

Application of stereolithography prototypes for gas dynamic tests and visualization

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Abstract. The article presents the advantages of using a laser stereolithography apparatus (SLA) technology as compared with the traditional production technology and other rapid prototyping technologies. The authors described the seven-year experience of laboratory prototyping of experimental samples for multiple gas dynamic studies. On the basis of generalization of experience, the basic requirements for such experimental samples were formulated. During the comparison of different prototyping technologies, it was shown that the stereolithographic model meets all other requirements better.

1. Introduction

Gas-dynamic research always needs gas-dynamic experiments carried out by blowing gas (or washing liquid) of the experiment subjects mounted in the testbench. However, the timing of these experiments is often decisive for the entire research project. Experimental equipment for creating liquid and gas flows (compressors, pumps, pipes, valves, etc.) and for parameters registration (LDA-, PIV-sensors, flow-, pressure-, temperature-meters, etc.) is quite versatile for any gas-dynamic research. And the time range for fitting this equipment for current application is small in comparison with the time of whole research. So, the timing of manufacturing of the experimental samples often determines the timing of the whole work. In this regard, it is urgent to explore the theme about the usage of a rapid prototyping technology for creation of experimental models for gas-dynamic research. This paper describes the advantages of laser stereolithography for using it with this purpose, because it creates models with properties which meet the requirements of the experimental samples for gas-dynamic studies best [1].

In recent years, rapid prototyping technologies are widespread. The diversity of these technologies allows one to find the most suitable one for a particular purpose [2, 3]. But the right choice is not possible without the full awareness of the advantages and disadvantages of various technologies [4, 5].

2. Requirements for prototypes

Some 3D printers, despite the attractive prices of equipment and consumables, are suitable only for visual prototyping as obtained prototypes are unsuitable for gas-dynamic studies because of low strength, porosity, non-resistance in chemically-aggressive liquids. On the other hand, the price range is also important factor as there are technologies of metal direct laser sintering. Despite an extremely high price of the equipment and materials, as well as an attractive rate of direct production of metal samples, prototypes, obtained by sintering powders, have fairly rough surface (as in sand casting). The



additional step of grinding the outer surface increases the production time and there is no way for polishing hollow parts.

Since the Interdepartmental Laboratory of Rapid Prototyping was established in Samara University many experimental models have been created for a dozen gas-dynamic research conducted in the Scientific and Educational Center of the Fluid-Dynamic Research. Among them are:

- A model of small turbomachinery [6] (Fig. 1a,b);
- A model of the secondary surfaces for testing turbomachinery [7] (Fig.1c).
- A catalyst model [8] and the catalytic burner (see Fig.2a).
- A burner model for the study of the flow PIV-method (Fig.2b);
- Models of vane pumps (Fig.3a).
- Honeycomb models to assess its resistance (Fig.3b).
- Scale models [9, 10, 11] of elements of the new gas turbine engine (GTE) (Fig.3c).

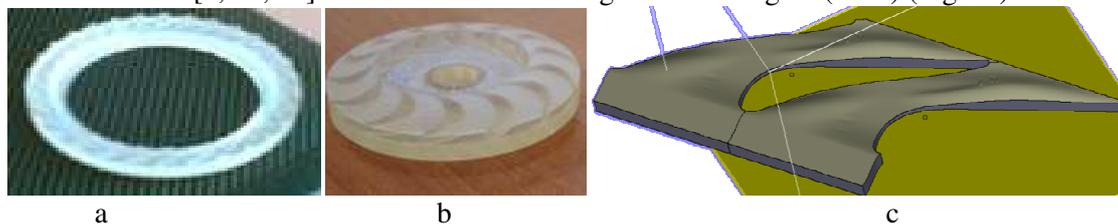


Figure 1. Samples of models: a – a nozzle unit; b – closed impellers; c – a hub surface model of the blade channel.

Experience of creation of such experimental samples allowed formulating the basic requirements for the experimental samples for gas-dynamic studies:

- the material should have sufficient strength, stiffness and toughness to withstand the forces generated by impinging gas or liquid flows, the vibration of the stand, as well as centrifugal and gravitational loads: samples often have cantilevered fixing and can be subjected to rotation;

- the material must be impermeable to gas or liquid, should not absorb or hold up on itself actively in working environment, should be resistant to liquids studied (fuel, oil, gas). When evaluating the test media, not only the performance of the body should be taken into account, but also the additional components required for the measuring instruments. For example, for LDA- and PIV-flow meters seeding particles of water vapor or mist are required. In the latter case, there is a possibility of high concentration mist deposition on the sample in the form of an oil film.

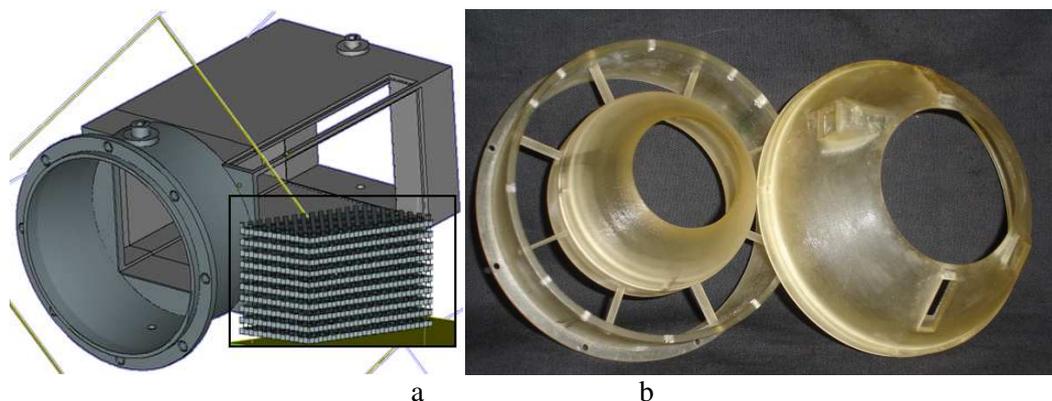


Figure 2. Samples of models: a – a catalyst model and a filler block for research by the PIV-method;

b – a pilot burner pattern with transparent windows in the outer PIV-flow part of the inner zone.

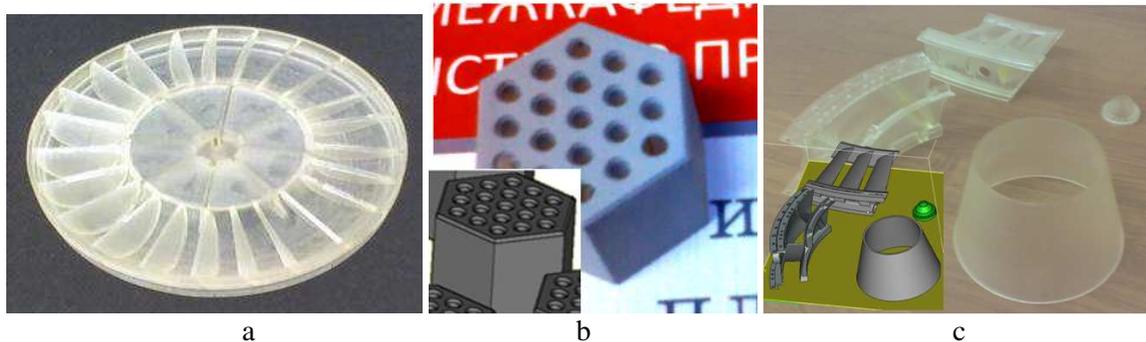


Figure 3. Samples of models: a – a pump impeller for hydrodynamic tests; b – a honeycomb model for investigation of a resistance coefficient; c – scale models of GTE elements.

Not all prototyping technologies make it possible to meet the above-mentioned requirements [11]. A stereolithography model completely satisfies them as follows.

1. A stereolithography polymer from which the model is made, has a high chemical resistance, sufficient to carry out any research: the material is practically inert to liquid hydrocarbons (gasoline, kerosene, petroleum and synthetic oils), for tens of minutes can withstand the impact of strong solvents (alcohol, petroleum solvents, acetone), hot streams (up to 100°C) of water and air. Under strong heating during experiments with burning it does not melt and retains its original shape. These properties allow the use of stereolithography prototypes, even for fire tests. For example, in studies of the fuel injector ignition combustion process, a complete prototype plastic edge occurs within 0.5-1.5 sec., which allows one to fix the ignition and combustion process with a high speed camera, and a PIV-meter size and droplet distribution.

2. The material is a hard, dense, non-porous, homogeneous structure, impervious to liquid media. It allows us to create experimental models of complex spatial forms channels with the guaranteed separation of certain internal cavities even thin septa (1-2 mm thick). Despite the fact that the prototype is formed by layerwise solidification of the material, a substantially uniform structure is obtained: the individual layers can not be separated mechanically or chemically. So, no need to worry that some part of the channel will be blocked or peeled off due to a prolonged exposure to water flow of the upper layer of the prototype. Although other technologies of prototyping, for example, layered lamination, "peeling" layers of the prototype are not uncommon, but they are simply unacceptable during the gas-dynamic studies of complex channels.

3. High specific strength is sufficient for test rotating models [9]. As stereolithography resin strength is 30-80 MPa (higher values for the cases of cold chemical inert fluids) and its density is 1.0-1.1g/cm³, its specific strength has the value of $(27 \div 80) \times 10^3 \text{ m}^2/\text{s}^2$ comparable with the specific strength of pure aluminum (about $20 \cdot 10^3 \text{ m}^2/\text{s}^2$) or titanium (about $70 \cdot 10^3 \text{ m}^2/\text{s}^2$). This leads to a significant capacity of stereolithography models to withstand the inertial forces which arise when there are gas-dynamic tests of rotating impellers and turbine impeller pumps. When loading, inertial gas-blades model forces can bend, changing its shape, which introduces an error as the results of the experiment, so the use of compliant materials for the test is unacceptable. A stereolithography model has a high rigidity, so there is almost no flex under any loads up to a complete destruction.

4. the material is well-grindable and well-polishable. For studies, in which the surface roughness is important, prototypes can be polished to any degree of smoothness until obtaining glossy surfaces. In addition to grinding, it can be used by any coloring paints and varnishes, including heat-resistant ones. A high adhesion stereolithography polymer provides high-quality paint adhesion to the substrate, which ensures that there is no peeling both in the mechanical and chemical action. Also, this feature allows us to create composite models, glued piece by piece, including the different types of materials. In this model, the parts can be glued together without the possibility of subsequent disassembly (using strong adhesives) and create disassembling bonded parts (using silicone adhesive sealants). In the

latter case, the adhesive residue can be easily removed from the surface of the parts due to the dense structure (absence of porosity) of solid photopolymer.

Furthermore, we should designate certain characteristics of the experimental samples for gas-dynamic studies that allow the use of additional advantages of laser stereolithography:

- Often the prototypes form is round or rectangular with large internal cavities, i.e. actually models represent a complex set of thin walls. The volume of the material forming the wall-partition is only a small part of the bounding volume of the model;

- The form of samples for gas-dynamic studies tend to "streamline": with smooth contours, gradual curvature changes, a large number of fillets, etc. This is primarily due to the need to ensure the smooth channels for gas flow, but also due to strength considerations.

These features make it possible to realize the additional benefits of laser stereolithography:

- In the "solid", there is a hardened polymer only, and a liquid polymer merges back from all internal surfaces and can be reused. Firstly, it greatly reduces the cost of the final prototype, and secondly, allows the creation of such details that are one-piece and can not be performed using conventional techniques or other rapid prototyping techniques (Fig. 4,5). For example, the use of the technology of sheet laminating materials will not allow one to remove the unwanted parts from the inside one-piece parts.

- During formation of the prototype, it is supported by so-called "supports" created from the same material as the prototype itself. With smooth lines of the prototype, there is the minimum number of supports, as opposed, for example, to 3-D printing technology (Fig. 6). While developing stereolithography prototypes, support layers are formed only for heavily overhanging surfaces, and are not for universal application;



Figure 4. Elements of ready-made turbomachinery.

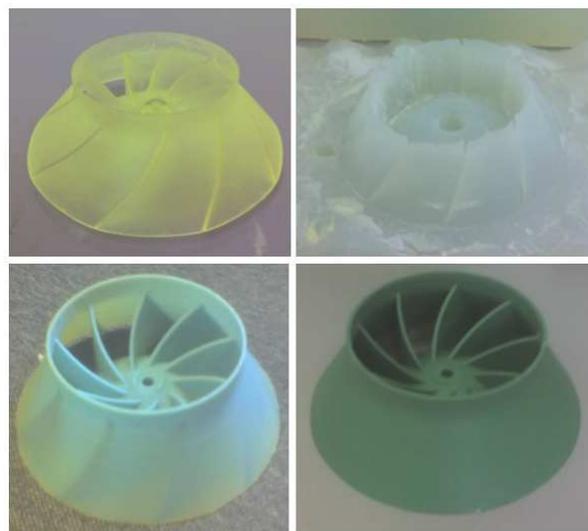


Figure 5. The steps of manufacturing the impeller: a stereolithography prototype, made of silicone mold, a cast in silicone stencil (for further casting metal, the cast in the sand mold is made of metal from parts).

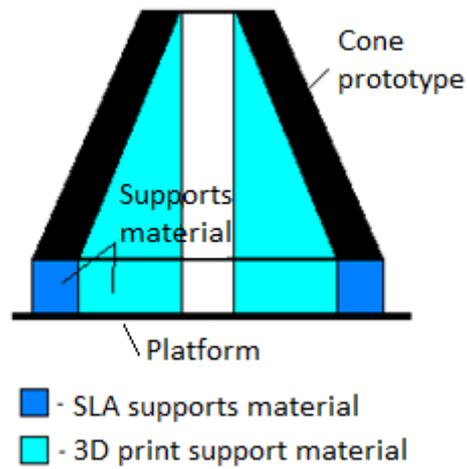


Figure 6. The difference of the volume of the support material using technologies of stereolithography and 3D-printing.

Also the stereolithography prototypes can be used twice: the first phase of the experimental samples for gas-dynamic tests is conducted on a model of working bodies, and after preliminary tests - on the master model intended for the manufacture of metal samples for experimental fire tests (Fig.6, 7).



Figure 6. Creating a flue for the rocket engine (top to bottom): the master model, silicon mold, the wax metal casting.



Figure 7. Creating a metal impeller for the micro-turbine engine (left to right): wax, a silicone mold, a metal casting.

3. Conclusion

Thus, in the manufacture of prototypes for gas-dynamic research, it is advantageous to use a laser stereolithography technology, as the models, obtained using this technology, fully meet the requirements of the experimental samples for gas-dynamic studies.

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References

- [1] Levy G.N., Schindel R., Kruth J.P. 2003 Rapid manufacturing and rapid tooling with layer manufacturing (LM) technologies, state of the art and future perspectives. *CIRP Annals - Manufacturing Technology* **52** (2)
- [2] Pham D.T., Gault R.S. 1998 A comparison of rapid prototyping technologies. *International Journal of Machine Tools and Manufacture* **38** 10-11
- [3] Levy G.N., Schindel R., Kruth J.P., 2003 Rapid manufacturing and rapid tooling with layer manufacturing (LM) technologies, state of the art and future perspectives. *CIRP Annals - Manufacturing Technology* **52** (2)
- [4] Lan P.-T., Chou S.-Y., Chen L.-L., Gemmill D. 1997 Determining fabrication orientations for rapid prototyping with stereolithography apparatus, *CAD Computer Aided Design* **29** (1)
- [5] Mishra A.K., Thirumavalavan S., 2014 A Study of part orientation in rapid prototyping, *Middle - East Journal of Scientific Research* **20** (9)
- [6] Kolmakova D., Popov G., Shklovets A. and Ermakov A. 2014 Techniques and Methods to Improve the Dynamic Strength of Gas Turbine Engines Compressor Rotor Wheels. *In Proceedings of the ASME 2014 Gas Turbine India Conference GTINDIA2014* (New Delhi, India) Paper No. GTINDIA2014-8203
- [7] Shablil L. S., & Dmitrieva I. B. 2014 Blade geometry transformation in optimization problems from the point cloud to the parametric form. *Russian Aeronautics* **57**(3) 276-282
- [8] Zubrilin I. A., Dmitriev D. N., Matveev S. S., & Matveev S. G. 2015 Numerical investigation of the nonreacting swirling flow structure downstream of industrial gas turbine burner with the central body. *Paper presented at the Proceedings of the ASME Turbo Expo 4A*, doi:10.1115/GT2015-42181
- [9] Popov G., Baturin O., Kolmakova D., and Krivcov A. 2014 “Improvement Results of TK-32 Turbocompressor Turbine with Gas- Dynamics And Strength CAE-Systems”, *International Journal of Engineering and Technology* **6**(5) 2297-2303
- [10] Krivcov A., Shablil L., & Baturin O. 2014 Account the mutual influence of the simulation components of GTE. *Gas Turbine India Conference, GTINDIA 2014* doi:10.1115/GTINDIA2014-8211
- [11] Ermakov A.I., Shklovets A.O., Popov G. M., Kolmakova D. A. 2014 Investigation of the Effect of the Gas Turbine Compressor Supports on Gas Flow Circumferential Nonuniformity. *Research Journal of Applied Sciences* **9** (10) 684-690