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INFLUENCE OF WING TIP SHAPE ON LONGITUDINAL STABILITY OF GLIDER AIRPLANE MODEL

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Abstract: *There were analyzed four different wing tip shapes. The coefficient of restoration, CR, is given by the ratio of the largest half wing to the smaller half wing in horizontal projection. Flight is stable for CR = 1.00. The influence of wing thickness profile is high. Increasing in the thickness from 5 mm to 15 mm (3 times), CR increases by 48% (5 mm) and 34% (15 mm). Increasing tilt angle, γ, CR increases from 1.00 to ∞ for γ = 0^o, respectively, 80^o (α = 10 °) (α - angle of the wing tip to the horizontal), then jump to -∞ and grow with negative values. CR increase from 1.00 to ∞ jumping to -∞ for γ = 60°, with α = 30°. Sideslip occurs when model aircraft has horizontally the longitudinal axes and wing is verticals. Airplane model is in an unstable area, for γ = 80^o, respectively, 60^o for α = 10^o, respectively, 30^o. The wing tip should be made of straight lines not rounded.*

Key words: *Glider airplane model, wing end shape, longitudinal stability.*

1. INTRODUCTION

Free flight airplane models (glider rubber, engine) have wing as main element of lifting.

The aerodynamic force is upward on the wing together with the resistant force. The wing tips produce the induced resistance force. Horizontal tail assembly (partially aerodynamic upward force), vertical empennage, and fuselage produce aerodynamic resistance force.

The ideal shape of the wing, seen from front or back, is parabolic. It can be approximated by straight lines as follows: V, U, U optimum, and W [1-4].

Making a model airplane glider wing in U optimum, both wood and composite material, it noted greater stability in determalizing when tips were ended in straight lines than when they were upper side rounded, the underside remaining straight.

Shape wing tips can influence the longitudinal stability of model airplane glider, rubber or moto model. In this article is studying the link that exists between longitudinal stability and wing model aircraft tips shape.

2. PRINCIPLE OF THE METHOD

It is considered the rear wing seen in Figure 1, with wingspan **2a** and constant depth **t**. The constant thickness profile is **g** and half wings angle to the horizontal is **α**. Wing contour is designated by the ABCDEF letters.

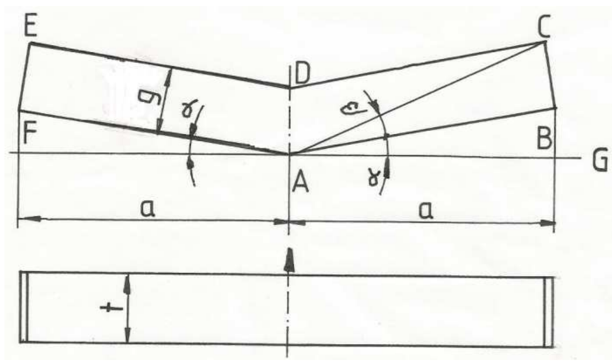

Figure 1. Airplane model wing: top – rear view, down: top view. The arrow indicates the flying direction.

The **β** angle is defined in the ABC triangle. The wing has position as in Figure 1, in horizontal flight, each half wing have its projection on AG horizontal, Figure 1, equal to a – half wing span.

Wing lift is proportional to **2at** (multiplied by the cosine of the angle of incidence) and of a half wing is at. Since the depth, t, is constant, the lift

The lift on half wings changes, if the model plane tilts left, Figure 2, proportional to their horizontal projections on AH horizontal. Tilting model - wing is γ. Half wings projections on AH horizontal are a1, a2, a3, and a4. Sustentation is proportional to the projections.

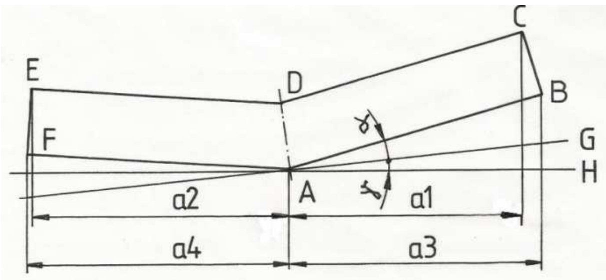

Figure 2. Model airplane γ tilted to the left.

Geometric results, Figure 2:

$a1 = AC.\cos(\alpha + \beta + \gamma);$ (1)

$a2 = AE.\cos(\alpha + \beta - \gamma);$ (2)

$a3 = AB.\cos(\alpha + \gamma);$ (3)

$a4 = AF.\cos(\alpha - \gamma);$ (4)

$AC = AE = (AB^2 + BC^2)^{1/2}$ (5)

wing is proportional to **2a**, respectively **a** for the half wing. Half wings ensure equal lifts in horizontal flight.

$\gamma = \text{arc tg } BC/AB.$ (6)

The γ angle is considered positive, when model airplane tilts to the left and negatively when tilts to the right.

It is introduced the concept of **coefficient of restoration**, CR, given by: CR1 = (a2 or a4) / (a1 or a3) for $+\beta$ and CR2 = (a1 or a3) / (a2 or a4) for $-\beta$. The coefficient of restoration is defined as the ratio of the largest span to the lower span of those two half wings. When it is over unity the model flight restore to the horizontal flight, when lift of both half wings is equilibrated – airplane being horizontal. The minimum value, of equilibrium, in horizontal flight is 1.00.

3. CALCULATIONS

It is considering four applications by changing numerical parameters of different dimensions, according to Table 1, resulting in four different wings.

The γ angle is taken in domains of 0 - 90° and 0 - -90°.

Tabel 1

Wing variants

Variant	AB=AF, mm	α^o	BC=EF, mm	AC=AE, mm	β^o
I	60	10	5	60.21	4.76
II	60	10	15	61.85	14.04
III	60	30	5	60.21	4.76
IV	60	30	15	61.85	14.04

The calculations, for the version of the wing I, are given in Table 2.

Tabel 2.

Variant I, results

γ^o	a1, mm	a2, mm	a3, mm	a4, mm	CR1	γ^o	a1, mm	a2, mm	a3, mm	a4, mm	CR2
0	58.22	58.22	59.09	59.99	1.00	0	58.22	58.22	59.99	59.09	1.00
10	54.67	60.00	56.38	60.00	1.06	-10	60.00	54.67	60.00	56.38	1.06
20	49.47	59.96	51.96	59.09	1.15	-20	59.96	49.47	59.09	51.96	1.15
30	42.75	58.09	45.96	56.38	1.26	-30	58.09	42.75	56.38	45.96	1.26
40	34.74	54.46	38.57	51.96	1.41	-40	54.46	34.74	51.96	38.57	1.41
50	25.67	49.18	30.00	45.96	1.64	-50	49.18	25.67	45.96	30.00	1.64
60	15.83	42.40	20.52	38.57	2.07	-60	42.40	15.83	38.57	20.52	2.07
70	5.50	34.33	10.42	30.00	3.29	-70	34.33	5.50	30.00	10.42	3.29
80	-5.00	25.22	0.00	20.52	∞	-80	25.22	-5.00	20.52	0.00	∞
90	-15.34	15.34	-10.42	10.42	-1.47	-90	15.34	-15.34	10.42	-10.42	-1.47

Note: Yellow background is for **a3** (γ = 0 – 90°) and **a3** și **a1** (γ = 0 - -90°) for the highest values between **a1** and **a3**. Orange background is for **a2** and **a4** (γ = 0 – 90°) and **a4** (γ = 0 - -90°), for the highest values between **a2** and **a4**.

The calculations, for the version of the wing II, are given in Table 3.

Tabel 3

Variant II, results

γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR1	γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR2
0	56.49	56.49	59.09	59.09	1.00	0	56.49	56.49	59.09	59.09	1.00
10	51.25	60.00	56.38	60.00	1.06	-10	60.00	51.25	60.00	56.38	1.06
20	44.46	61.70	51.96	59.09	1.19	-20	61.70	44.46	59.09	51.96	1.19
30	36.32	61.52	45.96	56.38	1.34	-30	61.52	36.32	56.38	45.96	1.34
40	27.07	59.47	38.57	51.96	1.54	-40	59.47	27.07	51.96	38.57	1.54
50	17.01	55.61	30.00	45.96	1.85	-50	55.61	17.01	45.96	30.00	1.85
60	6.42	50.06	20.52	38.57	2.44	-60	50.06	6.42	38.57	20.52	2.44
70	-4.36	43.00	10.42	30.00	4.13	-70	43.00	-4.36	30.00	10.42	4.13
80	-15.02	34.62	0.00	20.52	∞	-80	34.62	-15.02	20.52	0.00	∞
90	-25.20	25.20	-10.42	10.42	-2.42	-90	25.20	-25.20	10.42	-10.42	-2.42

Note: Yellow background is for **a3** (γ = 0 – 90°) and **a3** şi **a1** (γ = 0 - -90°) for the highest values between **a1** and **a3**. Orange background is for **a2** and **a4** (γ = 0 – 90°) and **a4** (γ = 0 - -90°), for the highest values between **a2** and **a4**. Identical as Table 2.

The calculations, for the version of the wing III, are given in Table 4.

Tabel 4

Variant III, results

γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR1	γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR2
0	49.47	49.47	51.96	51.96	1.00	0	49.47	49.47	51.96	51.96	1.00
10	42.75	54.67	45.96	56.38	1.23	-10	54.67	42.75	56.38	45.96	1.23
20	34.74	58.22	38.57	59.09	1.53	-20	58.22	34.74	59.09	38.57	1.53
30	25.65	60.00	30.00	60.00	2.00	-30	60.00	25.65	60.00	30.00	2.00
40	15.83	59.96	20.52	59.09	2.92	-40	59.96	15.83	59.09	20.52	2.92
50	5.50	58.09	10.42	56.38	5.57	-50	58.09	5.50	56.38	10.42	5.57
60	-5.00	54.46	0.00	51.96	∞	-60	54.46	-5.00	51.96	0.00	∞
70	-15.74	49.18	-10.42	45.96	-4.72	-70	49.18	-15.74	45.96	-10.42	-4.72
80	-25.22	42.40	-20.52	38.57	-2.07	-80	42.40	-25.22	38.57	-20.52	-2.07
90	-34.33	34.33	-30.00	30.00	-1.14	-90	34.33	-34.33	30.00	-30.00	-1.14

Note: Yellow background is for **a3** (γ = 0 – 90°) and **a3** şi **a1** (γ = 0 - -90°) for the highest values between **a1** and **a3**. Orange background is for **a2** and **a4** (γ = 0 – 90°) and **a4** (γ = 0 - -90°), for the highest values between **a2** and **a4**. Identical as Table .

The calculations, for the version of the wing IV, are given in Table 3.

Tabel 5

Variant IV, results

γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR1	γ°	a1, mm	a2, mm	a3, mm	a4, mm	CR2
0	44.46	44.46	51.96	51.96	1.00	0	44.46	44.46	51.96	51.96	1.00
10	36.32	51.25	45.96	56.38	1.23	-10	51.25	36.32	56.38	45.96	1.23
20	27.07	56.49	38.57	59.09	1.53	-20	56.49	27.07	59.09	38.57	1.53
30	17.01	60.00	30.00	60.00	2.00	-30	60.00	17.01	60.00	30.00	2.00
40	6.42	61.70	20.52	59.09	3.01	-40	61.70	6.42	59.09	20.52	3.01
50	-4.36	61.52	10.42	56.38	5.90	-50	61.52	-4.36	56.38	10.42	5.90
60	-15.00	59.47	0.00	51.96	∞	-60	59.47	-15.00	51.96	0.00	∞
70	-25.20	55.61	-10.42	45.96	-5.34	-70	55.61	-25.20	45.96	-10.42	-5.34
80	-34.62	50.06	-20.52	38.57	-2.44	-80	50.06	-34.62	38.57	-20.52	-2.44
90	-43.00	43.00	-30.00	30.00	-1.43	-90	43.00	-43.00	30.00	-30.00	-1.43

Note: Yellow background is for **a3** (γ = 0 – 90°) and **a3** şi **a1** (γ = 0 - -90°) for the highest values between **a1** and **a3**. Orange background is for **a2** and **a4** (γ = 0 – 90°) and **a4** (γ = 0 - -90°), for the highest values between **a2** and **a4**. Identical as Table 2.

4. DISCUSSION OF RESULTS

Wing I variant

Relations (1-6) were used for the calculation of "wing I variant" in Table 2. Looking at the results in Table 2 it is noted the values **a1** and **a3** decrease with the as γ increases. For all γ values, **a3** has higher values than **a1**. Quantities **a1** and **a3** are dependent on cosine (including of γ angle). Quantities **a1** and **a3** reach negative values; **a3** passes through 0.00 mm at $\gamma = 80^o$. Quantities **a2** and **a4** increases to values $\gamma = 10°$, when both reach the value of 60.00 mm, and then continues to decrease, maintaining in the positive domain. **a4** size has a value greater than **a2** for γ = 0 - 10°, then prevailing **a2** value. Quantity **a2**, left half wing, is FA projected, Figure 2, for γ = 0 - 10°, then **a4** is the AE projection for γ = 10 - 90°.

The coefficient of restoration, CR1, starts at 1.00 for $\gamma = 0^o$ and increases reaching ∞ for $\gamma = 80^o$. It has a value of -1.47 at 90^o. Plotted, it has asymptote at $\gamma = 80^o$, where jumps to $-\infty$ and then begins to rise.

Decreasing values of γ (0 - - 90^o), it is noted a decrease of a1, a2, a3, and a4, similar as in increasing of γ (0 - 90°). Quantity **a4** continuously decreases from 59.09 mm, respectively, -10.42 mm of $\gamma = 0^o$, respectively, -90^o. It passes through 0.00 mm at -80^o, like **a3** one, in the γ increase from 0^o to 90^o. Instead **a3** increases from 59.09 mm ($\gamma = 0^o$) at 60.00 mm for $\gamma = -10^o$ when AB becomes horizontally, projecting its entire length on HA, Figure 2.

It is noted, CR2 - restoration coefficient for negative values of γ angle have the same values for γ decrease from 0^o to -90^o, as CR1 in the growth of γ from 0^o to 90^o. It starts with the value of 1.00, at $\gamma = 0^o$, then increases taking successive positive values, and at $\gamma = -70^o$ has a value of 3.29 and then at -80^o is ∞ and at -90^o has the value of -1.47, making the jump from $+\infty$ to $-\infty$ at $\gamma = 80^o$.

Wing II variant

Wing presents a vertical symmetrically vertical plan passing through AD, perpendicular to AG, Figure 1.

Table 3 presents the results calculated with the equations (1-6) for wing II variant.

It is found, in the $\gamma = 0 – 90^o$ domain, the higher values are to **a4** of 59.09 mm and 60.00 mm for $\gamma = 0^o$, respectively, 10^o. Then **a2** becomes larger, decreasing from 60.00 mm to 25.20 mm for $\gamma = 10°$, respectively, 90°. Instead **a3** is greater than **a1**, but decreased from 59.09 mm to -10.42 mm for $\beta = 10°$, respectively, 90°. It passes through 0.00 mm at $\gamma = 80^o$.

The coefficient of restoration, CR1, increases continuously from 1.00 to ∞ for $\gamma = 0^o$, respectively, 80^o. Then it becomes negative, making the jump from + ∞ to $-\infty$ and reaches -2.42 for $\gamma = 90^o$.

In the γ = 0 - -90^o domain, **a3** is greater than **a1**, increases from 59.09 mm to 60.00 mm, for $\gamma = 0^o$, respectively, -10^o. From $\gamma = -10^o$, **a1** continues to decline from 60.00 mm to 25.20 mm for $\gamma = -90^o$. Quantity **a4** decreases continuously as γ decreases, from 59.09 mm to -10.42 mm, for $\gamma = 0^o$, respectively, -90^o. It passes through 0.00 mm for $\gamma = -80^o$.

The coefficient of restoration, CR2, increases from 1.00 to ∞ for $\gamma = 0^o$, respectively, -80^o, then suddenly becomes $-\infty$ and increases to -2.42 for $\gamma = -90^o$.

The calculated values for "wing II variant" are higher than for "wing I variant", as a result of the larger thickness of the wing profile from 5 mm to 15 mm. It is noted the increase of the coefficient of restoration, CR1 or CR2 up to 26 % for $\gamma = \pm 70^o$, and 65 % at $\gamma = \pm 90^o$. Jump of instability occurs in domains (γ and -γ) at $\gamma = 80^o$.

Wing III variant

In Table 4 shows the results of calculations with equations (1-6) applied to wing III variant. Variant III is different from variant I by the angle $\alpha = 30^o$, instead of 10°.

Quantity **a4** increases from 51.96 mm to 60.00 mm for $\gamma = 0^o$, respectively, 30°, then the value is greater than **a2** and **a4** and starts to decrease, from 60.00 mm to 34.33 mm for $\gamma = 30°$, respectively, 90°. Quantity **a3** is superior on the whole field for γ = 0 - 90^o and decreases from 51.96 mm to 0.00 mm for $\gamma = 0^o$, respectively, 60°, continuing with negative values up to -30.00 mm for γ = 90°.

It is noted that the coefficient of restoration, CR1, increases from 1.00 to 5.90 for γ = 0°, respectively, 50°. It becomes ∞ and dive -∞ at γ = 60°, increases to -4 72 and finally to -1.14 for γ = 70°, respectively, 90°.

In the case of γ = 0 - -90°, tilt to the left, it generates constant values of the quantities **a2** and **a4** from 51.96 mm to 0.00 mm for γ = 0°, respectively, 60° and then at -30.00 mm for γ = -90°. Quantity **a3** is greater than the value **a1** in the interval γ = 0° - -30°, increasing from 51.96 mm to 60.00 mm for γ = 0°, respectively, -60°. From the angle of -30°, dominant **a1**, falls from 60.00 mm to 34.33 mm for γ = -30°, respectively, -90°.

The coefficient of restoration, CR2, increases from 1.00 to ∞ for γ = 0°, respectively, -60°, dives to -∞, then increases to -4.72 and -1.14 for -70°, respectively, -90°.

Wing IV variant

Table 5 contains data on wing IV variant. Compared to the III variant the thickness of the BC triples the size from 5 mm to 15 mm.

The quantity **a3** begins with 51.96 mm for γ = 0°, dropping to 0.00 to 60°, then become negative, reaching -30.00 mm for γ = 90°. Quantity **a4** starts with 51.96 mm, increasing to 60.00 mm for γ = 0°, respectively, 60°, then **a2** becomes dominant as 60.00 mm for γ = 30° and lower at 43.00 mm for γ = 90°.

Coefficient of restoration, CR1, increases from 1.00 to ∞ at 60°, then dives to -∞, than grows to -1.43 for γ = 90°.

In the negative angle of γ, **a3** is predominantly by -30°, then **a1** from -30° to -90°. The quantity **a4** is predominant against **a2** from 0° to -90°, reaching 0.00 mm at -60°.

The coefficient of restoration, CR2, increases from 1.00 to ∞ for 0°, respectively, -60° and from to -∞ to -1.43 at -90°.

The wind tips should be made of straight lines not rounded. This shape is less aerodynamically and during failing in a vertical wing position, it makes to change glider's position into horizontally.

5. CONCLUSIONS

We analyzed four different tip wings: I (α = 10°, g = 5 mm), II (α = 10°, g = 15 mm), III (α = 30°, g = 5 mm, and IV (α = 30°, g = 15 mm); (where: α - angle made by the tip of the wing to the horizontal, g - thickness of the profile). In all cases a length of 60 mm was half wing length, Figures 1 and 2, AB.

Airplane model viewed from the rear, wing similarly, Figure 1.

It was considered tilts to the left, γ = 0° - 90°, being positive and to the left, as negative for 0° - -90°, in increments of 10°.

In horizontal flight, the two half wings projections are equal in area and wingspan (constant depth).

The coefficient of restoration, CR, is given by the ratio of the largest projection of a half wing to the other half wing projection on horizontally. The flight is stable for CR = 1.00, representing a minimum. The aircraft model for positive high values tends towards to the stable position and for negative values, it becomes unstable.

Increasing the γ angle CR increases from 1.00 to ∞ for γ = 80° (α = 10°), then jump to -∞ at the same angle increase to negative values. The phenomenon occurs at γ = 90° - 10° = 80°.

The same phenomenon of remarkable growth of CR from 1.00 to ∞, diving to -∞ and increasing the negative values at the angle γ = 60°, with α = 30° to the wing. The phenomenon occurs at γ = 90° - 30° = 60°.

Sideslip phenomenon occurs in flight when model aircraft has the longitudinal axis horizontally and wing is vertical. Aircraft model is in an unstable situation, falls into this position, not going back to the normal flying position, are covered by instability (γ = 80°, respectively, 60°, for α = 10°, respectively, 30°). Counted angle is at the tip of the wing. Aircraft model falling down in this position may break its wing dihedral.

Influence of wing thickness profile is high. As the thickness increases from 5 mm to 15 mm (3 times), as CR increases by 48 % (5 mm) and 34 % (15 mm).

To increase the longitudinal stability of the airplane model, the half wings tip angle $\boldsymbol{\alpha}$ to the horizontal is necessary small (10° - 18°) and increasing the thickness of the wing profile (6 - 8 % of depth). The thickness profile influence is less than that of the angle influence.

The wing tip should be made of straight lines not rounded.

Vertical half wing, upper side, makes the aircraft model to be in a very unstable position.

Accordingly, the **α** angle should be as low as possible to increase the chance of stability in flight.

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INFLUENȚA CAPETELOR ARIPII
ASUPRA STABILITĂȚII LONGITUDINALE A AEROMODELULUI PLANOR

Rezumat: Au fost analizate patru forme diferite de vârfuri de aripă. Coeficientul de restaurare, CR, este dat de raportul dintre proiecţia cele mai mari jumătăţi de semiaripă la proiecţia celeilalte semiaripi, pe orizontală. Zborul este stabil pentru CR = 1,00. Influența grosimii profilului aripii este mare. Creșterea în grosime de la 5 mm la 15 mm (de 3 ori), CR crește cu 48% (5 mm) și 34% (15 mm). Creșterea, γ, face ca CR să crească de la 1,00 la ∞ pentru $\gamma = 80^o$ ($\alpha = 10°$) (α - unghiul vârfului aripii față de orizontală), apoi sare la $-\infty$ și să crească cu valori negative. CR creștere de la 1,00 până la ∞ apoi saltul la $-\infty$ pentru $\gamma = 60°$, cu $\alpha = 30°$. Derapajul apare atunci când modelul are axa longitudinală orizontală și aripa verticală, este într-o zonă instabilă, pentru $\gamma = 80^o$, respectiv, 60^o pentru $\alpha = 10°$, respectiv, 30^o.

Cuvinte cheie: *Aeromodel planor, forma capetelor aripii, stabilitate longitudinală.*

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