Renishaw plc

New Mills, Wotton-under-Edge,
Gloucestershire, GL12 8JR
United Kingdom

T +44 (0)1453 524524
F +44 (0)1453 524901
E uk@renishaw.com

www.renishaw.com

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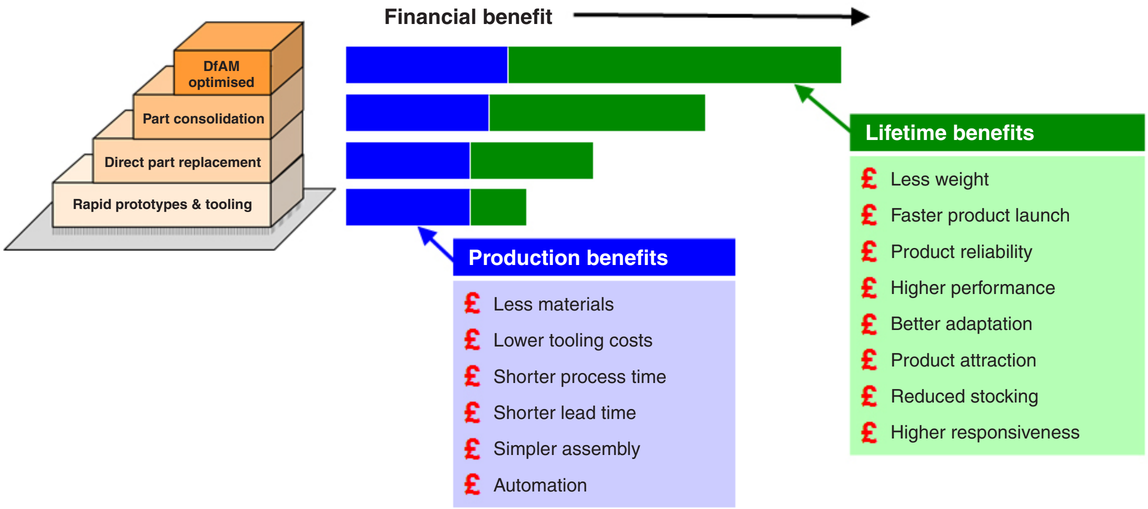
DfAM strategy - create 'design space' for maximum AM impact



What do we mean by DfAM strategy?

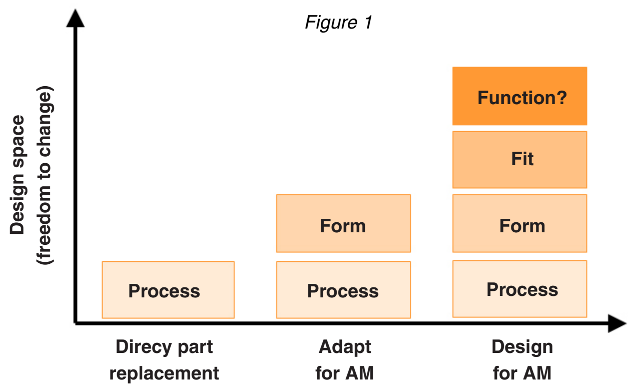
In the feature article *DfAM essentials - print parts efficiently and effectively*, I explained some of the technical characteristics and constraints of the laser melting process and how this drives rules for part features and the additive manufacturing (AM) build specification. This knowledge is tactical - it helps us to build successfully what we have designed, but doesn't tell us what we could design.

This post looks at the higher level strategic considerations around how far we can push our design to yield the best performing product.

How much freedom do you have?

AM gives us tremendous freedom to design innovative products, with its unique capability to build intricate and customised parts. Carefully applied, these design strategies can result in cost-effective, light-weight, high performing products that create valuable benefits during their lifetime of use. I have discussed these capabilities and benefits at length in my articles *Additive impact part #1* and *Additive impact part #2.*

Figure 1



How many of these AM capabilities we can exploit, and how much benefit we can accrue, will depend on the level of freedom or constraint that we are operating under. Another way of thinking about this is the size of the 'design space' within which we can optimise our design (see Figure 1).

Direct part replacement

At one extreme, there may be no freedom to change the part design at all - i.e. AM is being used simply for direct part replacement. We have chosen to keep the design fixed as the cost and time required to prepare, prove and qualify a new design may be prohibitive. The AM part must be a form, fit and function replacement for the existing part, with no changes to its shape or to its interfaces with other elements of the system. The only change is the process - i.e. a switch to AM, which can bring time compression and automation benefits through elimination of complex tooling and manual processing, and perhaps also reduced material consumption through near-net-shape manufacture.

Component-level adaptation

If our design space expands to the component level, then we can make changes to the form of the component to take account of AM process capabilities and limitations. Here the AM part must be a fit and function replacement for the current part, but we have freedom to change both the process and the part form. In this case we can adapt for AM (AfAM), often delivering significant weight, cost and performance advantages.

System-level ‘clean sheet’ design

If our design space extends beyond the component and out to a system or sub-system level, then we can truly design for AM (DfAM). We have the opportunity to create a ‘clean sheet’ design that fully exploits the capabilities of AM. Now even the component’s function may be open for change, as well as its fit, form and the process used to make it. By influencing design decisions at a system level, we can optimise the performance of the product, not just the part.

Case study - hydraulic manifold

So let’s look at how this plays out in practice by considering a common design problem: a hydraulic manifold for a circuit operating at pressures in the order of 200-500 bar. This is a weight limited application and comprises a simple circuit consisting of two check valves, a solenoid valve and their associated outlet ports (male insert type).

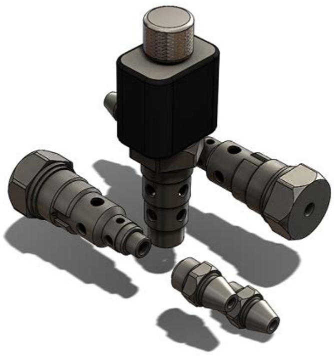
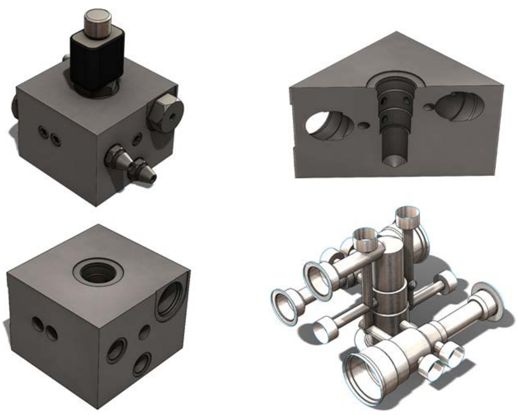


Image above: key elements of a hydraulic manifold circuit

Conventional design - block manifold

We’ll start with the default option - a conventional block manifold designed with machining processes in mind. This design has a mass of 4.6 kg (10 lbs).

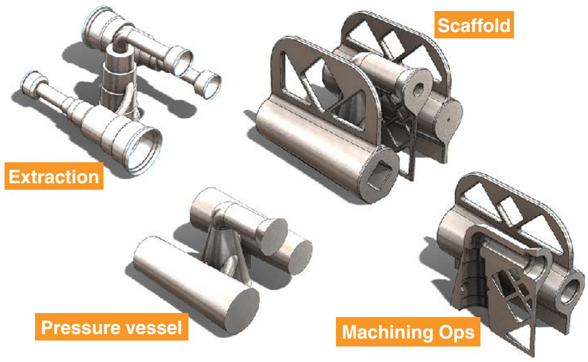


The benefits of this simple approach are that the design phase is relatively straightforward and that the manufacturing cycle time for this simple circuit is short. The limitations are that we get sub-optimal fluid transfer performance due to the cross-drilled pipe network, the part is massive and therefore compromises product performance whilst using material inefficiently, and that we require eight additional pressure plug parts to complete the assembly.

Adapt for AM (AfAM)

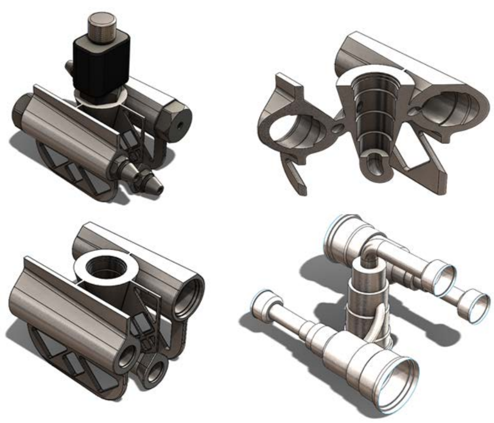
Now let’s see how we can improve this design by optimising the form of our manifold to suit an AM process. Remember that the hydraulic circuit has to stay the same, as does the positioning of the valves to mate with the surrounding pipework.

The AfAM design flow for the manifold starts with extraction and streamlining of the flow paths, around which we then create pressure vessels designed to withstand the specified loads. Next we determine the part orientation during build and apply a scaffold, which ties the valve elements together and provides support during the build process. Finally we consider the machining operations needed to create precision interface surfaces.



This process is explored in more detail in my post Minimal manifolds, which describes the application of AM to a more complex manifold design.

In our simple example, the result is a much more compact manifold, now with a mass of just 1.0 kg (2.2 lbs) - a 78% reduction. This ‘drop in’ replacement for the block manifold also features improved flow performance and requires no pressure plugs.



So good progress. However, there are still some limitations. Horizontal passages need supports, and we must leave sufficient material on for finish machining. We also find that such lightweight parts are naturally less rigid than their more massive counterparts, and this can complicate the finish machining process.

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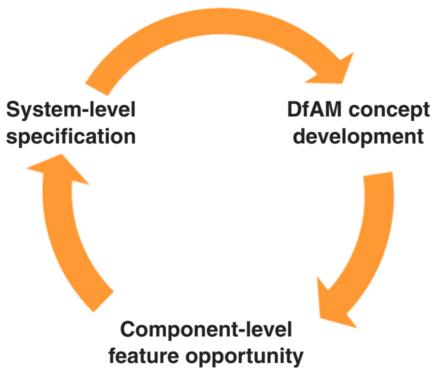
Design for AM (DfAM)

What can we do if we remove the remaining constraints and expand the design space out to the system level. The answer is 'quite a lot', but firstly some words on the DfAM process.

A true DfAM optimised product is always a clean sheet design that focuses on maximising performance for a particular application. Despite the freedom that AM offers us, we should still follow a rigorous design methodology as we would for any other design task, with engineering due diligence in areas such as cost/benefit analysis, concept evaluation, design optimisation and modification for manufacturability.

With AM product design, we see a closely coupled relationship between system-level specification, the DfAM work on our component, and the opportunities for component and system performance improvements that this throws up. AM's rapid manufacturing capability suits an iterative approach to product design optimisation:



In the case of our manifold, opening up the design space to the system level enables substantial further improvements. We can align all of the valves to point in the same direction so that the part is fully self-supporting, whilst also minimising the material needed to connect the flow channels. The compact part is also inherently more rigid and the valve alignment simplifies the finish machining task. We are also able to consolidate the outlet ports into the design, whilst further reducing the weight to just 0.4 kg (0.88 lbs) - less than half the AfAM design and a 91% reduction compared to the original block manifold.

Although DfAM of this nature is immensely powerful, it is fair to say that it is also demanding. The CAD work is often complex, whilst our system-level engineering and design must be flexible in order to react to and incorporate the potential advantages of DfAM.

Version	Mass (kg)	Saving
Conventional	4.6	-
AfAM	1.0	78%
DfAM	0.4	91%

Summary

AM really is a field where you get out what you put in. If you are able to give yourself the design space to think and work at a system level, then you can deploy more AM capabilities to create remarkably efficient and capable products.

DfAM optimised parts will be lighter, higher performing, faster to build and therefore more cost-effective than direct replacements or adapted designs.

If you fully embrace the capabilities of AM, then you can develop products with market-leading performance and a compelling business case.

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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