Improving the quality of FDM 3D printing of UAV and aircraft parts and assemblies by parametric software changes

R S Zagidullin, N I Zezin and N V Rodionov
Department of Aircraft Manufacturing and Quality Management in Mechanical Engineering, Samara National Research University, 34 Moskovskoye shosse, Samara 443086, Russia
zagidullin_radmir@mail.ru

Abstract. The article analyses and presents the classification of defects in parts obtained by FDM 3D printing technology. A fault tree has been built for the functional and structural analysis of the factors causing defects in parts produced by FDM 3D printing technology. Using the constructed fault tree, a method is proposed for eliminating defects in parts obtained by FDM 3D printing technology, based on parametric changes in software.

1. Introduction
Additive technologies (AT) are generating a paradigm shift, replacing traditional “subtractive” production technologies with “adding” ones. Such well-known manufacturing companies as Boeing, Airbus, SpaceX, Blue Origin, Rocket Lab and others are increasing the number of 3D-printed parts in their product designs every year [1]. AT allow to reduce production costs and costs at the stage of technological preparation of production to exclude the development of a technological process and tooling, and, therefore, will reduce the cost of products and reduce the time to market.

Fused deposition modeling (FDM) is currently the most widespread and inexpensive type of AT. FDM 3D printing technology consists in building a 3D model from a molten polymer filament, which flows through the print head onto the desktop. FDM 3D printing makes it possible to obtain parts of almost any geometric shape from polymer materials. With the advent of composite and high-temperature polymer materials for 3D printing, FDM technology is widely used in aircraft construction, especially in the production of parts and assemblies for aircraft and unmanned aerial vehicles (UAVs) [2–4].

However, with FDM 3D printing, users of additive equipment, especially beginners, are faced with various defects that are caused by unsatisfactory chosen parameters of the 3D printing process, imperfections in the design of the 3D printer, and the preparation of the 3D model for printing. This paper proposes a method for improving the quality of FDM 3D printing by parametric changes in the software (SW) of additive equipment.

2. Application of FDM 3D printing in the production of UAVs and aircraft
With the advent of new polymer materials reinforced with carbon fiber and metal powders, FDM 3D printing technology is increasingly being used every year in the production of parts and assemblies for UAVs and aircraft. The advantage of FDM 3D printing in the production of UAVs and aircraft is the
ability to use a bionic design method. Below are examples of FDM 3D printing applications in aircraft and drone construction.

Currently, in the aircraft industry, FDM 3D printing has found wide application for the manufacture of air ducts for aircraft and helicopters. Air duct assemblies and parts obtained using FDM 3D printers are used in Boeing 787 airliners, F/A-18, F-35 fighters and Bell 429 helicopters [2]. Figure 1 shows the details and units of the air ducts of the indicated aircraft and helicopters.

Figure 1. Parts and units of air ducts obtained by the technology of FDM 3D printers [2].

Russian engineers are also actively involved in introducing parts and assemblies obtained using FDM 3D printing into the production of Russian aircraft. Figure 2 shows air ducts for the MC-21 aircraft [3].

Figure 2. Air ducts obtained by FDM 3D-printers for the MC-21 aircraft [3].

In addition to air ducts, FDM 3D printers are used to manufacture interior parts for aircraft and helicopters.

Unlike aircraft construction in drone construction, using FDM 3D printing, you can make not only individual parts and assemblies, but the entire UAV body. So engineers from the University of Sheffield designed and manufactured the UAV body, completely manufactured using an FDM 3D printer [2, 4]. Figure 3 shows a UAV from the University of Sheffield.

Figure 3. UAV of the University of Sheffield [4].
Every year, UAV and aircraft manufacturing companies are expanding the range of parts and assemblies obtained by FDM 3D printing technology.

3. Classification of defects in parts obtained by FDM 3D printing technology

Based on the analysis of parts obtained by FDM 3D printing technology, a classification of the most arising part defects has been compiled:

a) the first layer of the part during 3D printing does not stick to the desktop;
b) clogged print head nozzle;
c) overheating of the polymer material;
d) the polymer material is not sufficiently extruded;
e) too much polymer material is extruded;
f) the formation of hairlines between parts of the printed part;
g) the formation of breaks in the upper layers of the part;
h) separating the layers of the printed part;
i) small parts of the part are not printed;
j) the formation of waviness on the surfaces of the printed part;
k) tearing inside parts;
l) scratches on the surfaces of the printed part;
m) high surface roughness.

FDM 3D printing also introduces other types of defects. However, they occur less often than the ones listed above and therefore will not be considered in this article.

4. Fault tree

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table should be used.

A fault tree was built for the functional-structural analysis of the factors causing defects in parts in FDM 3D printing.

Fault tree analysis is a technique for identifying and analyzing factors that may contribute to the occurrence of some undesirable event. The fault tree can be used for qualitative analysis — identification of potential causes and ways of failure, defects, or for quantitative — to calculate the probability of a vertex event in the presence of information about the probabilities of event-factors [5].

In this work, defects of parts produced by FDM 3D printing technology are used as failures. To build a fault tree, it is necessary to draw up a technological process, determine the work items and describe the functions of the work items [6].

The FDM 3D printing technological process consists of the following operations:

1) equipment calibration;
2) preparation of a 3D model for 3D printing;
3) download the file (G-code) to the 3D printer;
4) 3D printing of the part;
5) removing of a part from the working chamber of a 3D printer;
6) post-processing of the printed part (if necessary).

Work items are factors that affect the operations of a process. The working elements of the technological operations of FDM 3D printing are:

1) operator;
2) 3D printer;
3) tools (probe, spatula for extracting a part from the working chamber, sanding tool for post-processing);
4) 3D printer software;
5) a slicer program for processing a 3D model and translating it into G-code.
Functions are described for each work item below. Functions are the purpose of a workflow item for performance. A process work item function reflects the input to a process activity for creating process / product functions. These are controllable process parameters that provide the characteristics of the technological operation and products [6].

Figure 4 shows the FDM 3D printing fault tree of UAV parts and assemblies.

As you can see from Figure 4, the operator's work in the slicer program causes the largest number of potential failures. A slicer program is a program for processing a 3D model, selecting technological parameters and 3D printing modes, and then translating a 3D model into machine code (G-code) that a 3D printer understands. The reason for the failures is the lack of knowledge and experience (which is especially typical for novice operators) and the lack of normative and technical documentation (methodology) with proposals and recommendations for eliminating defects in parts. Calibration of the 3D printer desktop also plays an important role.
5. Methodology for improving the quality of FDM 3D printing of parts and assemblies of UAVs and aircraft due to parametric software changes

Using the constructed fault tree for the 3D printing process, a method for improving the quality of FDM 3D printing was developed, based on parametric changes in the slicer program and 3D printer software. The basis of the technique is a table in the rows of which the types of defects are listed, and the columns list the possible causes of defects and the ways to solve them using changes in the 3D printer software code, machine code (G-code) and parametric changes in the slicer program.

Figure 5 shows a fragment of the table from the developed methodology.

| No | Defect type | Cause of the defect | Solution using 3D printer SOFTWARE | Solution by changing the G-code | Solution using a slicer program |
|----|-------------|---------------------|-------------------------------------|-------------------------------|-------------------------------|
| 1  | First layer of the part does not stick to the 3D printer desktop | 1. overfill the first layer with high print speed; 2. incorrect table heating setting; 3. incorrect height of the first layer; 4. the desktop is not aligned. | #define AUTO_BED_LEVELING_3POINTER #define AUTO_BED_LEVELING_LINEAR #define AUTO_BED_LEVELING_LINEARAR | 1. MBS1 Z0 (setting zero Z offset) G28 (Packing, reset with zero Z offset) G29 (calibration after setting the desired calibration mode) 2. DEFAULT_MAX_FEEDRATE [500, 500, 20, 45] 3. BED_MAX_TEMP 150 | 1. Lower the print speed 2. Set a different table temperature 3. Change the layer height |
| 2  | Polymer material not extruded enough | 1. low extrusion rate; 2. mismatch of the polymer thread diameter. | #define DEFAULT_NOMINAL_FILAMENT_DIA = 3.00 | #define PREVENT_LENGTHY_EXTRUDE #define EXTRUDE_MAX_LENGTH 200 | 1. M200 DN (to set the extruder diameter N) 2.M220 S80 (Set the feed rate to 80%) G01 F50 (Requires PWRETRACT) | 1. Set the thread diameter 2. To increase the value of the flow |
| 3  | Haltlines formation | 1. the distance of retraction; 2. long extrusion speed; 3. high temperature of the extruder. | #define RETRACT_LENGTH 1 | #define RETRACT_FEEDRATE 45 | #define HEATER_0_MAXTEMP 285 | 1. G1 F00 (Set the retraction value mm) 2. G00 F00 (Set the feed rate to mm/min) | 1. Set the "retraction distance parameter" 2. Set the "retraction speed parameter" |

Figure 5. Fragment of a table from the methodology for improving the quality of FDM 3D printing.

The advantage of the developed methodology is the ability to quickly eliminate defects in parts and components without interfering with the design of the 3D printer.

6. Conclusions and discussion

Thus, a methodology has been developed that will allow operators of additive equipment to quickly find and eliminate defects in FDM 3D printing and obtain high-quality products. The technique is mainly aimed at helping novice operators who do not have the knowledge and experience in eliminating defects in parts and assemblies obtained by FDM 3D printing technologies. It should be noted that this technique does not take into account design imperfections and failures of components and mechanisms of 3D printers. Further research will be aimed at finding dependencies between defects and nodes and mechanisms of additive equipment and at improving the design using modern quality tools and robust design [7–10].

Acknowledgments

The authors express their gratitude for valuable advice in planning the study and scientific advice to Doctor of Technical Sciences, Professor Antipov Dmitry Vyacheslavovich and Candidate of Technical Sciences, Associate Professor Dmitriev Alexander Yakovlevich of the Department of Aircraft Production and Quality Management in Mechanical Engineering, Samara National Research University.

References

[1] Dmitriev A Ya, Zagidullin R S and Mitroshkina T A 2019 *IOP Conf. Series: Materials Science and Engineering* 714 012006
[2] Malfitano B 2018 3D printing in the aircraft industry *Additive technologies* (*Electronic Materials*)

[3] "Irkut" corporation 2020 3D printing elements structures of aircraft on-board systems from thermoplastic materials *The Union of Aviation Industrialists* (*Electronic Materials*)

[4] University of Sheffield Advanced Manufacturing Research Centre 2020 FDM-printed fixed wing UAV (*Electronic Materials*)

[5] Melnikov A Yu and Solomko Yu A 2016 *Science management: theory and practice* (Kiev: The Institute of the Economy of Industry of the NAS of Ukraine) pp 166–172

[6] Antipov D V and Klentak A S 2019 *Proceedings of Samara Scientific Center of the Russian Academy of Sciences* vol 22 (Samara: Federal State Budgetary Institution of Science Samara Federal Research Scientific Center of Russian Academy of Sciences) pp 11–15

[7] Dmitriev A Ya, Mitroshkina T A and Vashukov Yu A 2016 *Robust design and technological preparation for the production of aircraft products* (Samara: SSAU) p 76

[8] Zagidullin R S, Barinov P V, Burkova V A, Glushkov S V and Mitroshkina T A 2019 *Quality and life* 2 (22) (Moscow: Academy for quality)

[9] Dmitriev A and Mitroshkina T 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* 476 012009

[10] Flores I, Coatanea E, Salmi M and Tuomi J 2014 *1st International Symposium on Robust Design* (*Electronic Materials*) pp 135–145