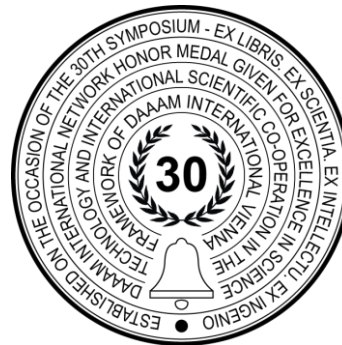


ADDITIVE MANUFACTURING OF UNMANNED AERIAL VEHICLE

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Abstract

The objective of this paper is to design a process of manufacturing an unmanned aerial vehicle. The evaluated aircraft will be the 'Bubak' which belongs to the A3 category. This aircraft is usually made out of balsa wood and plywood and its wings are covered with aircraft-grade paper. Traditionally most of the parts are made by cutting and sanding the materials mentioned above by hand. The rapid advancement of additive manufacturing technology in recent years has made it possible to use this new approach to manufacture most of the parts of this aircraft. Therefore this article evaluates the ins and outs of both approaches to see how they compare to each other. Because this type of aircraft is designed to stay in the air using as little energy as possible, it is a good candidate for making an additively manufactured unmanned aerial vehicle (UAV), which can be used in a variety of applications including remote areas mapping or agricultural land assessments. Arguably, the most important and complicated part of the aircraft is the wing. For this reason, the manufacturing of this part is evaluated.

Keywords: Additive manufacturing; FDM; Unmanned aerial vehicle; Part orientation

1. Introduction

A3 is a category of motorless model gliders used for competition purposes mainly in the Czech Republic. The maximum area of the wings is constrained. As the name of the category suggests, it can't be greater than the size of an A3 sheet of paper. The minimum weight is also limited, it can't be lower than 150 grams. During the competition, lift-off is achieved by pulling the aircraft on a 25-meter string. The plane is then separated from the pull string and the goal is for it to stay in the air as long as possible. The model called 'Bubak' from the A3 category is used for evaluation in this paper. Because of the nature of the competition, several important factors influence the design and manufacturing of the aircraft. These are mostly weight, aerodynamics, and the ability to utilize thermals. [1], [2]

Traditionally A3 models are built from aircraft grade plywood and balsa wood. These two materials make the skeleton. The most time-consuming part of the process is manufacturing the wings. They consist of leading edge, trailing edge, spars, and a number of ribs. All of these parts must be shaped very accurately to match the design perfectly. This requires an expert worker with great attention to detail to achieve a desirable result. This makes the commercial production of this aircraft difficult and expensive. This problem can be solved by additive manufacturing. [3]

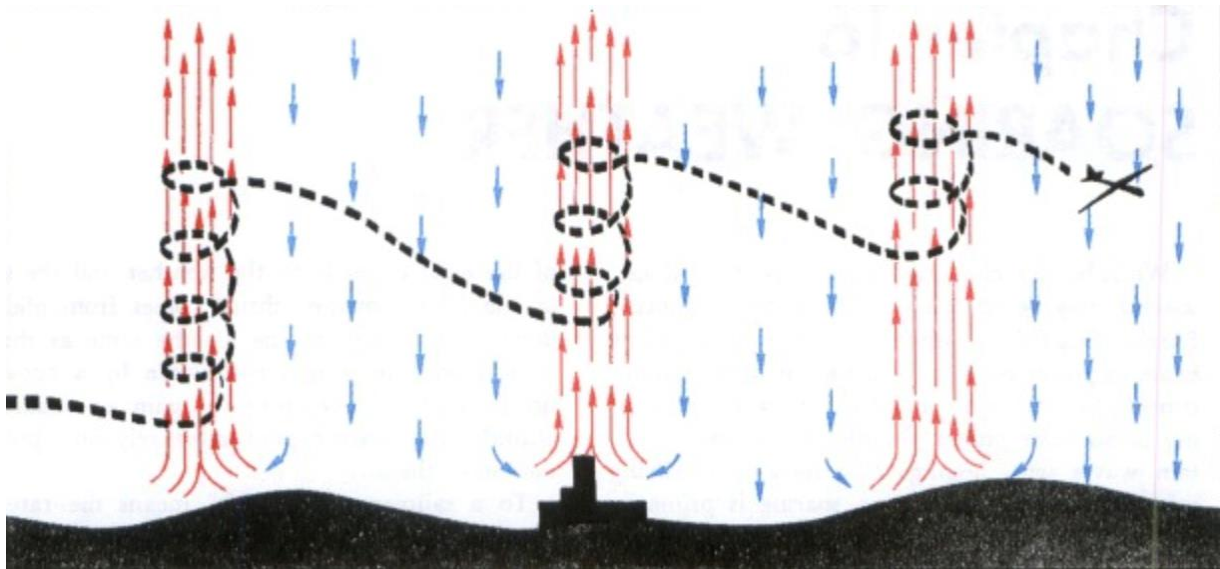


Fig. 1. Aircraft that uses thermals [3]

At the moment several companies focus on additively manufactured UAVs (e.g. 3D Lab Print). These are however made for leisure activities and do not primarily focus on high flight efficiency. Therefore, the goal of this paper is to develop a manufacturing method to create a UAV that has the potential for an industrial application. Because the whole UAV is a complex subject, this article focuses on the manufacturing of the main wing, which is the most important part in terms of flight efficiency. Additive manufacturing is a fairly modern manufacturing technology, but it is being rapidly developed and the cost of this technology continually decreases. There are many methods of additive manufacturing, however, this paper focuses on the fused deposition modelling method (FDM). Because FDM machines are very affordable and the findings of this paper can therefore be used by a large number of manufactures. [4], [5]

2. Limitations of the used manufacturing method

In additive manufacturing, the correct part orientation is crucial for successful and effective results. The first thing to consider is the need for support structures. Put simply, supports are generally needed at parts of the object that would otherwise be hanging in the air. Unfortunately, supports usually greatly prolong the print time, waste print material, leave an undesirable surface finish on the part, and require time-consuming postprocessing. The second most important factor is the staircase effect issue. This effect may result in serious surface roughness on some segments of the printed object, thus the proper orientation is required to ensure surface quality on the critical parts of the product.

In FDM, objects are built by selectively depositing melted material layer by layer. For this process, thermoplastic materials in the form of a long string are used. This material is called filament and it is heated and pushed through a nozzle. The movement of the nozzle is numerically controlled and therefore complex shapes can be created. There are many materials used in FDM printing. The most common filament materials used are PLA, ABS, and PETG. This paper will focus on using PLA because it has favourable mechanical properties and is very simple to work with. [6], [7]



Fig. 2. Staircase effect [5]

3. Design and experimental manufacturing process

Almost anything may be made using an additive manufacturing method. Firstly, a CAD model of the desired shape must be created. The physical limitations of the manufacturing method must be considered in the design. For example, most FDM machines are limited to building a volume of 220x220x250 mm. Subsequently, the CAD data needs to be prepared for printing using a program called 'slicer', where parameters like layer height, infill, and support structures are defined. Lastly, the print data is sent to the machine and the build process starts.

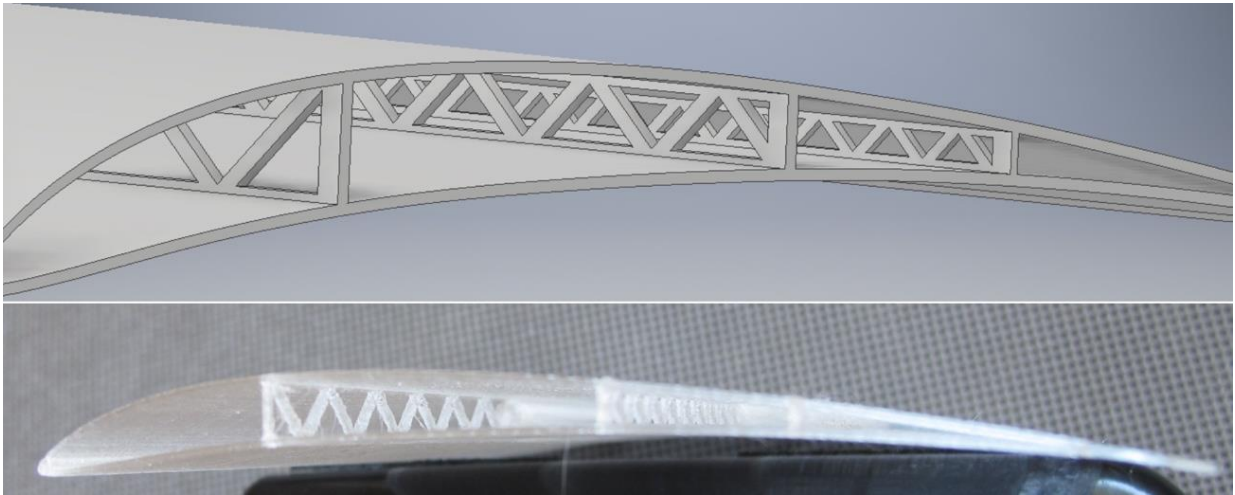


Fig. 3. Structural design of the wing

The wing of an A3 model aircraft is definitely one of the objects that can be created by additive manufacturing. Firstly, a CAD model is created, based on airfoil B 6356 which is used in the original aircraft. The wing consists of 0.4 mm thick shell and three support beams (see Fig. 3). This design ensures low weight and enables the use of the most common (0.4 mm) extruder nozzle in the FDM 3D printer. Due to the limited print area of most machines, the wing also needs to be divided into several parts and fitted with the connection features. Unlike the traditional paper outline of the wing, the surface can be created by the FDM machine. High precision and the best possible surface finish is required to ensure good aerodynamics. To achieve this and eliminate the staircase effect, the part must be printed in a vertical direction. Each layer will be a cross section of the wing (see Fig. 4).

When printing such thin and tall objects, vibrations might cause surface roughness at top of the part. The singularity of this manufacturing solution is the use of unique side support structures (see Fig. 4.) that minimize the vibrations of the object during the manufacturing process. These supports are positioned 0.1 mm from the wing surface. This gap ensures sufficient side support while maintaining surface quality and provides easy removal of the supports. When all the sections of the wing are printed they can be simply glued together using cyanoacrylate glue. Considering the connection strength of the glue bond, all the parts should be held securely in place. [8], [9], [10]

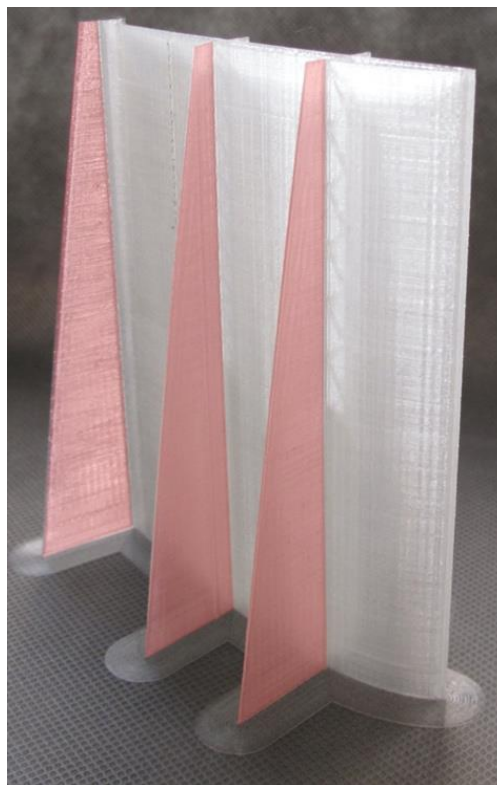


Fig. 4. Section of the wing printed with red support structures

Parameter	Value
Perimeter speed	40 mm/s
Layer height	0.15 mm
Nozzle temperature	200 °C
Bed temperature	60 °C
Machine	Ultimaker 2+
Nozzle diameter	0.4 mm
Material	PLA

Table 1. Selected process parameters

4. Results of the experiment

4.1. Physical properties

In terms of surface roughness, the traditionally built wing is superior to the additively manufactured example. This is caused by both defects occurring at the layer change point and defects caused by the external supports. Surface roughness as well as the profile shape were evaluated visually by an expert aircraft manufacturer. The additively manufactured wing will also be heavier, since the surface is a 0.4 mm thick layer of plastic, in comparison to the much thinner paper. However, these disadvantages are highly relevant mostly in the competitive scenario and could be addressed by using a different material or by making thinner outer walls.

In terms of bending stiffness, the wing part will be easily able to withstand the criteria required for safe flight. Bending stiffness was tested on electro-mechanical testing machine Zwick. To summarize, the evaluation of physical properties suggests that the wing should be functional. Therefore, all its segments can be manufactured with the parameters mentioned above.



Fig. 5. Test of bending stiffness

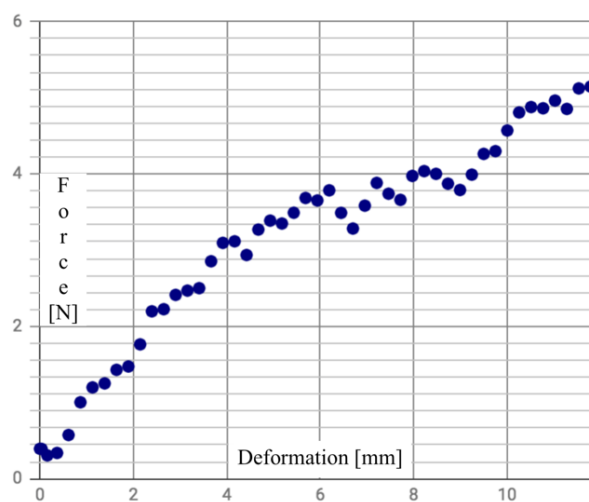


Fig. 6. Results of the bending stiffness test

4.2. Required expertise

The traditional build approach relies on hand tools. The only electronic tool is the printer used for printing the plans. Precise work with hand tools requires high skill, long hours of training, and strong attention to detail. All these things can be learned, but they require dedication to the task and often also tuition by an experienced worker. For an inexperienced individual, all these factors may result in a frustrating build process and inferior flight capabilities of the final product. Additively manufacturing an aeroplane wing requires the creation of a CAD model and the designer has to know their way around the software. This also demands a significant amount of time spent in training. However, once a correct CAD design is created almost anyone can use it. The slicing software and user interface of most FDM machines are very simple to operate. Therefore, almost anyone who owns a 3D printer and the CAD model can make the wing even with a limited amount of training. The shape, dimensional accuracy, and surface finish will be almost the same every time. This means that unlike the conventional approach, precise and repeatable results can be achieved easily with additive manufacturing.

4.3 Finance

For both approaches to manufacturing this part, the initial cost is the most significant investment. The upfront cost for tools for the traditional method of manufacturing will be significantly lower, around 37€. However, the cost of training a worker, depending on various factors, could be anywhere from 500€ to 1000€. A capable machine for additive manufacturing, that will be able to produce parts reliably, will cost around 400€. In terms of material cost, both approaches are equivalent and the raw material should not be more expensive than 2€. These amounts are however based on the personal experience of the author and therefore may be slightly inaccurate.



Fig. 7. The finished first part of the wing

5. Conclusion

The suggested additive method of manufacturing wings for the UAV should result in a functioning product. Aircraft built additively using the FDM method will be heavier and their aerodynamics will be inferior in comparison to the traditional manufacturing method. This will result in a shorter time spent in the air and higher energy requirements. This is clearly shown in the previous chapter. However, in the terms of manufacturing costs and repeatability the additive manufacturing method is more advantageous.

The method described in this paper needs further development. Firstly, steps should be taken to minimize the weight of the wing. This can be achieved by using different material (e.g. LW-PLA) or by using a smaller nozzle and therefore decreasing the wall thickness. Secondly, the rest of the wing segments has to be manufactured and the whole wing tested. Thirdly, the body has to be designed in CAD and manufactured. Lastly, the whole aircraft needs to be assembled and tested. To conclude, this paper clearly shows that the suggested method of additively manufacturing a UAV is possible and could be effective for the industrial application.

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