COMPOSITE LANDING GEARS FOR LIGHT AIRCRAFT AND HELICOPTERS.

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Abstract

Original designs of composite blades with a hollow cross section and the buckle joint for transferring load from metal fittings into composite blade structure are presented. The tests carried out showed that such blades display good load-deflection characteristic. The analyses of the failure modes allow to set certain rules that should be followed in the design of a blade structure. Load-deflection characteristic of a typical undercarriage equipped with composite spring blades is almost linear. It can be modified with the use of energy absorbing device and auxiliary shock absorber. Examples of such modifications are presented.

Introduction

Main landing gears for small aircrafts and helicopters often have shock absorbers in the form of spring blades made of metal or composite material. Such the undercarriages are simple and reliable, and almost ideal from standpoint of maintainability. Table1 presents some other features of spring and oleo-pneumatic shock absorbers. The weak point of an undercarriage equipped with spring shock absorbers is its moderate efficiency,(Fig.1).The choice of material used for spring blades often depends on service conditions as well as on manufacturing facilities and skills.

Tab.1

	spring shock absorber	oleo-pneumatic
design	+	-
manufacturing	+	-
fabrication cost	+	-
weight/efficiency	-	+
aerodynamics	-	+
maintains	+	-

Table2 indicates main advantages and disadvantages resulting from use of metal or composite material. A clear advantage of composites is seen in their resistance to fatigue and corrosion, good dumping characteristic and feasibility for shaping. Also, the inspection of coefficients of energy absorption capacity over mass for various candidate materials, indicates superiority of composites, (Fig.2). On the other hand, more effort must be put into designs of a composite structure of blades and manufacturing process. Also design of joints connecting composite blades with a fuselage and an axle is relatively more complicated than it would be in a case of metal blades. General procedure of designing a landing gear of a minimum weight, having sufficient strength and energy absorption capacity, undergoing assumed deflection and developing assumed load factor is out of scope of this paper.

Tab.2

	composite spring leaf	metal spring leaf
design	-	+
manufacturing	-	+
weight		
resistance to UV rad.	-	+
resistance to elev. temp.	-	+
resistance to corrosion	+	-
fatigue resistance	+	-
fittings	-	+
dumping	+	-
torque rigidity	+	-

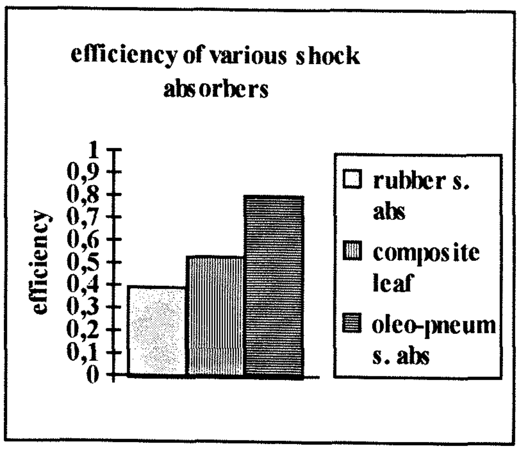

FIGURE 1. Efficiency of various shock absorbers.

Such procedures are given for example in (1),(2). Instead, the authors present some ideas that allowed :

-to improve efficiency of a spring landing gear,

- to avoid ground resonance,

-to reduce weight of blades, and

-to transfer properly a load from metal fittings onto

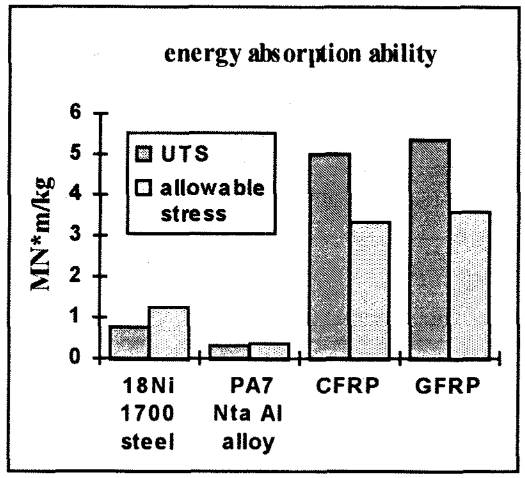

FIGURE 2. Energy absorption ability of various materials.

composite blades. Also, main features of the fabrication methods applied for manufacturing the blades are described and the results of the static and dynamic tests that have been carried out to prove the compliance with JAR22, FAR23 and FAR27 are provided. The presented ideas found application in design of composite undercarriages for the light aircraft of Q_{max}=1650kg, motor glider of Q_{max}=650kg, and light helicopter of Q_{max}=1800kg.

Design of blades

General Consideration

A preliminary analysis of energy absorption capacity of two the most common configurations of spring undercarriages done with the simplified models, Fig.3, indicates that design "a" is more suitable. The undivided beam can undergo larger deflection, it develops lower reactions at fittings and it does not require as many fittings as configuration "b".

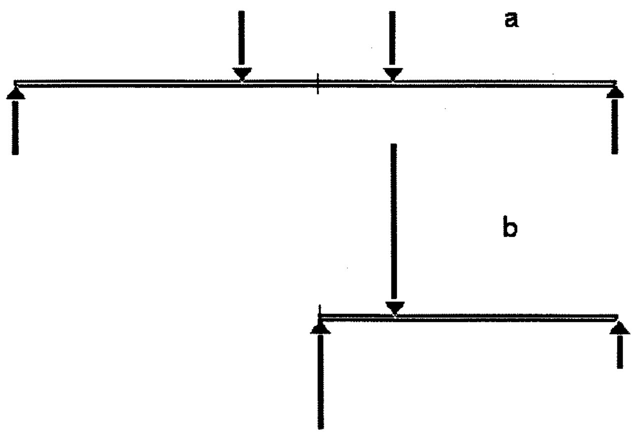

FIGURE 3. Common configuration of spring blades

A weak point of design "a" is visible in a case of damage, (an entire blade must be replaced by a new one). Also, if an airplane is of relatively high moment of inertia with the respect to its longitudinal axis design "a " may be less efficient than design "b". The analysis of various shapes of a camber line of a blade leads to conclusion that its curvature does not effect significantly energy absorption capacity of an undercarriage. Important dimensions are the track of an undercarriage and elevation of main fittings over the ground. The proportion of these dimensions effects side displacement of wheels, side loads resulting from this displacement and load-deflection characteristic. Unfortunately, configuration of an undercarriage and a geometry of blades often depend on conditions resulting from a design of a fuselage and can be modified in a certain range only.

Devices modifying load-deflection characteristic.

Load-deflection curve for a typical spring landing gear is shown in Fig.4. Efficiency, η, defined as

$\int_0^c p(f)df / F_{0abc}$ is relatively low. FAR27 allow for yielding of members of an undercarriage under limit loads. It means that the load-deflection characteristic, (curve a), shown in Fig.5 is acceptable.

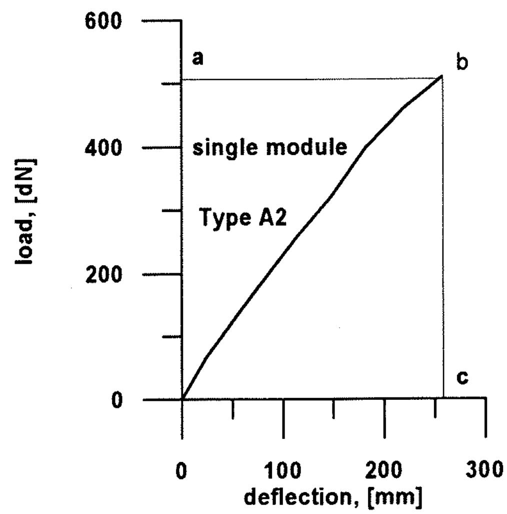

FIGURE 4. Load-deflection characteristic of the single module of Type A

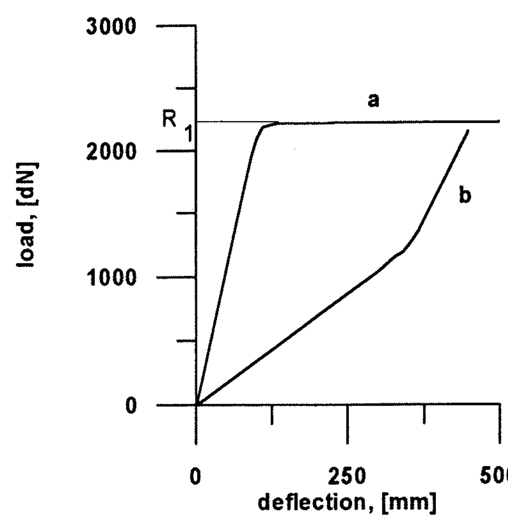

FIGURE 5. Blades equipped with a) energy absorbing device, b) auxiliary rubber shock absorber

Such load-deflection characteristic was obtained with the additional energy absorbing device. It could be mounted at the end of the spring blade in the manner sketched in Fig.6. If the blade end reaction, R, reaches R_1, (Fig.5), the blade will start to tear apart the segments of the energy absorbing device. The device was designed in the form of a metal, grooved plate,(Fig.7). The depth of the groves varied to produce desire load-displacement characteristic, (Fig.8). It was adjusted in such a manner that the resultant load-deflection curve of the complete undercarriage,(composite blade and energy absorbing device), was represented by curve a shown in Fig.5. Such an undercarriage offered high efficiency but was stiff and could require additional dampers to eliminate ground resonance.

Curve b in Fig.5 presents load-deflection characteristic with hardening. The efficiency of an undercarriage having this type of characteristic is low but such characteristic is desired from the standpoint of ground resonance. It can be obtained with the help of an auxiliary rubber shock absorber, (Fig.9). The resultant load-deflection characteristic of the complete undercarriage depends not only on the load-deflection characteristics of the auxiliary rubber shock absorber and the composite blade but also on the configuration of the end section of a blade. It can be modified in a certain range according to the needs , (Fig.10)

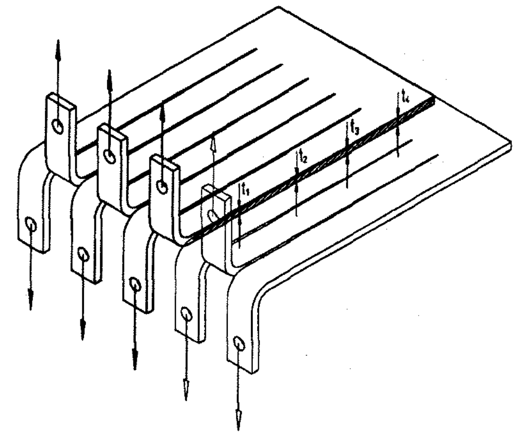

FIGURE 7. Energy absorbing device

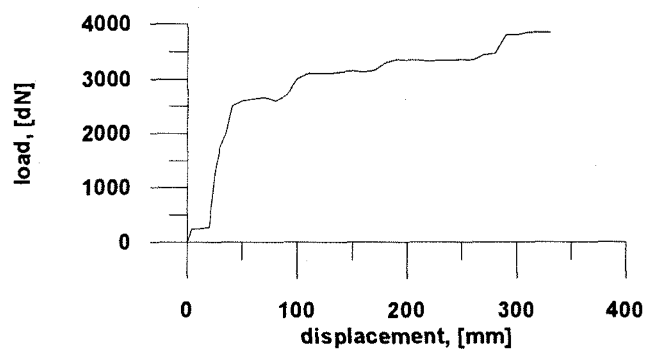

FIGURE 8. Load-displacement characteristic of the energy absorbing device

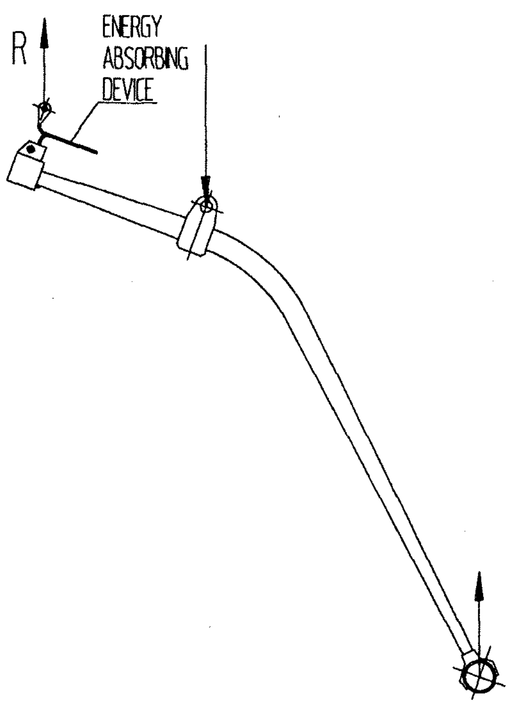

FIGURE 6. Composite blade equipped with the energy absorbing device.

Design of the blades

Blades of two different structures designated as types A and B were considered. Type A was optimised to offer required energy absorption capacity and possibly low weight. Expected load factor was relatively high and exceeded four

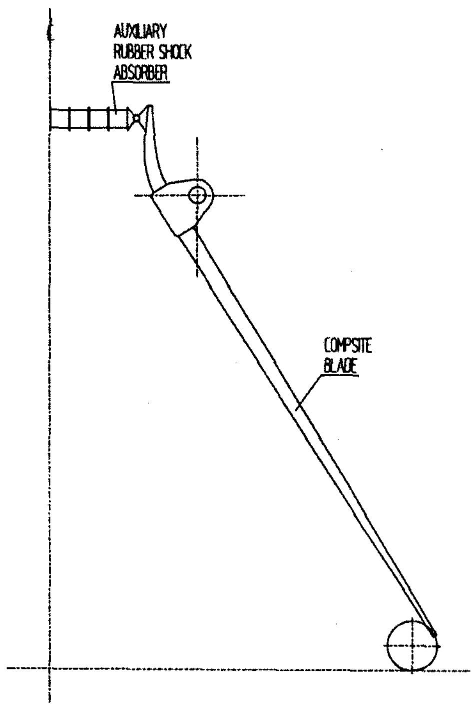

FIGURE 9. Composite blade equipped with an auxiliary rubber shock absorber

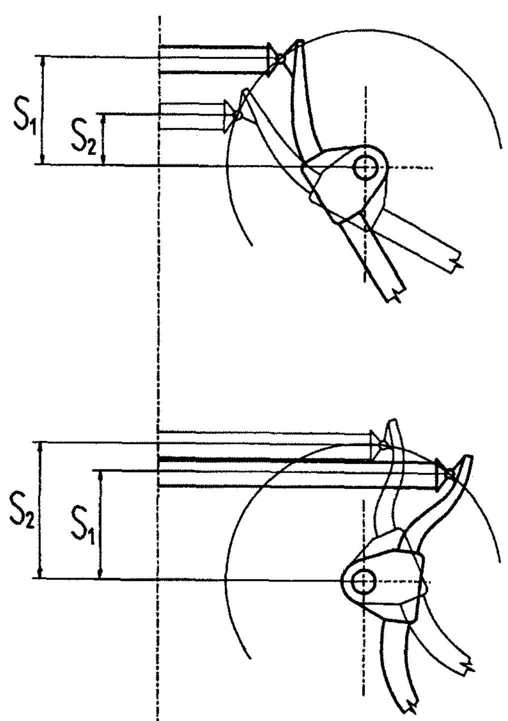

FIGURE 10. Possible configurations of the blade-rubber shock absorber connection.

Type B was designed to develop minimum load factor and small increase in weight was acceptable.

For Type A the design idea of function separation was applied. The blade was of a multi box structure, (Fig.11). It consisted of webs, flanges and envelope,(skin). Since the webs and skin were expected to carry horizontal loading and torque they were reinforced with fabric of strands at 45° with the respect to the longitudinal axis of the blade. The flanges should resist bending and were reinforced with roving. The cross-sectional area of the flanges and their separation varied along the blade to produce constant stress condition. Such design is load efficient. It results in relatively uniform normal stress in flanges and allows to take full advantage of the strength offered by the material used. Two variants of Type A structure designated as types A1 and A2 were proposed. The structure of Type A1 contained webs of the same length, equal to the length of the blade, (Fig.11). The structure of Type A2 had one half of the webs eliminated from the region of relatively low shearing force to reduce weight of the blade, (Fig.12). In the case of the helicopter, because of ground resonance, possible low initial stiffness of an undercarriage, (curve b in Fig.5), was desired. For this purpose Type B blade was suitable, Fig.13. The height of the blade was minimise to produce maximum possible compliance. To maintain sufficient strength its cross section was solid regardless the fact that the normal stress drops to zero for y=0 and such a structure is not weight efficient. The blade, (Fig.13) was made of non woven unidirectional fibers. The load factor developed by an undercarriage equipped with this kind of blades was relatively low and the cross-sections of the external parts of the blades placed between the skid and main fittings were expected to be large enough to provide sufficient longitudinal and cross strengths. Therefore no additional reinforcement was placed in those regions. Only small parts of the blades between the ends and main fittings required two extra layers of fabric having strands

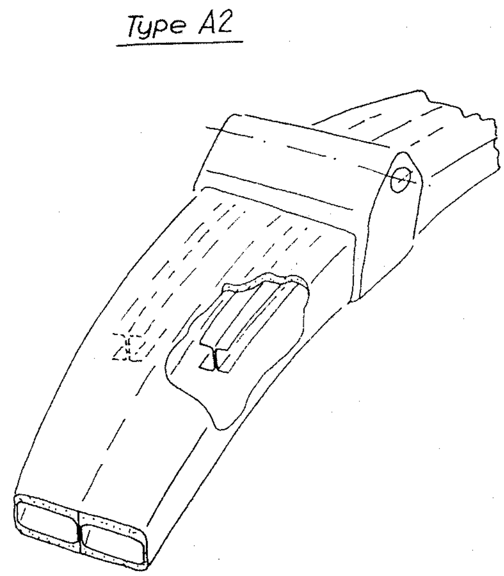

FIGURE 12. Blade of type A2 structure

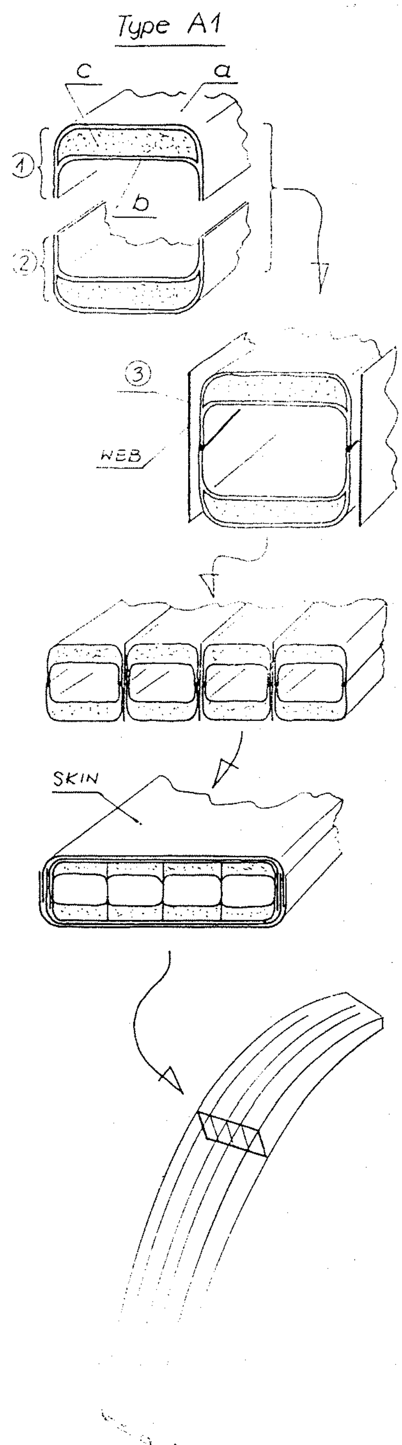

FIGURE 11. Manufacturing breakdowns of type A1 blade

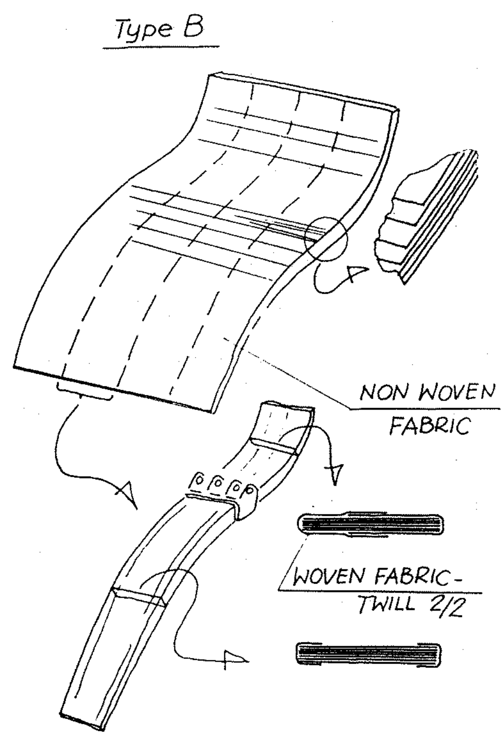

FIGURE 13. Manufacturing breakdowns of type B blade

having strands at 45° with the respect to the longitudinal axes of the blades.

Design of the fittings.

Proper design of fittings connecting composite parts with the fuselage is one of the most difficult problems. In the case of a metal blade the connection can be done in the traditional way with the use of bolts. However low bearing strength of GFRP does not allow for such solution . Figure 14 presents an original idea of the "buckle" joint that was incorporated in all the fittings . Composite strap (1) is locked by metal parts (2) and (3) and its front and rear parts are puled and pushed respectively. The shear stress developed at the strap-blade interface transfers the load from metal part(2) onto the blade. The integrity of the blade structure is maintained. Such design provides an excellent resistance to fatigue. In addition the joint can be put apart and easily inspected during service.

Manufacturing

The blade was made from glass roving and fabric impregnated with epoxy resin system Ep52+Z1. The manufacturing process was divided into two main steps: fabrication of blades and nesting the fittings. The manufacturing breakdowns of the multi box blade, (Type A1), and the typical module are shown in Fig.11. The blade comprised four modules, three webs and envelope. Each module for fabrication purpose was divided into two sub modules upper(1) and lower(2) . Each of the sub modules was composed of outer(a) and inner(b) shells, and tapered roving flange of varying height,(c). The sub modules were formed in the convex and apex molds in the following steps: 1)forming the outer shell(a), 2)forming the rowing flange(c), 3)forming the inner shell(b), 4)curing, (2 hours at 20°C), 5)gluing together sub module(1) and sub module(2), 6)curing,(10 hours at 20° C), 7)removing the module from the molds and cleaning.

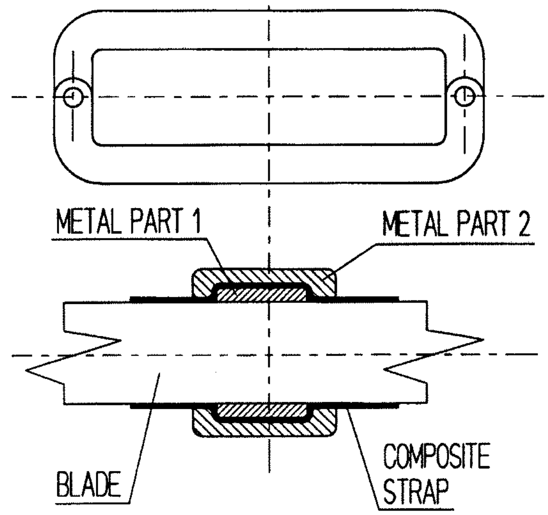

FIGURE 14. Buckle joint

Simultaneously, the webs (3) were formed, cured , (10 hours at 20°C), and trimmed. Next, the modules and webs were glued with each other to form the multi box structure of the blade In the next step, the fitting nests and the buckle joints were formed, and the metal parts,(fittings), were mounted. Finally, the blade was enveloped in two layers of fabric and postcurred, (4 hours at 60°C). The manufacturing breakdown of the solid blade, (Type B), is shown in Fig.13. The blade was formed in the following steps: 1)forming a wide composite plate in the mold of the curvature corresponding to the curvature of the blade, 2)curing,(24h at 20°C+6h at 55°C), 3)cutting the plate into strips to produce semifinished blades, 4)tailoring the semifinished blades, 5)wrapping the sides of the semifinished blades with fabric tapes, 6)curing,(24 hours at 20°C+6 hours at 55°C), 7)forming the fitting nests, the buckle joints, and mounting the fittings, 8) curing ,(24 hours at 20°C+6h at 55°C) and postcurring ,(10 hours at 80°C).

Tests

Chronologically first, the composite blades for the

the tests carried out to check the design of the blades for the aircraft landing gear are presented as the most interesting.

General program of tests.

1.Preliminary static test of the module: loading up to limit and ultimate loads at 20° and 54°C respectively

2. Static tests of the complete blade: loading up to limit and ultimate loads at 20° and 54°C respectively

3. Creep test of the complete blade: 21 days under static load at service conditions

4. Dynamic, (drop), tests of the complete undercarriage, (blade + wheel+tire): demonstration of the limit and reserve energy absorption capacities, the tests carried out at 20°C and 54°C

5. Preliminary fatigue test of the undercarriage: 25 000 loadings corresponding to n=1.2-1.3 and 10 000 loadings corresponding to n=1.4-1.6.

In the case of the helicopter undercarriage the metal energy absorber was a new feature and the result of the energy absorption capacity test is presented. Three pieces were tested at room temperature and CHS=0.2m/min. The dynamic tests are in progress.

Results

Figure 4 shows the load-deflection characteristic of the single module of Type A2 blade tested at 20°C. It failed by end splitting, (Fig.15), resulting from not sufficient cross-sectional area of the webs in tapered end part of the blade. The failure was caused by high shear stress. Figure 16 depicts load deflection characteristic of complete Type A2 blade with reinforced end section. The failure of the blade occurred in the vicinity of not supported ends of short webs, which collapsed, (Fig.17). The analysis indicated that in this region, the webs were subjected not only to shearing force

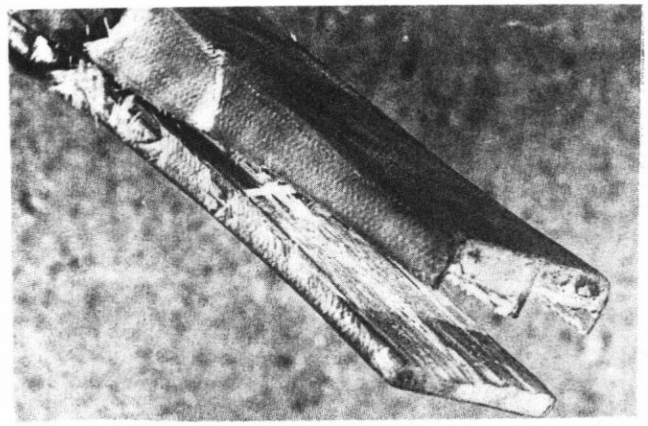

FIGURE 15. Type A2 blade. Failure by end splitting

but also to unexpected compression resulting from distortion, (curvature), of the flanges. Figure 18 and 19 present load-deflection characteristic of Type A2 and Type A1 blades loaded at 20 °C and 54°C. The failure of Type A1 blade was caused by local buckling of fibers,(Fig.20) in the vicinity of the offset of reinforcement.

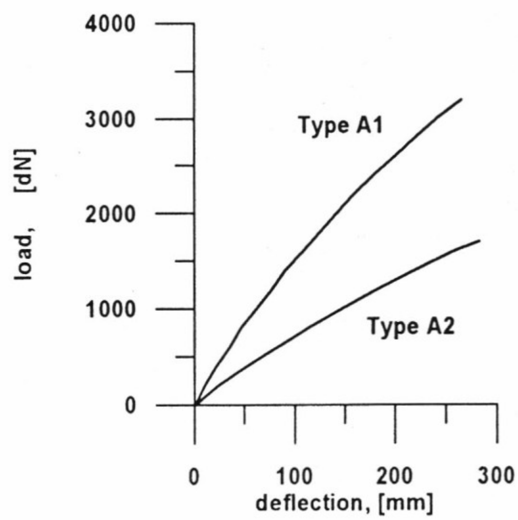

FIGURE 16. Load-deflection characteristics of type A blades

Figure 21 presents result of creep test. The blade of Type A2 had been subjected for 21 days to the load equal one half of the maximum weight of the airplane then unloaded. After that time the deflection increased of about 7% . The blade recovered after 10 minutes.

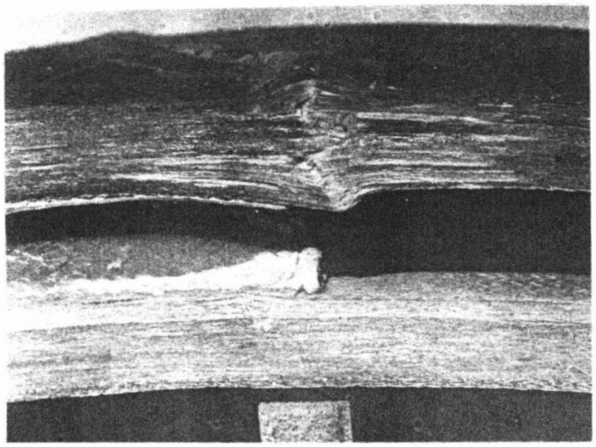

FIGURE 17. Type A2 blade. Failure by collapse of the auxiliary webs followed by buckling of the flange.

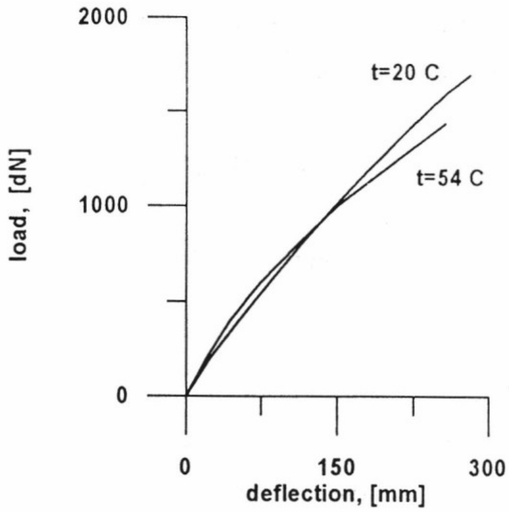

FIGURE 18. Effect of temperature on load-deflection characteristic of type A2 blades

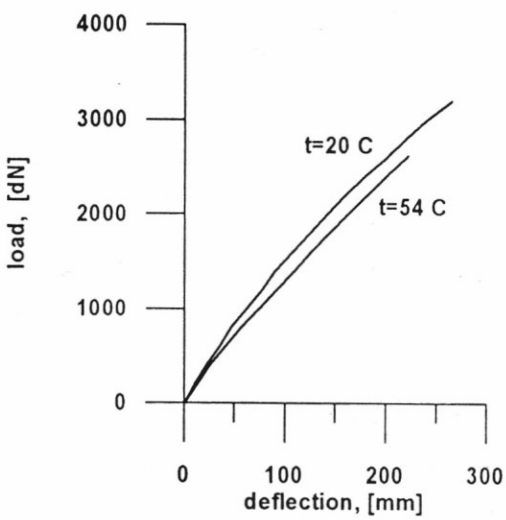

FIGURE 19. Effect of temperature on load-deflection characteristic of type A1 blades

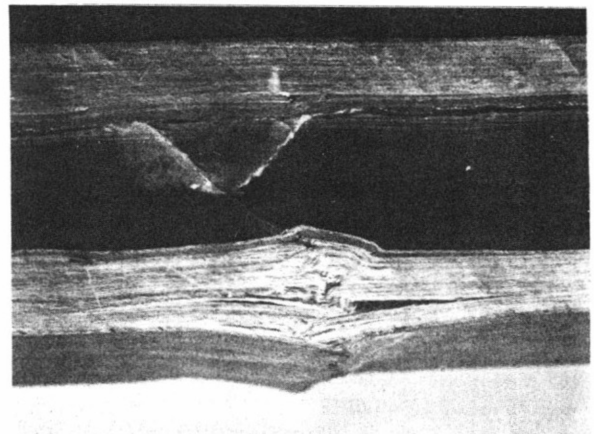

FIGURE 20. Type A1 blade. Failure by a local buckling of fibers in the vicinity of the reinforcement offset

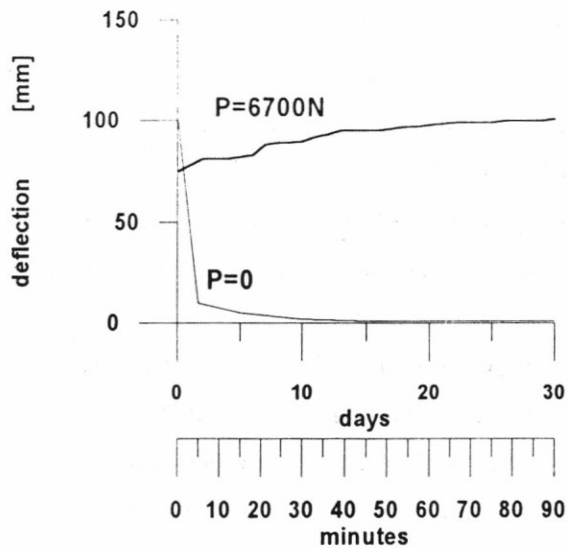

FIGURE 21. Creep test of type A2 blade

The results of dynamic tests are presented in Fig.22. Inspection of the "buckle" joints done after preliminary fatigue test did not reveille any damage of the composite structure of the blade.

Figure 8 presents typical static, (CHS=0.2m/min), load-displacement characteristic of the metal energy absorber. Three energy absorbers were tested. The load-displacement characteristics were consistent and the average energy absorption capacity calculated from this tests was about 10kNm.

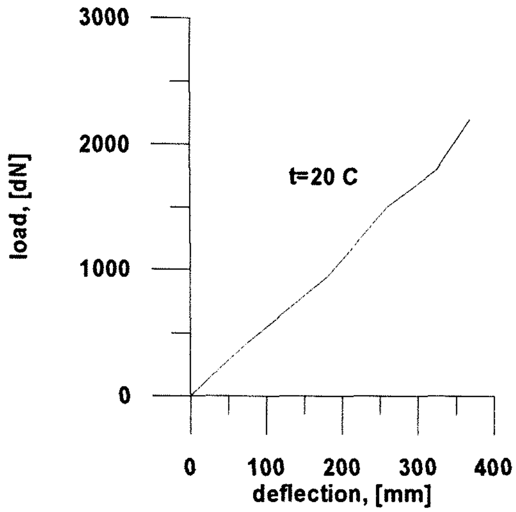

FIGURE 22. Dynamic load-deflection characteristic of type A2 blade equipped with a pneumatic

The curves in Fig.16 display clearly an effect of insufficient number of webs in Type A2 structure.

Influence of temperature is illustrated by the curve in Figs. 18 and 19. It is interesting that the decrease in stiffness is lower than in strength.

References.

1.Rainer Schutze, Theoretical and experimental investigations on landing gear spring blades out of fiber reinforced plastic for small aircraft, ESA Technical Translation, Sept.1976

2.N. S. Currey, Aircraft Landing Gear Design: Principles and Practices, AIAA, Inc, 1988