Engineering analysis of composite aircraft beam element

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Abstract. At present, one of the most promising directions of aircraft engineering is the use of composite materials for airframe manufacture. Hence, it is necessary to study the properties of materials and their compositions, to be able to carry out the engineering analysis of thus made structures and to simulate their behavior under different loading conditions. The use of calculation complexes for the systems using composite materials makes it possible to effectively determine the required properties of composite materials and improve the bearing capacity of the system, rationalize its design. The engineering calculation of the system stiffness properties using the finite-element method was performed. Two versions of models made of composite materials and a model made of isotropic alloy B95 were compared.

1. Introduction
In most engineering industries, beam elements are the most common structural elements. In most cases they experience simple types of loads or their combination: compression, tension and shear. The application of composite materials for making walls and flanges makes it possible to reduce weight and increase wear resistance of the structure quite efficiently.

The paper solves the problem of calculation of a composite beam under the influence of the main generalized force factors, which allows optimizing the models for current loads.

As is known from the scientific discipline Strength of Materials, the beam in each section is subject to three generalized force factors: sideforce, axial force and bending moment. Taking this into account, let us calculate the beam structure under the influence of tensile, bending and side loads. Beam flanges work mainly for tension-compression, and the walls work for shear. Therefore, the girders of a composite beam should be reinforced lengthwise and the wall – at an angles of ±45°. This scheme provides the maximum possible tensile-compression and shear strength of composite materials [1].

| Property             | Longitudinal elastic modulus, MPa | Transversal elastic modulus, MPa | Poisson’s ratio | Yield stress, MPa |
|----------------------|----------------------------------|----------------------------------|-----------------|-------------------|
| Alloy B95            | 74000                            |                                  | 0.3             | –                 |
| Composite material T300/5208 | 153000                          | 10900                           | 5600            | 0.3               | 100               |

2. Methods and Models
Three simulation models with the same geometry and boundary conditions were created for the calculation. The first calculation for tension (Fig. 1) and the second calculation for bending (Fig. 2)
were made for beam with the length of 1000 mm, pinched on one side. The axial force is applied to the second end in 8000Н for the first calculation and transverse value of 4000Н for the second one.

The third calculation for shear (Fig. 3) is performed for the section of this beam close to pinching. Two parallel forces of 100Н in sections are simulated at a distance of 10 mm from each other.

**Figure 1.** Full beam displacement (tensile load) (max 0.154 mm)

**Figure 2.** Full beam displacement (bending load) (max 158.2 mm)
Figure 3. Full beam displacement (lateral load) (max 0.002 mm)
Three beam options are used to consider the properties of composite beams (Fig. 4):
- from material B95;
- from composite material with the long reinforcement filaments T300/5208 in which all filaments are placed along a beam;
- from composite material in which the girders are placed along a beam axis, and the filaments in a wall – at an angle of ±45°.

![Figure 4. Options of a beam mathematical model corresponding to material properties](image)

### 3. Results and Discussion

The results of the analysis are shown in Table 2, which shows the maximum deformations for each model and calculation.

| Beam manufacturing option                              | Deformation caused by lateral load, mm | Deformation caused by bending load, mm | Deformation caused by shear load, mm |
|---------------------------------------------------------|----------------------------------------|---------------------------------------|-------------------------------------|
| from an aluminum alloy B95                             | 0.296                                  | 295.8                                 | 0.0005                              |
| from a composite material with unidirectional fibers   | 0.154                                  | 158.2                                 | 0.002                               |
| from a composite material with wall filaments at an angle of ±45° | 0.214                                  | 178.6                                 | 0.0008                              |

The table shows that the composite beams much better perceive bending and lateral loads and weigh much less. At the same time, the shear load is better perceived by the B95 alloy. Compared to unidirectional fibers, the difference is 4 times. However, the use of the proposed option of filament orientation (± 45°) allows achieving a result close to the alloy.

Thus, the best option for the sum of factors is the third beam model. With respect to the classical isotropic material, the advantage of bending and stretching is evident.

Nevertheless, the third model has some disadvantages. For composite materials the shear load is the most dangerous since such loads may “peel” adhesive compositions. For this model, this is extremely relevant, since in the connection of the flanges with the wall there is a joint of fibers directed at an angle and directed along the axis of the beam.

Thus, in order to ensure high tensile-compression and shear-reinforced wall strength, it is first necessary to strengthen the shelf with the layers of ± 45 ° to increase the shear bearing capacity, second, to increase the contact zone of the wall with the shelf in order to reduce the tangential stresses in the zone of their connection [1].

In order to increase the shear strength for this option of the beam element, it is necessary to use a beam scheme with “shoulders”. These are extensions of the wall layers on the shelf layers (Fig. 5).
The connection strength of the flange to the wall and the shear strength of the flange are thus ensured. The comparison of beam calculation with shoulders and without them for shear under the action of the bending load is carried out against the shear safety coefficient according to Hoffman theory (Fig. 6). In the hazardous section of the flange joint with the wall, the coefficient for the beam with shoulders is 0.13357, for the beam without shoulders – 0.43845, which confirms the ability of the shoulders to prevent the shift of material layers in the joint section.

Figure 5. Beam with shoulders

Figure 6. Safety coefficient for beam model with shoulders

4. Conclusion
The conducted experiments make it possible to conclude that composite materials can be used in beam structures: composite beams are not only able to give better qualities in terms of their mass
characteristics, but can also exceed classical aviation materials in rigidity characteristics. By properly selecting the beam reinforcement method according to the operating conditions, both the required stiffness and strength characteristics can be achieved. Thus, the use of reinforcement at an angle relative to the axis of the beam was advantageous in terms of bending and axial tension, and the shoulders offset potentially dangerous destruction at the joint of the wall and the flange when exposed to shear.

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