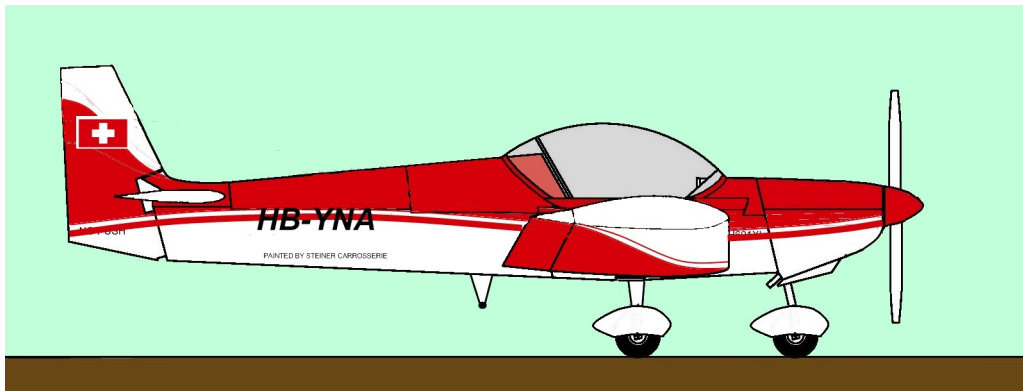

CZECH AIRCRAFT WORKS ZENAIR CH601XL ZODIAC

LOAD TESTS / STRESS ANALYSIS



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Table of Content

<u>1</u>	<u>OVERVIEW</u>	<u>3</u>
1.1	INTRODUCTION	3
1.2	MODIFICATIONS (UPGRADE PACKAGE)	3
1.3	LOAD TESTS / STRESS ANALYSIS	4
1.4	MODIFICATION LIST.....	5
<u>2</u>	<u>WING</u>	<u>6</u>
2.1	LOAD TEST RESULTS.....	6
2.2	WING SHEAR AND BENDING MOMENT	7
2.3	TANGENTIAL FORCE	9
2.4	WING TORSION.....	9
2.5	UNSYMMETRICAL FLIGHT CONDITIONS.....	9
<u>3</u>	<u>FUSELAGE</u>	<u>10</u>
<u>4</u>	<u>HORIZONTAL TAIL.....</u>	<u>11</u>
<u>5</u>	<u>VERTICAL TAIL</u>	<u>12</u>
<u>6</u>	<u>CONTROL SURFACE.....</u>	<u>13</u>
6.1	AILERON	13
6.2	WING FLAP	13
6.3	AILERON + ELEVATOR TRIM TAB	13
<u>7</u>	<u>CONTROL SYSTEM.....</u>	<u>14</u>
<u>8</u>	<u>ENGINE MOUNT.....</u>	<u>15</u>
<u>9</u>	<u>GROUND LOADS</u>	<u>16</u>
9.1	DROP TESTS CZAW SPORTCRUISER	16
9.2	LOAD TESTS CZAW SPORTCRUISER	16
9.3	NOSE GEAR: ZENAIR STRESS ANALYSIS	16
<u>10</u>	<u>CONCLUSIONS.....</u>	<u>17</u>
<u>11</u>	<u>REVISIONS.....</u>	<u>18</u>
<u>12</u>	<u>ATTACHMENTS / REFERENCES.....</u>	<u>18</u>

1 Overview

1.1 Introduction

Different load tests and stress analysis' were performed and prepared for the 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 a photo assembly guide was prepared by Zenair with directions for the upgrade and modification of the aircraft.

The official designator for update aircraft is CH601XL Model B.

This analysis was revised by two independent aviation engineers. Nevertheless it is of informal character only and the author doesn't take any responsibility if parts of the analysis are incorrect.

1.2 Modifications (Upgrade Package)

The upgrade package for the Zenair/CZAW CH601XL Model 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 unmodified¹ 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 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 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 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. Amongst others the strength of the nose gear is analyzed in this document.

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 Gear Legs

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, the SportCruiser, uses the exact same gear legs and gear leg mounting as the CZAW CH601XL. 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 implemented.

1.4 Modification List

The differences between the original CH601XL (CZAW CH601XL), the partially modified CH650 Zenair 650 mod.) and the fully upgraded CH601XL 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"
6ZU1-2	Wing root doubler at spar cap bolts	n/a	t = 0,032"
6ZU1-3/4/5	Nose rib angles, bottom cap angle	n/a	n/a
6ZU1-6	L-angle at top of rear spar	n/a	t = 0,040"
6ZU1-7	Rear channel doubler	n/a	n/a
6ZU1-8	Doubler plate at rear spar aileron hole	n/a	t = 0,032"
6ZU2	Wing attachment bolts	AN5	AN5
6ZU2-1	Center spar aluminium top doubler	n/a	t = 0,063", riveted and glued to top of center spar only
6ZU2-2	Seat front bottom L-angle	n/a	t = 0,063"
6ZU2-4	Spar uprights, wing center spar	n/a	n/a
6ZU2-6f	Front wing uprights	t = 0,040"	t = 0,063"
6ZU2-6r	Rear wing uprights	t = 0,040"	t = 0,063"
6ZU2-7/8	Spar bottom angles	t = ***	t = ***
6ZU2-9	Bottom skin doubler	n/a	n/a
6ZU3-1	Bellcrank support channel	n/a	n/a
6ZU3-2	Side doubler, fuselage between seat panel and center spar	n/a	n/a
6ZU3-3	Attach plate, at fuselage for rear spar	t = 0,063"	t = 0,063"
6ZU3-4	Seat angles	n/a	n/a
6ZU3-5	Upright doubler	n/a	n/a
6ZU3-Z	Z-angle fuselage side panel	n/a	n/a
6ZU4-1/2	Aileron stick control stop	n/a	n/a
6ZU4-L	L-angles, rear top and bottom wing skins	n/a	n/a
6ZU4-L	L-angles aileron trim servo	n/a	n/a
additional	Aileron gussets	n/a	n/a
additional	Aileron mass balance	n/a	n/a
			t = 0,125"
			t = 0,125", doubler has different geometry which results in additional strength
			additional angles at inner 3 nose ribs, bottom cap angle between NR#1 and NR#2
			t = 0,040"
			t = 0,040"
			t = 0,032"
			NAS6205
			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)
			t = 0,063"
			t = 0,25", 4 L-angle spar uprights between top and bottom spar caps
			t = 0,125"
			t = 0,063"
			t = 0,063"
			t = 0,032"
			t = 0,040", U-profile
			t = 0,063"
			t = 0,125"
			t = 0,040", additional L-angles at lower side of seat panels
			t = 0,032", strengthens connection between center spar, wing uprights and fuselage longerons
			t = 0,025", at fuselage side panel in front of main center spar
			t = 0,040"
			t = 0,025", L-angles on rear wing panels along the entire wing span
			t = 0,025", strengthens the support of the aileron trim servo
			Gussets at aileron rib #1 and #2
			Implemented according to UK LAA modifications

2 Wing

2.1 Load Test Results

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 loads with minor permanent deformation:

Zenair Structural Test to ASTM-SLSA (28. September 2009) <i>„Zenair CH650 mod.“</i>											
NrPosition		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
10M(t,RW)	[Nm]	-1077	-1077	-886	-676	-360	-44	271	209	146	81
11M(t,LW)	[Nm]	-2957	-2957	-2766	-2557	-2240	-1924	-1609	-1228	-849	-463

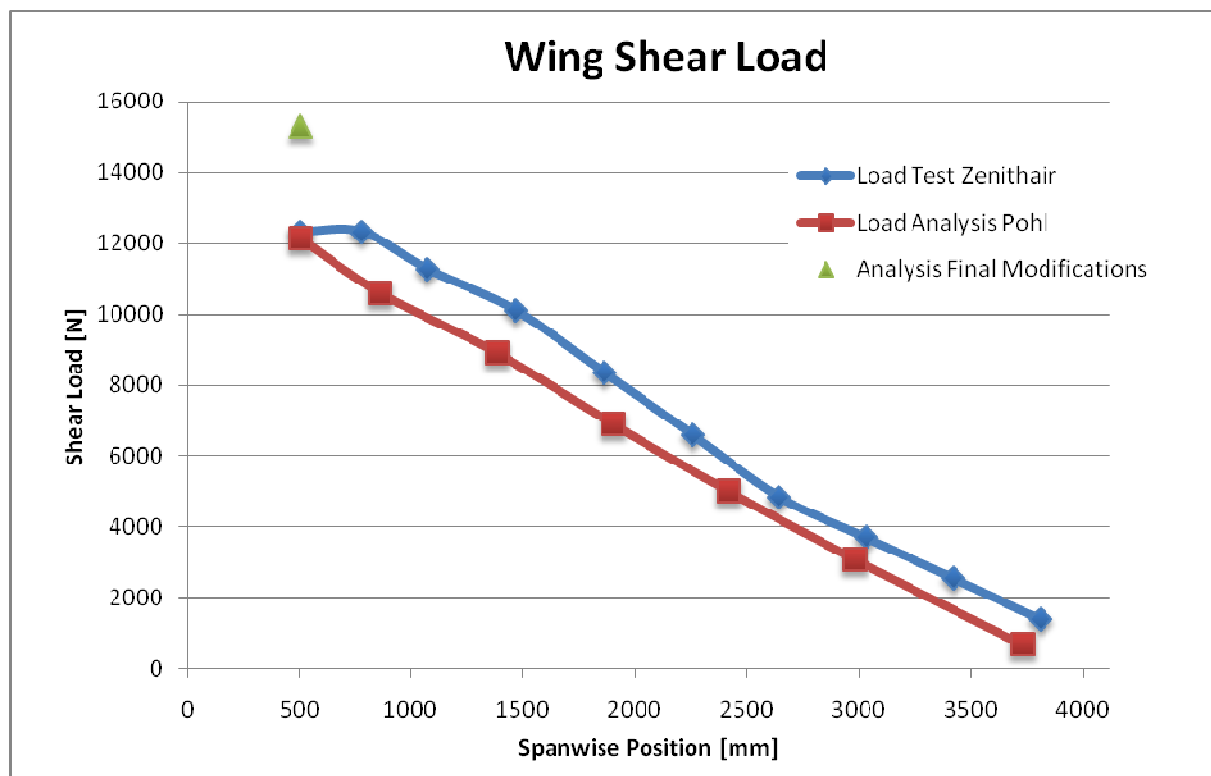
CZAW tested an unmodified Zodiac CH601XL. The results of the wing load test are summarized in the following table. The wing failed at the indicated loads after more than 3 seconds (buckling of upper spar cap):

CZAW Load Test for Ultralight Category (20. June 2002) <i>“CZAW CH601XL“</i>										
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), very 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), very conservative load inside fuselage of 245 kg.

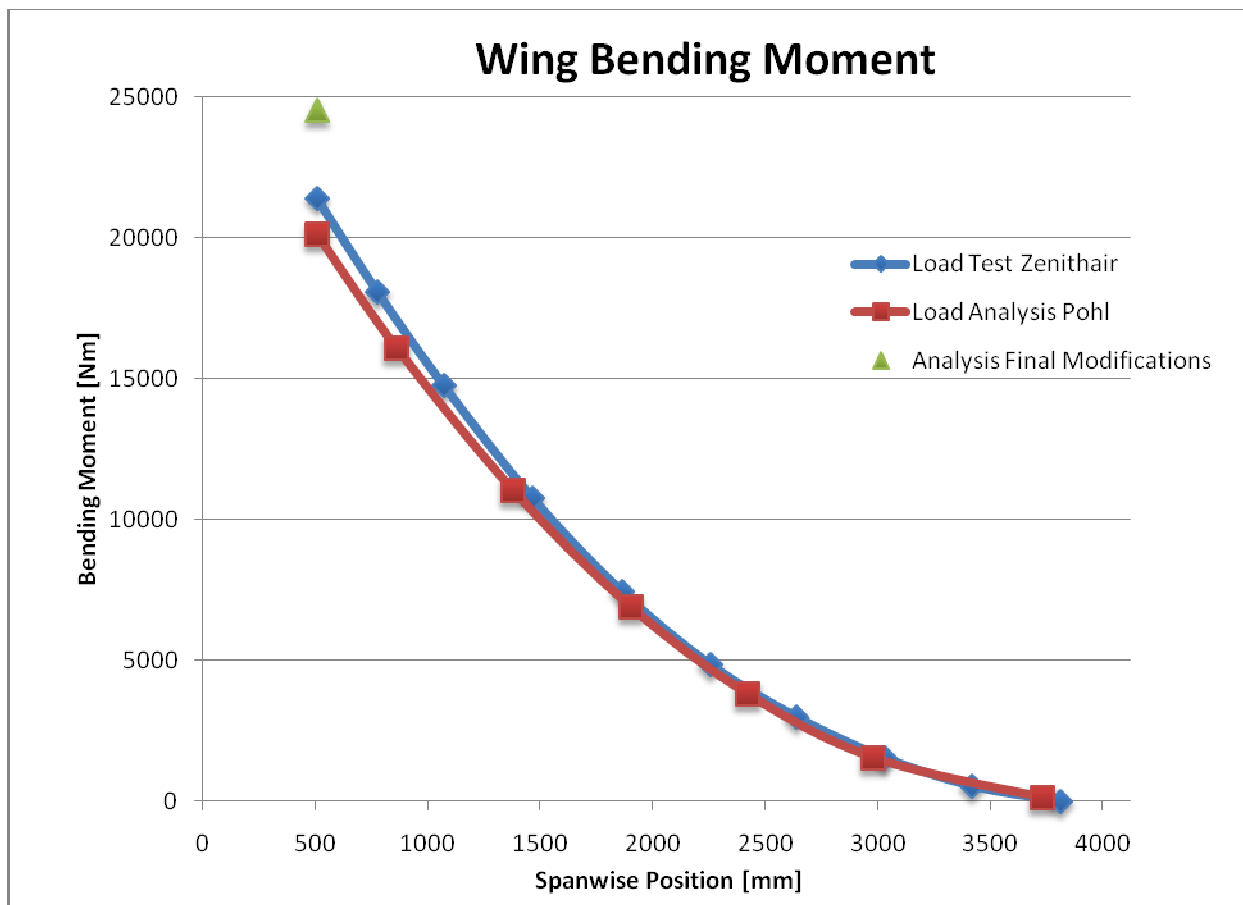
The wing shear load (load analysis and Zenair CH650 mod. load test) is shown in the following graph.



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 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), very conservative load inside fuselage of 245 kg.
Load Analysis	Strength Analysis Zenair CH650Final	Additional Safety Factor	Remarks
20'129 Nm	24'515 Nm	+ 22 %	Load Analysis: MTOW = 600 kg, minimum fuel (20 L), very conservative load inside fuselage of 245 kg.

The wing bending moment (load analysis and Zenair CH650 mod. load test) is shown in the following graph.



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 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 Unsymmetrical Flight Conditions

WING TORSION MOMENT – UNSYMMETRICAL 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 calculated 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 %	

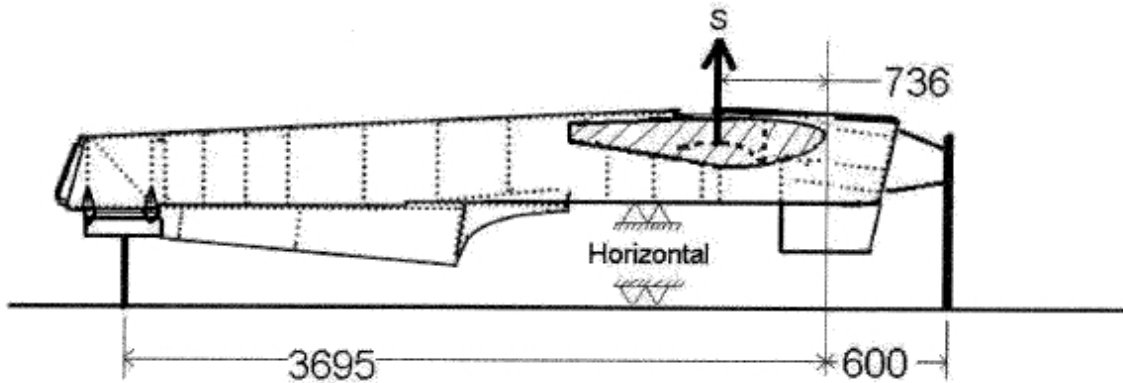
It is shown by load tests (and proved by the strength analysis), that the wing withstands all required static loads for a MTOW = 600 kg (MZFW = 585 kg).

3 Fuselage

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
Engine Mount			
- 4'305 N	- 5'628 N	+ 31 %	
Cabin Floor			
- 9'607 N	- 10'590 N	+ 10 %	
Horizontal Tail			
- 3'270 N	- 2'726 N ²	- 17 %	Strength of rear fuselage and horizontal tail attachment points is confirmed in following Zenair CH650 mod. load test (see below).

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 tested too:



Maximum load on the wings: $S = 2 \cdot (1'140 + 44)kg \cdot 9,806 = 23'221N^3$

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			
- 3'270 N	- 7'223 N	+ 121 %	

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

² Load on horizontal tail: see chapter 4 Horizontal Tail.

³ 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 %	Zenair stress analysis confirms required strength of horizontal tail (see below).

The load does not fully cover the requirements of the load analysis. However during the test the horizontal tail did not show any signs of permanent deformation. This suggests, that there was a sufficient margin to structural failure.

In addition the stress analysis performed by Chris Heintz, Zenair (Zenair Analysis) shows, that the horizontal tail withstands all loads defined/required by the load analysis. The basic parameters of the Zenair Analysis were:

Ultimate surface distribution: $w_{HT,ult} = 189 \frac{kg}{m^2}$

Ultimate load on horizontal tail: $L_{HT,ult} = w_{HT,ult} \cdot A_{HT} \cdot g = 189 \cdot 1.84 \cdot 9.806 = 3'410N$

HORIZONTAL TAIL Ultimate Loads			
Load Analysis	Stress Analysis Zenair Analysis	Additional Safety Factor	Remarks
-3'270 N	-3'410 N	+ 4 %	

It is shown by the load test and strength analysis, that the horizontal tail withstands 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 %	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 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.

<i>It is shown by the load tests, that the ailerons and wing flaps withstand all required static loads (MTOW = 600 kg).</i>

7 Control System

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

Chris Heintz' proved in his load and stress analysis (Zenair Analysis), that the control system withstands the requirements of ASTM-F2245.

8 Engine Mount

The Rotax 912 ULS engine mount was tested in vertical direction on the CZAW CH601XL aircraft. The maximum load on the engine mount was 574 kg. No lateral force was applied during the test.

The required load (according to CS-VLA/load analysis) can be calculated from lateral and vertical load:

Resulting required load :
$$F_{resulting} = \sqrt{1'665^2 + 4'305^2} = 4'616N$$

ENGINE MOUNT – VERTICAL LOAD Ultimate Loads			
Load Analysis	Load Test CZAW CH601XL	Additional Safety Factor	Remarks
4'616 N	5'629 N	+ 22 %	The load of the load analysis (4'616 N) is the resulting force of required vertical and lateral load.

In addition, a stress analysis was performed by the author of this document (FEM simulation). This stress analysis confirms that the engine mount withstands all required loads.

It is shown by load tests and a strength analysis, that the Rotax engine mount withstands the required static loads (MTOW = 600 kg).

9 Ground Loads

The drop tests on the CZAW CH601XL aircraft with standard nosewheel and modified composite main gear were performed for a MTOW = 450 kg (European ultralight category). They do not cover the requirement for a MTOW = 600 kg.

The strength of the nose gear is covered in Chris Heintz' strength analysis and load tests performed on a CH601.

CZAW's successor of the CH601XL, the SportCruiser, uses the exact same composite main gear legs and gear leg mounting as the CH601XL. CZAW performed several tests for a MTOW = 600 kg according to CS-VLA requirements.

9.1 Drop Tests CZAW SportCruiser

Test 1: Level landing with inclined reactions

	CS-VLA	Drop Test CZAW	
Weight	436 kg	436 kg	✓
Drop height	28.9 cm	28.9 cm	✓

Test 2: Tail-down landing

	CS-VLA	Drop Test CZAW	
Weight	436 kg	436 kg	✓
Drop height	28.9 cm	28.9 cm	✓

Test 3: Level landing

	CS-VLA	Drop Test CZAW	
Weight	436 kg	436 kg	✓
Drop Height	65.0 cm	65.8 cm	✓

9.2 Load Tests CZAW SportCruiser

Test 4: Side load conditions

	CS-VLA	Test CZAW	
Vertical load	600 kg	605 kg	✓
Sideloading inward	300 kg	317 kg	✓
Sideloading outward	450 kg	454 kg	✓

Test 5: Braked roll conditions

	CS-VLA	Test CZAW	
Vertical load	600 kg	765 kg	✓
Brake load (rearward)	480 kg	555 kg	✓

9.3 Nose Gear: Zenair Stress Analysis

The strength of the nose gear is proven in the load and strength analysis and by load tests of the CH601HDS (predecessor of the CH601XL).

It is shown by the load test and strength analysis, that the gear of the CH601XL withstands the required loads (MTOW = 600 kg).

10 Conclusions

The static strength of the modified CH601XL 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
(fuselage, wing, empennage, 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

12 Attachments / References

[Attachment] FAA Special Airworthiness Information Bulletin SAIB CE-10-08

[Attachment] AMD Safety Alert / Safety Directive (Nov 7, 2009)

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

[Attachment] Modification drawings (latest revised drawings dated Jan 25, 2010)

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

Czech Aircraft Works (CZAW) CH601XL Strength Tests

Festigkeitsnachweis Motorträger Rotax 912 ULS, Martin Pohl (22. September 2009)

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

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