COMPOSITE JOINTS OF AEROSTRUCTURES

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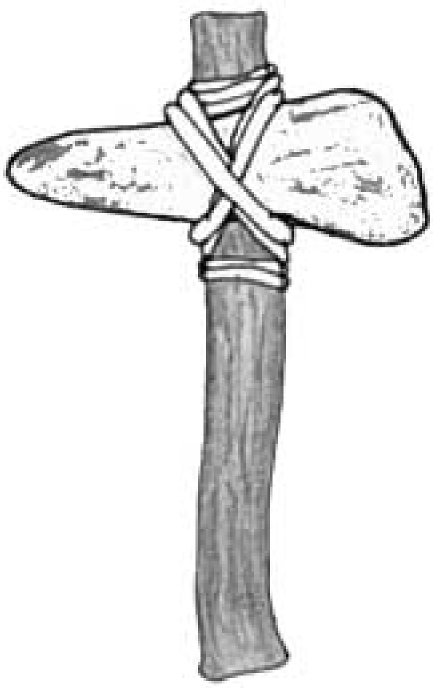
The paper presents the idea and also static tensile tests and fatigue tests of composite node joints of load-bearing structures. This innovative idea of joints of composite construction is an alternative solution for classical concept of the node joint. Results of tests are very promising. It has been suggested that presented idea of composite node joint could also be applied to use in more complex structures. Composite node joints with kevlar, glass and carbon component has been tested. This idea is patented.



Basic prehistoric idea…

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1. INTRODUCTION

Joints of structure members are one of most difficult objects to design. This rule applies also to frame and truss structure designs. Common ways of beams or tubes linkage in such structures are: screw, bolt or welding connections.

Also in airframe truss structures, especially aircraft fuselage truss structures, most common are welded node connections. Elements in such trusses are usually formed from thin walled tubes and made from weldable steel.

Such steel is usually very resistant to microcracks resultant from influence of temperature field of welding process.

For welding stresses release, complete trusses are heat–treated, so appropriate, big size stoves are needed. Local, workshop heat–treatment of truss nodes alone, often used as substitute, is not always giving satisfactory results.

Another unfavourable technological phenomena is warping from internal structure stresses, often resulting from internal stress in the structure. Often it leads to the need of an overhaul or scrapping of such a costly product as fuselage truss or engine mount.

Human factor in form of highly trained welding personnel has also essential importance, because thinwalled tube welding, particularly in joints, where several truss tubes meet, especially at truss nodes, requires very high professional skill.

Pre-welding preparing tasks, precise cutting and bevelling edges of truss tubes to minimize distance of welded elements are also greatly increasing the cost of such structures.

It is almost impossible to eliminate microcracks and residual welding stresses from applied welding heat and material shrinkage. So, non–destructive testing is in order to detect dangerous starting cracks, which can lead to development of fatigue failures, which, in turn, can lead to violent complete structural failures. Sometimes, minor importance rod buckling can lead to starting cracks in multi–rod truss node, and in consequence, loads from other rods in this station can destroy it.

Riveting can be used as alternative to welding in truss node joints, but this method demands use of gusset plates, complicating design in case of complex multiple–rod, multiple–plane truss node.

Overhauls of such structures are also relatively complex in nature, because failed rod replacement (cutting and welding) or new gusset–plate riveting must be performed when whole truss structure is mounted in a jig, to protect design dimensions and geometry.

2. CONCEPTION – COMPOSITE JOINT IDEA

From historic standpoint, it must be marked that outstanding Polish designer, Dipl. Eng. Krzysztof Kotliński, was the forerunner of the use of composites in truss nodes construction*. Whole series of one and two–person ice–boats with their fuselage load structure made from dural tubes with composite truss nodes, was designed according to his idea. Those ice–boats performed very well on ice under sail, and were so light that they could be transported strapped on a mini automobile (Fiat 126) roof rack.

Ice–boat structure with composite truss nodes structure designed by Krzysztof Kotliński can be seen (as a fragment) on Fig. 2.1.

** Son of late Dipl. Eng. Jerzy Kotliński (well–known designer with helicopters: Trzmiel, Łątka), he is actually living and working in USA.*

Fig.2.1. Ice–boat frame–truss fuselage structure made from dural tubes with composite joints in nodes

Fig. 2.3. Ultralight, two–seat DEKO–5 airplane with fuselage structure according to composite joints conception

Fig. 2.4. Carriage of Parafan powered paraglider

One of the later designs of fast, two–seat racing iceboat with fuselage in which all heavy loaded nodes were made with composite joints is presented in Fig.2.5. Note the runner to runnerbeam (elastic tranverse girder) mount, shown in Fig. 2.6. Later, at first, a very limited design trial of such composite connections in airframe structures was made during development of ultralight, two–place *Fregata* airplane (Fig. 2.2), designed by K.Kotliński and A.Chmura team, and in much bigger range, during development of *DEKO*–5 airplane designed for L. Dakowski by M.Dębski and K. Kotliński team.

To conclude with these short historical reminiscences, one can recall M. Dębski and A. Komor* design of paraglider carriage with composite truss nodes and ducted double, counter–rotating propeller (Fig. 2.4 and [30]), registered patent of Marek Dębski. It was a second design of this type in the world, next to *Paraglider* from the USA.

Fig. 2.2. Fregata airplane (photo: D. Dębski)

Fig. 2.5. Two–seat racing iceboat with composite joints construction fuselage frame

A composite joint of structures idea is based on application of composite materials as joining element to the primary elements of load–bearing structure.

Reinforcement material can be in form of tapes or fabrics, made from glass, carbon or Kevlar fibres [15], [16], [17], saturated with suitable resins and hardened, e.g. epoxy resin from *Epidian* range.

* ***Andrzej Komor*** *M.Sc. Ph.D., outstanding biomechanical engineer, graduate of MeiL (aviation) faculty of Warsaw University of Technology, killed in airplane crash 3rd of march 1991 in Colorado Springs, USA.*

Fig. 2.6. Fast, two–seat iceboat with composite joints

Fig. 2.7. Single–seat composite joints racing iceboat

In case of joint made with roving fibers, connection can be made in „anatomical" tie form, analogical to bone – tendon connections existent in living creatures.

Possibility of joint form creation, optimal for given structure construction, is a very important property of such joints.

So, when it is necessary to create a structure similar to truss, with low stiffness node joints, it is possible to lead the joint ties (tendons) in such way, that in result we obtain a specific, low stiffness joints in truss nodes.

However, in case, when we design a structure with similar to frame workload character, proper lead of ties (tendons) in joints can give us relatively stiff girders mounting in node.

To obtain a specific level of redundancy, so one element failure cannot lead to whole node destruction, it is possible to link each node member „separately", so forced member extraction will not destroy the joint and the whole structure.

It is essential for super stiff systems, in which failure of only one element allows the structure to bear the loads.

Next, very important attribute of idea presented in this paper is possibility to join structure elements produced from various materials, often that are very difficult to join with other methods.

This allows designer of the structure to optimise construction by use of the most appropriate materials with most desired properties and attributes, which results in such important parameter as minimal total construction mass.

Cutting-off linking tendons of failed element and tying-in new tendons of a new, replacement element make overhaul of such joint.

Multiplicity of the joint is an essential feature and manifests itself in progressive failures of most stressed roving fibres. This points to a fact that structure with such joints will fail gradually (not violently), which is a very positive design attribute from an exploitation safety point. Such design will warn about its overload or structural failure with bigger-than-normal structure deformations.

Fig. 2.8. Final assembly of DEKO–9 airplane in No.3 Military Air Works, Dęblin, Poland

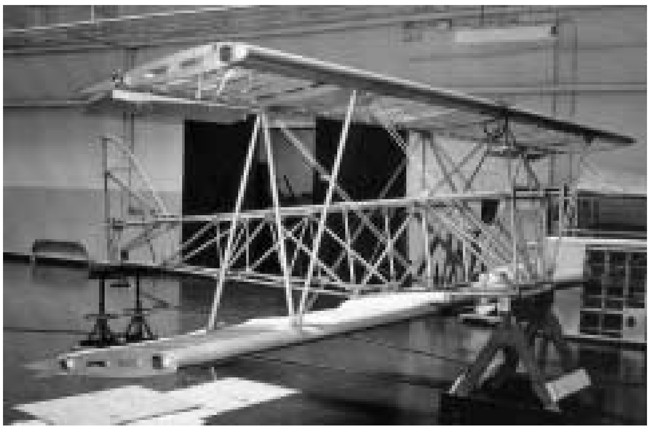


Fig. 2.9. Load bearing structure of DEKO–9 Magic airplane. Truss fuselage shown, made according to composite joints idea

Fig. 2.10. DEKO–6 Whisper airplane fuselage structure

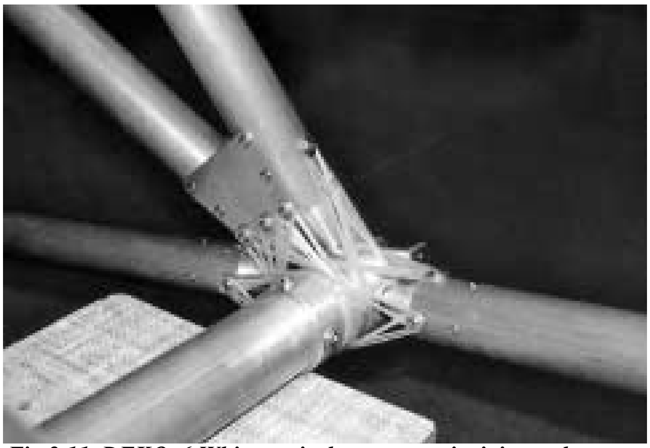


Fig.2.11. DEKO–6 Whisper airplane composite joint node

3. EXPERIMENTAL VERIFICATION OF JOINTS ACCORDING TO PROPOSED CONCEPTION

3.1 SURVEY OF STATIC STRENGTH

One of many possible models of composite joints, coaxial connection of PA7 dural tubes ϕ 30mm x 1.5mm size, and representative to aircraft structures, was tested.

Three kinds of joints were tested, with glass, Kevlar and carbon fibers reinforcements.

Epoxy resin Epidian 53 type was used as composite matrix.

Drawing 3.1 shows three types of composite joints* that were strength tested in static tests, fatigue tests and residual strength tests.

Matrix and warp materials data [3, 15, 17, 18, 19, 20] are presented in Table 3.1.

Tests were made on MTS strength machine (Fig. 3.2) in Laboratory of the Institute of Machine Design Fundamentals, Warsaw Institute of Technology. To provide appropriate handling of samples, special chucks were designed and made [2, 4] to provide multiple fastening of thin-walled tubes linked with composite joints.

All three kinds of joints were manufactured with assumption of the same coefficient of volume amplification, equal to 0,5.

Figures 3.2 and 3.3 show fastening of composite joints specimen on strength test machine and example of joint destruction resulting from tensile strength test run. Figure 3.4 shows composite joint (representing a production example of load-bearing structure of real construction) connecting tubes of different diameters and capable to transfer axial stretch and compression loads and also more complex load states.

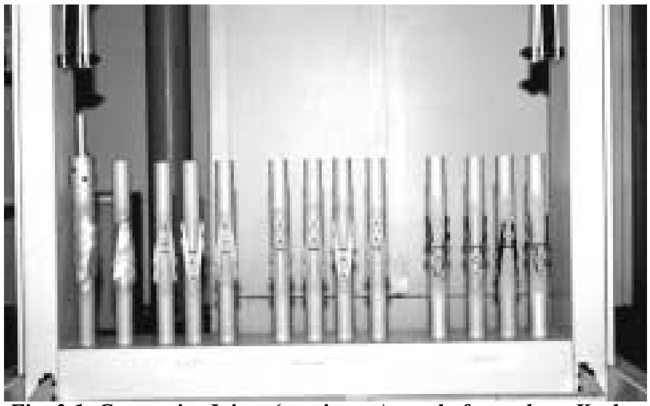


Fig. 3.1. Composite Joints (specimens), made from glass, Kevlar and carbon fibers, prepared to strength tests.

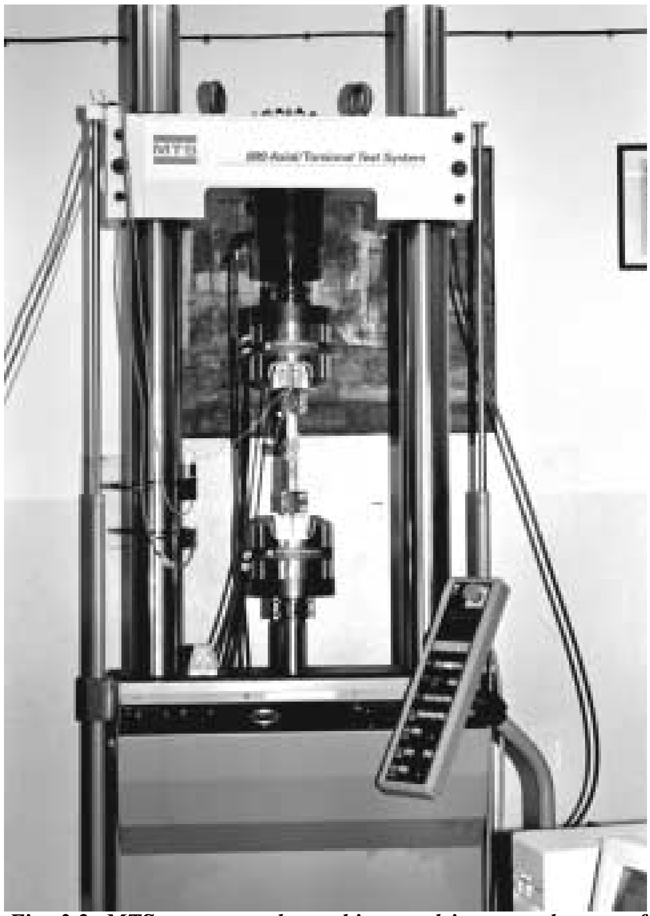


Fig. 3.2. MTS test strength machine used in strength tests of composite joints specimens.

Fig.3.3. Example of Kevlar composite joint destruction as result of static strength test.

** Composite joints samples, truss structure, research stands elements and their assembly were prepared in cooperation with Military Aircraft Works no 3, Dęblin, by Deco Aircraft Group leaded by col. eng. Wiesław Pachelski.*

3.1.1 FINDINGS OF TESTS AND CONCLUSIONS

Figures: 3.5, 3.6 and 3.7 present the process of specimen stretching force in function of its elongation, more precisely: in function of machine chuck displacement.

Measured and recorded machine chuck displacement is a sum of composite joint displacement and a displacement of the tubes, connected by the joint. (free tubes length, measured outside chucks equals to 190 mm, approximately).

Table presented below shows results of static strength tests made on three specimens of composite joints, with various construction of joint for each specimen. Safety coefficient is also presented, computed as ratio of destructive load to linear elongation range load.

Characteristic to this connection is gradual destruction of composite joint with load increase. It is a result of successive rupture of most exerted composite strands with relatively big elongation of the joint. Destruction does not have an explosive character and is manifested by big displacements with preservation of increased load-carrying ability of the joint.

It is a very positive feature, especially in very exerted, load-bearing structures like airplane structures – fuselage trusses or frames, highly loaded aggregate hardpoints (Fig. 5.1), or insertion regions of concentrated forces.

3.2 SURVEY OF FATIGUE STRENGTH AND RESIDUAL STRENGTH

3.2.1 SELECTION OF LOADS FOR FATIGUE TESTS OF COMPOSITE JOINTS

In the paper ([7] Fig.3.12) it was shown that maximum fatigue wear for load–bearing structures of manoeuvring airplanes happens in load range corresponding to values of $\psi = 0.60 - 0.80$ of permissible loads – *Pdop*.

If such composite joint will be a bearing member of such structure, the load in fatigue test will be:

$$P = \psi \cdot Pdop \qquad (1.1)$$
$$Pdop = Pn / v_0$$

Where: *Pn* - destructive load for composite joint confirmed in test (Table 3.2) and safety coefficient $v_0 = v \cdot v_1 \cdot v_2$, being a product of basic safety coefficient $v = 1.5$ and additional coefficients for composite structures, values of which, according to [21] are: $v_1 = 1.18$ and $v_2 = 1.19$, respectively.

3.2.2. RESULTS OF FATIGUE TESTS AND RESIDUAL STRENGTH OF COMPOSITE JOINTS

Coefficients v_1 v_2 take into account increased scatter of strength and negative effect of raised temperature on strength of composite structures. Loads, assumed for fatigue tests and tests results are shown in Table 3.3.

Tests in positions 1, 2, and 3 were conducted with frequency of 3*Hz*.

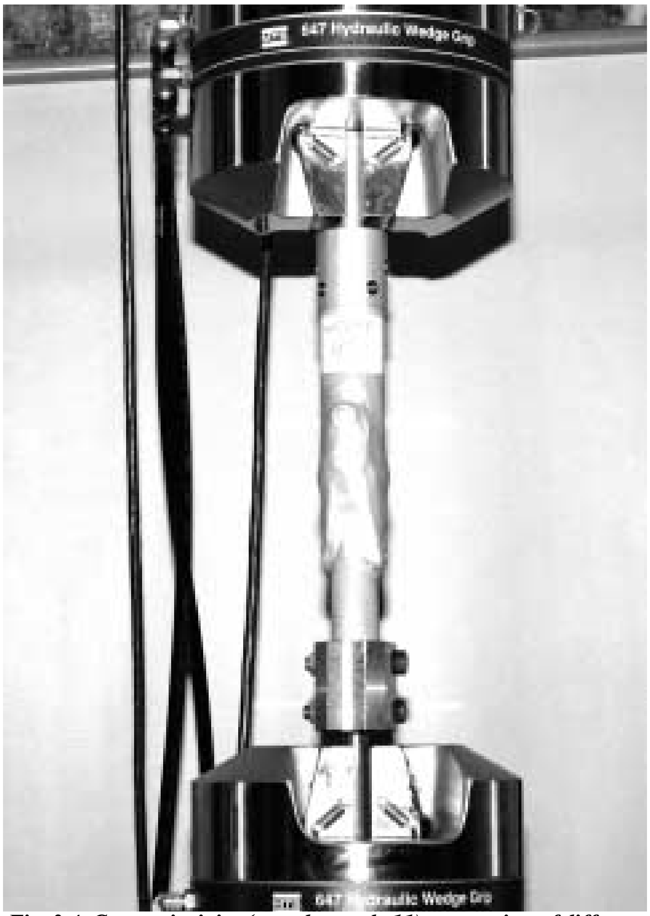


Fig. 3.4. Composite joint (sample - node 11) connection of different diameter tubes-joint is capable to transfer complex load states.

To verify composite joint of this type behaviour, also in alternating load sign condition (loads are commutative and are passing through zero level), fatigue test was made for joint presented in Fig. 3.4. It is an example of construction composite joint able to bear complex loads. In test 98000 symmetric load cycles +/- 7 *kN* with frequency 1 *Hz* were imitated, without any sign of composite joint destruction.

The question still remains, will such intensive fatigue load decrease joint static strength, so the ability to bear its design loads?

Therefore so, to estimate composite joint residual strength, static tensile strength test was performed, in result of which the revealed value of joint strength was not diminished in comparison with composite joint not previously fatigue tested. The result of the test is presented on fig.3.10 and table 3.3 item 4.

During fatigue tests of composite joints, after previously defined number of cycles, hysteresis loop relation of specimen elongation relative to axial force was recorded for several cycles.

Table 3.1. Basic data of materials used to composite joints preparation.

Reinforcement	Marking	tex	Density	Modulus of elasticity	Yield strength	Producer
Warp	-	g/1000 m	g/cm^3	MPa	MPa	-
Glass fibre	ER3003	2400	2.49	73000	3400	Krosno
Kevlar fibre	Kevlar 49	806	1.44	120000	2900	Du Pont
Carbon fibre	T 700 SC	804	1.78	227000	4630	Toray Ind. Inc.
Matrix - epoxy resin	Epidian 53	-	1.15	3350	65	Sarzyna

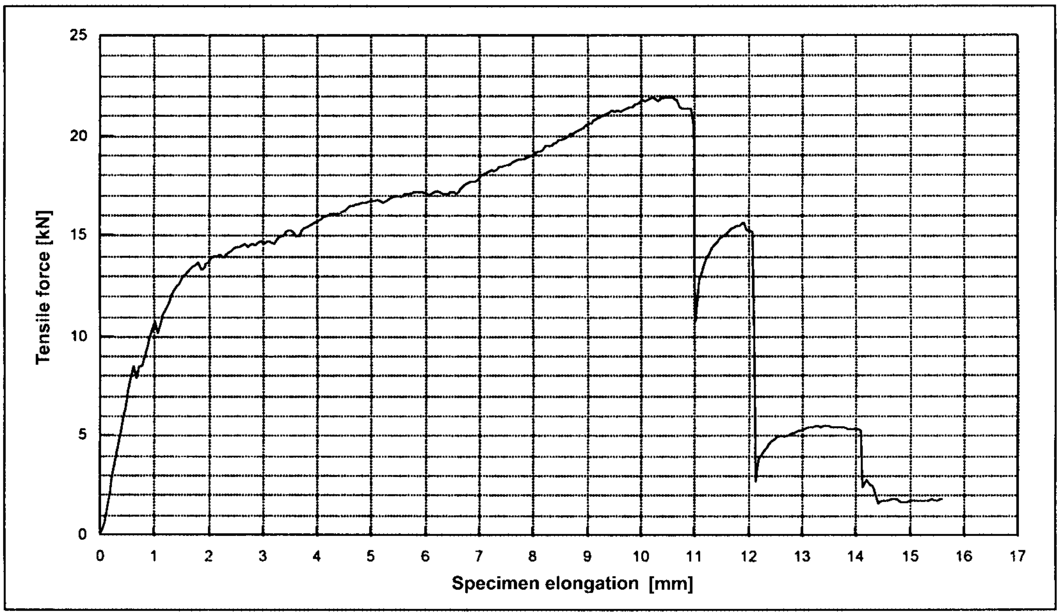


Fig. 3.5. Rupture test - specimen SO-1. Composite joint as coaxial connection of PA7ta dural pipes ϕ 30 x 1.5mm, made from glass roving ER - 3003 on Epidian 53 epoxy matrix with amplification coefficient 0,5.

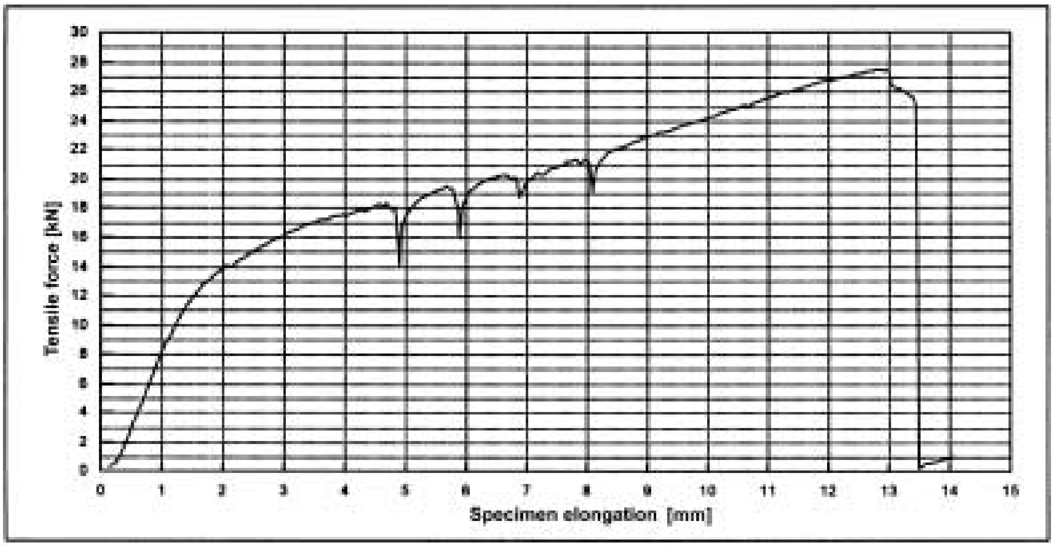


Fig. 3.6. Rupture test - specimen WO-1. Composite joint as coaxial connection of PA7ta dural pipes ϕ 30 x 1.5mm, made from roving Carbon T700SC 12K on Epidian 53 epoxy matrix with amplification coefficient 0,5.

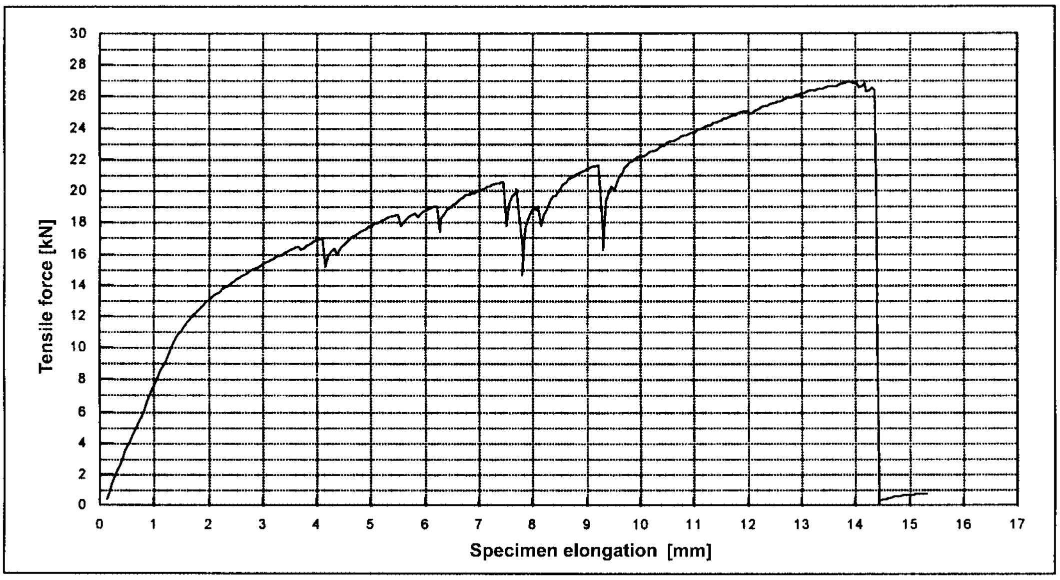


Fig. 3.7. Rupture test - specimen KO-1. Composite joint as coaxial connection of PA7ta dural pipes ϕ 30 x 1.5mm, made from roving Kevlar 49 on Epidian 53 epoxy matrix with amplification coefficient 0,5.

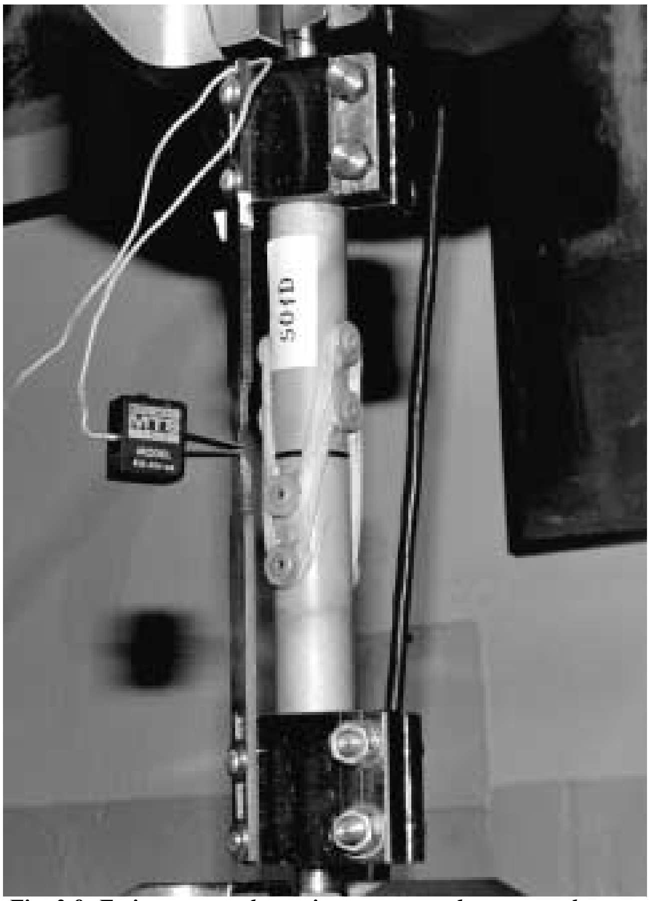


Fig. 3.8. Fatigue strength specimen mount, also mounted extensometer shown

It was necessary to measure specimen elongation directly for credible measurement of such hysteresis loops, because indirect measurement with automatic strength machine displacement transducer was affected by dead zone error. A special mount for MTS extension meter type COD was made and instrument was mounted.

This set-up allows measuring relative displacement of specimen mounting chucks, which can be accepted for specimen elongation, which is a sum of elongation of linked elements (dural pipes) and composite joint elongation.

During fatigue tests at assumed load levels, glass composite joint was intact at stipulated base of 100000 load cycles, but Kevlar and carbon composite joints were destroyed by fatigue failure of joint-connected structural elements.

Easily seen hysteresis loops testify ability of such joints to disperse energy, so they have ability to dampening. It is a very positive attribute for vibration-endangered load–bearing elements, e.g. self-induced flutter-type vibrations. In future work on such type of connections, joints dynamic attributes must be researched.

On the basis of research already done, it is difficult to quantitatively estimate dampening attributes of such joints, mainly because such conception allows to create practically any number of specific solutions in real structures. Three basic elements have essential meaning here – design of the composite joint, load amplitude and load frequency. In our case, composite joints worked with extremely high exertion, so their load values were comparable to maximum permissible loads.

Static and fatigue strength data presented here as results of research of isolated composite joints, allowed to design and produce a complex space truss structure, similar to real aircraft load-bearing structure.

Table 3.2. Statement of static tests results.

Item	Node (specimen)	Linear elongation range	Destructive load Pn	Destruction type	Joint stresses at destruction	Safety coefficient (3)/(2)
	(1)	(2)	(3)	(4)	(5)	(7)
	[-]	[kN]	[kN]	[-]	[MPa]	[-]
1	Glass (S0-1) Fig. 3.5	8.7	22	composite rupture	314	2.5
2	Kevlar (K0-1) Fig. 3.7	11	27	composite rupture	386	2.5
3	Carbon (W0-1) Fig. 3.6	11	27.5	catch rupture	393	2.5

Table 3.3. Assumptions and results of fatigue tests and residual strength of composite joints.

Item	Joint (specimen)	Safety coefficient ν_0	Destructive load ***Pn*** acc. to Tabl.3.2	Permissible load ***Pdop***. (3)/(2)	ψ *(6)/(4)*	Load assumed in fatigue test ***P***	Number of cycles (6) represented in test	Failure mode	Residual strength
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	[-]	[kN]	[kN]	[kN]	[-]	[kN]	[-]	[-]	[kN]
1	Glass (S0–2D)**	2.11	22	10.4	0.67	0.1, +7	100000	no failure	24.3 (Fig. 3.9)
2	Kevlar (K0–1D)	2.11	27	12.8	0.78	0.1, +10	51780	fatigue rupture of connected elements	-
3	Carbon (W0–1D)	2.11	27.5	13	0.77	0.1, +10	57900	fatigue rupture of connected elements	-
4	Glass Fig. 3.4	2.11	22	10.4	0.95*	-7, +7	98000	no failure	22 (Fig. 3.10)

**** - using Oding reduction formula, equivalent load was assumed as $P = 7 \cdot 2^{1/2}$ [kN]***
***** - specimen S0-1D was destroyed in result of strength machine failure.***

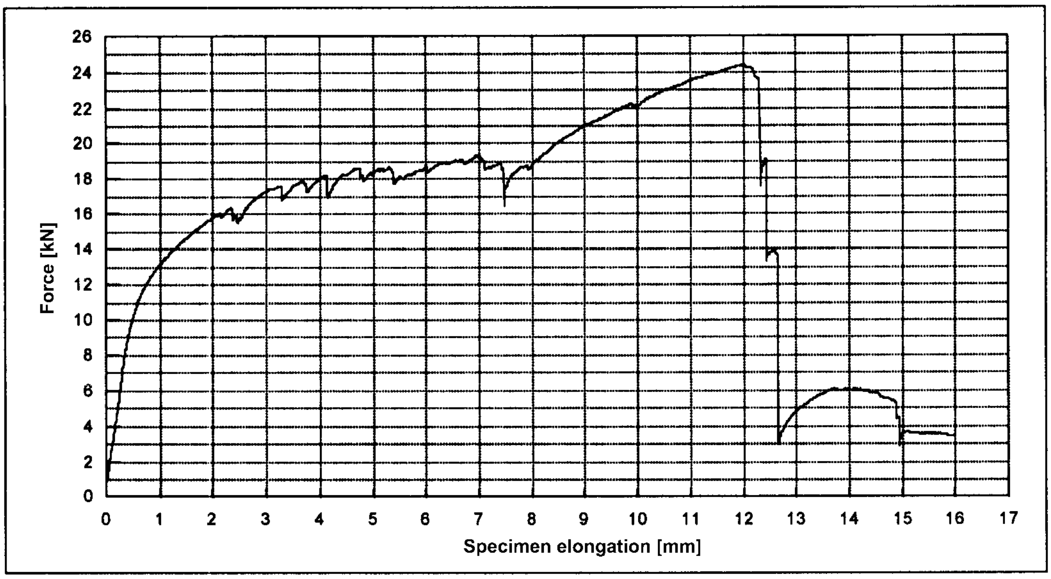


Fig. 3.9. Composite joint residual strength (specimen S0-2D) after 100000 load cycles 0.1 ,+ 7 kN, (Fig 3.11). Joint as coaxial connection of PA7ta dural pipes ϕ 30 x 1.5mm, made from glass roving ER - 3003 on Epidian 53 epoxy matrix with amplification coefficient 0,5.

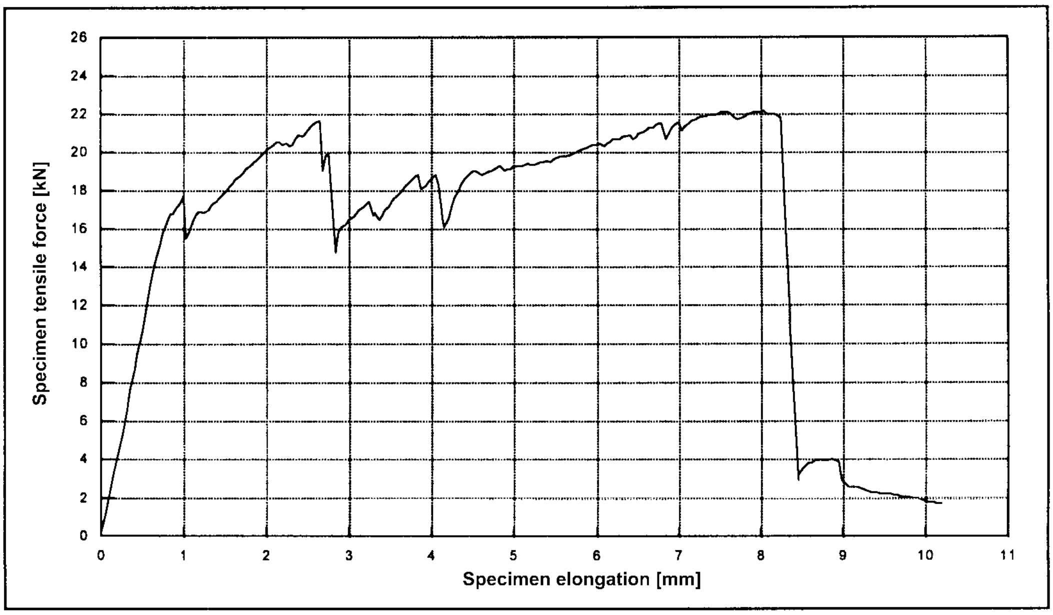


Fig. 3.10. Joint residual strength (Fig. 3.4) after 98000 load cycles ± 7 kN. Composite joint as coaxial connection of PA7ta dural pipes ϕ 30 x 1.5mm and ϕ 40 x 2 mm, made from glass roving ER - 3003 on Epidian 53 epoxy matrix with amplification coefficient 0,5.

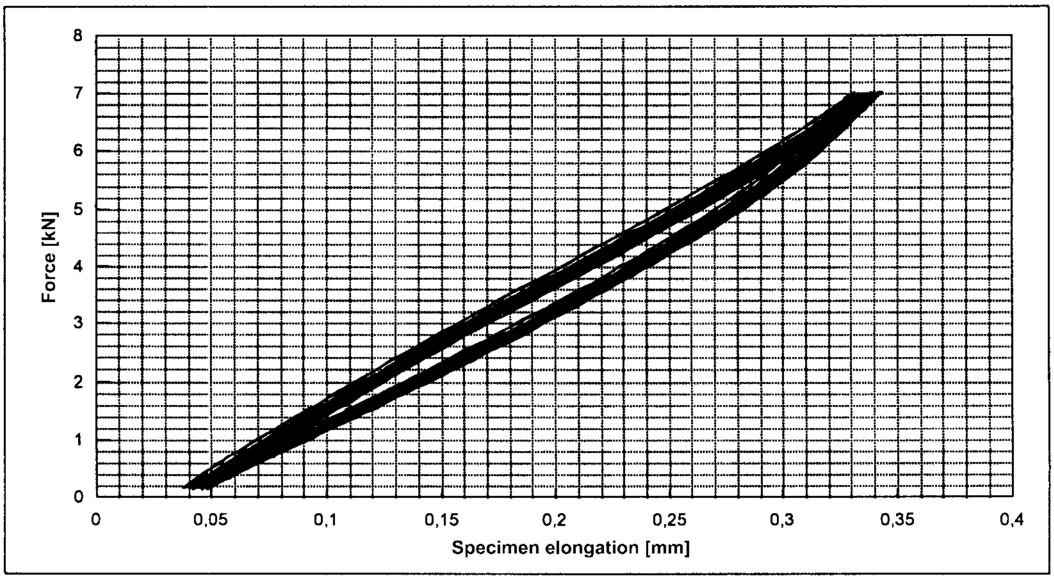


Fig. 3.11. Glass composite joint – specimen S0-2D, fatigue tests with load cycle: 0.1, + 7 kN and frequency 3 Hz. Record of several successive strain force versus specimen elongation loops, after every 10000 load cycles in 10000 to 100000 cycles range.

4. DESIGN AND CONSTRUCTION OF AIRCRAFT FUSELAGE TRUSS STRUCTURE ACCORDING TO PROPOSED CONCEPTION

4.1. CONCEPTION

Data analysis [3] and strength tests of specimens with joints [1, 2, 4] made from composites:
- glass,
- carbon
- and Kevlar

confirmed correctness of assumed conception of joints and allowed for making a next step. It was decided to design and build a truss structure, possibly similar to real structure. Aircraft-type structure was chosen, because of high exertion of constructions of this type. So production of truss structure of this type was decided. This choice was also dictated by good knowledge of loads for such type of construction. That fact is very important in estimation of fatigue exploitation loads.

To limit production costs the existing mounting jig was used and it allowed realising more complex and more representative load–bearing structure. Off course, other, much simpler examples of such constructions may be girder truss, mast truss, and frames. However, more complex construction was chosen, also with conviction about pertinence of testing a structure with the highest demands for proposed joints conception.

Thus very demanding criteria of valuation for proposed conception of composite joint load–bearing structures was created. These valuation criteria are capability to bear designated loads with maximum structure exertion and lowest structure weight. These are very harsh valuation criteria, resulting from low safety coefficients, typical for aeronautical structures.

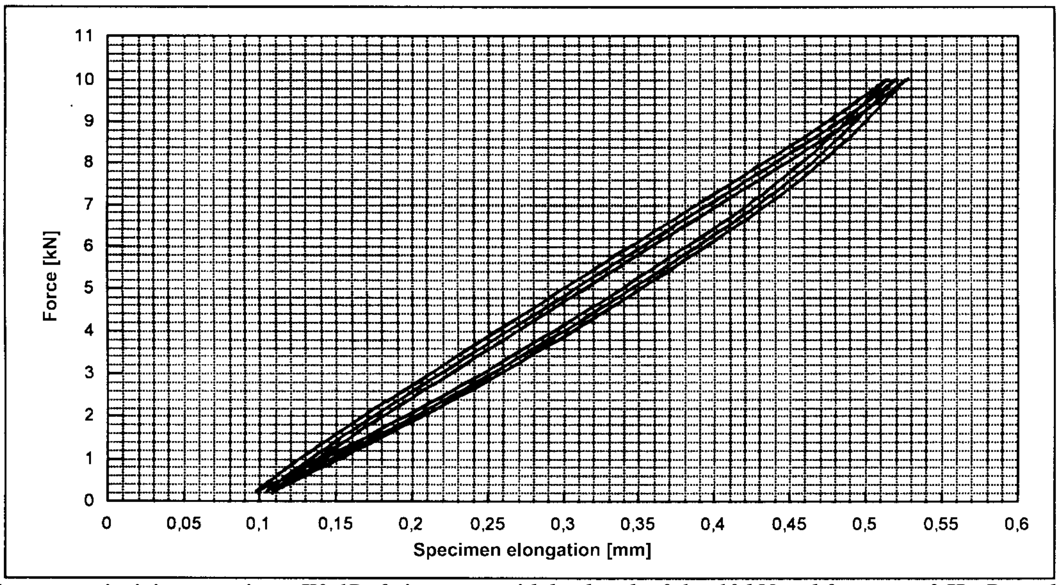


Fig. 3.12. Kevlar composite joint – specimen K0-1D, fatigue tests with load cycle: 0.1, +10 kN and frequency 3 Hz. Record of several successive strain force versus specimen elongation loops, after every 10000 load cycles in 10 000 to 30 000 cycles range.

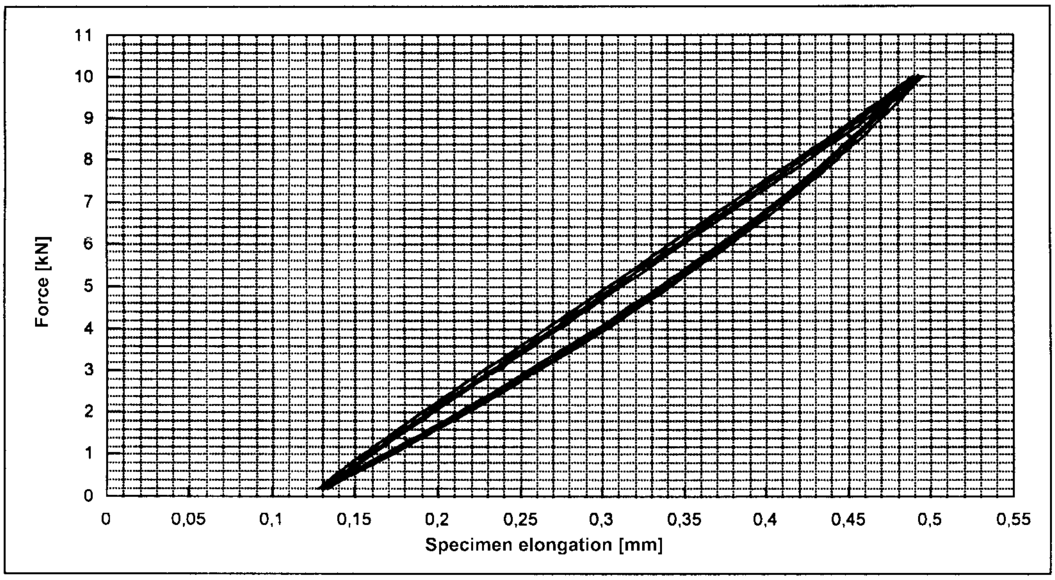


Fig. 3.13. Carbon composite joint – specimen W0-1D, fatigue tests with load cycle: 0.1, +10 kN and frequency 3 Hz. Record of several successive strain force versus specimen elongation loops, after every 10000 load cycles in 10000 to 30000 cycles range.

4.2. FUSELAGE TRUSS GEOMETRY – see Fig.4.1.

4.3. PRODUCTION ENGINEERING

1. Materials preparation
- Pa7ta dural anodising
- preparation of caps from a Pa7ta dural and caps anodising
- preparation of blinds from a Pa7ta dural and blinds anodising
- preparation of working stand for roving saturation with mixture of saturation rate of 50%.
- preparation of resins (Epidian 53 and Epidian 410), Z1 hardener and rivets.

2. Making of sub-assemblies:
- making of rivet holes
- riveting of caps (hooks) to pipes with blind (pop) rivets,
- mounting of pipe blinds
- covering of pipes in joint area with anti-corrosive primer and separating agent.

3. Mounting of sub-assemblies in mounting jig, according to structure geometry:
- positioning of pipes in a jig, pipes with mounted hooks and blinds,
- pipe mounting in a jig,
- geometry checks of size and positioning.

4. Preparation of saturation composition (Epidian 53 + hardener Z1).

5. Making of composite joints:
- covering of joint area with protective lacquer to protect parts from corrosive resin,
- linking of tubes with saturated roving strands according to documentation describing explicitly workmanship of each joint,
- after setting of saturated roving strands, fill spaces between roving cluster ant tube faces with composition (Epidian 410 resin with Z1 hardener) and cover whole surface of the joint with this composition,
- for aesthetic reasons composite joint may be profiled with soft covering material.

Tabl.4.1. Truss structure geometry – joints coordinates (Fig. 4.1)

Node coordinates			
node number	x [mm]	y [mm]	z [mm]
1	0	320	0
2	696	320	0
3	1375	320	0
4	2075	251	88
5	2825	177	183
6	3625	99	284
7	4425	20	385
8	4425	20	725
9	3625	127	725
10	2825	233	725
11	2175	320	725
12	1425	320	725
13	735	320	725
14	0	320	725
44	0	0	0
Coordinates of left-side nodes, symmetrical to 0xz plane are not given in table			

4.4. WORKMANSHIP

In truss workmanship, peculiarity of a previously accepted composite joint conception demands an exact analysis of labour of each joint. It brings to such roving hooks placement and such roving strands layout, which are adequate for each joint and each truss member loads. It closes the design and workmanship stage of composite joint truss structure as research object. Figure 4.2 shows a mounting jig used in truss production and Figure 4.3 shows complete truss structure, which was designed in accordance to the composite joint conception and mounted in this jig. This structure is practically identical to the fuselage truss structure of DEKO – 9 Magic airplane.

In next work phase, by:
- development of research program and selection of test loads,
- design and construction of research test stand,
- initiation and realisation of truss structure fatigue tests.

appreciation and verification of assumed composite joint conception has been made.

4.5 CONCLUSIONS

Fundamental conclusions resulting from production of the fuselage truss as a load–bearing structure, are:
- *possibility of making such construction types in relatively rude, primitive workshop environment,*
- *possibility of connecting practically any kind of material in one joint, impossible or very difficult to connect with other technologies,*
- *simplicity of overhaul or maintenance of damaged structure,*
- *possibility of optimal composite joint design through selection of optimal model of joint labour,*
- *design and construction of such structure, especially a very stressed one demands a full understanding of whole structure labour as well as each essential structure element labour alike.*

Tabl.4.2. Selection of truss members

Truss members	
Member node – node	Tube cross section outside diameter x wall thickness
11 – 14	ϕ 40 x 2.0
8 – 11	ϕ 30 x 1.5
1 – 14	ϕ 30 x 1.5
14 – 44	ϕ 30 x 1.5
14 – 13	ϕ 30 x 1.5
1 – 13'	ϕ 30 x 1.5
3 – 13	ϕ 30 x 1.5
13 – 13'	ϕ 40 x 2.0
2 – 13	ϕ 30 x 1.5
3 – 11	ϕ 30 x 1.5
13 – 44	ϕ 30 x 1.5
5 – 11	ϕ 30 x 1.5
6 – 10	ϕ 30 x 1.5
7 – 9	ϕ 30 x 1.5
3 – 1	ϕ 40 x 2.0
7 – 3	ϕ 30 x 1.5
remaining	ϕ 20 x 1.0

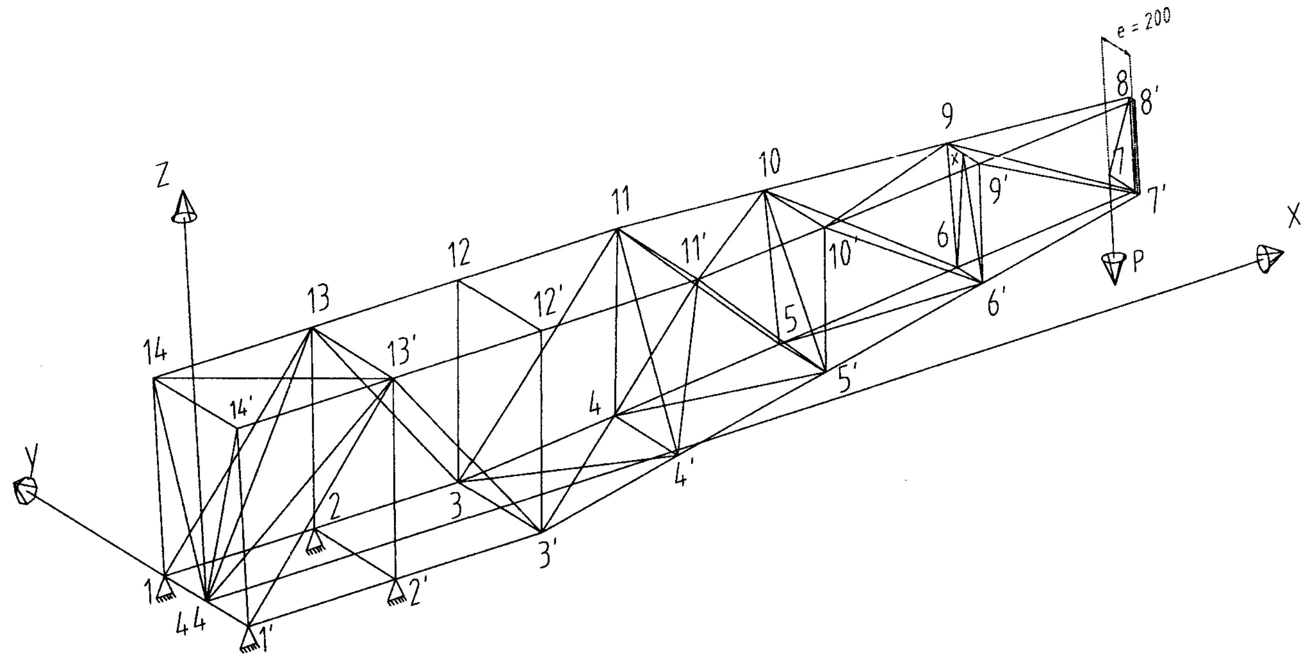


Fig. 4.1. Space view of the truss structure with joints designation, joints 1, 2, 1', 2' are test stand mounting joints, P load force in fatigue test placed on radius e = 200 mm, xz plane is the (airplane) symmetry plane PSS

Fig. 4.2. Production mounting jig for fuselage truss structure of DEKO-9 Magic airplane and used in building a composite joint truss structure (WZL-3 Dęblin)

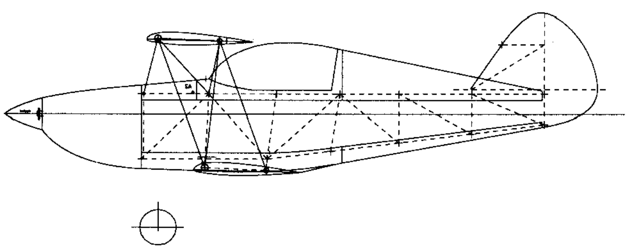


Fig. 5.1. VLA category sports airplane load–bearing structure schematics, this airplane was taken as a model to define loads in truss structure fatigue test.

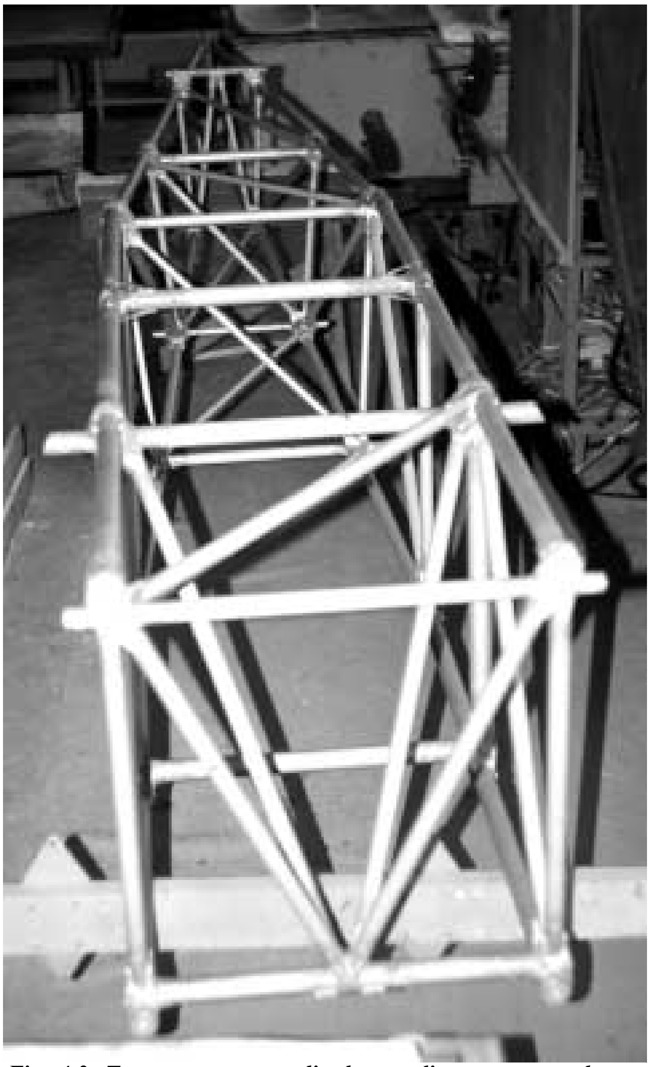


Fig. 4.3. Truss structure realized according to proposed conception of composite joints of load-bearing structures.

5. FATIGUE TESTS OF TRUSS STRUCTURE

5.1 LOADS SELECTION

Lacking other data and making a fatigue test load selections adequate to designed and build structure, following assumptions were made:

- truss structure is a VLA - class airplane load–bearing structure, designed to JAR–VLA rules [5],
- main structure fatigue loads are horizontal empennage manoeuvre loads; therefore they are airplane manoeuvre loads,
- airplane is a highly manoeuvrable, aerobatic one, and this considerably increases exploitation loads and load–bearing structure strain, particularly from fatigue loads point of view.

Basic parameters of a class VLA airplane are given in table 5.1, airplane chosen as model necessary to define real loads to truss structure fatigue tests, chosen on basis of selected data given in paper [6].

Item	Parameter	Value
1	Q - maximum take-off weight*)	750 kg
2	S - wing area	15.4 m^2
3	b_H - horizontal empennage span	2.4 m
4	n_z - limit load factor	+ 6 / - 3
5	S_H - horizontal empennage area	2.2 m^2
6	ρ - longitudal airplane radius of inertia	1.3 m
7	l_H – distance from airplane c.g. to lift center of horizontal empennage	3.7 m
8	V_A - airplane manoeuvring speed	212 km/h (59 m/s)

Table 5.1. Parameters of airplane choosen as model (Fig. 5.13)

According to formula given on page 1 - Appendix B2 [5] we receive horizontal empennage maximum force increase ΔP_H in symmetrical airplane manoeuvre, from load coefficient $n_z = 1$ to pull up, with maximum load factor value $n_z = 6$:

$$\Delta P_H / W = \rho^2 / g / l_H / V_A \cdot 20.1 \cdot (n_z \cdot (n_z - 1.5)) =$$
$$1.3^2 / 9.81 / 3.7 / 59 \, (20.1 (6 \cdot (6-1.5))) = 0.43 \quad (5.1)$$

where : W - airplane weight,

$$W = Q \cdot g = 750 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 7360 \text{ N},$$

in that case:

$$\Delta P_H = 0.43 \cdot W = 0.43 \cdot 7360 \text{ N} = +/- 3165 \text{ N} \quad (5.2)$$

It means that horizontal empennage maximum force increase in symmetrical airplane manoeuvre with $n_z = 1$ to $n_z = 6$ should do not cross value of 43% maximum airplane weight.

In level steady state flight, force on horizontal empennage necessary to balance the airplane, lacking other data, can be valued at 5% of airplane weight.

$$P_{Hr} = 0.05 \cdot W = 0.05 \cdot 7360 \text{ N} = 370 \text{ N} \quad (5.3)$$

Empennage total force is a sum of balance force and manoeuvre force increase

$$P_{H\,max./min.} = P_{Hr} +/- \Delta P_H \quad (5.4)$$

In symmetrical manoeuvre this force, as horizontal empennage aerodynamic force resultant, lays in airplane symmetry plane (PSS), and, from assumption, does not introduce twisting of airplane fuselage - if we assume ideal symmetry of airplane aerodynamic structure relatively PSS, of course.

To create more critical labour conditions, we introduce asymmetrical, but lifelike structure loads.

With empennage span $b_H = 2.4$ m one can assume that on each empennage side, distance to lifting force:

$$b_0 = 1/2 \, b_H = 2.4 / 2 = 1.2 \text{ m (Fig. 5.2).}$$

Next, according to point 427 [5], for right side of empennage one can assume value of force P_P:

$$P_P = 1/2 \cdot P_{H\,max./min.} \quad (5.5)$$

and for left side of empennage value of force P_L:

$$P_L = 1/2 \cdot (1 - 0.1 \cdot (n_z - 1)) \cdot P_{H\,max./min.} \quad (5.6)$$

It is easy to show that with overload factor $n_z = 6$, resultant of these forces have the value:

$$P_{max./min.} = 3/4 \, P_{H\,max./min.}$$

and lays in distance of:

$$e = 1/6 \, b_0 = 1/6 \cdot 1.2 = 0.2 \text{ m} = 200 \text{ mm}$$

from PSS plane.

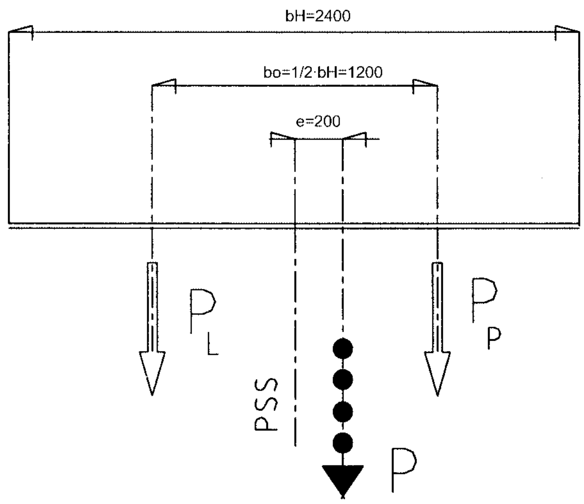


Fig. 5.2. Airplane horizontal empennage forces

How computational analysis and experience shows the greatest fatigue wear of manoeuvring airplane load–bearing structures, computed as derivative of fatigue wear in relation to structure load or in relation to load coefficient (in may be airplane vertical load coefficient n_z) happens not for the extreme, greatest loads, but for intermediate loads, within the brackets of 50 % to 80 % of maximum loads range [7] Fig. 3.12. It is because of fact that for construction fatigue is not a value of load important, but a relative frequency of load occurrence. Association of these two factors in this load range gives greatest fatigue wear. Increase of the airplane manoeuvrability transfers maximum of the airplane fatigue wear to greatest loads range.

To allow for the greatest, but real structure exertion possible, it was taken that load in fatigue test will be set at the 75% of maximum permissible load level. In permissible loads valuation, mass loads resulting from airplane pitching angular acceleration should be taken into account.

** One of fundamental limitations of these rules for the designer is maximum airplane weight limit of 750 kg*

According to [5] 423 b, angular acceleration from sudden elevator movement can be estimated as:

$$\varepsilon = 20.1 / V_A \cdot (n_z \cdot (n_z - 1.5)) =$$
$$= 20.1 / 59 \cdot (6 \cdot (6 - 1.5)) = +/- 9.2 \; rd/s^2 \quad (5.7)$$

Taking the real assumption that sum of empennage mass and tail wheel mass is equal to m_0 = 16 kg, mass load from angular acceleration will be:

$$\Delta P_H = \varepsilon \cdot l_H \cdot m_0 = 9.2 \cdot 3.7 \cdot 16 = 545 \text{ N} \quad (5.8)$$

It finally defines a load cycle that should be imitated in fatigue test:

$$P_{max.} = 0.75 \cdot P_{max.} =$$
$$= 0.75 \cdot (3/4 \cdot (370 \text{ N} + 3165 \text{ N} - 545 \text{ N})) = 1680 \text{ N} \quad (5.9)$$
$$P_{min.} = 0.75 \cdot P_{min.} =$$
$$= 0.75 \cdot (3/4 \cdot (370 \text{ N} - 3165 \text{ N} + 545 \text{ N})) = -1270 \text{ N} \quad (5.10)$$

5.2 ESTIMATION OF NUMBER OF LOAD CYCLES EQUIVALENT TO ONE–HOUR FLIGHT OF MANOUVERABLE AIRCRAFT

Airplane wing loads, especially bending moment's distribution, are practically proportional to airplane vertical load factor n_z, and more strictly, to the airplane vertical acceleration. There were no basis to assume that tail loads are proportional to vertical acceleration and vertical load coefficient n_z, until in flight measurements and their analysis were made within the dedicated research program (on *SB Lim*-2 airplane, during development of *I*-22 *Iryda* airplane).

Other data lacking, it will be safer to assume that airplane load spectrum taken as model for real loads in truss structure fatigue test will be not more severe in fatigue loads sense than presented in Fig. 5.3 manoeuvring airplane spectrum. This assumption, of course, takes identical relation between two airplane loads in their value and frequency range.

However, maximum load factor for manoeuvring airplane equals n_z = 7.5 and for model airplane n_z = 6, respectively

Hourly in-flight fatigue wear for shown above load spectrum, presented in paper [12], page 44, equals:

$$D\,[1/h] = 10422 \quad (5.11)$$

with 48 load cycles for one-hour flight.

Extreme values of load factor in manoeuvring airplane load spectrum are:

$$n_z = 7.5 \text{ and } n_z = -2.0$$

According to Oding hypothesis, fatigue equivalent (resulting in the same fatigue damage) load cycle, equals:

$$n_{zr} = \sqrt{(7,5(7,5-(-2)))} = 8,4 \quad (5.12)$$

Value of 75% of above computed coefficient n_{zr} is:

$$n_{zr\,0.75} = 0.75\, n_{zr} = 0.75 \cdot 8.4 = 6.3 \quad (5.13)$$

Number of cycles resulting in one-hour flight construction fatigue wear and equivalent to fatigue wear from assumed manoeuvring airplane load spectrum will be:

$$lc = D / n_{zr0.75}{}^{\alpha} = 10422 / 6.3^4 = 6.6 \; cycles \quad (5.14)$$

where exponent $\alpha = 4$ was assumed (as for dural structures)

Because of loads for fatigue test were assumed at the 75% of maximum permissible loads level, so this number of cycles representation in truss structure fatigue test means representation of loads conformed to one hour flight of model airplane. It is truss structure durability estimation, based on fatigue test load representation formulated in number of flight hours.

$$T = l / lc \quad (5.15)$$

where:

l – number of load cycles represented in fatigue test in number of flight hours,

T – truss structure durability [hourly flight time],

lc – above mentioned equivalent.

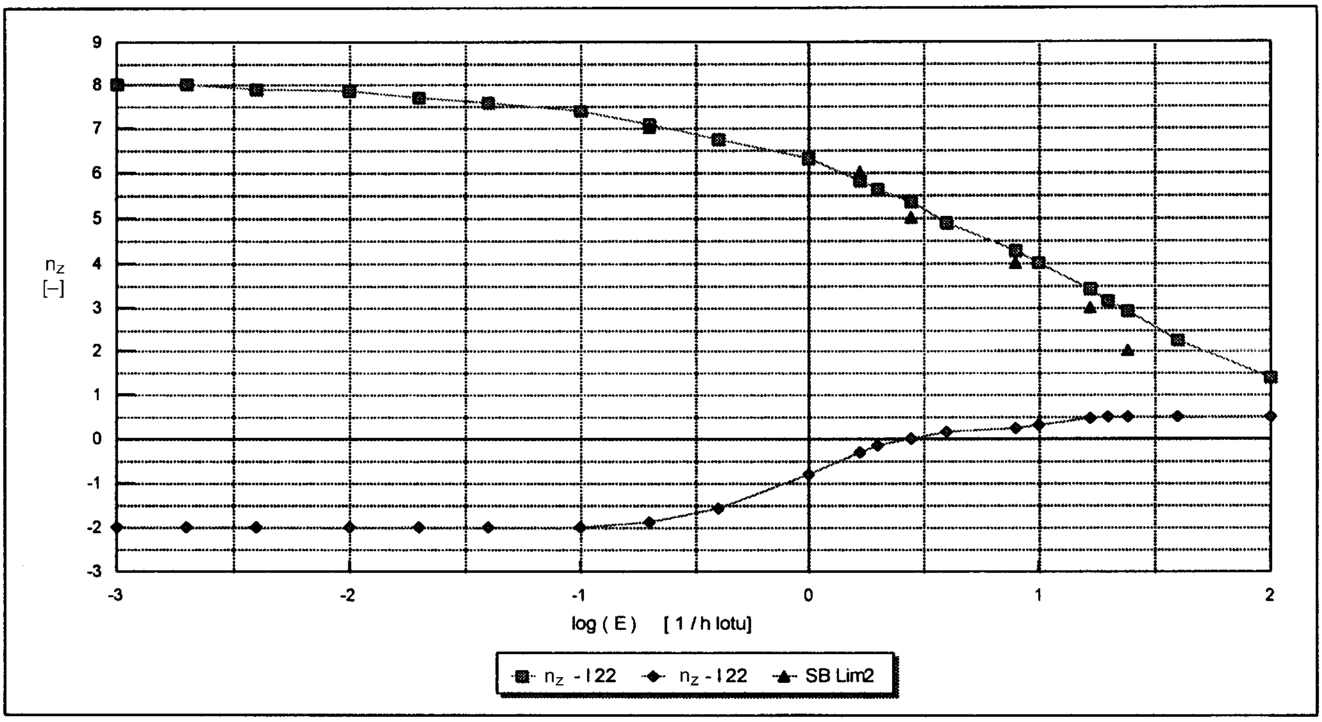


Fig. 5.3. Example of manoeuvring airplane load spectrum (PZL I-22 Iryda acc. to [13])

5.3. VALUATION OF TRUSS STRUCTURE STIFFNESS CRITERION AS AIRCRAFT LOAD – BEARING STRUCTURE.

5.3.1. BENDING STIFFNESS CRITERION

Besides strength criterion, airplane load–bearing structures must comply, and their fulfilment must provide substantial amount of static and fatigue tests, also fulfilment of stiffness criterion for such structure is very essential. It results from necessity of providing resistance to self-induced, flutter-type vibrations in whole airplane speed range. Proper criteria are defined in airplane building rules, e.g. [8], and fulfilment of these rules should be documented in computational analysis during design stage (e.g. [9, 10]) and confirmed later, after construction of the prototype, in real structure compliance tests. To qualify a composite joint truss structure from a stiffness point of view, British airplane building rules were used.

According to these rules, **bending stiffness criterion** is:

$$K = 1/V_D\,(F_V / L'/S')^{1/2} \geq 0.12 \qquad (5.16)$$

where, assumed real values of constructional parameters for light and very light airplanes (VLA class) are, respectively:

V_D [kt] - maximum permissible diving speed expressed in knots (1kt = 1.852 km/h),

$$V_D = 345 \text{ km/h} = 345/1.852 = 186 \text{ kt}.$$

F_V [lbf ft/rd] - vertical plane fuselage bending stiffness, measured between node positioned in L' of mean chord of a supplemental wing and elevator hinge axle.

L' [ft] distance between a node positioned in L' of mean chord of a supplemental wing and elevator hinge axle

$$L' = 3800 \text{ mm or } 3.8 \text{ m} /0.3048 = 12.5 \text{ ft}.$$

S' [sq. ft] - horizontal empennage area

$$S' = 2.2 \text{ m} = 2.2 / 0.3048^2 = 23.7 \text{ sq.ft}$$

The load applied in fatigue test [11] was

$$P_{max} = +1680 \text{ N},$$
$$P_{min} = -1270 \text{ N}$$

and vertical displacements of joints in nodes no. 7 and 8 of truss structure, corresponding to these loads were, respectively (Fig. 5.7):

$$f_{max} = -12.9 \text{ mm}, f_{min} = +10.1 \text{ mm}$$

Fuselage bending angle acc. to [5]:

$$\alpha_V = \text{arctg}\,(|f_{max} - f_{min}|/L') = |-12.9 - 10.1|/3800 = 0.00605 \text{ rd}$$

Bending moment:

$$Mg_V = (P_{max} - P_{min})\,L' = (1680 - (-1270))\,3.8 = 11210 \text{ Nm}$$
$$F_V = Mg_V / \alpha_V = 11210/0.00605 = 1853000 \text{ Nm/rd}$$

In Imperial units:

$$F_V = 1853000 / 9.81/0.4536 /0.3048 = 1366000 \text{ lbf ft / rd}$$

$$\boxed{K = 1/V_D\,(F_V / L'/S')^{1/2} = 1/186(1\,366\,000/ 12.5/23.7)^{1/2} = 0.365 \gg 0.12}$$

5.3.2. TORSIONAL STIFFNESS CRITERION

Torsional stiffness criterion has a view

$$K = 1/V_D\,(F_S / s'/S')^{1/2} >= 0.036 \qquad (5.17)$$

where

s'[ft] - half of horizontal empennage span (according to Table 5.1)

$$s' = b_H / 2 = 2.4 / 2 = 1.2 \text{ m} = 3.94 \text{ ft}.$$

F_S [lbf ft/rd] - fuselage torsional stiffness measured between node localized in L' of mean chord of a supplemental wing and elevator hinge axle.

For mentioned above test loads range, respective twist angles were, respectively:

$$\alpha_{max} = -0.22\,°, \ \alpha_{min} = +0.20\,°$$

These recorded angles were truss structure twist angles on length of $l = 2929$ mm between nodes 2 and 6 (Fig. 5.1 and Table 4.1). For this criterion should be used a twist angle per length $L' = 3800$ mm. Assuming therefore (for safe side) linear relation between twist angle and stations distance for angle measurement, from linear interpolation we receive:

$$\alpha_{max} = -0.22°\cdot 3800 / 2929 = -0.29°,$$
$$\alpha_{min} = +0.20°\cdot 3800 / 2929 = +0.26°.$$

Twist angle:

$$\alpha_S = |\alpha_{max} - \alpha_{min}|\pi /180\,° = 0.00959 \text{ rd}$$

Twisting moment:

$$Mg_S = (P_{max} - P_{min})\,e =$$
$$= (1680 - (-1270))\,0.2 = 590 \text{ Nm}$$

where e - force arm relatively PPS plane, $e = 0.2$ m (Fig. 5.1)

$$F_S = Mg_S / \alpha_S = 590 / 0.00959 = 61500 \text{ Nm/rd}$$

In Imperial units:

$$F_S = 61500 / 9.81 / 0.4536 / 0.3048 = 45300 \text{ lbf ft / rd}$$

definitively:

$$\boxed{K = 1/V_D\,(F_S / s'/ S')^{''} = 1 / 186\,(45300 / 3.94 / 23.7)^{''} = 0.118 \gg 0.036}$$

Tested truss structure meets torsional and bendings criteria, required for airplane load–bearing structure. It is essential that in a whole fatigue test, torsional and bending stiffness does not changed, meeting above-mentioned criteria with sufficient margin.

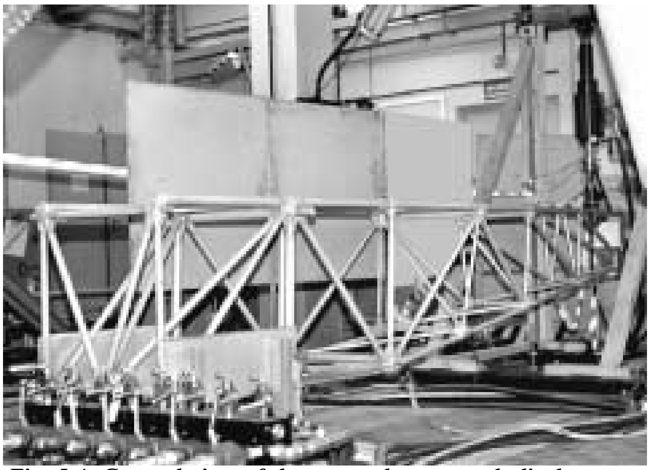


Fig. 5.4. General view of the research test stand, displacement sensors can be seen.

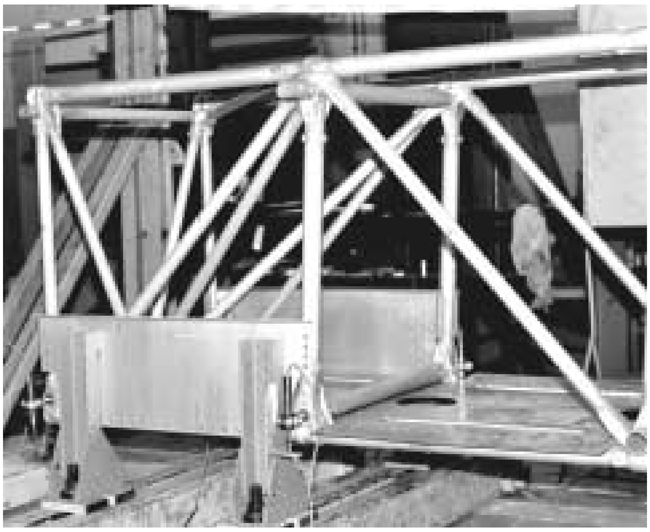


Fig. 5.5. General view of truss structure mount, displacement sensors can be seen

Table 5.2. Axial forces in structure truss members for fatigue test loads (relations: 5.9, 5.10)

Item	member node–node	Member force in N, per force: *Pmax.*=1680N	*Pmin.*= -1270N
1	3 - 4	-2480	1870
2	4 - 5	-2750	2080
3	5 - 6	-1950	1480
4	6 - 7	94	-71
5	7 - 8	-1680	1270
6	9 - 8	-3220	2430
7	10 - 9	-81	61
8	11 - 10	1650	-1250
9	3 - 11	-1530	1160
10	4 - 11	13	-10
11	5 -11	1260	-955
12	5 - 10	-926	70
13	6 - 10	2330	-1760
14	6 - 9	-1390	1050
15	7 - 9	3780	-2860
16	3’ - 4’	-3540	2680
17	4’ - 5’	-3650	2760
18	5’ - 6’	-3230	2440
19	6’ - 7	-3180	2410
20	9’ - 8	3220	-2430
21	10 ‘ - 9’	2840	-2150
22	11’ - 10’	3040	-2300
23	3’ - 11’	137	-103
24	4’ - 11’	-208	157
25	5’ - 11’	181	-137
26	5’ - 10’	59	-45
27	6’ - 10’	-123	93
28	6’ - 9’	242	-183
29	7 - 9’	-443	335
30	4’ - 4	-122	92
31	5’ - 5	-165	125
32	6’ - 6	55	-41
33	10’ - 10	-109	83
34	11’ - 11	-65	49

Item	member node–node	Member force in N, per force: *Pmax.*=1680N	*Pmin.*= -1270N
35	1 - 14	955	-722
36	1 - 13	5530	-4180
37	2 - 13	-6350	4800
38	3 -13	1760	-1330
39	3’ - 12’	8	-6
40	13’ - 12’	3390	-2560
41	14’ - 13’	0	0
42	1’ - 14’	1160	-875
43	1’ - 13’	3900	-2950
44	2’ - 13’	-4370	3300
45	3’ - 13’	457	-346
46	12’ - 12	-2	2
47	13’ - 13	-462	349
48	14’ - 14	519	-392
49	44 - 14	-1030	777
50	44 - 14’	-1260	950
51	44 - 13	1650	-1240
52	44 - 13’	1880	-1420
53	13’ - 14	-178	134
54	12’ - 11’	3390	-2560
55	12 - 11	3690	-2790
56	3 - 4’	-132	10
57	4 - 5’	315	-238
58	10’ -9	336	-254
59	11’ - 10	401	-303
60	4’ - 11	297	-225
61	5’ - 10	-245	185
62	9’ - x	-62	47
63	x - 9	-104	79
64	6’ - x	-174	131
65	6 - x	21	-16
66	3 - 12	14	-11
67	13 - 12	3690	-2790
68	14 - 13	134	-101

5.4. RESULTS OF FATIGUE TESTS OF TRUSS STRUCTURE

To perform fatigue tests a research test a stand and a tested object mounts were designed and produced.

Figure 5.4 shows a general view of the test stand, Figure 5.5 shows a way of truss mounting, and also Figure 5.6 shows a joint for introduction of test force.

On all these figures, displacement sensors for measurement of truss displacement can be seen.

For fatigue tests results evaluation, following tasks were performed:

- computations of forces in truss members, results are presented in Table 5.2
- computations of structure displacements presented on Figures 5.8 and 5.9
- strain marking in structure stiffening plates in the test stand structure mounting region for loads in fatigue test and for test stand mounting method (Figs 5.10, 5.11).

Computations were made with MSC/PATRAN Ver.8.1 [29] finite element method software.

Force values and number of cycles realized in fatigue test are computational estimation of fatigue loads for each truss member for a given computational model. In reality, character of a tested system is passable between truss and frame structure, what was taken into account in computational model. In result of fatigue tests according to program [11] it was represented:

70000 *load cycles* +1680 N , -1270 N *with frequency* 0.1 Hz.

without any failures in tested structure and without change of stiffness characteristics.

According to relations 5.14 and 5.15 number of cycles for load represented in test (5.9, 5.10) fatigue equivalent to one hour of flight equals 6.6 cycles per hour of flight and nominal fatigue durability will be:

$$T = l / lc = 70000 / 6.6 = 10600 \textit{ flight hours} \quad (5.18)$$

Assuming real value of reliability coefficient $\eta = 5$, tested object service life can be estimated as class VLA (Very Light Aircraft) sport airplane load–bearing structure:

$$R = T / \eta = 10600 / 5 = 2120 \textit{ flight hours} \quad (5.19)$$

It is a sufficiently big value for this class of airplane.

System displacements in seven places were recorded during tests that allowed to define displacement of the joint number 7 relative truss mounted joints.

Records were made every 2000 represented load cycles and three successive cycles were recorded.

Figures 5.7 and 5.7a shows layered traces of joint no. 7 vertical displacement and truss bending angle in function of load force, worked out on basis of registrations made after every 10000 load cycles.

This comprehensive drawing allows ascertaining that structure behaves linearly, without visible hysteresis.

After 70000 load cycles, recording of the test data was cancelled. After 150000 cycles fatigue test was interrupted, assuming that safe life of the truss was achieved.

Truss static test was performed next, to determine the residual strength of the truss. In this test, joint in point no.13 was destroyed, under force of P = 7339 N.

Fig. 5.7b. shows results of this test.

Realisation of truss structure fatigue tests was confirmed in a written report [22]*.

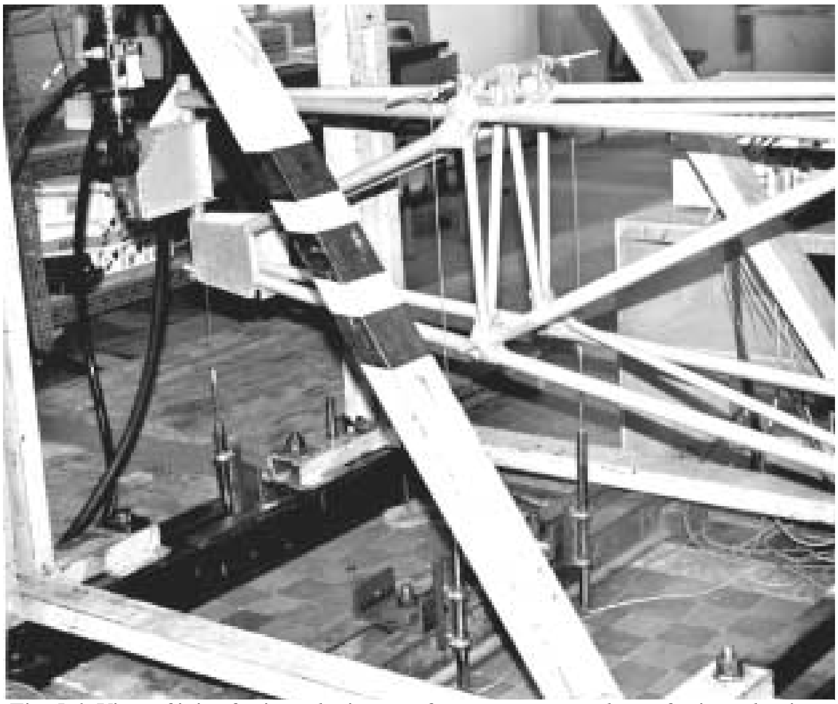


Fig. 5.6. View of joint for introducing test force, actuator and arm for introduction of bending and twisting loads can be seen, also displacement sensors can be seen

* after work closure, the test was continued with successive load increase every 10000 cycles, but it was assumed that achieved fatigue resistance is sufficient to practically confirm in conception of composite joints and future conception documentation has sense only in real load–bearing structure designs.

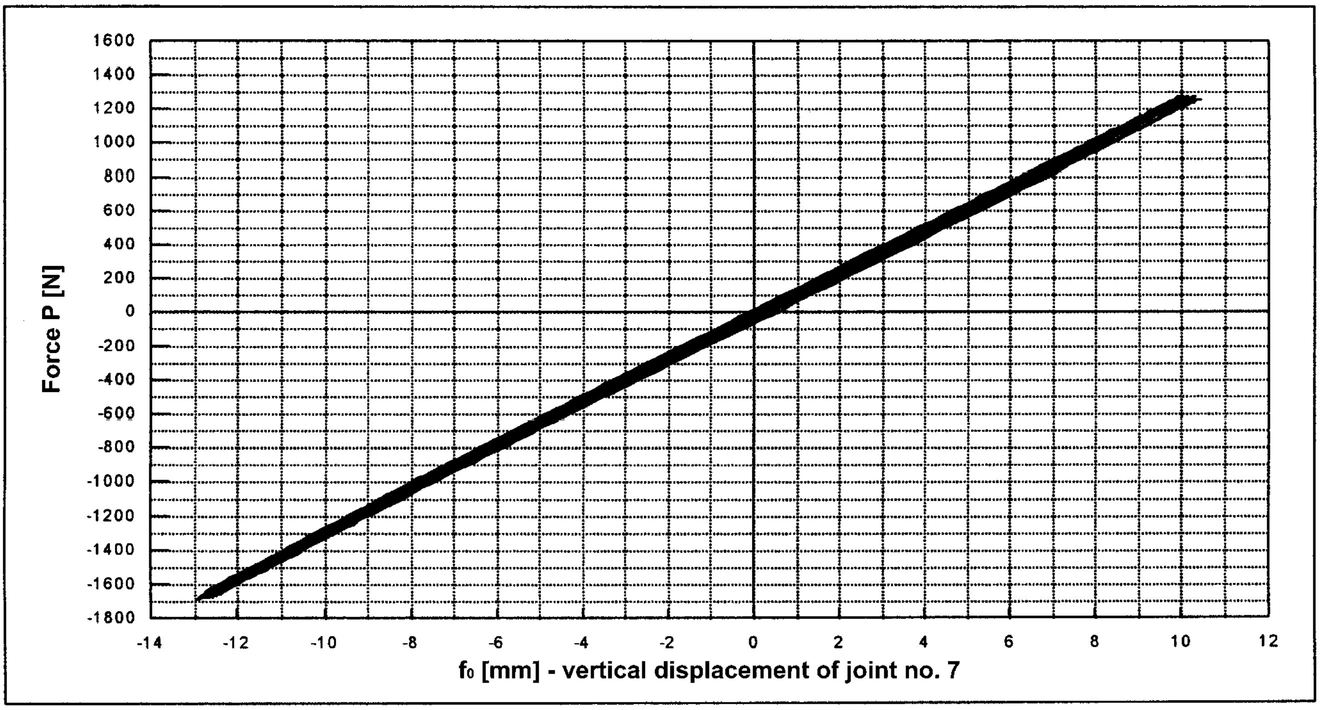


Fig. 5.7. Layered traces of joint no 7 vertical displacements in function of load force after representation of 10000, 20000, 50000, 60000 and 70000 load cycles

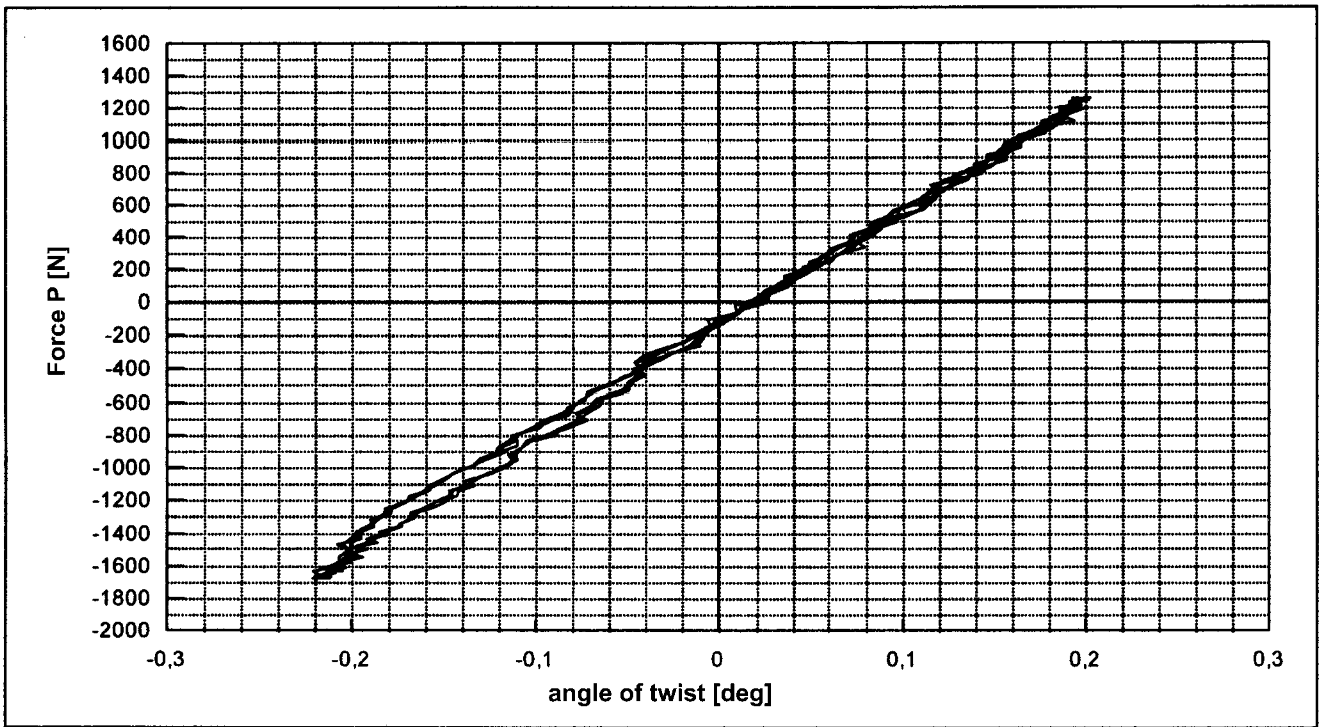


Fig. 5.7a. Example of truss twist angle on distance between joints no 2 and 6 recorded after representation of 50000 load cycles

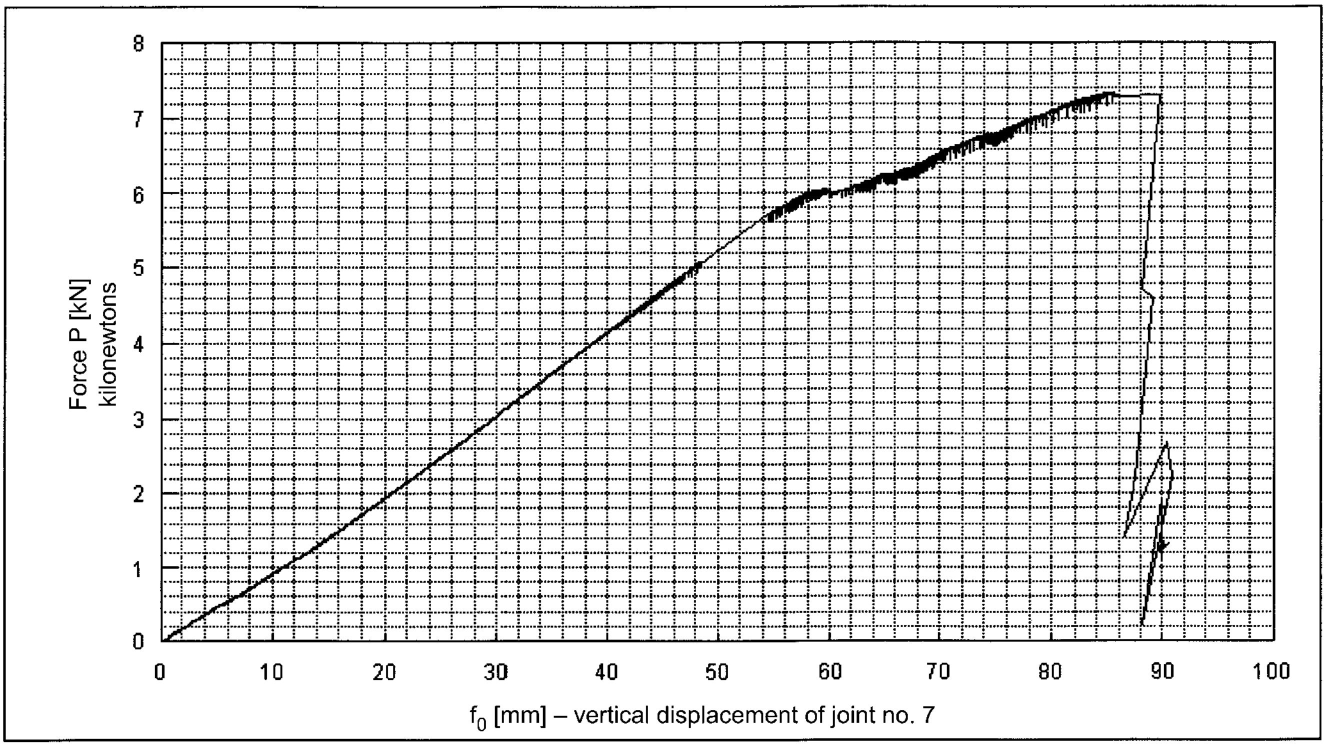


Fig. 5.7b. The residual strength of the truss after 150000 cycles +1680N , -1270N with 1 Hz frequency. Picture below shows destroyed composite joint in point no. 13

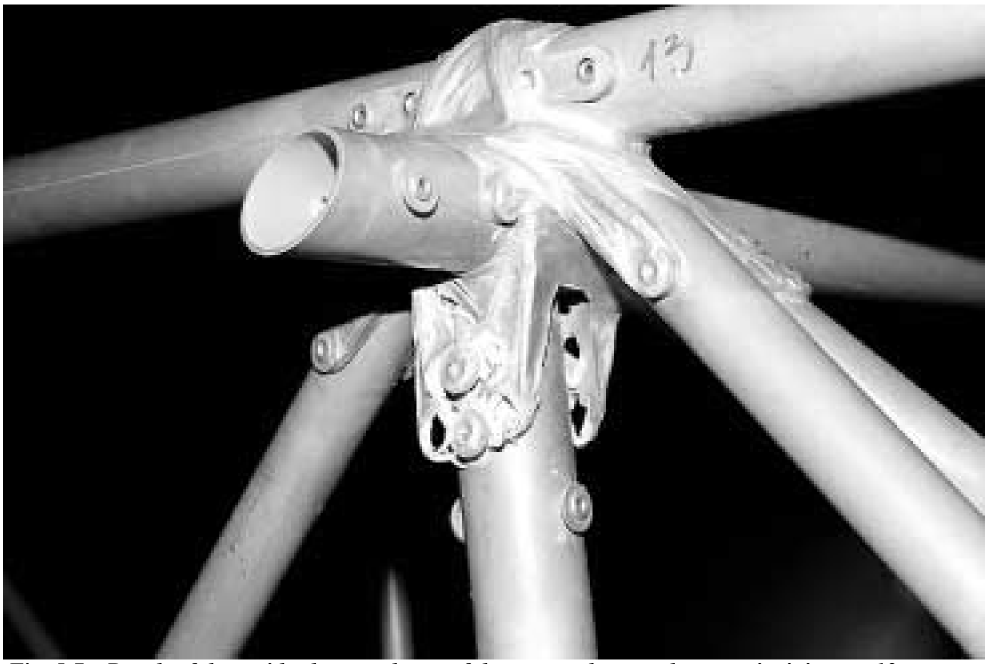


Fig. 5.7c. Result of the residual strength test of the truss – destroyed composite joint no. 13

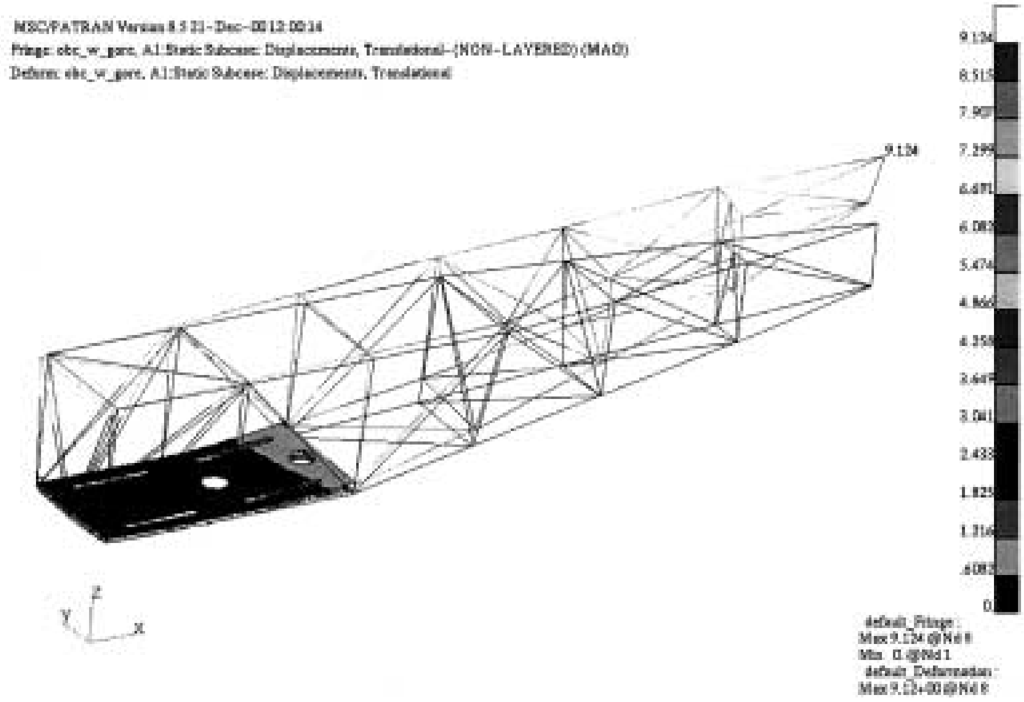


Fig. 5.8. Computational values of vertical displacement for load 1270 N directed upwards

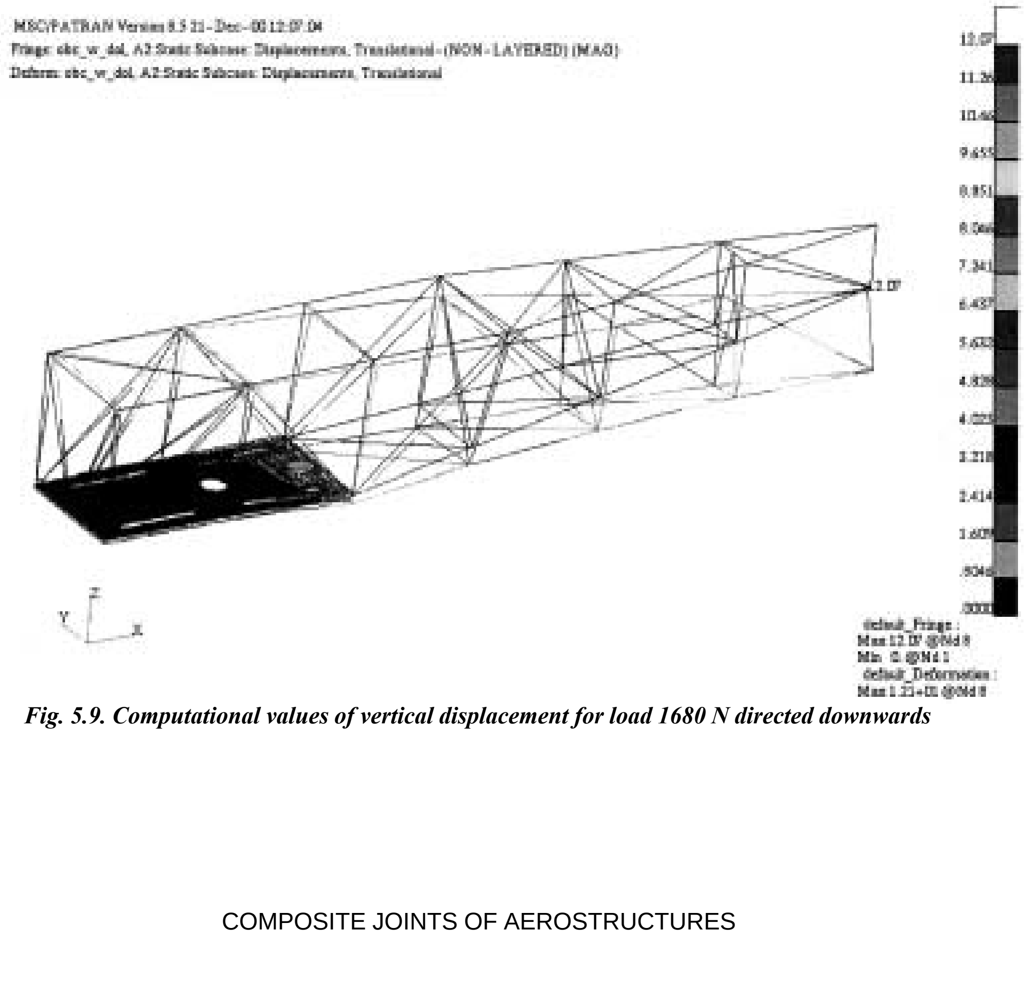


Fig. 5.9. Computational values of vertical displacement for load 1680 N directed downwards

Fig. 5.10. Computational values of strain in truss closing plate in a test stand mounting area for load 1270 N directed upwards

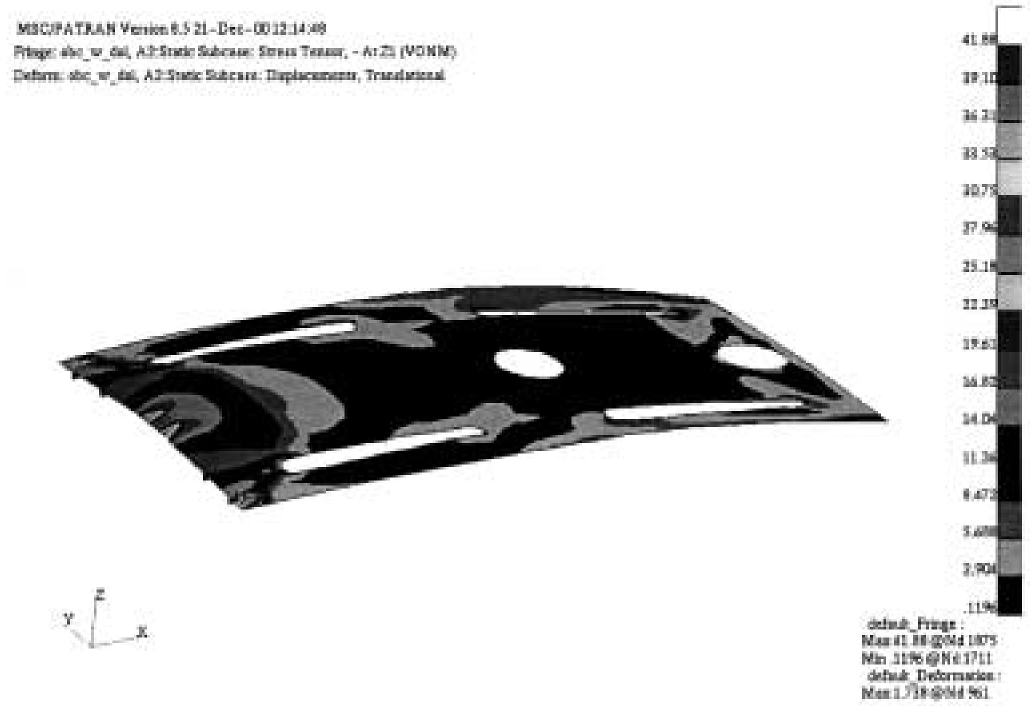


Fig. 5.11. Computational values of strain in truss closing plate in a test stand mounting area for load 1680 N directed downwards

6. APPLICATIONS

As it was mentioned before, first designs where such connection types were applied was the ultra–light airplane Fregata (Fig. 2.2) Application range was, in this example, limited to the second importance joints. Possibility of building this airplane with load–bearing structure made with this joint convention as very cheap and simple one, but idea was abandoned (what a pity!) because of new projects commencement, in spite of the fact that the plane was and still is a wonderful alternative to very popular today motorized paragliders.

In was mentioned earlier that other constructions with composite joints structures listed several iceboats, yachts, and catamarans, developed and constructed by Krzysztof Kotliński, M.Sc, unmistakably forerunner in this field.

These constructions outclassed the classic DN-type iceboats of wooden construction. Several failures of these ice–boats that happened in their exploitation have shown extraordinary resistance of these composite joints connections to high load damages, especially after impact.

Actually, a very essential step in application of joints of this type was joint development in cooperation with foreign aviation firm and construction of a *DEKO*-9 *Magic* sport airplane prototype, whose fuselage load–bearing structure is made as dural truss with composite joints, solution **optimal from strength, lightness, and production costs point of view**. As this airplane is designated to full aerobatics, elementary training and glider towing, one should consider its heavy construction strain. Performed measurements of static and fatigue strength of structure of this type with loads adequate to airplane type, confirm legitimacy of joint conception proposed here. Parallel to prototype construction a research project was realized, whose results are base of this publication. The static test of the fuselage truss has been made in thermal chamber, in 55°C temperature, to the safety coefficient $\nu_0 = 1.8$; $(\nu_1 \cdot \nu = 1.19 \cdot 1.5 = 1.79)$. Accepted composite joint conception contributed greatly to only 24 month task of 10 person crew, from first drawing to finished prototype of complex aeroplane, full of innovatory ideas.

Actually aeroplane in–flight tests are made and next designs are prepared, aviation type and other, stationary load–bearing structures. This paper maybe will contribute to further application of this conception, meeting objective of more perfect load–bearing structures of various constructions. One should mention currently developed ultra light recreational and patrol aeroplane, load–bearing structure of which, shown on Fig. 6.1, in substantial fragments is made according to composite joint conception presented here. Great public interest and response after publication of several papers describing the complete work [1, 2, 4, 14, 23, 24, 25, 26, 27, 28], work presented here, is promising for future development and is also resulting in already realized foreign contacts.

Figure 6.5 shows schematicaly the load–bearing structure of a airship. It is a next example of possible application of our composite joint idea. Optimum solution for such structure will be use of composite node joints and tubular truss members. This allows designer to obtain a lowest structure mass and minimize fabrication costs.

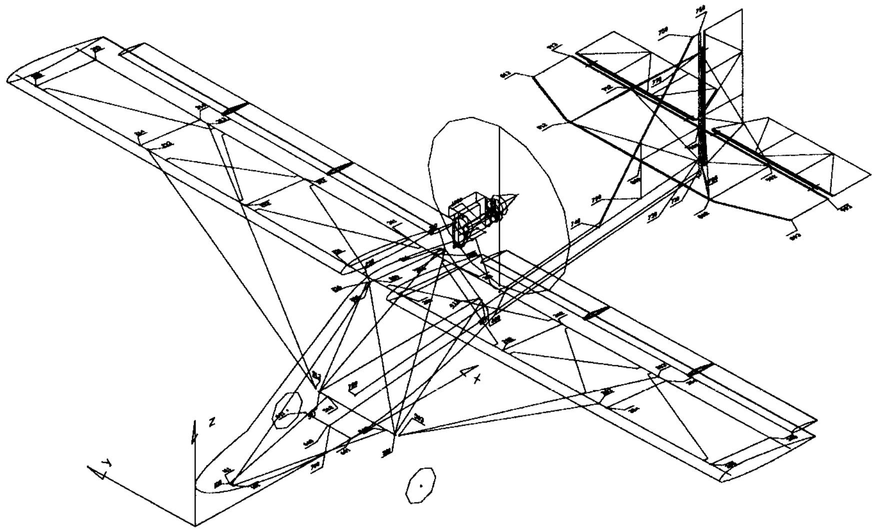


Fig. 6.1. Load–bearing structure schematics of DEKO-6 Whisper airplane

Fig. 6.2. DEKO-9 Magic airplane prototype on international air show ILA'2000 - Berlin. Design parameters of this airplane helped to design a composite joint truss fuselage and to specify loads for testing

Fig. 6.2a. DEKO-9 Magic airplane prototype during flight tests

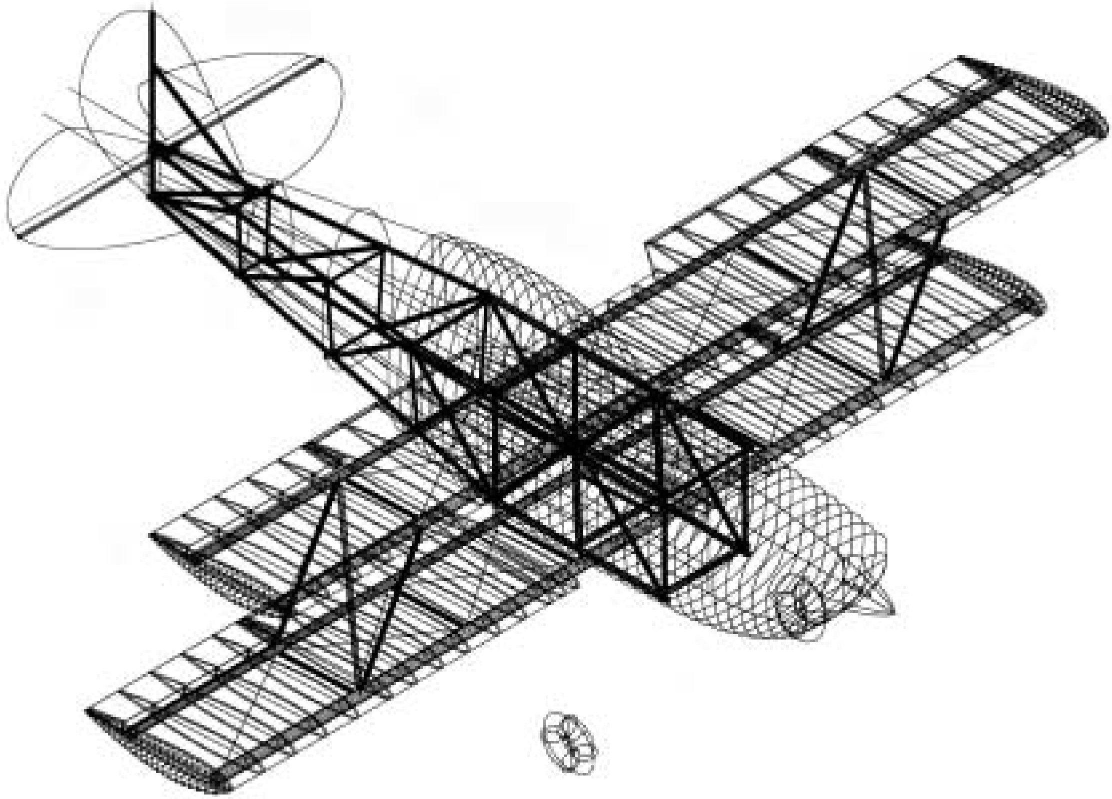


Fig. 6.3. Geometry and load–bearing stucture of DEKO-9 Magic aeroplane

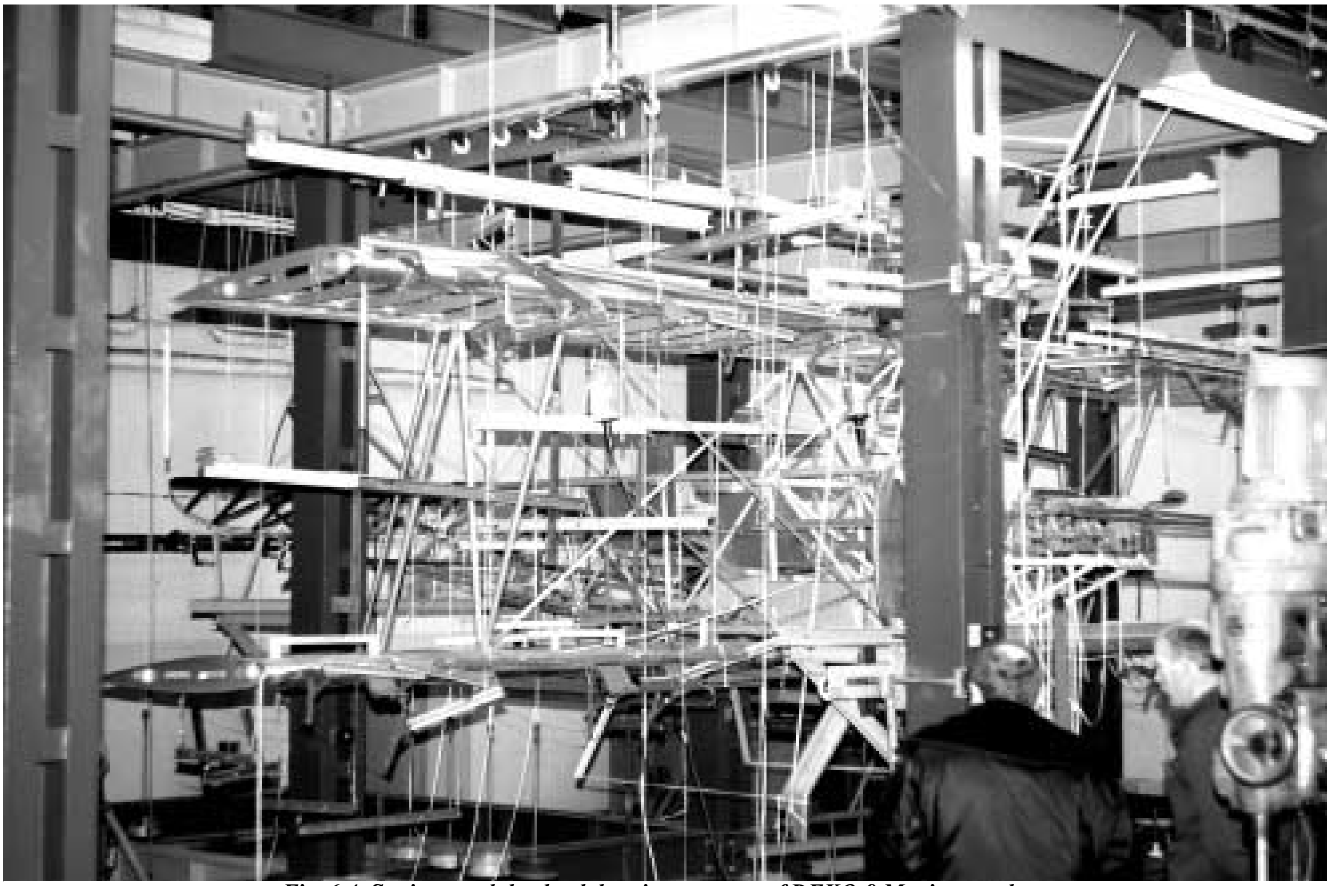


Fig. 6.4. Static test od the load–bearing stucture of DEKO-9 Magic aeroplane

7. CONCLUSIONS

Because of fact that research object structure is much the same as real load–bearing construction and was treated with fatigue loads adequate to destination loads, rationality of its application may be confirmed for such joints in very stressed structures, like aircraft. Whole structure weighing 30 kilos may function as a main load–bearing element of the 750 kilos total weight aerobatic airplane.

<u>Thus, next developement steps are quite reasonable, like application of the idea to the airplane designs and to the other structures for which lightness and manufacturing simplicity and unrestricted possibility of various materials members linkage has paramount importance.</u>

Application of composite joins of this type makes optimal and competitive designs possible, competitive to traditional structures, actualy designed and used. In case of industrial designs its may also bring significant economic effects.

Utilization of idea of composite joints may simplify design process and lower manufacturing and production costs of load–bearing structures of various constructions.

Major examples in this area may be fuselage truss structures of light airplanes, truss joists, frame joists or mixed construction joists, masts or sledge helicopter undercarriage nodes…

To recapitulate, it can be said that this original conception of composite joints of members in load–bearing structures allows for:

– linking of non-weldable elements or difficult to connect with other technologies,
– design of the joint according to its optimal working model,
– use of cheaper materials, e.g. dural trusses instead of steel welded ones,
– welding stresses and deformations avoidance, deformations resulting from relaxation of inside welding strains.
– limitation of necessary defect diagnostics checkouts, use of simpler tooling and less qualified personnel

Findings of research work presented here allowed for creation of database, giving great possibilities of elaboration and use of gathered experience and results of research in specific design and production of joints of this type.

Rich photographic and video documentation of stress tests of separate joints and fatigue test of structure is also included in this database. Technical documentation for test stands, composite joint specimens, truss structure, its mount and force insertion members was also made.

Patent rights for such joints were applied during this research. Composite joints copyright © reserved to M. Dębski and K. Kotliński [23].

There are plans for work continuation by inclusion of this conception in real airplane design (Fig. 6.1, Fig. 6.2) and making full research cycle, ending with airplane certificate.

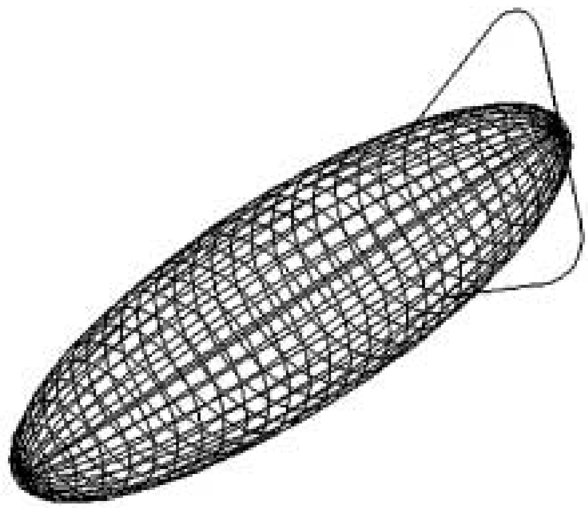
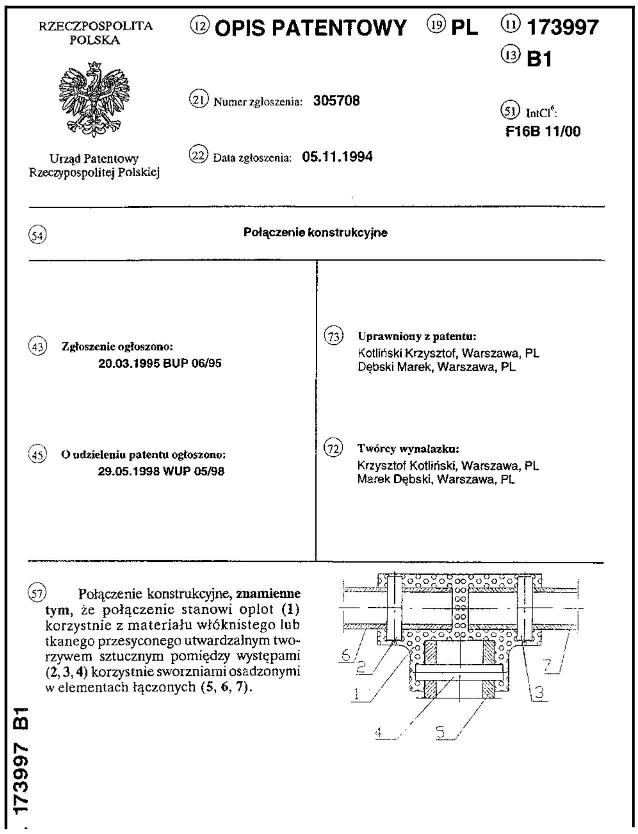


Fig. 6.5. Load–bearing structure of the airship



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(73) **Uprawniony z patentu:**
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Dębski Marek, Warszawa, PL

(72) **Twórcy wynalazku:**
Krzysztof Kotliński, Warszawa, PL
Marek Dębski, Warszawa, PL

(57) Połączenie konstrukcyjne, **znamienne tym**, że połączenie stanowi oplot **(1)** korzystnie z materiału włóknistego lub tkanego przesyconego utwardzalnym tworzywem sztucznym pomiędzy występami **(2, 3, 4)** korzystnie sworzniami osadzonymi w elementach łączonych **(5, 6, 7)**.

173997 B1

Fig. 6.5. M.Dębski and K.Kotliński patent for composite joints of load–bearing structures

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D. Dębski M. Dębski, K. Gołoś

WĘZŁY KOMPOZYTOWE USTROJÓW NOŚNYCH

Streszczenie

W pracy przedstawiono badania wytrzymałości statycznej i zmęczeniowej jednego z wielu możliwych rozwiązań węzłów kompozytowych, wiążących elementy stanowiące strukturę nośną konstrukcji. Przedstawiona koncepcja jest alternatywną propozycją dla klasycznych rozwiązań połączeń. Badaniom poddano węzły kompozytowe ze wzmocnieniem wykonanym z włókien (rovingów): szklanych, kevlarowych i węglowych.

М. Дембски, . Голось, Д. Дембски

КОМПОЗИТНЫЕ УЗЛЫ КОНСТРУКЦИИ

Резюме

В работе представлены исследование статической и устаростной прочности, одним из многих возможных решении композитные узлов связывающих элементы, которые составляют основу несущей конструкции. Представленная концепция является альтернативной для классических решений конструктивных узлов. Исследованиям подданы композитные узлы усиление выполненным волокном: стеклянным, кевляровым и углевым.