DESIGN, OPTIMISATION AND TECHNOLOGY OF CARBON COMPOSITE AXIAL FLOW FAN ROTOR BLADE OF LIGHT AIRCRAFT PROPULSION SYSTEM

Ing. Robin Poul, Doc. Ing. Daniel Hanus CSc.
Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Automotive, Railway and Aerospace Engineering

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Abstract

Our work is focused on design of carbon composite fan rotor blade. This fan is part of propulsion system for small aircrafts, which is composed from four-stroke four-piston motorcycle engine (108 kW @ 7605 rpm) and fan connected with the engine by composite driveshaft. Aerodynamic and strength design was done to obtain proper shape and reinforcement layup. In this work technological design is mainly examined aimed to find the most suitable structure with respect to required mechanical properties of the whole system and its dynamic behavior. We analyzed the SP Systems SPRINT technology feasibility of the blade. This technology is alternative to RTM, which is usualy used for parts like blades.

1 Propulsor Description

The introduced propulsion system is designed for ultra-lightweight aircraft. Propulsion system consists of four stroke motorcycle engine Yamaha R1, connected by driveshaft with axial-flow, one-stage fan with pre-rotator - rotor arrangement. The pre-rotator contains 17 fixed vanes made of carbon fibers reinforced epoxy resin. Vanes are connected with the hub and outer shroud by adhesive bonds. Pre-rotator works also like the driveshaft bearing support. The driveshaft passes through the pre-rotator hub. The rotor consists of 13 blades connected by means of pins with the Al-alloy hub. Rotor blades are made of carbon-epoxy composite with the foam core. The driving engine was tested to obtain realistic values of power and torque as function of revolutions. The power and torque curve can be seen on the figure 1. Based on the engine properties, dimensions of the fan and duct were chosen.

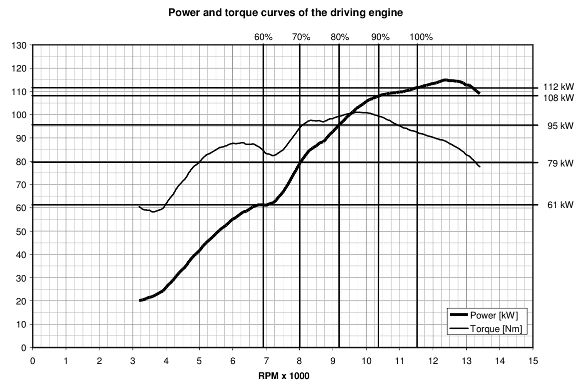

Fig. 1. Torque and power curve.

2 Thermodynamic Design of the Air Duct

For the analysis of the flow conditions in the air duct the iterative thermodynamic algorithm was designed. This algorithm divides the duct into four sections: inlet, upstream the fan, downstream the fan and outlet nozzle. This algorithm was used to estimate thrust curves, axial velocity through the fan and mass flow rate. Scheme of the algorithm is in the figure 2. From this scheme the thrust curve was obtained and proper diameter of the outlet nozzle chosen.

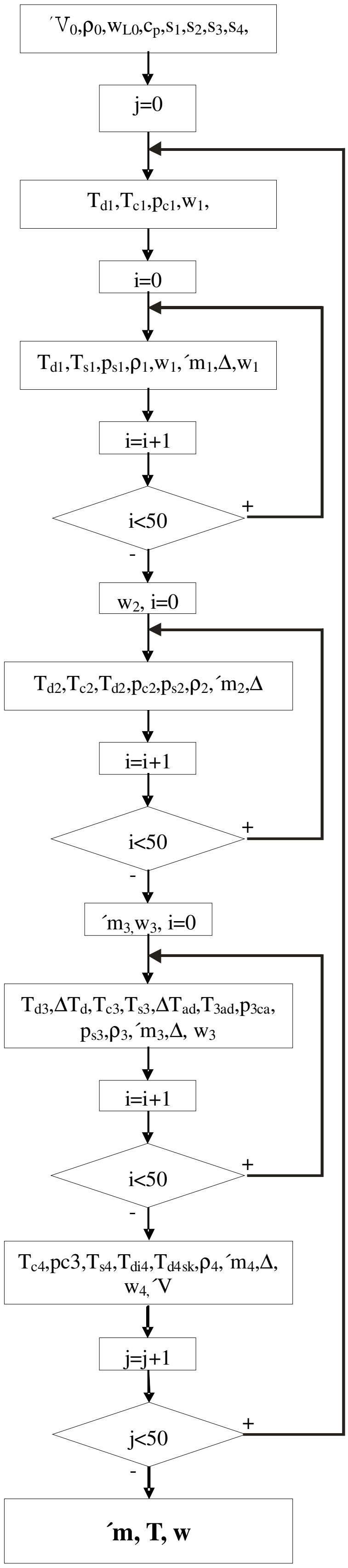

Fig. 2. Scheme of the iterative thermodynamic algorithm.

Symbols used in the fig. 2 are as follows:

- V is volumetric flow rate,
- ρ is density,
- w is axial velocity of air,
- s is cross-section area of the duct,
- T with index is temperature,
- p is pressure,
- ´m is mass flow rate and
- T without index is thrust.

Indexes:

- 0 is initial condition,
- 1,2,3,4 are stage identificators,
- c is overall (pressure and temp.),
- s is static (pressure and temp.),
- d is dynamic (press. and temp.) and
- ad is adiabatic.

3 Aerodynamic Design of the Rotor Blade

Axial flow downstream from the rotor is required for the design point. No stator is used. Pre-rotator vanes are used to unify flow field and to protect the rotor from objects sucked in the inlet. The design point was chosen as: flight velocity of 40 m/s, conditions according to 0 m ISA.

A method for aerodynamic design of a fan is described in [1]. The fan is designed for optimal isentropic efficiency in the design regime and on the assumption that the distribution of the tangential component of the velocity corresponds to a free vortex. The rotor blade and stator vane profiles have the NACA 65 A 010 profile, parabolicaly modified in the rear part and wrapped around the circular arc centerline. To fulfill the assumption of axial direction of the air leaving the rotor, we took into account the deviation angle between blade trailing edge direction and the real air stream. Angle of attack to the leading edge of the blade is chosen as 0 degrees. Modified Constant rule is used for estimation of the deviation angle:

$$\delta^* = \frac{0{,}23 \cdot \varepsilon \cdot \sqrt{\frac{s}{c}}}{1 - 0{,}23 \cdot \sqrt{\frac{s}{c}}} \qquad (1)$$

where: s/c is relative blade density and
ε is angle of flow deflection.

For technological reasons the hub and duct diameters are constant along the fan axis. The hub diameter is 252 mm, and the duct diameter is 560 mm. The next task is to check the Mach number on the blade surface to prevent the occurrence of shock waves. Two approximate methods were used for this check. The first was to find the local velocity maximum of the blade compared with the mean velocity between the rotor blades. The second method is based on lift and drag coefficients, and is described in [1]. Details of designed blades are in figure 3 and 4.

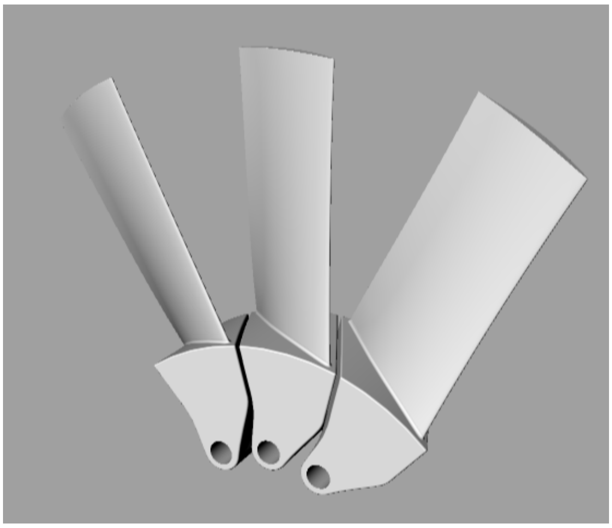

Fig. 3. Three rotor blades assembled.

4 Manufacturing Technology

Two different technologies are taken into account. Resin Transfer Molding (RTM) is the technology usually used for complicated shapes like this rotor blade. Fig. 6. shows the scheme of mold and pre-form setting. This technology gives the advance of relatively cheep tooling. On the other side lower reinforcement content is reached when compared with prepreg or Sprint technology. The low reinforcement content was the reason, why another technology - Sprint - was chosen. Sprint is invented by the SP Systems Ltd. This progressive technology combines the reinforcement in the form of fabric or stitched textile with film of resin placed on the reinforcement. Processing consists of evacuation of mold and application of increased temperature for certain time. This assures high homogenity of material with minimum necessary content of resin and minimum void content in final laminate. Sprint technology allows us to produce structure shown in fig. 5. The setup is nearly the same as shown in figure 6, only without the resin intake. Source of heat have to be attached.

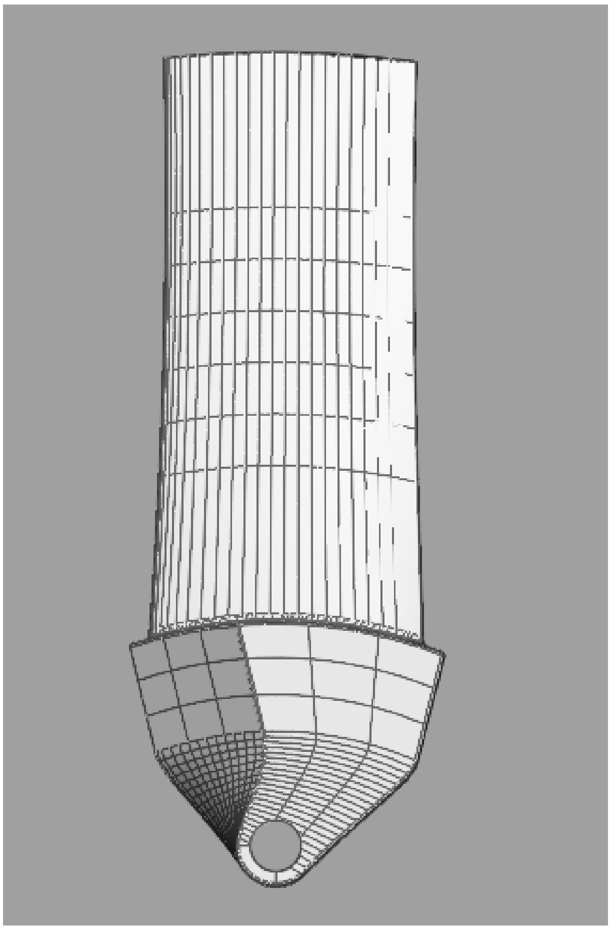

Fig. 4. Model of the rotor blade.

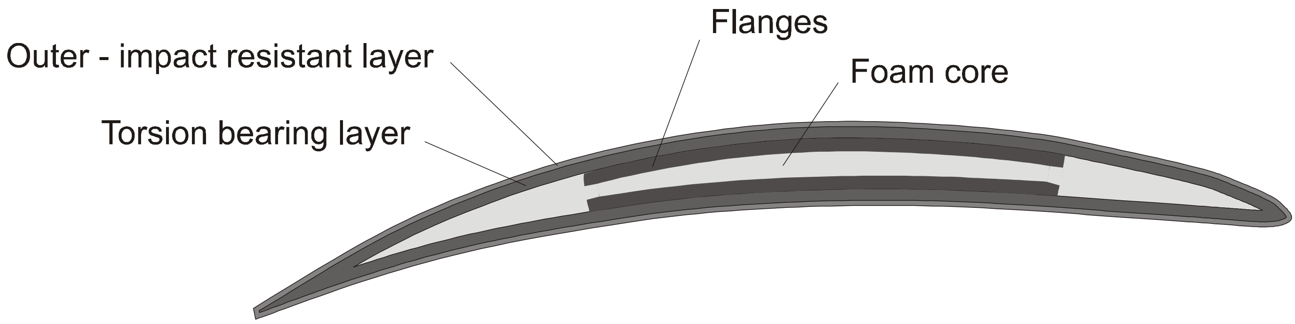

Fig. 5. Internal structure of the blade.

The blade internal structure had to be designed with respect to the fact, that air tight membrane is applied to flanges and internal surface of the blade skin. This requirement is fulfilled by the air bag inserted into the mold between upper and lower half of the blade and pressurized. The cavity created is filled with epoxy foam to form the core. This allows us to produce both flanges in one piece creating loop around the pin. This solution significantly increases strength of the blade which is loaded mainly by axial force.

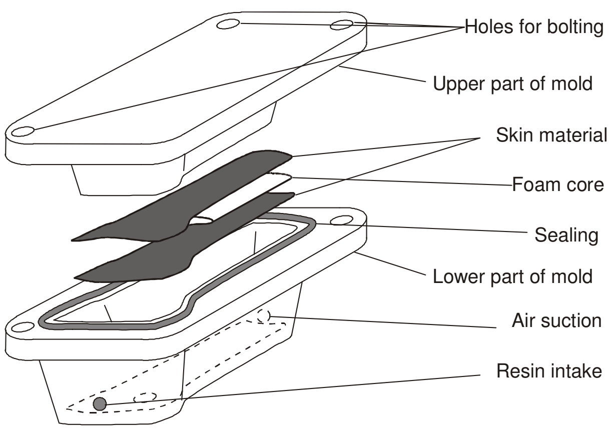

Fig. 6. Scheme of RTM setup.

5 Conclusion

Some preliminary technological tests were accomplished and the chosen technology seems to be the good way to produce rotor blades with small scattering of mechanical properties. Aerodynamic tests are planned to verify the design results and choice of the design point.

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