Applying design for additive manufacturing to existing aerospace parts

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Abstract. Additive Manufacturing has widely been used in the aerospace industry. However, local uptake in the aerospace industry has been slow with mostly additively manufactured polymer parts being used. The Advanced High Performance Reconnaissance Light Aircraft (AHRLAC), which is a locally produced military aircraft, is well positioned to prove the local capabilities in Metal Additive Manufacturing to the local Aerospace industry. Two parts of this aircraft were identified through prior experience in Additive Manufacturing and taken through the Design for Additive Manufacturing process. The identified parts were a forward cockpit control cable mount and a canopy guide. The parts were redesigned using topology optimisation and, in both instances, a weight, cost, and lead time reduction was achieved.

1 Introduction

Additive Manufacturing (AM) is the process of building parts through the addition of material on a layer-by-layer bases, as opposed to the more traditional way of removing material to create parts [1]. Within this, Metal Additive Manufacturing (MAM) exists, which is AM focused only on metals [2]. One of the more advanced technologies in MAM is Laser Powder Bed Fusion (LPBF) and is broken down as follows: a Computer Aided Design (CAD) is created and computer software is used to slice the CAD model into virtual two-dimensional layers, which forms part of the process parameters of an AM machine. The sliced files are sent to the LPBF machine, where metal powder is deposited in a thin layer on a build plate and a laser is used in conjunction with a scanner to melt the slice of the part onto the powder layer. The powder bed is moved down by the thickness of one layer and a new powder layer is deposited. The process is repeated until each consecutive slice has been melted and simultaneously fused to the previous one, forming the solid parts. The un-melted powder is recovered for re-use and the build plate with the manufactured parts removed from the machine. [3]

Aerospace is one of the industries that greatly benefits from using AM, especially MAM. The advantages of using MAM in the production of aerospace parts are the reduction in lead time, along with part costs, MAM allows the freedom to design and manufacture complex parts, the ability to manufacture complex parts to reduce their weight, consolidating multiple

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parts of an assembly into a single part and the improvement of performance of the aircraft (lighter means better fuel economy, shorter take-off distance, or heavier payloads, etc.) [4,5]. Additionally, cost is independent from complexity, and dependent on only part volume and part orientation.

Design for Additive Manufacturing (DfAM) is the process that is followed to either modify an existing part design or create an entirely new one to ensure that the full advantage is taken of AM's capabilities [6]. There are many different tools that a designer can use that streamline the process and assist in obtaining a final part in a shorter amount of time. One of these tools is Topology Optimisation (TO). TO is a process that optimises the material usage within a given design space with a defined set of load cases and rules set by the designer. The aim of TO is to maximise the performance of a part for the lowest possible weight of the part. This is done by "mathematically modelling and optimising for factors such as external forces, load conditions, boundary conditions, constraints, and material properties within the design envelope" [7].

This feasibility study set out to prove to the local Aerospace Industry how its adoption can positively influence an organisation. This will both help the local Aerospace Industry become more competitive internationally and help grow the local MAM industry. The AHRLAC is a locally designed and manufactured aircraft and is ideally placed to prove to the local aerospace industry how the adoption of MAM can be of great benefit. Existing parts on the aircraft will be taken through the DfAM process and manufactured, after which a cost, weight and lead time comparison will be made to the original designs.

2 Methodology

This research identified five non-critical parts on the AHRLAC to take through the DfAM process (the DfAM process that was followed is shown in Fig. 1). These parts were analysed according to their complexity, potential for improvement in performance and potential for lead time/cost reduction. Two of these parts will be focused on in this paper. The two parts were the canopy guide and the forward cockpit control cable mount. The parts were classified according to the NASA-STD-6030 [8] standard to determine which tests will be required for qualification purposes to implement the parts on the aircraft in the future. 2 was obtained from the NASA standard and used for the classification. Both parts were classified as Class C because the consequence of their failure would be negligible, meaning that their failure during flight will not result in catastrophic failure of the aircraft.

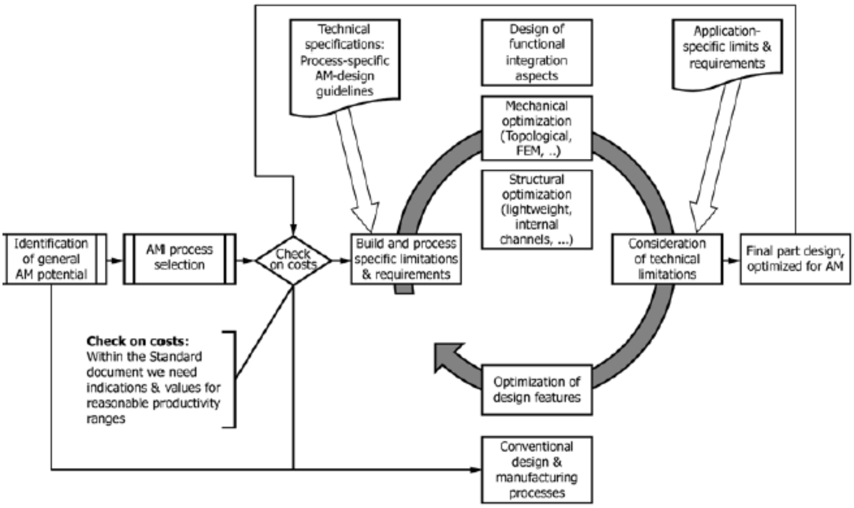

Fig. 1: Design for AM process flow diagram [9]

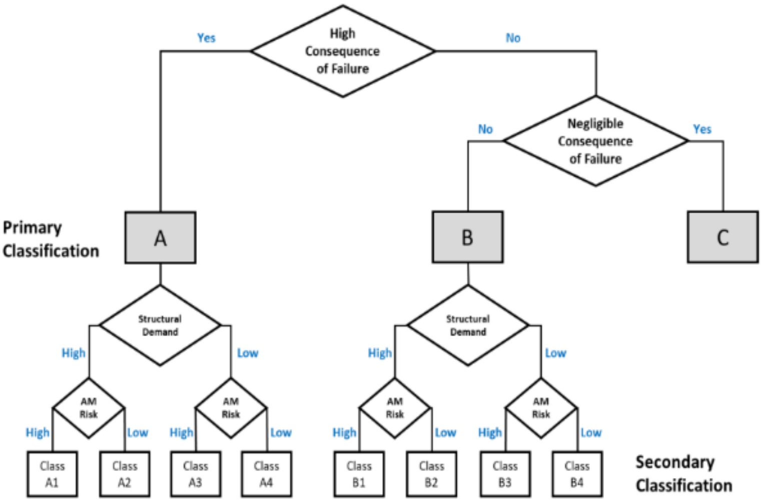

Fig. 2: AM part classification [8]

Loads and boundary conditions for the parts were obtained from Paramount Aerospace Industries (PAI), as well as the Computer Aided Design (CAD) models for each of the parts. Additional information was received to develop an understanding of the application of the parts and how they function. The CAD models were loaded into the TO software, MSC Apex Generative Design, where a design space was created using the information received. The loads and boundary conditions were then applied, and a TO was carried out by the software. A Finite Element Analysis (FEA) was conducted to confirm that the final parts would be able to handle the given loads. Siemens NX was used for the FEA and the background solver was Nastran. The loads and boundary conditions used for the FEA were the same as was used in the TO. Both parts were then manufactured using a LPBF machine.

3 Results

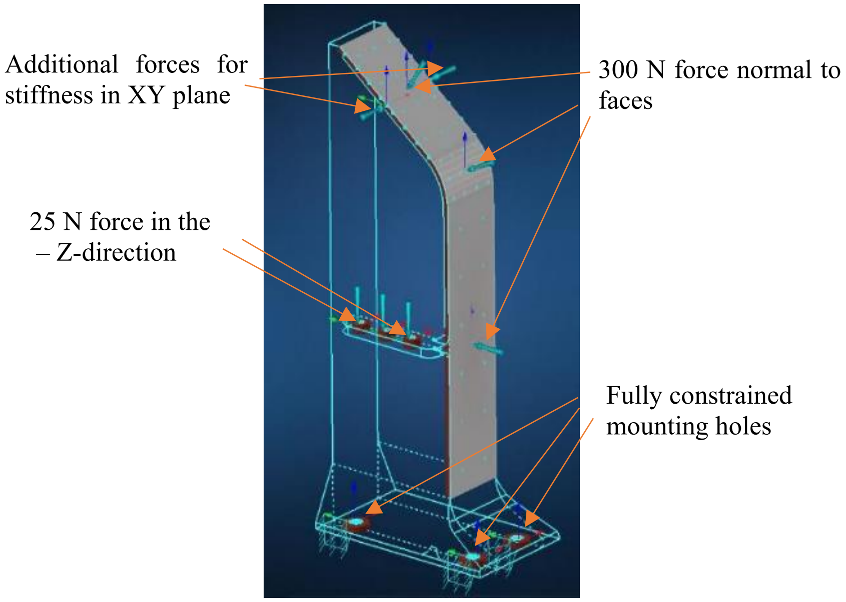

Fig. 3: Loads and boundary conditions for canopy guide

3.1 Canopy guide

The original CAD model for the canopy guide is shown in **Error! Reference source not found.** (left). The loads and boundary conditions that were used in Apex Generative Design are shown in Fig. while the blue outline in the figure shows the design space that was created for the optimisation. 25 N forces were added to prevent the software from discarding the three mounting holes during the optimisation process. These holes are used to mount safety pins before take-off. The optimisation was conducted, and the resulting design is compared to the original in Fig. 4.

FEA was performed on the optimised design to confirm that it would be able to handle the worst-case scenario forces. The worst-case was seen as a 300 N force on the diagonal

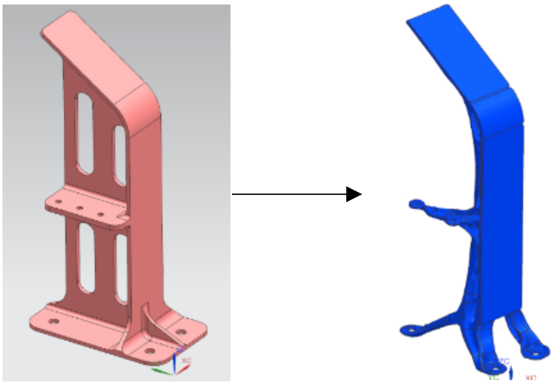

Fig. 4: Original CAD vs. optimised design

face on the top of the part (same as in Fig. 3). The result of the analysis is shown in Fig. 5. The highest stress that was observed was on one of the mounting holes, while the rest of the part experienced low stress. The high stress is not considered critical at this stage as these mounting interfaces can be thickened to reduce stress and risk of failure. Addititonally, the high stresses were only observed in individual mesh elements around the mounting holes. Thus, the result is seen as acceptable at this stage, considering that these areas will be thickened in the following iteration.

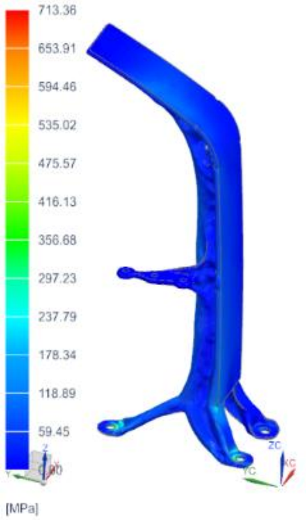

Fig. 5: FEA results for canopy guide

The canopy guide was manufactured in AlSi10Mg, and the result is shown in Fig. 6. The cost of MAM of the part was R7,015.00. Taking the additional post-processing costs into account, the total cost for the MAM part is around R7,940.00 as opposed to the cost of CNC machining the original part of R8,6000.00. A cost reduction of 7.7 % was thus achieved. Table 1 compares the weight of the original part with the weight of the optimised version. A weight reduction of 35 % was achieved. The lead time was also reduced from two weeks to one.

Fig. 6: Printed part in AlSi10Mg

Table 1: Canopy guide volume and weight comparison

	Volume (mm^3)	Weight (g)
Original	32983	85.8 (AL 7050)
Optimised design	19900	55.8 (AlSi10Mg)

3.2 Forward cockpit control cable mount

This part consists of three different parts along with threaded inserts. It is used to mount control cables underneath the pilot's seat in the cockpit. Some load is experienced by the part from the control cables, but the load is not considered as significant. AM enables the consolidation of an assembly of parts, as multiple parts can be manufactured as one. Part consolidation decreases assembly time and the number of manufacturing processes needed.

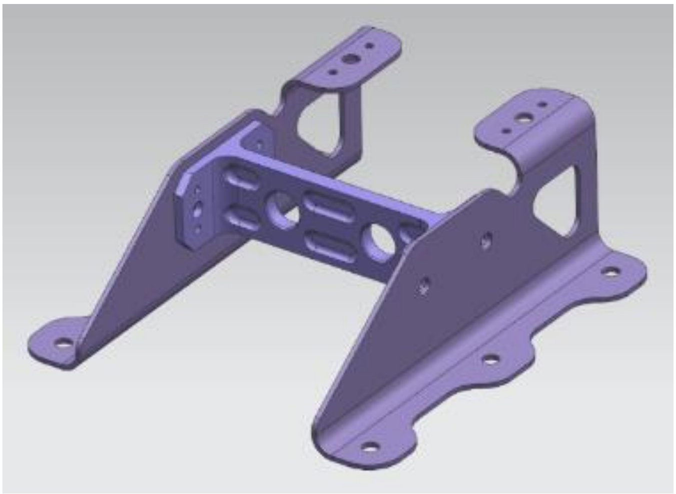

Fig. 7: Original CAD model for control cable mount

The software has the ability to consolidate multiple parts within an assembly into a single part and then to TO that part according to the provided loads and boundary conditions (fig. 8). The assembly of parts was imported into MSC Apex Generative Design. A design space was created to encompass all the parts.

Different events were created to account for the different loads that act upon the bracket, for instance where the 830 N load on each cable is applied at the same time in both directions, and in opposite directions. The part consolidation and topology optimisation were conducted, and an initial result obtained.

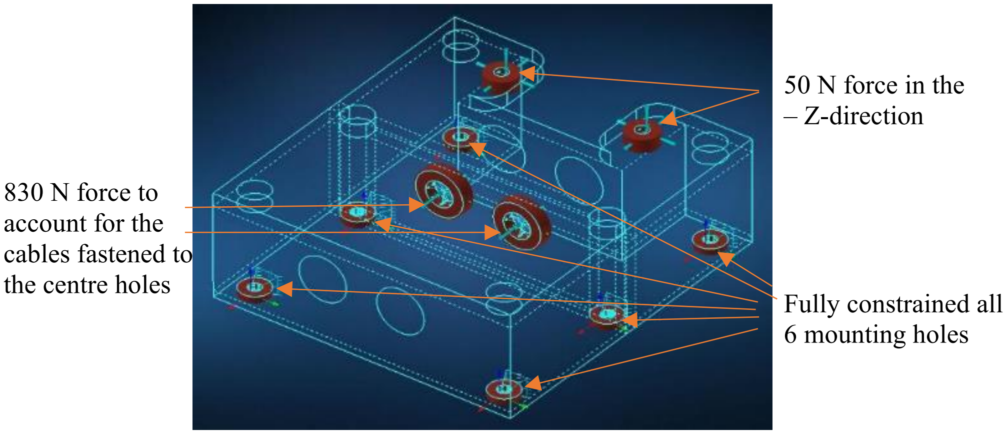

Fig. 8: Loads and boundary conditions for control cable mount

After obtaining the initial results, the loads and boundary conditions were changed to obtain a more feasible design. One of the changes was to add a 50 N force in both the negative and positive x- and y- direction along with the other two 50 N forces. This was to create stiffness in additional planes. Fig. 9 shows the optimisation result of the final iteration. It can be observed that three of the mounting holes could be removed during the optimisation process.

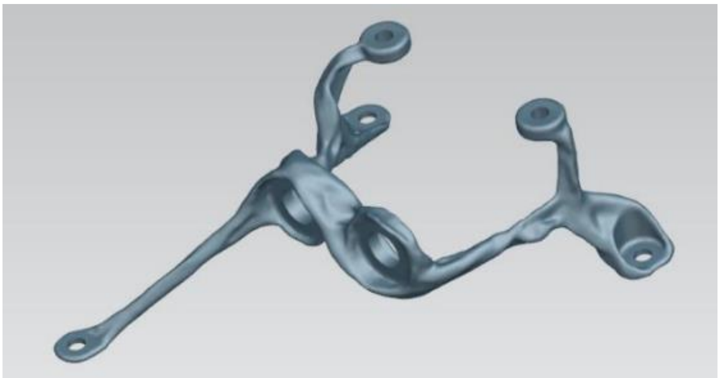

Fig. 9: Optimisation result for the control cable mount

FEA was conducted on the optimised design to confirm if it would be able to handle the worst-case loads acting on it. All three mounting holes were fully constrained. Four different load events were considered when determining the worst-case scenario. These four load cases were an 830 N force acting on both holes through which the control cables are routed, then alternating directions, and then in the opposite direction. The result is shown in Fig. 10. Again, the only possible problem that was observed was on the mounting holes, which is where the highest stress was located. However, when investigating these areas, the high stresses were only observed in a few elements of the mesh around the mounting holes. It was determined that the design will be sufficient. However, these mounting interfaces can be thickened if a problem does occur due to the loads from the cables.

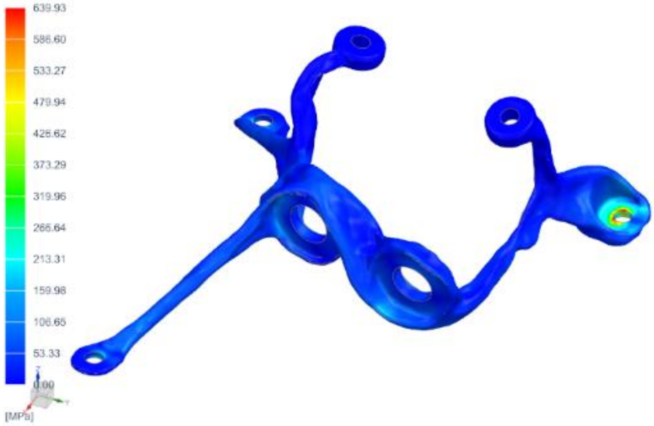

Fig. 10: FEA result for control cable mount

The control cable mount was manufactured through MAM in AlSi10Mg as shown in Fig 11. A weight comparison is given in table 2. According to the information received from PAI, the manufacturing cost of the current design is R11,500.00. The cost to have the new design manufactured was R6,595.00. Thus, the optimised part will be 43.7 % cheaper to manufacture than the original and weigh 58% less, potentially providing both a significant cost and weight benefit over the original design. In this case, the lead time was also reduced from four weeks to one weeks.

Fig. 11: Manufactured control cable mount

Table 2: Weight comparison of control cable mount

	Volume (mm3)	Weight (g)
Original	36347	98.7 (Al 7050)
Optimised design	15400	41.5 (AlSi10Mg)

4 Conclusion

It is concluded that it was successfully shown that there are clear benefits to using MAM in the local Aerospace industry, from a weight and cost saving perspective. A cost reduction of 7.7% was achieved on the canopy guide with a weight reduction of 35 %, whereas the control cable mount had a cost saving of 43.7 %, with a weight reduction of 58%. Lead time reduction could also play a significant role in convincing the local Aerospace industry to adopt this technology. Other than the two parts used in this research, there are hundreds of others that could be similarly optimised. This would increase the profitability and performance of the aircraft and in turn make it more competitive.

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