Multicriteria optimization of 3D printed wing using PLA reinforced with carbon fiber

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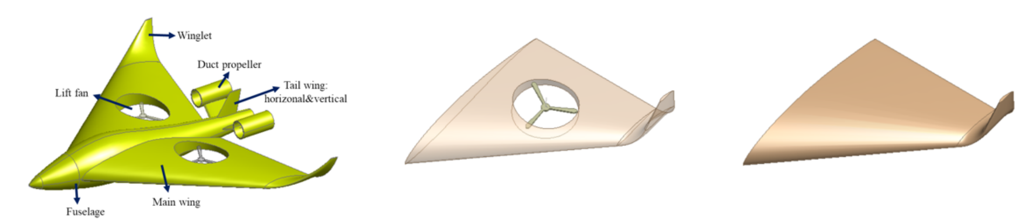
Abstract. The purpose of this work is the optimal conception of a wing built using fused deposition modeling (FDM), which is one of the main additive manufacturing (AM) process. PLA reinforced with carbon fiber was selected for the filament as we have defined their mechanical properties in previous work. The optimization approach use hybrid strategy based on surface response method with kriging model and a heuristic method to avoid to be trapped in local minimization/maximization. The objective functions for this optimization are the weight, the drag (functions to minimize) and the lift (function to maximize) with respect to the failure criteria of the composite material used to build the fuselage. The challenge for this kind of optimization is the multilevel aspect, as it requires firstly to get the optimal parameters of the model before getting the optimal distribution of thicknesses.

WING STRUCTURE AND MATERIAL USED FOR FDM PROCESS

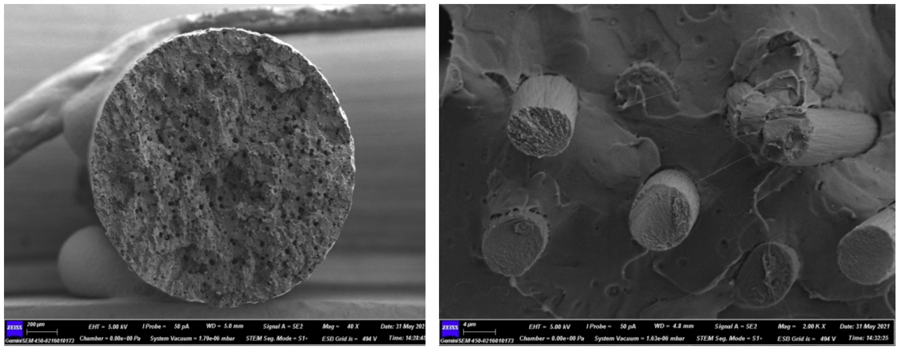
The wing structure used in this optimization process was inspired from one hybrid UAV project that we have already defined the external shape and the limitations (1,2). However, two additional parts were added to the previous work, one concerns the integration of 3D printed material (3,4) and the other one is related to the global optimization of composite material using kriging model and surface response (5–8). Figure 1 describes the wing structure with and without the central fan (used for the vertical and take-off landing VTOL-UAV) (1).



(a) (b) (c)

Figure 1. (a) Description of the UAV concept (b) Wing frame with the central fan (b) Wing frame without the central fan

Concerning the material filament used for the FDM process it consists of a PLA filament of 1.5mm (Fig.2.a) reinforced with 15% of carbon fibers as described in Fig.2.b.



(a) (b)

Figure 2. (a) View of the 3D printing filament (b) distribution of the carbon fiber inside the PLA

The wing was built using multilayers deposits with the following orientations +45 and-45 degrees. The orientation and the stacking can be seen in the Fig.3.a. The voids that appeared after the FDM deposit were studied and taken into account in previous work (10). Figure.3.b. shows one edge after traction test of one sample for the material characterisation.

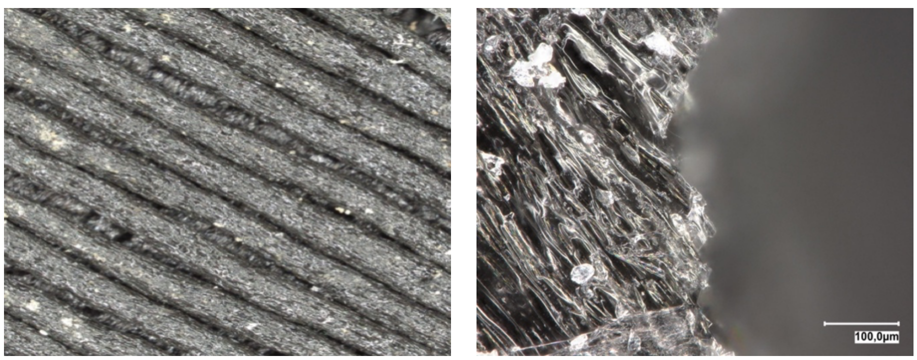


Figure 3. (a) View of the 3D printing fuselage of the wing where we can notice the layers (b) after traction test so that we can see the failure mode at micron-scale.

MULTICRITERIA OPTIMIZATION APPROCH

The main objective of this multicriteria optimization is to reduce both the total weight of the wing structure M_{wing} and its maximum deformation D_{max}. In addition to the design parameter, the optimal design is also subjected to other limitations in order to reduce the risk of the failure mode. The first limitation, concerns the safety factor SF that should be greater than 5 to granter structure security. The second limitation is related to the maximum deformation D_{max} that should be less than 2% of wing span. The mathematical formulation can be seen in equation 1.

The design parameters are the descriptions of the span and the chord parts of the wing (*incident angle, chord length,* $span\ of\ plain\ wing, span\ of\ winglet, ratio\ of\ plain\ wing\ tip,$ *Ratio of winglet tip*) in addition to the thicknesses (Fig. 4). In this section, design of experiment method was used to create the pool of the initial solutions that are evaluated using CFD method (*using Fluent software*) to get more accurate points of the estimation. After this first loop, a surface response is then built to mimic the mechanical response of the wing under the external loading (1,11). It is very useful in such case to reduce the cost and the time consuming. Then, a heuristic approach based on genetic algorithm (8,12,13) was used for the multicriteria optimization to get the Pareto front. Final conception was then selected from this front line.

$$\begin{cases} min\,\{M_{wing}\} \\ min\,\{D_{max}\} \\ S.T.\begin{cases} D_{max} \leq 20mm \\ SF \geq 5 \end{cases} \end{cases} \tag{1}$$

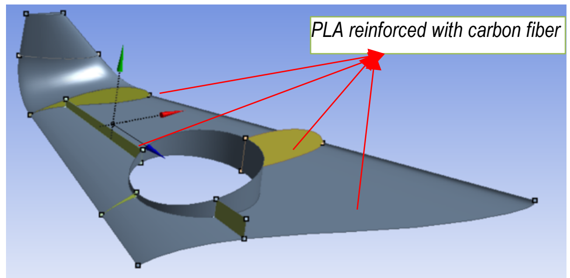


Figure 4. Design parameters and the different parts that were reinforced with composite material

NUMERICAL RESULTS

At the convergence of the optimization process described above, a Pareto front is obtained in Fig. 5. The relative errors between the surrogate approach and CFD prediction were less than 2%. The optimal objective functions obtained at the pareto front are: weight of the wing M_{wing} =3.36kg, maximum deflection $D_{max} = 19.93mm$ and the safety factor SF=7.52. The distribution of the Von Mises stress with the optimal parameter is presented in Fig.6.

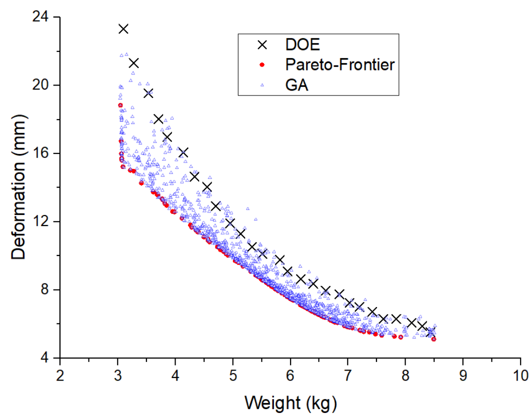


Figure 5. Pareto finale front obtained with the hybrid approach.

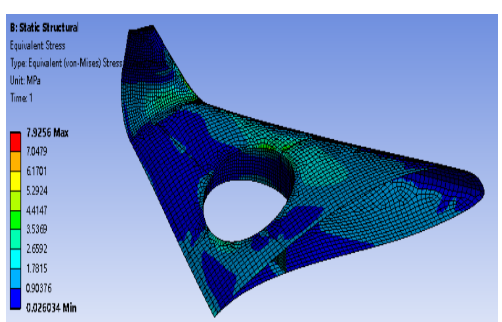


Figure 6. Von Mises stress distribution with the optimal parameter.

CONCLUSION

The hybrid optimization approach that we have presented allows us to design and to build efficiently a 3D composite structure of a wing used for our new concept of VTOL-UAV. Stress distribution and maximum deflection were within the defined limitations. Among the perspective to improve our design and the mechanical response is to study further the influence of the voids for the mentioned material. This may allow us to build more accurate FE prediction. This investigation will surely require advance Micro CT scan and high performance computing.

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