NEW TECHNOLOGY OF LAYERED STRUCTURES IMPLEMENTED IN SELECTED GYROPLANE COMPONENTS

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Abstract

The paper presents work carried out by Institute of Aviation for the project entitled "Implementation of new material technology in aviation products of Artur Trendak Aviation Company". The aim of the work is to develop innovative components using new technology of bonding the high-strength aluminum alloy elements and give them functional qualities, that had not been previously used in ultra-light aviation. The final stage will be the commercialization of those structures on ready-made autogyros of AAT Company. Works are focused on improving material efficiency indicators for the critical components of aviation construction, which should translate into their level of safety, as well as the main operational advantages preferred by the customer. As a part of work, the numerical analysis were carried out, i.e. strength and stiffness tests for a number of layered structure variants. In the next step, based on optimized technology, the critical components of gyroplane, such as rotor blade, hub connector, gyroplane mast and undercarriage leg, were made and tested on bench stand.

1 General Introduction

Since the beginning of the 21st century, a very dynamic development of light and ultra-light designs has been taking place in the world. It resulted from high demand for "alternative" aircrafts, as compared to the complex, very expensive, certified machines offered by the "big" aviation industry. Thanks to the technological progress, the advanced technologies are available for small, dynamic companies which are producing aircraft structures ,that set the new trends in aviation. Hence, the proposed solutions are dedicated for applications primarily in light flying machines, that are based on simple, cost-effective and therefore the most widespread technologies. For example the technology of vacuum bag method, used during the process of composite lamination.

The current state of the art, in terms of proposed solutions, is based on expensive technologies, and demands the complex technical facilities, available only to large industrial companies.

Fiber metal laminates (FML) have been known since 20th century. There is a number of patents and articles related to FMLs composites [9, 10, 11, 21, 22]. However, the dynamic development of fiber metal laminates occurred in the early 21st century. The FMLs are the hybrid materials, consisting of alternatively arranged thin layers of metal and layers of polymer – fiber composite permanently bonded together. Hybrid laminates such as GLARE (aluminum alloy and glass fibers laminates), CARALL (aluminum alloy and carbon fibers laminates) and ARALL (aluminum alloy and aramid fibers laminates) are described in the literature [12, 20]. Numerous research [2, 6, 7, 8, 15] conducted over the years shows, that laminates with permanent bonding between aluminum and fiber composite provides more resistance to propagation of cracks at cyclic loading, very good resistance to impacts by means of concentrated forces at low material density, also has the anti-corrosion parameters, (excluding CARALL [20, 3] laminates).

Unfortunately, the high technology regime, as well as high manufacturing cost, makes those technologies available only to large aviation companies (e.g. Airbus for its A380) only. For example all GLARE grades are based on prepregs with unidirectional spaced S-glass fibers in the Cytec FM 94 polymer matrix, using autoclave methods. The GLARE laminate structure is shown in Figure 1 [5].

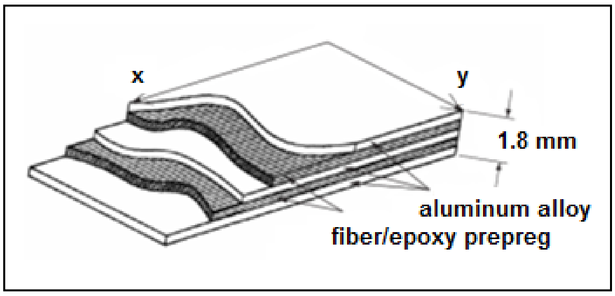

Fig. 1. Configuration of fiber/metal/epoxy hybrid composite [5]

Paper presents and describes technology of preparing selected components of aircraft (in particular rotorcraft), by using metal-composite hybrid structures, dedicated to light and ultra-light aviation.

2 The Idea of Layered Structures for 'Small' Aviation

The applications of bonding elements in the design of light aircraft constructions - gyroplanes, were proposed in the project "New Autorotation Rotor" [23]. The solution of bonding blade root with the mounting element (so-called "socket" [14, 18]), was examined and proposed to increase the strength of blade root to prevent damage. Based on these experiments, a number of tests and research were carried out.

First of all, various adhesive substances, previously used in aviation and those that appeared on the market recently, were examined. Next, the available literature [16] was analyzed and tests were conducted of using epoxy resin and nanofillers (in our case, carbon nanotubes). In the search for solutions, the final focus was on metal- fiber composite connections.

During numerous FEM strength analyzes, parallel to the tests of various bonding materials samples (including strength tests and environmental tests) a best solution has been found, that can be implemented for light and ultra-light aircraft components.

3 The Manufacturing Technology of Layered Structures

The essence of the work is widspreading the technology of bonding high-strength aircraft aluminum alloys, e.g. 7075 T6 alloy, into hybrid aluminum-composite sandwich structures. It is possible to implement in the workshop of a small aviation company and therefore could be used within the techniques of manufacturing and technical facilities existing in each company currently producing lightweight composite aircraft structures.

Materials discussed in article are materials consisting of an aluminum alloy sheet layers, a polymer composite layers, of the system shown in Table 1, both glued with an adhesive substance, in particular a modified thixotropic two-component epoxy resin.

Tab. 1. Variants of layered structures

	No of layered structure variants		
Layer	**1**	**2**	**3**
Aluminum alloy	Yes	Yes	Yes
Glass or carbon fiber	No	Yes	No
Glass or carbon fiber laminates	No	No	Yes
Modified thixotropic two-component epoxy resin	Yes	Yes	Yes

Technology of hybrid elements is assumed to use the same type of instrumentation which is used in the manufacturing of polymer composites in negative forms. That gives the final shape to the elements being formed. The following figures show three variants of the technology described above. In the first variant, as shown in Figure 2, a layer consisting of pre-shaped aluminum alloy sheet with quantity and contour adjusted to the local load of the element (1), and adhesive layer

(2), is bonding aluminum sheets, in particular a modified thixotropic two component epoxy resin. The whole element is placed in a negative stiff composite form (3).

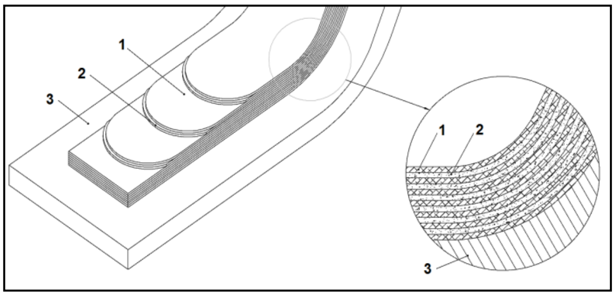

Fig. 2. The layers orientation in the layered structure for variant # 1

Figure 3 shows 2nd variant of component structure that consist of pre-shaped aluminum alloy sheet with quantity and contour adjusted to the local load of the element (1), and layer bonds the aluminum alloy sheets and increases the strength of the element, consisting of glass or carbon fabrics supersaturated with an adhesive substance. In particular a modified thixotropic two-component epoxy resin (2) is used. As before, the whole element is placed in a negative, stiff, composite form (3).

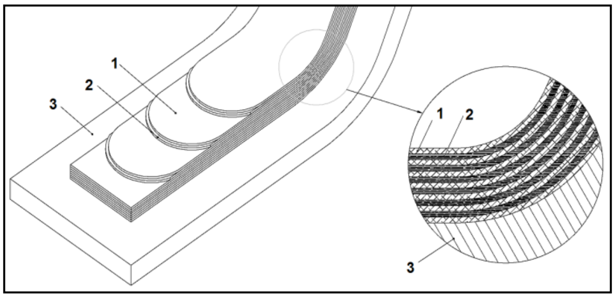

Fig. 3. The layers orientation in the layered structure for variant # 2

The last 3rd variant of the hybrid layers of aircraft structural elements are shown in Figure 4. Those consists of three layers. As previously: pre-shaped aluminum alloy sheet with quantity and contour adjusted to the local load of the element (1), a layer of adhesive substance, in particular a modified thixotropic two-component epoxy resin that joins the aluminum sheet with the polymer composite, and layer of a polymer composite based on glass or carbon fabrics saturated with epoxy resin (3). The element is placed in a negative, stiff, composite form (4).

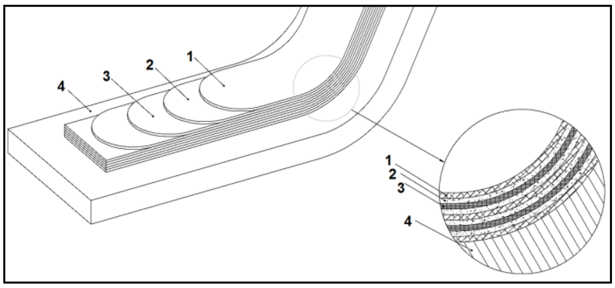

Fig. 4. The layers orientation in the layered structure for variant # 3

4 Selected Gyroplane Construction Elements

As a technology demonstrators the three critical structural components of a gyroplane were selected. One of the elements is a rotor blade connector. The connector design can be very simple, consisting of two flat bars, arranged parallel to each other and perpendicular to the axis of rotor rotation as shown in Figure 5.

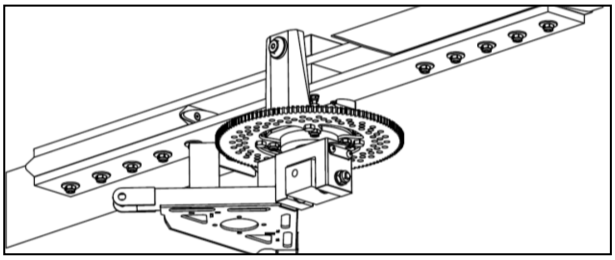

Fig. 5. General view of the gyrocopter head with the simple rotor blade connector

A more complex design, with positive cone angle, has been shown in Figure 6 [17]. It is known, that the use of a design conning angle greater than 0°, positively affects the reduction of the blade bending moment in thrust plane. Particularly it happens in the zone of the blade root. [4, 19]. Proposed blade connector solutions, with positive conning angle, assume a significant simplification of the structure in relation to the one currently used.

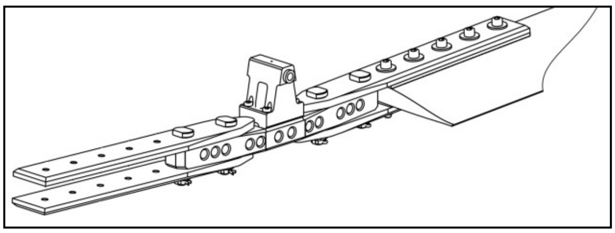

Fig. 6. View of the "Tercel" gyroplane connector with a positive cone angle

Furthermore, the connector arms of equal stiffness cause significant stress concentration in the first, extreme fastening screw. Currently, using the technology described in section 3, the technological grading can be performed in subsequent layers of connector, to increase the share in transmitting forces from the rotor blade to the other screws. The visualization of above described solution is shown in Figure 7.

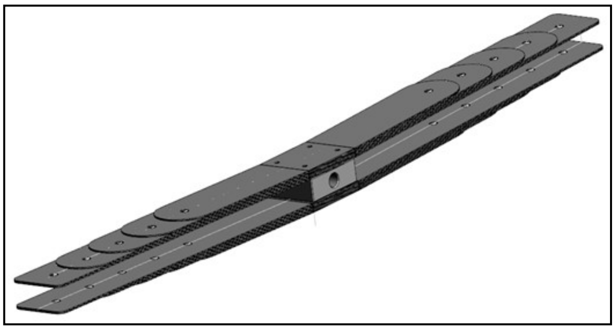

Fig. 7. View of gyroplane connector with a positive cone angle for implementation in hybrid laminates technology

Another component, made as a demonstrator of hybrid technology, is the undercarriage leg of the gyrocopter (Figure 8). The external outline has been maintained the same as original, without any additional optimization, in order to ease a comparison the characteristics of the existing solution with the new one.

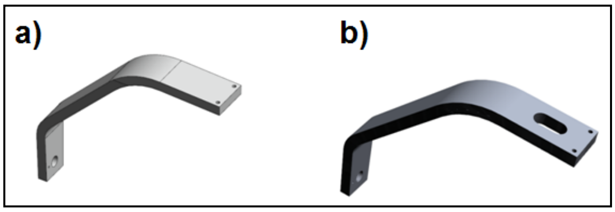

Fig. 8. View of existing solutions (a) and landing gear of the new proposal (b)

The required symmetry of the aluminum and composite layers in the hybrid structure, and the behavior on both sides of the aluminum surface element, is less susceptible to damage, and forces to increase the thickness of this element in relation to the base - landing gear leg made of aluminum alloy. Increase in thickness, however, does not increase the mass of the component. In addition, a relief hole was provided within the least loaded part of the undercarriage leg, i.e. in the area of fixing the undercarriage leg to the gyroplane fuselage.

In the nodal areas and bending radii of the landing gear contour, full filling of the hybrid material has been preserved, whereas the vulnerable zone has been made less stiff by elimination of several material layers from the neutral axis. That way, the main deformation takes place there, where the structure can be easily modified and the elastic characteristics can be optimized in subsequent variants.

The third technology demonstrator is the gyroplane mast. The basic idea, when designing a new gyroplane mast, is to preserve the existing attachment nodes to the airframe of the gyroplane and the rotor head (Figure 9).

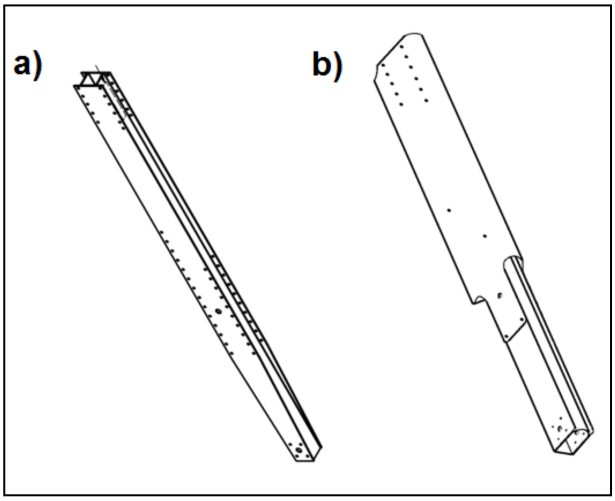

Fig. 9. General view of the mast in the version used on gyroplanes (a) and modified (b)

The new mast is a bonded multi-circuit pipe made of 1 mm thick aluminum alloy sheet and composite laminate layer of the same thickness. In the new solution, the part of the mast located above the gyroplane's fuselage was given a streamlined shape which eliminates the need for additional overlays and aerodynamic covers. At the same time, the increased load-bearing length of the mast pipe provides greater stiffness in the longitudinal and torsional plane, necessary during rotor pre-rotation (Figure 10).

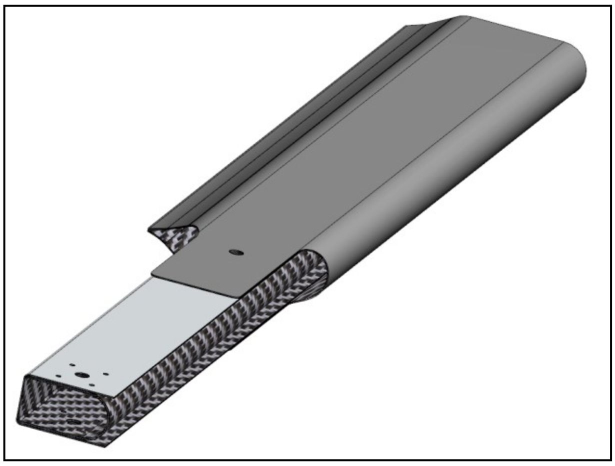

Fig. 10. View of gyroplane mast for implementation in hybrid technology

Ultimately, the final work will be used to develop the internal structures of the above-mentioned elements, so that they are able to be substitutes for the ones used so far.

5 Loads Analysis and Calculation

Prior to the design of the structures presented in paragraph 4, preliminary loads have been determined based on the requirements of aviation regulations and known load cases for these components from earlier tests and calculation. Determining the load was also the cause for performing numerical calculations (FEM analysis) of the elements presented in the previous paragraph, which were part of the works of preparing aluminum – glass or carbon laminate hybrid elements.

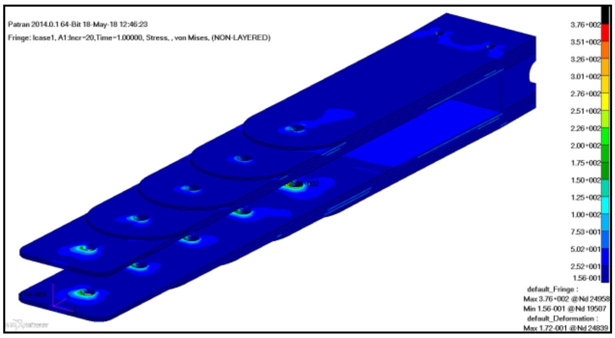

Fig.11. Von Mises stresses calculated for rotor blade connector

Analyzes of such elements are as themselves new, and require a different approach to the problem, than when modeling standard composite solutions. Numerical analyzes for the three selected gyrocopter components are presented in (Figures 11,12 and 13). Due to the complexity of the structure and loads, the Von Mises Stress was used as a tool to predict the quality of the component.

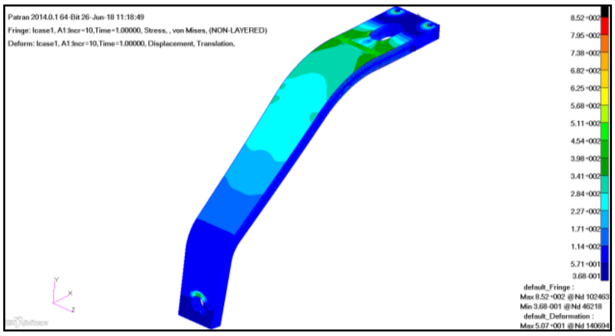

Fig. 12. Von Mises stresses calculated for landing gear leg

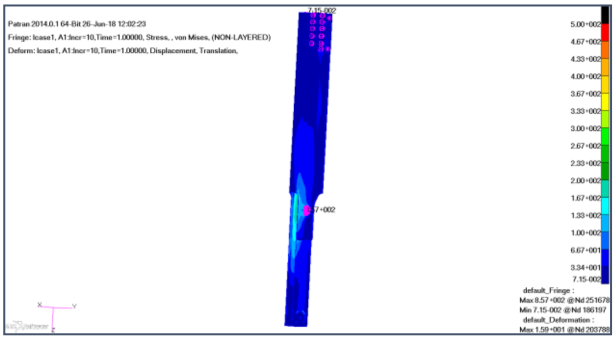

Fig. 13. Von Mises stresses calculated for gyroplane mast

Validation of durability properties will take place in subsequent stages at research stands and then – ultimately - in the process of proving the quality to the aviation authorities, which is based on specified aviation regulations [1, 13].

6 Demonstrators of Sandwich Technology

The process of preparing the demonstrators is described in the previous paragraphs. For each of the elements a negative form (tool) was prepared, in which the subsequent layers of the hybrid structure were arranged. In the first stage, the aluminum forms were prepared according to drawings (shown in Figure 14).

Fig. 14. Aluminum forms for gyroplane landing gear leg

Then, before the lamination process, the aluminum sheets were pre-bent. After finishing the application of subsequent layers, the whole element was closed with a vacuum bag (Figure 15).

Fig.15. Gyroplane landing gear leg in a vacuum bag

The article presents only the demonstrators technology of gyroplane blade connector and landing gear leg, because the mast is still under construction. The finished elements are shown in Figures 16 and 17.

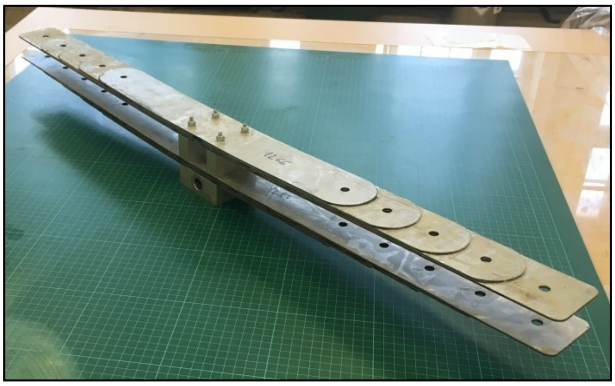

Fig. 16. Gyroplane rotor blades connector prepared in hybrid technology

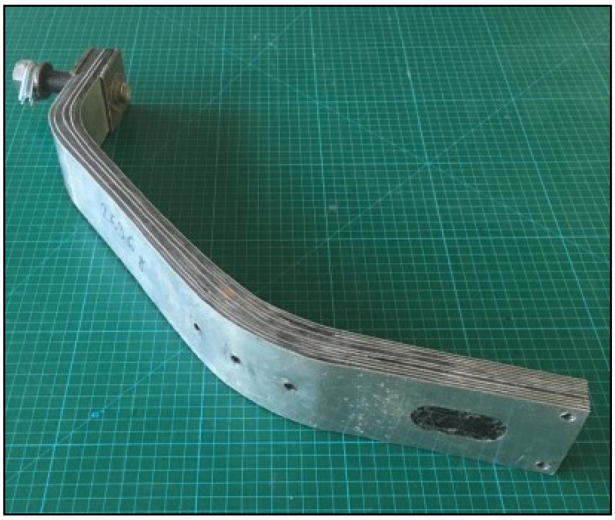

Fig. 17. Gyroplane landing gear leg prepared in hybrid technology

4 Bench tests

This paper discusses stiffness and strength tests of demonstrators based on which the calculation methods have been validated.

First the global stiffness (torsion and flexural stiffness) of the rotor blades connector arms was determined. The assumption of the technology was of greater susceptibility to bending on this component. Below, in Figure 18a and 18b, the load schemes are shown and in Figure 19 the test stand of the gyroplane blade connector during stiffness tests has been depicted.

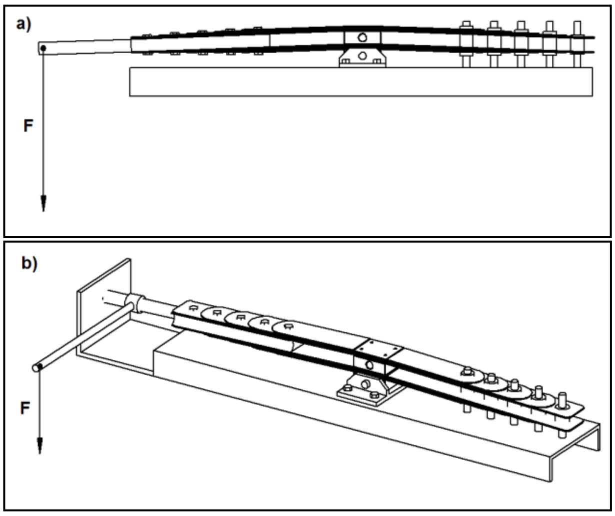

Fig. 18. Load scheme: a) flexural stiffness b) torsion stiffness

Fig. 19. Test stand

The connector was loaded the same way, as during the gyroplane flight. The stiffness of the hybrid connector is compared to the aluminum connector (currently used on the gyrocopter) and is about 2 times lower (as shown in Table 2).

Tab. 2. Rotor blades connector stiffness comparison

	Hybrid technology rotor blade connector	Aluminum alloy rotor blade connector
Torsion stiffness, **GI_0**, Nm^2	2058.58	3814.50
Flexural stiffness, **EJ_0**, Nm^2	4876.42	11444.69

In the next stage, the rotor blade connector was tested to 150% of the permissible (according basis of aviation requirements) loads i.e. to 80932.50 N. The connector has not been damaged or permanently deformed.

Then a static test of the landing gear leg was carried out (Figure 20 and 21). During the test it turned out, that the component does not carry 100% of the assumed loads.

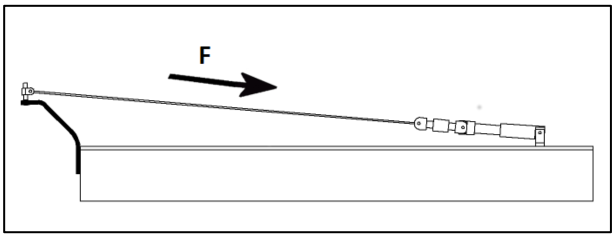

Fig.20. Load scheme of landing gear leg

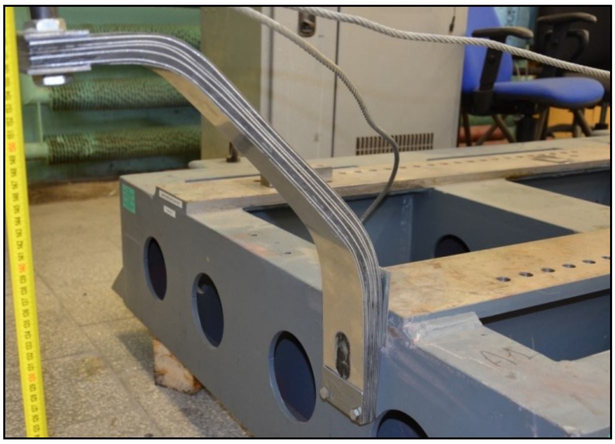

Fig.21. Test object mounted on the test stand

After stand tests, further numerical analysis of the construction and arrangement of the layers in the hybrid composite structure were conducted. Due to the complexity of the layered structures design a special tool was prepared. The tool allows to determine the level of stress in subsequent layers of the sandwich structure. This facilitates the selection of the optimal thickness of the layered structure for the gyrocopter subassembly. Additionally, the decision was made to change the shin section from square to oval, and the implementation of the landing gear leg connected as currently it is made entirely of carbon composite in the AAT company. Figure 22 makes an overview of the re-design landing gear leg.

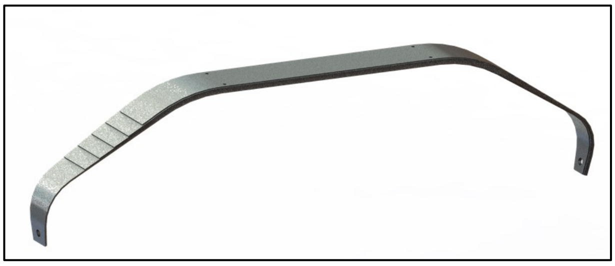

Fig. 22. New concept of the landing gear

7 Conclusion

New layered structures can have a significant impact on the development and improvement of new design in light and ultra-light aviation. Using this composite material properties, it is possible to design various properties (including flexible and torsional stiffness) of the subassembly in different cross-sections and adapt to the local effort of the element. In the case of a gyrocopter rotor blade connector it is possible to achieve lower stiffness of the flexing arms of the connector, which can act as an flexible hinge, thus reducing the bending moment in the base of the blade. Furthermore, the new technology gives the possibility of making a connector with a built-in dihedral angle, which additionally reduces the bending moment in the blade's root.

The components made using this technology are also around 30 - 40% lighter, which is very important for economic reasons. Moreover, those new technologies, dedicated to small aviation, require new, simple computational methods, that can be easily implemented in small aviation companies. Currently, such a simple calculation method is being developed in order to help with selection of number and thickness of hybrid material layers.

The technology, discussed in the paper, is innovative and will certainly find application in multiple elements of gyroplanes. Furthermore the next step in the development of this technology, is to transfer it to aircraft design, e.g. as a wing spar.

Works are going to be continued, so currently the strength and dynamic tests are carried out and also tests according to aviation regulations and flight tests of selected elements are prepared.

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