6	-0.083	0.1275	-0.0350	-101.6	-116.7	-0.1495	-0.1490	-0.0430	-0.0409
-9.0	0.009	0.0928	-0.0554	-99.0	-114.1	-0.0803	-0.0600	-0.0623	-0.0622
-6.2	0.070	0.0587	-0.0912	-96.2	-111.3	-0.0193	0.0115	-0.0961	-0.0974
-4.2	0.284	0.0299	-0.1236	-94.2	-109.3	0.1152	0.1954	-0.1274	-0.1330
-2.2	0.483	0.0165	-0.1174	-92.2	-107.3	0.2405	0.3661	-0.1200	-0.1297
0.0	0.665	0.0142	-0.1145	-90.0	-105.1	0.3601	0.5254	-0.1156	-0.1289
2.1	0.843	0.0134	-0.1089	-87.9	-103.0	0.4859	0.6871	-0.1076	-0.1245
4.3	1.019	0.0153	-0.1070	-85.7	-100.8	0.6195	0.8531	-0.1025	-0.1228
6.6	1.190	0.0235	-0.1060	-83.4	-98.5	0.7566	1.0188	-0.0976	-0.1213
8.8	1.361	0.0297	-0.1061	-81.2	-96.9	0.9029	1.1901	-0.0928	-0.1215
11.3	1.479	0.0476	-0.1110	-78.7	-93.8	1.0178	1.3168	-0.0029	-0.1222
14.3	1.478	0.1078	-0.1270	-75.7	-90.8	1.0318	1.3266	-0.1077	-0.1369
17.8	1.354	0.2090	-0.1460	-72.2	-87.3	0.9348	1.2144	-0.1300	-0.1571

table 4 C_l, C_d and $C_{m0.25}$ as a function of α for Re = 4 * 10^5. Calculated values of α - 90°, α - 105.1°, $\{C_l \cos(\alpha - 90°) + C_d \sin(\alpha - 90°)\}$, $\{C_l \cos(\alpha - 105.1°) + C_d \sin(\alpha - 105.1°)\}$, $C_{mh0.25}$, and $C_{mh0.23}$ for point H according to figure 8

The calculated values of $C_{mh0.25}$ and $C_{mh0.23}$ as a function of α are also given in figure 9. In figure 9 it can be seen that the $C_{mh0.3}$-α and $C_{mh0.35}$-α curves deviate strongly from the original $C_{m0.25}$-α curve. The $C_{mh0.35}$-α curve is even positive for 4.4° < α. The main effect is caused by the fact that point H lays further from the airfoil nose in stead of the turning point taken at the quart chord point. The fact that point H lays half way the blade thickness has only a limited effect as it mainly affects the influence of the drag on C_{mh}.

The $C_{mh0.25}$-α curve also differs from the $C_{m0.25}$-α curve as given in figure 6 as $C_{mh0.25}$ is increasing rather strongly for 4° < α < 10°. This effect is mainly caused by the drag.

For a pitch control system it is easy if C_{mh} is about constant for a large α range. It can be seen that the $C_{mh0.23}$-α curve is almost constant. The average value of $C_{mh0.23}$ is about -0.125 for -3° < α < 13° so for a rather large α range of 16°.

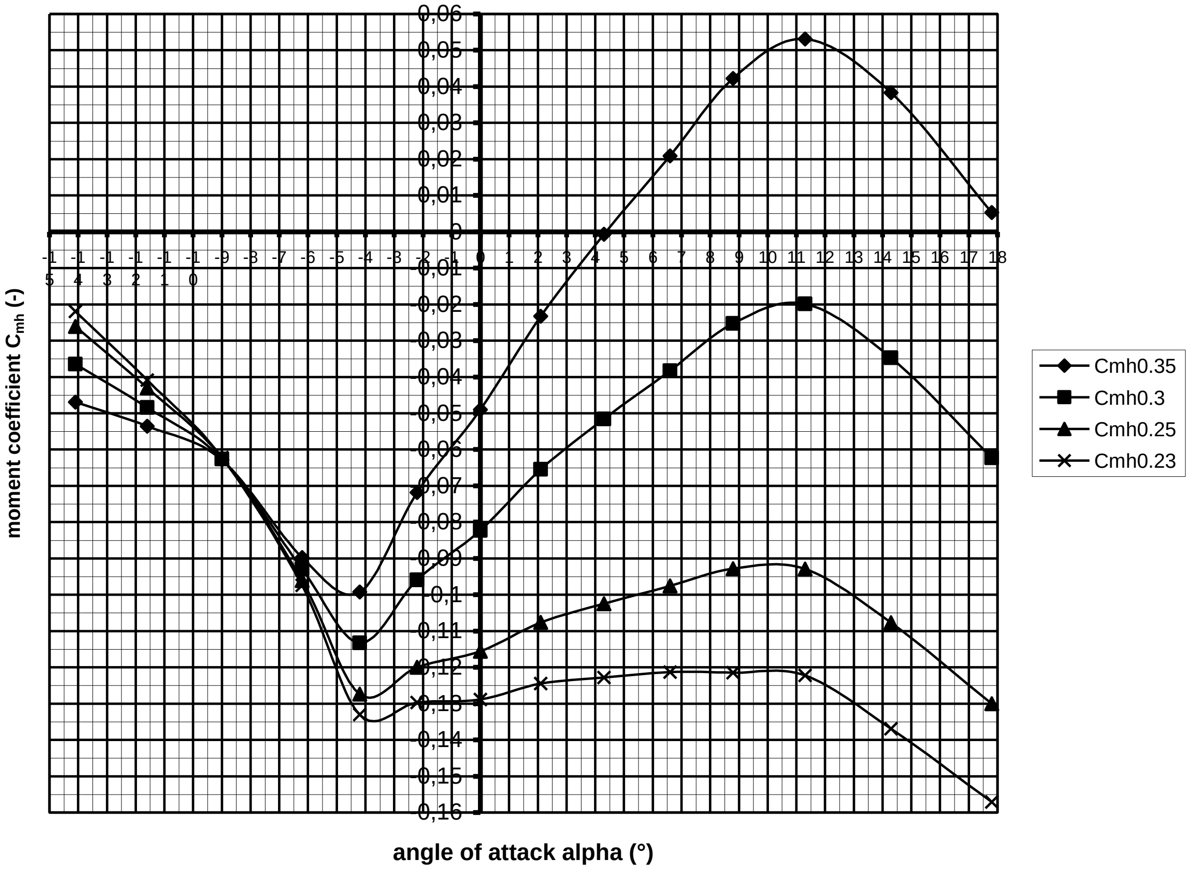

fig. 9 $C_{mh0.35}$-α, $C_{mh0.3}$-α, $C_{mh0.25}$-α and $C_{mh0.23}$-α curves for Gö 711 airfoil for Re = $4 * 10^5$ for point H lying half way the airfoil thickness according to figure 8

5 References

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4 Kragten A. Calculations executed for the 2-bladed rotor of the VIRYA-5 windmill (λ_d = 7, Gö 711 airfoil) meant for the connection to a 34-pole PM-generator for driving the 1.1 kW asynchronous motor of a centrifugal pump. Description of the 34-pole generator, August 2016, reviewed February 2022, public report KD 614, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.