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FUSELAGE TEST OF A SMALL AIRCRAFT ACCORDING TO CS-23 REQUIREMENTS

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Abstract. This article describes a static strength test of a fuselage of a small aircraft. Tests were done according to CS-23 requirements. The test program was firstly analysed and then a methodology of the entire test was created and the test could be built. The requirement of the submitter was that the bending and torque moment and shear force had to be as close as possible to calculated loads. This problem requires many loading forces along the length of the fuselage, and we had to solve how to load several tonnes along the 7 meters. For this purpose, a loading tree and rollers were used. The conclusion of this article describes how using rollers with the loading tree changes forces and describes the test arrangement.

Keywords: test, fuselage, measurement, force.

1. Introduction

Aircraft testing is an extended branch of aerospace science, and its development is closely related to the increasing requirements of traffic safety. Development of all aircraft requires certification tests to approve their strength. The requirements for strength and deformations are specified by (Certification… 2003):
a) the structure must be able to support limit loads without detrimental, permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation;
b) the structure must be able to support ultimate loads without failure for at least three seconds, except local failures or structural instabilities between limit and ultimate load are acceptable only if the structure can sustain the required ultimate load for at least three seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the three seconds limit does not apply.

The organization and description of these tests are very difficult because the submitter established curves of loads along the length of the fuselage with some concentrated forces developed by the rudder or horizontal tail, and these forces had to be applied simultaneously. The loading system had to correspond to these conditions. The fuselage was about 7 meters long, and it took up a large space in the testing laboratory.

The program test involved a total of five loading cases, but here only the main two are described.

2. Case manoeuvre loads of vertical surfaces

The case of vertical surface loads in the second phase of manoeuvring is typical of maximal torque moment of the fin with a combination of maximal shear

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force. The centre wing hinges to the testing equipment and then the testing grid attached the fuselage. It was done by this way in all tested cases.

The applied forces were taken from the test program of the submitter (Tab 1) (Kozak 2007). There are three axes of applied loads T_X, T_Y and T_Z.

Table 1. Total load forces – case manoeuvre of vertical surfaces

		Forces and moments at the test								
Position of cut	Coor-dinates	ΔTX	ΔTY	TY	MZ	ΔTZ	TZ	MY	MV	MX
	[m]	[N]	[N]	[N]	[Nm]	[N]	[N]	[Nm]	[Nm]	[Nm]
GSS	0,000	0	0	0	0	0	0	0	0	0
A	0,631	0	0	0	0	0	0	0	0	0
B	0,672	0	0	0	0	0	0	0	0	0
C	0,795	0	0	0	0	0	0	0	0	0
D	0,920	0	0	0	0	0	0	0	0	0
TPJ	1,056	0	0	0	0	0	0	0	0	0
E	1,097	0	0	0	0	0	0	0	0	0
1a	**1,350**	0	**-6500**	-6500	0	**6000**	6000	0	0	-1300
1	2,000	0	0	-6500	-4225	0	6000	-3900	**5750**	-1300
2	2,305	0	0	-6500	-6208	0	6000	-5730	**8448**	-1300
2a	2,620	0	0	-6500	-8255	0	6000	-7620	**11234**	-1300
2b	2,785	0	0	-6500	-9328	0	6000	-8610	**12694**	-1300
3P	2,948	**1069**	0	-6500	-10387	0	6000	-9588	**14136**	-1300
PZ	2,950	0	0	4603	-10784	0	-14598	-9600	**14449**	7359
3Z	2,952	0	0	4603	-10772	0	-14598	-9572	**14423**	7359
mz	**3,200**	0	**-5700**	-1097	-9633	0	-14598	-6039	**11376**	7359
4P	3,509	0	0	-1097	-9972	0	-14598	-1616	**10102**	7359
ZZ	3,511	0	0	3827	-9975	0	758	-1609	**10104**	-4732
4Z	3,513	0	0	3827	-9967	0	758	-1611	**10096**	-4732
5	4,060	0	0	3827	-7874	0	758	-2025	**8130**	-4732
6	**4,450**	0	**-1500**	3827	-6381	0	758	-2321	**6790**	-4732
7	4,890	0	0	2327	-5357	0	758	-2654	**5979**	-4732
8	5,515	0	0	2327	-3903	0	758	-3128	**5002**	-4732
9	**6,165**	0	0	2327	-2390	**-4250**	758	-3621	**4339**	-4732
10	6,866	0	0	2327	-759	0	-3492	-1173	**1397**	-4732
11	**7,074**	0	**-2327**	2327	-275	0	-3492	-360	**453**	-4732
12	**7,177**	0	0	0	0	**3492**	-3492	0	0	-4732
13	7,535	0	0	0	0	0	0	0	0	0
	total	**1069**	**-16027**			**5242**				

Description of applied forces in global system of coordinates – GSC (Fig 2):

- ΔTX = 1069 N force applied to index plane of fuselage near wall No. 3.
- ΔTY = -6500 N force applied to point 5 at the dummy engine.
- ΔTY = -5700 N force applied into cockpit.
- ΔTY = -1500 N force applied to the baggage hold.
- ΔTY = -2327 N force applied at dummy (Fig 1).
- ΔTZ = 6000 N force applied at point 4 at the dummy engine.
- ΔTZ = -4250 N force applied to index plane of fuselage near wall No. 9.
- ΔTZ = 4560 N a calculated force from TZ = 3541 N on the fin and TZ = 1019 N on the dummy of the horizontal tail.
- Force ΔTY = -6500 N and force ΔTZ = 6000 N were calculated as ΔTYZ = 8846 N with angle 42.7°.
- The force on the fin ΔTZ = 3541 N and the force on the dummy of the horizontal tail ΔTYZ = 2540 N were connected with the global loading tree.

The application of all forces on the fin and on the dummy of the horizontal tail is in figure 1.

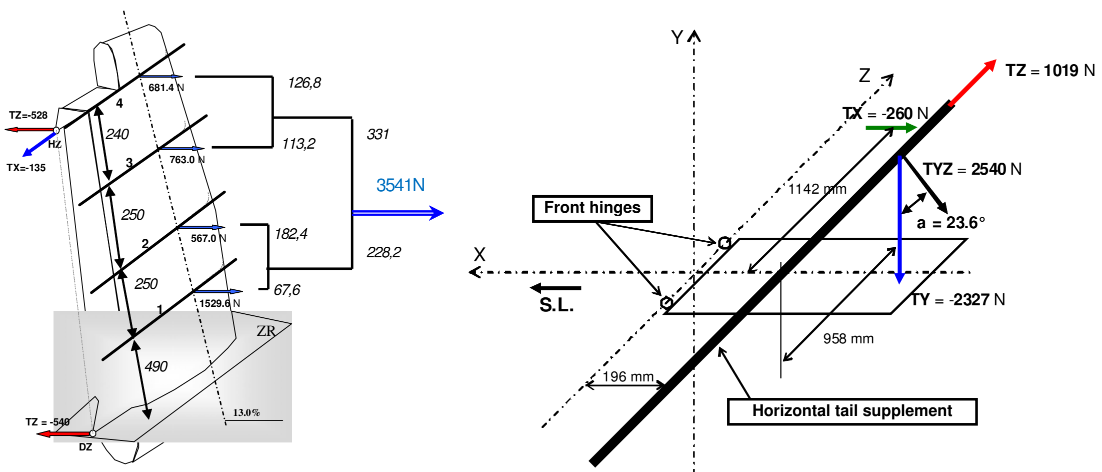

Fig 1. Forces applied at the fin and the horizontal tail dummy

On the horizontal tail supplement, the following loads were applied:

- TX = -260 N applied to the dummy of the horizontal tail at coordinate Z = 1142 mm – loaded by bag weight.
- TY = -2327 N applied to the dummy of the horizontal tail at coordinate Z = 958 mm.
- TZ = 1019 N applied to the dummy of the horizontal tail.
- Forces TY and TZ were summarized (T_{YZ} = 2540 N, α = 23.6°) and T_{YZ} was applied to the dummy of the horizontal tail.

In figure 2 is the proposed organization of the test and the loading tree to make out required forces (Jebacek 2007).

The actual realization of this test is shown in figures 3 and 4.

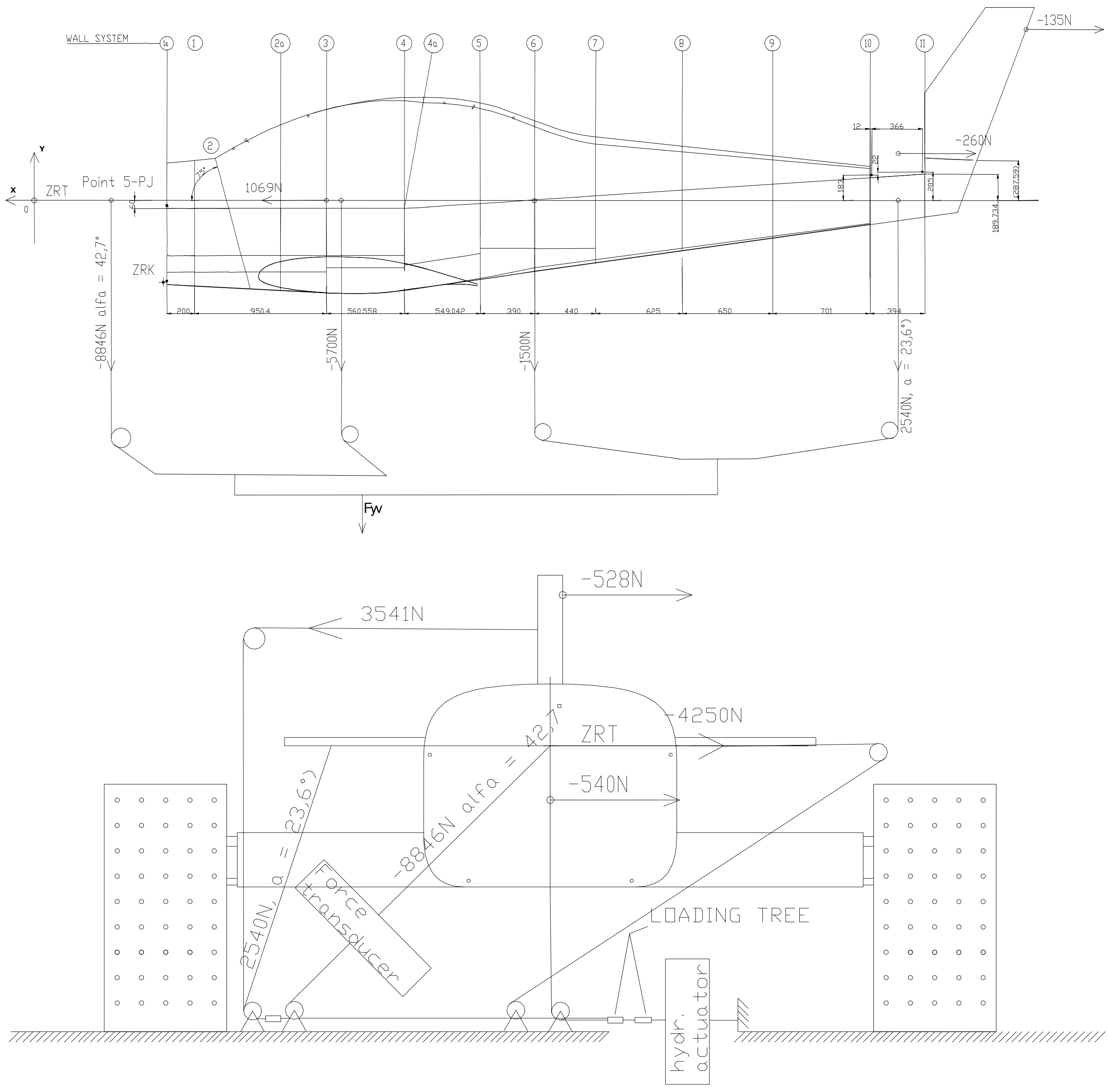

Fig 2. Proposed organization of the test – case manoeuvre of vertical surfaces

Fig 3. Realization of the test – case manoeuvre of vertical surfaces

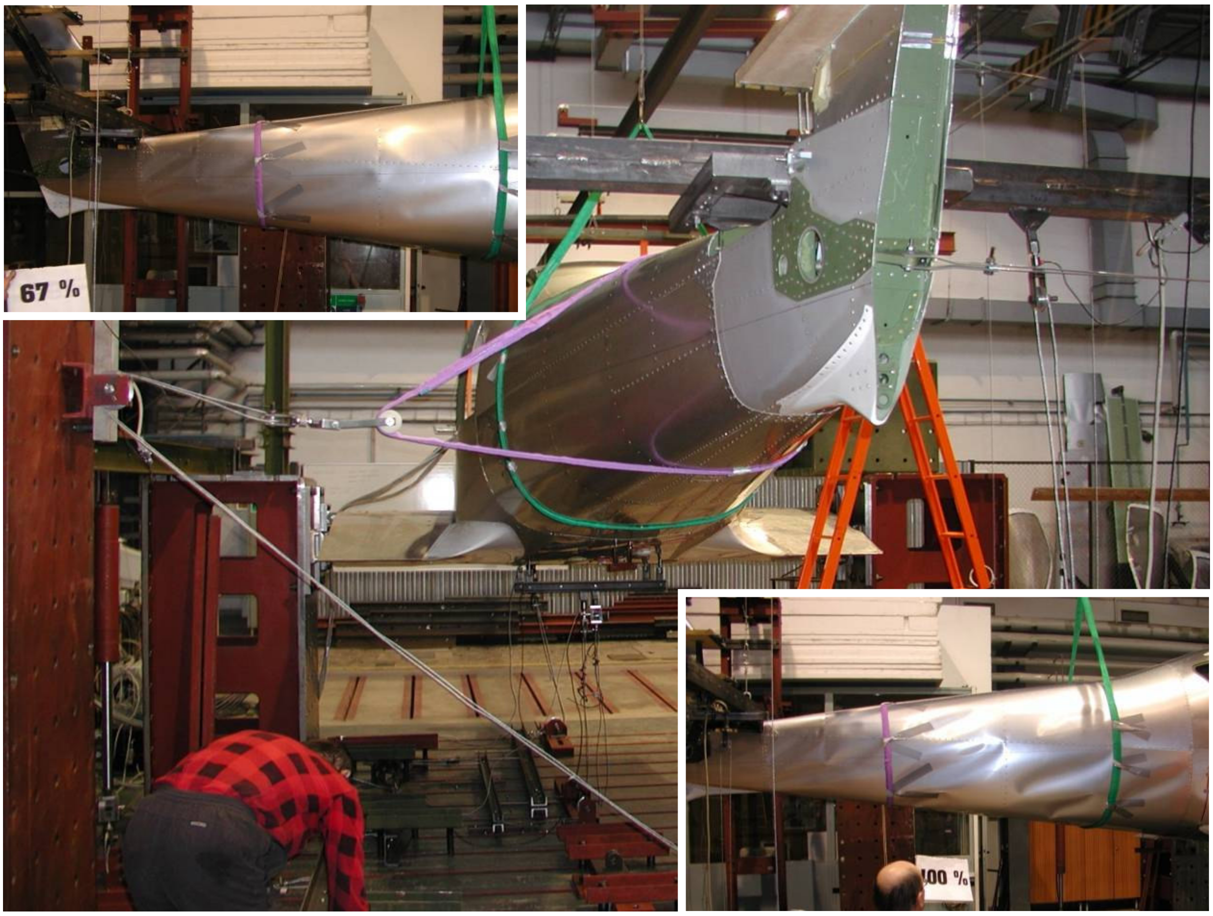

Fig 4. The application of force and deformation of the fuselage during the test

3. Combination case

This case consists of these two cases (Kozak 2007):

- Steady manoeuvre at V_D speed.
- Positive gust load on the wing at V_C speed.

The case of steady manoeuvring is typical with a maximal bending moment for the rear part of the fuselage, and the case of positive gust on the wing had a maximal bending moment at the front of the fuselage. After a short analysis, these cases were merged.

The applied forces resulted from the test program of the submitter (Tab 2) (Kozak 2007). Forces ΔTY were applied to the axis of symmetry of the fuselage.

Description of applied forces in the global system of coordinates – GSC (Fig 2):

- -4070 N force TX applied to the index plane of the fuselage near wall no. 3, independent hydraulic actuator.
- -24245 N force T_{y1} applied to Z = -0.125 m. Force was applied to the engine dummy.
- -4280 N force T_{y2}, calculated from ΔT_{y1} = -2065 N in cut 1a and ΔT_{y1a} = -2215 N in cut 1.
- -1463 N, -3673 N, and -5500 N T_{y2aV} forces were connected into resultant force -10636 N and applied to cut X = 2662 mm.
- -3393 and -9735 N are forces T_{y3} and were connected into resultant force -13128 N and applied to the dummy of the seats in cut X = 3057 mm.
- -3393 N and -3170 N forces near the web No. 3 and No. 4 were summarized and the resultant T_{y4} = -6954 N was applied to the passenger seats.
- -3554 N and -6251 N were summarized and the resultant T_{y5} = -9805 N was applied to the dummy of the horizontal tail in coordinate X:

$$X = \frac{(-3554*6.878-6251*7.244)}{(-3554-6251)} = 7.111 \text{ m}$$

The application of all forces ΔT_Y and proposed test organization is in figure 5 (Jebacek 2007). Individual hydraulic actuator applied the ΔTX. The mass of loading preparation was balanced. True realization of this test is shown in figure 6. There it is shown that the loading system of forces ΔT_Y had to be divided and loaded by two individual hydraulic actuators.

The order of the test was done this way:

1) fin test – manoeuvre of vertical surfaces (two cases, see above);
2) fin test – gust on vertical surfaces;
3) fuselage test – negative gust on the wing at speed V_C;
4) fuselage test – combination case (see above).

Procedure of testing:

- Loading on limit load, unloaded.
- The check of permanent deformation.
- Loading up to ultimate load, holding time 3 seconds.
- Unloading.

During the performance of cases 2) and 3), the control systems were checked. In the combination case, the fuselage structure did not carry the required loads and the test was finished. Displacements were not measured, but about 18 strain gauges were installed on the structure.

Table 2. Total load forces – case manoeuvre of vertical surfaces

Position of cut	Coor-dinates [m]	ΔTX [N]	ΔTY [N]	TY [N]	MZ [Nm]	souřadnice Z [m]	ΔMX [Nm]	MX [Nm]
		Forces and moments at the test						
GSS	0,000	0	0	0	0	0	0	0
A	0,631	0	0	0	0	0	0	0
B	0,672	0	0	0	0	0	0	0
C	0,795	0	0	0	0	0	0	0
D	0,920	0	0	0	0		0	0
TPJ	1,056	0	**-24245**	-24245	0	**-0,125**	**-3031**	-3031
E	1,097	0	0	-24245	-994	0	0	-3031
1a	1,800	0	**-2065**	-26310	-18038	0	0	-3031
1	2,000	0	**-2215**	-28525	-23300	0	0	-3031
2	2,305	0	**-1463**	-29987	-32000	0	0	-3031
2a	2,620	0	**-3673**	-33661	-41446	0	0	-3031
2b	2,785	0	**-5500**	-39161	-47000	0	0	-3031
3P	2,948	**-4070**	**-3393**	-42554	-53383	0	0	-3031
PZ	2,950	0	0	28789	-51149	0	0	-1100
3Z	2,952	0	0	28789	-51091	0	0	-1100
mz	3,095	0	**-9735**	19054	-46974	0	0	-1100
4P	3,509	0	0	19054	-39057	0	-1100	-1100
ZZ	3,511	0	0	17589	-39048	0	0	831
4Z	3,513	0	**-3170**	17589	-39013	**-0,083**	**263**	831
5	4,060	0	**-3784**	14419	-31126	**-0,150**	**568**	568
6	4,450	0	0	10635	-26978	0	0	0
7	4,890	0	0	10635	-22299	0	0	0
8	5,515	0	**-830**	10635	-15652	0	0	0
9	6,165	0	0	9805	-9279	0	0	0
10	**6,878**	0	**-3554**	9805	-2288	0	0	0
11	**7,244**	0	**-6251**	6251	0	0	0	0
12	7,402	0	0	0	0	0	0	0
13	7,535	0	0	0	0	0	0	0
	Total	**-4070**	**-69878**					

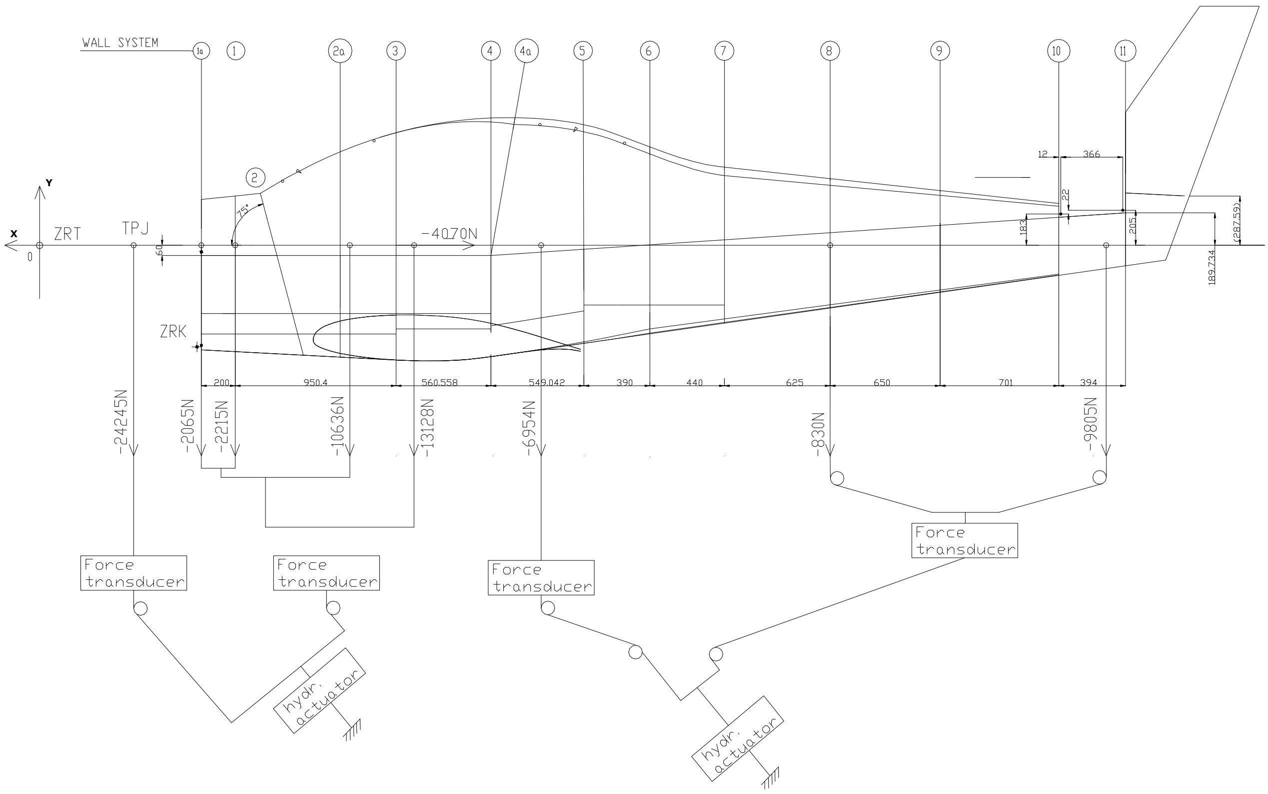

Fig 5. Proposed organization of the test – combination case

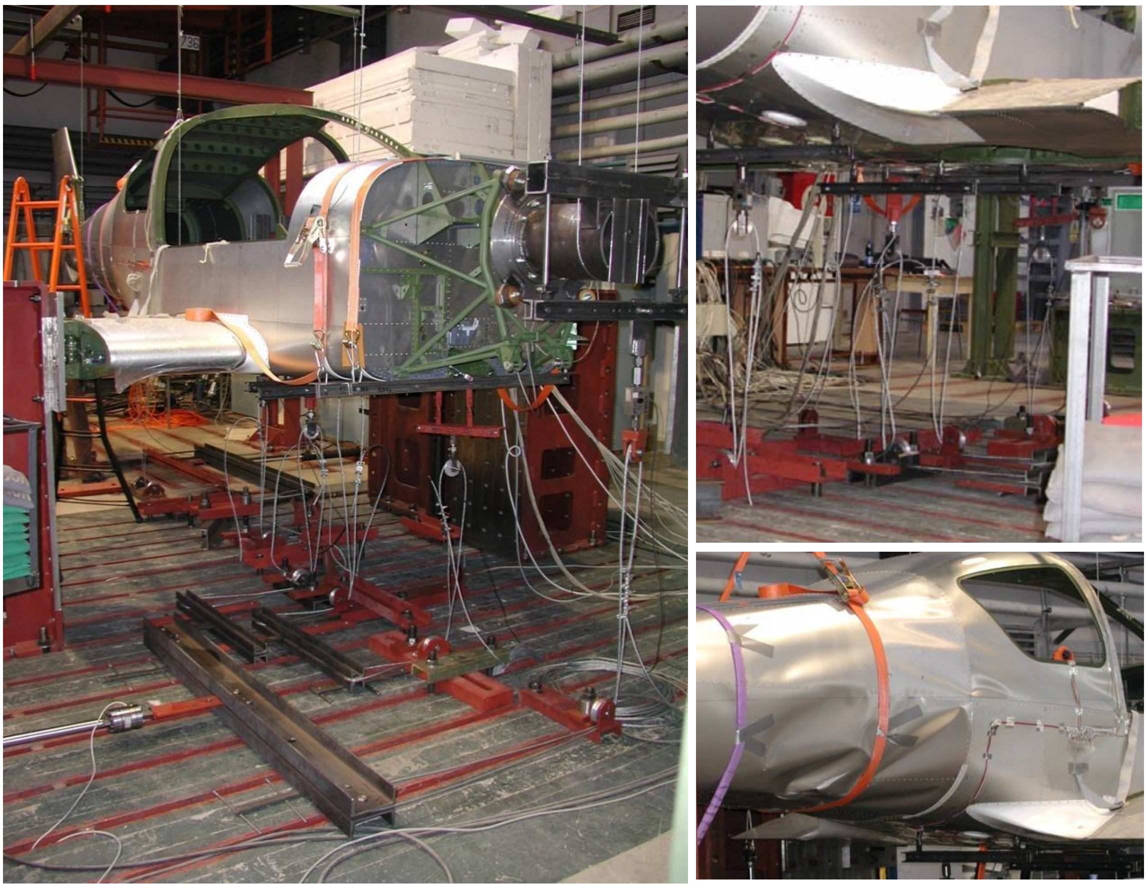

Fig 6. Realization of the test – combination case and deformation of tested specimen

4. Conclusions

From the performance of the test, we confirmed that the test was built very well, and we did not note any problems, and we can say that the proposed system of fuselage testing is suitable.

One problem we had to solve was loading with the help of the rope and the rollers. The rollers do not carry the total force in the rope; there are some losses caused by friction error. This decrease depends on the magnitude of the force and the angle of the roller wrapping. That is why we connected all force transducers between the tested specimen and the rollers. Because we measured total force in the loading tree, we can set the ratio between applied force and the force really reached.

This system needs more force transducers, but we are able to monitor directly the forces required by the submitter.

In the next tables, there is a comparison of measured and required forces during the performance of all tests mentioned.

Table 3. Forces in the individual cuts during the test (required and really reached) – combination case

Ty1	% req. force Ty1	Ty2	% req. force Ty2	Ty3	% req. force Ty3	Ty4	% req. force Ty4	Ty5	% req. force Ty5
[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]
3064	12.6	539	12.6	1639	12.5	686	9.9	981	10.0
7121	29.4	1268	29.6	3917	29.8	1900	27.3	2942	30.0
11952	49.3	2124	49.6	6585	50.2	3316	47.7	4903	50.0
23350	96.3	4146	96.9	12953	98.7	6497	93.4	9298	94.8

Table 4. Total forces during the test – combination case

Ftot. summ. Ty1+Ty2+Ty3+Ty4	% req. force	Ftot. meas. hydr. actuator	% req. force	Deference in Ftot. – Ftot. meas.
[N]	[%]	[N]	[%]	[%]
5965	12.3	6670	13.7	-1.5
14295	29.4	15878	32.7	-3.3
24125	49.6	26750	55.0	-5.4
47239	97.2	52472	108.0	-10.8

Table 5. Forces in the individual cuts during the test (required and really reached) – case manoeuvre of vertical surfaces

F_{ML}	% req. force F_{ML}	$F_{wall\ 3}$	% req. force $F_{wall\ 3}$	$F_{wall\ 6}$	% req. force $F_{wall\ 6}$	$F_{wall\ 9}$	% req. force $F_{wall\ 9}$	F_{HT}	% req. force F_{HT}	F_{fin}	% req. force F_{fin}
[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]
905	10.2	587	10.3	155	10.3	424	10.0	262	10.3	354	10.0
2674	30.2	1731	30.4	462	30.8	1256	29.5	759	29.9	1062	30.0
4429	50.1	2873	50.4	769	51.3	2086	49.1	1268	49.9	1771	50.0
6183	69.9	4005	70.3	1075	71.7	2935	69.1	1776	69.9	2479	70.0
8784	99.3	5693	99.9	1540	102.6	4226	99.4	2547	100.3	3541	100.0

Table 6. Total forces during the test – case manoeuvre of vertical surfaces

$F_{summ.}$	% req. force	$F_{tot.\ meas.}$	% req. force	Deference in $F_{summ.}$ - $F_{tot.\ meas.}$
[N]	[%]	[N]	[%]	[%]
2748	10.4	2929	11.1	-0.7
8126	30.8	8488	32.2	-1.4
13496	51.2	14118	53.5	-2.4
18873	71.6	19773	75.0	-3.4
26932	102.1	28407	107.7	-5.6

From what is mentioned above we can say that the losses dramatically depend on the magnitude of the force. In the case manoeuvre of vertical surfaces and the rollers wrapping close to an angle of 180 degrees, the total deference with maximal force was only 5.6 %. In the combination case with nearly double force but the angle of the rollers entirely 90 degrees, the total deference at maximal force was 10.8 % between applied load at the start of the loading tree and the force on the tested specimen.

We can say that the effect of rollers wrapping is less important than the magnitude of the force. Consideration of this fact is needed when designing similar tests.

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MAŽO LĖKTUVO LIEMENS BANDYMAI PAGAL CS-23 REIKALAVIMUS

Ivo Jebáček

S a n t r a u k a

Straipsnyje nagrinėjamas mažo lėktuvo liemens statinis stiprumas. Bandymai buvo atliekami pagal CS-23 reikalvimus. Pirmiausia buvo analizuojama bandymų metodologija ir programa, po to buvo sudaryta bandymų seka. Pateikėjas reikalavo, kad lenkimo ir sukimo momentų bei skersinių jėgų apkrovos būtų kiek galima artimesnės apskaičiuotoms apkrovoms. Reikėjo apkrauti liemenį jėgomis daugelyje vietų, tad tyrėjams teko spręsti, kaip išdėstyti daug tonų 7 metrų atkarpoje. Šiam tikslui buvo panaudotas apkrovų medis ir skridiniai. Šio straipsnio išvadose apibūdinta, kaip keičiamos jėgos naudojant skridinius ir apkrovų medį. Taip pat aprašyta bandymų įranga.

Reikšminiai žodžiai: bandymai, liemuo, matavimas, jėga.