H1 – 01 10 – 00022S
Wing Design

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1 SUMMARY

This report contains H1 wing design and defined design structure.

Statement of conformity

This report is done in accordance to ASTM F2245-13b + CS-LSA amendment 1 additional requirements.

ASTM Appendixes;

- "X1 SIMPLIFIED DESIGN LOAD CRITERIA FOR LIGHT SPORT AIRPLANES" and
- "X3. ACCEPTABLE MEANS OF GUST LOAD FACTOR CALCULATIONS" and
- "X4. ACCEPTABLE MEANS FOR CALCULATING GUST LOADS ON STABILIZING SURFACES"

are utilised.

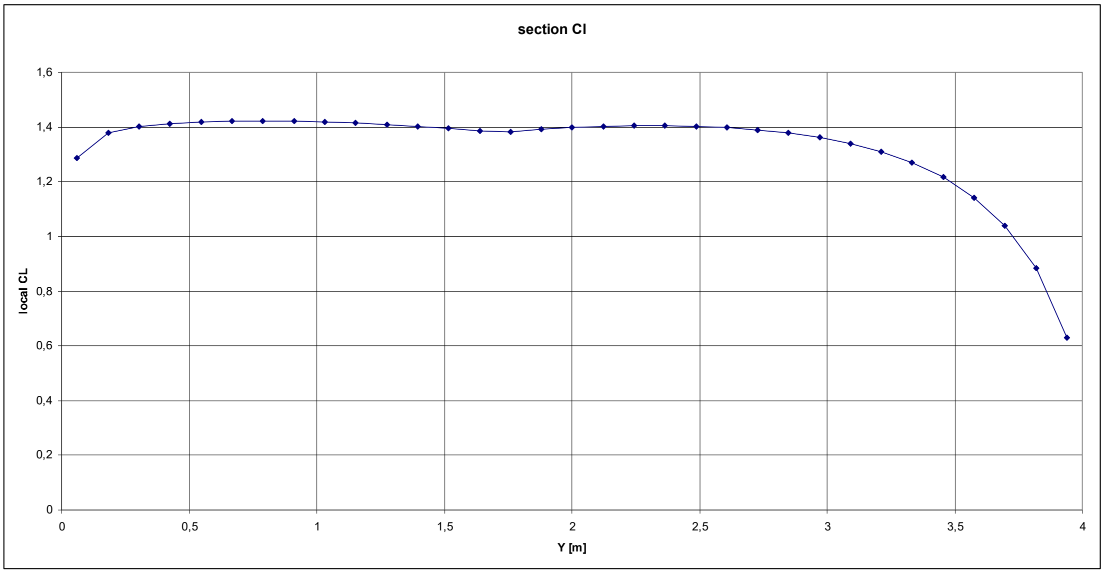
2 BASIC CALCULATION

2.1 Aerodynamical calculations

2.1.1 Wing lifting data

Lifting characteristics of wing are calculated in document 01 10-0014S

Graph for alfa 16 deg with flaps at 0 deg corresponding to Wing Cl of 1,475 which correspond to air speed of 93,8 km/h at 499 kg.



Wing Cl 1,475 corresponds to airspeed of

2.1.2 *Wing moment data*

Wing moment data was calculated along lift data with Linair program. Here is graphic summary of this data:

ASTM 5.2.2.4 states to use moment coefficient of at least +/- 0,025, the calculated values are more, so they are used.

2.1.3 *Mean aerodynamical chord*

Wing is bouble tapered.

Root chord at aircraft centerline: 1,306 m

Mid chord, Y=1,699 m: 1,228 m

Tip chord, Y = 3,984 m: 0,718 m

Beyond tip chord, a fairing is designed. With it total span is 8,136 m.

Root chord X position: 0,370 m

mid chord X position: 0,38918 m

tip chord X position: 0,51572 m.

Using adaptation of PDAS program form http://www.pdas.com/

Results:

Wing area: 8,81 m²

MAC: 1,121 m

Y mac at 1,827 m

X of mac: 0,415 m

2.2 Tail aerodynamical values

2.2.1

3 DESIGN SPEEDS

3.1 Design values general

The selected design airspeeds are calibrated airspeeds (CAS).

For manouvering limits, CS-23 utility category values for positive loads are used, allowing gentle aerobatic manouvers like barrel roll, etc. Negative limit is taken form ASTM (higher than CS23 U cat limit).

Maneuverign limits are chosen to be + 4,4 g and -2,0 g.

For landing conditions maneuvering limits are chosen to be + 2,0 g and -0,0 g.

3.2 Design maneuvering speed VA

ASTM X1.1

For minimum design maneuvering speed V_A the following applies:

$$V_{Amin} = 2{,}17 \times \sqrt{\frac{n_1 \times W}{S}} \cdot kts$$

V_{Amin} = 2,17 * sqr(4,4*499*g/8,76) = 107,6 kts = 199,3 km/h

We select our design maneuvering speed VA 200 km/h

3.3 Design flap speed in landing configuration VF

ASTM X1.1

For design flap speed in landing configuration V_F following applies:

$$V_{Fmin} = 1.59 \times \sqrt{\frac{n_1 \times W}{S}} \cdot kts$$

V_{Fmin} = 1,59 * sqr(4,4*499*g/8,76) = 78,9 kts = 146,1 km/h

We select our design flap speed VF 147 km/h

3.4 Design Cruise Speed VC

ASTM X1.1

$$V_{Cmin} = 2{,}46 \times \sqrt{\frac{n_1 \times W}{S}} \cdot kts$$

V_{Cmin} = 2,46 * sqr(4,4*499*g/8,76) = 122,0 kts = 226,0 km/h

V_H is estimated to be 283 km/h.

ASTM X1.2.5.2 defines that V_C need not be more that 0.9 V_H (=0,9 * 283 km/h = 254,7 km/h).

V_{Cmin} = 226,0 km/h = 122,0 kts.

We select our design cruising speed to be VC 235 km/h.

3.5 Design dive speed V_D

ASTM X1.1

$$V_{Dmin}=3{,}47\times\sqrt{\frac{n_1\times W}{S}}\cdot kts$$

V_{Dmin} = 3,47 * sqr(4,4*499 g/8,76) = 172,1 kts = 318,8 km/h

But need not to exceed

$$1{,}4\times V_{Cmin}\times\sqrt{\frac{n_1\times W}{S}}\ \text{kts}$$

V_{Cmin} = 226,0 km/h = 122,0 kts, so the value V_{Dmin} need not exceed is

V_{Dmin} = 1,4 * 122,0 * sqr(4,4*499 g/8,75) = 340,4 km/h = 183,8 kts

We select our design dive speed to be VD 330 km/h.

3.6 High lift devices

If flaps or similar high lift devices to be used for take-off, approach, or landing are installed, the aeroplane, with the flaps fully deflected at V_F, must have limit manoeuvring load factor for this condition. These limits must be determined.

Limit manoeuvring load factor with flaps extended is selected to be +2,0 g.

3.7 Never exceed speed V_{NE}

ASTM 4.1.1.2

V_{NE} must be less than or equal to $0.9V_{DF}$ and greater than or equal to $1.1V_C$. In addition, V_{NE} must be greater than or equal to V_H.

V_{DF} may be less than or equal to V_D (ASTM 4.1.1.1).

Lower limits for V_{NE} are:

V_H = 283 km/h (lower limit)
1,1 V_C = 235 km/h*1,1 = 258,5 km/h (lower limit)
0.9 V_{DF} <= 0,9 VD = 297 km/h (upper limit)

So VNE must be between 283 and 297 km/h

We select our never exceed speed to be VNE 297 km/h.

4 LOAD FACTORS

4.1 Design limit flight load factors

ASTM table X1.1

Values of table X1.1 are used. But see 3.1.

The positive limit manoeuvring load factor n_1 is selected to be 4,4.

The negative limit manoeuvring load factor n_2 is defined to be -2,0.

For manoeuvring flaps down limit load factor is defined to be + 2,0 g, negative load flap open is 0,0 g.

Table X1.2:

Factor K is V_{Csel}/V_{Cmin} = 235/226 = 1,040

n_1*W/S = 51,4 lb/sqft
so: $n_3 = 4,4$

Table X1.3

Factor K is V_{Csel}/V_{Cmin} = 235/226 = 1,040
n_1*W/S = 51,4 lb/sqft
so: $n_4 = -2,0$

Notation of X1.1:

n_1	4,4
n_2	-2,0
n_3	4,4
n_4	-2,0
n_f	2,0
n_{f-}	0,0

4.2 Gust load factors (wing)

ASTM X3

The gust load factors may be computed as follows:

$$n = 1 + \frac{\frac{1}{2} \times \rho_0 \times V \times a \times K_g \times U_{de}}{\frac{Mg}{S}}$$

or

$$n = 1 - \frac{\frac{1}{2} \times \rho_0 \times V \times a \times K_g \times U_{de}}{\frac{Mg}{S}}$$

where;

Kg = $\frac{0{,}88\mu_g}{5{,}3+\mu_g}$ = gust alleviation factor;

μ_g = $\frac{2 \times (\frac{M}{S})}{\rho \times \bar{C} \times a}$ = aeroplane mass ratio;

Ude = derived gust velocities referred to (m/s) 15 or 7,5 m/s;

ρ_0 = density of air at sea level (1,225 kg/m³);

M/S = wing loading (kg/m²); 499/8,76 = 57,0 kg/m²

$\bar{C}$ = mean geometric chord (m); 1,117 m

g = acceleration due to gravity (9,81 m/s²);

V = aeroplane equivalent speed (m/s); and

a = slope of the aeroplane normal force coefficient curve C_{NA} per radian. Value of 4,669 $^1/_{rad}$ is calculated for our wing at 0 deg flap setting.

Note: Formula for gust alleviation factor, see appendix 1 of this report.

With these values we get:

aeroplane mass ratio = 17,8354
gust alleviation factor = 0,6784

And with gusts of 15 m/s at Vc and 7,5 m/s at Vd we get;

Vc	n+	4,40	g
Vc	n -	-2,40	g
Vd	n+	3,39	g
Vd	n -	-1,39	g

4.3 Engine mount

ASTM 5.10.1.2, 5.2.9

Engine emergency landing condition load factors are:

Up n = 3
Forward n = 10
Lateral n = 1,5

From engine torque conditions;

Limit takeoff torque and power simultaneously with 75% of n1. For calculations this is calculated at VY speed. Engine produces during takeoff an estimated of 1500 N of thrust at climb speed.

Limit continuous torque and power simultaneously with 100% of n1. For calculations this is calculated at VA speed. Engine produces during takeoff estimated of 870 N of thrust at VA speed.

5 V-N DIAGRAM

Combining previous paragraphs we get aircraft’s V-n diagram.

Selected speed are:

V s0	77	km/h
V s	90	km/h
V a	200	km/h
V c	235	km/h
V ne	297	km/h
V d	330	km/h
V f	147	km/h

Calculated gust envelope is:

	v [km/h]	n
V c	235	4,40
V d	330	3,39
V d	330	-1,39
V c	235	-2,40

V-n diagram is:

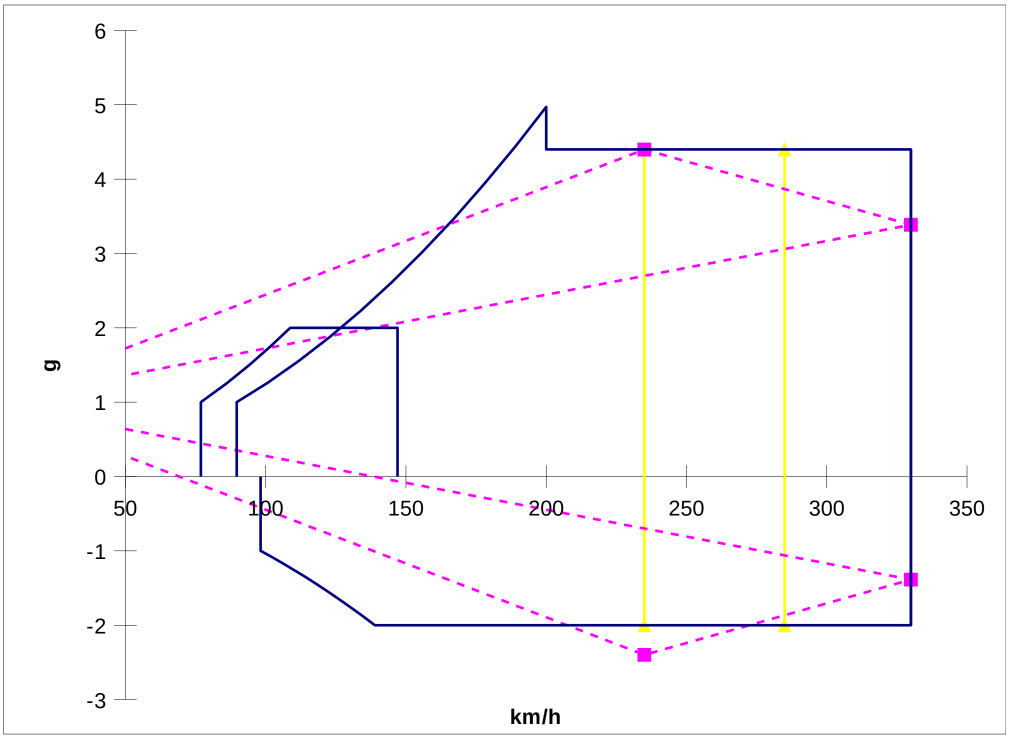
Gust envelope is presented with dashed lines.

Points of this envelope, and corresponding lift coefficients are:

	km/h	g	Cl

A	200	4,4	1,140
C	235	4,4	0,9709
D	330	4,4	0,6914
VD	330	0	0
H	139	-2,0	-1,1073
F	235	-2,0	-0,6546
E	330	-2,0	-0,4661

These Cl values represent maximum take-off weight.



5.1 Horizontal tail

5.1.1 Gust loads

ASTM X4

Dimensions and other values see, Error: Reference source not found.

From X4.1

ΔL_{HT} = 2117,6 N at V_C

ΔL_{HT} = 1486,8 N at V_D

At trim condition, cg at forward limit, max mass, tail loads are:

VC (235 km/h), g = 1

CL total: 0,213

Tail lift = -439,2 N (down)

At VD, (330 km/h) g=1

CL total: 0,108

Tail lift = -900,2 N (down)

So gust conditions are:

VC

Up gust

Tail load = trimmed force + ΔL_{HT}

Tail load = -439,2 +2117,6 N = 1678,4 N

Down gust

Tail load = trimmed force - ΔL_{HT}

Tail load = -439,2 – 2117,6 N = -2556,8 N

VD

Up gust

Tail load = trimmed force + ΔL_{HT}

Tail load = -900,2 + 1486,8 N = 586,6 N

Down gust

Tail load = trimmed force - ΔL_{HT}

Tail load = -900,2 – 1486,8 N = -2387,0 N

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5.1.2 *Manouvering loads*

ASTM X1.4.3

For horizontal tail with span of 2,56 m and chord of 0,711 m.

Design maneuvering wing loading:

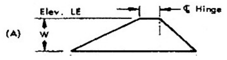
$$n1*W/S\ [N/m^2]$$
$$= 4,4 * 4895,19 / 8,76$$
$$= 2460\ N/m^2$$

From figure X1.4;

Average surface loading, w [N/m²]

$$w = 1545\ N/m^2$$

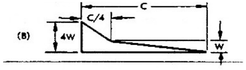
For up and down loads, distribution is Table X1.2 (A).



Using this distribution (dimensions from Specification 4.5), total symmetrical load is:

2557 N

For unsymmetrical loads, distribution is Table X1.2 (B).



Using this distribution (dimensions from Specification 4.5), total unsymmetrical load is:

On one side 1409 N
On other side 916 N

5.2 Vertical tail

5.2.1 *Gust loads*

ASTM X4

Dimensions and other values see, Error: Reference source not found.

From X4.2

ΔL_{VT} = 1613 N at V_C

ΔL_{VT} = 1132 N at V_D

5.3 Calculation load cases

LC1
VC down gust
Horizontal tail
tail load -2556,8 N (down) total

LC2
VC up gust
Horizontal tail
tail load 1678,4 N (Up) total

LC3
unsymmetrical manouvering load VA
Horizontal tail

On one side	1409 N
On other side	916 N

LC4
gust load vertical tail VC
1613 N

6 OTHER LOADS

6.1 Engine mount

Rotax OM for 912ULS, 5.10.1

Engine mount load are defined in ASTM 5.2.9.

Engine (including propeller) installed mass is 90 kg, acting from engine center of gravity. Mount weights 10 kg.

Engine power and torque

Takeoff	73,5 kW 5800 rpm
Max continuous	69 kW 5500 rpm
Gearbox ratio	1:2,43
Number of cylinders	4

Max takeoff power case yields calculation moment of 596,1 Nm.

Max continuous power case yield moment of 582,2 Nm.

Limit takeoff torque and power simultaneously with 75% of n1. For calculations this is calculated at VY speed. Engine produces during takeoff estimated of 1500 N of thrust at climb speed. As this can achieved in pull-out pitch-up rate is 0,608 rad/s. Propeller (+ engine crankshaft) moment is 25,6 Nm. Limit continuous torque and power simultaneously with 100% of n1. For calculations this is calculated at VA speed. Engine produces estimated of 870 N of thrust at VA speed.

As this can achieved in pull-out pitch-up rate is 0,602 rad/s. Propeller (+ engine crankshaft) moment is 23,3 Nm.

Emergency landing cases (ASTM 5.10). Emergency landing case load factors are:

n = 3 up,

n = 10 for engines and ESD(s)) forward, and

n = 1.5 lateral.

Max power case

down	2647,8	N
torque X	588,1	Nm
torque Z	43,8	Nm
forwards	1500	N

Max continuous case

down	3530,4	N
torque X	582,2	Nm
torque Z	23,3	Nm
forwards	870	N

Emergency landing case 1

forwards	8826	N

Emergency landing case 2

Up	2648	N

Emergency landing case 3

sidewards	1324	N

6.2 Wheel landing gear

ASTM 5.8

Required drop height is

$$dropHeight[cm]=1{,}32\times\sqrt{\frac{W}{S}}$$ = 28,8 cm

7 STABILITY

As a baseline longitudinal stability is calculated using book ‘Piero Morelli; Static stability and Control of sailplanes, 1976’ as reference.

Following values for different limits were calculated

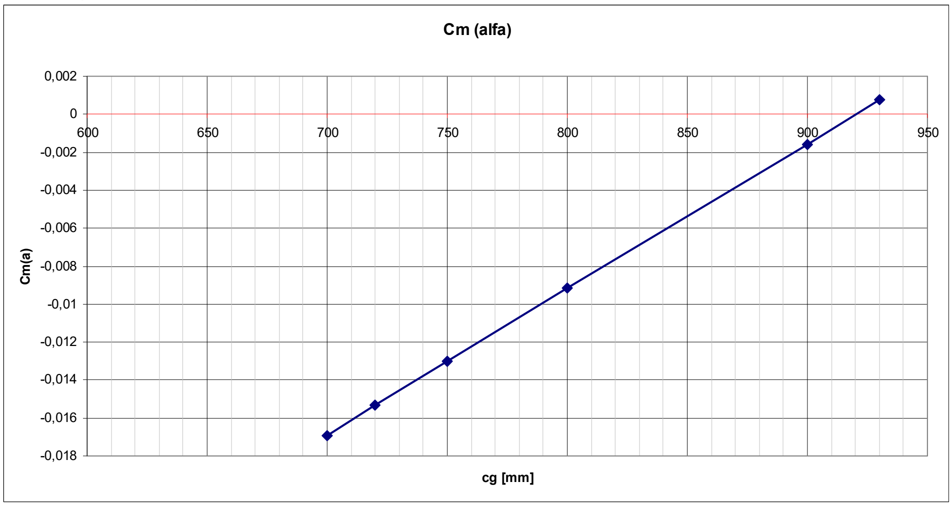
Pull up, Clmax n=1	-1 %	forward
Pull up, Clmax n=1, ground effect	7 %	

Pull up, Va, n max	-17 %	limits
Stick free neutral point	39,3 %	rear
dP/dn=-1(kg/g) pull, SL	43,8 %	limits
stick free manouvring point, high altitude	41,8 %	
stick fixed neutral point	52,4 %	
dP/dn=-0,5(kg/g) pull, SL	45,1 %	
stick fixed manouvring point, at high altitude	53,9 %	
stick free manouvring point, SL	45,0 %	
stick fixed manouvring point, SL	57,3 %	

Preliminary c.g limits are taken as 25% - 35% MAC, meaning 695 mm to 807 mm from datum.

Using Linair 4 program with model during trim condition calculation neutral point was calculated. Calculation result is stick fixed neutral poin. Linair 4 is a multisurface program taking into effect wing/tail interactions.

Flying mass used is 499 kg. Calculation is made at speed of 235 km/h (Cl 0,463).



This yields neutral point of 922 mm (45,2% MAC). Which is in close proximity of analytical results (above).

Front limit will be limited by taxing/takeoff/landing characteristics, which are hard to estimate on paper. Also the front limit is where real life loading is hardest to do. So it will be estimated with prototype, what cg is feasible to reach in real life.

Preliminary center of gravity limits are:
forward limit 25 % mac equalling 695 mm from datum
rear limit 35% mac equalling 807 mm from datum.

---- END ----

Appendix 1, A hidden mistake in CS-LSA / ASTM F2245

The formula which are used to calculate gust load factors.
The calculation order how formula operations are performed is different in rules of different origin.

In ASTM F2245/16c it is found in X 4.1
Gust alleviation factor is given as [$0.88\ ug/5.3 + ug$]

In CS-VLA 341 this same factor is given as [$0.88\ ug / (5.3+ug)$]
Same as in CS.23.341 [$0.88\ ug / (5.3+ug)$]

In FAR-23 this is found as paragraph 23.341. And in the current electrical form it is given as:
$Kg=0.88\mu g/5.3+\mu g$=gust alleviation factor;

but in historical FAR-23 achieve it is different!
Amdt. 23-34, Eff. 02/17/87
$Kg = 0.88\ ug / (5.3 +ug)$ = gust alleviation factor;
Amdt. 23-42, Eff. 02/04/91
$Kg = 0.88\ ug / (5.3 +ug)$ = gust alleviation factor;
Amdt. 23-48, Eff. 03/11/96
$K\ g=0.88\mu g/5.3+\mu g$=gust alleviation factor;

So something happened in 1996 for FAR 23 when the layout of rule was changed.
This same formula was then (probably) transferred to ASTM F2245.

Taking a real life value for mass ratio ug e.g. 12.17
ASTM/FAR formula gives Kg = 14.2
EASA CS and older FAR formula gives Kg = 0.613

Difference is large and that ASTM/FAR formula yields gust load factor which is unrealistically high.
In this design that ASTM/FAR formula gives gust load factors of about 55 g (fifty five) which is pretty high!
That older formula (and CS-VLA) gives gust load factors of 3.33 g, which is about what to expect.