

GENERATIVE DESIGN STRATEGIES FOR LIGHTWEIGHT INTERNAL STRUCTURE IN TANDEM WING SMALL UAVs

George Răzvan BUICAN, Constantin-Mihaita AGAPIE

“Transilvania” University of Braşov, Romania (buican.george@unitbv.ro,
constantin.agapie@student.unitbv.ro)

DOI: 10.19062/2247-3173.2024.25.16

Abstract: *This research employs generative design methodologies to optimize the internal structure of a small unmanned aerial vehicle (UAV) configured with tandem wings, with the explicit goal of achieving a lightweight architecture. The need for UAV internal structures to prioritize weight reduction while upholding structural integrity facilitates the application of generative design techniques. Through a meticulous analysis of generative design principles and their application in UAV structural engineering, this study highlights the potential advantages and challenges inherent in integrating generative design strategies into the development of tandem wing UAVs. The insights presented aim to underscore the opportunities involved in harnessing generative design methodologies to achieve lightweight yet robust internal structures for tandem wing small UAVs.*

Keywords: *Aerospace, Fixed-Wing UAV, Generative Design, Additive Manufacturing*

1. INTRODUCTION

Through additive manufacturing [1], Unmanned Aerial Vehicles (UAVs) have become more affordable while maintaining structural strength. The use of generative design tools allows for weight reduction while preserving structural stability and strength. This paper focuses on the application of these tools to achieve the most optimized structural design with the lowest possible weight.

Weight is one of the prime factors that decides if an aerial structure will fly or not, thus, improvements that positively impact weight reduction are crucial for the aerospace industry. Such improvements must be implemented with the objective of maintaining the structural strength of the aircraft.

In the present paper, we have used a 3D model of a Tandem Wing UAV that has no internal structure and analyzed the optimal construction method for this design using generative AI. [2]

To conduct the analysis, we first needed to define key parameters for the UAV, such as its weight, flying altitude, maximum speed, and the weight of its components.

Most of these initial factors have been chosen in accordance with **EASA Easy Access Rules for Unmanned Aircraft Systems** for a Class 2 UAV such as: the maximum takeoff weight of 4 kg, maximum flying altitude of 120m. [3]

Given that the purpose of this paper is the fabrication of a small and very lightweight UAV, the maximum weight, including the components has been chosen to be no more than 1 kg. The maximum speed of the UAV being 25 m/s and the cruise speed 15 m/s.

For the UAV's fuselage, we modeled a structure optimized for aerodynamic efficiency and then imported it into the generative design software Fusion 360. [4]

2. REQUIREMENTS AND DATA NECESSARY FOR GENERATING THE STRUCTURE



FIG. 1 Setting the objectives and limits of the analysis

To generate the initial internal structure, we required data including the approximate maximum weight of the UAV with all components and the minimum factor of safety for the design.

After generating structures with a target mass of 4 kg, which resulted in completely filled designs, we decided to lower the target weight from 4 kg to 1 kg, including components.

The safety factor was set to 2.00 instead of 1.50 to ensure additional structural strength. (see Fig.1)

As far as the 3D model is concerned, we have modelled an initial structure and gave it no internal structure. Independent parts have been used for modelling in order for the structure to be generated individually on each of them if needed.

Regarding the 3D model, we initially created a structure without any internal structural components. Independent parts were used in the modeling process to allow the structure to be generated individually for each part if necessary.

A thickness of 0.6 mm has been applied to the surface of the wings, while the fuselage surface has a thickness of 2 mm. (see Fig. 2)

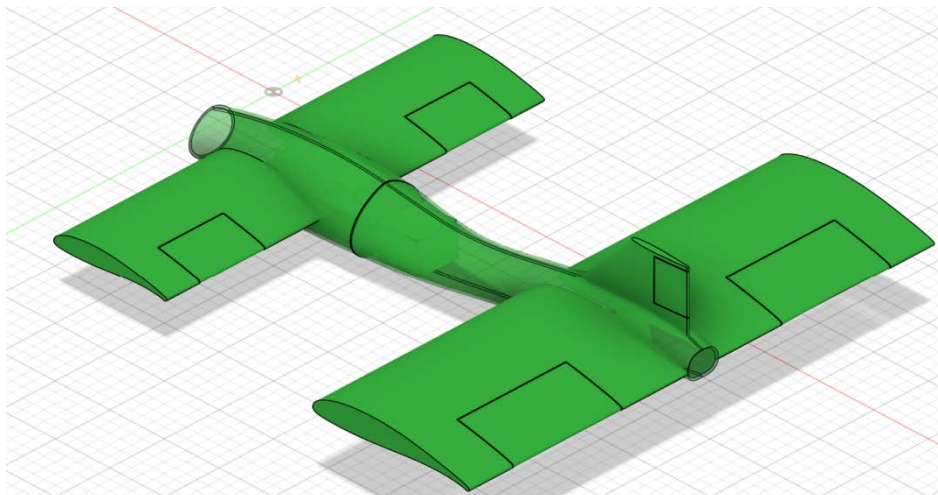


FIG. 2 Initial 3D model

The loads acting on the UAV play a critical role in utilizing generative design for generating an internal structure. These loads must be accurately defined because incorrect values can lead the software to generate an internal structure that is either excessively strong (if the loads are overestimated) or overly susceptible to failure (if the loads are underestimated). Accuracy in load specification is therefore paramount to achieving an optimized and reliable design.

To ensure precision, we conducted multiple calculations to determine the loads accurately. In cases where approximations were necessary, we intentionally overestimated the loads to prioritize a stronger structure over one that might be weaker. This approach aims to enhance the structural integrity of the UAV. [5]

All weights were applied according to their respective parts within the UAV to ensure an accurate center of mass. This meticulous approach enables the software to perform precise calculations based on the weight distribution of the components.

Table 1. Main loads acting on the UAV

Parameter name	Value	UM
Force on the Z axis generated by engine at 15 degrees alfa	5.176	N
Resistance generated at 20% engine power	0.848	N
Maximum Cruise Lift	15.922	N
Surface in direct contact with air	2	mm ²
Load from air on direct contact surfaces	10.252	N
Propeller torque	10	N/mm

The software automatically calculated gravity for each component, ensuring accurate force application. Forces on the Y axis were applied assuming the UAV yaws to the right.

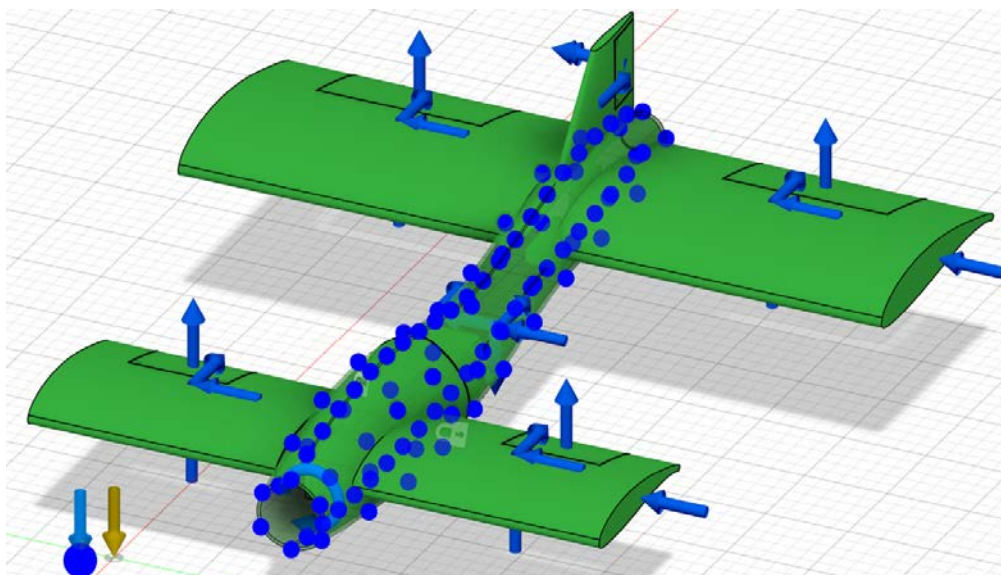


FIG. 3 Loads acting on the UAV

To initiate the generation process, obstacles were modeled to prevent the software from building over existing structures and to avoid forming bridges between main components such as wings, which could reduce aerodynamic performance (see Fig. 5).

This approach also ensured better control over the internal structure to accommodate essential UAV components like the engine and flight controller.

To prevent the software from generating structures over electrical parts, baseline replacements for components were 3D modeled and integrated into the obstacle geometry. These components were scaled up by 1.1 times to ensure that the generated structure would not hinder the installation of these components into the UAV (see Fig. 4).

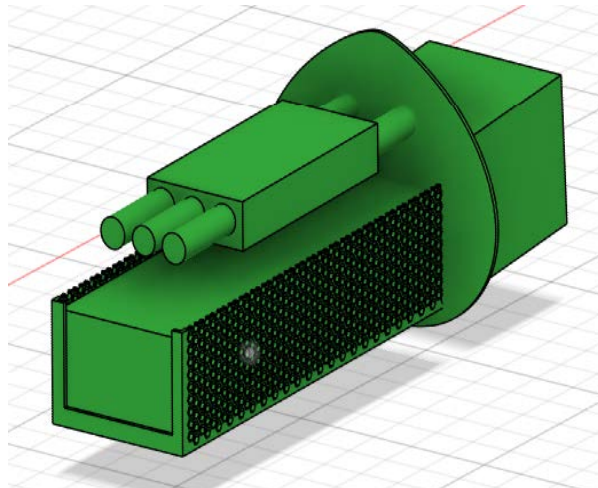


FIG. 4 Modelled components

The initial generations of the structure exhibited higher weight and more errors compared to subsequent iterations, but they served as a baseline and provided a starting point for future generations. The factor of safety was higher than anticipated, with the lowest being around 35. To achieve a lighter yet robust model, additional obstacle geometry was introduced into the model.

Subsequent generations focused on selected designs that aligned with our objectives, allowing us to refine and improve the structural characteristics we were aiming for.

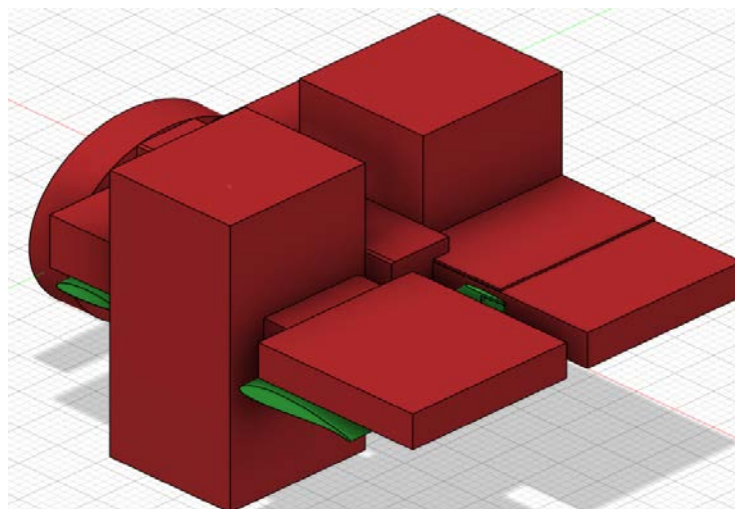


FIG. 5 Modelled obstacle geometry

As for the material chosen for the generation process, we opted for Polylactic Acid (PLA) due to its favorable mechanical properties relative to its weight. Additionally, PLA is known for its ease of use in additive manufacturing processes [6].

3. RESULTS AND IMPROVEMENTS

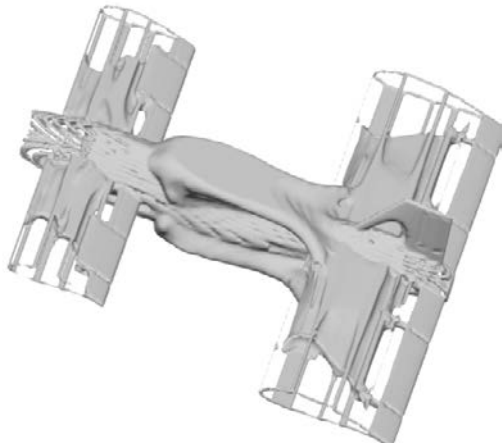


FIG. 6 Generated design 1

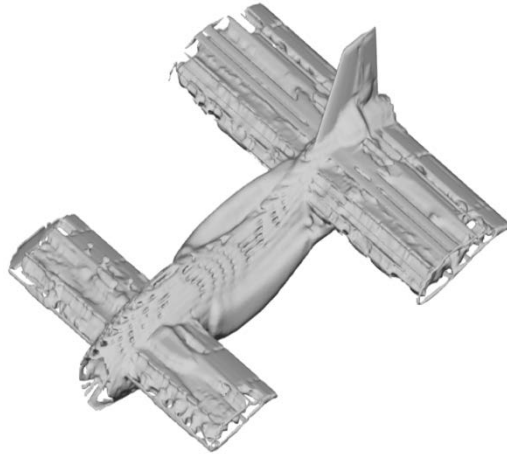


FIG. 7 Generated design 2

As an example, we selected the structure generated in FIG. 6 and introduced multiple geometries to prevent the generation from extending beyond the exterior of the model, while also focusing on generating internal structures in specific areas such as the wings of the UAV [7].

This approach proved highly effective, leading to subsequent generations that were more precise and improved in terms of aerodynamic performance (see Fig. 10).

Volume (mm ³)	1.008e+6
Mass (kg)	1.15
Max von Mises stress (MPa)	2.103
Factor of safety limit	2
Min factor of safety	12.809
Max displacement global (mm)	43.175

FIG. 8 Data regarding the final generation

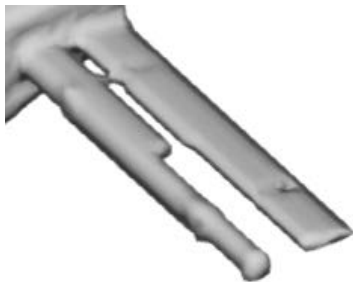


FIG. 9 Internal structure generated for a single wing



FIG. 10 Internal structure of the final generation

In the subsequent structures, we successfully kept the weight around 1 kg, meeting our initial target, while maintaining a factor of safety that, although still high, averaged about 15, lower than in the initial generations. After generating these structures, we have the option to either use the models that performed well in the study as baseline models for 3D printing, or analyze the structures to identify opportunities for improvement, particularly in terms of weight reduction

Through these studies, we determined that the model can be further enhanced by examining where and how the structure was generated. Our focus is on refining it into a more conventional design based on insights observed from generative design (see Fig.11).

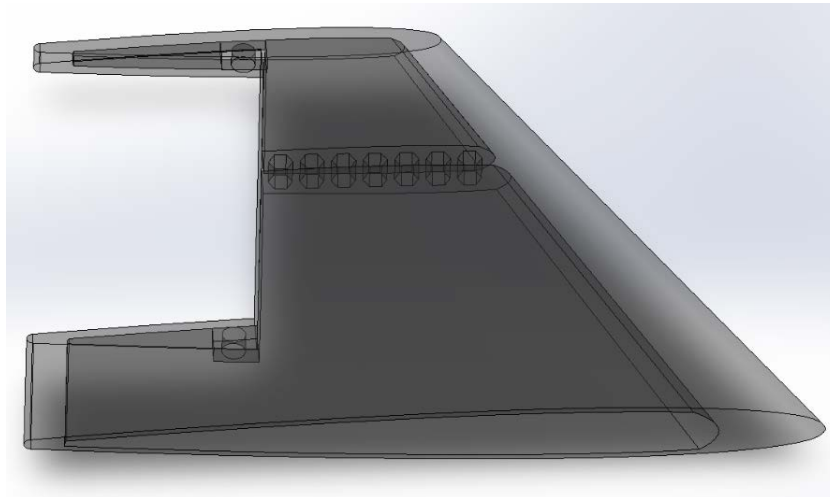


FIG. 11 Example of a modelled part after analyzing the generated model

For instance, leveraging generative design's preference for supporting wings with multiple Y-axis bars, we can integrate this approach into our UAV modeling process by adding extra supports to areas identified by the software as necessary. Furthermore, we can explore and model different shapes based on their aerodynamic properties, informed by the analysis of each design iteration.

4. CONCLUSIONS

This study aimed to investigate the capabilities and limitations of generative design tools for aerospace structures. The lightweight structure generated for the UAV design is suitable for easy 3D printing, making it a practical choice for designing and manufacturing such vehicles. In our case, the entire structure can be printed in approximately 50 hours using a sufficiently large 3D printer. The printing time can be further decreased by segmenting the model into parts and using multiple smaller 3D printers.

By utilizing generative design tools, we can achieve enhanced performance and extended flight durations due to the reduced weight of the structure. Furthermore, cost savings can be realized by opting for a less powerful engine, as the decreased weight eliminates the need for higher power output.

Generative design is a rapidly advancing field, and its application in the development of aeronautical structures requires ongoing exploration. It serves as a robust engineering tool capable of analyzing, testing, and iterating numerous designs, including unconventional structures that might otherwise be overlooked for their perceived performance limitations.

REFERENCES

- [1] N. Guo, M. C. Leu, *Additive manufacturing: technology, applications and research needs*. In *Higher Education Press and Springer-Verlag*, Berlin, 2013;
- [2] J. W. Bottomley, (1977), *Tandem-Wing Aircraft*, *Aerospace*, vol. 4, October 1977. pp. 12–20;
- [3] European Aviation Safety Agency. Easy Access Rules for UAS, September 2022. Available at www.easa.eu.int, accessed on 13 February. 2024;
- [4] F. Buonamici, M. Carfagni, R. Furferi, Y. Volpe, L. Governi, *Generative Design: An Explorative Study*, In *Computer-Aided Design and Applications*, May 2020;
- [5] T. Kier, G. Looye, J.W. Hofstee, *Development of Aircraft Flight Loads Analysis Models with Uncertainties for Pre-Design Studies*, In *Proc. of IFASD 2005, International Forum on Aeroelasticity and Structural Dynamics*, 2005;
- [6] L. Ranakoti, B. Gangil, S. K. Mishra, T. Singh, S. Sharma, R.A. Ilyas, S. El-Khatib, *Critical Review on Polylactic Acid: Properties, Structure, Processing, Biocomposites, and Nanocomposites*, June 2022;
- [7] H. Chun, *A Study on Application of Generative Design System in Manufacturing Process*, In *IOP Conf. Series: Materials Science and Engineering 727*, 2022, JIANGSU.