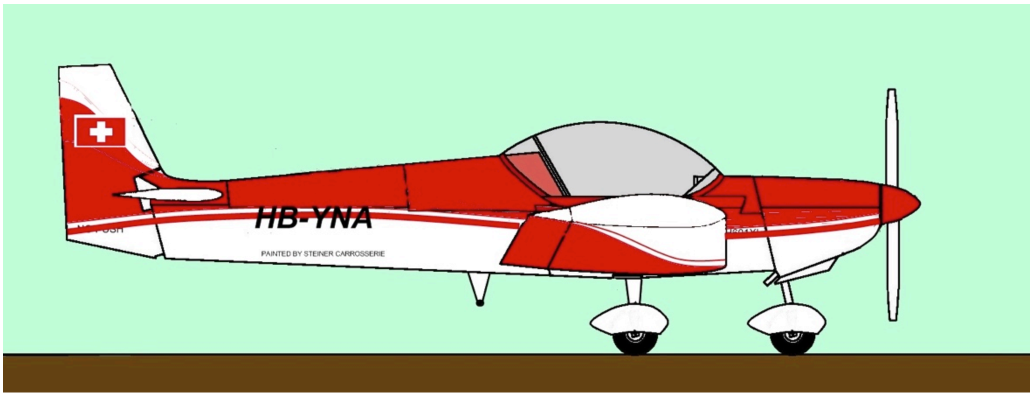
CZECH AIRCRAFT WORKS
ZENAIR CH601XL-B ZODIAC

LOAD TESTS / STRESS ANALYSIS



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1 Overview

1.1 Introduction

Different load tests and stress analysis' were performed and prepared for the original Zenair/CZAW CH601XL. The Zenair factory demonstrator aircraft first flew in 2002. After the occurrence of several unexplained inflight-breakups of CH601XLs, several aviation authorities grounded the airplane in 2008 and 2009.

On Nov 7, 2009, the FAA issued a Special Airworthiness Information Bulletin SAIB CE-10-08 for the Zodiac CH601XL (http://www.zenithair.com/news/ntsb-astm-4-09a.html) [Attachment]. The FAA is urging SLSA owners/operators and is strongly recommending to amateur-built/E-LSA owners/operators of the Zodiac CH601XL and CH650 aircraft to comply with actions outlined in the Safety Alert / Safety Directive by AMD.

AMD, manufacturer of the Zodiac CH601XL S-LSA (factory-built aircraft) issued this Safety Alert / Safety Directive (Nov 7, 2009) [Attachment] which outlines procedures required to resume normal operations, including upgrades detailed on modification drawings (latest revised drawings are dated Jan 25, 2010) [Attachment].

Zenair Europe also issued Safety Notice ZE-2009-04 (Nov 22, 2009) [Attachment] which is valid for aircraft manufactured by CZAW and a MTOW = 600 kg. The SN directly references to the Safety Alert / Safety Directive issued by AMD.

In addition Zenair prepared a photo assembly guide with directions for the upgrade and modification of the aircraft.

The official designator for update aircraft is CH601XL Model B, hereinafter called CH601XL-B.

Independent aviation engineers revised this analysis. Nevertheless it is of informal character only and the author doesn't take any responsibility if parts of the analysis are incorrect.

Note: Throughout this analysis, the term "Additional Safety Factor" is used. The additional safety factor is on-top of the required safety factor to ultimate load. The resulting safety factor to limit load is therefore the product of required safety factor and additional safety factor.

1.2 Modifications (Upgrade Package)

The upgrade package for the Zenair/CZAW CH601XL Model B (CH601XL-B) includes the following major structural modifications:

A. Wing

- Strengthened wing upper main spar cap angle
- Wing main spar root doubler
- Wing upper rear spar cap angle
- Wing rear spar root doubler
- Aileron mass balancing
- Reinforcement of the aileron bellcrank
- L-angles top and bottom skins

B. Fuselage

- Strengthened wing uprights
- Main spar bottom angle doublers
- Main spar top doublers
- Main spar uprights
- Strengthened rear center spar attach plates
- Aileron control stick stop
- Fuselage side panel reinforcements

Drawings of the upgrade package can be found in the attachment.

1.3 Load Tests / Stress Analysis

A. Czech Aircraft Works CH601XL Load Tests (*CZAW CH601XL*)

Czech Aircraft Works conducted a load test on an unmodified [1] CH601XL airframe. The wing was loaded up to structural failure. All other structural components (e.g. horizontal tail, vertical tail, gear, engine mount) were stressed to the load calculated in CZAW's load analysis.

In this document, the abbr. *"CZAW CH601XL"* refers to the load tests performed by Czech Aircraft Works on an unmodified CH601XL.

B. Zenair CH650 Wing Load Test (*Zenair CH650 mod.*)

Zenair performed a wing load test on a partially modified CH650 airplane (the CH650 has the exact same wing and center wing structure as the CH601XL). The final upgrade modifications, as outlined in the Safety Alert / Safety Directive, are even more extensive and provide additional strength (see next paragraph C). The differences between the original CH601XL (CZAW CH601XL), the partially modified CH650 (Zenair 650 mod.) and the fully upgraded CH601XL-B are listed in subchapter 1.4.

In this document, the abbr. *"Zenair CH650 mod."* refers to the load test performed on the partially modified Zenair CH650 wing.

C. Zenair CH650 Analysis of Final Reinforcements (*Zenair CH650 Final*)

Chris Heintz, designer of the Zodiac, evaluated and analyzed the strength of the final upgrade modifications that are part of Safety Alert / Safety Directive for the Zodiac CH601XL-B and CH650 ("Static test and further reinforcements – Evaluation by Chris Heintz").

In this document, the abbr. *"Zenair CH650 Final"* refers to the analysis for the final reinforcements of the CH650 wing.

D. Zenair Load Tests and Stress Analysis for CH601XL (*Zenair Analysis*)

Chris Heintz, designer of the CH601XL, prepared a stress analysis for the aircraft that also includes load test results.

In this document, the abbr. *"Zenair Analysis"* refers to the stress analysis and load tests performed by Chris Heintz, former chief designer at Zenair.

E. Czech Aircraft Works SportCruiser (*CZAW SportCruiser*) – Load tests for main gear

The load test results provided in the "Zenair Analysis" are valid for aircraft with the original aluminium main gear only. CZAW conducted drop tests with a CH601XL with composite main gear legs. However these tests were performed for a MTOW = 450 kg (European Ultralight category) only.

CZAW's successor of the CH601XL-B, the SportCruiser, uses the exact same gear legs and gear leg mounting as the CZAW CH601XL-B. The CZAW SportCruiser is designed as a Light Sport Aircraft (LSA) and therefore gear drop and load tests were performed for a MTOW = 600 kg.

In this document, the abbr. *"CZAW SportCruiser"* refers to the load tests performed on the main gear of the Czech Aircraft Works SportCruiser.

[1] „Modified" in this context/document means: upgrade package (AMD SA/SD, Nov7, 2009) is installed.

1.4 Modification List

The differences between the original CH601XL (CZAW CH601XL), the partially modified CH650 Zenair 650 mod.) and the fully upgraded CH601XL-B are shown in the following table:

LIST OF MODIFICATIONS CH601XL

Version		**CZAW CH601XL**	**Zenair CH650 mod.**	**Zenair CH601XL final**
Description		Original Czech Aircraft Works CH601XL according to drawings dated 01/2002	Zenair CH650 with partially modified wing structure - as used by Zenair for the wing load	Zenair CH601XL according to FAA SAIB CE-10-08 (Nov 7, 2009)
Part No	**Part Description**			
6ZU1-1	Extruded L-angle bolted to 6W3-2 (wing top spar cap)	t = ***", not extruded	t = 0,125"	t = 0,125"
6ZU1-2	Wing root doubler at spar cap bolts	n/a	t = 0,032"	t = 0,125", doubler has different geometry which results in additional strength
6ZU1-3/4/5	Nose rib angles, bottom cap angle	n/a	n/a	additional angles at inner 3 nose ribs, bottom cap angle between NR#1 and NR#2
6ZU1-6	L-angle at top of rear spar	n/a	t = 0,040"	t = 0,040"
6ZU1-7	Rear channel doubler	n/a	n/a	t = 0,040"
6ZU1-8	Doubler plate at rear spar aileron hole	n/a	t = 0,032"	t = 0,032"
6ZU2	Wing attachment bolts	AN5	AN5	NAS6205
6ZU2-1	Center spar aluminium top doubler	n/a	t = 0,063", riveted and glewed to top of center spar only	t = 0,063", doubler has different geometry which results in additional strength and is riveted to top of center spar and top spar caps (solid rivets and AN3-bolts)
6ZU2-2	Seat front bottom L-angle	n/a	t = 0,063"	t = 0,063"
6ZU2-4	Spar uprights, wing center spar	n/a	n/a	t = 0,25", 4 L-angle spar uprights between top and bottom spar caps
6ZU2-6f	Front wing uprights	t = 0,040"	t = 0,063"	t = 0,125"
6ZU2-6r	Rear wing uprights	t = 0,040"	t = 0,063"	t = 0,063"
6ZU2-7/8	Spar bottom angles	t = ***	t = ***	t = 0,063"
6ZU2-9	Bottom skin doubler	n/a	n/a	t = 0,032"
6ZU3-1	Bellcrank support channel	n/a	n/a	t = 0,040", U-profile
6ZU3-2	Side doubler, fuselage between seat panel and center spar	n/a	n/a	t = 0,063"
6ZU3-3	Attach plate, at fuselage for rear spar	t = 0,063"	t = 0,063"	t = 0,125"
6ZU3-4	Seat angles	n/a	n/a	t = 0,040", additional L-angles at lower side of seat panels
6ZU3-5	Upright doubler	n/a	n/a	t = 0,032", strengthens connection between center spar, wing uprights and fuselage longerons
6ZU3-Z	Z-angle fuselage side panel	n/a	n/a	t = 0,025", at fuselage side panel in front of main center spar
6ZU4-1/2	Aileron stick control stop	n/a	n/a	t = 0,040"
6ZU4-L	L-angles, rear top and bottom wing skins	n/a	n/a	t = 0,025", L-angles on rear wing panels along the entire wing span
6ZU4-L	L-angles aileron trim servo	n/a	n/a	t = 0,025", strengthens the support of the aileron trim servo
additional	Aileron gussets	n/a	n/a	Gussets at aileron rib #1 and #2
additional	Aileron mass balance	n/a	n/a	Implemented according to UK LAA modifications

2 Wing

2.1 Load Test Results

Zenair CH650 Mod.

The results of the wing load test on the modified Zenair CH650 (*Zenair CH650 mod.*) are summarized in the following table. The wing withstood the indicated ultimate loads with minor permanent deformation:

Zenair Structural Test to ASTM-SLSA (28. September 2009)
„Zenair CH650 mod.“

Nr	Position		root	1	2	3	4	5	6	7	8	9
1	Y	[mm]	507	777	1072	1467	1862	2257	2642	3032	3422	3812
2	X(RW,aft LE)	[mm]		556	556	556	556	556	312	312	312	312
3	X(LW,aft LE)	[mm]		556	556	556	556	556	712	712	712	712
4	Shear Center	[mm]		375	375	375	375	375	375	375	375	375
5	Wing CG	[mm]		535	535	535	535	535	535	535	535	535
6	W(Wing)	[kg]		4	7	6	6	5	5	4	4	3
7	W(Load)	[kg]		104	112	173	173	173	113	113	115	139
8	T	[N]	12335	12335	11277	10111	8357	6602	4858	3702	2555	1390
9	M(b)	[Nm]	21412	18082	14755	10761	7460	4853	2982	1539	542	0
10	M(t,RW)	[Nm]	-1077	-1077	-886	-676	-360	-44	271	209	146	81
11	M(t,LW)	[Nm]	-2957	-2957	-2766	-2557	-2240	-1924	-1609	-1228	-849	-463

CZAW CH601XL

CZAW tested an unmodified Zodiac CH601XL. The results of the wing load test are summarized in the following table. The wing failed at the indicated loads after more than 3 seconds (buckling of upper spar cap):

CZAW Load Test for Ultralight Category (20. June 2002)
"CZAW CH601XL"

Nr	Position		root	1	2	3	4	5	6	7
	Test for wing shear and bending moment									
12	Y	[mm]	507	875	1387	1899	2420	2981	3542	3892
13	W(Wing)	[kg]	4	7,5	7,5	6	6	5	3	3
14	W(Load)	[kg]	175	147	130	220	95	167	90	107
15	T	[N]	11502	9747	8232	6884	4668	3677	1991	1079
16	M(b)	[Nm]	17315	13728	9514	5989	3557	1494	378	0
Nr	**Test for wing torsion moment**									
17	X(aft Shear C.)	[mm]		1025	1025	1025	1025	1025	1025	
18	W(Load)	[kg]		48	43	40	55	70	96	
19	T	[N]	3864	3824	3280	2785	2334	1736	1000	29
20	M(b)	[Nm]	7274	5866	4187	2761	1545	571	10	0
21	M(t)	[Nm]	-3538	-3538	-3056	-2623	-2221	-1668	-965	0

2.2 Wing Shear and Bending Moment

WING SHEAR Ultimate Loads			
Load Analysis	**Load Test** ***Zenair CH650 mod.***	**Additional Safety Factor**	**Remarks**
12'134 N	**12'335 N**	**+ 2 %**	Load Analysis: MTOW = 600 kg, minimum fuel (20 L), conservative load inside fuselage of 245 kg.
Load Analysis	**Strength Analysis** ***Zenair CH650 Final***	**Additional Safety Factor**	**Remarks**
12'134 N	**15'297 N**	**+ 26 %**	Load Analysis: MTOW = 600 kg, minimum fuel (20 L), conservative load inside fuselage of 245 kg.

The wing shear load (blue = load analysis Pohl, red = Zenair CH650 mod. load test, green = Zenair CH650 Final load analysis) is shown in the following graph (Fig. 1).

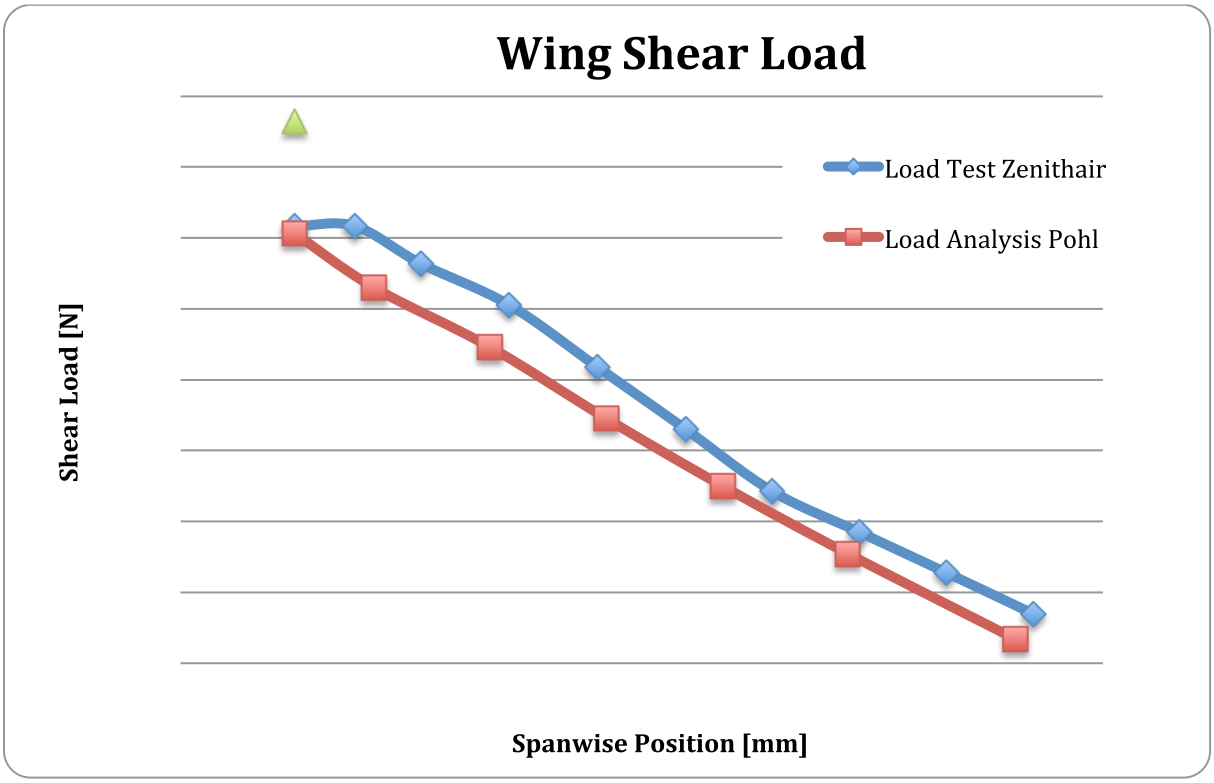

Fig. 1: Wing shear load (analysis and load test)

The modified wing withstands all shear loads up to the most critical aircraft weight (MTOW = 600 kg, 20 L of fuel). Taking into account the results of the strength analysis of the wing with final modifications (*Zenair CH650 Final*), the additional safety margin of the wing strength (shear loads) is greater than +26%.

WING BENDING MOMENT Ultimate Loads			
Load Analysis	**Load Test** ***Zenair CH650 mod.***	**Additional Safety Factor**	**Remarks**
20’129 Nm	**21’412 Nm**	**+ 6 %**	Load Analysis: MTOW = 600 kg, minimum fuel (20 L), conservative load inside fuselage of 245 kg.
Load Analysis	**Strength Analysis** ***Zenair CH650 Final***	**Additional Safety Factor**	**Remarks**
20’129 Nm	**24’515 Nm**	**+ 22 %**	Load Analysis: MTOW = 600 kg, minimum fuel (20 L), conservative load inside fuselage of 245 kg.

The wing bending moment (blue = load analysis Pohl, red = Zenair CH650 mod. load test, green = Zenair CH650 Final load analysis) is shown in the following graph (Fig. 2).

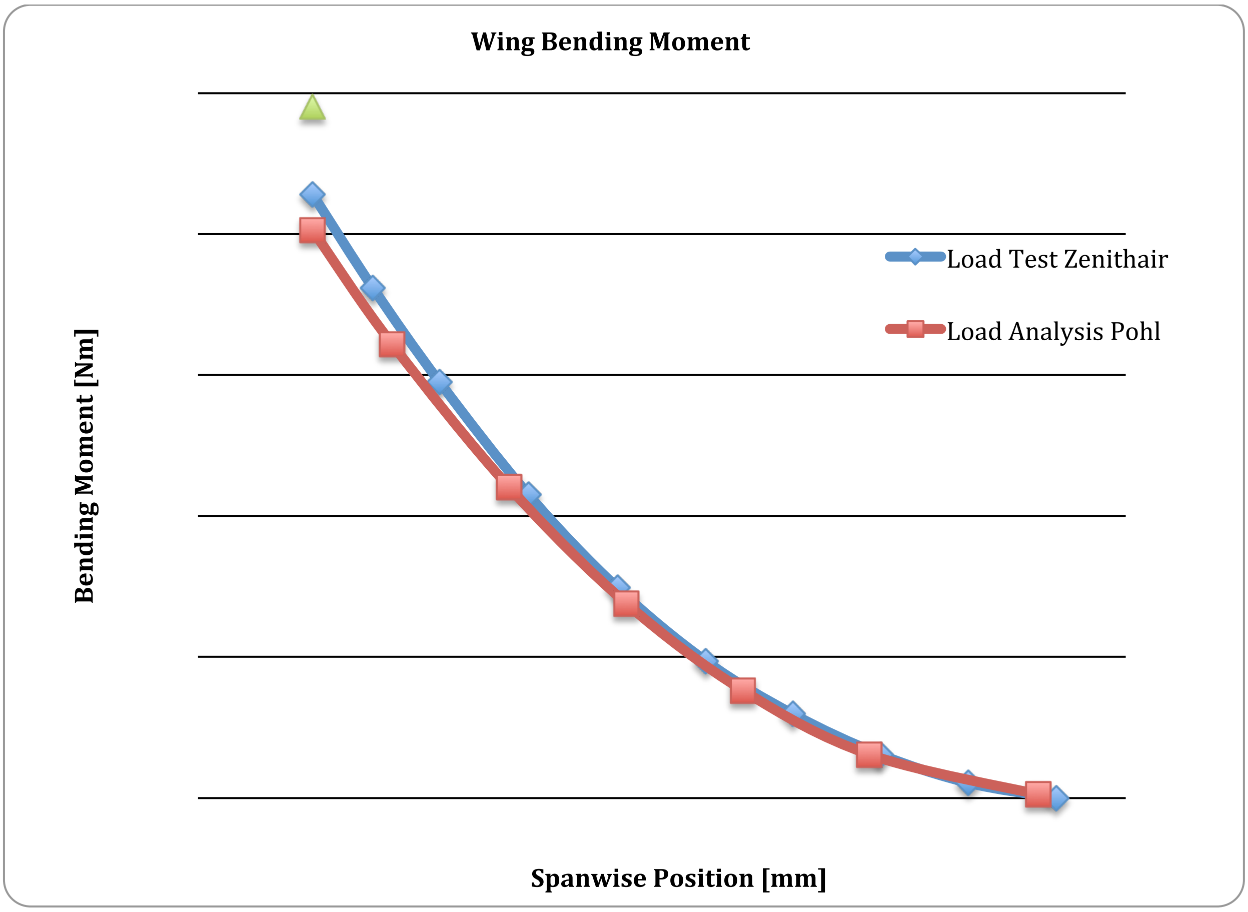

Fig. 2: Wing bending moment (analysis and load test)

The wing withstands all bending moment loads up to the most critical aircraft weight (MTOW = 600 kg, 20 L of fuel). Taking into account the results of the strength analysis of the wing with final modifications (*Zenair CH650 Final*), the additional safety margin of the wing strength (bending moments) is greater than +22%.

2.3 Tangential Force

The tangential force on the wing, calculated in the load analysis, was not specifically tested in one of the load tests.

2.4 Wing Torsion

WING TORSION MOMENT Ultimate Loads			
Load Analysis	**Load Test** ***Zenair CH650 mod.***	**Additional Safety Factor**	**Remarks**
-2'811 Nm	**-2'957 Nm**	**+ 5%**	The wing load test setup was based on both shear/bending moment (MTOW = 600 kg, n = 3,8) and torsion moment.
Load Analysis	**Strength Analysis** ***Zenair CH650 Final***	**Additional Safety Factor**	**Remarks**
-2'811 Nm	**-3'677 Nm**	**+ 31%**	

2.5 Asymmetrical Flight Conditions

WING TORSION MOMENT – ASYMMETRICAL FLIGHT CONDITIONS Ultimate Loads			
Load Analysis	**Load Test** ***CZAW CH601XL***	**Additional Safety Factor**	**Remarks**
-3'463 Nm	**-3'538 Nm**	**+ 2 %**	The shear and bending moment stress on the wing during the CZAW load test was only 50% of the calcu-lated normal loads at MTOW = 600 kg, n = 3,8.
Load Analysis	**Strength Analysis** ***Zenair CH650 Final***	**Additional Safety Factor**	**Remarks**
-3'463 Nm	**-3'677 Nm**	**+ 6 %**	

It is shown by load tests (and proved by the strength analysis), that the wing of the CH601XL-B withstands all required static loads for a MTOW = 600 kg.

3 Fuselage

CZAW CH601XL

The strength of the fuselage was tested on a CZAW CH601XL airframe (engine mount = 574 kg, cabin floor = 1'080 kg, horizontal tail = 273 kg).

FUSELAGE LOADS Ultimate Loads			
Load Analysis	**Load Test** ***CZAW CH601XL***	**Additional Safety Factor**	**Remarks**
Load applied at engine mount			
- 5'311 N	**- 5'628 N**	**+ 6 %**	
Cabin Floor			
- 9'607 N	**- 10'590 N**	**+ 10 %**	
Load applied at horizontal tail attachment			
- 4'271 N	**- 2'726 N**	**- 36 %**	Strength of rear fuselage and horizontal tail attach-ment see below resp. chapter "Horizontal Tail".

Zenair CH650 mod.

The test setup of the modified CH650 wing test (*Zenair CH650 mod.*) was such, that the strength of the rear fuselage/horizontal tail attachment points was also tested (Fig. 3).

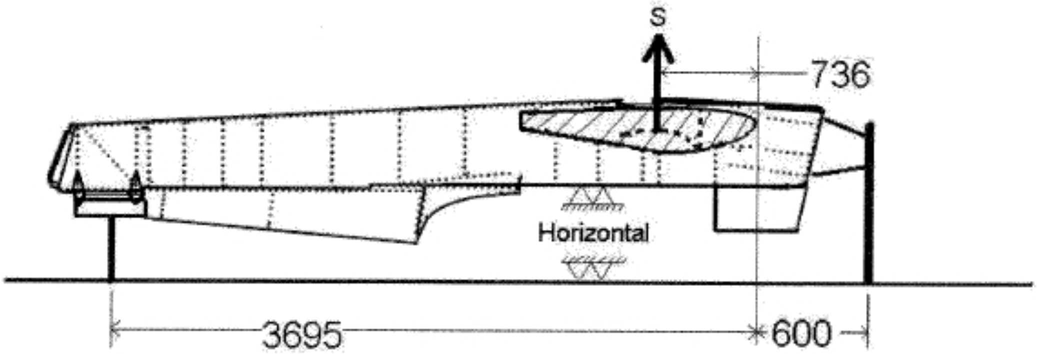

Fig. 3: Zenair CH650 mod. wing load test setup

Maximum load on the wings: $S = 2 \cdot (1'140 + 44) \cdot 9{,}806$=23'221N [2]

Force on horizontal tail attachments: $F_{HT} = S \cdot \frac{736+600}{3695+600} = 7'223N$

FUSELAGE LOADS Ultimate Loads			
Load Analysis	**Load Test** **Zenair CH650 mod.**	**Additional Safety Factor**	**Remarks**
Horizontal Tail attachments **(negative wing lift / load)**			
- 4'271 N	**- 7'223 N**	**+ 69 %**	

It is shown by the load tests, that the fuselage of the CH601XL-B withstands all required static loads (MTOW = 600 kg).

[2] Load on wing: 1'140 kg sand bags / 44 kg wing weight

4 Horizontal Tail

The horizontal tail was tested in negative direction on the CZAW CH601XL airframe. The maximum load on the horizontal tail was 273 kg + 5 kg (weight of the HT), which corresponds to a test load of **2’726 N**.

HORIZONTAL TAIL Ultimate Loads			
Load Analysis	**Load Test CZAW CH601XL**	**Additional Safety Factor**	**Remarks**
-3’270 N	**-2’726 N**	**- 17 %**	For stress analysis of the horizontal tail see following paragraph.

As the tested load does not fully cover the requirements of the load analysis, the ultimate strength of the horizontal tail must be further investigated by a stress analysis.

4.1 Chordwise Load Distribution

According to CS-VLA Appendix A11 the simplified limit surface loadings and distributions for the horizontal tail can be used (Fig. 4, two distributions A and B must be considered).

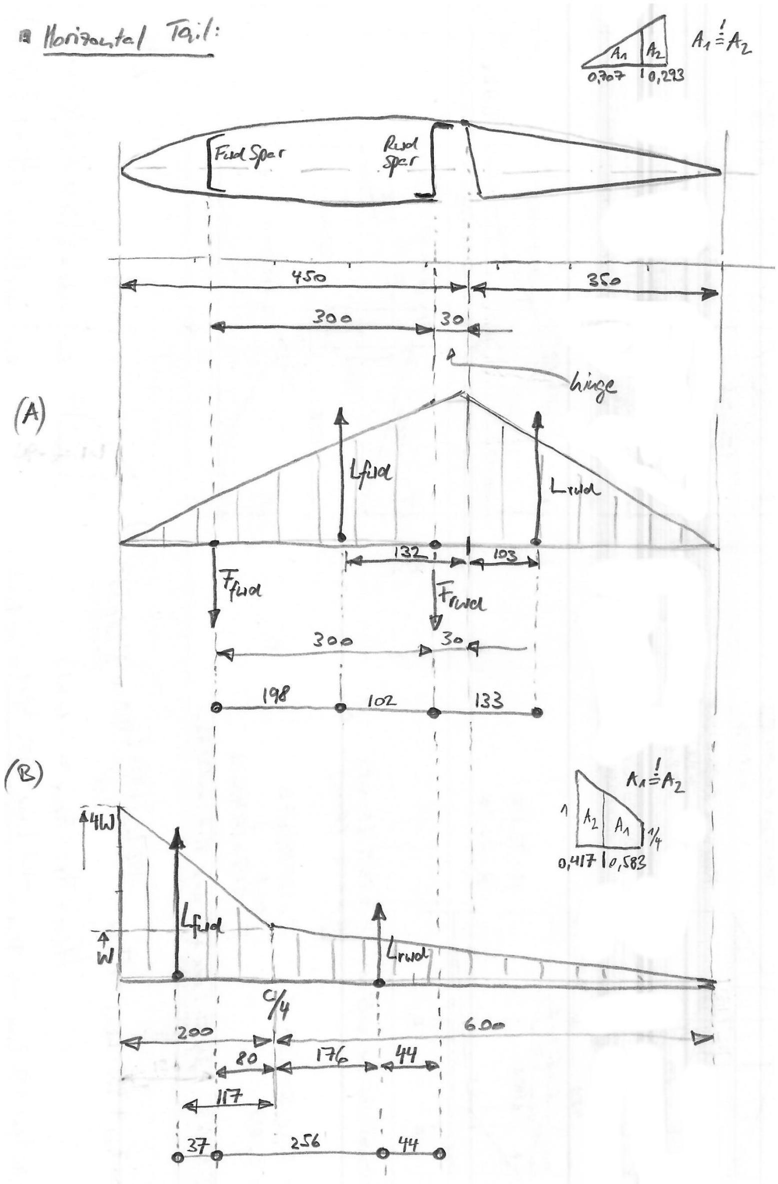

Fig. 4: Chordwise lift distribution horizontal tail

Loads for surface loading/distribution (A)

Forward part of wing lift: $L_{fwd} = \frac{450}{800} \cdot L_{HT,ult} = 0{,}56 \cdot 3'270N = 1'839N$

Rearward part of wing lift: $L_{rwd} = \frac{350}{800} \cdot L_{HT,ult} = 0{,}44 \cdot 3'270N = 1'431N$

Forward spar load: $F_{fwd} = \frac{-133 \cdot L_{rwd} + 102 \cdot L_{fwd}}{300} = -10N$

Rearward spar load: $F_{rwd} = \frac{198 \cdot L_{fwd} + 433 \cdot L_{rwd}}{300} = 3'280N$

Loads for surface loading/distribution (B)

Forward part of wing lift: $L_{fwd} = \frac{5}{8} \cdot L_{HT,ult} = 0{,}63 \cdot 3'270N = 2'044N$

Rearward part of wing lift: $L_{rwd} = \frac{3}{8} \cdot L_{HT,ult} = 0{,}44 \cdot 3'270N = 1'226N$

Forward spar load: $F_{fwd} = \frac{44 \cdot L_{rwd} + 337 \cdot L_{fwd}}{300} = 2'476N$

Rearward spar load: $F_{rwd} = \frac{-37 \cdot L_{fwd} + 256 \cdot L_{rwd}}{300} = 794N$

Maximum (ultimate) spar loads from surface loading/distribution (A) and (B)

Forward spar load: $F_{fwd} = 2'476N$

Rearward spar load: $F_{rwd} = 3'280N$

4.2 Spanwise Load Distribution

The spanwise (uniform) load distribution of the horizontal tail on each spar is (Fig. 5):

Front spar: $\bar{p} = {}^{F_{fwd}}/_{b_{HT}} = {}^{2'476}/_{2{,}3} = 1'077\,\frac{N}{m}$

Rear spar: $\bar{p} = {}^{F_{rwd}}/_{b_{HT}} = {}^{3'280}/_{2{,}3} = 1'426\,\frac{N}{m}$

The ultimate horizontal tail tension load and bending moment at the front and rear attachment points can be calculated accordingly (Fig. 5).

Front spar:

- Ultimate load: $T_{fwd,HT} = 1'120N$
- Ultimate bending moment: $M_{fwd,HT} = 582N$

Rear spar:

- Ultimate load: $T_{rwd,HT} = 1'562N$
- Ultimate bending moment: $M_{fwd,HT} = 855N$

Note for direction of H.T. loading

The horizontal tail upper side / lower side geometry and structure is symmetrical (with a symmetrical airfoil). Therefore it is sufficient to test and analyze the horizontal tail strength in one direction only.

For the horizontal tail attachment points at the rear fuselage, it is also irrelevant if the load is acting up or down. The attachment points at the fuselage and at the H.T. spar are designed such that tear-out strength and tension strength of the joint are higher than the bearing strength of the joint.

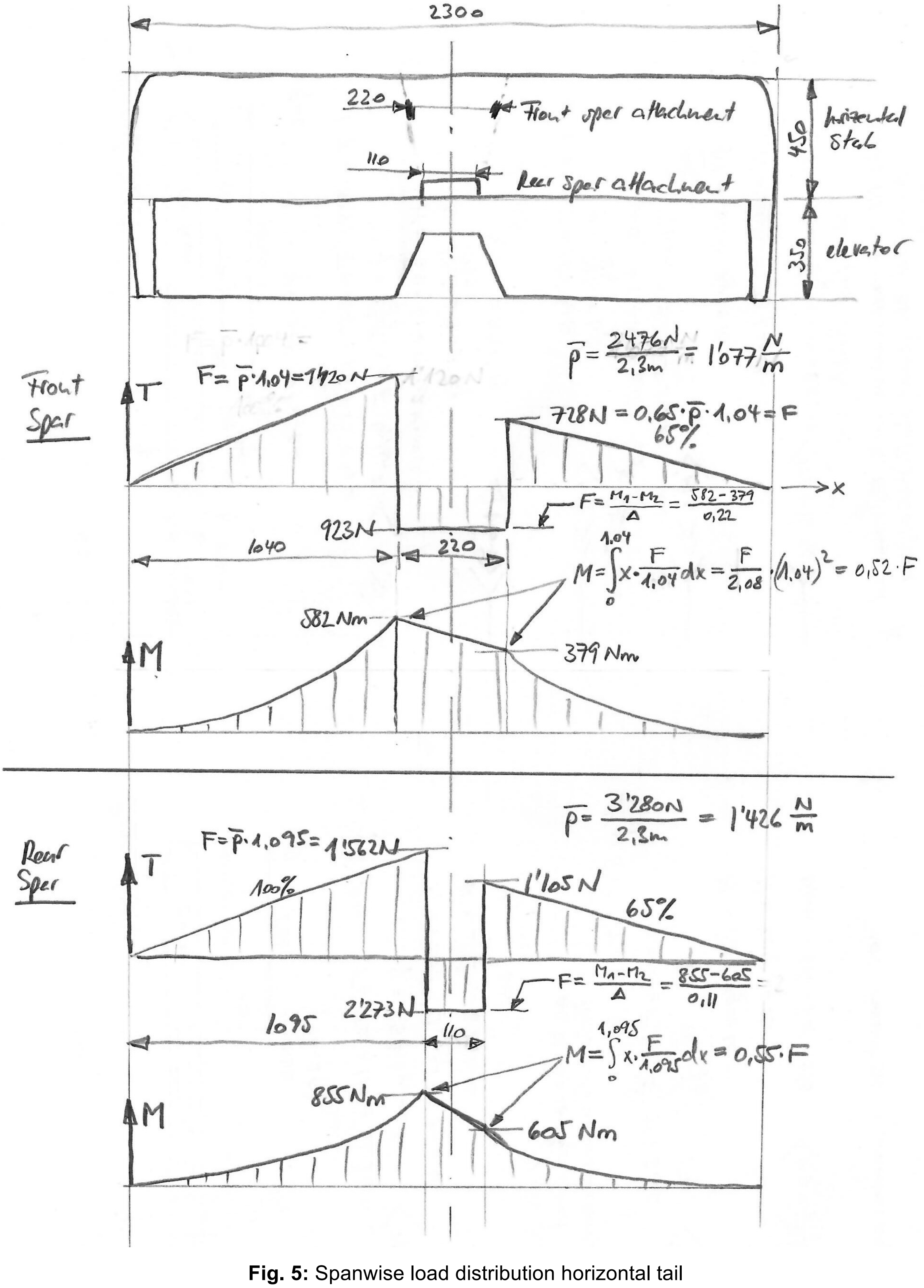

Fig. 5: Spanwise load distribution horizontal tail

The moment of inertia *I* and the first moment of area *Q* for the front spar beam (C-channel) and the rear spar beam (Z-profile) are calculated by using an online calculation tool (*SkyCiv.com*). The shear flow *q* and shear stress *τ* can be calculated accordingly.

Shear flow: $q = T \cdot {}^{Q}/_{I}$

Shear stress: $\tau = {}^{q}/_{t}$

A shear web analysis performed by Chris Heintz [*Ref Zenair Analysis*] considers both buckling shear stress (τ_0) and the maximum shear stress (τ_{poss}) for long webs, no holes, no uprights (Fig. 6). The results are confirmed by [*Ref Hertel "Leichtbau", Timoshenko "theory of elastic stability", NACA ARR Dec 1942, Bruhn*] and by load tests performed by Zenair.

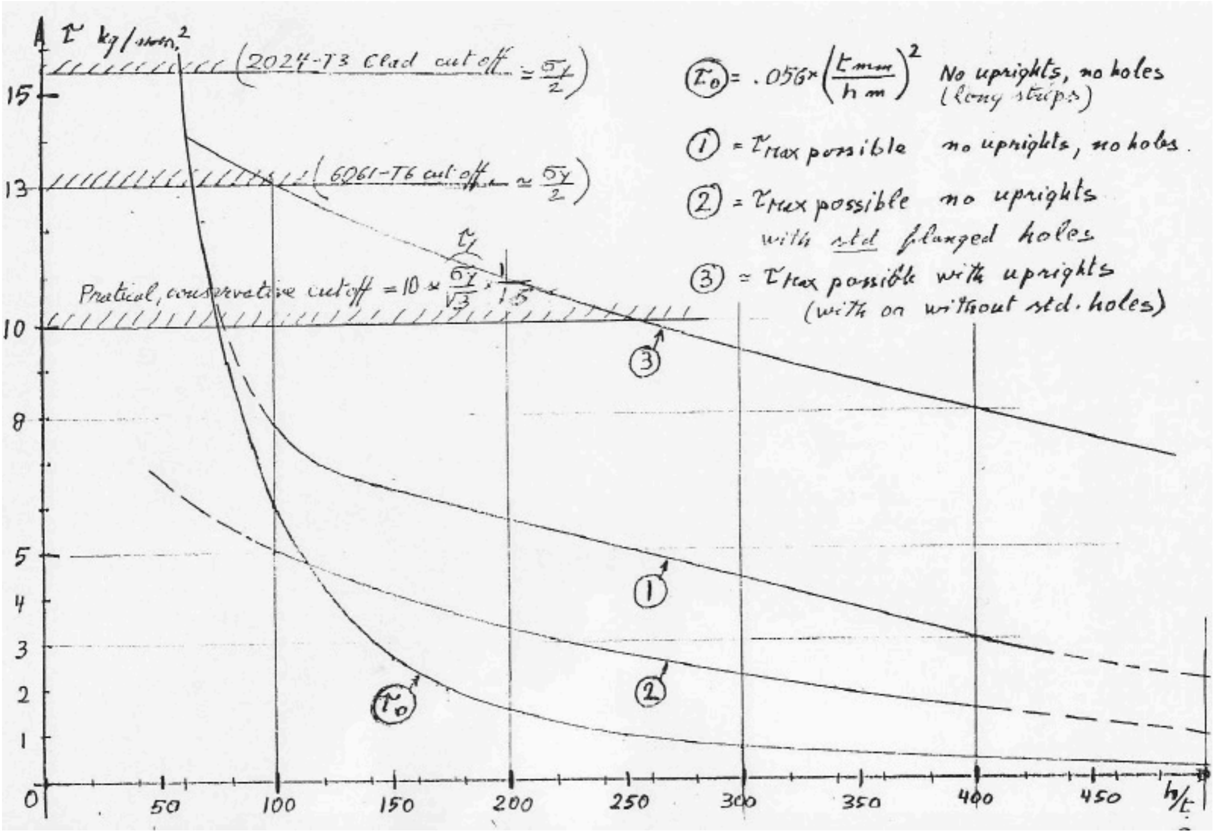

Fig. 6: Shear web analysis (max. shear web versus ratio web height/thickness)

Many compression tests have shown that for extrusions/L-angles a realistic and slightly conservative maximum compression stress is [*Ref 6061-T6 material data sheet, Aerospace Specification Metals*]:

$$\sigma_{poss} = \frac{\sigma_{tu}+\sigma_{ty}}{2} = \frac{310+276}{2} = 293\,\frac{N}{mm^2}$$

For bent-up shaped spars (front spar: C-channel, rear spar: Z-profile) the normal loads due to the wing bending moment exert compression/tension stress on the upper and lower spar cap (here the L-shaped end of the spar profile). According to a theory by "Von Karman" [*Ref Zenair Analysis*], the effective stressed spar cap area can be simplified as follows (Fig. 8).

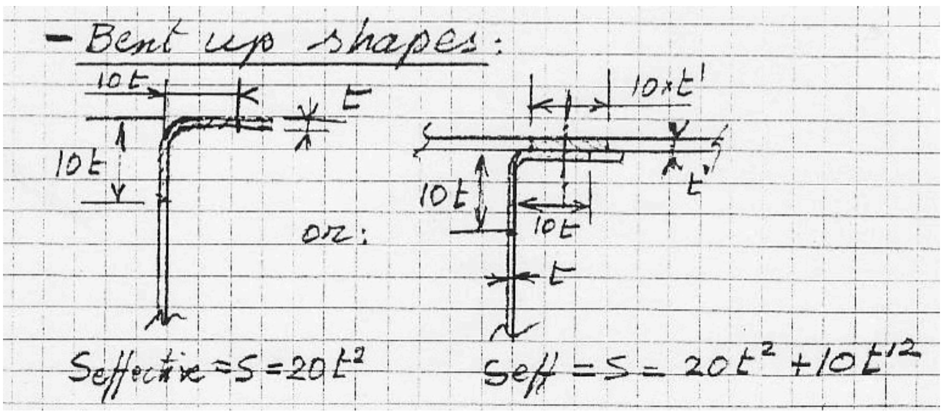

Fig. 7: Bent up shapes, „Von Karman" theory

Effective stress on spar cap: $\sigma_{eff} = \frac{N}{S_{eff}}$ with $N = {}^{M}/_{h_{web}}$

Front spar

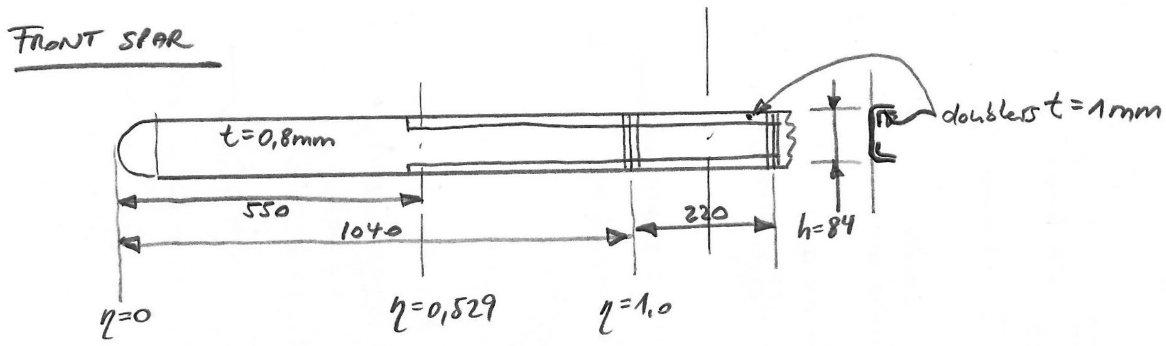

Fig. 8: Front spar geometry

Position η=0,529

Tension at position η (ult): $T_{fwd,0,529} = \eta \cdot T_{fwd,HT} = 0{,}529 \cdot 1'120 = 592N$

Shear flow (ult): $q = 592 \cdot {}^{1'371}/_{94'893} = 8{,}6\,\frac{N}{mm}$

Shear stress (h/t = 105, ult): $\tau = {}^{8{,}6}/_{0{,}8} = 10{,}8\,\frac{N}{mm^2}$ $\ll \tau_0 = 60\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\tau) = {}^{60}/_{10{,}8} - 1 =$ +456%

Bending moment at position η (ult): $M_{fwd,0,529} = \eta^2 \cdot M_{fwd,HT} = 0{,}280 \cdot 582 = 163Nm$

Tension/compression stress (ult): $\sigma_{eff} = \frac{163000}{84} \cdot \frac{1}{20 \cdot 0{,}8^2} = 152\,\frac{N}{mm^2}$ $\ll \sigma_{poss} = 293\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\sigma_{eff}) = {}^{293}/_{152} - 1 =$ +93%

Position η=1,0

Tension at position η (ult): $T_{fwd,1} = T_{fwd,HT} = 1'120N$

Shear flow (ult): $q = 1'120 \cdot {}^{1'371}/_{94'893} = 16{,}2\,\frac{N}{mm}$

Shear stress (h/t = 105, ult): $\tau = {}^{16{,}2}/_{0{,}8} = 20{,}2\,\frac{N}{mm^2}$ $\ll \tau_0 = 60\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\tau) = {}^{60}/_{20{,}2} - 1 =$ +197%

Bending moment at position η (ult): $M_{fwd,1} = M_{fwd,HT} = 582Nm$

Ult. tension/compression stress (ult): $\sigma_{eff} = \frac{582000}{84} \cdot \frac{1}{20 \cdot 0{,}8^2 + 20 \cdot 1^2} = 211\,\frac{N}{mm^2}$ $\ll \sigma_{poss} = 293\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\sigma_{eff}) = {}^{293}/_{211} - 1 =$ +39%

The results are conservative:

- Bending moment M with assumed spanwise constant/uniform distribution
- Loads carried by spar only, neglecting the support of the horizontal tail skins

Rear spar

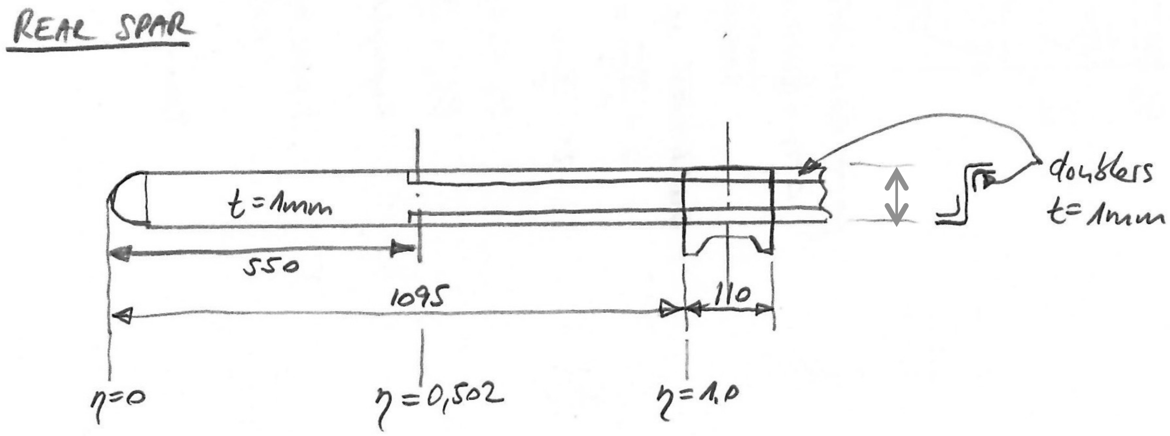

Fig. 9: Rear spar geometry

Position η=0,502

Tension at position η (ult): $T_{rwd,0,502} = \eta \cdot T_{rwd,HT} = 0{,}502 \cdot 1'562 = 784N$

Shear flow (ult): $q = 784 \cdot {}^{1'590}/_{105'080} = 11{,}9\,\frac{N}{mm}$

Shear stress (h/t = 80, ult): $\tau = {}^{11,9}/_{1,0} = 11{,}9\,\frac{N}{mm^2}$ $\ll \tau_0 = 80\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\tau) = {}^{80}/_{11,9} - 1 =$ +572%

Bending moment at position η (ult): $M_{rwd,0,502} = \eta^2 \cdot M_{rwd,HT} = 0{,}252 \cdot 855 = 215Nm$

Tension/compression stress (ult): $\sigma_{eff} = \frac{215000}{80} \cdot \frac{1}{20 \cdot 1{,}0^2} = 134\,\frac{N}{mm^2}$ $\ll \sigma_{poss} = 293\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\sigma_{eff}) = {}^{293}/_{134} - 1 =$ +119%

Position η=1,0

Tension at position η (ult): $T_{rwd,1} = T_{rwd,HT} = 1'562N$

Shear flow (ult): $q = 1'562 \cdot {}^{1'590}/_{105'080} = 23{,}6\,\frac{N}{mm}$

Shear stress (h/t = 105, ult): $\tau = {}^{23,6}/_{1,0} = 23{,}6\,\frac{N}{mm^2}$ $\ll \tau_0 = 80\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\tau) = {}^{80}/_{23,6} - 1 =$ +239%

Bending moment at position η (ult): $M_{rwd,1} = M_{rwd,HT} = 855Nm$

Tension/compression stress (ult): $\sigma_{eff} = \frac{855000}{80} \cdot \frac{1}{20 \cdot 1{,}0^2 + 20 \cdot 1^2} = 267\,\frac{N}{mm^2}$ $\ll \sigma_{poss} = 293\,\frac{N}{mm^2}$

Additional safety factor: $S.F.(\sigma_{eff}) = {}^{293}/_{267} - 1 =$ +10%

The results are conservative:

- Bending moment M with assumed spanwise constant/uniform distribution
- Loads carried by spar only, neglecting the support of the horizontal tail skins

4.3 Horizontal Tail Attachment to Rear Fuselage

CS-VLA Appendix A / table 2 indicates that the load distribution on the horizontal tail should be asymmetrically (for normal category airplanes, see Fig. 5):

- 100% on one side
- 65% on other side

The resulting ultimate loads on the horizontal tail attachment points (including fitting factor of 1,2) are:

Front H.T. attachment (ult): $T_{fwd,fitting} = 1{,}2 \cdot (1'120 + 923) = 2'452N$

Rear H.T. attachment (ult): $T_{rwd,fitting} = 1{,}2 \cdot (1'562 + 2'273) = 4'602N$

Strength data AN3 bolt / Avdel "Avex" A5 rivet

The strength data of the AN3 aircraft bolt (d = 4.76 mm) can be found in known technical literature [*Ref David Peery*]:

Maximum shear AN3 bolt: $F_{AN3,shear} = 9'473N$

Maximum tension AN3 bolt: $F_{AN3,tension} = 9'855N$

The strength of the Avdel "Avex" A5 blind rivet is confirmed by numerous shear tests [*Ref Zenair Analysis*]:

Maximum shear Avdel "Avex" A5: $F_{A5,shear} = 800N$

H.T. front attachment

Attachment plate to H.T. spar: $t = 1.6mm \ / \ Rivets: 8x\ A5$ $F_{A5} = 8 \cdot 800 = 6'400N$

Additional safety factor: $S.F.(HT\ rivets) = {}^{6'400}/_{2'452} - 1 =$ +161%

Attachment plate fuselage: $t = 2\ x\ 1.6mm \ / \ Rivets: 8x\ A5$ $F_{A5} = 8 \cdot 800 = 6'400N$

Additional safety factor: $S.F.(7xA5) = {}^{6'400}/_{2'452} - 1 =$ +161%

Attachment bolt (steel): *AN3*

Additional safety factor: $S.F.(bolt) = {}^{9'473}/_{2'452} - 1 =$ +286%

Bearing strength: $P_b = \frac{T}{d \cdot t} = \frac{2'452}{4{,}76 \cdot 1{,}6} = 319 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 607 \frac{N}{mm^2}$

Additional safety factor: $S.F.(bearing) = {}^{607}/_{319} - 1 =$ +90%

H.T. rear attachment

Attachment plate to H.T. spar: $t = 1.6mm \ / \ Rivets: 10x\ A5$ $F_{A5} = 10 \cdot 800 = 8'000N$

Additional safety factor: $S.F.(HT\ rivets) = {}^{8'000}/_{4'602} - 1 =$ +74%

Attachment plate fuselage: $t = 2\ x\ 1.6mm \ / \ Rivets: 7x\ A5$ $F_{A5} = 7 \cdot 800 = 5'600N$

Additional safety factor: $S.F.(9xA5) = {}^{5'600}/_{4'602} - 1 =$ +22%

Attachment bolt (steel): *AN3*

Additional safety factor: $S.F.(bolt) = {}^{9'473}/_{4'602} - 1 =$ +106%

Bearing strength: $P_b = \frac{T}{d \cdot t} = \frac{4'602}{4{,}76 \cdot 3{,}2} = 302 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 607 \frac{N}{mm^2}$

Additional safety factor: $S.F.(bearing) = {}^{607}/_{302} - 1 =$ +101%

It is shown by the load test and strength analysis, that the horizontal tail of the CH601XL-B and its fuselage attachment points withstand the required static load (MTOW = 600 kg).

5 Vertical Tail

The vertical tail was tested on the CZAW CH601XL airframe. The maximum load on the vertical tail was 99,5 kg, which corresponds to a test load of **976 N**.

VERTICAL TAIL Ultimate Loads			
Load Analysis	**Load Test CZAW CH601XL**	**Additional Safety Factor**	**Remarks**
837 N	**976 N**	**+ 14 %**	Additionally Zenair stress analysis confirms required strength of vertical tail.

The applied load covers the requirements of the load analysis. After testing of the vertical tail there was no sign of plastic deformation. This suggests, that there was an even greater margin than +14% to the structural failure of the vertical tail.

It is shown by the load test, that the vertical tail of the CH601XL-B withstands the required static load (MTOW = 600 kg).

6 Control Surface

6.1 Aileron

The aileron was tested on the CZAW CH601XL airframe with a maximum test weight of 96 kg. This corresponds to a test load of **942 N**. The weight was distributed according to the CS-VLA requirements “Aileron III”.

AILERON Ultimate Loads			
Load Analysis	**Load Test CZAW CH601XL**	**Additional Safety Factor**	**Remarks**
575 N	**976 N**	**+ 70 %**	

6.2 Wing Flap

The wing flap was tested on the CZAW CH601XL airframe with a maximum test weight of 119 kg. This corresponds to a test load of **1’170 N**. The weight was distributed according to the CS-VLA requirements “Wing Flap IV”.

WING FLAP Ultimate Loads			
Load Analysis	**Load Test CZAW CH601XL**	**Additional Safety Factor**	**Remarks**
878 N	**1’170 N**	**+ 33 %**	

6.3 Aileron + Elevator Trim Tab

The trim tabs were not tested on an actual structure.

It is shown by the load tests, that the ailerons and wing flaps of the CH601XL-B withstand all required static loads (MTOW = 600 kg).

7 Control System

The strength of the control system was tested in the CZAW CH601XL load test, however the loads applied did not correspond to the requirements of CS-VLA.

Stress analysis

Consecutively a stress analysis for the primary control system (stick ➔ elevator / stick ➔ ailerons / pedals ➔ rudder) is created.

Control operational tests

In addition Zenair performed an operational test on all primary flight controls. The corresponding control surface was loaded to limit resp. ultimate load (aileron: load on both control surfaces, one up/one down). Then the control stick resp. rudder pedal was moved all the way to the control stops in both directions and the deflections were measured. The results are at the end of the following chapters for each primary flight control.

7.1 Elevator Control

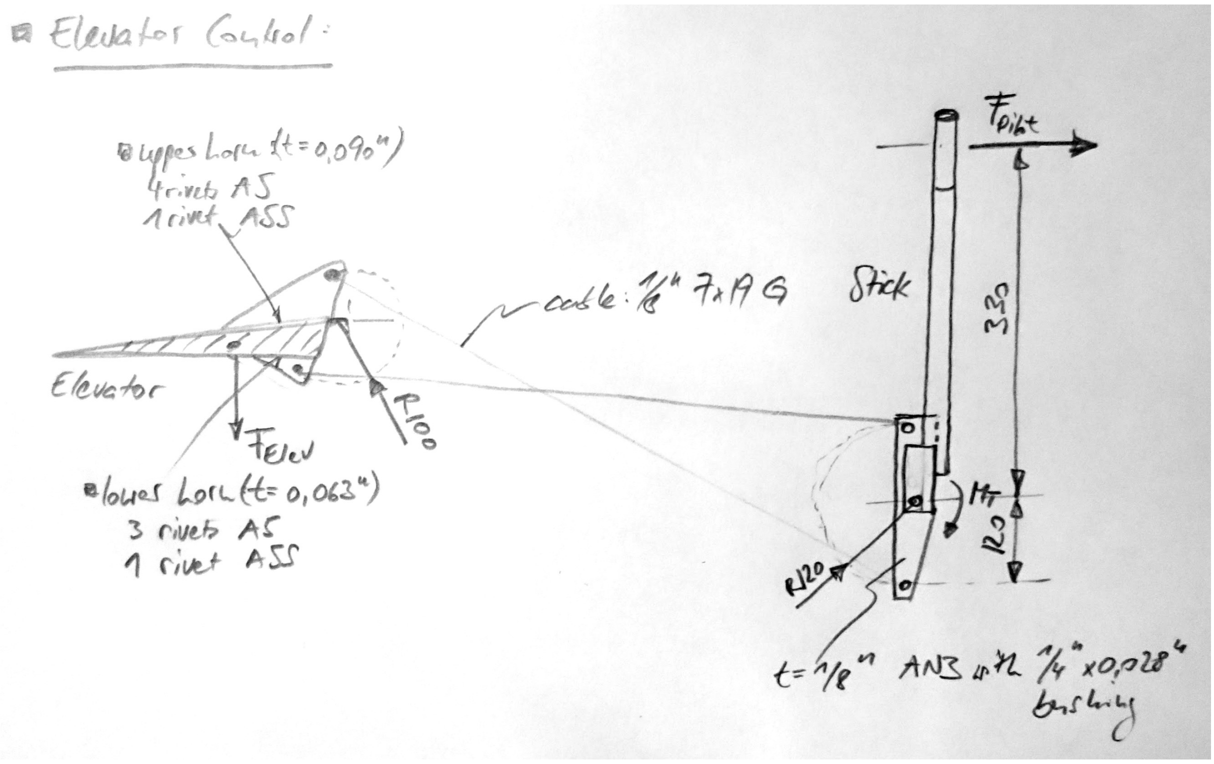

Fig. 10: Elevator control system

Control stick

Pilot force on (aileron) control stick: $F_{S,Elev} = 445N$ *see Load Analysis*

Bending moment control stick: $M_{S,Elev} = F_{S,Elev} \cdot 0{,}33 = 147Nm$

Max. stress in control stick: $\sigma_{S,Elev} = \frac{M_{S,Elev}}{W_{S,ax}} = \frac{M_{S,Elev}}{\frac{\pi}{32}\left(\frac{D^4-d^4}{D}\right)} = \frac{147'000}{\frac{\pi}{32}\left(\frac{28{,}6^4-26{,}8^4}{28{,}6}\right)} = 280\,\frac{N}{mm^2}$

Safety factor control stick (bending): $S.F. = \frac{670}{280} = 2{,}39$ *material: Steel 4130N*

Additional safety factor: $S.F.(stick) = {}^{2{,}39}/_{1{,}5} - 1 = +60\%$

Control stick bearing load (AN3): $F_{S,AN3} \approx 2 \cdot F_{Cable,max} = 2 \cdot 1'403 = 2'851N$ *(conservative!)*

Bearing strength (AN3 <> t=1/8"): $P_b = \frac{F_{S,AN3}}{d \cdot t} = \frac{2'851}{4{,}76 \cdot 3{,}2} = 187 \frac{N}{mm^2} \ll \sigma_{bear} = 607 \frac{N}{mm^2}$

Safety factor bearing: $S.F. = \frac{607}{187} = 3{,}25$ *AN3 in steel 4130N t = 1/8"*

Additional safety factor: $S.F.(bearing) = \left({}^{3{,}25}/_{2{,}0}\right) - 1 =$ +62%

Max. stress control horn: $\sigma_{S,elev\_horn} = \frac{M_{S,Elev}}{W} = \frac{M_{S,Elev}}{\frac{1}{6} t \cdot b^2} = \frac{147'000}{\frac{1}{6} 3{,}2 \cdot 37^2} = 201 \frac{N}{mm^2}$

Safety factor control horn: $S.F. = \frac{670}{201} = 3{,}33$ *material: Steel 4130N*

Additional safety factor: $S.F.(elevstick\_horn) = {}^{3{,}33}/_{1{,}5} - 1 =$ +50%

Control cables

The elevator cable tension should be F_{Cable} = *40 lbs +/- 5 lbs* (*Zenair Service Bulletin [Ref]*).

Tension in control cables: $F_{Cable,max} = \frac{M_{S,Elev}}{0{,}12} + F_{Cable} = \frac{147}{0{,}12} + \frac{45}{2{,}2} \cdot 9{,}806 = 1'426N$

Safety factor control cable: $S.F. = \frac{8'900}{1'426} = 6{,}24$ *cable: 1/8"-7x19G*

Additional safety factor: $S.F.(elev\_cable) = {}^{6{,}24}/_{1{,}5} - 1 =$ +316%

Safety factor bearing bolt (AN3): $S.F. = 2 \cdot \frac{9'473}{1'426} = 13{,}3$ *(2x as shackle "double sided")*

Additional safety factor: $S.F.(bolt) = {}^{13{,}3}/_{2{,}0} - 1 =$ +564%

Elevator horn

Tension force on each elev horn: $F_{elev,horn} = F_{Cable,max} = 1'426N$

Shear strength A5S rivet: $F_{A5S,shear} \approx 3'000N$ *limited by rivet hole strength*

Ultimate rivet strength (lower horn = 3x resp. upper horn = 4x rivet A5, 1x rivet A5S)

Lower (critical) elevator horn: $F_{elev\_horn,A5} = 3 \cdot F_{A5,shear} + F_{A5S,shear}$

$F_{elev\_horn,A5} = 3 \cdot 800 + 3'000 = 5'400N$

Safety factor rivets A5/A5S: $S.F. = {}^{5'400}/_{1'426} = 3{,}79$

Additional safety factor: $S.F.(A5\_elev\_horn) = {}^{3{,}79}/_{1{,}5} - 1 =$ +153%

Bearing strength at (critical) lower elevator horn (AN3 <> t=0,063"): $P_b = \frac{T}{d \cdot t} = \frac{1'426}{4{,}76 \cdot 1{,}6} = 187 \frac{N}{mm^2} \ll \sigma_{bear} = 386 \frac{N}{mm^2}$

Safety factor bearing: $S.F. = \frac{386}{187} = 2{,}06$ *AN3 in 6061-T6 t = 0,063"*

Additional safety factor: $S.F.(bearing) = \left({}^{2{,}06}/_{2{,}0}\right) - 1 =$ +3%

Elevator: Control operational tests (by Zenair)

The limit and ultimate test load were achieved by putting load on the elevator, then counteract by the control stick all the way to the control stops.

Limit test load at control stick: $M_{Elev,lim} = 123Nm$

Ultimate test load at control stick: $M_{Elev,ult} = 183Nm$

Safety factor elevator control system: $S.F. = \frac{M_{Elev,ult}}{M_{S,Elev}} = \frac{183}{147} = 1{,}25$

ELEVATOR DEFLECTION				
CASE	ELEVATOR			
Theoretic deflection	UP 30 - 32	DOWN 27 - 30		
Measured no load	31.5	27.5		
At limit load	29.5	25.5		
At ultimate load	28.0	24.0		

No jamming, interference, excessive friction nor excessive loss of deflection was present neither at limit nor at ultimate load.

The elevator control stops were tested at ultimate load.

7.2 Aileron Control

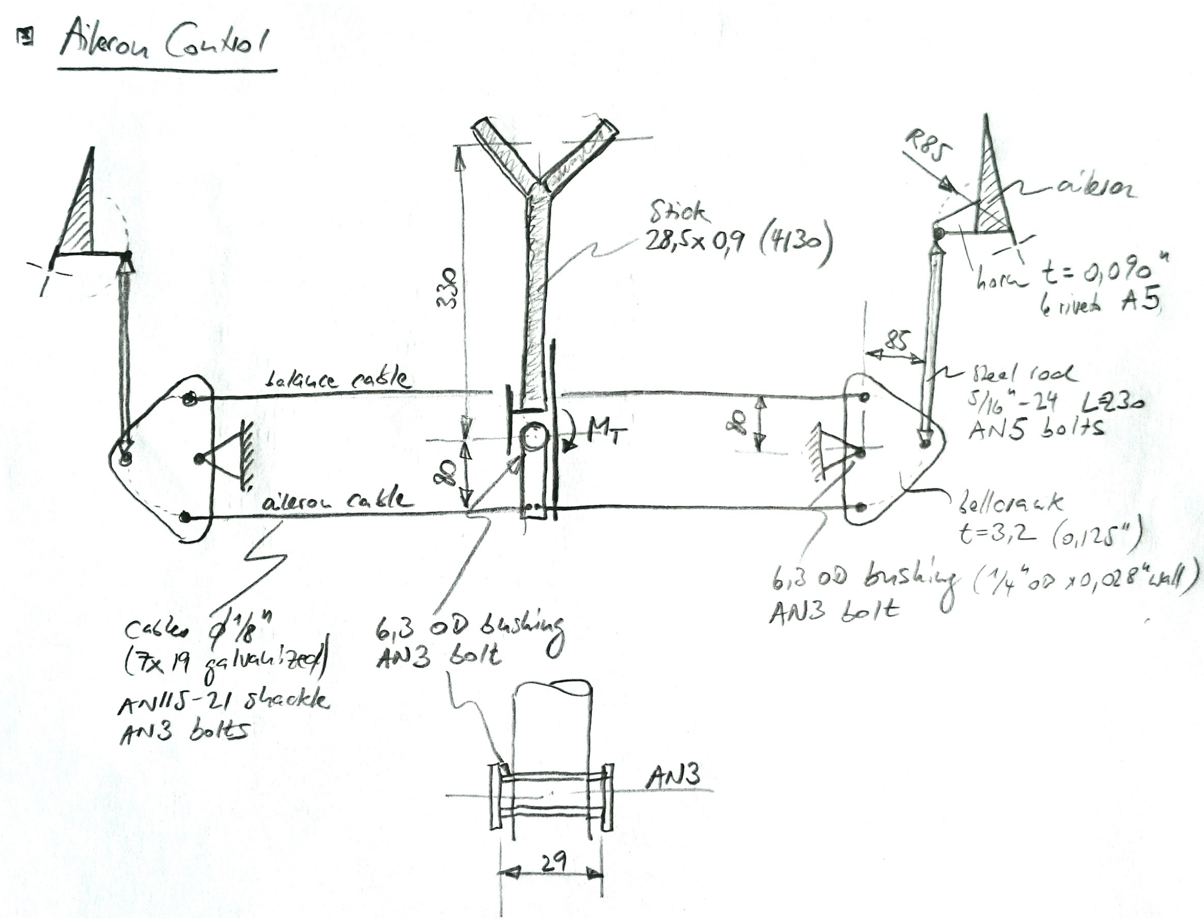

Fig. 11: Aileron control system

Control stick

Pilot force on (roll) control stick: $F_{S,Ail} = 264N$ *see Load Analysis*

Bending moment control stick: $M_{S,Ail} = F_{S,Ail} \cdot 0{,}33 = 87{,}1Nm$

Max. stress in control stick: $\sigma_{S,Ail} = \frac{M_{S,Ail}}{W_{S,ax}} = \frac{M_{S,Ail}}{\frac{\pi}{32}\cdot\left(\frac{D^4-d^4}{D}\right)} = \frac{87'100}{\frac{\pi}{32}\cdot\left(\frac{28{,}6^4-26{,}8^4}{28{,}6}\right)} = 166\,\frac{N}{mm^2}$

Safety factor control stick (bending): $S.F. = \frac{670}{166} = 4{,}04$ *material: Steel 4130N*

Additional safety factor: $S.F.(stick) = {}^{4{,}04}/_{1{,}5} - 1 =$ +169%

Shear on AN3-bearing bolt (limit): $F_{S,AN3} = \frac{M_{S,Ail}}{d_{S,torque}} = \frac{87.1}{0{,}0277} = 3'146N$

Safety factor AN3-bolt: $S.F. = \frac{9'473}{3'146} = 3{,}01$ $\gg 2{,}0\ (S.F. pivot\ bearing)$

Additional safety factor: $S.F.(bearing) = {}^{3{,}01}/_{2{,}0} - 1 =$ +51%

Torque tube

Max. stress in torque tube: $\sigma_{tube} = \frac{M_{S,Ail}}{W_p} = \frac{M_{S,Ail}}{\frac{\pi}{16}\cdot\left(\frac{D^4-d^4}{D}\right)} = \frac{87'100}{\frac{\pi}{16}\cdot\left(\frac{28{,}6^4-26{,}8^4}{28{,}6}\right)} = 83\,\frac{N}{mm^2}$

Safety factor torque tube (torque): $S.F. = \frac{670}{83} = 8{,}07$ *material: Steel 4130N*

Additional safety factor: $S.F.(torque\_tube) = {}^{8{,}07}/_{1{,}5} - 1 =$ +438%

Max. stress torque tube control horn: $\sigma_{tube\_horn} = \frac{M_{S,Ail}}{W} = \frac{M_{S,Ail}}{\frac{1}{6} \cdot t \cdot b^2} = \frac{87'100}{\frac{1}{6} 3{,}2 \cdot 32^2} = 159 \frac{N}{mm^2}$

Safety factor torque tube control horn: $S.F. = \frac{670}{159} = 4{,}21$ *material: Steel 4130N*

Additional safety factor: $S.F.(torque\_horn) = {}^{4{,}21}/_{1{,}5} - 1 =$ +181%

Control cables

The aileron cable tension should be F_{Cable} *= 30 lbs +/- 5 lbs* (*Zenair Service Bulletin [Ref]*).

Max. tensile force on control cable: $F_{Cable,max} = \frac{M_{S,Ail}}{r_{torque\_horn}} + F_{Cable} = \frac{87{,}1}{0{,}08} + \frac{35}{2{,}2} \cdot 9{,}806 = 1'245N$

Safety factor control cable: $S.F. = \frac{8'900}{1'245} = 7{,}15$ *cable: 1/8"-7x19G*

Additional safety factor: $S.F.(aileron\_cable) = {}^{7{,}15}/_{1{,}5} - 1 =$ +377%

Safety factor bearing bolt (AN3): $S.F. = 2 \cdot \frac{9'473}{1'245} = 15{,}2$ *(2x as shackle "double sided")*

Additional safety factor: $S.F.(bolt) = {}^{15{,}2}/_{2{,}0} - 1 =$ +660%

Bearing strength (AN3 <> t=1/8")
conservatively with bearing strength
for Aluminium 6061-T6: $P_b = \frac{T}{d \cdot t} = \frac{1'245}{4{,}76 \cdot 3{,}2} = 81 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 386 \frac{N}{mm^2}$

Safety factor bearing
(torque tube horn and bellcrank): $S.F. = \frac{386}{81} = 4{,}77$ *AN3 in 6061-T6 t = 1/8"*

Additional safety factor: $S.F.(bearing) = \left({}^{4{,}77}/_{2{,}0}\right) - 1 =$ +138%

Bellcrank

Resultant force in bellcrank bearing: $F_{bellcrank} \approx \sqrt{\left(F_{T,max} + \frac{F_{T,max}}{2}\right)^2 + F_{T,max}{}^2} = 1{,}8 \cdot F_{T,max}$

$F_{bellcrank} \approx 1{,}8 \cdot 1'245 = 2'244N$

Safety factor bearing bolt (AN3): $S.F. = 2 \cdot \frac{9'473}{2'244} = 8{,}44$ *(2x as bearing "double sided")*

Additional safety factor: $S.F.(bolt) = {}^{8{,}44}/_{2{,}0} - 1 =$ +322%

Compression/tension in steel rod: $\sigma_{ail,rod} = \frac{1}{2} \cdot \frac{M_{S,Ail}}{r_{torque_{horn}}} \cdot \frac{1}{\pi \cdot \left(\frac{d_{ail_{rod}}}{2}\right)^2} = \frac{1}{2} \cdot \frac{87{,}1}{0{,}08} \cdot \frac{1}{\pi \cdot 3{,}30^2} = 16 \frac{N}{mm^2}$

Comment: *absolutely uncritical, also against buckling* $\lll$

Aileron horn

Resultant force on aileron horn: $F_{ail,horn} = \frac{M_{S,Ail}}{80} \cdot \frac{80}{85} = \frac{87'100}{85} = 1'025N$

Ultimate rivet strength (6x rivet A5): $F_{ail\_horn,A5} = 6 \cdot F_{A5,shear} = 6 \cdot 800 = 4'800N$

Safety factor rivets A5: $S.F. = {}^{4'800}/_{1'025} = 4{,}68$

Additional safety factor: $S.F.(A5\_ailhorn) = {}^{4{,}68}/_{1{,}5} - 1 =$ +212%

Bearing strength (AN3 <> t=0,090"): $P_b = \frac{T}{d \cdot t} = \frac{1'025}{4{,}76 \cdot 2{,}3} = 94 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 386 \frac{N}{mm^2}$

Safety factor bearing
(torque tube horn and bellcrank): $S.F. = \frac{386}{94} = 4{,}11$ *AN3 in 6061-T6 t = 0,09"*

Additional safety factor: $S.F.(bearing) = \left({}^{4{,}11}/_{2{,}0}\right) - 1 =$ +105%

Aileron: Control operational tests (by Zenair)

The limit and ultimate test load were achieved by putting loads on both ailerons (one up/one down), then counteract by the control stick all the way to the control stops.

Limit test load each aileron: $M_{1Ail,lim} = 44{,}2Nm$ $\approx \left(\frac{1}{2} \cdot M_{S,Ail} = 43{,}6Nm\right)$

Ultimate test load each aileron: $M_{1Ail,ult} = 66{,}3Nm$

Safety factor aileron control system: $S.F. = \frac{2 \cdot M_{1Ail,ult}}{M_{S,Ail}} = \frac{2 \cdot 66{,}3}{87{,}1} = 1{,}52$

Additional safety factor: $S.F.(aileron\_opstest) = \left({}^{1{,}52}/_{1{,}0}\right) - 1 =$ +2%

AILERON DEFLECTION				
CASE	RIGHT AILERON		LEFT AILERON	
Theoretic deflection	UP 10.5 – 12.5	DOWN 10.5 – 12.5	UP 10.5 – 12.5	DOWN 10.5 – 12.5
Measured no load	11.8	11.3	11.2	11.5
At limit load	10.9	10.5	10.4	10.6
At ultimate load	10.3	9.8	9.8	10.0

No jamming, interference, excessive friction nor excessive loss of deflection was present neither at limit nor at ultimate load.

The aileron control stops were tested by further increasing the load on the control surface:

Control stop test: $M_{1Ail,stop} = 71{,}6Nm$

7.3 Rudder Control

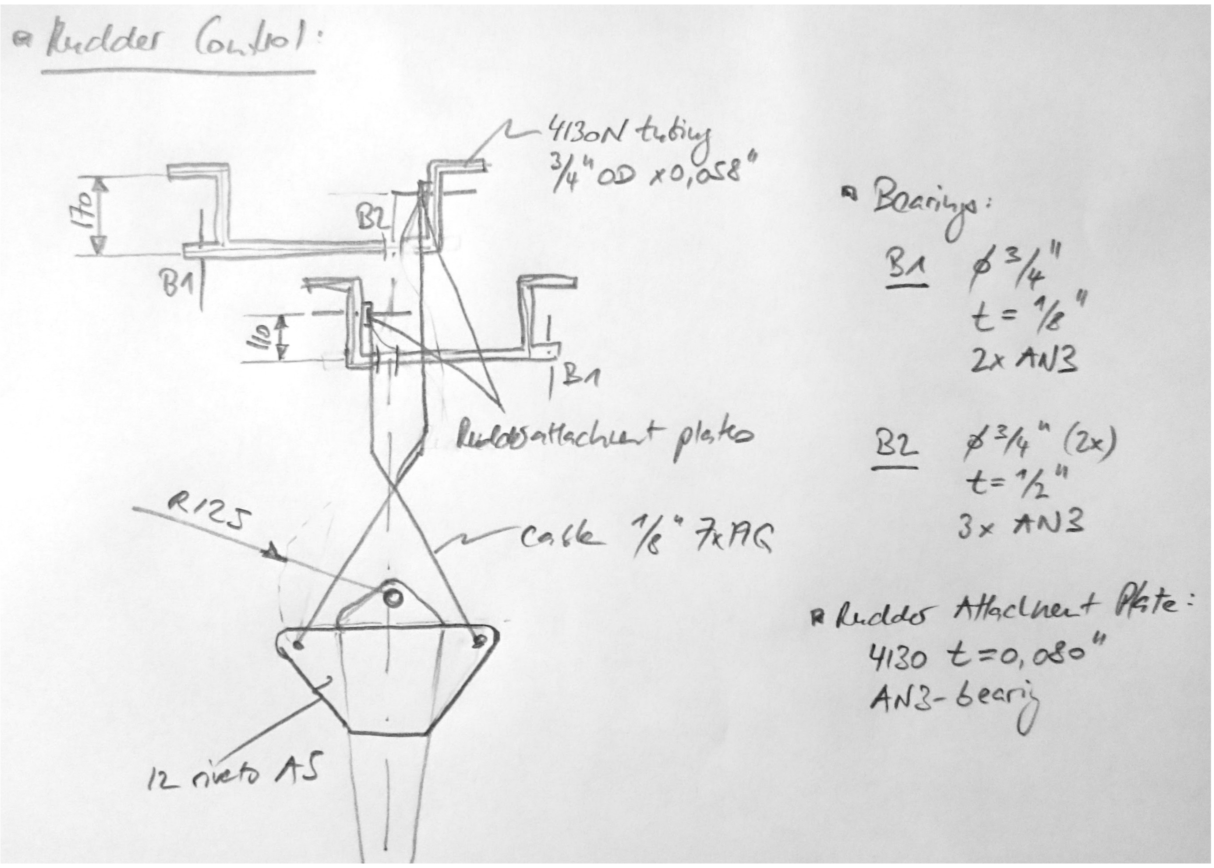

Fig. 12: Rudder control system

Rudder pedals

The critical case for rudder control system (rudder pedals, control cable, control horns) when both pedals are pushed simultaneously:

Pilot force on each rudder pedal: $F_{Rud} = 1000N$ *see Load Analysis*

Bending moment rudder pedal: $M_{Rud} = F_{Rud} \cdot 0{,}17 = 170Nm$

Max. stress in rudder pedal: $\sigma_{Rud} = \frac{M_{Rud}}{W_{S,ax}} = \frac{M_{Rud}}{\frac{\pi}{32} \cdot \left(\frac{D^4-d^4}{D}\right)} = \frac{170'000}{\frac{\pi}{32} \cdot \left(\frac{19{,}1^4-15{,}1^4}{19{,}1}\right)} = 401 \frac{N}{mm^2}$

Safety factor rudder pedals (bending): $S.F. = \frac{670}{401} = 1{,}67$ *material: Steel 4130N*

Additional safety factor: $S.F.(rudder) = {}^{1{,}67}/_{1{,}5} - 1 =$ +11%

Shear force on pedal bearing (side): $F_{B,RudPedal} = F_{Rud} \cdot \frac{60}{170} = 353N$

Max. shear in bearing: $P_b = \frac{T}{d \cdot t} = \frac{353}{19{,}1 \cdot 3{,}2} = 6 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 386 \frac{N}{mm^2}$

Comment: *absolutely uncritical, all three rudder pedal bearings* ≪≪≪

Attachment of bearings: *with AN3 bolts on fuselage floor, absolutely uncritical* ≪≪≪

Control cables

The rudder cable tension should be F_{Cable} *= 22 lbs +/- 5 lbs* (*Zenair Service Bulletin [Ref]*).

Max. tensile force on control cable: $F_{Cable,max} = 1'000N$

Safety factor control cable: $S.F. = \frac{8'900}{1'000} = 8{,}90$ *cable: 1/8"-7x19G*

Additional safety factor: $S.F.(aileron\_cable) = {}^{8{,}90}/_{1{,}5} - 1 =$ +493%

Pedals control cable attachment horn bearing strength (AN3 <> t=0,080"): $P_b = \frac{T}{d \cdot t} = \frac{1'000}{4{,}76 \cdot 2{,}0} = 105 \frac{N}{mm^2}$ $\ll \sigma_{bear} = 386 \frac{N}{mm^2}$

Safety factor bearing conservatively for Alu 6061-T6: $S.F. = \frac{386}{105} = 3{,}68$ *AN3 in 6061-T6 t = 0,08"*

Additional safety factor: $S.F.(bearing) = \left({}^{3{,}68}/_{2{,}0}\right) - 1 =$ +84%

Safety factor bearing bolt (AN3): $S.F. = 2 \cdot \frac{9'473}{1'000} = 18{,}9$ *(2x as shackle "double sided")*

Additional safety factor: $S.F.(bolt) = {}^{18{,}9}/_{2{,}0} - 1 =$ +847%

Rudder horn

Resultant force on rudder horn: $F_{Rud,max} = 2 \cdot F_{Rud} = 2'000N$

Ultimate rivet strength (12x rivet A5): $F_{ail\_horn,A5} = 12 \cdot F_{A5,shear} = 12 \cdot 800 = 9'600N$

Safety factor rivets (A5): $S.F. = \frac{9'600}{2'000} = 4{,}8$ *(2x as shackle "double sided")*

Additional safety factor: $S.F.(A5\_rudderhorn) = {}^{4{,}8}/_{1{,}5} - 1 =$ +220%

Bearing strength cable attachment analog to bearing strength at rudder pedal cable horn attachment.

Rudder: Control operational tests (by Zenair)

The limit and ultimate test load were achieved by putting load on one side of the rudder, then counter-act by the rudder pedals all the way to the control stops.

Limit test load rudder pedal: $M_{Rud,lim} = 144Nm$

Ultimate test load rudder pedal: $M_{Rud,ult} = 216Nm$

Safety factor rudder control system: $S.F. = \frac{M_{Rud,ult}}{M_{Rud}} = \frac{216}{170} = 1{,}27$

RUDDER DEFLECTION				
CASE	RUDDER			
Theoretic deflection	LEFT 20 – 22	RIGHT 20 - 22		
Measured no load	22.0	21.2		
At limit load	20.1	19.4		
At ultimate load	18.5	18.0		

No jamming, interference, excessive friction nor excessive loss of deflection was present neither at limit nor at ultimate load.

The rudder control stops were tested at ultimate load.

It is shown by the a stress analysis and by control operational load tests, that the primary control system of the CH601XL-B withstand all required static loads (MTOW = 600 kg).

8 Engine Mount

8.1 Load tests

CZAW CH601XL-B

The Rotax 912 ULS engine mount was load tested in vertical direction on the CZAW CH601XL-B aircraft only. The maximum load on the engine mount was 574 kg. Neither lateral + thrust force nor engine torque was applied during the test.

CZAW SportCruiser

The engine mount for the CZAW CH601XL-B is identical to the engine mount of its succeeding model CZAW SportCruiser. A thorough load test was performed on the engine mount of the SportCruiser [Ref]. Three load test cases based on ASTM F-2254-04 were performed. The test results cover the CS-VLA requirements.

ENGINE MOUNT – VERTICAL LOAD + TORQUE (CS-VLA 361) Ultimate Load			
Load Analysis	**Load Test Case 1 CZAW SportCruiser**	**Additional Safety Factor**	**Remarks**
4’304 N	**5’648 N** *(576 kg)*	**+ 31 %**	No permanent deformations and failures were found after the load was applied to the engine mount.
882 Nm	**1’118 Nm** *(114 kg.m)*	**+ 27 %**	

ENGINE MOUNT – SIDE LOAD (CS-VLA 363) Ultimate Load			
Load Analysis	**Load Test Case 3 CZAW SportCruiser**	**Additional Safety Factor**	**Remarks**
1’506 N	**2’118 N** *(216 kg)*	**+ 41 %**	No permanent deformations and failures were found after the load was applied to the engine mount.

8.2 Finite element analysis (FEA)

A finite element analysis prepared by Martin Pohl [Ref], confirms the strength of the engine mount. The FEA was based on the open-source software Frame3DD. Frame3DD is a program for the static and dynamic structural analysis of two- and three-dimensional frames and trusses with elastic and geometric stiffness [Ref].

It is shown by load tests and proved by the FEA strength analysis, that the Rotax 912ULS engine mount of the CH601XL-B withstands the required static loads (MTOW = 600 kg).

9 Ground Loads

The drop tests on the CZAW CH601XL aircraft with standard nosewheel and composite main gear were performed for a MTOW = 450 kg (European ultralight category, drop weight = 329 kg, limit drop height = 0,25 m, ultimate drop height = 0,38 m). They do not cover the requirement for a MTOW = 600 kg.

9.1 Main Gear: Drop Tests CZAW SportCruiser

The strength of the main gear is confirmed by load tests on the CZAW SportCruiser. The CZAW SportCruiser is CZAW's successor of the CH601XL-B (also sold temporarily by Piper Aircraft as PiperSport) and uses the exact same composite main gear legs and gear leg mounting as the CH601XL-B. CZAW performed several drop and load tests on the main gear for a MTOW = 600 kg according to CS-VLA requirements.

Test 1: Level landing with inclined reactions

	CS-VLA	Drop Test CZAW	
Weight	426 kg	436 kg	**+ 2 %**
Drop height	28.9 cm	28.9 cm	**OK**

Test 2: Tail-down landing

	CS-VLA	Drop Test CZAW	
Weight	426 kg	436 kg	**+ 2%**
Drop height	28.9 cm	28.9 cm	**OK**

Test 3: Ground dynamic load test

	CS-VLA	Drop Test CZAW	
Weight	426 kg	436 kg	**+ 2%**
Drop Height	65.0 cm	65.8 cm	**+ 1%**

9.2 Main Gear: Load Tests CZAW SportCruiser

Test 4: Side load conditions

	CS-VLA	Test CZAW	
Vertical load	600 kg	605 kg	**+ 1%**
Inboard sideload	450 kg	454 kg	**+ 1%**
Outboard sideload	300 kg	317 kg	**+ 6%**

Test 5: Braked roll conditions

	CS-VLA	Test CZAW	
Vertical load	600 kg	765 kg	**+ 28%**
Brake load (rearward)	480 kg	555 kg	**+ 16%**

9.3 Nose Gear: Load Test Zenair CH600/CH601

The strength of the nose gear is proven by load tests on the CH601HDS (predecessor of the CH601XL). The test results (Fig. 13) are part of the document “Zenair CH6001/CH601 Stress Analysis” by Chris Heintz (1990) [*Ref*].

The nose gear, the nose gear attachment and the forward fuselage structure of the CH600 are identical to the CH601XL-B’s nose gear. The stress analysis of Chris Heintz, designer of the CH601XL-B, also references to this load test.

- Shock absorber is kept in the static/extended position (cable replacing the shock cord)
- Fuselage is held down by fixture at upper longeron at fuselage C.G.
- Down load at engine mount is held constant by dynamometer at F = 3’726 N (380 kg)
- Wedge below nose wheel with specified inclination introduces forward/rear/side load

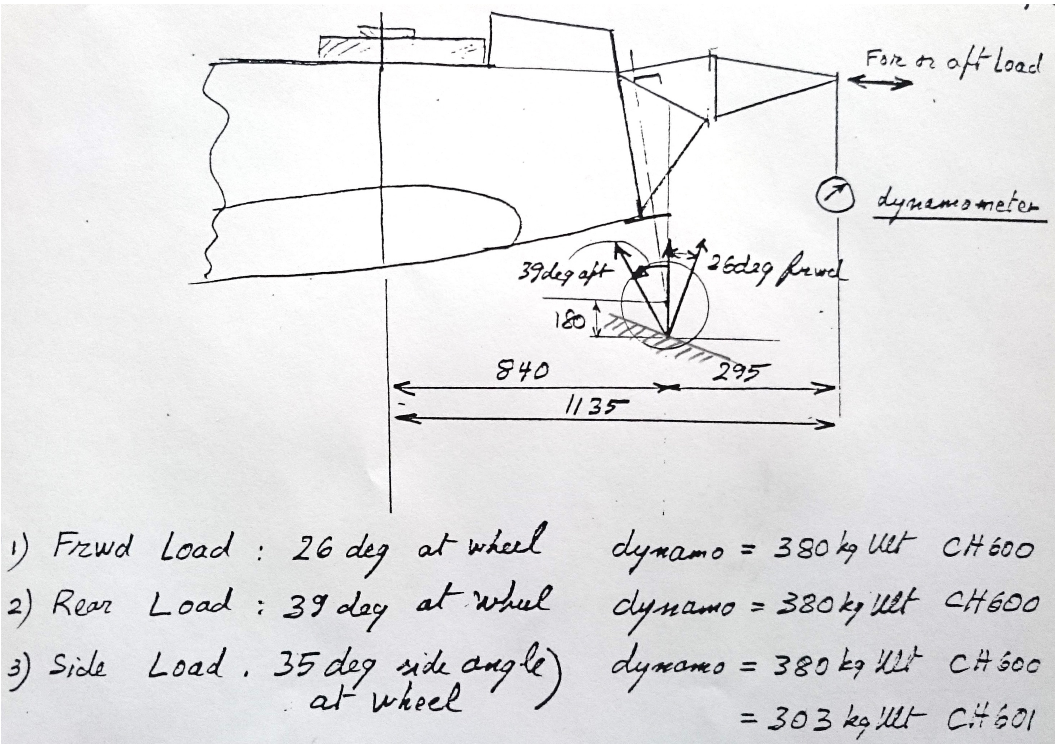

Fig. 13: Load test on CH600 nose gear

Resultant vertical load at nose gear: $F_v = \frac{840+295}{840} \cdot 3'726 = 5'034N$

Rear load, wheel inclination -39°: $F_{fwd} = F_v \cdot \tan(39°) = 0{,}81 \cdot 5'034 = 4'076N$

Forward load, wheel inclination 26°: $F_{fwd} = F_v \cdot \tan(26°) = 0{,}49 \cdot 5'034 = 2'455N$

Side load, wheel inclination 35°: $F_{fwd} = F_v \cdot \tan(35°) = 0{,}70 \cdot 5'034 = 3'525N$

Test 4: Side load conditions

	CS-VLA	Test CH600	
Vertical load	5’019 N	5’034 N	**OK**
Rearward drag load	4’015 N	4’076 N	**+ 2%**
Forward load	2’008 N	2’455 N	**+ 22%**
Side load	3’513 N	3’525 kg	**OK**

It is shown by load tests and a FEA analysis, that both nose and main gear of the CH601XL-B withstand the required loads (MTOW = 600 kg).

10 Conclusions

The static strength of the modified CH601XL-B covers and exceeds all requirements of CS-VLA Appendix A.

It is shown by load tests and several strength analysis' that

the upgraded CH601XL Model B aircraft structure (CH601XL-B)
(fuselage, wing, empennage, controls, gear and engine mount)

withstands all required static loads
according to CS-VLA Appendix A (MTOW = 600 kg).

11 Revisions

30.3.2010	Version 1.0	
22.4.2010	Version 1.1	Several minor corrections
14.1.2011	Version 1.2	New graphs “Wing shear loads” and “Wing bending moments” Several minor corrections
6.5.2011	Version 1.3	Change of aircraft designator to CH601XLB
30.1.2016	Version 2.0	Several minor corrections Stress analysis for horizontal tail FEA for engine mount Control system stress analysis
10.2.2016	Version 2.1	Load test CZAW engine mount

12 Attachments / References

FAA Special Airworthiness Information Bulletin SAIB CE-10-08

AMD Safety Alert / Safety Directive (Nov 7, 2009)

Zenair Europe Safety Notice ZE-2009-04 (Nov 22, 2009)

Modification drawings (latest revised drawings dated Jan 25, 2010)

Zenair Zodiac CH650 Structural Test to ASTM-SLSA (October 6, 2009)

Zenair CH600/CH601 Stress Analysis, Chris Heintz (1990)

Czech Aircraft Works (CZAW) CH601XL Strength Tests

Festigkeitsnachweis Motorträger Rotax 912 ULS, Martin Pohl (25.1.2016)

Load Analysis CZAW CH601XL-B, Martin Pohl (30.1.2016)

Zodiac CH601XLSA Stress Analysis and tests, Chris Heintz (Nov 2005)

Zenair CH650 Evaluation of Final Reinforcements, Chris Heintz (March 6, 2010)

Zenair Europe Service Bulletin ZE-2008-01 (October 28, 2008)

Frame3DD, Duke University, Durham, NC

CZAW SportCruiser, Engine Mount Strenght Test Report, Jiří Konečný