ROYAL ACADEMY OF ENGINEERING

Additive manufacturing: opportunities and constraints

A summary of a roundtable forum held on 23 May 2013
hosted by the Royal Academy of Engineering

November 2013
ISBN: 978-1-909327-05-4
www.raeng.org.uk/AM

Published by
Royal Academy of Engineering
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3 Carlton House Terrace
London SW1Y 5DG

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Fax: 020 7930 1549
www.raeng.org.uk

Registered Charity Number: 293074

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Front cover photo: Dental framework being made by the additive manufacturing process of selective laser melting © Renishaw

Inside front cover photo: © EPSRC Centre for Innovative Manufacturing in Additive Manufacturing

Introduction

Photo: Stereolithography (SLA)
© Econolyst

As media interest in Additive Manufacturing (AM) grows, those involved in the sector are making efforts to integrate AM technologies into the UK's manufacturing mix. Unlike most conventional manufacturing techniques, AM forms objects by building matter up, rather than removing it. Paired with computer-aided design (CAD) software, this technique affords the creation of new types of object with unique material properties. But while AM is widely billed as 'the next industrial revolution', in reality there are still significant hurdles for successful commercialisation of the technologies.

In May 2013, the Royal Academy of Engineering held a roundtable meeting to discuss the condition of the UK's AM sector. Attendees from research and industry explored the many advantages AM offers industry and discussed the need to push AM technologies to the next stage of development in order to make them a more attractive proposition for business.

There is a wide range of technologies accommodated under the umbrella of AM, with varying benefits, disadvantages and potential. Any analysis of the sector must differentiate between the kinds of technologies used and the value they can create. This report aims to disaggregate the elements with an appreciation of the diverse benefits and challenges that AM methods present.

In 2012, the Technology Strategy Board (TSB) funded an Additive Manufacturing Special Interest Group (AM-SIG) activity which published a report *Shaping our national competency in additive manufacturing*[1]. The report concluded that although the UK is clearly engaged in the development of AM technologies and applications, it is far from leading in any one specific area, hence the importance of developing a clear forward strategy.

It also discussed how AM is not only a disruptive technology that has the potential to replace many conventional manufacturing processes, but also an enabling technology allowing new business models, new products and new supply chains to flourish. However, it remains a nascent technology exploited today by only a small number of early global adopters.

The Royal Academy of Engineering roundtable forum was attended by the current leading academics, industry representatives and manufacturers of note in the additive manufacturing sector in the UK. This report is a summary of the state of the art and collective opinion of a group of influential people.

Defining terms

Those attending the roundtable meeting most often used the terms 'AM' and '3D printing' to refer to the sector, tending to employ AM as the umbrella term and when referencing industrial uses of the technology. The label '3D printing' tended to be used in reference to consumer-focused desktop-based AM, using plastics and other non-metal materials.

Manufacturing for growth – the developing AM and 3D sectors

Photo: MakerBot mixtape printed using fused deposition modelling (FDM) © Econolyst

In 2009, the expiration of key 3D printing patents for fuse deposition modeling (FDM) paved the way for today's thriving open source 3D printing movement and the initial rise of the MakerBot[2], a simple at-home desktop 3D printer. The upcoming February 2014 expiry date for key patents targeting laser sintering additive technology, the lowest-cost 3D printing technology, the world of fabrication possibilities could likely change again.

The global market AM products and services grew 29% (compound annual growth rate) in 2012 to over $2 billion[3]. Unit sales of professional-grade, industrial systems reached nearly 8,000 units in 2012[3] (excluding the sales of personal 3D printers that sell for under $5,000). This is an increase from an estimated 6,500 units in 2011[3] and demonstrates a growth trend of industrial AM systems sales worldwide.

AM and 3D printing industry (products and services) worldwide projected value

2015	$4 billion
2017	$6 billion
2021	$10.8 billion

Source: Wohler's Report 2013[3]

Significantly faster, the global growth of personal 3D printers averaged 345% each year from 2008 to 2011[3]. In 2012, interestingly, the increase was estimated at only 46.3%[3]. Most of these machines are being sold to hobbyists, do-it-yourselfers, engineering students, and educational institutions.

The use of AM for the production of parts for final products continues to grow. In ten years it has gone from almost nothing to 28.3% of the total product and services revenue from AM worldwide[3]. Within AM for industry, there has been a greater increase in direct part production, as opposed to prototyping (AM's traditional area of dominance). Within direct part production, AM serves a diverse list of products and sectors including consumer electronics, textiles, film effects, jewellery and musical instruments.

Econolyst Managing Director and Principal Consultant Dr Phil Reeves

"IN 2012, THERE WERE 70,000 CONSUMER 3D PRINTERS SOLD AT AN AVERAGE PRICE OF $1,500 EACH. THAT'S A $105 MILLION INDUSTRY ALREADY IN TWO YEARS – EVEN WITHOUT CONSIDERING THE VALUE OF MATERIALS, SOFTWARE AND THE PRODUCTS THAT COME OUT OF IT."

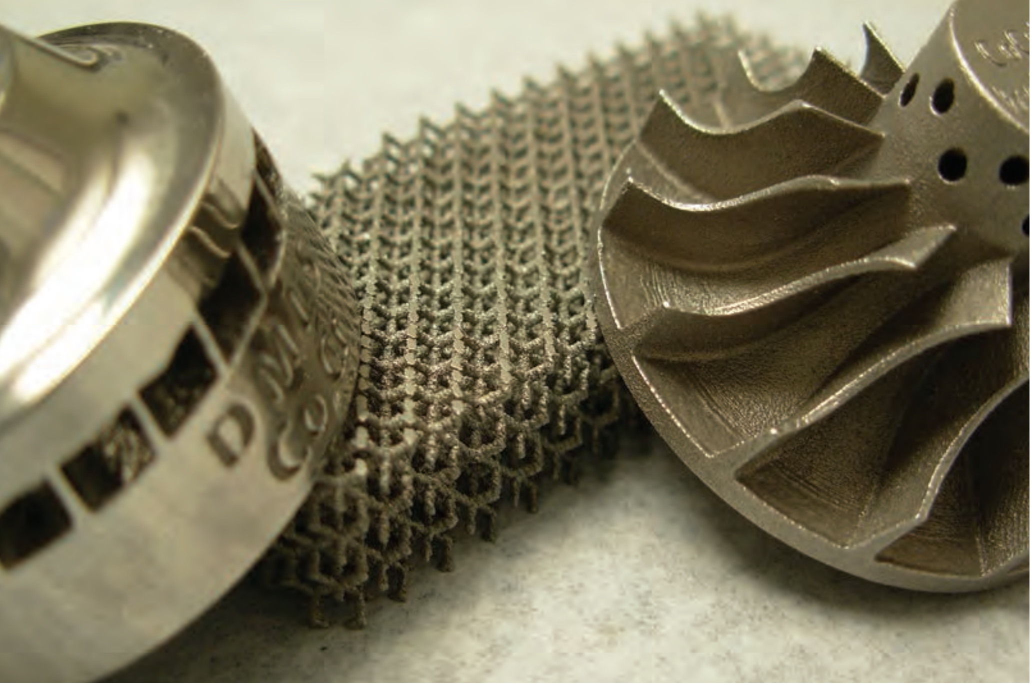


Photo: Examples of direct metal laser sintering (DMLS) © Econolyst

CASE STUDY

GE AND MORRIS TECHNOLOGY
Graham Tromans

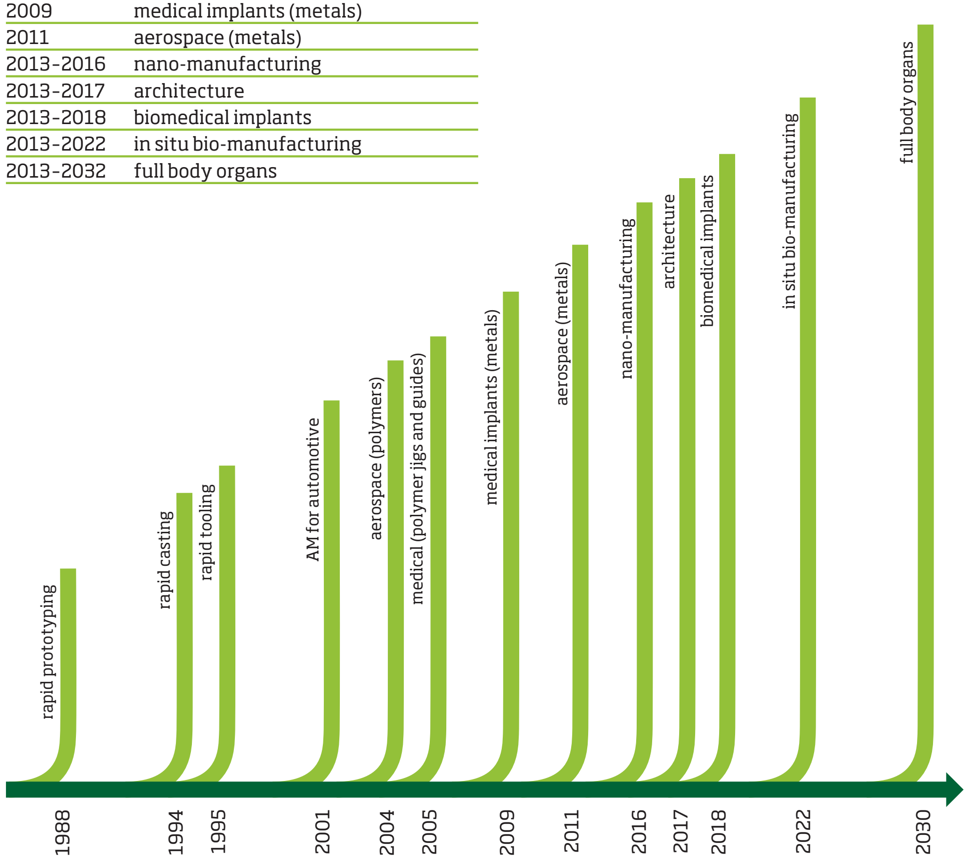
The automotive and aerospace industries are two of the main beneficiaries of AM. In 2012, GE Aviation bought AM Morris Technologies, one of the biggest metal additive manufacturers in the world. GE is ramping up AM manufacturing of aero engine fuel nozzles. The conventional method of making fuel nozzles requires making 20 separate parts and welding them together, "which is extremely labour-intensive and has a high scrap rate," said Graham Tromans, Principal and President of AM consultancy GP Tromans Associates. AM allows the creation of pre-assembled nozzles. GE predicts that, by late 2015/16, it will make 10–20 fuel nozzles for each engine using AM, or 25,000 a year. The company also envisages that 50% of a jet engine will be additive manufactured within current lifetimes.

Three of the fastest-growing areas for AM include the medical and dental, automotive and aerospace sectors. AM's success in the biomedical sector rests with its ability to create customised prosthetics, implants, replacement tissues and intricate body parts, including blood vessels. Growth in the automotive sector "is part of the resurgence of the UK car industry," said Peter Marsh, author and manufacturing journalist. "You can say now that AM is a force in the world of cars that it wasn't five years ago. And with £1 billion being injected into the UK car manufacturing[4], there are any number of new opportunities for using AM to make bespoke and non-bespoke parts." The largest adopter has been the aerospace industry with the entrance of metals-fed AM machines into the industry in 2011, resulting in good take-up of the technology owing to advantages of speed, cost and materials rationalisation.

AM applications timeline

This timeline lays out past, present and potential future AM developments and applications.
(courtesy of Graham Tromans)

1988–1994	rapid prototyping
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013–2016	nano-manufacturing
2013–2017	architecture
2013–2018	biomedical implants
2013–2022	in situ bio-manufacturing
2013–2032	full body organs



Efficiency, creativity, accessibility – the advantages of AM

AM's unique processes, techniques and technologies open up new ground for innovation and offer a range of logistical, economic and technical advantages.

Low-volume production

For appropriate products, AM replaces machine tooling. This allows for cheap, low-volume production and facilitates personalised and customised products. "Customisation is a real business opportunity, especially in the healthcare sector," said Professor Richard Hague, Director of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing at the University of Nottingham.

Author and manufacturing journalist Peter Marsh described how customisation revives ancient notions of manufacturing: "Customisation brings a service dimension back, with providers asking the client to specify the kind of products they want. This is how blacksmiths worked in the past, but the problem was that only rich people could afford it. AM makes customisation accessible."

Lower-cost production

Another benefit of AM over traditional machine tooling is the lower cost of manufacture. "The fact that AM can make manufacturing cheaper is important in pushing the technology out to businesses," said Kenny Dalgarno, Professor of Manufacturing Engineering at Newcastle University.

Photo: 3D printed Garmin mount
© RaceWare Direct

CASE STUDY

RACEWARE DIRECT

Last year, bicycle accessories distributor RaceWare Direct began manufacturing mounts for GPS cycling computers. Uniquely to the market, the mounts are 3D printed, in nylon, making customisation and personalisation – such as incorporating logos – the products' prime selling points. AM's low-volume manufacturing method allows multiple design iterations that can continue until the mounts perfectly fit the individual and different bikes and riders. This has helped to take Raceware's mounts to the high end of the market. 3T RPD Chief Executive Officer Ian Halliday said: "This company is succeeding because it understands 3D printing, knows its own market, has spotted an opportunity, possesses vision and determination and understands the benefits AM offers its product and customers."

Aerospace manufacturer EADS, now called Airbus Group, buys over $400 million of titanium feedstock every year. Hybrid production incorporating AM can help reduce its outlay on the high-value material. "Because of the buy-to-fly business case and the inefficiencies of tooling, which wastes valuable materials, we have a business case for AM," said EADS Innovation Works Research Team Leader Jon Meyer.

There is also a lead time benefit for the raw material. Large billets of titanium need to be ordered one or two years before they are used. However, the same material in powder form can often be purchased immediately.

Responsive production

For low-volume production, AM offers faster lead times than traditional manufacturing methods. For example, in Formula One motor racing, engineers are using AM to manufacture parts in a highly reactive way. "They can now analyse the car's performance while it goes round the circuit and have a new part getting ready before it finishes the race," said Graham Tromans, Principal and President of AM consultancy GP Tromans Associates.

Rolls-Royce is verging on using AM to manufacture entire components. Neil Mantle, Head of the Rolls-Royce Centre of Competence in Additive Layer Manufacturing, explained, "We can go from a CAD geometric design to the finished component in a month instead of a year. These are big time savings."

CASE STUDY

ROLLS-ROYCE

Rolls-Royce is considering embarking on the additive manufacture of entire components because of the benefits of faster production and reduced costs that it offers. Says Rolls-Royce's Neil Mantle: "At the launch of an engine programme we start to consider forgings, and AM gives us a great opportunity here because conventional methods of manufacture can take 40, 50 or even 60 weeks, while a component using AM will take one month." Likewise, he praised the improved buy-to-fly ratio on materials: "Sometimes we machine away 90% of the materials to create the final component, but with AM that figure is much reduced." Neil Mantle added that while AM offers distinct advantages, investing in AM machines will require Rolls-Royce to feel confident of their economic viability and that the processes will be as robust and reliable as traditional methods.

Photo: Selective laser sintered (SLS) gears © Econolyst

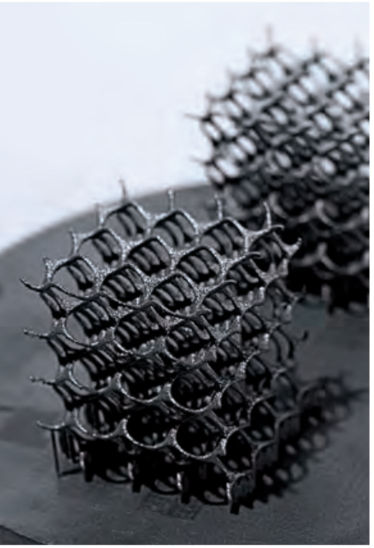


Photo: Lattice formed by selective laser melting (SLM) © Econolyst

Shorter supply chains

AM has the capacity to simplify and shorten the manufacturing supply chain. Graham Tromans explained: "If you are manufacturing these parts on site then you don't need transportation, and you remove unnecessary international shipping, so manufacture is nearer to the consumer." This could create opportunities for local, regional or national manufacturing centres, and already supports on-site rapid prototyping.

Democratisation of production

3T RPD Chief Executive Officer Dr Ian Halliday drew parallels between AM and the internet revolution, citing the democratising impact the internet has had on the publishing and entertainment industries.

Graham Tromans conjectured that, "the deskilling of design and production could be a big driver in its uptake". But other participants questioned whether AM would result in deskilling, at least at the higher end of the technology. This technology allows the creation of more complex objects, which would compel users to think back to first principles, asking 'what is it that this object is trying to do?' rather than 'how do I make this one better than the last one?' It may require more skill, not less.

3T RPD Chief Executive Officer Dr Ian Halliday

"AM HAS THE SAME ATTRIBUTE AS THE INTERNET, WHICH IS DEMOCRATISATION."

Optimised design

The capacity of AM to allow the "fundamental rethinking and redesign of products" can result in better components, said Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham. AM facilitates latticed designs, which are impact-absorbing and endow AM-made components, particularly for the automotive sector, with an "enhanced mechanical response", said Professor Richard Hague. Lattices also allow the production of much lighter components, offering economic and environmental benefits.

Because AM allows the construction of more complex geometries than traditional manufacturing techniques such as injection moulding, it is possible to create pre-assembled items with multiple moving parts. "You can finally make what you wanted to make all along, instead of having to compromise, which means improved performance, reliability and weight rationality," said Dr Ian Halliday. Making objects in one piece with movable parts also means that there are savings in assembly and maintenance.

CASE STUDY

CROFT FILTERS

After 27 years making and supplying industrial filters, in Spring 2012, Croft Filters bought an AM machine. "About three years ago, we decided to look at whether we could offer companies some energy savings through the filters we were making," explained Croft Filters Director Neil Burns. Upon investigation, the company found that 13% of all energy use in industry is spent on pumping, "So we thought, let's try to optimise the filters by bringing the holes in line". As a result of a feasibility study from the TSB, Croft worked with Lancaster University on a new design "which does the trick, saving up to 15% of all energy used in pumping," said Neil Burns. "The design freedoms are so exciting because they let us design solutions to customers' problems and we believe the company will grow by offering additive manufactured filters alongside those manufactured conventionally."

CASE STUDY

VIRGIN UPPER CLASS MONITOR ARM

In a Technology Strategy Board (TSB) funded project for Virgin Atlantic, the arm holding the TV monitor in the airline's Upper Class seats was redesigned for AM. Latticing reduced the arm's weight by 50%, saving 0.5 kilograms for every unit, in turn saving $45,000 worth of fuel across the 30-year lifetime of the aircraft. "You can make an economic case for AM on that one component," said Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham.

To make the most of the potential of AM techniques, designers have to adapt their approach for the technologies. This requires moving away from the idea of replicating what is already made in other ways. Designers are free to move away from creating things that can be computer numerical controlled (CNC) machined and should not be constrained by the idea that things have to be built up in layers. Cambridge University Professor of Laser Engineering Bill O'Neill asked: "Why do you want to produce in layers? We need to move away from this trap of 'I have to slice it, layer it, glue it', otherwise we will never make more than touchy-feely design aids and novelties."

Photo: Virgin arm monitor formed by selective laser melting (SLM)

The road ahead – challenges and opportunities for AM

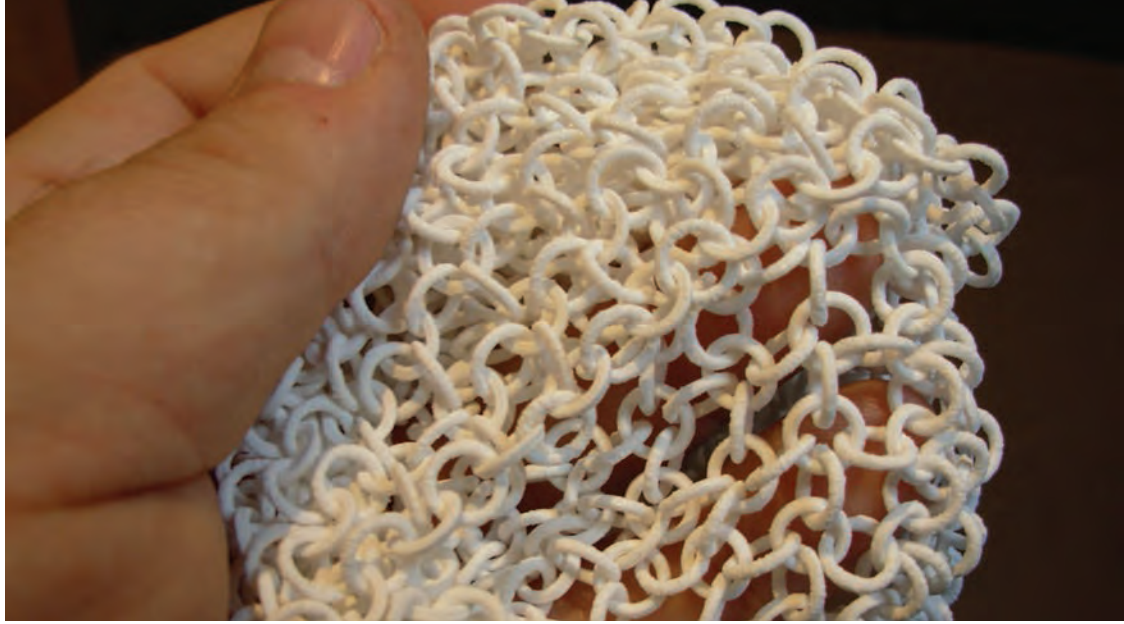


Photo: Selective laser sintered (SLS) chainlink © Econolyst

Despite its clear benefits, AM remains beset by technological issues and suffers from the lack of a supportive framework, underfunding and a lack of industry standards. During the meeting, attendees carefully enumerated the problems and suggested possible solutions.

Materials

There is a demand for better materials to use as feedstock for AM and 3D printing. The development of machines that can process metals by sintering (creating objects from powders) is helping to open up the processes to industrial users. However, while new metal alloys such as Scalmalloy[5] address manufacturers' needs, polymers require greater research and development. Professor Bill O'Neill, Cambridge University Professor of Laser Engineering, described existing UV resins for stereolithography as "toxic – you wouldn't want to lick them." Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham, called materials "the real issue and the biggest opportunity in AM".

In addition, while metals used in AM processes are often recyclable, polymers quite often are not – and the feedstock comes with significant embedded energy from the processes used to create it. As well as focusing on the functional aspects of materials, a cradle-to-cradle view needs to be taken on the ways that they are produced and recycled.

Software

Today's CAD programs are considered inadequate for designing for AM. "CAD is still designed for traditional manufacturing routes such as injection moulding, and in particular CAD is most readily applied to things which have lots of circles and straight lines," said Andy Keane, Professor of Computational Engineering and Head of Aeronautics at the University of Southampton, with corroboration from Professor Richard Hague, Director of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing at the University of Nottingham. "Existing CAD systems are absolutely useless for exploring the design freedoms of AM. Biomimetics? You can't do that with CAD. We need new design systems," said Professor Richard Hague. As well as restricting design, CAD interfaces do not tend to be user-friendly. Both elements should change to make the most of AM techniques – especially for the non-expert designer.

Data management

Data are the language without which AM would not function. While AM methods have been in existence for around 25 years, it is data management which is the new aspect of the technology, with the potential to accelerate uptake of AM. However, Professor Bill

O'Neill highlighted "a data issue which means there currently isn't enough computer memory to store the data required to produce a one-metre cubed functional part". CRDM Director Graham Bennett believes that rather than advancements in the machines themselves, software developments are what will "drive the industry forward".

Sustainability

Low-volume production offers opportunities for customisation and it can reduce materials use due to its efficient geometries, but its benefits are not universal. "You do not get energy-reducing economies of scale in AM like you do in traditional methods of manufacturing such as injection moulding," said Dr Chris Tuck.

Pouring water on the popular notion that local manufacture is intrinsically more sustainable, Dr Chris Tuck said: "Global supply chains in conventional manufacturing are actually very efficient – so just because we can bring it local doesn't mean we should".

While manufacturers are driven by efficiency goals that lower their carbon footprint, homemakers can be relied upon to be wasteful, argued Dr Chris Tuck. "The average consumer throws away a huge proportion of the food that they buy, so why would they be any different with 3D printing?" He also pointed out the "massive issue" that materials used in AM are often non-recyclable. However, while 3D printers in the home could encourage waste, industry is more driven toward efficiency and AM can support this by supporting single or small-run printing, and not making more stock than is needed.

Dr Chris Tuck offered solutions to AM's environmental issues, including using parallel production to improve efficiencies and speeding up the production process to reduce energy use. He also suggested that companies using AM undertake "holistic analyses that include how you extract and generate the raw materials, as well as the relatively tiny manufacturing aspect"

However, AM can support a drive to sustainability through what it enables rather than necessarily through its own processes. By reducing the weight of structures, it can reduce the energy use in aerospace, delivering significant fuel savings *(see Virgin case study on page 12).*

Affordability

The financial overheads for running machines and buying feedstock are potential barriers to the commercialisation of AM. Graham Bennett likened the 3D printing industry to the paper printing industry: "In both, it is the materials that the suppliers make their money on." He claimed a "huge disparity" between the cost of nylon for injection moulding –about £5 per kilo – and for 3D printing – about £50 for the same amount.

However, there is a difference between polymers and metals. In polymer sintering, a large proportion of powder is usually thrown away as it is currently not possible to recycle through the machine. With metals, most of the unused powder can be recycled for laser sintering (but not yet in most electron beam processing).

Speed

While low-volume production is faster than conventional manufacturing, higher volumes are considerably slower. "This is another problem that we face in getting companies to use AM," said Graham Bennett. He believes we will need a new generation of AM machines if we are to replace injection moulding and casting machines, "because AM simply cannot do what the present technologies can do."

Making parts in parallel production (side by side in the machine) significantly speeds up the process, allowing AM to start competing with conventional manufacturing methods such as injection moulding.

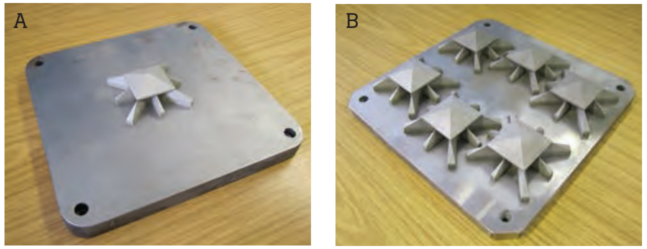


Figure 1
A) Single-part build – with one part placed in the centre of the work space; B) Full build – as many parts as possible placed in the work space. Making parts in parallel production significantly speeds up the process

Credit Dr Chris Tuck

CASE STUDY

NUCLEAR ADVANCED MANUFACTURING RESEARCH CENTRE (AMRC), UNIVERSITY OF SHEFFIELD

"AM is becoming increasingly interesting to the nuclear industry," said Keith Bridger, Head of Welding and Materials Engineering at Nuclear AMRC at the University of Sheffield. Currently, the nuclear industry machines all components, with the vessels it requires made from ring forgings. Keith Bridger is interested in using AM to make non-pressure retaining lugs on steam generators. "The real driver for this is that current forging capacity in the world isn't big enough to make enough of these lugs, so we need to make smaller forgings, which AM can do while also improving the components' material properties," he said. But a stopper on AM's use in the nuclear industry is the current lack of standards. The nuclear industry is wary of AM because, "we don't know what the performance is, which is vital when you have reactors that last 60 years and components that need to have a failure rate of one in 10 million," said Keith Bridger.

Reliability

It is difficult for AM technologies to compete with traditional techniques on reliability and reproducibility. "For companies looking for a rejection rate of just a few parts per million, there is no way our technology can come close to that," said Graham Bennett.

Potential solutions to the problem came from several quarters. BSI Programme Manager Alex Price suggested developing a set of standards that "could help guarantee a level of reproducibility". Graham Bennett called for "huge investment" to improve machines, while Professor of Manufacturing Engineering at Newcastle University Kenny Dalgarno and Head of the Additive Manufacturing Research Group at Loughborough University, Professor Russell Harris, suggested that hybrid processing – in which AM is used alongside conventional techniques – might result in greater capabilities.

Intellectual property

The potential for users of AM to inadvertently infringe copyright was named "a serious concern" by 3T RPD Chief Executive Officer Dr Ian Halliday. This is made easy by 3D scanners that can copy an object for reprinting in 3D. There is also the issue of unknowingly printing illegal or restricted items – for example, a part for a gun in isolation may not be obviously identifiable as such. EADS Innovation Works Research Team Leader Jon Meyer suggested a potential technological solution to these problems: "British academics in other fields are currently developing image recognition software that could benefit the AM sector by identifying suspicious geometries and protecting companies from litigation. This is an area that the UK could get into early."

Standards

Those present at the meeting called for a set of standards to provide much needed assurances to businesses and manufacturers that AM processes, materials and technologies are safe and reliable.

In his presentation on standards creation, BSI's Alex Price sought to demonstrate the UK's leadership on AM standards. He said, "BSI is trying to position itself better on the innovation curve. We believe we could develop a series of standards that gives the UK a position within the marketplace."

BSI Programme Manager Alex Price

"STANDARDS BREATHE CONFIDENCE INTO THE INDUSTRY."

Alex Price described BSI's intention of applying "tried and tested" formal standards to the sector, while leaving room for open innovation. "We are discussing where we can develop standards in the areas of testing and materials specifications, with the UK particularly prominent in the issue of data transfer at the moment."

Global standards are already advancing through the ASTM International Technical Committee F42 on Additive Manufacturing Technologies[6] and The International Organization for Standardization (ISO) ISO/TC 261 Additive Manufacturing Technical Committee[7].

Business funding

"The government is being terribly half-hearted about funding existing companies to get into AM," said Peter Marsh, author and manufacturing journalist. Dr Ian Halliday explained a similar reluctance among banks to risk investing in manufacturing SMEs, saying, "On one hand banks are being told not to fail and on the other they are being told to lend money to SMEs."

As a partial solution, Peter Marsh suggested linking consumer product developers, "for whom 3D printing is a buzzword," with venture capitalists.

Photo: Blue Peter unmanned aerial vehicle built by 3T University of Southampton

Cambridge University Professor of Laser Engineering Bill O'Neill

"WE NEED TO TARGET INVESTMENT IN THE CRITICAL AREAS OF TECHNOLOGY REQUIREMENTS, WHICH ARE DATA AND INTERFACES. WE NEED NEW MACHINE CONCEPTS, WE NEED TO THINK BEYOND THE CONVENTIONAL LAYER APPROACH. WE NEED NEW MATERIALS AND WE NEED RADICAL TRANSFORMATIONS."

Education

Opportunities – education

The importance of educating everyone about AM, from the youngest school pupils to potential investors and leaders of industry, emerged strongly during the day's discussions – with particular focus on primary education. "If we are going to make progress in this sector then we have to get this technology into the hands of younger minds," said Professor Bill O'Neill.

But it is not just about educating young people about AM, but using AM as a tool in education. Professor Russell Harris described installing a printer in a primary school as "very successful in engendering enthusiasm among the children for design and technology."

Graham Bennett, whose company CDRM offers AM services to schools, rued the fact that AM isn't on the school syllabus. Since the meeting took place government announced changes to the national curriculum (July 2013). Revisions include secondary school pupils learning how to use specialist tools such as 3D printers in design and technology. The changes will come into force in 2014. These changes to the curriculum were devised with input from the Design and Technology Association (DTA) and Royal Academy of Engineering, as well as other industry representatives.

EADS Innovation Works Research Team Leader Jon Meyer

"IT IS INEVITABLE THAT THE MORE PEOPLE YOU HAVE KNOWING ABOUT A TECHNOLOGY, THE MORE LIKELY YOU ARE TO HAVE GOOD IDEAS POPPING UP."

However, Dr Rhys Morgan, Education and Skills Policy Manager at the Royal Academy of Engineering who helped shape the new curriculum for Design and Technology and Computing in schools in England argued that AM will struggle to meet the needs and expectations of thirty pupils in a typical D&T class because of the speed of the current processes. He added that costs of consumables and service contracts for AM machines which are robust enough for classroom use would also be prohibitively expensive for many schools.

Graham Bennett cautioned that, "Teachers are not into 3D printing because they don't understand the technology and are embarrassed because the kids race ahead of them on the software – and so they resist taking it into the classroom." To make the most of this enthusiasm, it is essential to ensure that teachers have support and training in using the technology, that accessible software is available to schools, and that materials are available that are safe for students to handle. Industry and government should work together to target investment in AM for education, to make the most of the technologies and the learning that it can support.

Cambridge University Professor of Laser Engineering Bill O'Neill

"WE ARE OLD FOGIES. THESE TECHNOLOGIES CAPTURE THE IMAGINATIONS OF YOUNG PEOPLE, WHO THINK DIFFERENTLY ABOUT MAKING RIGHT FROM THE OUTSET."

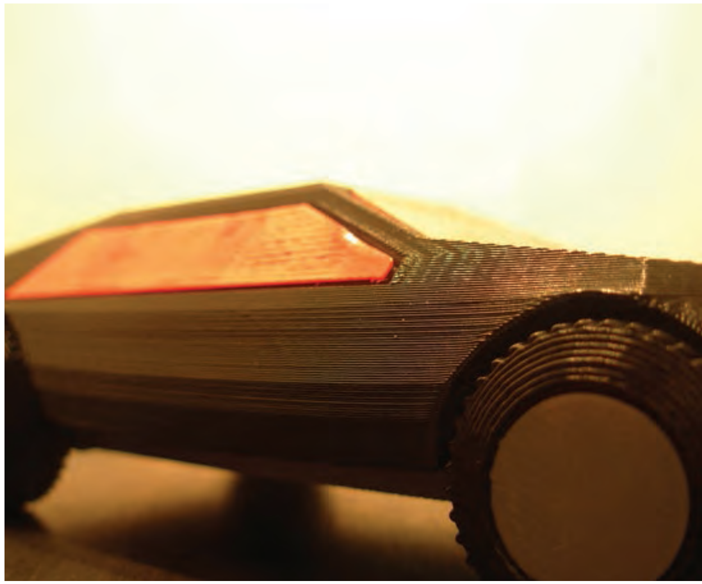


Photo: MakerBot car printed using fused deposition modelling (FDM) © Econolyst

Forging a future for AM

Media attention

In February 2011, *The Economist* published an article, 'The printed world[8],' which 3T RPD Chief Executive Officer Ian Halliday described as, "a tipping point for the media that has since produced global awareness of AM – which is no longer just for geeks".

Many at the meeting welcomed the mainstream media attention, claiming that it attracts funding, engages young people and raises awareness of the technology among business owners. Others perceived a drawback in the media's focus on the homemaker 3D printing movement rather than manufacturing applications. "We are losing the opportunity to talk to an industrial audience about AM's real value to the UK manufacturing industry," said Graham Tromans, Principal and President of AM consultancy GP Tromans Associates.

About 16,000 articles on AM and 3D printing were published in 2012, compared with about 1,600 articles in 2011[3]. AM has enjoyed consistent attention from the international media, financial magazines, and the general public. The constant exposure continues to drive interest among investors and many others.

Cambridge University Professor of Laser Engineering Bill O'Neill

"RATHER THAN ASK WHAT ADDITIVE MANUFACTURING HAS DONE FOR YOU - THE ANSWER TO WHICH IS CLEAR: IT HAS GIVEN YOU A CAREER - ASK WHAT YOU HAVE DONE FOR IT."

Fostering UK innovation

Currently, the UK has just one industrial AM machine producer, Renishaw. Attendees described this as "a shame" in light of "25 years of investment". In his opening presentation, Cambridge University Professor of Laser Engineering, Bill O'Neill called for "clearer strategic thinking" and exhorted his fellow academics: "Rather than ask what additive manufacturing has done for you – the answer to which is clear: it has given you a career – ask what you have done for it." AM is a technology with strong roots in the UK. For example the RepRap desktop 3D printer, which uses a FDM process, was the first low-cost 3D printer and originated in Bath before being bought out by a US company.

Stimulating R&D through competitions

In December 2012, The TSB and research councils launched a competition[9] which will fund 18 innovative 3D printing research and development projects with £8.4 million in UK government funding[10]. This aims to overcome some of the technology adoption barriers outlined in this report such as high cost, inconsistent material properties, lack of applicable industry standards, unexpected pre-and post-processing requirements and the failure to exploit the new design freedoms offered. Dr Ian Halliday welcomed the initiative, saying, "this is the way to generate growth in the UK."

CRDM Director Graham Bennett called for more competitions "to encourage technology stretch," suggesting a competition to create a 100% 3D-printed car would be especially relevant to the current industry.

Creating clusters

Creating AM business clusters could create opportunities for cross-pollination of ideas between companies, accelerating innovation. Author and manufacturing journalist Peter Marsh claimed that clusters are undergoing a "comeback", while Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham, asserted, "enabling entrepreneurial hothouses and clusters will get us the next Google".

Royal Academy of Engineering's Education and Skills Policy Manager Dr Rhys Morgan

"WE NEED TO ADDRESS NEW IDEAS FROM PEOPLE WHO ARE LEFT-FIELD OF ENGINEERING, BECAUSE WE ARE LOOKING FOR THE EQUIVALENT OF A KILLER APP – IN THIS CASE A KILLER BIT OF AM."

Finding mavericks

Peter Marsh believes AM would benefit from attracting maverick figures in the mold of entrepreneur James Dyson and designer Thomas Heatherwick. "Mavericks are the kind of people that would have a go at 3D printing," said Marsh. "They may occasionally lack technological expertise or funding but they have the right mind set."

He identified these figures as archetypally British. "People around the world like the British way of doing things. James Dyson has succeeded because he thinks differently, he is determined, gifted and personable and will keep on going against all the odds. Britain probably has more of these characters, and they should be backed," said Marsh. "I do not believe that British manufacturing should remake itself in the image of Germany or the US – we have to make use of what we have got."

Photo: Bloodhound SSC
© Siemens NX

CASE STUDY

BLOODHOUND SSC

"This is the epitome of a maverick project" said Dan Johns, Materials, Processes and Technologies Engineer in the Bloodhound project, which will attempt to break the current land speed record in 2014. "We don't follow any rules, we are not regulated as such, we don't patent anything and we have an open innovation policy – and we think this car is a great platform for AM," he said. Bloodhound used AM to make the car's titanium nose-tip and elements of the cockpit. "We are picking applications for AM that make sense," said Dan Johns. Additive manufacturing the nose-tip offered cost benefits, while customisation drove the use of AM in the cockpit. "The grips are reverse-engineered from driver Andy Green's hands, with the button configuration following the arc of his thumb," explained Dan Johns.

Building a framework

Defining the sector

Defining the differences between 3D printing and AM to create clearer market segmentation could help the AM and 3D printing sector attract public and private investment. Commerical Manager of the Centre for Additive Layer Manufacturing at the University of Exeter Dr Sara Flint said, "Separating out the market and creating a clearer map of which technology suits which applications would help. For instance, at the bottom end of 3D printing, it is about opening up the market to new people, and at the top end it is about improving materials and making inline processing happen."

It is also important to understand the different benefits created by different versions of the technology. Simple 3D printers can support education and research through rapid prototyping. More sophisticated machines can be used in industry affording savings in materials used, and to create more economic, lightweight products. The technologies span across systems that are cheap and accessible to expensive and specialised – and different machines serve very different purposes.

Roundtable attendees agreed that a government drive to roadmap AM's future would be welcomed. Loughborough University Professor of Manufacturing Technology Phill Dickens said, "We need a joined-up plan that lays out specific deliverables, timings and responsibilities." Others around the table agreed, with Mike Murray, BAE System's Head of Airframe Integration, asking for the UK "to define a timescale and lay out a technology trajectory".

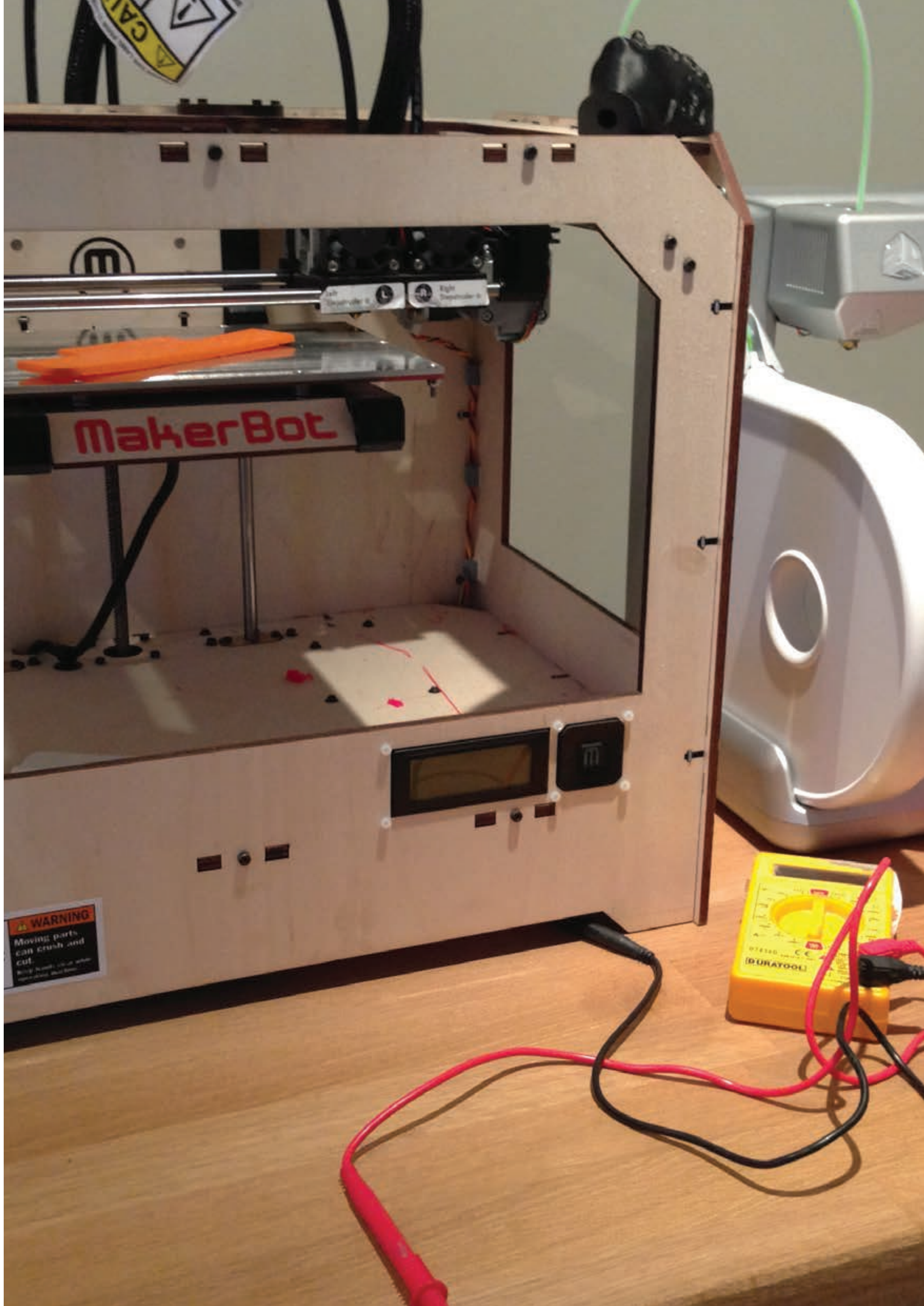


Photo: MakerBot consumer printer
© Econolyst

Photo: Examples of stereoliography (SLA) © Econolyst

Highlights

The UK is one of the world's leading sources of AM-related knowledge and research activity. It has been suggested that the technology will have the potential to print architecture and whole organs within the next 20-25 years. And one of the greatest future capabilities for AM will be in its convergence with other high value manufacturing solutions.

The AM industry has experienced tremendous growth in 2012 with the global market for AM products and services growing 29% (compound annual growth rate) to over $2 billion[3]. Industrial AM systems also experienced an increase in sales worldwide in 2012, with nearly 8,000 units sold[3].

Often heralded as 'the next industrial revolution', in reality AM has faced technological issues and challenges since its creation in the 1980s. In order to move the technology past these barriers there must be focused attempts to improve the materials used as feedstock, CAD programs, machine speed, product reliability, and the safeguarding of IP.

The technology's advantages in efficiency, creativity and accessibility have sparked optimism within the media and also in education. The new UK national curriculum, to be introduced in 2014, will include secondary school pupils learning about 3D printers in design and technology.

In the UK, AM is well established and continues to grow. This report identifies specific barriers to wider technology adoption. Targeted improvements in these areas, in combination with the technology's intrinsic advantages, will forge a competitive future for AM in the UK.

To follow on from the roundtable forum, the participants identified the next questions that could be addressed:

1. How can we encourage multidisciplinary research to move the field forward fast enough for greater economic benefits?
2. CAD software as it stands today cannot realise the creative freedom afforded by AM. We need new design systems. How do we encourage national digital and design literacy?
3. The AM industry urgently needs technologies to detect IP infringement and manage the vast amounts of data transferred and processed. Law and new business models can protect the industry from IP infringement and litigation. Can the UK get in on this early enough to lead?
4. AM will run on new business models - fast-changing with high levels of customisation. How can these non-traditional models attract sufficient finance?
5. What funding opportunities should be offered to boost AM?
6. Who should drive the development of industry standards for AM?
7. Viable businesses in AM in healthcare already exist. What is the best strategy for growth in AM healthcare?
8. How will we get the next generation excited about manufacturing? Children will be learning about 3D printing in the school syllabus and through educators adopting it as a teaching tool. How else can this be encouraged and supported?

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Appendix 1: Roundtable programme

Welcome and introductions
Chair: *Professor Sir Mike Gregory CBE FREng, Director, Institute for Manufacturing, University of Cambridge*

Introductory session
Additive manufacturing: changing the UK manufacturing landscape
Professor Bill O'Neill, Professor of Laser Engineering, University of Cambridge

Session 1: The nature of additive manufacturing

Part 1 – What can be gained from additive manufacturing and when?
Horizons, timescales and unforeseen uses
Graham Tromans, Principal Consultant and President, G P Tromans Associates

The sustainability issue
Dr Chris Tuck, Additive Manufacturing and 3D Printing Research Group, University of Nottingham

Part 2 – From subtractive to additive manufacturing: changing ways of thinking and working
Importance of design and the move to multi-functionality
Professor Richard Hague, Director, EPSRC Centre for Innovation Manufacturing in Additive Manufacturing, University of Nottingham

Additive Manufacturing: accelerating innovation through co-operation and consensus
Alex Price, Programme Manager, BSI

Session 2: The benefits of additive manufacturing to the UK – can additive manufacturing drive growth?

The benefits of additive manufacturing to the UK: can the new processes drive growth?
Peter Marsh, Author of The New Industrial Revolution and journalist

Business models and opportunities for UK manufacturing
Dr Ian Halliday, CEO, 3T RPD Ltd

Session 3: Case studies – current UK industry applications of additive manufacturing

Panel discussion: the advantages of additive manufacturing to UK industry

Keith Bridger, Head of welding and materials engineering, Nuclear AMRC

Neil Burns, Director, Croft Filters Ltd

Dan Johns, Materials, Process & Technologies Engineer, Bloodhound SSC

Neil Mantle, Head of Centre of Competence, Rolls-Royce

Jon Meyer, Research Team Leader, EADS Innovation Works

Appendix 2: Roundtable participants

Details reflect affiliations at the time of the meeting.

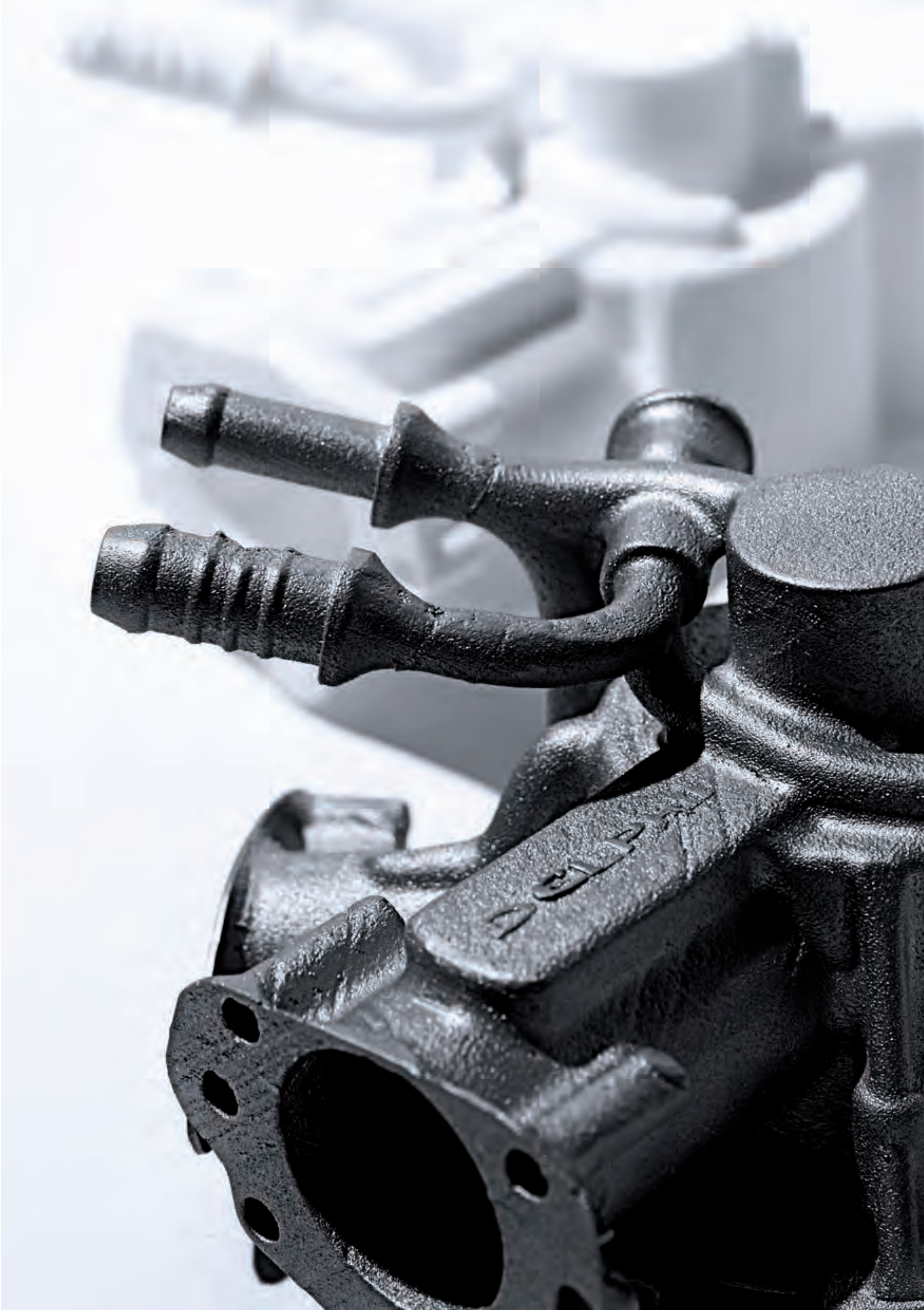
Name	**Affiliation**
Professor Sir Mike Gregory CBE FREng (Chair)	Institute for Manufacturing, University of Cambridge
Graham Bennett	CRDM Ltd
Keith Bridger	Nuclear AMRC, University of Sheffield
Neil Burns	Croft Filters Ltd
Antony Chapman	EPSRC
Professor Kenny Dalgarno	Newcastle University
Professor Phill Dickens	Loughborough University
Dr Sara Flint	Centre for Additive Layer Manufacturing (CALM), University of Exeter
Dr Ross Friel	Loughborough University
Professor Nigel Gilbert FREng	University of Surrey
Dr Ian Halliday	3T RPD Ltd
Professor Richard Hague	EPSRC Centre for Innovation Manufacturing in Additive Manufacturing, University of Nottingham
Professor Russell Harris	Loughborough University
Professor Neil Hopkinson	University of Sheffield
Professor Ian Hutchings FREng	University of Cambridge
Dan Johns	Bloodhound SSC
Dr Robert Kay	Loughborough University
Professor Andy Keane FREng	University of Southampton
Neil Mantle	Rolls-Royce
Peter Marsh	Author of *The New Industrial Revolution and journalist*
Jon Meyer	EADS Innovation Works
Dr Tim Minshall	Institute for Manufacturing, University of Cambridge
Dr Rhys Morgan	Royal Academy of Engineering
Dr Letizia Mortara University of Cambridge	Institute for Manufacturing,
Mike Murray	BAE Systems Warton
Professor Bill O'Neill	University of Cambridge
Alex Price	BSI
Dr Phil Reeves	Econolyst Ltd
Dr Allan Rennie	Lancaster University
Simon Scott	Renishaw
Professor Will Stewart FREng	UCL; University of Southampton
Dr Chris Sutcliffe	Manufacturing Science and Engineering Research Centre, University of Liverpool
Graham Tromans	G P Tromans Associates
Dr Chris Tuck	Additive Manufacturing and 3D Printing Research Group, University of Nottingham
Robin Wilson	TSB
Professor David Wimpenny	Manufacturing Technology Centre

Appendix 2: Roundtable participants continued

In attendance

Name	Affiliation
Suzy Antoniw	Science Museum
Natasha McCarthy	Royal Academy of Engineering
Emily Pacey	Writer
Beverley Parkin	Royal Academy of Engineering
Philippa Shelton	Royal Academy of Engineering

Photo: A pump formed by selective laser melting (SLM) © Econolyst



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