

Metal to Plastic 3D Printed Bayonet Component

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Abstract - The given assignment for design in this project was to substitute plastic in place of aluminum bayonet present in the side mirror assembly of a 4-wheeler. Weight reduction, cost reduction and the maintenance or improvement of performance were the desired targets of this study. This aluminium part in use has served the last few years but does have a number of disadvantages to its current construction which are principally weight and also the production time and expense for a cast then machined component. Nylon 6/6 (30% glass filled) was chosen as the replacement material because of its general mechanical properties and dimensional stability. It was also chosen since it was appropriate for modern manufacturing techniques. A new part geometry was generated in CATIA V5 to make the part's material usage as low as possible while not sacrificing its performance and dimensional properties. A manufacturing method, Fused Deposition Modelling (FDM) was employed to produce the part. This is a rapid prototyping technique, also known as additive manufacturing which can save on material scrap and cycle times. In addition to designing the geometry of the part and manufacturing the physical part through FDM the moulding behaviour of the plastic part was analyzed using Moldflow 4.0 in order to predict and prevent manufacturing defects. Compared to the Aluminium plastic material demonstrated to be much more resistant to impacts, lightweight and also much cheaper.

Index Terms - Bayonet, Aluminium, Nylon 6/6, CATIA V5, FDM, Additive Manufacturing, FEA, Moldflow, Automotive Components.

I. INTRODUCTION

The current motor car passenger mirror assembly has required specifications of lightweight, strength and relative low production cost. The center of the entire assembly and a rather simple part not to miss is the bayonet. This is used as a means to unfold/fold this entire assembly, mount it to the door, and route electrical wires throughout the

assembly. This component was traditionally an aluminum part and aluminum was well suited for it; strong, not too heavy, well known and easy to machine. With constant pressure for lighter vehicles and lower cost of manufacture, it would be expected that part of the bayonet was also put under pressure. The objective question was; is it possible to substitute an aluminum bayonet with a plastic component, and still achieve the required functionality of such an application? Yes, this report has shown it is possible - if the material is selected properly and manufacturing processes designed appropriately.

A. Introduction to the Bayonet Component

Bayonet - this component is part of the assembly of the car side mirror unit. When the wing mirror needs to be pushed in (when parallel parking) for example, this can easily be done because of the bayonet joint (with an internal small spring) intended to fold in and jump back again. This section also acts as the connector between the housing for the mirror assembly and the passenger door of the car. Wires that go to the indicator lamp are also routed via a hole bored into the bayonet thus it is also an electrical pathway for the wires too.



Fig. 1: Aluminium Bayonet Component

II. PROPERTIES OF ALUMINIUM

The second most popular metal, structurally, after steel, throughout the world, is aluminium. There are certain individual properties that contribute to its dominance across applications, which are inherently very hard to replicate at a similar cost. A number of these properties have been useful to mention here as

they define some kind of base, of which any replacement has to cover about half the way to meet.

A. Density and Weight

With a density of around 2700 kg/m, some one-third of that of steel, this figure explains why aluminum has been classified as a lightweight structural material - one with desirable mechanical performance for reasonable weight-related costs; especially valuable in automotive applications where any weight reduction, however infinitesimal, may have some bearing on fuel consumption and handling characteristics. Steel is less dense and so it will be less heavy. If we compare the density of steel which is only just below 2700kg/ m³ with steel density being about 2/3rds of steel density, this is why steel is being used more as a light construction material. The economical affordable material concerning the mechanical properties, relevant from the cost vs weight, in especially automotive context it's beneficial to some extent concerning the fuel consumption and feel of driving, in terms of reducing the weight of car as extreme lightweight construction..

B. Mechanical Strength

The tensile strengths of aluminum alloys vary widely from approximately 70MPa for pure aluminum up to 700 MPa for heavily alloyed and heat-treated alloys. The range typically expected for the common extruded alloys found used for components is typically 150 to 300 MPa. One interesting property is that while steels are prone to brittle behaviour at cold temperatures, there is no tendency for aluminum, which can easily be utilized for applications where use in the cold will be experienced. Strength will begin to fall above about 100 C for all components.

C. Thermal and Electrical Properties

Aluminium is a good conductor of heat and electricity. Its properties as electrical conductor can be related, its mass is roughly half than that of the same electrical conductor of copper and its thermal conductivity is good for heatsinks, however, the bayonet part is not suitable for those two.

D. Corrosion Resistance

Another, and more practical, property of aluminum is that it has a thin, exceptionally stable oxide layer which is always present on its surfaces in air, and which reforms when it is scratched off. It also offers, in most conditions, a protective quality. This top layer can however be strengthened artificially by the use of an anodising process.

E. Formability and Machinability

Aluminium is a very formable metal and can easily be extruded into complex profiles and rolled into very thin sheets or foils. It bends easily and draws well. This material can be easily accepted by conventional machining tools such as mills, drills,

taps and reamers. The cutting energy is relatively low and thus it is easily machinable to close tolerances. As it is so easily machined it is with subtractive processes that the problem of the production of swarf and thereby the loss of material occurs.

F. Other Notable Properties

Aluminum is a non magnetic material. This is an advantage if it is desired to avoid any form of electro magnetic interference. It is a non-toxic material and a non-corrosive metal which gives it wide scope of application. As it's very shiny and reflects all of visible light, as well as infra red radiation, it can also be seen to be an application of reflective surfaces. Also a big benefit is that when its lifecycle is over it is 100% recyclable and can be melted down to be re-used with only one-tenth of the energy needed to process the metal from the ore.

III. PROPERTIES OF NYLON 6/6 (30% GLASS FILLED)

The proposed substitute material to be used to replace the candidate is 30% by weight glass fibre reinforced Nylon 6/6. This is an engineering thermoplastic that has found use in an increasingly wider number of application areas once the monopoly was shared solely by metals. This grade has become beneficial due to the following characteristics: Nylon is intrinsically tough with good chemical resistance and is easy to process while glass fiber has a tendency to push stiffness and strength into levels comparable to light alloys. It can be described structurally as (NH-(CH)₂-NH-CO-(CH)₂-CO)_n with the glass fibers spread evenly in the matrix.

A. Density and weight

Density of 30% GF Nylon 6/6 is within the region 1.35-1.40 g/cm³. So compared to aluminium (2.7 g/cm³) a part made from this material will be approximately 1/2 the weight for the same geometry. This size reduction leads to a significant weight saving

when translated into automotive applications for something like the bayonet (averaged across the whole of the automotive population).

B. Mechanical strength

The stiffness and strength of the Nylon matrix are enhanced dramatically by the glass fibers. Increase the strength to 150-250Mpa. This is over 2x strength than unreinforced Nylon. The flexural modulus is approximately three times greater than the neat resin. This is enough to carry all normal loads expected in the bayonet—the force required to rotate under spring load, and the force between the mirror housing and the door.

C. Thermal properties

The heat deflection temperature is of the order of 200 C and is quite significantly greater than for plain Nylon. HDT is of the order of 490 F (254 C) when the load is 66psi (0.46 Mpa). This

suggests that the HDT is well above the typical operating temperature for an external automotive component.

D. Dimensional stability

Finally another benefit of GF Nylon compared to Nylon. Dimension stability of parts. Because standard Nylon absorbs moisture, there is a relatively large change in dimension. Glass fibers, have a fairly good degree of stability, and they do not expand and contract. In a case of fitting the part accurately, it may be a significant advantage to the part in question.

E. Wear and chemical resistance

The rate of wear is starting to approach that of intrinsically lubricated bearing materials and scratch & abrasion resistance is significantly increased with the use of glass fibers. This material is immune to attack from fuels and oils. Chemical resistance limitations are those encountered with normal Nylon although this incorporates lack of resistance to water uptake, which is the main factor. However this is somewhat negated by the glass fibers sensitivity to water.

F. Impact resistance and electrical properties

Nylon, which has inherently tough structure is able to transmit and even strengthen its good impact strength through addition of glass fiber. The good impact resistance is desirable since the mirror assembly is likely to suffer from impact. Nylon is an electrical insulator.

Table I: Material Comparison — Aluminium vs. Nylon 6/6 (30% GF)

Property	Aluminium	Nylon 6/6 (30% GF)
Density	~2700 kg/m ³	~1350–1400 kg/m ³
Weight	Higher (heavier)	~50% lighter than aluminium
Tensile Strength	70–700 MPa	150–250 MPa
Strength-to-Weight	Moderate	High
Stiffness (Young's Modulus)	~69 GPa	~8–12 GPa
Thermal Resistance	Good (>100°C loss)	Good (HDT ~200°C with GF)
Corrosion Resistance	Excellent	Excellent (no corrosion)
Machinability	Excellent	Good (3D

		printable)
Manufacturing Method	Casting, machining	3D printing, injection molding
Production Time	Higher (multi-step)	Lower (layer-by-layer AM)
Material Waste	More (machining losses)	Minimal (additive process)
Impact Resistance	Moderate	Good
Wear Resistance	Moderate	High
Cost	Higher	Lower (especially in AM)
Moisture Absorption	None	Present (minor effect)

IV. PLASTIC MATERIAL SELECTION

From the selected list of engineering plastics, the most suitable material for this application needed to be sieved through. The candidates were chosen based on what their mechanical characteristics, if it would be possible to process this part on the current manufacture processes, if the information regarding the material and process would be readily available within the project, and the cost of both the material and the process.

PEEK (Polyether ether ketone) with 30% glass was investigated, its mechanical and thermal properties are excellent and was identified at the beginning of the design stage but was uneconomical when considering injection moulding or additive manufacture as PEEK is more expensive than the others. This material was discounted due to cost.

PPE (Polyphenylene ether) was rejected for reasons similar to those listed above and was discarded due to cost and a lack of readily commercially available plastic with competitive properties at a reasonable cost. Of the three remaining in the short list PBT (Polybutylene terephthalate), Acetal (POM) and Nylon 6/6 with 30% glass, all are suitable for injection moulding and all are at a relatively similar cost. It was the Nylon 6/6 GF30 that was selected for use in the application due to the stiffness of the material. When using 30% glass fill, Nylon has a higher flexural modulus than PBT or POM giving it resistance to deflection under the spring load and under general load.

V. ADDITIVE MANUFACTURING - FDM PROCESS

Additive Manufacturing (AM), otherwise known as 3D printing was the chosen method of manufacture for this part. Of the AM processes that are available, FDM was chosen because of its ability to build complex parts from engineering plastics, more specifically filled nylon, and because it was a cheap way of producing functional parts without expensive tooling that would be required using a technique such as injection molding. The process starts by taking the 3-D CAD model constructed in CATIA V5, which is then translated into an STL file. This is then used to form the instructions which will be sent to the printer, the STL file is used by slicing software which will translate it into X, Y movements and Z movements between layers (G-code). The material is a thermoplastic that comes in a filament format wound on a spool which is pushed through a heated head which melts the plastic and extrudes the filament. The liquefied plastic solidifies once it has been applied and bonds with the material that has already been printed forming a part.

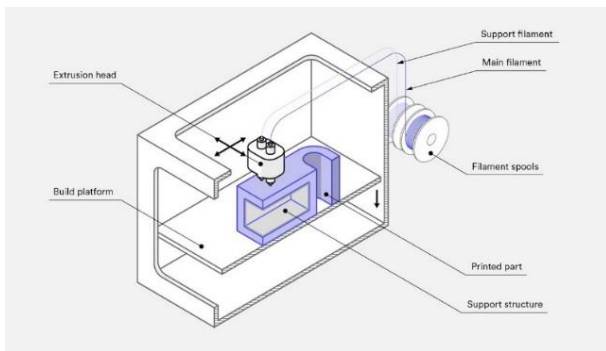


Fig. 2: FDM process — layer-by-layer deposition of thermoplastic filament

A. FDM Machine Specifications

The bayonet was produced on a standard FDM printer with a high quality dual extruder (capable of high resolution at fairly high extrusion rates) machine with 0.2mm accuracy-sufficient given the tolerances required on this part. All filament is stored in a dry, sealed environment to prevent water absorption (especially important for hygroscopic Nylon 6/6).

B. FDM Process Characteristics

FDM is suitable for this project due to several properties. Its layered structure does not impose a need for further tooling when complex internal shapes are to be produced, like the wiring channels within the bayonet. There is little waste, as material is only added where required; in supporting structures and (where parts have failed) in misplaced layers; both vastly less wasteful than swarf from machining. There is a useful trade-off to be made between weight and stiffness via choice of infill density, a parameter that is not usually adjustable when

manufacturing parts. Surface finish cannot be ideal, but visible layer lines can be post-processed.

C. Infill and Shell Optimisation

The printed object using FDM is not an solid object; it is a two part structure: a shell (the exterior of the part, printed several passes which gives to the most surface quality and stiffness) and a infill (internal structure printed with low density so reduce weight and printing time and, provide a support through the thickness). The infill percentage used for this section was 20-40% and this seems like a reasonable balance between weight and load carrying capacity of the part. The shell thickness was 1-2mm. The higher the infill percentage, the greater the strength of the part would be, but print time and cost of materials would also increase which is probably not needed where the bayonet is being used..



Fig. 3: CATIA BAYONUT MODEL

D. Common FDM Materials

There are so many types of thermoplastic materials for the FDM printer to be employed. For desktop printing, the PLA is widely used due to moderate print temperature and surface quality, but with limited resistance to thermal effects and strength. The ABS provides the highest strength, ductility and resistance to thermal effects, but it is harder to print, especially, the part would warp while printing in the free space, which can be addressed by the heated enclosure. PETG provide a compromise, with the level of ease to print more similar to PLA but with a bit higher strength and chemical resistance, and with less warpage. The nylon possesses extremely high strength, wear resistance and is perfect for long-term use, but requires high temperature during printing and strict control over moisture content of the filament. An example would be PA 6/6 GF30 as used here. The highest end of the scale are the high performance materials of PEI and PEEK, intended for the extremely demanding, high temperature, and high chemical resistance applications.

VI. PROCESS DEFECTS AND SOLUTIONS

Like any manufacturing method, FDM also has a number of defect associated with it that must be understood and managed to

allow for a viable component which satisfies the dimensional requirements and the mechanical specification.

A. Warping

Warping is arguably the most common of all the FDM defects and it occurs due to the thermal gradient existing between the hot layer of plastic just laid down, and the cold layer underneath. As the plastic cools and contracts the resultant stresses are applied over the entire part and this can lead to the lower edges of the part pulling upward distorting especially the flat surfaces of the part. In order to manage this print platform and build chamber temperature must be carefully controlled. Bed adhesives suitable to the specific material and the avoiding of large flat surfaces is beneficial (or at least corner fillets so that sharp angles do not become points of high stress).

B. Layer Adhesion

The bond between successive layers is what contributes to the final strength of the component along the Z axis and as such must be sufficient. The layer bonding depends upon the extrusion temperature of the filament. If too low, the plastic does not melt and fuse correctly; if too high, it begins to degrade and forms strings across the build bed. Printing speed and filament feed rate also influence the layer bond strength.

C. Support structures

The design of the bayonet was found to have features which demanded supports as they had overhangs and as such would not print on their own. Support structures are just an additional build using the same material that is built with the part, which is removed afterward. Since removal from the interior of the part would be difficult, a re-design of the component was made so that all internal geometry was self-supporting. With more work on the project further improvement could be made in the design, perhaps on a dual extruder machine where a water dissolvable filament is used to create support structures.

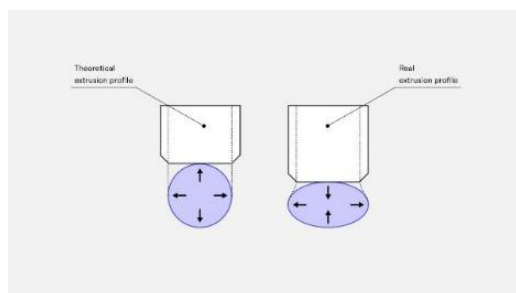


Fig. 4: Support structure in FDM — temporary material removed post-print

D. Surface Finish and Post-Processing

As all layers are being printed with the FDM method they are building up steps on all curved surfaces, with this plus the need for good contact with the mirror assembly (with which smooth

surface finish was necessary for fit/operation of bayonet), it was necessary to post process the surfaces by sanding through progressively finer grits of paper and coating over the layer junctions to "seal in" the layer boundaries and localized machining of close fit surfaces where necessary. Although very time consuming it gave a usable component.

VII. CAD MODELLING AND ANALYSIS USING CATIA V5

A. An Introduction to CATIA V5

CATIA (Computer-Aided Three-dimensional Interactive Application) is owned by Dassault Systèmes and it is a set of CAD/CAM/CAE software applications currently used extensively in the areas of mechanical, aerospace and automobile design. This software suite encompasses the whole process of product development; starting from the initial design concept through the detail 3D modeling, the engineering analysis and eventually the production planning process. CATIA V5 was chosen for this project in order to allow the parametric development of the bayonet geometry so that each design variable can be easily updated and the whole model updated accordingly. The analytical features were also useful in order to verify that the developed geometry performed as required before any production could be attempted in reality.

B. The Modeling Strategy

The geometry of the bayonet was modeled as follows: first a 2D sketch was produced by referencing the existing aluminum part to dictate the required geometry and this was extruded in 3D by using the standard feature modeling tools. Pad was used to extrude the geometry while Pocket was used to subtract material. A Rib feature was employed to generate a swept solid and Fillet features were added to all interior corners and any features known to have high stress concentration in order to minimize peak stresses when the structure was loaded. The functional geometry was also checked against the mating features of the mirror to ensure it would assemble correctly and modified if necessary.

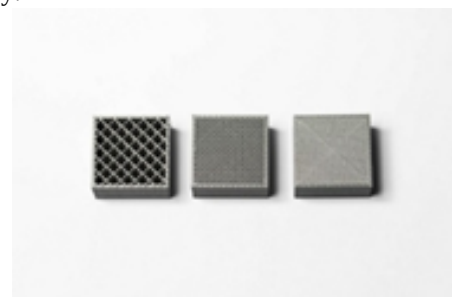


Fig. 5: SUPPORTING MATERIAL

C. Data for CAD Model

From the CATIA model, geometric and mass properties were directly fed into subsequent manufacturing and analysis operations. The volume was 4.9246 cm and the projected area was 17.8290 cm. After assigning Nylon 6/6 (30% GF) to the

model, with the given density between 1.35-1.40 g/cm, the mass of the part became 7.08 g, far less than aluminum equivalent. It had quite a complex shape, difficult to be cast, with many post machining steps required.

D. Mesh and Moldflow Analysis Data

The geometry was meshed with a dual-domain mesh type, a mesh quality and match of 85.9%, and an average aspect ratio of 3.03. These values are well within reasonable limits to provide meaningful moldflow analysis. Critical data extracted from the Moldflow analysis included one optimized gate location, 0.6412 seconds for filling time, a maximum injection pressure of 9.56 MPa and a cooling time of 20 seconds. These results confirmed that the part is relatively straightforward to injection mold, with a low tendency for problems such as short shots and weld lines in inappropriate locations.



Fig. 6: 3d Printed bayonet component

E. The Role of CATIA in the preparation of the model for 3D Printing

Once more, the model generated in CATIA can be fed into the additive manufacturing workflow. The model geometry is then translated into an STL file format. It is this file format which the FDM slicing software uses. The orientation of the model during the modelling process will have been considered in relation to the 3D printing process; critical surfaces are likely to be oriented to maximize supports, and features load-bearing when supported in-plane, with strength, will be oriented this way inherent to FDM processes. With iterative designs, the changes are made, and re-translated so the toolpath generation costs are minimal..

VIII. ADVANTAGES OF 3D PRINTING FOR THE BAYONET COMPONENT

There would be several arguments of preferring to build bayonet by additive manufacturing (FDM) compare to manufacture aluminum part through casting and machining. Some specific arguments exist that are important enough to list: combined

together they make a case that the change in process is as important as the change in materials.

A. Weight Saving

Compared to the aluminum, Nylon 6/6 GF30 is less dense, making the shape equivalent roughly one half the weight. On an automobile, for example, with two bayonet assemblies on two doors, while each part is small on its own, the combined saving of weight for thousands of part cycles over the life of a production vehicle represents a significant reduction

. B.Material Efficiency

Only areas where the part has geometry are built using FDM, opposed to subtractive manufacturing where the desired geometry would be carved from a block of aluminum, generating swarf waste from unwanted aluminum removed. FDM material utilization for the part is ~100%; the generated support structures are 'waste'. Both cost and environmental benefits can be seen from a high material utilization.

C.Freedom of Geometry

The internal channels, internal strengthening (lattice/internal ribs), undercut profiles, etc are not a challenge for FDM without subsequent machining processes or tooling. The internal wire channels of the bayonet, for example, can just be holes in CATIA and they become solid plastic components through the build process of FDM.

D.Speed & Cost of low volume production

With conventional methods the long time for mold or casting manufacture of an aluminum part and the associated tooling cost and time are completely removed in a low volume or prototyping situation. Changes are made to the part's CATIA file and printing recommences - delivery hours or days not weeks away.

E.Ease of design iteration

If after initial testing a slight dimensional error needs correction such as a slightly more loose fit at the door interface or a stronger internal rib to support the unexpected load stress concentration; the modification is a simple change in CATIA and a rapid turn around can be achieved as per above. With cast aluminum the tool modification and time involved for this is prohibitive.

F.Reduced assembly complexity

Components where features, which previously were integral parts of the component (e.g. A channel for wire leads integrated into a part's structure), were separate parts that needed to be

manufactured and then assembled, can now be a single built part. Having fewer components in an assembly can reduce the chance of assembly error. Fewer fasteners or adhesives will also be needed.

IX. RESULTS AND DISCUSSION

Overall the Nylon 6/6 (30% GF) bayonet that was produced as part of this project meets the demands of the original Aluminium part and demonstrates several advantages over the original;

The weight saving of approximately 50% on the original part is arguably the most easily noticeable and quantifiable benefit brought about by changing to a plastic material. A saving of 7.08g has been achieved on the bayonet, a benefit that is greatly magnified when produced at a fleet level. The material exhibits increased strength to weight over the original part. This benefit arises from the significantly lower density of GF30 Nylon compared to Aluminium. The tensile strength is less for GF30 Nylon than Aluminium, but this is outweighed by the considerably larger strength to weight of the Nylon material (26.6MPa/g for GF30 Nylon compared to 19.4MPa/g for Aluminium).

The impact test demonstrates that the plastic bayonet can sustain the impact forces generated by a collision without exhibiting a failure (cracking) of the part, which is highly desirable as the wing mirror unit can often be exposed to similar damage during every day use. Casting defects can occur during die-casting of aluminium, and they result in weakened regions on the part, these will not be present in the FDM produced Nylon component; reliability is likely to be greater.

The Moldflow demonstrates that the component can be injection molded, suggesting that at high volume the part is manufacturable if the component were to be moved to production. No defects were produced in the Moldflow analysis, such as short shots, undesirable weld line positions or sink marks on critical working surfaces. The predicted fill time was 0.6412 seconds and the injection pressure was 9.56MPa, these values were well within acceptable limits of a molding machine.

With regards to cost, reducing the requirements for casting, machining and post-machining will increase the rate of manufacture and decrease the manufacturing time. Furthermore the raw material costs are significantly lower for polymer compounds than those for aluminum alloys used within the aerospace industry. The overall cost is therefore substantially less for the replacement part.

X. CONCLUSION

On the whole the Nylon 6/6 (30% GF) bayonet that was produced during this project fulfilled the requirement of the original Aluminium part and was seen to offer various improvements over the original;

The approximate 50% weight saving over the original part is perhaps the most easily quantifiable and noticeable improvement resulting from the move from Aluminium to plastic. A weight saving of 7.08g was achieved for the bayonet alone; a benefit which would be greatly amplified at fleet level. A strength to weight improvement over the original part was found to exist for the replacement part. This is due to the considerably lower density for GF30 Nylon in comparison to Aluminium. Although the tensile strength for GF30 Nylon is less than Aluminium the very significantly greater strength to weight of the Nylon compound (26.6MPa/g compared to 19.4MPa/g for Aluminium) more than makes up for this difference.

It has been seen that the plastic bayonet can withstand the impacts sustained during a collision and not exhibit a (cracked) failure of the part which is highly desirable as in everyday life, impacts equivalent to that on a wing mirror unit can be expected, and can even lead to damage. It is possible for defects to exist on a cast aluminium part which would weaken it, and will be avoided when manufacturing the FDM manufactured Nylon part making it more reliable.

The Moldflow has shown that the part could be injection molded if it were to go into mass production and that a high quality, flaw-less part could be produced, no undesirable weld line locations, sink marks on critical surfaces or short shots have appeared during this analysis. This part can be expected to be moldable. The predicted fill time and injection pressure was shown to be at reasonable levels (0.6412s fill time and 9.56MPa injection pressure).

With reference to cost, the absence of post machining processes (such as casting of metal, followed by machining of it) will reduce the time spent manufacturing the part. It is also the case that polymer raw material costs are significantly less than those incurred for an Aluminium alloy suitable for an aircraft part. Therefore the cost of producing a replacement part can be greatly reduced.

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