Design of a structurally optimized bioinspired structural arrangement of carbon composite fuselage of unmanned aerial vehicle based on parametric modeling

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Abstract. Currently, the industry of unmanned aerial vehicles (UAV) is actively developing. They perform a wide range of different civilian and military tasks. Depending on the task, stringent requirements are imposed on the design, but the key ones are low weight, high strength and survivability. Satisfying these requirements will increase the payload mass and extend the life of the product. This can be ensured by the use of polymer composite materials (PCM) based on carbon fibers and new structural arrangement. This is especially true for the main element of the UAV frame – the fuselage. The work is devoted to an urgent task – the development of a new UAV composite structural layout. Structural-optimized structures are considered: bioinspired, auxetic, grid structures. A comparison of the developed options with the classical structure of the frame is carried out. A variant that exceeds the classical layout in terms of mass and strength up to 25% is selected. Main layout parameters are determined.

1 Introduction

To improve the characteristics of the developed UAV, new solutions in the field of the frame are needed. Together with composite materials [1], this will increase the strength, reliability, service life and reduce the weight of the product. This will have a positive effect on the intended purpose of the UAV – the mass of the payload, the flight time. For a classic aircraft-type UAV, the main element of the frame is the fuselage. Engineers of leading aviation firms and teams of research institutes are working on improving this design. The fuselages of various aircraft and their components are being developed [2]. Various optimization methods [3], including topological [4-5], are used to determine the configuration of the force set and the main elements from metal-matrix [6] and polymer [7] composite materials. Various loading conditions [8] and features in experiments [9] are taken into account. Calculations are carried out to determine the periodic structures [10] similar to the grid force sets that reinforce the skin [11]. These anisogrid structures have been successfully used in rocket technology for a long time, and now they are beginning to

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be mastered in aircraft construction. Algorithms for calculating and optimizing the finned structure of irregular [12] and regular [13] configurations are being developed. The number, shape, geometric parameters of elements are determined. The stability of the structure is taken into account depending on the location of the ribs [14]. In the last decade, there has been particular interest in two types of structures. The first are bioinspired structures developed based on natural objects. In particular, shell structures based on bamboo are considered for the fuselage [15]. The second type is auxetic structures [16], which make it possible to increase the bearing capacity of the entire product [17]. It should be noted that the manufacture of the described structures, including those from PCM [18], is possible with the help of developing technological methods, for example, additive technologies. In this area, methods have been developed for extrusion of continuous carbon fibers with polymer resin [19] for cylindrical shells by layer-by-layer stacking, taking into account the resulting material properties [20]. Based on the foregoing, the development of aircraft elements, taking into account weight reduction without loss of carrying capacity [21], in particular the fuselage through the use of advanced research areas, is an urgent task.

2 Source data

2.1 Subject of research

The fuselage compartment of an aircraft-type UAV, located behind the wing, was considered as an object of research (Figure 1).

The main structural material is carbon fiber fabric. The Table 1 shows characteristics of carbon fabric.

Table 1. Physico-mechanical properties of carbon fabric.

Density, kg/m^3	1580
Layer thickness, mm	0,285
Tensile modulus, along an axis 1[a] / 2[b], GPa	174,3 / 174,3
In–Plane shear modulus, GPa	2,9
Poison's ratio	0,32
Tensile (Compressive) strength, along an axis 1 / 2, GPa	2,7 (2.9) / 2,7 (2.9)
In–Plane shear strength, GPa	0,1
[a] Warp [b] Weft	

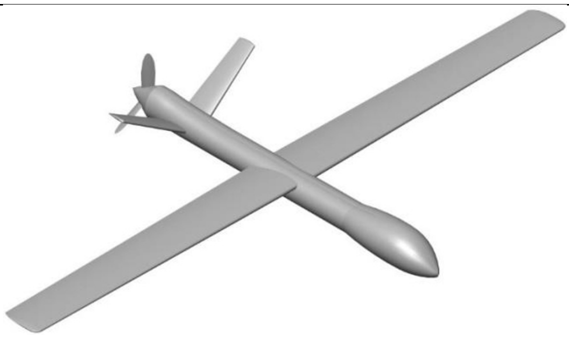


Fig. 1. Appearance of the UAV

2.2 Structural loads

The following loads were considered:
- airload;
- own weight of the unit and payload weight of 30 kg.

The load calculation was carried out for a maneuver at an altitude of 1500 m at a speed of 200 km/h (turn).

Airload were determined using the Ansys software package in the CFX module [22] (Figure 2). An irregular mesh was created with discretization on the surface of the UAV. The total number of elements was about 1.5 million. The input and output parameters of the flow (Inlet and Outlet) corresponding to the flight mode are set. The environmental parameters were set in accordance with the values of the parameters of the standard atmosphere for a given height. Figure 3 shows a view of the distribution of aerodynamic pressure over the surface of the device.

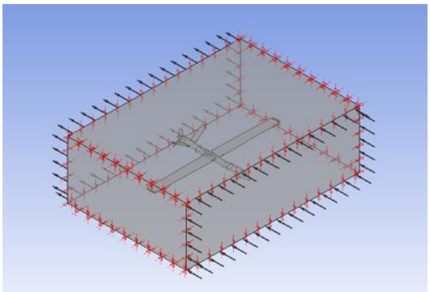


Fig. 2. View of the calculation model

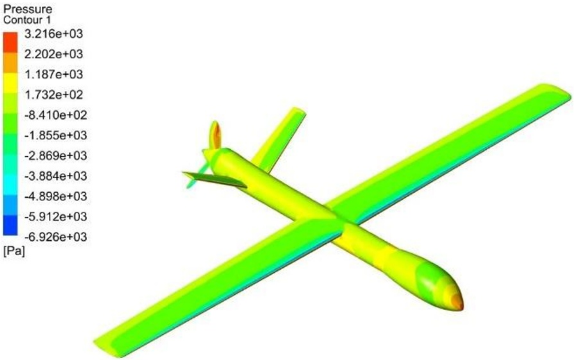


Fig. 3. Distribution of aerodynamic pressure over the UAV surface, Pa

2.3 Structural arrangements of the fuselage

Eight different power circuits of four types were designed and considered.

The first type is the classic power layout with stringers, frames (scheme 1 – Figure 4) and power beams (scheme 2 – Figure 5). The thickness of the frame was 5 mm, the height was 25 mm, the thickness of the stringer was 2 mm, the height was 15 mm, and the skin thickness was 1.5 mm.

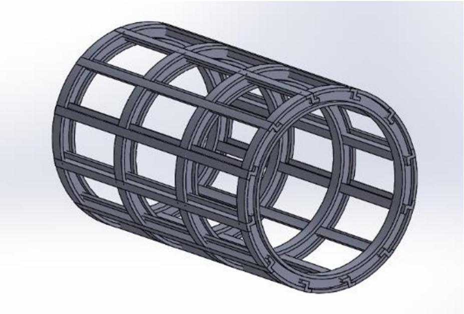


Fig. 4. Structural arrangement 1 with I-beam frames and z-shaped stringers; cover not shown

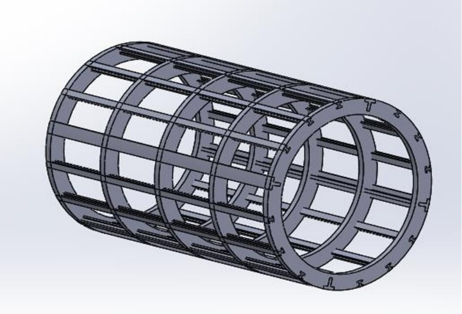


Fig. 5. Structural arrangement 2 with T-spars, T-shaped frames and I-shaped stringers; cover not shown

The second type is grid structures. Scheme 3 is an intermediate option between the classic and grid designs. Six frames are double walls, inclined at 15 ° relative to the vertical, with a thickness of 2 mm, a height of 25 mm. Scheme 4 – anisogrid construction. Ten stringers are directed clockwise and ten stringers are directed counterclockwise.

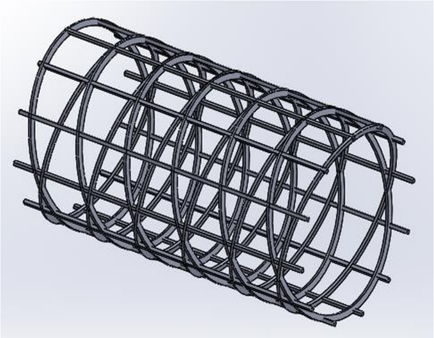


Fig. 6. Structural arrangement 3 with inclined frames; cover not shown

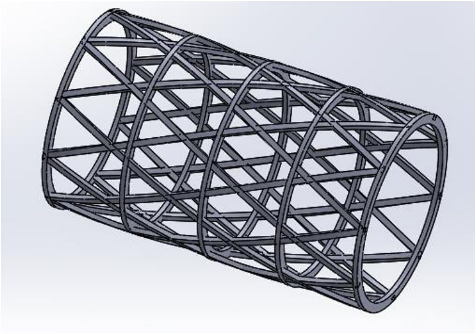


Fig. 7. Structural arrangement 4 grid design; cover not shown

The third type is auxetic structures. The main element of the design is the reverse hexagon. Two types of reverse hexagons are considered (Figures 8, 9) and power circuits corresponding to them (Figures 10, 11). Of the hexagons, ring representative power elements are assembled, the number of which for the fuselage section is ten.

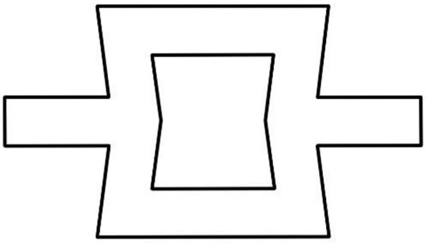


Fig. 8. Reverse hexagon 1

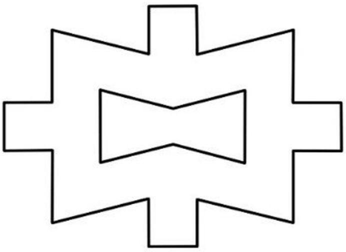


Fig. 9. Reverse hexagon 2

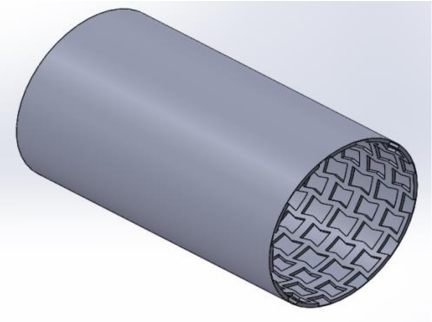


Fig. 10. Structural arrangement 5 based on reverse hexagon 1

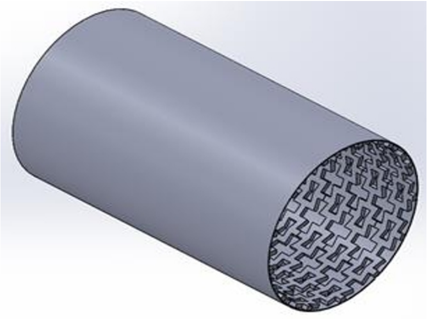


Fig. 11. Structural arrangement 6 based on reverse hexagon 2

The fourth type is bioinspired constructs. Structural arrangement are create on the basis of bamboo structure with a double and triple shell, reinforced with 1.5 mm thick jumpers (Figures 12, 13).

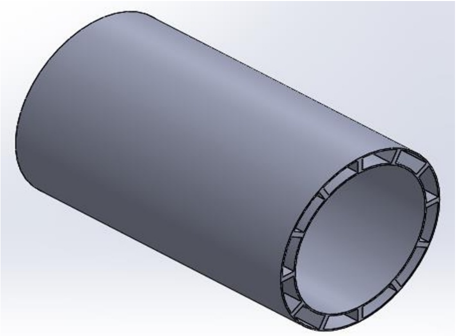


Fig. 12. Structural arrangement 7 with double shell

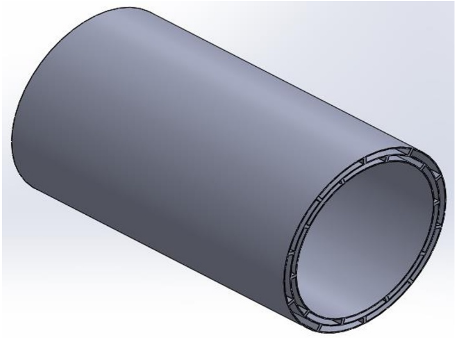
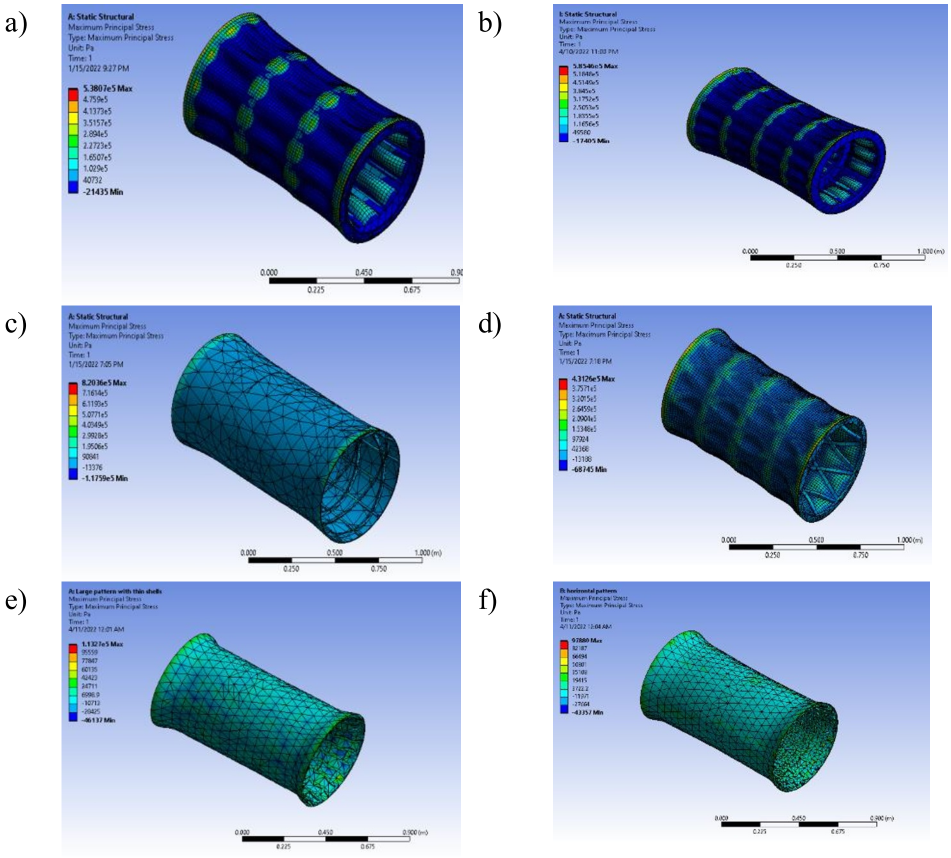


Fig. 13. Structural arrangement 8 with triple sheath

3 Results

As a result of the calculation of the stress-strain state of eight different fuselage SA under the action of the operational load, the values of mass, displacement and stress were obtained and analyzed. В качестве примера As an example, Figure 12 shows the distribution of normal stresses along the X axis for the circuits considered.



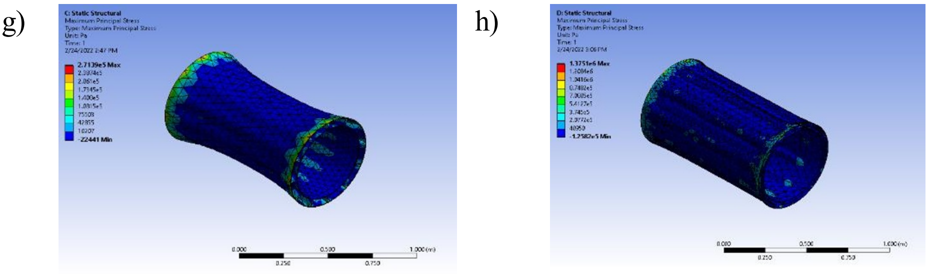


Fig. 14. Normal stresses along the X axis for (a) – scheme 1, (b) – scheme 2, (c) – scheme 3, (d) – scheme 4, (e) – scheme 5, (f) – scheme 6,(g) – scheme 7, (h) – scheme 8

Figure 13 shows the results of the distribution of options for three parameters (mass, deflection, stress).

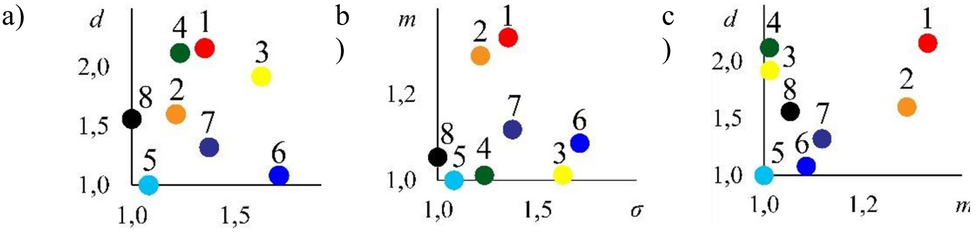


Fig. 15. Distribution of variants of relative units by:: (a) – stress (σ) and deformation (d); (b) – stress and mass (m); (c) – mass and deformation

The optimal SA, from the obtained ones, can be determined both by introducing an additional parameter, for example, cost, and by choosing the shortest distance to the theoretical center (TC) according to the equation (1):

$$K = \left[\frac{\left(m_{TC} - m_i\right)^2}{m_{AM}^2} + \frac{\left(d_{TC} - d_i\right)^2}{d_{AM}^2} \frac{\left(\sigma_{TC} - \sigma_i\right)^2}{\sigma_{AM}^2} \right]^{1/2}$$

where m_{TC}, d_{TC}, σ_{TC} – TC mass, deformation and stress values, m_i, d_i, σ_i – variant mass, deformation and stress values, m_{AM}, d_{AM}, σ_{AM} – arithmetic mean mass, deformation and stress values.

As a result, it was found that the closest to the TC is the auxetic design option 5 (the hexagon is oriented with a straight edge along the axes of the frames).

4 Conclusion

In this paper, based on the parametric modeling of eight geometric models, the design of the fuselage of an unmanned aerial vehicle made of carbon composite materials was developed.

The advantage of the selected power circuit of the auxetic type over the classical one is up to 25% in terms of mass, strains and stresses.

The work is the initial stage of research into promising power circuits.

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