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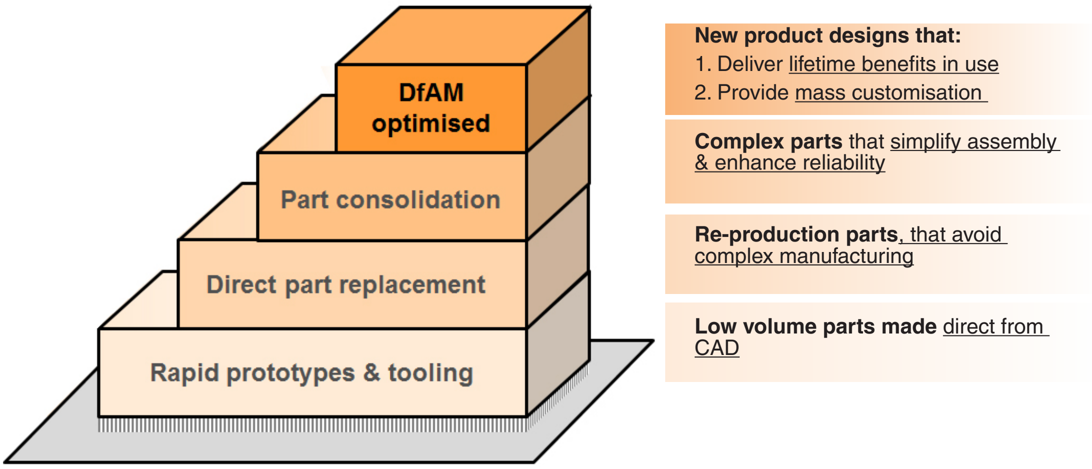
Additive impact part #2 - how additive manufacturing could disrupt your market

Metal 3D printing has the potential to shake up the way that we design and make products, creating opportunities for valuable innovations and whole new business models. In this second feature article of two, I am exploring the nature of the changes that additive manufacturing (AM) could bring to product markets, and the steps that companies can take to lead this disruption.

In the first post Additive impact part #1, I introduced a staircase model of AM adoption, and explained how the production and lifetime benefits of AM increase as you move up through the levels. These benefits build up as you employ more and more of the unique characteristics of AM.

Having explored the first two steps of the staircase in part #1. In this feature article, I will detal the two upper steps.

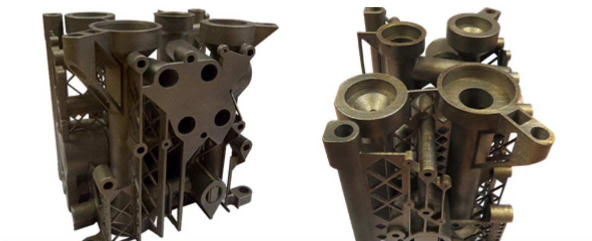


Level 2 - Part consolidation

This is the first step where we start to change the design of our product to take advantage of AM's ability to make complex shapes. In this instance, we are looking to simplify our product by combining collections of parts into a single, integral build. There are three AM capabilities in play at this level:

Feature rich components

Details can be designed in and built directly, rather than requiring additional process steps



Manifold with complex pipework and struts

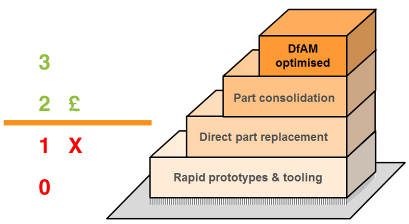
a. Feature-rich components

AM enables detailed features to be designed and built into components in a single operation, rather than requiring additional process steps. We take complexity out of the process and put it into the part.

Consolidating these multiple steps into a single additive operation reaps many production cost benefits including; reduced tooling costs, shorter overall processing time, shorter lead time, and replacement of complex assembly processes with a single, automated build.

Production benefits

- £ Lower tooling costs
- £ Shorter processing time
- £ Shorter lead time
- £ Simpler assembly
- £ Automation



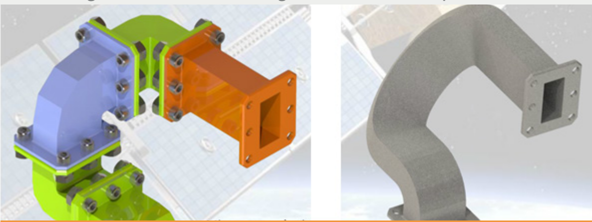
b. Removal of joints

Joints find their way into product designs to enable complex shapes to be produced that cannot be formed in a single conventional manufacturing operation. Joints mean mating features, fixings, connectors, gaskets and seals. They add to the part count, the weight, the processing time and the assembly time of a product. They also create points of potential weakness and mismatch between parts that have been separately manufactured, resulting in potential failure modes and performance shortfalls. Joints are best avoided!

AM enables complex shapes - e.g. the twisting waveguide shown below - to be made in a single operation. This can lead both to cost savings in assembly and to a range of lifetime benefits in use.

Removal of joints

Combining an assembly of parts into a single component, removing interfaces, bonds, gaskets and clamps



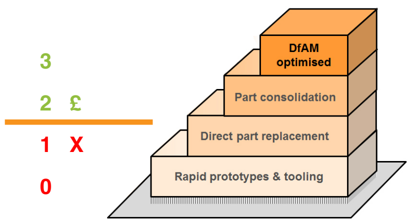
One-piece microwave guide for space application

Production benefits

- £ Simpler assembly

Lifetime benefits

- £ Less weight
- £ Faster product launch
- £ Product reliability
- £ Increased performance



c. Mechanisms

It is possible to produce interlinked mechanisms in a single AM build, that then require no further assembly. The results can be neat, functional and highly attractive.

Mechanisms

Multi-component mechanisms built together in an inter-linked state

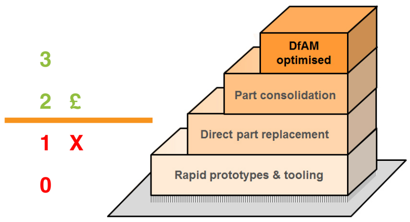
Interlocking titanium 'heartvalve' necklace

Production benefits

- £ Simpler assembly
- £ Automation

Lifetime benefits

- £ Faster product launch
- £ Product attraction



Level 3 - DfAM optimised

So now we've reached the top step, where the most advanced capabilities are deployed. We are employing Design for AM (DfAM) principles to take full advantage of the freedom available to us. Here, everything is open to optimisation, resulting in some radical and customised solutions. There are quite a few capabilities to think about here:

a. Hollow / porous structures

Many parts are produced conventionally with solid structures, even though a hollow structure is often as strong, simply because it is too difficult or expensive to access the material in the middle. AM enables hollow structures to be readily produced in a single operation, with the added bonus of reduced material use and shorter build times. Lattices can also be used to lighten components, often by as much as 50%, whilst retaining stiffness.

b. Topological optimisation

Another technique for light-weighting is topological optimisation. The principle here is to define the interfaces that the component has with the rest of the mechanism and the loads that it has to carry. Then we look at the stresses in the material that these loads induce and remove material that is under the least strain. This leaves the most efficient way for the material to transmit the specified loads.

The example below is a bracket in a space application, where weight really is at a premium. The conventional bracket evolves into a hollow freeform shape - we call it the 'fingers of fate' - reducing mass by a third. The lead time to design and produce a radical new design can also be surprisingly short.

Hollow / porous structures

Replace solid structures with shelled or lattice-filled designs

Solid valve body — Lattice-filled design

50% mass reduction

Topological optimisation

Part shape optimised to transmit loads with unstressed material removed

Conventional bracket — Optimised design

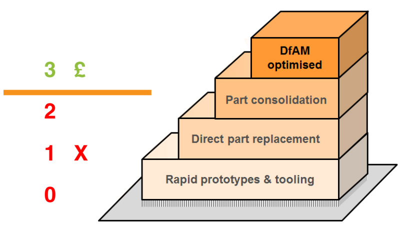
34% mass reduction, 10 week design & build

Production benefits

- £ Less wasted materials
- £ Shorter processing time

Lifetime benefits

- £ Less weight

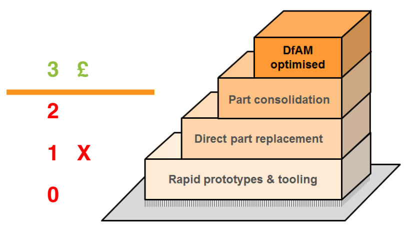


Production benefits

- £ Less wasted materials
- £ Lower tooling costs

Lifetime benefits

- £ Less weight
- £ Faster product launch



c. Improved aesthetics

AM gives us the freedom to design unusual, organic forms, which can be used in creative ways to design attractive products, such as jewellery.

d. Increased surface area

Load-bearing interfaces often require a large surface area to ensure good adhesion. This is particularly true in orthopaedic implants, where clinicians want to promote integration between the metal implant and the neighbouring bone, to build a strong bond and to prevent 'stress shielding' and subsequent surgical revision. This is currently an area of intense research, with investigations into osseointegration with regular and irregular lattices designs.

Another application that benefits from large and carefully designed interface surfaces is bonding of metal and composite parts.

Improved aesthetics

Freedom to produce unusual and graceful shapes

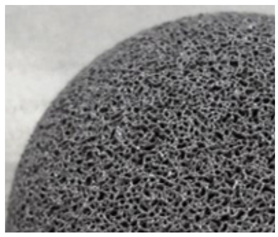
Aorta necklace

Increased surface area

Complex and textured surfaces enabling different interfaces with other system or anatomical elements

Load bearing orthopaedic implant lattices designed to encourage bone regrowth

Random lattice femoral cup exterior (in partnership with Imperial College, London)



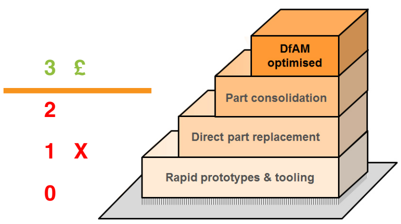
Production benefits

£ Simpler assembly

Lifetime benefits

£ Better adaption

£ Product attraction



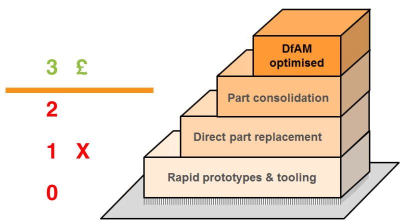
Production benefits

£ Less wasted materials

Lifetime benefits

£ Increased performance

£ Better adaption



e. Increased heat transfer

Heat exchangers are a great application for AM. To maximise heat transfer between one fluid and another, a heat exchanger ideally comprises a network of complex micro-channels with thin primary walls, and complex secondary surfaces. The unique capability of AM to produce detailed internal and external features cost-effectively means that more efficient heat exchangers are possible, enabling either lighter weight, or higher performance, or both. This is of obvious interest for motorsport, road vehicle design and green energy applications.

Conformal cooling, mentioned in feature article part #1 in the context of mould tool design, can also be applied to components that require cooling during their use. Intricate channels that follow the component surface enable heat to be efficiently carried away from the component core.

f. High strength alloys

The difficulty of machining some alloys can prevent their practical use, even though they may exhibit highly desirable thermal and mechanical properties. AM is essentially a welding process, and so, provided the alloy can be 'atomised' into a powder, it may be possible to process such challenging materials using laser techniques. Exotic alloys are generally expensive, so minimising waste through near-net-shape processing is also helpful.

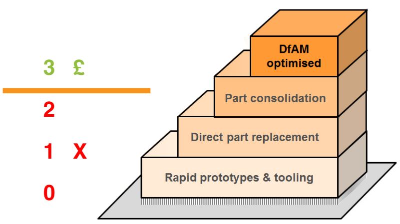
Increased heat transfer

Intricate fluid micro-channels and complex external surfaces, enabling greater heat flow per unit volume

Compact aluminium heat exchanger for a race car

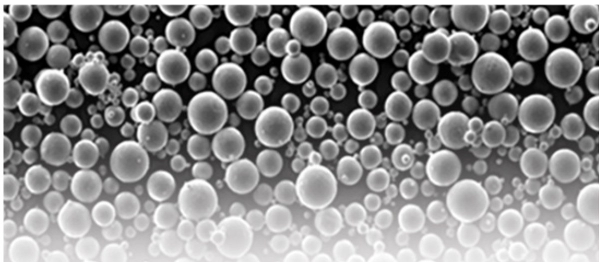
Production benefits
- £ Less wasted materials
- £ Lower tooling costs
- £ Simpler assembly

Lifetime benefits
- £ Increased performance



High strength alloys

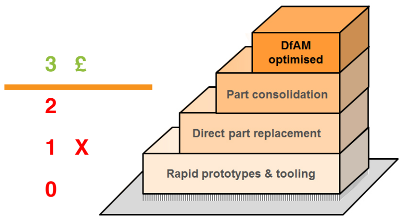
Fully dense and high strength alloys, those that are not used now due to poor machinability



Process exotic / expensive alloys with no waste

Production benefits
- £ Lower tooling costs

Lifetime benefits
- £ Product reliability
- £ Increased performance



g. Architectured materials

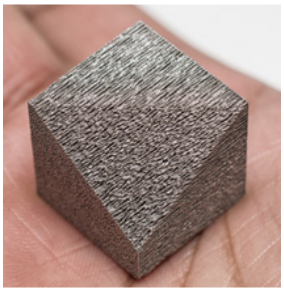
AM's ability produce fine lattices opens up the possibility to make metal 'foams' with carefully tailored properties. Such micro-structured materials could be designed to include anisotropic properties - e.g. different stiffness and thermal conductivity in different planes. This is a bit like topological optimisation, but on a microscopic scale. Standard and bespoke architectured materials open up new possibilities for lightweight, high performance products. The examples below are provided by Betatype.

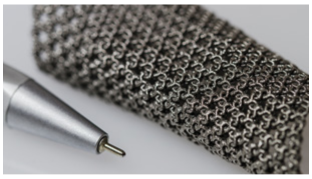
h. Build the bill of materials

Because AM requires no tooling, you can combine different elements of a product together in a single build. This means that you can make all the major components of a product in one go, so that they can then be post-processed and assembled together. This makes for easier scheduling, reduced stocking, and offers the option to combine this with localised production and mass customisation for superior service.

Anisotropic properties

Metal 'foams' exhibiting different stiffness and thermal conductivity in different planes





'Architectured' materials with bespoke mechanical properties

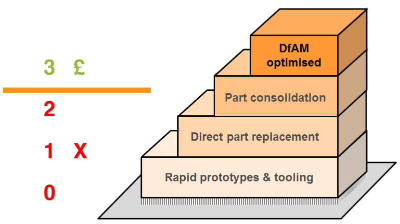
Image courtesy of Betatype

Production benefits

£ N/A

Lifetime benefits

£ Product attraction
£ Increased performance
£ Better adaption



Build the Bill of Materials

Produce a suite of parts to construct a product in a single build

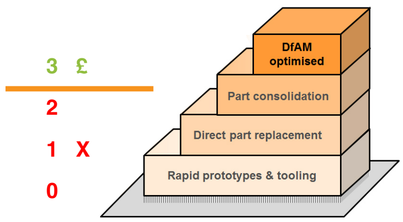
Bike frame kit on a build plate (l) and assembled (r)

Production benefits

£ Shorter lead time
£ Simpler assembly

Lifetime benefits

£ Reduced stocking



i. Mass customisation

Provided that you have a CAD model for the part you're trying to make, it makes very little difference in terms of cost and build time if that part is exactly the same as others that have gone before, or if it is slightly different. The lack of tooling required for AM means that customised part production can be very cost-effective. A great example of this is Renishaw's dental implants business - we make hundreds of unique restorations every day, based on designs sent to us by different dental laboratories. These are consolidated into a single build to keep costs low.

Mass customisation relies on an effective upstream process chain: accurate measurement of the situation in which the part will be deployed, user-friendly CAD design of the custom product, and software to convert the CAD model into a producible AM build.

The benefit to the user of customised parts is better adaptation to its context, which can lead to easier fitting, better outcomes, and a higher value service. When combined with other AM capabilities, customised production opens up opportunities to disrupt mass produced business models.

Mass customisation

Matching of product design to its context in use, creating optimised forms and interfaces

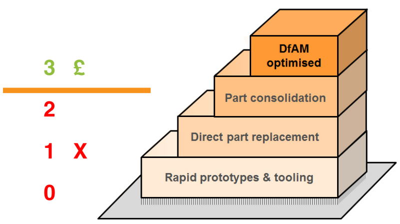
Production benefits

£ Lower tooling costs

Lifetime benefits

£ Product reliability

£ Increased performance



Summary - part #2

So we've completed our journey to the top of the staircase, employing more and more AM capabilities along the way. Of course, it's not essential to use all of these in your AM product - just pick those that will create the greatest value for your customers, and save you the most in bringing your innovative new product to market.

I hope that this framework is useful to help you to analyse how AM could impact on your market, and to think about the approach that you could take to lead the change in your sector.

Next steps

Visit www.renishaw.com/amguide for more educational resources and to access downloadable versions of feature articles and white papers by Renishaw authors.

About the author

Marc Saunders, Director of AM Applications

Marc Saunders has over 25 years' experience in high tech manufacturing. In previous positions at Renishaw, he played a key role in developing the company award-winning RAMTIC automated machining platform, and has also delivered turnkey metrology solutions to customers in the aerospace sector.

Marc manages Renishaw's global network of Additive Manufacturing Solutions Centres, enabling customers who are considering deploying AM as a production process to gain hands-on experience with the technology before committing to a new facility.

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