INSIGHT

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Introduction

Additive manufacturing (AM), also known as 3D printing, is used to describe the technique by which components or added features are built in layers direct from digital data, without the need for dedicated tooling and all the associated investment costs. The introduction of AM has brought a whole range of new opportunities to manufacture components with complex geometries. As with any manufacturing approach its application must be very carefully considered against cost, rate and product quality requirements.

08 ADDITIVE MANUFACTURING

Applications in Aerospace

EXECUTIVE SUMMARY

This INSIGHT paper has been compiled to disseminate the findings of an aerospace sector consultation enabled through a partnership with Additive manufacturing UK. This INSIGHT paper looks at the opportunities and challenges associated with the implementation of additive manufacturing technologies and how the benefits can be recognised across the aerospace structures, systems and propulsion communities.

The paper gives an aerospace specific focus which builds on Additive manufacturing UK's 2017 multi-sectorial national strategy paper "Leading additive manufacturing in the UK". Recommendations are provided for the civil aerospace sector to develop and exploit opportunities for a highly disruptive technology that has the potential to transform future aircraft platforms.

Metal powder bed fusion has been up to now, the primary focus of the aerospace industry but other technologies such as direct energy deposition are gaining in their significance in the UK sector. This is reflected in this INSIGHT paper where six key topics have been addressed to accelerate additive manufacturing (AM) within the UK aerospace sector.

1. **Materials for AM:** Develop the quality and productivity of AM material processes including powder generation, control of material properties and re-use of effluent powder.
2. **AM end-to-end Process:** Develop the end-to-end AM proc ess, including high value design for AM, digital manufacturing, post-processing and validation & verification.
3. **Certification and Standards:** Setting the standards for AM use in aerospace, including material use and achieving accurate and repeatable parts. Overcoming the certification obstacles associated with new AM processes.
4. **Cost:** Detailing and communicating the through-life cost implications of using AM in aerospace, including the identification of prohibitive costs and modelling of value added.
5. **Supply Chain:** Integrating the supply chain in AM and linking to academia. Ensuring that UK capability is realised to manufacture AM parts at a competitive price that address the sector requirements.
6. **AM and disruption:** Recognising the disruptive influence of additive manufacturing. Enabling the value of AM on current platforms and providing currently unrealised opportunities on next-gen platforms.

The ATI works alongside other national initiatives which have been set up to address AM in the aerospace sector including the Industrial Strategy Challenge Fund (ISCF) and the Made Smarter review. In this, the ATI will contribute to the acceleration of additive manufacturing technology opportunities through helping the formation of suitable technology projects that address the key requirements identified in this INSIGHT.

Leading UK aerospace manufacturing organisations were consulted as part of this document's preparation, and all recognise AM as a fundamental part of their future manufacturing strategies.

National Centre for Net Shape and Additive manufacturing - £14.2m

This project was funded jointly by the ATI and Innovate UK. It was undertaken by the MTC to establish the National Centre for Additive manufacturing. The aim of the centre is to develop production-ready additive manufacturing processes, to overcome barriers to wide-scale adoption, and to work on legislative and standardisation issues for this emerging activity.

The Centre has delivered over 100 projects for companies across the supply chain, including the manufacture of a flight-test front-bearing housing for the Trent XWB-97 engine. The project resulted in a 30% improvement in lead time and led to the largest aero engine structure to fly, incorporating AM components.

WHAT IS ADDITIVE MANUFACTURING?

The term additive manufacturing (AM), also known as 3D printing, is used to describe the manufacturing process by which components are built by adding material layer by layer, controlled directly from digital data. AM has no need for dedicated tooling, with its associated investment costs, and hence is highly flexible, with a short lead time. Companies have been using this technique in the UK since the late 1980s in a prototype environment to aid product development. In the 1990s the UK became one of the leading countries in using AM within the product development arena. Until recently, due to limitations in material properties and deposition rate, it has been largely a prototyping technique.

Advances in materials and machine technology mean that AM is now a truly transformational cross-sector technology that is having a disruptive impact on design, manufacturing, location, supply chains and business models. It enables new and better designs to be realised at lower cost, enhanced productivity and greater sustainability. AM is particularly appropriate for high value application areas including:

- Aerospace (small volumes, weight constraints)
- Space (small volumes, extreme weight constraints)
- Oil & Gas (one-off's, in-field repairs)
- Motorsport & premium automotive (low volume, customised parts)
- Medical (personalised parts)
- Customised consumer products

Figure 1: UK based Renishaw's RenAM 500Q additive manufacturing solution

The ATI has funded several projects with Renishaw as partners including DRAMA, HORIZON and WINDY. These projects have enabled the UK to develop as a leader of AM solutions

There are a range of distinct AM processes, from laser powder bed to plastic material parts created through vat polymerisation, which have varying process details and equipment needs. Aerospace requirements mean that the most applicable processes are powder bed fusion and direct energy deposition. These are detailed below.

Powder Bed Fusion

Powder bed additive manufacturing involves using a high energy heat source such as a laser or an electron beam to melt and fuse material powder particles together. The process involves spreading a uniform layer of powder material over a build platform. The heat source fuses the first cross section of the build from this layer, before the machine spreads another layer of powder on top and the process repeats for the next cross-section of the build. Un-fused powder remains in position but is removed during post processing. The materials used, and typical parts created by powder bed fusion are shown in Figure 2 and Table 1:

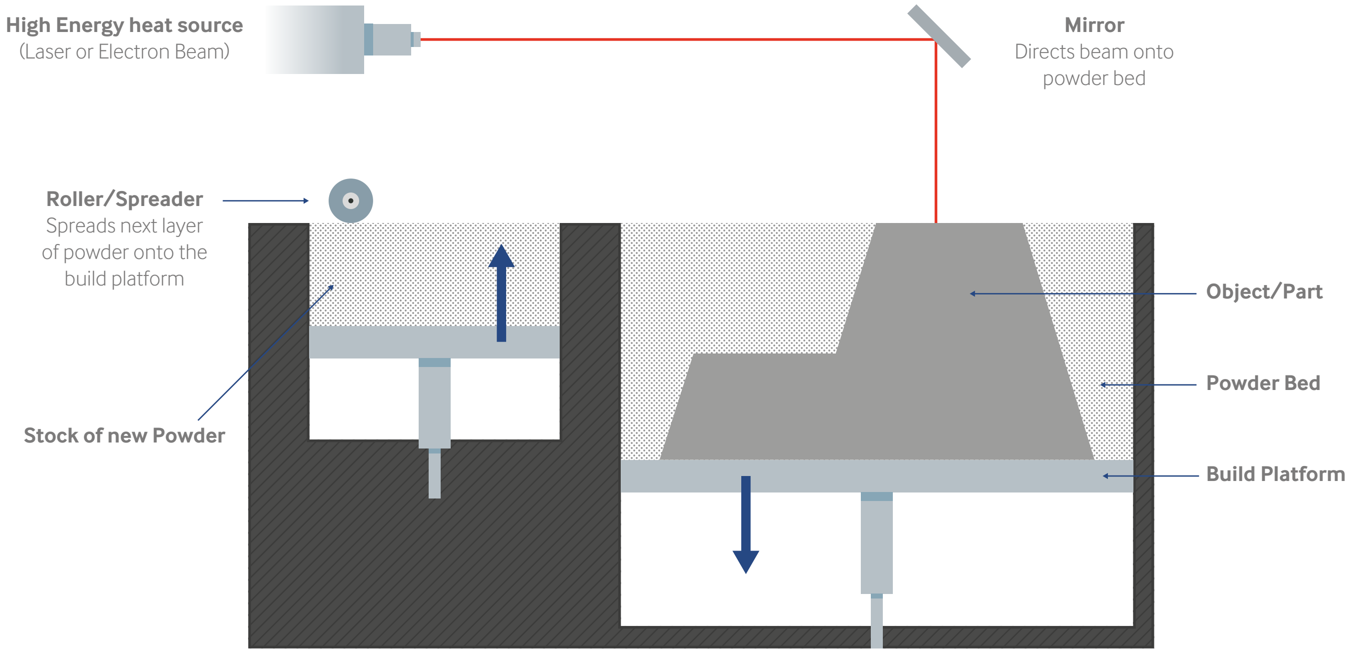


Figure 2: Typical Powder Bed Fusion machine layout

Classification	Material	Type	Typical Aerospace Component
Powder Bed Fusion	**Metal**	**Structural**	Borescope plug, Oiljet, Heat exchanger, Pipework, Ducting, Mounting brackets Vanes, Fuel Nozzle, Combustor head, Combustor tile
		System	Seat buckle, Hinge bracket
		Propulsion	Control valve, Hydraulic manifolds
	Polymer	**Structural**	Interior fittings
		Propulsion	Design prototypes
	Ceramic	**Propulsion**	Casting cores

Table 1: Typical aerospace components manufactured by powder bed fusion

Direct Energy Deposition (DED)

Direct Energy Deposition is typically used for larger scale builds. The process generally has a metal-depositing nozzle combined with a high energy heat source such as a laser, mounted on a multi-axis arm. The nozzle deposits powdered metal or wire metal and the heat source melts the deposited material onto the build below it. The arm allows metal to be deposited from many positions. As with powder bed fusion, the object or part is built up in layers. The materials used, and typical parts created by direct energy deposition are shown in Figure 3 and Table 2.

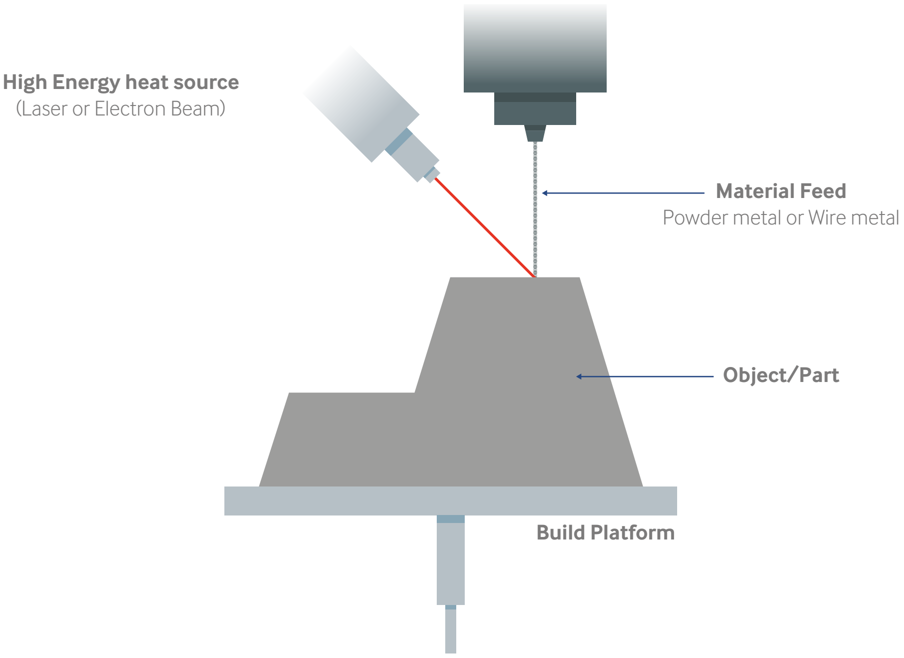


Figure 3: Typical Direct Energy Deposition machine layout

Classification	**Material**	**Type**	**Typical Aerospace Component**
Direct Energy Deposition	**Metal (powder)**	**Structural**	Premium seat frames
		Propulsion	Bearing Housing
	Metal (wire feed)	**Structural**	Spar Element, Rib elements, Seat Frame

Table 2: Typical aerospace components manufactured by Direct Energy Deposition

There are several other types of additive manufacturing techniques. Material Jetting and Binder Jetting work in similar ways to inkjet printers and use polymer ‘drops’ to build layers of an object. Vat polymerisation works by using an ultraviolet light to locally cure specific points to build a solid within a vat of a liquid photo-sensitive polymer resin.

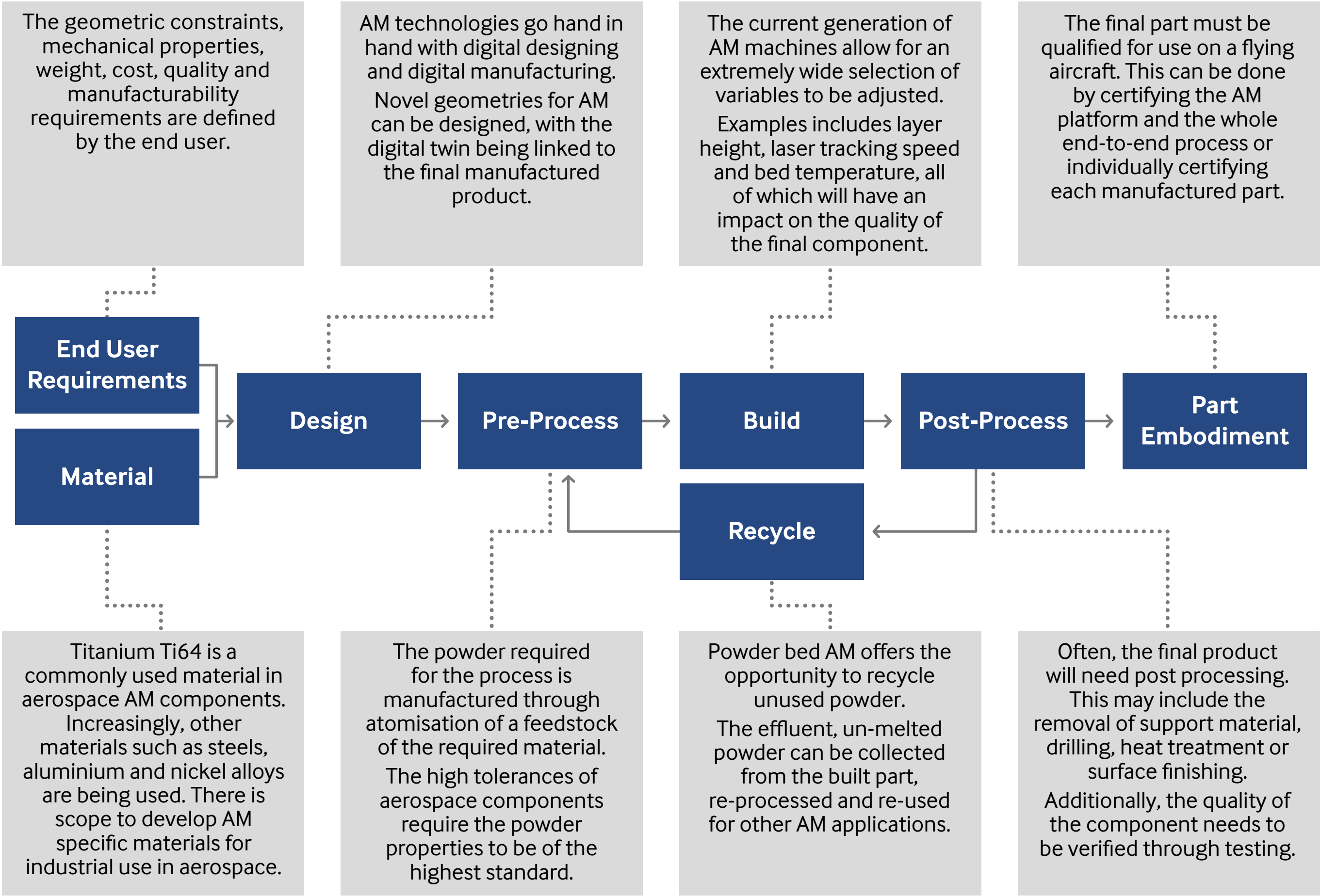
Digital Reconfigurable Additive Manufacturing Facilities for Aerospace (DRAMA) - £11.6m

The ATI supported the formation of DRAMA which is funded by the ISCF. This project will deliver a world-first, digitally twinned, reconfigurable AM capability which will be at the forefront of AM technology. The facility will be available for use by UK enterprises across the full supply chain and provide an effective validation platform for industry users of digital AM processes.

The end-to-end powder bed AM process

Conventional manufacturing methods routinely centre on processes such as joining, fabrication, casting, forging and machining. Powder bed AM, however, requires a completely different material feedstock preparation and the equipment used is different to conventional processes. There are challenges which are unique to powder bed AM in achieving part compliance. (See Table 3, below)

Powder bed AM has a distinct set of steps within the production process (see Figure 4), each of which provide both benefits and challenges that must be considered holistically to generate the potential economic system level benefits. Within aerospace, powder bed AM has been the most widely adopted process so far with continual iterations and developments to powder bed platforms.



The geometric constraints, mechanical properties, weight, cost, quality and manufacturability requirements are defined by the end user.

AM technologies go hand in hand with digital designing and digital manufacturing.
Novel geometries for AM can be designed, with the digital twin being linked to the final manufactured product.

The current generation of AM machines allow for an extremely wide selection of variables to be adjusted.
Examples includes layer height, laser tracking speed and bed temperature, all of which will have an impact on the quality of the final component.

The final part must be qualified for use on a flying aircraft. This can be done by certifying the AM platform and the whole end-to-end process or individually certifying each manufactured part.

Titanium Ti64 is a commonly used material in aerospace AM components. Increasingly, other materials such as steels, aluminium and nickel alloys are being used. There is scope to develop AM specific materials for industrial use in aerospace.

The powder required for the process is manufactured through atomisation of a feedstock of the required material.
The high tolerances of aerospace components require the powder properties to be of the highest standard.

Powder bed AM offers the opportunity to recycle unused powder.
The effluent, un-melted powder can be collected from the built part, re-processed and re-used for other AM applications.

Often, the final product will need post processing. This may include the removal of support material, drilling, heat treatment or surface finishing.
Additionally, the quality of the component needs to be verified through testing.

Figure 4: Flow diagram of the end-to-end additive manufacturing process

The benefits of Additive manufacturing

Additive manufacturing can provide several benefits to the end user – these are shown in Figure 5. It is worth noting that all six benefits identified below ultimately lead to a reduction in processing costs to the end user.

Design and Weight

AM enables functional design, unconstrained by geometrical issues imposed by conventional machining. This allows designers to explore:

- **Novel and complex Geometries**
- **Topologically optimised** parts which meet functional requirements
- **Functionally graded materials** using hybrid manufacturing techniques
- **Part unitisation** leading to reduced assemblies. All of which will offer significant weight savings to the final component(s).

Personalisation and Customisation

Future aircraft may be customised for specific routes and ranges. AM allows for a high degree of personalisation, enabling **bespoke products** to be delivered at speed.

AM makes it viable to produce one-off items or **small batch sizes** at a reasonable cost, even in serial production.

Lower Capital Expenditure

Parts manufactured through AM **remove the need for bespoke tooling.** The costs of tools and jigs can be prohibitive and often limit the push for design improvements as products mature.

Benefits of AM

Local Manufacture/ Repair

Equipment and raw materials can be relatively easily distributed on a global basis. This, coupled with a growth in digital architectures such as blockchain, provides a **significant opportunity for the MRO** (Maintenance, Repair and Overhaul) sector.

AM can also support the **maintenance of legacy products.** Repairs and low-volume replacements, where legacy tools have retired or become obsolete, can be addressed using AM.

Reduced Lead Time

Large blocks of high performance material, for example some forgings and castings, can have very long delivery times - years in some cases. With AM, it is possible to use a simple material form, such as wire or powder, to build up a large part. This wire or powder is available with much **shorter lead times** and often at lower cost.

This also **removes the requirement for 'data drops'** early in the design cycle which often impedes the optimisation of components.

Reduced Material Use

AM provides a nearer net shape solution than traditional manufacturing techniques. This leads to a **reduction in material scrap and an improved buy-to-fly ratio.**

With more unitised parts, there is also a reduced need for fastening and adhesion when assembling components.

Figure 5: The benefits of additive manufacturing

The benefits of additive manufacturing can lead to a transformative shift in aerospace manufacturing.

These benefits can be even greater when combined with other manufacturing techniques and ideologies. Emerging manufacturing processes such as functionalised components and hybrid manufacturing unlock many new opportunities beyond those mentioned above. These are considered by the ATI to be the longer-term targets for AM processes.

The ability to combine AM with other operations such as laser surface finishing or embedded electrical circuitry will allow manufacturers to build more complex and intelligent aerospace components.

Hybrid Manufacturing

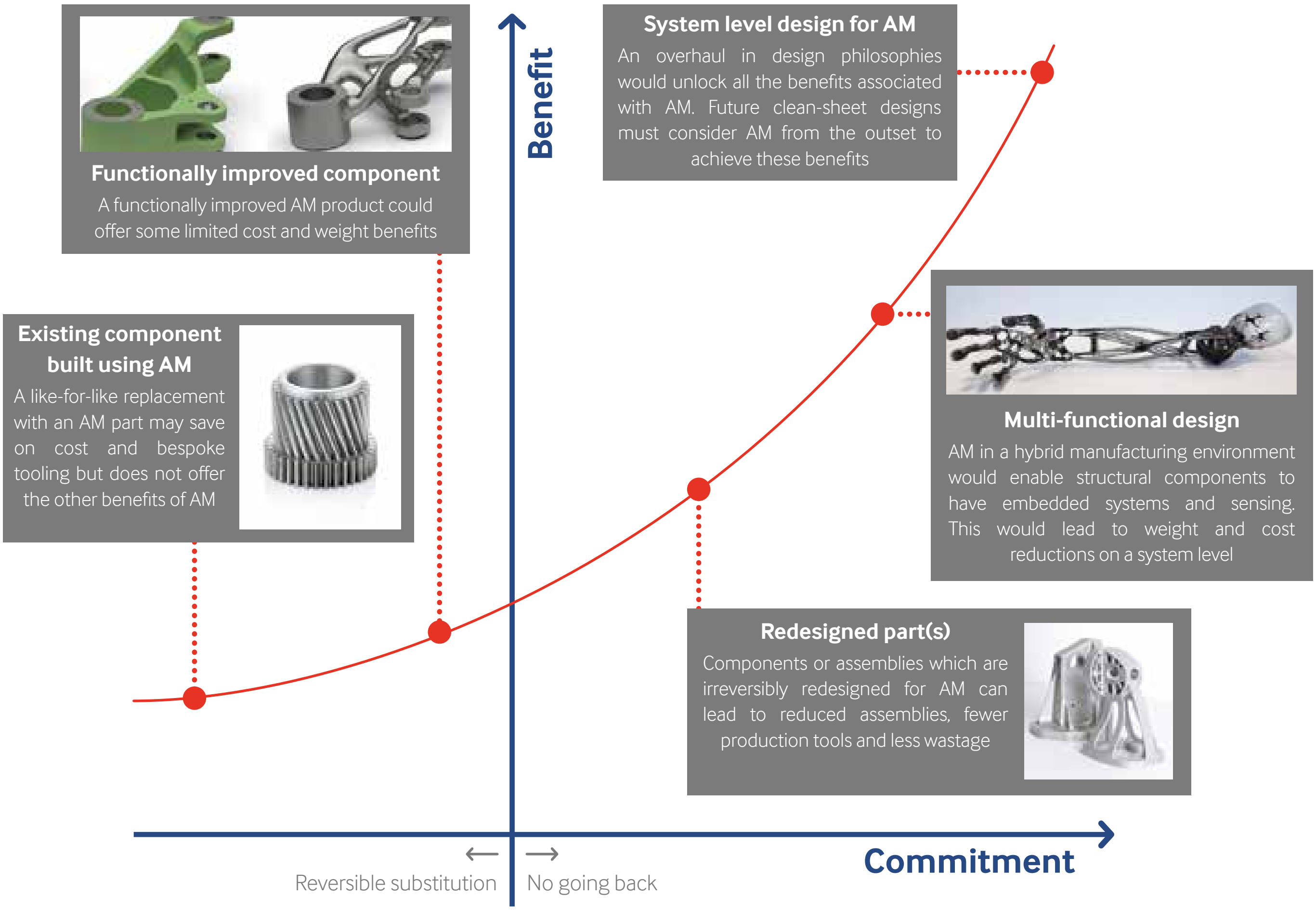
Hybrid manufacturing is the process of combining two or more manufacturing techniques into one single platform.

These processes could include:

- Additive manufacturing
- Traditional subtractive machining such as milling
- Drilling
- Printing circuit boards & embedding systems
- Coating or cladding of components
- Surface finishing
- Laser treatments
- Multi-material processes (such as composite layup)

The benefits of AM vs the required commitment

Additive manufacturing is still in its infancy for safety critical and primary aerospace components. As a result, only some of the benefits mentioned above are beginning to be realised. Figure 6 illustrates that the greatest benefits are achieved when the aerospace sector commits to manufacturing more components using AM[5].



Existing component built using AM

A like-for-like replacement with an AM part may save on cost and bespoke tooling but does not offer the other benefits of AM

Functionally improved component

A functionally improved AM product could offer some limited cost and weight benefits

Redesigned part(s)

Components or assemblies which are irreversibly redesigned for AM can lead to reduced assemblies, fewer production tools and less wastage

Multi-functional design

AM in a hybrid manufacturing environment would enable structural components to have embedded systems and sensing. This would lead to weight and cost reductions on a system level

System level design for AM

An overhaul in design philosophies would unlock all the benefits associated with AM. Future clean-sheet designs must consider AM from the outset to achieve these benefits

Figure 6: The benefits of AM vs the required commitment

CHALLENGES

Along with the benefits of the end to-end additive manufacturing process, there also come challenges for the adoption of this technology in aerospace application. These are set out in Table 3:

Cost

Although AM is recognised as being capable of reducing manufacturing costs in the long-term, there are still many short term prohibitive costs which have hindered its widespread adoption. These include:

- The high costs of high quality AM machines
- The high level of investment required to certify and qualify AM parts
- The cost associated with training engineers to design for AM

A recent Ernst and Young global study on Additive Manufacturing[3] showed that 40% of businesses surveyed identified cost as a major hurdle when implementing AM.

Materials

In the AM process, the material and the component are created in the same instant. This means AM parts have unique mechanical properties. Materials developed specifically for AM are still in their infancy and more research in this area is necessary.

Process

Aerospace AM suppliers are still understanding the potential limitations throughout the entire end-to-end AM process. Factors include scalability, throughput, size restrictions and availability of AM machines. There is also a challenge to verify the final AM part - It is difficult to non-destructively test (NDT) complex AM parts and in-line process verification can add time and cost.

Certification & Standards

The ATI's technical and specialist advisory groups identified certification as the biggest challenge to adopting additive manufacturing in aerospace. Conventionally manufactured parts are often selected as they carry less risk for qualification.

Additionally, there are limited data libraries, limited standards for tests or materials and relatively unproven methods for NDT (non-destructive testing). This puts further constraints on material development for AM, testing of AM components and qualification of AM parts.

Supply Chain

The UK is amongst the global leaders in knowledge generation and successful application of AM. However, there are deficiencies in the supply chain for manufacturing using AM. Long established business practices within the sector, such as supply chain relationship management and minimum risk procurement impede the opportunity presented within the supply chain.

AM and Disruption

Within AM, there are intrinsic risks of digital disaggregation which make it potentially easy for certain parts of the digital supply chain to be commoditised. There are also recognised risks of cyber security, knowhow and IP leakage leading to reduced ability to differentiate product offerings.

Table 3: The challenges facing additive manufacturing in aerospace

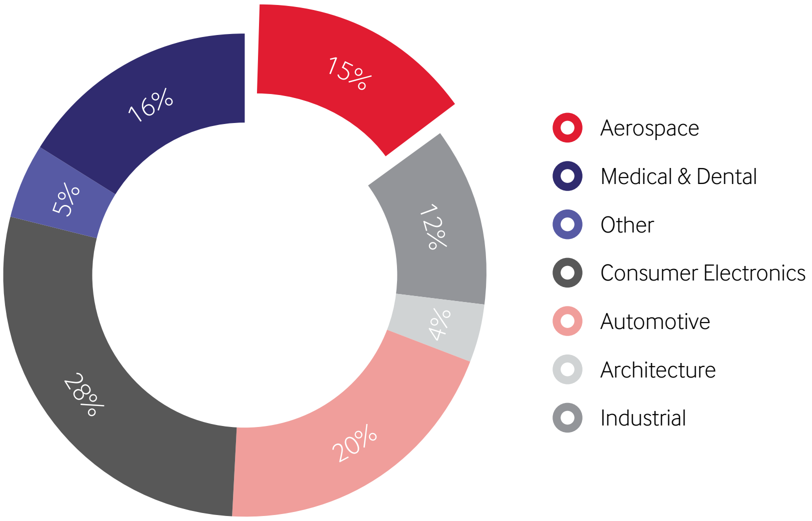
Overcoming these challenges is paramount in accelerating the acceleration of additive manufacturing within the aerospace sector. The ATI will work with industry and across other support mechanisms to develop suitable technology projects which address the challenges described above.

FUTURE MARKET AND OPPORTUNITIES

Driven by strong economic growth in emerging markets, demand for air travel is on the rise. There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally, and this fleet is expected to double in size over the next 20 years.

The through-life-support opportunities associated with the growing number of aircraft are estimated at over US$1.9 trillion between 2016 and 2035. This growing market and associated through-life support offers major opportunities for additive manufacturing.

Figure 7 shows the forecasted additive manufacturing market in 2025. $3.2 billion is attributed to the aerospace AM sector (in both products and services). Additive manufacturing in the aerospace sector is poised to grow at a 26% compound annual growth rate (CAGR) until at least 2025.



$21.5 Billion

Forecasted global AM
market in 2025

$3.2 Billion

Forecasted Aerospace AM
market in 2025

Figure 7: A snapshot of the additive manufacturing Market in 2025

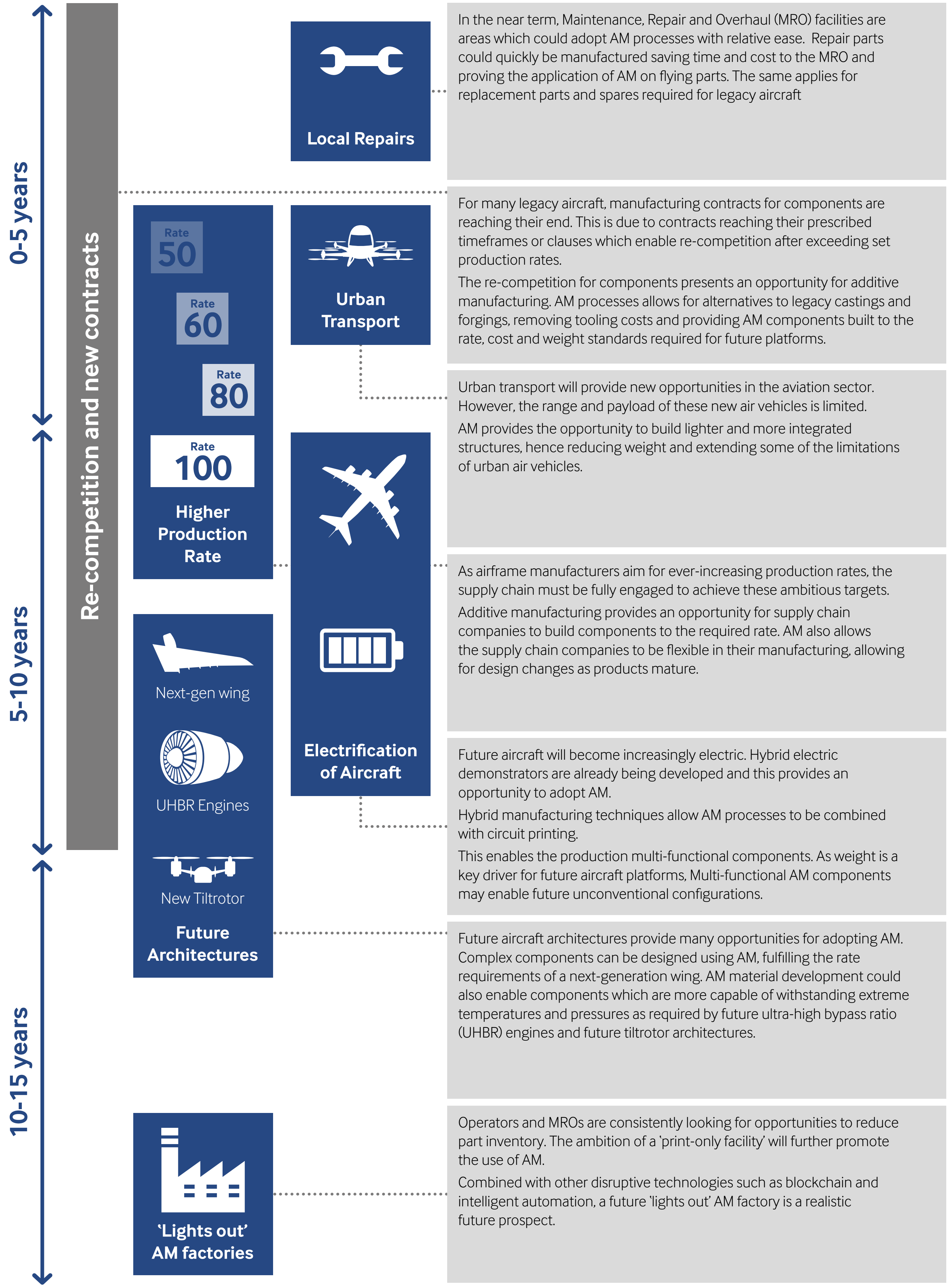
HORIZON (AM) - £13.4m

The ATI funded HORIZON project was a collboration between GKN, Renishaw, Autodesk, Delcam and the universities of Warwick and Sheffield.

The project developed AM techniques into viable production processes for aerospace parts and components over 3.5 years. Outputs of the project included developing wire EDM processes and a fully functional material analysis lab.

The project has helped enhance UK business competitiveness, create 12 highly skilled jobs, and ensure that the UK remains at the forefront of cutting-edge technology development in a rapidly developing field. The GKN site in Filton grew from 2 to 10 AM machines.

Emerging aerospace trends are offering ‘clean sheet’ projects with the prospect of radically re-thinking product architectures – This presents great opportunities to adopt AM. Figure 8 provides an indicative view of the aerospace market and highlights where AM can be an enabling technology on future platforms.



In the near term, Maintenance, Repair and Overhaul (MRO) facilities are areas which could adopt AM processes with relative ease. Repair parts could quickly be manufactured saving time and cost to the MRO and proving the application of AM on flying parts. The same applies for replacement parts and spares required for legacy aircraft

For many legacy aircraft, manufacturing contracts for components are reaching their end. This is due to contracts reaching their prescribed timeframes or clauses which enable re-competition after exceeding set production rates.

The re-competition for components presents an opportunity for additive manufacturing. AM processes allows for alternatives to legacy castings and forgings, removing tooling costs and providing AM components built to the rate, cost and weight standards required for future platforms.

Urban transport will provide new opportunities in the aviation sector. However, the range and payload of these new air vehicles is limited.

AM provides the opportunity to build lighter and more integrated structures, hence reducing weight and extending some of the limitations of urban air vehicles.

As airframe manufacturers aim for ever-increasing production rates, the supply chain must be fully engaged to achieve these ambitious targets.

Additive manufacturing provides an opportunity for supply chain companies to build components to the required rate. AM also allows the supply chain companies to be flexible in their manufacturing, allowing for design changes as products mature.

Future aircraft will become increasingly electric. Hybrid electric demonstrators are already being developed and this provides an opportunity to adopt AM.

Hybrid manufacturing techniques allow AM processes to be combined with circuit printing.

This enables the production multi-functional components. As weight is a key driver for future aircraft platforms, Multi-functional AM components may enable future unconventional configurations.

Future aircraft architectures provide many opportunities for adopting AM. Complex components can be designed using AM, fulfilling the rate requirements of a next-generation wing. AM material development could also enable components which are more capable of withstanding extreme temperatures and pressures as required by future ultra-high bypass ratio (UHBR) engines and future tiltrotor architectures.

Operators and MROs are consistently looking for opportunities to reduce part inventory. The ambition of a 'print-only facility' will further promote the use of AM.

Combined with other disruptive technologies such as blockchain and intelligent automation, a future 'lights out' AM factory is a realistic future prospect.

Figure 8: An illustration of the future aerospace market and opportunities for additive manufacturing

TECHNOLOGY ROADMAPS

The following technology roadmap for AM represents the ATI's view of core areas that will need to be developed and a possible timescale for this work. The roadmaps consider technologies, architectures and methods & tools for additive manufacturing over the next fifteen years and beyond.

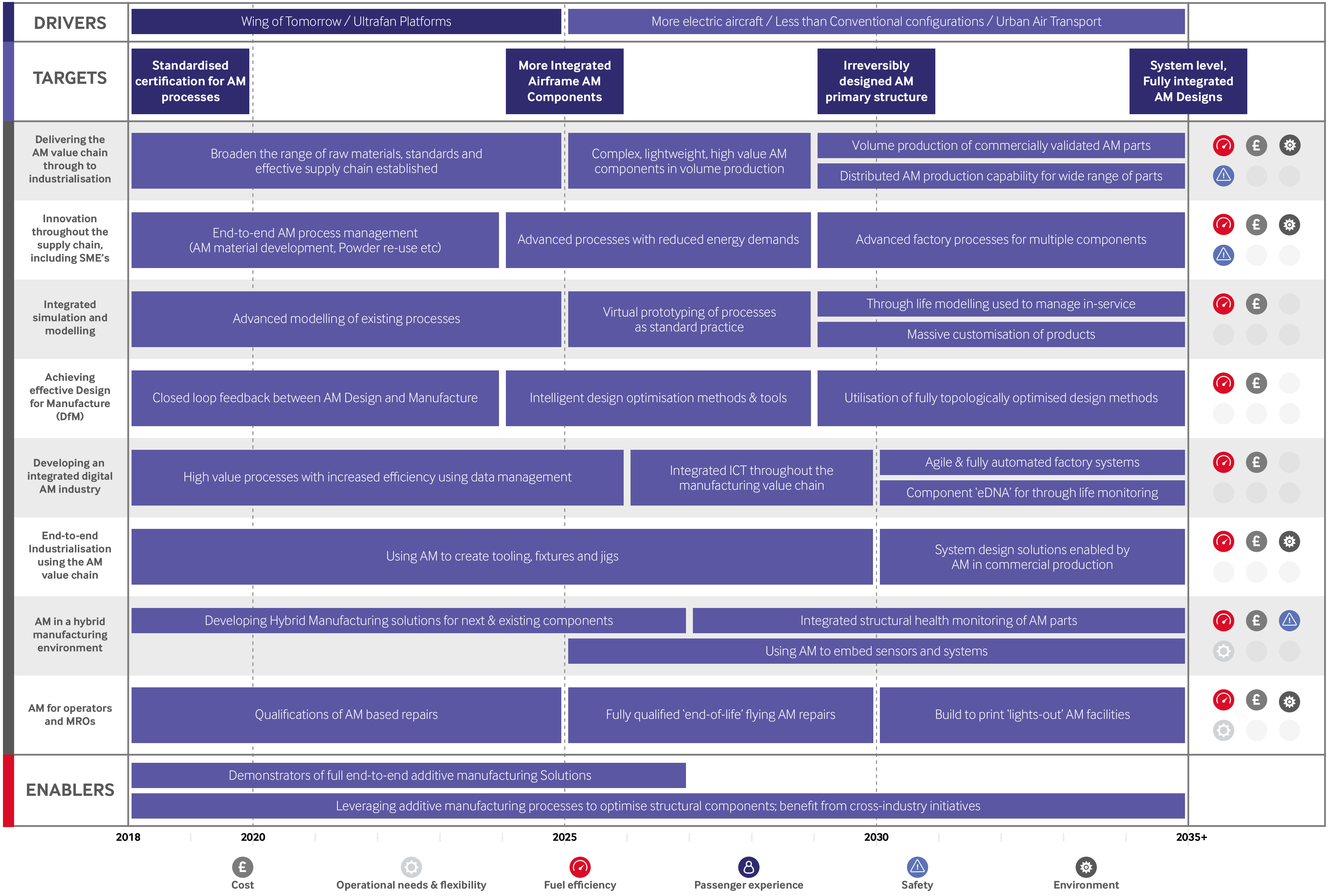
The main drivers reflect the market opportunities in the aerospace sector. The secure timeframe is centred around Airbus's 'Wing of Tomorrow' and Rolls Royce's 'Ultrafan' architectures. The exploit and position timeframes look ahead to more transformative opportunities such as electrification and disruptive ideas such as urban air mobility.

Targets for the development of additive manufacturing have been set and reflect these market drivers:

- **2020: Standardised certification for AM processes.**
  As one of the biggest barriers to adoption, certification and qualification of AM components must be addressed without delay in a collaborative and progressive manner.
- **2025: More integrated airframe AM components.**
  A short-term (2025) target is for AM components to be more integrated in to the airframe. This includes the successful demonstration of AM for repair and legacy products. This is in-line with targets from companies interviewed as part of this study.
- **2030: Irreversibly designed AM primary structure.**
  As illustrated in Figure 6, the benefits of AM are realised when components can no longer be replaced by conventional manufacturing. The medium-term (2030) goal is to realise this benefit for primary structures.
- **2035+: System level, fully integrated AM designs.**
  The long-term (2035+) target for AM is that new, clean-sheet aircraft platforms will consider a system-level design for AM from the outset. This would most likely consider hybrid manufacturing techniques and would lead to AM 'lights-out' facilities for spares and repairs.

A number of key topics to achieve these targets are listed in the roadmap below. Specific program areas are then itemised for each topic, with the implementation timescale, and the relationship of these to the ATI whole aircraft attributes indicated symbolically. Comment is invited on these Technology roadmaps as they will guide future investment decisions in this area.

Proposed projects will need to be supported with evidence of the barriers that they are addressing and the benefits they are realising within the UK's additive manufacturing landscape. Proposals with a collaborative exploitation will be favoured.



DRIVERS

Wing of Tomorrow / Ultrafan Platforms

More electric aircraft / Less than Conventional configurations / Urban Air Transport

TARGETS

Standardised certification for AM processes

More Integrated Airframe AM Components

Irreversibly designed AM primary structure

System level, Fully integrated AM Designs

Delivering the AM value chain through to industrialisation

Broaden the range of raw materials, standards and effective supply chain established

Complex, lightweight, high value AM components in volume production

Volume production of commercially validated AM parts

Distributed AM production capability for wide range of parts

Innovation throughout the supply chain, including SME's

End-to-end AM process management (AM material development, Powder re-use etc)

Advanced processes with reduced energy demands

Advanced factory processes for multiple components

Integrated simulation and modelling

Advanced modelling of existing processes

Virtual prototyping of processes as standard practice

Through life modelling used to manage in-service

Massive customisation of products

Achieving effective Design for Manufacture (DfM)

Closed loop feedback between AM Design and Manufacture

Intelligent design optimisation methods & tools

Utilisation of fully topologically optimised design methods

Developing an integrated digital AM industry

High value processes with increased efficiency using data management

Integrated ICT throughout the manufacturing value chain

Agile & fully automated factory systems

Component 'eDNA' for through life monitoring

End-to-end Industrialisation using the AM value chain

Using AM to create tooling, fixtures and jigs

System design solutions enabled by AM in commercial production

AM in a hybrid manufacturing environment

Developing Hybrid Manufacturing solutions for next & existing components

Integrated structural health monitoring of AM parts

Using AM to embed sensors and systems

AM for operators and MROs

Qualifications of AM based repairs

Fully qualified 'end-of-life' flying AM repairs

Build to print 'lights-out' AM facilities

ENABLERS

Demonstrators of full end-to-end additive manufacturing Solutions

Leveraging additive manufacturing processes to optimise structural components; benefit from cross-industry initiatives

NEXT STEPS FOR THE ATI

The ATI will work to identify suitable opportunities around the topic of additive manufacturing that generate technology impact and economic benefit for the sector. From the ATI's consultation, it is clear that different parts of the AM supply chain are at varying levels of development and adoption. The intention (by achieving the points below) is to bring the supply chain to a similar high standard of AM maturity.

The ATI will continue to work with other national initiatives such as the industrial strategy challenge fund (ISCF), DRAMA, Made Smarter, the National Centre for Additive Manufacturing (NCAM), and the All-party Parliamentary Manufacturing Group (APMG). The focus will be on the formation of suitable technology projects, coordination of activities and the dissemination of insights to people in organisations positioned to deliver these requirements.

Costs

- Action to address key technological barriers, notably in the areas of final part acceptability, volume development and cost management
- Identification of prohibitive costs in the AM value chain and means to reduce these

Materials

- Material databases, focussed initially on lower technology materials, to allow broader industry activity with potential for positive business return
- Standardising tests and qualification processes for new materials

AM end-to-end Process

- Platforms to enable 'design for AM' through links to High Value Design programmes
- A focus on validation and verification of the AM process (In-process, post process, NDT see ATI Product Verification INSIGHT)

Certification & Standards

- Defining certification and standards in AM through collaboration with manufacturers, standards organisations and regulatory bodies
- Defining a route to certification for material development in AM, testing of AM components and qualification of AM parts

Supply chain

- Increased collaboration amongst initiatives regarding AM technology awareness and skills development
- Understanding the digital supply chain required to enable a distributed manufacturing process. This includes research around cyber security and other digital platforms such as blockchain
- Develop supply chain capability to move from away from billet machining to near net shape + post processes using AM

AM as a disruptor

- Harness the benefits of additive manufacturing for ATI 'position' projects
- Use additive manufacturing as an enabling technology for next-generation platforms (Hybrid Electric, Urban Air, other unconventional aircraft)
- Combining AM with other processes in a Hybrid Manufacturing environment

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ACKNOWLEDGEMENTS

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GLOSSARY

AM	Additive Manufacture
DRAMA	Digital Reconfigurable Additive manufacturing facilities for Aerospace
ISCF	Industrial Strategy challenge fund
MRO	Maintenance, Repair and Overhaul
MTC	Manufacturing Technology Centre
NDT	Non-destructive Testing

WHO WE ARE

The **Aerospace Technology Institute** (ATI) is the objective convenor and voice of the UK's aerospace technology community. The Institute defines the national aerospace technology strategy that is used to focus the delivery of a £3.9 billion joint government-industry funded aerospace technology programme.

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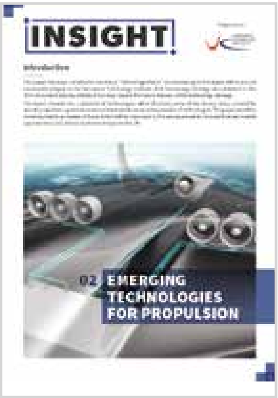
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02 EMERGING TECHNOLOGIES FOR PROPULSION


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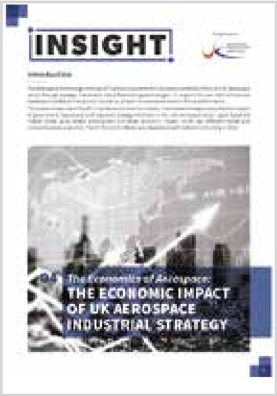
03 EMERGING TECHNOLOGIES IN COMMERCIAL AIRCRAFT SYSTEMS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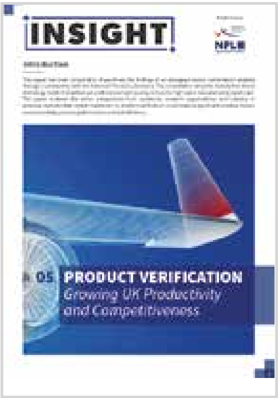
04 The Economics of Aerospace: THE ECONOMIC IMPACT OF UK AEROSPACE INDUSTRIAL STRATEGY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05 PRODUCT VERIFICATION *Growing UK Productivity and Competitiveness*


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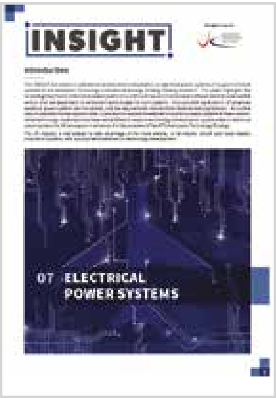
GRAPHENE EXPLOITATION *Material applications in aerospace*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07 ELECTRICAL POWER SYSTEMS