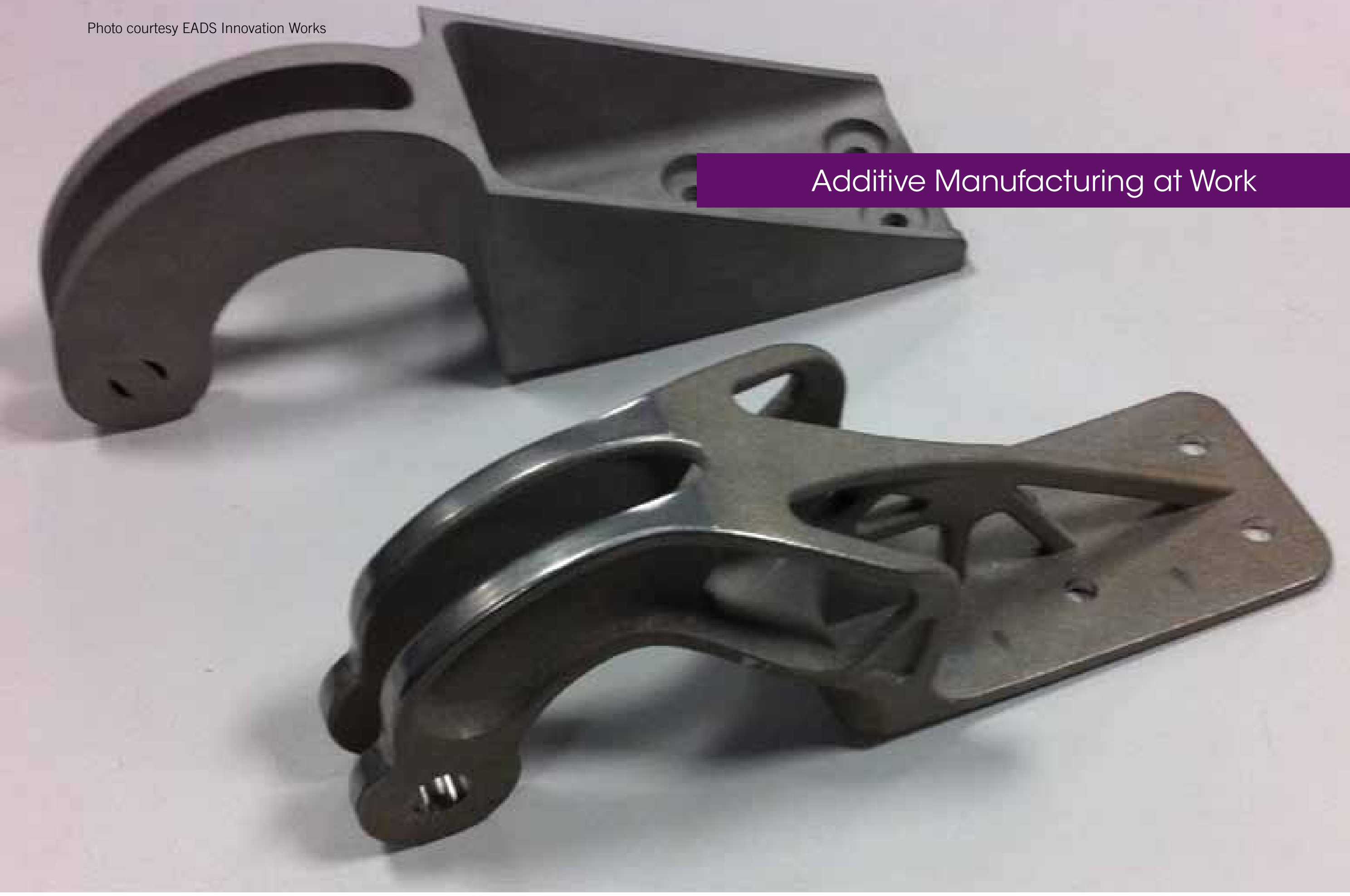
Photo courtesy EADS Innovation Works

Conventionally manufactured aircraft engine door hinge part (upper left) and additively manufactured part (bottom right) using topology optimization for design. The AM part offers the same strength at half the weight.

Additive
MANUFACTURING ADVANCES

The fast-growing frontier includes metals and mainstream parts production

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Additive manufacturing (AM) has never received so much attention. The Economist, Forbes, USA Today, and countless other mainstream and technical publications and blogs have brought the technology to the forefront. Large aerospace companies, such as Boeing, GE Aviation, and Airbus, are hard at work qualifying AM processes and materials for flight. Boeing, for example, now has 200 different AM part numbers on 10 production platforms, including both military and commercial jets. Meanwhile, the medical, dental, and consumer products


Photo courtesy Oak Ridge National Laboratory's Manufacturing Demonstration Facility

Hydraulic manifold designed for a new class of compact underwater robotic systems produced with interior lattice structures on an EBM system. The robot base and hydraulic pump, reservoir, and accumulator are integrated into one lightweight structure.

industries are excited about where AM is headed and how they might participate in the mounting wave of activity.

In the past, AM was used mostly to make models for visualization, prototypes for fit and function testing, and patterns for prototype tooling. Now, many organizations are focusing their energy on making parts that go into final products. This is the fastest growing segment of the industry, expanding to more than 20% of the AM market in the past eight years, according to research at Wohlers Associates. Using AM to produce prototypes is still popular and well understood because the industry has had more than two decades to practice and refine this application. The new frontier is the production of parts for products in general and for making metal parts in particular.

Additive manufacturing is now being recognized as a serious method of manufacturing. Many events conducted by industry, academia, and government have presented examples of how the technology is being applied to the production of parts for products. Most involve relatively small volumes of parts, such as tens or hundreds for the aerospace, medical, and jewelry industries. Two exceptions are the manufacture of custom-fit, in-the-ear hearing aids and dental copings for crowns and bridges. Millions of hearing aids and dental copings are being produced annually. Each product is unique in shape and size, and that's where AM excels. In the future, it will be difficult for conventional methods of manufacturing to compete in cases such as these.

Additive Manufacture of Metals

AM systems that produce metal parts have developed quickly. It was less than 10 years ago that these systems began to gain traction commercially. Even then, few organizations worldwide knew much about them and even fewer had seen parts. Today, seven companies—all in Europe—offer systems based on powder bed fusion technology and four offer systems that use directed energy deposition technology. Examples of powder bed fusion are direct metal laser sintering (DMLS) from EOS and selective laser melting (SLM) from Renishaw. Laser engineered net shaping (LENS) from Optomec is an example of directed energy deposition.

The most popular metal systems use a laser to heat and melt fine particles in a powder bed. Parts from these systems are impressive, especially the thin walls, surface finish, fine features, and small internal channels that are possible. Dental companies prefer to use these laser systems for copings because of the fine, detailed nature that is possible. Systems that instead use an electron beam as the energy source are much faster, but the surface finish and feature detail are not as impressive. In the case of some orthopedic implants, however, a rough surface is preferred. This, coupled with speed, is why many medical implant manufacturers have selected electron beam melting (EBM) systems from Arcam. Company CEO Magnus René said that 12 medical implant manufacturers in Europe, the US, and Asia are now using EBM. Most of them have implant products on the market that were produced with the technology. Example products are acetabular hip cups, hip stems, and spinal implants. Arcam is the only manufacturer to use electron beam energy in a powder bed.

Many metal parts that are currently being made by AM can be cost prohibitive, difficult, or impossible to produce using conventional methods, such as casting or machining. This gives AM an advantage, but only if the right types of parts are selected. Quality requirements play a role. Good feature detail and surface finish are possible and comparable to metal castings, but they do not match the surface quality of CNC-machined parts. If a part can be produced conventionally at a reasonable cost and the volume is relatively high, it is often best to go that route at the present time.

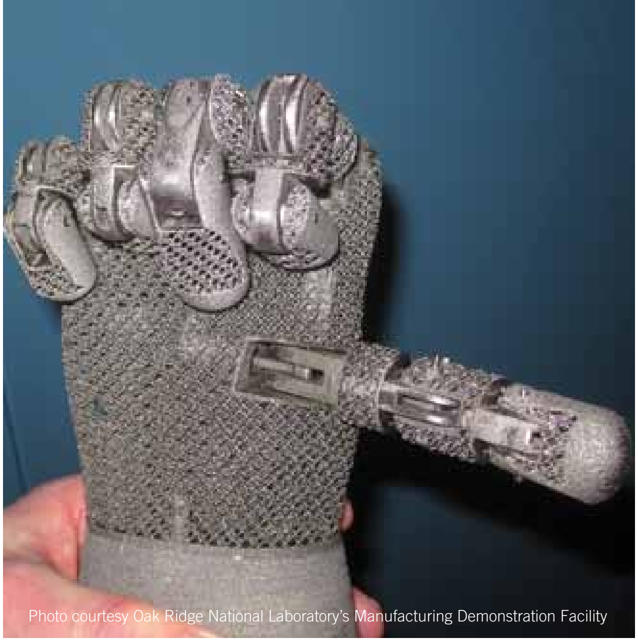
Photo courtesy Oak Ridge National Laboratory's Manufacturing Demonstration Facility

View of robotic hand.

Morris Technologies and its sister company, Rapid Quality Manufacturing, are running 20 DMLS systems and one EBM machine. When Morris purchased its first systems many years ago, it expected to use them mostly to produce inserts for plastic injection molds and other types of tooling. It turns out that 98% of the activity has been for the production of parts, not tooling. As of February 2012, the two companies had produced more than an estimated 30,000 parts total in 10 different alloys at a rate of about 6000 annually on its 21 systems. The metal AM systems are complemented by extensive CNC machining and other traditional processes.

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Many types of metals are available on metal AM systems. Among the most popular for medical and aerospace applications is the titanium alloy Ti-6Al-4V. Other metals used are cobalt–chrome, stainless steels, tool steels, aluminums such

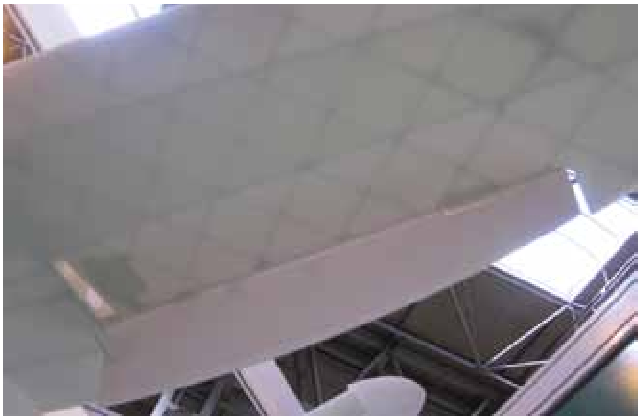

Photo courtesy Southhampton University and 3T RPD Ltd.

UAV wing with internal ribs for added strength and integrated hinged flap.

as AlSi10Mg and 6061T6, jewelry and dental gold alloys, and nickel-based superalloys such as Inconel 625 and 718. Aerospace-grade aluminums and other metals are in development. All of the unused metal powder can be recycled in the machines after sieving. With plastic laser sintering, about 35–40% of the powder surrounding the part(s) becomes waste and a similar amount of virgin powder must be added for each new build.

One of the challenges associated with metal AM is the need for anchors and supports. With plastic laser sintering, most parts do not require support structures because the surrounding unsintered powder supports overhanging features. With metals, overhanging and overhead features, and the part itself, must be connected to the build plate to prevent distortion and warping. After the build is complete and the powder bed and parts cool, these anchors and supports must be removed using conventional cutting tools or wire EDM. Anchors that are trapped in difficult-to-reach areas can be tough or impossible to remove. Also, the surface of the part can be scarred when removing them. The need for anchors is much greater with laser-based systems.

Industry standards are becoming increasingly important as companies apply AM to the production of final products. In January 2012, ASTM International Committee F42 on Additive Manufacturing Technologies approved F2924-12 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion. It is the first AM material standard by ASTM and it could give a boost to the additive manufacture of Ti-6Al-4V. Three additional ASTM standards—one each on terminology, testing, and a file format—are now in place, and many others are in development.

Lightweight Parts

A major benefit of AM is the ability to produce highly complex shapes and geometric features. Almost without exception, if a part can be modeled on a computer in 3-D, it can be sliced and printed, layer by layer, on an AM system. This includes fine lattice structures, honeycomb features, and just about anything imaginable. When optimizing the structural members of a lattice, for example, AM systems can produce very strong parts with minimal material. The aircraft industry is particularly interested in using this build technique to produce lightweight airplane parts. Already, unmanned aerial vehicles (UAVs) have been produced in this way and flown successfully. Not only does it result in lighter aircraft and less fuel, the build times are faster because much less material is processed. Also, designers can integrate moving parts in the design and build, such as hinged wing flaps, which was the case in one UAV that was flown.

With clever design, it is also possible to apply a concept known as topology optimization, a method of using mathematics to determine where to locate material in a part. When done correctly, it can optimize the strength-to-weight ratio of a part, somewhat like using optimally constructed lattice structures. Prior to AM, topology optimization was sometimes used at the conceptual phase of a new product, but it was usually too expensive or impractical to manufacture it in this way. With AM, it becomes feasible, so companies are now looking at it in an entirely new context.

The West is driving most advances in AM, including design innovation for additive manufacturing. AM has been in use for nearly two decades in many regions of the world, but advanced applications have been slow to catch on in many places. Asia has enjoyed the use of AM for prototyping, but organizations in most Asian countries—even Japan—have shown little interest in applying the technology to final part production. Consequently, making lightweight parts with AM is not relevant to these organizations because they are using AM to make prototypes and not finished products.

Some organizations in Australia and South Africa understand the design potential that AM brings and are exploring it further. The government of Australia (CSIRO) commissioned an additive manufacturing technology roadmap that was published about one year ago. This work, combined with a series of conferences in 2010 and 2011 in major Australian cities, have set things into motion for the country, especially for the manufacture of metal parts. Meanwhile, the South African government (CSIR) has teamed with Aerosud, a supplier to Airbus and Boeing, to develop a large and fast laser-based powder-bed fusion system for metal parts. The minerals used to make titanium are abundant in South Africa (second only to Australia), so the machine development program, called Aeroswift, is focused mostly on titanium part manufacturing.

Recent Trends and the Future

AM machines priced at under $2000 have developed quickly over the past three years. It is now possible to purchase a kit that you assemble for $500–$1000. The part quality, build volume, and reliability of these machines are not up to industry quality standards. Even so, they are providing opportunities for learning and experimentation to an entirely new group of users, many of whom are visible and vocal about what they are doing with these systems. Most of these machines are derivatives of the RepRap open-source project that emerged after the expiration of the original fused deposition modeling (FDM) patent by Scott Crump, founder and CEO of Stratasys.

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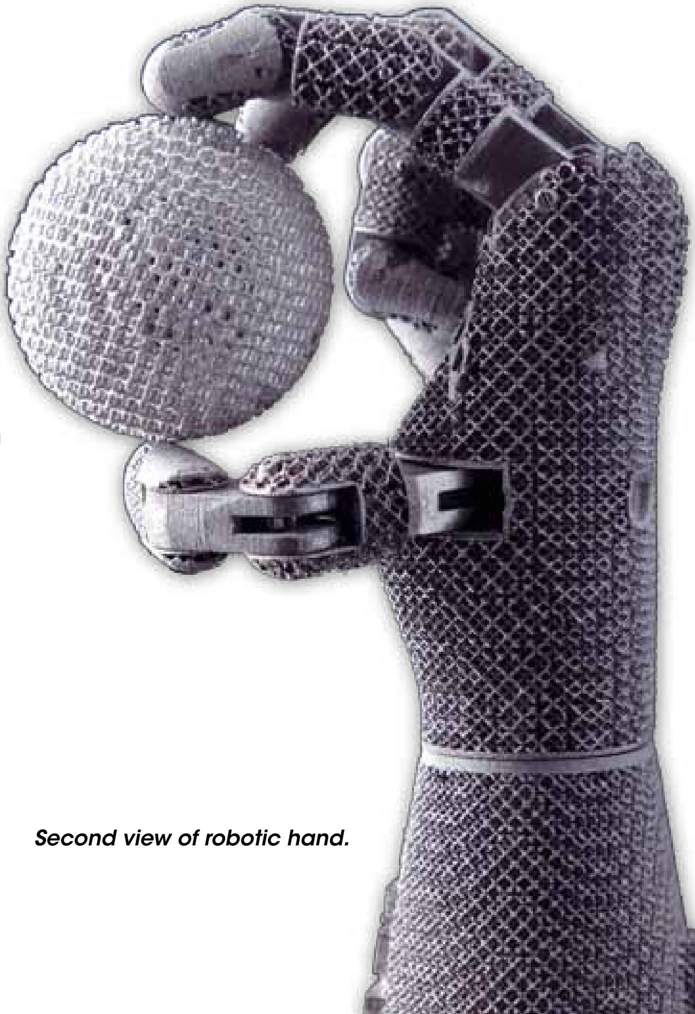
3-D content continues to be a "gating" factor in the growth and expansion of the AM industry. It is estimated that fewer than 3 million commercial CAD solid modeling seats are installed worldwide. Meanwhile, the world population is about 7 billion. This is not to suggest that everyone on the planet should create 3-D content. However, as new, easy-to-use, and often free design products become available, a larger number of people will create or influence 3-D design data. The popularity of Google SketchUp has helped. 3DTin and Tinkercad provide web-based interfaces that allow novices to create content easily. Autodesk 123D and Dassault's 3DVIA Shape are more involved products, but are currently free.

The idea of co-design and co-creation is also developing. Envision a professional designer that creates a 3-D model, such as a lighting design. This model can be uploaded to a special website and subsequently changed by anyone using simple, intuitive methods. Moving a slider bar, for example, might stretch or twist the design within certain pre-set limits. Entering text into a text box might place a name or phrase on the product. In this way, almost anyone can influence or personalize a design without being a designer.

In the future, we will also see other interesting developments, such as the printing of electronics and battery materials that conform to the shape of a product. This has been demonstrated, and a number of universities are currently seeking funds to develop it further. As key AM patents continue to expire, the door opens for new and possibly less expensive versions of established AM machines. This will also lead to a reduction in material cost because it will be more difficult for system manufacturers to lock customers into their materials as competitive systems become available.

Meanwhile, entirely new businesses and business models are emerging as products become less expensive and more people



Second view of robotic hand.

Photo courtesy Oak Ridge National Laboratory's Manufacturing Demonstration Facility discover what is possible. Examples are Shapeways, MyRobotNation.com, and the many RepRap-inspired businesses that are appearing. The manufacturer of the future will look nothing like a factory where hundreds or thousands of people come together to make millions of something. Instead, it could be student in a dorm room or an entrepreneur in a garage who is offering a special product or manufacturing service. This levels the playing field and opens up the possibility for professional and economic growth in both developed and underdeveloped regions of the world. With the ease of copying and manufacturing products, intellectual property litigation will also increase.

As AM continues to develop on multiple levels and in many directions, it will gain more momentum and respect as a method of manufacturing. Metal parts from some AM systems are already on par with their cast or wrought counterparts. As organizations qualify and certify these and other materials and processes, the industry will grow very large. In fact, additive manufacturing is poised to become the most important, the most strategic, and the most used manufacturing technology ever. **ME**

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