Sandwich composite fan blades for small aircraft ducted fan power unit

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Abstrakt

Rotorová lopatka je jednou z nejvíce zatížených částí pohonné jednotky. Konstrukce lopatky byla uzpůsobena pro použití kompozitních materiálů s ohledem na vlastnosti materiálu a technologické možnosti výroby. Oproti lopatkám kovové konstrukce je u kompozitní použita konstrukce s různě volenou orientací výztuže pro účinné přenášení zatížení. Příspěvek předkládá ucelený postup výroby a zkoušek rotorové lopatky.

Rotor blade is one of the most stressed partof the engine. Blade design was adapted for the use of composite materials with regard to the characteristics of the material and technological possibilities of production. Compared to metal blade design in composite blade design composite structures are chosen with different orientations of reinforcement for effective load transfer. The article presents a comprehensive process for the production and testing of rotor blade.

Key words

Ducted fan, composite materials, small aircraft, production technology.

1. Introduction

Presented sandwich composite fan blade is part of the ducted fan power unit for small sport planes. This ducted fan power unit is being developed at the Department of Aerospace Engineering Czech Technical University in Prague. Rotor blades is one of the stressed parts of the ducted fan power unit. Composite materials are used to achieve a lower weight of blade and corresponding lower load of blade itself but also other structures.

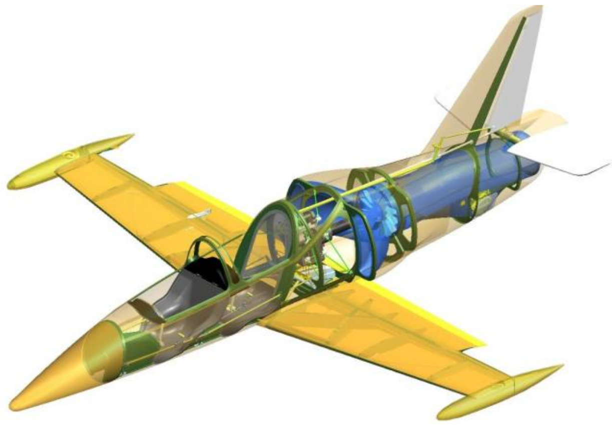

Fig. 1. *Proposal of a small sports plane with the ducted fan power unit.*

2. Blade design

Ultralight construction is characterized that it is structurally designed as a blade composite shell with foam core of very low density located through the volume of the blade consisting of aerodynamic leaf blade and the bead with a hinge. Shell of the blade is composed of several layers of composite with reinforcing fabric oriented for transferring torsional loads and flange of unidirectional reinforcements, which transmits the centrifugal load of the leaf blade to the hinge. Blade is made of several foam cores which provide the correct positioning of the internal stiffening structure from the carbon composite and metal bushings for mounting blades.

In Fig. 2 and 3 shows a blade structure, which consists of a foam core of the leaf blade 1, which is adjacent to the metal bushing hinge 2. Blade flange 3 surrounds the metal bushing and passes through the foot part of the blade to its tip. Foot part of the blade also consist of the foam cores 4. The entire surface of the blade is closed the outer composite shell.

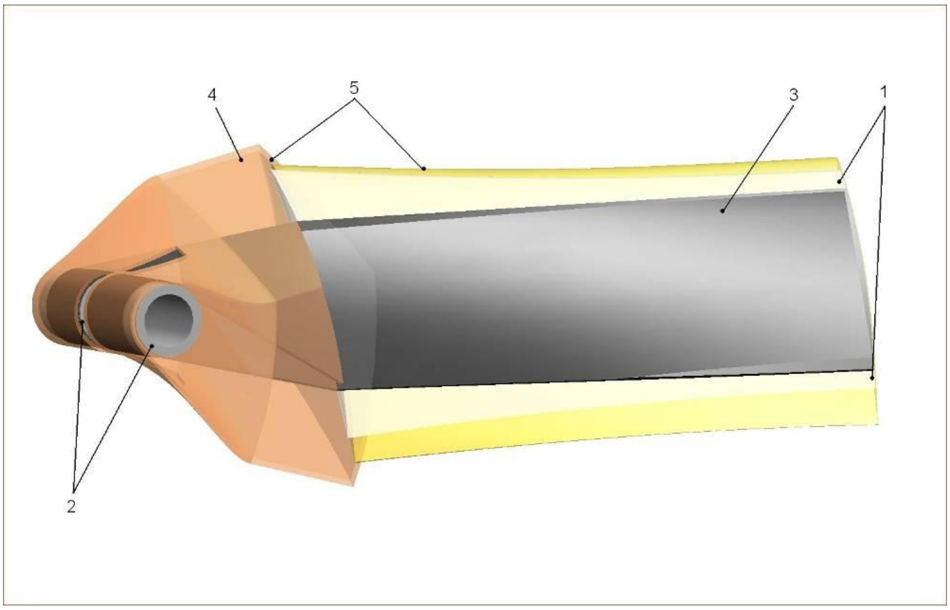

Fig. 2. *The blade consists of the outer composite shell 5, the foam core in the blade leaf 1, the foam core in the foot part 4, a metal bushing hinge 2, flange 3 enclosing the metal bushing*

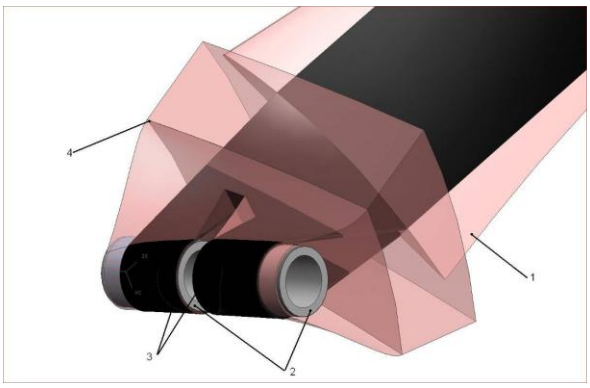

Fig. 3. *Design detail of foot part of the blade shows the relative positions of bushing 2, flange 3 and the foam core 4.*

Rotor of power unit consists of thirteen composite blades, which are mounted swingable by pins in rotor disk. This solution was chosen for the control of torsional vibrations from a direct drive engine.

Fig. 4. *Mounting of blades in the rotor disk.*

Rotor blade according to the technical solution transmit safely all traffic loads due to both the centrifugal force during rotation and second the pressure difference between the bed and the back sheet. Load by centrifugal force causing tensile force from the foot of blade to tip of blade absorbs hinge formed by bushing which is wrapped by the flange is designed as a beam with variable cross-section. Load of bend and torsion caused by aerodynamic forces is transferred by a closed shell profile.

3. Production technology

Regarding the demands on surface quality and dimensional accuracy of the rotor blade, three suitable technologies using closed mold were considered. It was an infusion RTM technology, low temperature prepregs, and resin film infusion. In the selection was necessary to take into account the availability of materials, their processing demands and the possibility of combining with other components of the rotor blade. From this perspective heat resistance of foam materials turned out as critical.

3.1 Foam core

Original idea of milled cores proved to be impractical with regard to the labor intensive production so materials that could be foamed in to closed form were searched for. Most appropriate seemed a two-part polyurethane system, but failed to provide sufficient heat resistance. Another try out was testing a mixture of epoxy foam. The resulting foam had a density approximately four times higher compared to polyurethane foam and its quality greatly depends on components quality. For these reasons, one-component polyurethane foam hardening by the atmospheric moisture was used for the production of precision foam cores. This material enabled production of foam cores with a temperature resistance and low density.

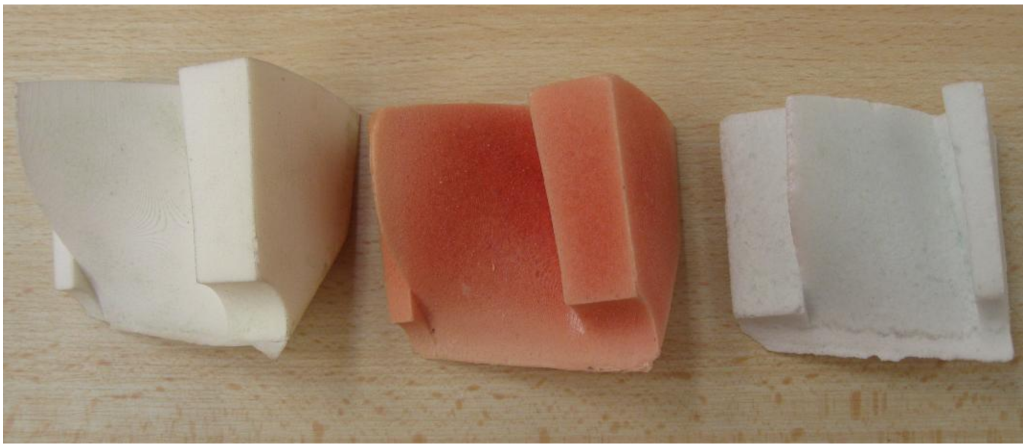

Fig. 5. *foam cores, from left: model, polyurethane core, epoxy core.*

3.2 Rotor blade

To select appropriate technology there were several tests of technology demonstrators. Chosen was resin film infusion. This technology allow considerable variation of matrix volume fraction, so it was possible to achieve a flawless blade surface. Epoxy foil was also used for binding various parts of the rotor blade. In-leaking of resin can be influenced by selecting the curing cycle.

Rotor blade manufacturing process

Blade assembly begins at the titanium bushings, which are compiled on a technological pin together with the spacer ring, which defines the space for mounting the rotor disk. Subsequently, the rotor blade foam core is attached and whole part is fitted up with layers of carbon flange and interleaved epoxy foil. The carbon flange has variable thickness corresponding transfering load. The next step is closing foot part of the blade with foam core connected again with epoxy foil. The whole rotor blade is then overlayed with required layer of carbon fabric and epoxy foil. Assembly precision of foam cores and fabrics is very important for subsequent insertion into the mold. After assembly mold has been inserted into the oven and curing at elevated temperatures.

Presented procedure is shown on the following figures.

Fig. 6. *The core of the leaf blade on the metal bushing and the addition of carbon flange and foot part foam core.*

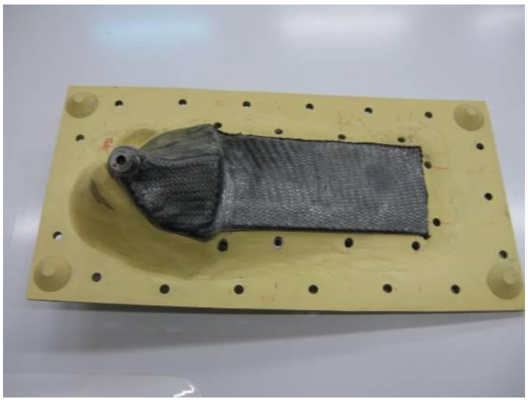
Fig. 7. *Semifinished blade inserted into a mold.*

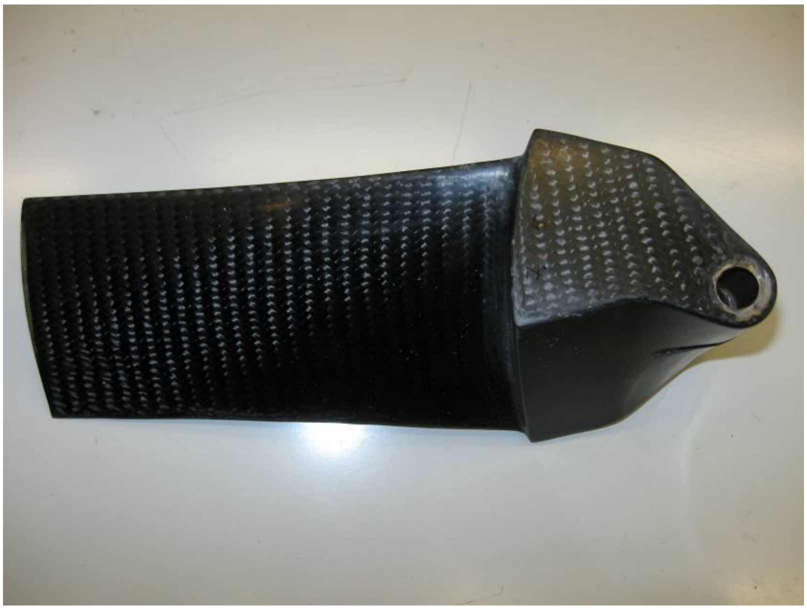
Fig. 8. *Finished rotor blade after milling of rotor disk mounting groove.*

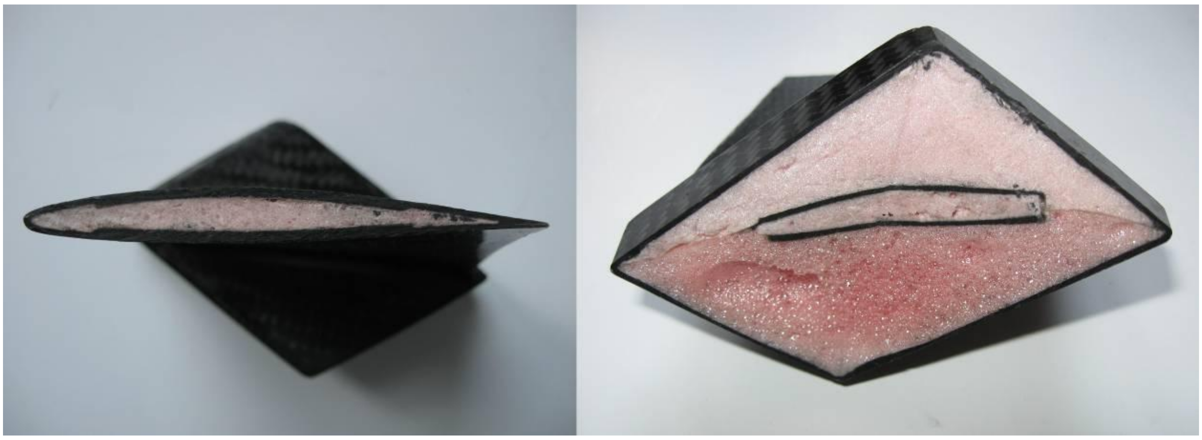
Fig. 9. *Finished rotor blade cuts*

Fig. 10. *Rotor setup*

After hardening, it is necessary to mill a hole in to the blade for attaching to the rotor disk. Weight of thus produced rotor blade is around 120g.

4. Rotor blade tests

To verify the characteristics of rotor blade were carried out strength, dynamic and operational tests.

4.1 Strength test

Strength tests of the foot part of the rotor blade were performed. A set of strength tests showed as critical attachment point of the rotor blade. Following the disorder analysis, rotor blade reinforce structure was adapted to suit the requirements of the directive. Rotor blade transfer load over 27 kN.

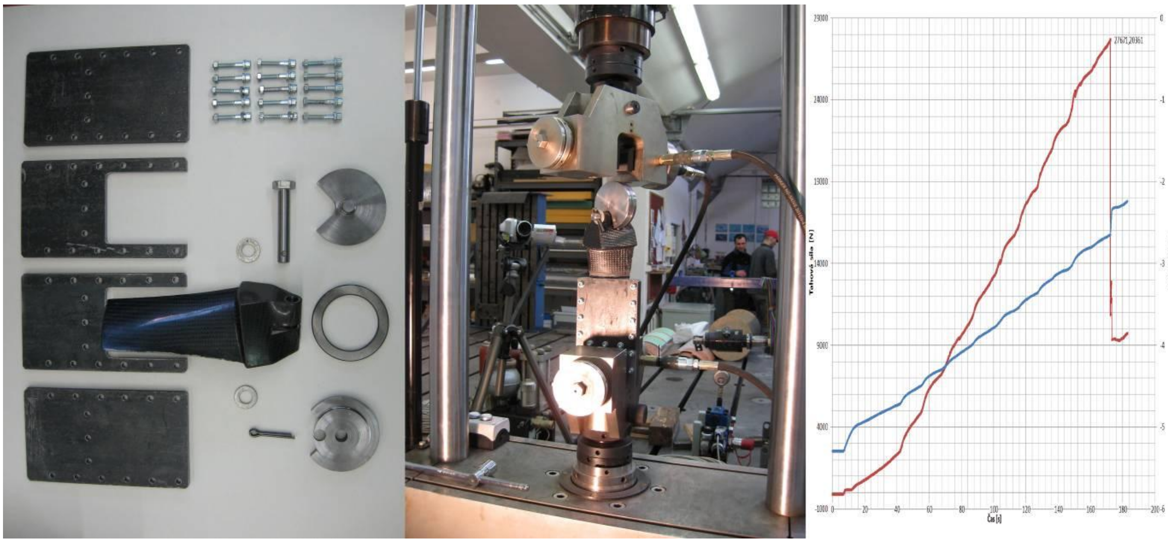

Fig. 11. *Preparation and setup of rotor blade strength tests, record of the test on the right side*

4.1 Dinamic test

Impact method was used for determination of natural frequencies of the rotor blade. The natural frequencies of the rotor blade are above exciting range of propulsion system.

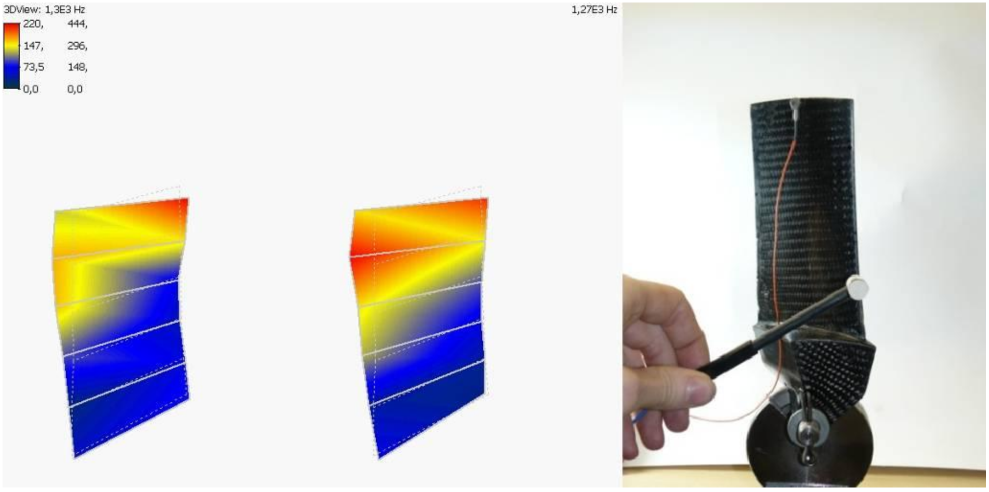

Fig. 12. *Frequency analysis of the rotor blade*

4.1 Operational test

After fulfilment of strength and dynamic requirements whole power unit was tested in a laboratory stand. Measured static thrust corresponded roughly 92% of the theoretical thrust.

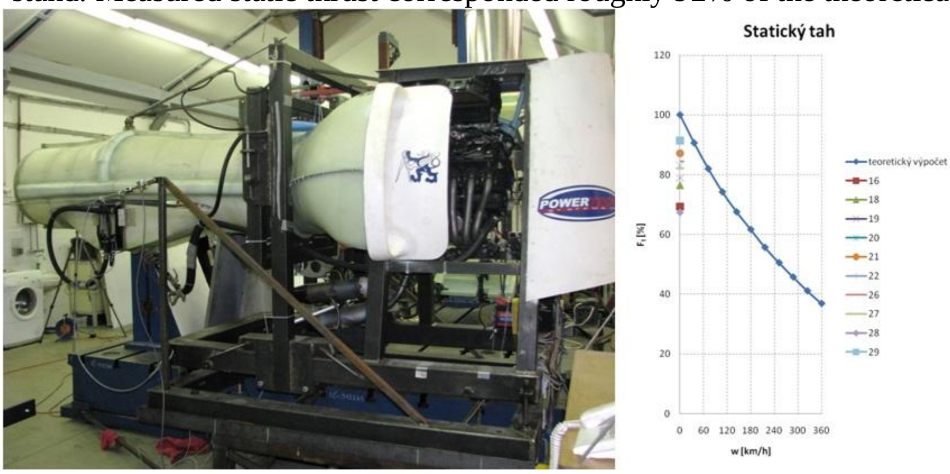

Fig. 13. *Laboratory stand*

Mobile tests to determine dynamic thrust for speeds up to 240 km/h followed. Results of this measurements are still processing.

Fig. 14. *Power unit mobile tests*

5. Conclusion

The possibility of producing rotor blade with epoxy foil technology using polyurethane cores was verified. The resulting weight of the rotor blade is 120 g at a load of 27 kN. Repeatability of production is dependent on the quality, especially the dimensional accuracy, of the foam cores. Dynamic balancing was not necessary for the complete rotor after assembly. Rotor blades meet not only laboratory tests but also stood the field test.