The hydroplane body development of design and topological optimization

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Abstract. This work is devoted to the study of the stress-strain state of the hydroplane body and its topological optimization. During laboratory tests, physical and mechanical properties of materials were identified, which are necessary for use in further calculations to study the stress-strain state of the hydroplane body, followed by reducing its weight, using topological optimization of the structure. The end result is a developed method for manufacturing the hydroplane body using additive technologies.

1. Introduction
Any aircraft is a compromise between lightness and strength, and the large range of materials available on the market allows you to print the body of an unmanned aerial vehicle (UAV) for a highly specialized task, without spending a lot of money for implementation. This paper presents a computer simulation of the hydroplane body based on studies of the physical and mechanical properties of materials used in the manufacture of the fuselage, and topological optimization of the body based on the study of the stress-strain state.

2. Materials and equipment
Tensile testing is the main and most common method for controlling the mechanical properties of materials [1]. The task is to select the optimal material for manufacturing the hydroplane fuselage using the additive method.

Reproducibility of the experiment results is achieved by repeated repetition. The minimum number of repetitions is 5 times. Experiments were performed for a plastic thread (the material before printing), a shell model (along and across the fibers), and a massive structure (the fibers are arranged at a 45-degree cross-to-cross angle). Figure 1 shows samples for tensile testing, according to ISO 527-2:2012 [2].

In the course of the experiments (table 1) it was found that PLA is the most optimal of the presented options of plastic threads. The tensile strength of the plastic thread is 45 MPa. The young's modulus for PLA plastic was also derived and differs from the passport data by 3%. The Poisson ratio is 0.39.
Figure 1. Standard for stretching ISO 527-2:2012. (a) – sample for the shell, fibers along the part, (b) – sample for the shell, fibers across the part, (c) – sample for a massive structure, fibers cross to cross at an angle of 45 degrees.

Table 1. Physical and mechanical properties of the materials.

| Material                           | Maximal stress, MPa | Elongation, mm | Young's modulus, MPa | Poisson ratio |
|------------------------------------|---------------------|----------------|-----------------------|--------------|
| Aerotex (filament)                 | 62.1                | 0.026          | 1557                  | -            |
| PLA (filament)                     | 45                  | 0.05           | 1332                  | -            |
| Total GF-30 (filament)             | 47.1                | 0.37           | 300                   | -            |
| Longitudinal shell made of PLA     | 35                  | 0.04           | 1447                  | -            |
| Cross shell made of PLA            | 25                  | 0.022          | 1032                  | -            |
| Massive construction of PLA        | 45.2                | 0.067          | 1335                  | 0.39         |

3. Computational model
The fuselage of a flying boat consists of a massive structure to which all the power elements are attached and where the payload is located. And the shell is necessary to improve the aerodynamic qualities of the aircraft, as well as for waterproofing and landing on the water surface (figure 2).

Figure 2. Scheme for developing the fuselage of a flying boat.
For further testing, it is necessary to select the design case where the maximum loads are applied to the UAV. There are landing, flight, and takeoff cases. The hydroplane must withstand loads, and the structure must not collapse during flight in all these cases. Consider the case during landing, when the maximum load occurs. The fuselage does not receive weight loads from the wing structure during flight, as it creates lift. During landing, the lift is noticeably reduced, thus the weight of the wing is transmitted to the fuselage through the connecting elements. Also, during a sharp loss of altitude, there is an overload that can reach up to 3g. The hydroplane has a wingspan of 1200 mm and a fuselage length of 758 mm. The maximum take-off weight with a payload is 2 kg. At point A in figure 3, there is a pivotally fixed support; at points B, C, and D, there is a pivotally movable support. \( m_1 = 0.2 \) kg (wing mass), \( m_2 = 0.05 \) kg (stabilizer mass), \( m_3 = 1 \) kg (payload mass), \( L = 0.3 \) m, \( l = 0.04 \) m, \( M = 1 \text{ N·m}^{-1} \).

![Figure 3](image-url)  
**Figure 3.** Loads applied to the hydroplane during take-off and landing.

The Von-Mises equivalent stresses of the massive structure and shell are shown below (figure 4).

![Figure 4](image-url)  
**Figure 4.** Mises equivalent stresses

4. **Results and discussion**  
After performing the calculation to obtain the resulting stresses, we proceed to topological optimization [3], which is an iterative operation, at each step the design VAT is estimated. If the stress in some areas is significantly less than the critical ones, then this area of the material (continuous medium) is removed from the calculation (figure 5, 6).
Figure 5. The first iteration of topological optimization of the hydroplane body.

Figure 6. The second iteration of topological optimization of the hydroplane body.

The design has a safety margin of more than 10 times. For aviation equipment, this is a huge margin and with the help of topological optimization, it was possible to reduce the weight by 70% without losing strength characteristics (figure 7).

Figure 7. Post-processing and printing.
5. Conclusions
The physical and mechanical properties of materials for the massive structure and shell of the hydroplane body, as well as the plastic thread itself, are revealed. Thus, in the course of tensile tests, the strength limits, young's modulus, and Poisson's Ratio were obtained. For shells, the properties were studied from longitudinal and transverse fibers. Computer models of an unmanned aerial vehicle were developed in the SolidWorks software package.

The calculation of the stress-strain condition of the hull of a seaplane has been done. Thus, it was possible to create a method for manufacturing the UAV body using additive technologies and topological optimization.

References
[1] Birger I A and Mavlyutov R R 1986 Resistance of materials (Moscow: Nauka) p 560
[2] ISO 527-2:2012 Plastics – Determination of tensile properties
[3] Bashin K A, Torsunov R A and Semenov S V 2017 Methods of topological optimization of structures used in the aerospace industry PNRPU Bulletin (Perm National Research Polytechnic University) 51 pp 51-60