ANALYSING THE GENERATIVE DESIGN OF PAYLOAD PART FOR THE 3D METAL PRINTING

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Resume

Additive manufacturing provides the possibility to print complex generative designed bodies. The research deals with redesigning a payload part of a camera holder using generative design for selective laser melting. The possibility of replacing the original polymer component with a metal printed component of a greater strength and the effect of different parameters of generative design were investigated. By comparing the generative design results obtained in several phases, the goal was to find a solution that can be used to replace the previous part and become printable with 3D metal printing. The internal stress values for each case and the amount of weight reduction that can be achieved were determined.
With the results obtained, the parts were prepared for printing. It is the key aspect of the industrial application of generative optimization.

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1 Introduction

In developing the vehicle components, processes and methods that provide a unique, targeted solution to a specific challenge are becoming more widespread. These processes also include generative design and the 3D printing technology [1]. By combining the two methods, new component solutions can be developed that did not exist before [2].

Generative design is a powerful tool for product optimization in Additive Manufacturing (AM) [3]. One of the reasons for using the topology optimization and generative design is the creation of new constructions that can be designed with less material and less weight [4]. The need for weight reduction [5] in vehicles is self-evident [6]. It is also important in the aircraft industry [7], but it may be needed in the building industry [8], in medical applications [9] as well as in many other areas [10].

Due to the rapid development, metal 3D printing technology has also appeared in component manufacturing. Applying additive manufacturing can replace previous component designs with new design solutions, which is also greatly aided by generative design [11]. One of the main application areas is the production of customized components, where complex component geometries with smaller pieces can be made with a shorter lead time [12]. The spread of advanced solutions within the vehicle industry in competitive sports started some years ago [13-14].

The research aim was to develop the methodology and a unique titan alloy component using the generative design that provides an additional competitive advantage over a specific component, with lower weight, higher safety factor and higher load capacity than the original polymer component.

2 Experiments

The component included in the investigation is a drone (or UAV) payload camera's moving bracket from polyamide (PA12) polymer of a weight of 223 g. The replacement of this component from titanium (Ti6Al4V) material was investigated by generative design in the PTC Creo 7.0.2.0. software. Figure 1 shows the original polymer model.

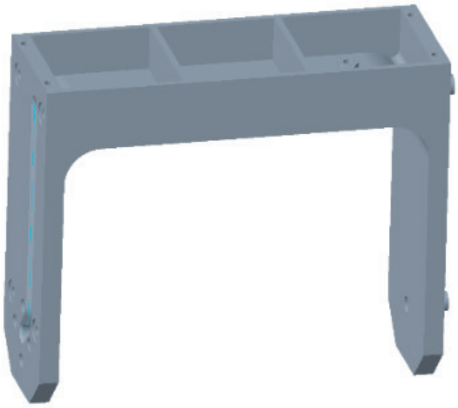
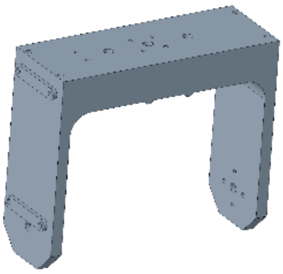
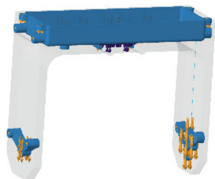
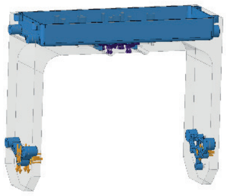
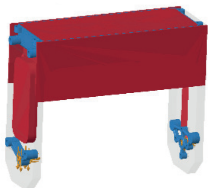


Figure 1 *The original polymer bracket part*

Table 1 *Illustration of design spaces in different phases of development*

Phase	Starting Geometry	Preserved Geometry	Excluded Geometry
A			
B			
C			
D			

The definition of a generative design study begins with modelling of the three main volumes. These are the starting geometry, the preserved geometry and the excluded geometry. The starting geometry is where the simulation can reorganize the structure. The preserved geometry contains the volumes what one would like to keep intact. It is essential to merge all the little geometry parts of the preserved geometries to bigger groups. If there were too many volumes that have a small size in the simulation, then the software would not be able to fine good solutions. In thiscase the simulation software will generate result with some separated volumes. In the Creo Generative Design application the preserved geometries must be part of the starting geometries. The excluded geometry is what the software must not use during the optimization process. The geometries used during the four development phases (A, B, C, D) are shown in Table 1. The starting geometry was the same in all the phases. The preserved and excluded geometries were the same in phases A, B and C. The preserved and the excluded geometries in phase D were modified. A lightweight preserved geometry and a much more complex excluded geometry were created to achieve the best result. This complex excluded geometry helped us to achieve the best form of the generated part with elimination of all the possible unacceptable geometries forms. The simplest possible starting geometry was produced due to authors' experience that the simpler starting geometry and the more complex excluded geometry provide the best results.

Then one must define the constraint(s) and load(s) of the part. The constraint of this part is a fixed constraint and the position of it is shown in Figure 2. In the case of this investigation only forces were used. The directions of these forces are shown in Figure 3. The magnitudes of the forces are shown in Table 2. Due to the weight of the carrier camera, a load of 100 N is expected. It is important to add some load to the separated preserved volumes. If there would be preserved volumes without load, then those volumes would not be the part of the solution. The software will leave those volumes intact and separated. However, for the simulation to create a favourable construct, more force had to be defined in the software and different values had to be applied.

After that, the definition of the case study is finished by setting the design criteria- and the fidelity

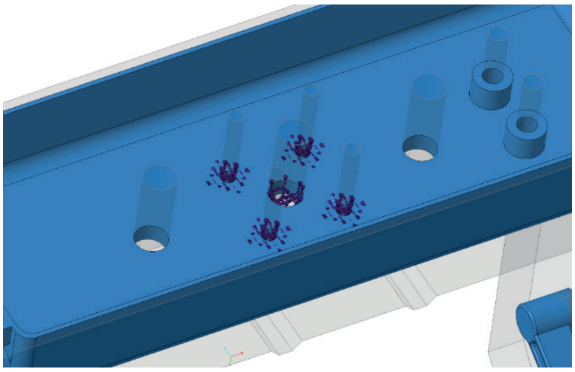


Figure 2 *The constraint of the part*

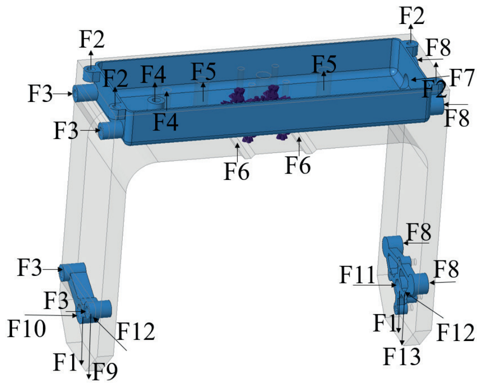


Figure 3 *The applied forces*

Table 2 *Parameters of forces and generative simulation*

Phase	F1 (N)	F2-F8 (N)	F9 (N)	F10 (N)	F11 (N)	F12 (N)	F13 (N)	Limit Volume (%)	Limit Mass (g)	Material Spreading (%)	Fide-lity (-)
A	100	1	-	-	-	-	-	30	-	80	5
B	1000	-	-	1000	1000	1000	-	19	-	90	5
C	20	-	-	20	20	-	-	18	-	80	5
D	-	-	1000	-1000	-1000	-	500	-	140	80	9

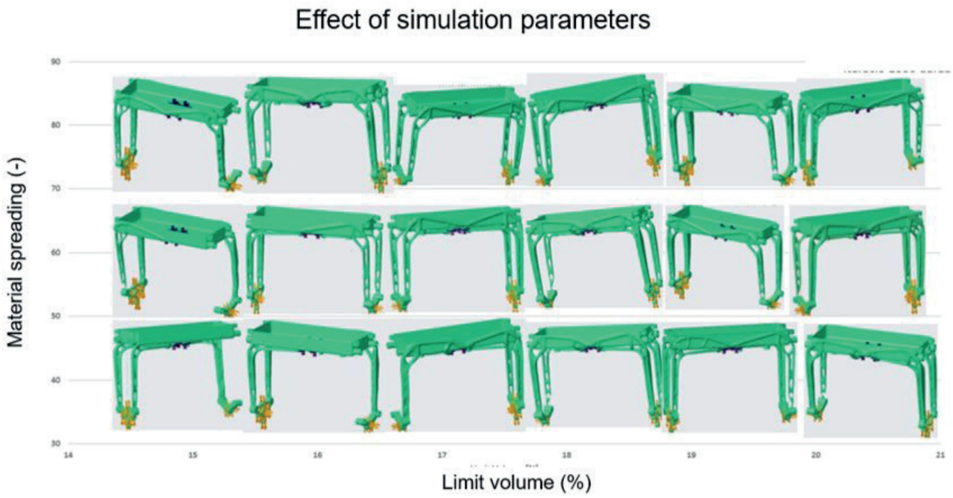


Figure 4 *Effect of material spreading and limit volume parameters to the design*

parameters. Those parameters can be seen in Table 2, as well. The limit volume or limit mass parameter sets the quantity of the reorganizable material. The percentage of the limit volume is related to the starting geometry. With this parameter the resulted weight can be predicted. If one wants to achieve lower weight, then one needs to decrease the lower Limit Mass value. If this parameter was too low, then the software would not be able to make an "unfinished" result. It is essential to see, that the preserved geometry mass will be a part of the Limit Volume. There is a certain point when the software is unable to make good result because there is not enough material to redistribute. The material spreading parameter sets the complexity of the result. This parameter can be set between 0 and 100. A lower material spreading value means a simpler result. The simulation with higher material spreading value will make more complex structures. To understand the relation between these two parameters different pairings were investigated. The output is the design change of the due to the simulation. This diagram can be seen in Figure 4. In this case it can be stated that higher material spreading value provide better result to us with lower limit value.

The fidelity parameter combines the element size and the iteration value. It can be set between 1 and 10. In the last phase of the development one simulation was 1000 iteration and the element size was 1.1 mm.

According to results from the previous simulation if one wants to lose as much weights as possible, one must set the higher fidelity value. The simulation with higher fidelity requires more time to finish. It is important to see that therefore we used high fidelity value only in the last phase when it was not avoidable.

After setting the simulation parameters, the simulation can be started. The data in the table contains the results of approximately 100 different test settings.

3 Results and discussion

As a result of the generative simulation, we obtained a design, stress distribution, deformation values and the mass of the formed design. The designs and stress states are illustrated in Figures 5, 6, 7 and 8. The simulation results can be sorted into four different development phases. Due to the difference in the force definition of the development phases (different directions and magnitudes), the maximum stresses to the original load were normalized to ensure the comparability of the results. The original stress results are shown in diagrams.

Development phase A results shown in the Figure 5. This was the preparation phase. There were several problems with these results. For example, the legs are too weak to resist side forces and the weight is more than the original plastic part. Other good example for the problems that the box part of the preserved geometry is missing in the stress distribution diagram, this means that it is not a part of the resulted body. The missing box also means some missing mass too. The main box part of the result geometry is thickened by the simulation. The thick wall is unnecessary and requires a lot of material. The lowest weight that could have been achieved in this phase was 297 g (without the box),and the highest stress was 9.5 MPa. It means that the structure was very over-designed because the yield strength of titanium alloy is 1000 MPa.

Development phase B is shown in Figure 6. This phase solved the leg weakness problem by redefinition of forces but did not solve the missing box problem. The magnitude of the new forces are bigger than the originals, but in this way, we could control the optimization process and significantly reduce the weights. We lose some weights with the elimination of the thick wall. The best result was 178 g (without the box) and the highest stress was 90 MPa. The maximum stress is also low, so we can decrease the limit mass further. With such parameters, further weight reduction has resulted solutions that are no longer technically acceptable, for example, 3-legged.

Development phase C is shown in Figure 7. In the third phase, the definition of the force was modified once again to further decrease the mass. This time we made simulation with smaller forces. The missing box problem was not solved in this phase. We achieved 172 g and the stresses decreased to 80 MPa. Below 172 g, the three-legged result appeared again. After that, we knew

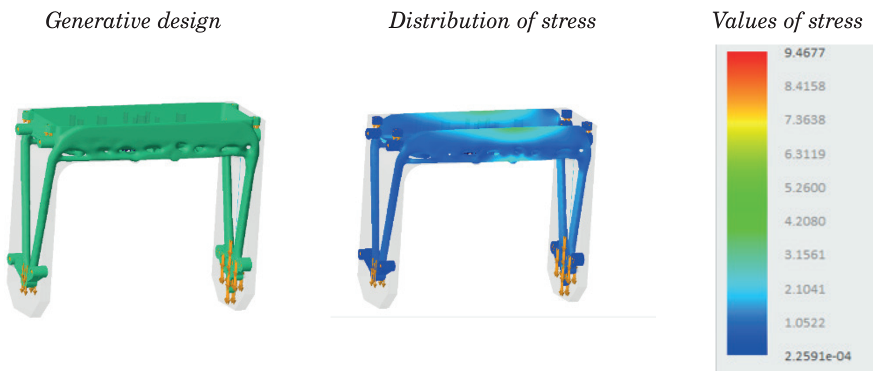


Figure 5 *Development Phase A*

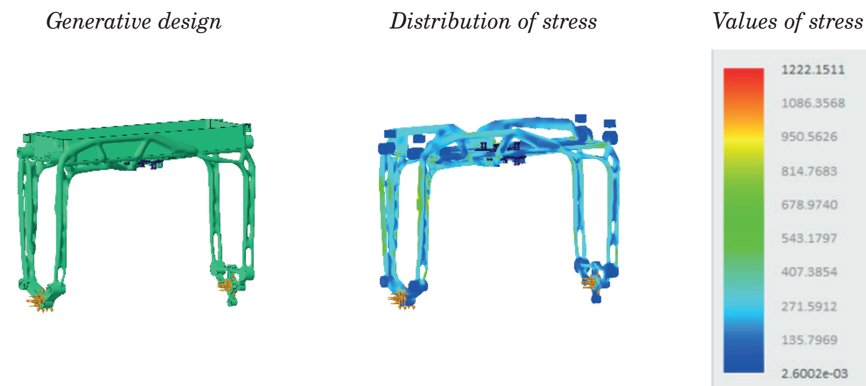


Figure 6 *Development Phase B*

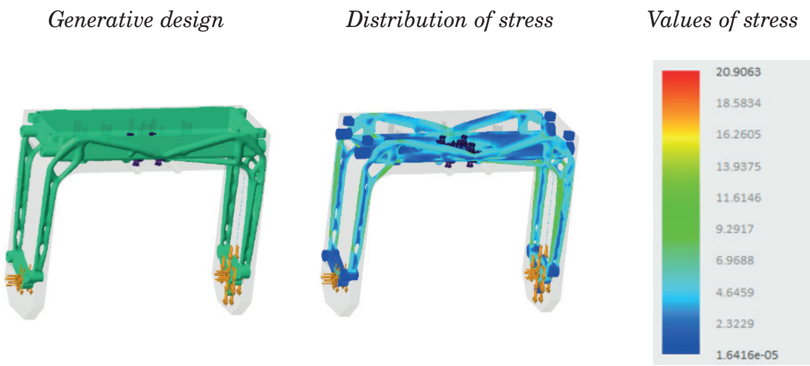
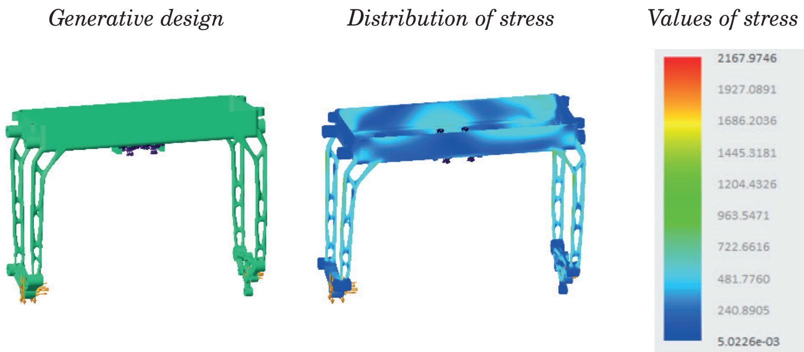


Figure 7 *Development Phase C*



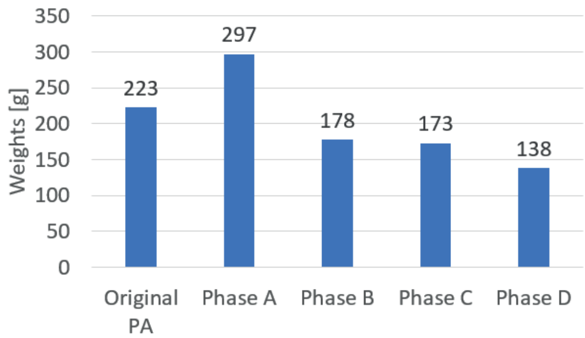


Figure 9 *Illustration of weight reduction in different development phases*

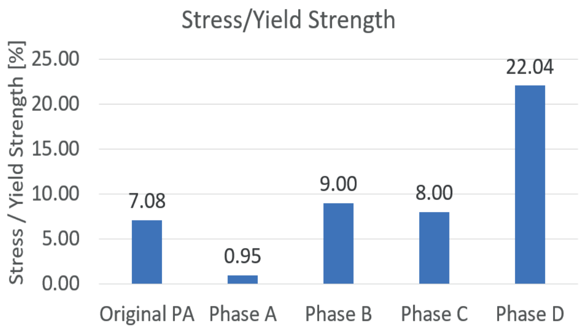


Figure 10 *Illustration of the stress rates in different development phases*

that the magnitude of the forces has a relatively small impact on results, but the direction of the force vector has a considerable impact. To avoid the three-legged according to this experience we have begun to develop the Phase D.

Development Phase D is shown in Figure 8. This phase was a long iteration phase. We constantly changed the excluded geometry, as complex as all the unnecessary structure parts have been erased. The missing box problem is finally solved. After these iterations, we achieved 138 g and the body remained a four-legged structure. We could achieve the highest stress (220 MPa), which meant that the better use of the load capacity of the material was done, but not yet entirely.

Figure 9 and Figure 10 show the component weights achieved during the different development phases (Figure 6) and the stress ratios relative to the yield point (Figure 10). In this diagram, the stress values were normalized for comparability. This was necessary because the magnitude of the applied forces was different during the simulation phases. Thus, the initial goal was partially achieved. In the current state of development, the component has 38% less weight than the initial polymer component. However, there are still large reserves due to the load capacity of the titan material, which will happen in the following development phase as we are planning.

4 Conclusions

With the investigation of the generative design possibilities, the following can be concluded:

- Generative design is a new tool for creating the complex structures for the 3D printing.
- Parameters used in generative software give very different solutions depending on the values set. The magnitude of the forces has a relatively small impact on the results, but the direction of the force vector makes a difference. Simpler starting geometry and more complex excluded geometry provide a better solution than inverting.
- It is necessary to lead the software to the desired solution. It is not yet fully automatic.
- In the case of the specific component, the polymeric material can be produced with a generically designed titanium material of a smaller weight and higher load capacity.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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