Manufacturing sound-absorbing structures by 3d-printing

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Abstract. In this research we developed the methods and technologies for manufacturing sound-absorbing structures (SAS) samples using Dimension SST 1200 and Envisiontec Perfactory XEDE units. While testing the technique, the shortcomings of both units were identified. To eliminate the identified shortcomings, we formulated some recommendations and adjusted the main stages of manufacturing SAS with the application of these methods. Experimental acoustic studies of the produced reference samples of the SAS on an interferometer with normal incidence of waves were carried out. Acoustic tests of samples of SAS manufactured with consideration of the developed technological solutions showed good sustainability of the obtained results, we revealed strong correlation with the samples from polymer composite materials manufactured using standard plant technologies.

1 Introduction

In the 21st century there is a rapid development of civil aviation and the air transportation market, which is a catalyst for economic growth. At the same time, the negative impact of aviation on the environment is increasing, especially in the near-airodrome areas. The ecology of aviation transport has become the most urgent problem, allocated by the International Civil Aviation Organization (ICAO), second to safety only [1]. One of the dominant components of the harmful impact of aviation on the environment is the noise created by aircraft. ICAO constantly tightens international standards for aircraft noise, standardizing its level in the takeoff and landing modes, forcing aircraft manufacturers to develop new technologies to reduce the noise [2]. One of the main components of aircraft noise is the noise generated by propulsion systems - turbojet two-loop engines (TTLE) [3].

The lining of aircraft engine channels by resonant sound-absorbing structures (SAS) is the main way to reduce the noise of an aircraft engine fan. SAS consists of a filler containing cells of various geometric shapes [4-9] (Figures 1a-c), as well as closed bottom and top perforated plating.

On the one hand, such a design is technologically simple, and the process of manufacturing the SAS is considerably simplified. On the other hand, existing SAS fabrication technologies cannot guarantee the defect-free creation of even such simple designs, as a result of which the acoustic characteristics of the manufactured SASs can differ markedly from those that are expected.

This effect reveals itself already at the stage of testing the samples of the developed SAS in installations "Interferometer with normal incidence of waves" and "Interferometer with flow". The results of tests of

identical samples of SAS, manufactured by the same technology, often differ from each other. Modern additive technologies would solve this problem by 3D printing the SAS samples and operational structures.

Fig. 1. SAS filler of various configurations:
(a) honeycomb core, (b) cells and (c) tubular core.

In this research, technologies for manufacturing samples of different size SAS (for a interferometer with

normal incidence of waves and an interferometer with a flow) were developed with different filling configurations using the Dimension SST 1200 and Envisiontec Perfactory XEDE installations (Figure 2).

a

b

Fig. 2. 3D printer: (a) Dimension SST 1200 (b) layer-by-layer synthesis EnvisiontecPerfactory XEDE.

Acoustic tests of printed SAS samples on an interferometer with normal incidence of waves were carried out.

2 Making reference samples for an interferometer with a normal sound wave drop

For the production of SAS reference samples for the interferometer with a normal fall of sound waves, FDM prototyping technology was used. In Fig. 2 the general view of the Dimension SST 1200 installation used to make samples for the interferometer is shown. The production cycle, in this case, is reduced to designing the sample shape in the SiemensNX 3D simulation program, converting it into an .stl format, compatible with a 3D printer, and printing the finished sample on the printer. However, features of 3D prototyping on this unit had both positive and negative sides. The technology of manufacturing on this equipment consists of layer-by-layer extensions of the detail by extrusion of a thread from ABS plastic [10]. The printer uses two materials: the main material, which is ABS-plus thermoplastic, and the support material that creates layers that support the

base material where necessary. In the absence of support material, significantly more than 5% deformation of the structure is observed. From open areas, support material is removed mechanically, for example, with a screwdriver or a stationery knife. From the hard-to-reach places, support material is removed by dissolving with a special chemical composition. Examples of models designed in Siemens NX are shown in Figure 3.

Fig. 3. Geometric models of the SAS developed in Siemens NX (a) with cubic filler, (b) honeycomb filler.

After building, using the software package supplied with the 3D printer, the model is divided into layers, the orientation of the detail in space is selected, as well as the thickness of the layer, the method of filling the solid sections (Solid, Hdensity, Lowdensity) is assigned. By optimally selecting the position of the detail, it is possible to reduce or completely eliminate the presence of a supporting material.

The SAS samples produced during this work are a closed cavity with a hole diameter of 2 mm. The production of a SAS sample, which has "closed" cavities, is accompanied by a number of technological problems, for example, filling the cavity of the resonator with support material.

The presence of a stagnant, "blank" area filled with support material, makes it impossible to remove support material using a dissolving liquid. To solve this problem, the lower non-perforated faces were removed in the developed geometric models. Later, during acoustic tests, we propose to use a special reinforced material that will ensure the acoustic closure of the tested samples. The use of this technology for manufacturing SAS samples by means of 3D printing from ABS plastic made it possible to use a minimum amount of supporting material. The process of manufacturing the samples of cellular SAS, using FDM prototyping technology, is presented in Figure 4.

Fig. 4. Making samples on a 3D printer.

In Figures 5a and 5b a general view of the SAS samples made for the interferometer is shown (with cubic and honeycomb filler).

Fig. 5. The manufactured samples of the SAS using the FDM technology: (a) with cubic filler, (b) honeycomb filler.

Thus, the SAS samples manufacturing process for carrying out experimental studies of acoustic characteristics on an installation "interferometer with normal incidence of waves" was carried out in the following order: 1) Development of three-dimensional models of SAS for an interferometer; 2) Development of the methodology and selection of production modes for samples using the FDM prototyping technology; 3) Manufacturing of SAS samples, using the FDM prototyping technology.

3 Making reference samples for a flow interferometer

Installation Envisiontec PerfactoryXEDE allows to manufacture the parts using the technology of stereo-lithography photopolymer material. For the development of the technique and the production of reference samples for the installation of a channel with a flow, computer models of the SAS were developed. Figure 6 (a, b) presents a general view of the three-dimensional computer models built in the Siemens NX software package. All computer models are generated in the STL data format. To further manufacture the samples, all models were converted into a voxel matrix using Perfactory Software Suite software (Figure 2b).

Fig. 6. General view of the geometric models built in Siemens NX (a) honeycomb filler, (b) tubular filler.

The stereo-lithograph printer has a platform that is immersed in the tank with a liquid photo polymer. It is located directly below the surface at the depth of the generated layer. The laser passes through the calculated surface of the grown section of the object, as a result of which the thin layer of the polymer photo solidifies. Then the platform descends lower, forming a next thin layer of liquid polymer over the hardened layer, and the laser again draws the next layer on the surface of the previous one.

Layer after layer, the platform is lowered into the depth of the tank until the object is completely constructed in a liquid photo polymer. A stereo-lithographic printer is one of the most accurate 3D printing equipment: the thickness of the generated layer is 0.06 mm; the accuracy in the Z-direction is 0.025 mm.

In addition, it is possible to use a large selection of photopolymer materials, such as: ABS, polypropylene, glass-filled nylon, as well as photopolymer materials with the addition of alumina, zirconium oxide, silicon oxide, paraffin wax. To manufacture the SAS samples, we used a non-toxic "cross-linked" acrylic photopolymer produced by Envisio Tec-USA.

When carrying out technological experiments, we developed the technology for manufacturing SAS samples, taking into account various design and technological features. According to the results of technological experiments, all computer models were equipped with drainage holes. The inclusion of drainage holes (Fig. 7) made it possible to prevent uneven filling of the photopolymer in the space between the cells, which can lead to strong deformations when the model

cures. At the same time, the presence of drainage holes allows to accelerate the process of complete drying and solidification of the model. The curing time without drainage holes is 4-6 weeks, with drainage holes - 2-3 weeks.

Fig.7. General view of the model on the rigging.

The technology for the production of samples of reference SAS for the «channel with a flow» installation includes the following steps: 1) development and construction of specialized, inclined rigging (inclined support devices) for constructing a model on the

installation platform (Figure 7); 2) Processing the rigging with a release coating; 3) The model is cut into 2D layers, the required number of layers is not less than 3000, the layer thickness is 100 μm ; 4) Assignment of construction modes: laser treatment of each layer of the model within 10,000 ms; 5) Setting the platform level to zero; 6) Extracting the model from the working area of the installation; 7) Washing the model in an alcohol bath from residues of the photopolymer material SI500; 8) Convective drying of the model produced at room temperature; 9) Model machining - removal of supports; Curing the photopolymer 1 day under an ultraviolet lamp, 14 days under normal daylight, fastening in the rigging to avoid deformations.

As a result, samples of SAS with high parameters of geometric dimensions of the aggregate and the location of the perforation were obtained. The general view is shown in Fig. 8.

Thus, according to the developed three-dimensional models, samples were produced using the technology of stereolithography of the photopolymer material and the prototyping installation EnvisiontecPerfactory XEDE.

Fig. 8. General view of samples printed on a 3D printer (a) cellular (b)

4 Experimental determination of acoustic characteristics of the reference SAS samples

Experimental acoustic studies of the SAS samples were carried out on the interferometer of the laboratory of noise generating mechanisms and modal analysis of the PNRPU (Figure 9). The experimental setup consists of a tube of circular cross-section, at one end of which there is a sample of a SAS, on the other - a speaker that irradiates the sample with acoustic waves. At some distance from the sample, there are microphones that record the acoustic pressure of the falling and reflected waves in time. Further, the recorded pressure is processed according to a special procedure, as a result of

which the impedance of the SAS sample is calculated. Usually two microphones are used for measurements, since the "transfer function method" used to determine the impedance is the simplest for calculations [10]. In the laboratory acoustic tests we studied the characteristics of reference samples, as well as samples manufactured using standard plant technologies from polymer composite materials.

Fig. 9. Complete and ready to work interferometer.

Based on the results of the tests, graphs of the dependence, the sound absorption coefficient α on the frequency f were obtained. Figure 10 shows the test results for a reference sample made of ABS plastic, as well as for a sample made of polymer composite materials.

Fig. 10. Dependence of the sound absorption coefficient on the frequency (1) SAS reference sample, (2) a sample made of polymer composite materials.

The analysis of the obtained results revealed that the absorption coefficient of the reference cellular cavity is 0.65, and the frequency is 1661 Hz, with a maximum spread of $\alpha = 0.01$, and a resonant frequency of 4 Hz. For a sample made of polymer composite materials, the absorption coefficient of the reference cellular resonator is 0.635, and the frequency is 1662 Hz, with a maximum spread of $\alpha = 0.015$, a resonant frequency of 3 Hz. A comparative analysis of the results revealed that the difference in the absorption coefficient does not exceed 2.31%, the resonance frequency difference does not exceed 0.05%.

Thus, the acoustic tests of printed SAS samples showed that their characteristics (impedance, sound absorption coefficient) have good qualitative agreement with samples manufactured using standard plant technologies. Small differences in the values of the characteristics are due primarily to the different rigidity of structures from different materials.

It can be stated that the creation of SAS models on the basis of 3D-printing for research work is already gaining increasing popularity. With the advent of the possibility of using inexpensive materials that provide the necessary heat-resistant, strength and weight characteristics, as well as the development of printing devices that allow the creation of large-sized structures, additive technologies can become the main way of manufacturing large-size SAS.

Conclusion

Based on the results of the conducted research, the following conclusions can be drawn:

1. Computer models of reference SASs were developed in STL format, as well as in the voxel matrix format for the interferometer and the "flow channel" setup;
2. The methodology for manufacturing the SAS samples is worked out and the modes of manufacturing are chosen for the interferometer using the FDM prototyping method;
3. Reference samples of the SAS for an interferometer with a normal sound wave drop were manufactured;
4. Technological experiments were carried out for the production of reference samples for the installation of a "channel with a stream";
5. The procedure was worked out and the modes of sample manufacturing for the channel with flow installation were selected using the technology of stereolithography of the photopolymer material with the Envisiontec Perfactory XEDE prototyping system;
6. A system of drainage holes has been developed, which made it possible to halve the curing time of the photopolymer and to reduce model deformations during the drying process;
7. Specialized and inclined rigging was developed and manufactured for constructing the overall model on the platform of the Envisiontec Perfactory layered synthesis unit XEDE PIDUU;
8. Experimental acoustic studies of the manufactured reference SAS samples were carried out on an interferometer with normal incidence of waves, good correlation has been found with the samples manufactured using standard plant technologies from polymer composite materials.

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