Research of the strength of structural elements (wing console) for aviation purposes obtained using 3d printing

A D Latypov, G V Moskvitin, O V Naumov and M S Pugachev
Mechanical Engineering Research Institute of RAS (Russian Academy of Sciences), Bardina street 4, Moscow, 101990, Russia

naumov57.on@gmail.com

Abstract. 3D printing technology allows you to obtain parts with a number of characteristics that have great importance for a number of areas, in particular small aircraft. The article presents a statistical and modal analysis of the naca0012 configuration wing console made of ABS and PLA plastics. These calculations allow us to draw conclusions about the possibility of using printing technology in the development and design of aircraft.

1. Introduction
Presently much attention is given to using 3D printing technology in the course of aircraft manufacturing. The peculiarity of this technology consists in layer-by-layer application. Different printing technologies have appeared at the moment, which make it possible to produce intricate-configuration parts that are as good as already existing ones. The application of such technology as 3D printing in some fields will help gain significant advantages. Specifically, aviation industry is worthwhile noting, where special attention is paid to the issues of weight-strength combinations. The usage of 3D printing technology helps solve problems in the course of building and designing aircraft, viz., get a required configuration of elements, units, reduced structure weight (as compared with the steel parts) and prime cost.

The purpose of this work is to analyze a possibility of using parts made by 3D printing when designing aircraft. In order to solve the formulated problem, the static and modal analyses of naca configuration wing have been carried out with the use of AutoCAD Inventor 2020 Professional software system. The grades of plastics are ABS (acrylonitrile-butadienestyrene) and ABS with polycarbonate. The data for calculation have been taken from the acquired results of static tests of samples produced by printing using 3D printer [1, 2].

2. Problem definition
The acquired mechanical characteristics of ABS plastic have been entered into materials base of Autodesk Inventor 2020 Professional design program, where modal and static analyses of outer wing panel of symmetrical airfoil naca0012 (n0012-il) for unmanned aerial vehicle have been carried out (figure 1). A mesh has been plotted for the panel, its parameters are shown in table 1. A choice of straight wing is substantiated by low speeds, however, the results of calculations of outer wing panel made of different plastics and comparison of the results thereof are of immediate interest. Dimensions: wing chord – 0.3 m, wing span – 2 m, sweep – 0.
Figure 1. Outer wing panel of airfoil-shaped profile naca0012 (n0012-il).

Table 1. Network configuration.

| Average dimension of elements, units | Average dimension of elements, units | Dissimilarity coefficient | Maximum turn angle |
|-------------------------------------|-------------------------------------|---------------------------|--------------------|
| 0.030                               | 0.200                               | 1.500                     | 60.00              |

Pressure of 5 kPa has been set over entire panel area and one of its ends has been rigidly fixed for static analysis of outer wing panel made of plastic. The load has been selected so for the proof von Mises stress that to match closely the material yield limit. Theoretically the plastic material begins to get damaged, where von Mises stresses become equal to the limiting ones.

The same load has been set mainly for comparing displacements and safety factors for ABS with polycarbonate featuring somewhat surpassing mechanical characteristics as compared with pure ABS.

Figure 2. ABS: (a) – von Mises stresses; (b) – displacement simulation result.

Figure 3. ABS safety factor.
The modal analysis makes it possible to assess natural vibrations frequency, which is one of the important parameters when estimating a possibility of using material for aircraft [3]. Figures 6, 7 show the results of investigations by modes giving the values of frequencies with limiting values for every type of plastic.

The results of modal analysis show the presence of frequencies, when the displacement maximum values appear being localized in different parts of the wing. Table 2 is given for comparative analysis of two plastics.

**Table 2. Calculation results.**

| Material | Density, g·cm⁻³ | Panel weight, kg | Yield limit, MPa | Young modulus, GPa | Displacement (max), mm | Safety factor (min) |
|----------|-----------------|-----------------|-----------------|-------------------|------------------------|---------------------|
| ABS      | 1.06            | 7.84            | 25.8            | 1.686             | 196.7                  | 1.15                |
| PC/ABS   | 0.35            | 2.64            | 54.4            | 2.78              | 118.7                  | 2.43                |
Figure 6. ABS: (a) – the first mode - 6.28 Hz, (b) – the second mode - 39.09 Hz, (c) – the third mode - 48.14 Hz, (d) – the fourth mode - 48.86 Hz.
Figure 7. ABS with polylactide: (a) - the first mode - 13.95 Hz, (b) – the second mode - 86.81 Hz, (c) – the third mode - 106.56 Hz, (d) – the fourth mode - 107.31 Hz.

The acquired results make it possible to come to a conclusion: plastic of ABS type with polycarbonate notably surpasses ABS with the assumption that its density is 3 times lower.

3. Conclusions
Proceeding from the performed investigations we arrive at the following conclusions:
• It is apparent proceeding from the test results that ABS plastic with polycarbonate features higher strength, but lower plasticity, while ABS plastic features strength 25% lower, at that, its plasticity is 14% higher.
• The calculation results have demonstrated that the panel weight made of ABS features weight 60% higher as compared with the same made of ABS with polycarbonate. A difference of displacements also amounts to around 45% in favour of smaller displacements of a panel made of ABS with polycarbonate. The safety factor with ABS with polycarbonate is 47% higher than that with ABS without admixtures.
• The parts manufactured with the use of technology of 3D printing of plastics can be used in aviation industry, where it will help reduce the weight of aircraft. It is also worthwhile noting the application of this technology in manufacturing unmanned aerial vehicles.
Acknowledgments
The authors would like to thank colleagues for important advices and assistance in preparing this article.

Reference
[1] Naumov O V, Moskvitin G V, Pugachev M S and Polyakov A N 2017 Investigation of stress-related and strength properties of ABS plastic when printing parts using 3D printer (Institute of Machines Science of Russian Academy of Sciences) pp 57–60
[2] Naumov O V, Moskvitin G V, Pugachev M S and Polyakov A N 2016 Experimental estimate (investigation) of strength of parts manufactured at 3D printer (Institute of Machines Science of Russian Academy of Sciences) pp 461–4
[3] Leontiev N V 2006 Application of ANSYS system for solving tasks of modal and static analysis Educational learning material for refresher training program Information systems in mathematics and mechanics (Nizhny Novgorod) p 101