PERIODICA POLYTECHNICA SER. TRANSP. ENG. VOL. 24, NO. 1, PP. 19-27 (1996)

AERODYNAMIC PARAMETER ESTIMATION OF THE CG CONTROLLED AIRPLANES

Tamás GAUSZ

Department of Aircraft and Ships
Technical University of Budapest
H-1521 Budapest, Hungary
Phone: 36 1 463 1795
e-mail: gausz @ PRO2gjt.bme.hu

Received: November 30, 1994

Abstract

The aim of this work is investigation of the air forces and their moments acting on the hang gliders. The hang gliders have elastic and flexible structure so the distribution of the air forces is characterised by the shape of the sail surface and the sail surface is either determined by the air force distribution. This research work is built on the theoretical calculations and practical measurings. The results of this investigation can be applied principally to flight mechanical calculations of the hang gliders.

Keywords: hang-glider, elastic deformation, load distribution.

1. Introduction

Well known that the hang-gliders have elastic and flexible structure. The load distribution of the air forces is characterised by shape of the sail surface and sail surface is also determined by the air forces distribution . The aim of this work is investigation of the air forces and their moments as a function of the load factor in steady case.

This research work is built on the theoretical calculations and practical measurings. The vortex panel method for the profiles – completed with the ground phenomena of fluid friction (given in [1] and [5]) and the advanced vortex line theory for the finite wings [2],[5] was applied in the theoretical part.

The measuring was executed on a concrete hang-glider type. During it we measured the hang-force of the pilot and the bending moment of the wing bar (near to the connecting point of the cross tube and the wing bar).

2. The Measurements and its Results

The measuring was executed during the flight on the third generation of hang-gliders. The geometrical characteristics shown in *Table 1* refer to the

Table 1.

y	h	α
0	2.679	α+1.05
1.7	2.333	α+1.92
2.555	1.843	α+2.62
3.41	1.642	α+2.62
4.16	1.469	α+1.74
4.9	1.181	α−0.87
5.39	0	0
[m]	[m]	[deg]

normal flight state. Here the y is a spanwise coordinate, h is the chord length and α is the angle of attack.

The normal flight state means that the resultant air force is equal to the weight (G=940 N) and of course the load factor (n) is equal to one.

Distribution of the angle of attack is a very important function. In the next calculations we will follow its varying. For determination the function we used the method of the least squares. The distribution can be approximated by the next polynom:

$$\alpha = a + b|y| + c|y|^2 + d|y|^3. \tag{1}$$

The resultant air force is equal to weight. From this condition we can determine the values of the polynom coefficients:

$a = 0.155000;$
$b = 0.010025;$
$c = 0.009457;$
$d = -\ 0.00249.$

As it is mentioned above the hang-force of the pilot and the bending moment of the wing bar were registrated. The hang-force was translated in a time by 0.998 seconds and its magnitude was transformated. One part of the results along with the beam moment are shown on *Fig. 1*.

It can be established that the covering is suitable. During total measuring time the correlation between two curves is 70.4%. It has been found that the wing bar's bending moment depends a lot on the hang-force. Naturally the other parameters influence this moment too, but fundamentally it is function of the hang-force.

Averaging some suitable intervals of the measurements we have found only two pairs of values (the mean values of the hang-force and the bending moment characterize the different flight states):

(940 N; 208 Nm)
(1756 N; 270 Nm)

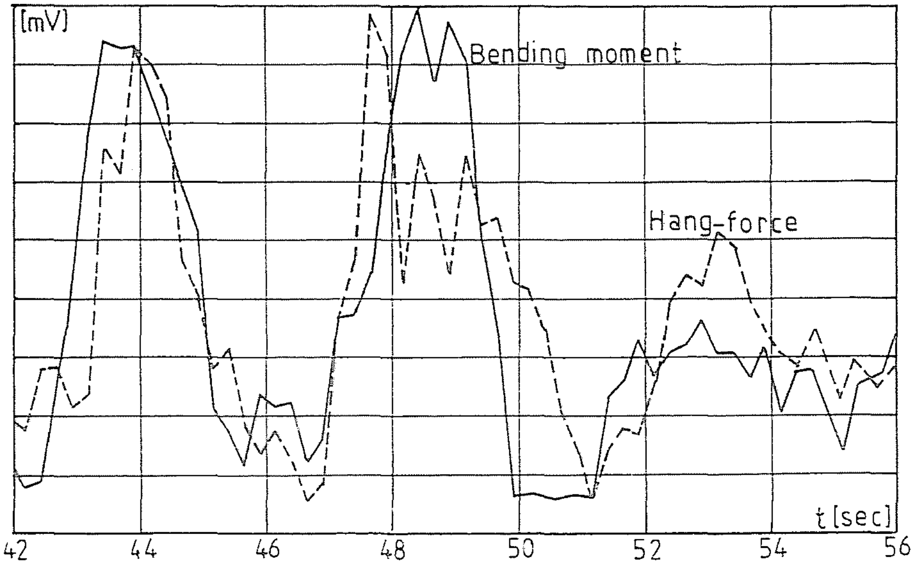

Fig. 1. Bending moment and hang-force

The first one is connected to the normal flight state when the load factor (n) is equal to one. In the second one the load factor is 1.87.

Because of a quite short measuring time it was impossible to choose much more steady considered pairs.

From the previous investigations [3] it can be declare that the maximum hang force is 2317 N with a confidence limit of 99.99%.

Presuming that the bending moment increases as a linear function of the hang force (this assumption gives us higher safety) we will get the maximum bending moment of 310 Nm. So safety coefficient of the braking will be equal to 1.92 .

3. Theoretical Investigations

During the theoretical investigation the first step was parameter identification for the steady flight state (940 N, 208 Nm).

The investigated hang-glider is built from similar profiles, only the chord length and the angle of attack of profiles varies with the wing span, as it is shown in *Table 1.* The profile characteristics are calculated by the advanced vortex panel method [1]. The profile is represented in *Fig. 2.*

The calculated lift-, drag- and moment coefficient - as a function of the angle of attack - are shown in *Table 2.*

It should be noted also that at the angle of attack about 8 degrees

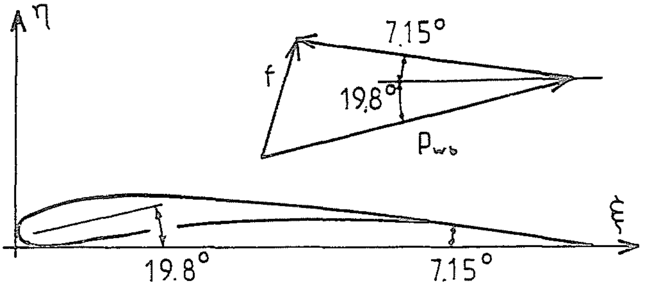

Fig. 2. Wing profile

Table 2.

α	c_L	c_D	c_m
−4	0.05	0.0247	−0.0573
−2	0.279	0.0168	−0.0568
0	0.5	0.0129	−0.0559
2	0.726	0.0058	−0.0546
4	0.95	0.0135	−0.0530
6	1.174	0.0203	−0.0511
8	1.397	0.0315	−0.0488
[deg]	[–]	[–]	[–]

the separation has just begun, thus it gets us the upper limit of the profile calculations.

In the ground load case (n=1) – for the given profile parameters – the lift distribution of spanwise can be calculated by using method [2]. Thus the lift coefficient for each profile of the wing would be found. With knowledge of the lift coefficient the pressure distribution of the chordwise and the resulting force of it can be calculated :

$$\mathbf{f} = \int p\,\mathrm{d}\mathbf{A}; \qquad \text{where} \qquad \mathbf{f} = (\,f_\xi\,)\,f_\eta$$

and p – pressure distribution;
f_ξ – force component in ξ-direction;
f_η – force component in η-direction;
ΔA – wing section surface.

Assuming that the reaction forces at the leading and trailing edge are tangential to the sail (the tangential direction is given in *Fig. 2*) the bending load distribution along the wing bar can be determined:

$$p_{wb} = [0.3108\ 2.089]\mathbf{f}$$

After double integration the result of the bending moment of the wing bar: 207.4 Nm. The measured bending moment tallies with the calculated one excellently.

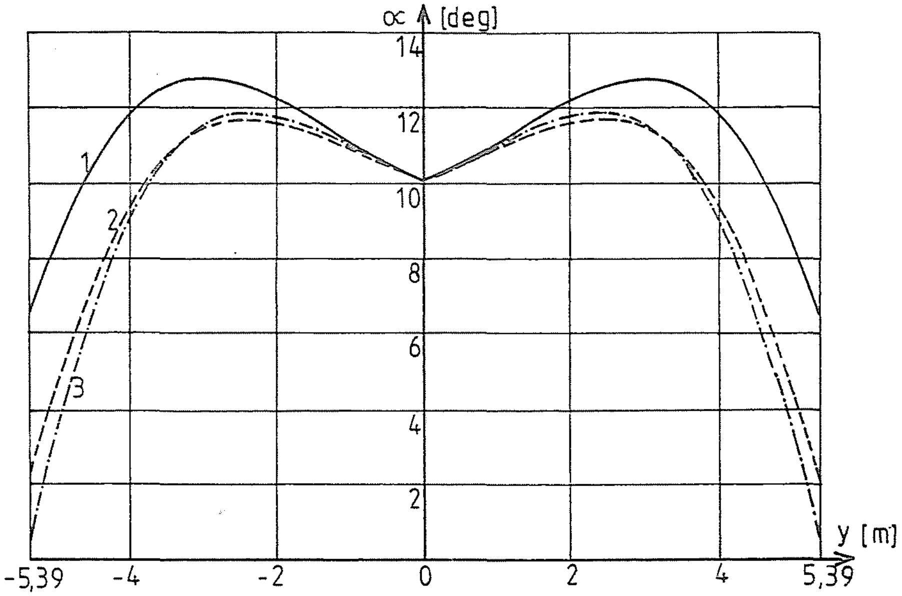

Fig. 3. Angle of attack distribution

The second step of this work is the investigation of the second measured value pair in steady flight state (1756 N, 270 Nm). In calculation a, b, c and d values were variated in such a way that the differences between the resultant air force and the given hang-force as well as the calculated and measured bending moment have to be small enough. The flight speed was chosen in such a way that the a value has to be constant. After calculation we have:

$a =$ 0.155000;
$b =$ 0.010025;
$c =$ 0.006856;
$d =$ −0.00249.

The third extrapolated state (2317 N, 310 Nm, n=2.46) was investigated, too. This is a semi-empirical state. Applying a = const. condition we will get the angle of attack's distribution relatively far from the stall.

Thus the coefficients are:

$$a = 0.15500;$$
$$b = 0.010025;$$
$$c = 0.008511;$$
$$d = -0.00299.$$

Belonging to these three different cases the distribution of the angle of attack is shown in *Fig. 3*.

In favour of the comparison the a values are equal, thus all of the curves have a common point: it is the angle of attack in the symmetry plane.

If the load factor increases then the distribution curve of the angle of attack along the outer part of the wing relatively decreases. It can be declared, too, that the wing by its own deformation reduces the loading on the outer part of the wing.

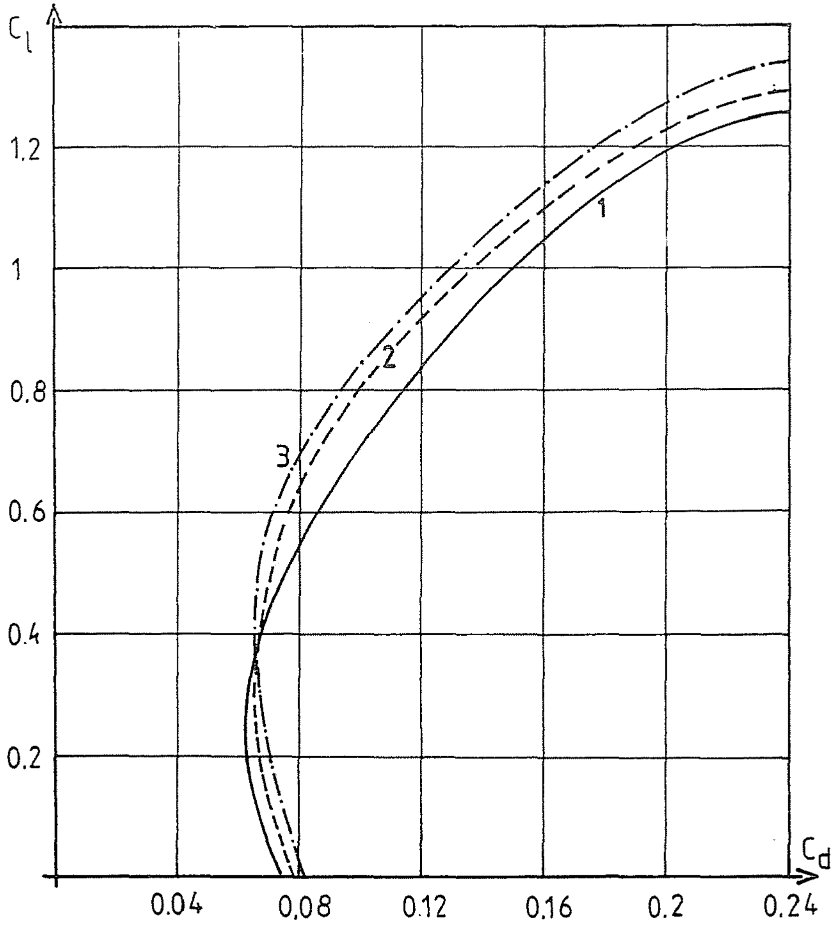

Fig. 4. Polar diagram

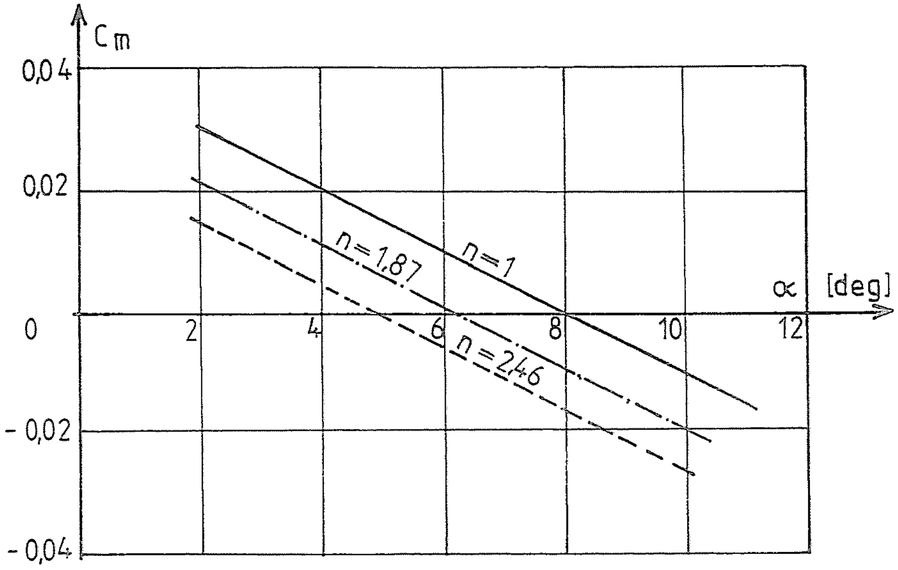

Fig. 5. Calculated moment coefficient

In the investigated interval we can introduce the extension of the angle of attack's distribution:

$$\alpha = a + b|y| + (0.0239 - 0.0208n + 0.063n^2)|y|^2$$
$$+(-0.00388 + 0.00224n - 0.000853n^2)|y|^3$$
$$1 \le n \le 2.46 \qquad (2)$$

By this formula we can calculate the distribution of the angle of attack for a given hang-glider type.

4. Aerodynamical Characteristics

On the grounds of these calculations the aerodynamical properties for a given hang-glider can be estimated as a function of the load factor namely the lift coefficient, the drag coefficient and the moment coefficient. In *Fig. 4* we can see the different polar curves. The first curve is given in [4]. (This is an old approximation.) The second curve was calculated on the grounds of the normal flight state and the third is the polar curve with the load factor equal to 1.87. The polar curve for the load factor of 2.46 is practically the same as the third curve.

The slope of the lift coefficient curve is practically constant. The expression of the lift coefficient of the hang-glider as a function of the load

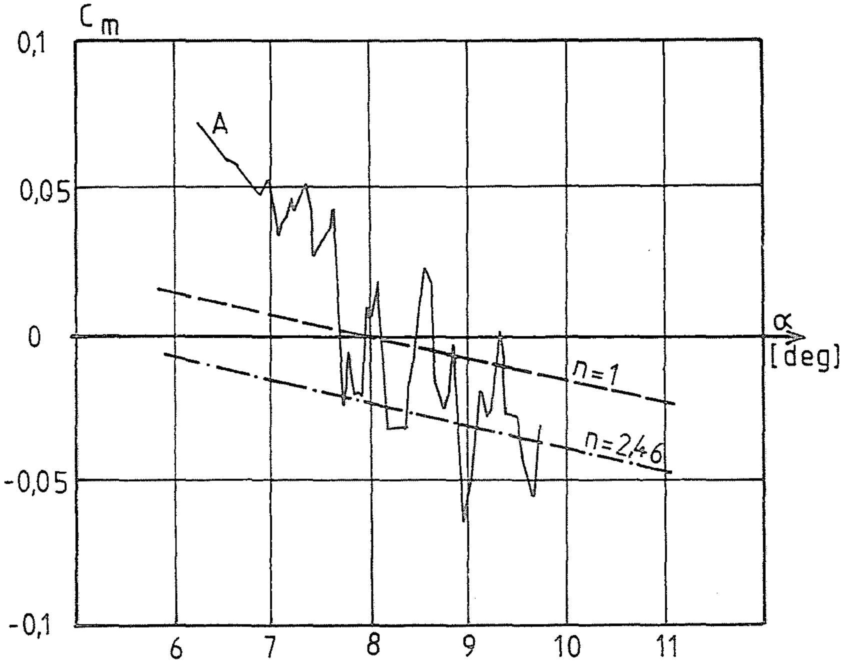

Fig. 6. Identified (A) and calculated moment coefficient

factor and the angle of attack is:

$$c_L = 0.08\alpha + 0.17 - 0.054n \tag{3}$$

$$\text{if} \quad 0 \leq \alpha \leq 0.244$$
$$\text{and} \quad 0 \leq n \leq 2.46$$

The change of the moment coefficient is the most significant and the most interesting thing (see it in *Fig. 5*).

It is very important that the values of the angle of attack at the trim position decrease with the increasing of the load factor. The moment coefficient as a function of the load factor and of the angle of attack (at a given CG position) is:

$$c_m = 0.005\alpha + 0.05052 - 0.01052n \tag{4}$$

$$\text{if} \quad 0 \leq \alpha \leq 0.244$$
$$\text{and} \quad 0 \leq n \leq 2.46$$

This gives us an additional stability. Surely if the hang-glider flies at the angle of attack about 8 degrees and if the disturbance increases the load factor, we would have positive additional moment. This moment decreases the angle of attack, thus the loading would be decreased.

In *Fig. 6* we are comparing the calculated moment coefficients with the identified values of the moment coefficient which can be found in [3]. This curve is marked with 'A'. We can establish a good correlation between these two results. The slope of the mean values of curve 'A' is practically identical with 'n=1' or 'n=2.46' curves. This property characterizes the static stability of the given hang-glider. But a lot of individual points are not between 'n=1' and 'n=2.46' curves, thus the moment coefficient is a function not only of the angle of attack and of the load factor but it depends on other parameters, too – the most important parameter is time derivate of the angle of attack (α).

The results of this calculation can be applied principally to flight mechanical investigation of the hang-gliders.

References

[1] GAUSZ, T.: Investigation and Extension of Validity of Vortex Panel Method Applying to an Airfoil, *Periodica Polytechnica* – in preparation.

[2] GAUSZ, T. Application of Three Dimensional Vortex Theory to the Finite Wings with General Form: *Periodica Polytechnica* – in preparation.

[3] SEREGÉLY, L. – GAUSZ, T.: Siklórepülők repülésmechanikai vizsgálata (Flight Mechanics Investigation of Hang-Gliders – in Hungarian) X. Magyar Repüléstudományi Napok, Szolnok, 1993.

[4] FILKÓ, A.: Siklórepülők repülésmechanikai jellemzőinek vizsgálata (Investigation of Flight Mechanics Characteristics of Hang-Gliders – in Hungarian) Diplomaterv, 1990.

[5] GAUSZ, T.: A felhajtóerő és az indukált ellenállás (Lift and Induced Drag – in Hungarian) BME Areo- és Thermotechnika Tanszék, 1990.