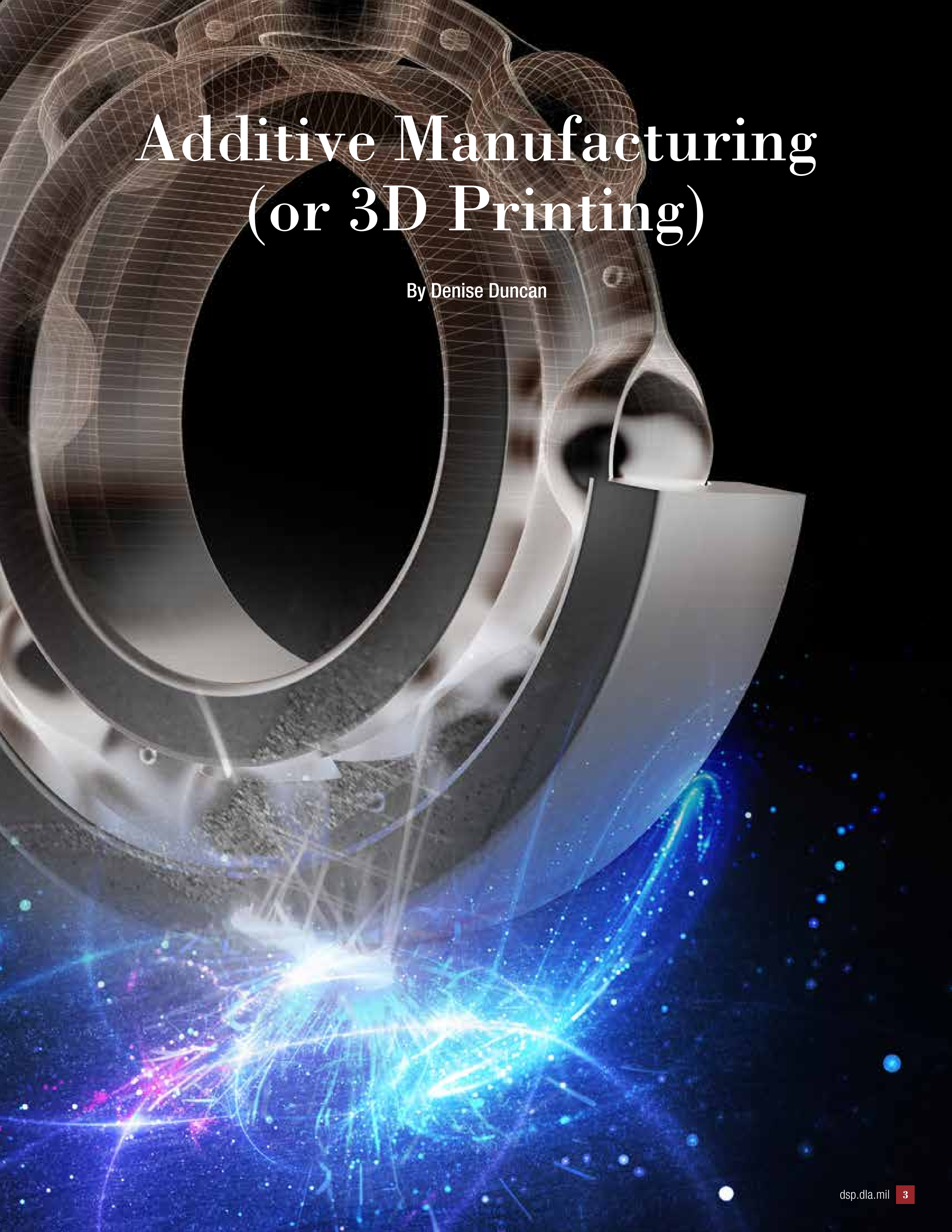
Additive Manufacturing (or 3D Printing)

By Denise Duncan



DoD's weapon and other systems keep soldiers, sailors, and airmen safe and effective in the field; and it takes over a billion parts per year to keep those systems running. When a new technology or process affects the logistics of providing those parts where and when needed, DoD pays attention; and so it is with the manufacturing process of additive manufacturing (AM), sometimes called "3D printing." AM has the potential to be a transformative technology, completely changing the way we think about designing, manufacturing, and delivering parts and goods. In 2012 ***The Economist*** called additive manufacturing "a third industrial revolution,"[1] and since then it has published eight additional articles on its growth in manufacturing. AM has achieved a foothold in the defense industrial base and will grow in use for certain types of parts.

Additive manufacturing is the process of building an object by depositing layers of material, one layer at a time. Contrast that approach with our current "subtractive" processes where we cut away or subtract (by milling, grinding, drilling, etc.) material from a block of metal or other material. To imagine one AM approach, picture a laser printer that, instead of ink cartridges, has cartridges filled with very fine powdered metal or plastic. A 0.1-millimeter-thick layer of powder is laid down, and a laser sinters the powder only in those places where a cross-section of the final object will be solid. The build platform drops a tenth of a millimeter, and the process is repeated. Videos of AM abound on the Internet, and viewing one or two of those will make the process more intuitive for the reader.[2]

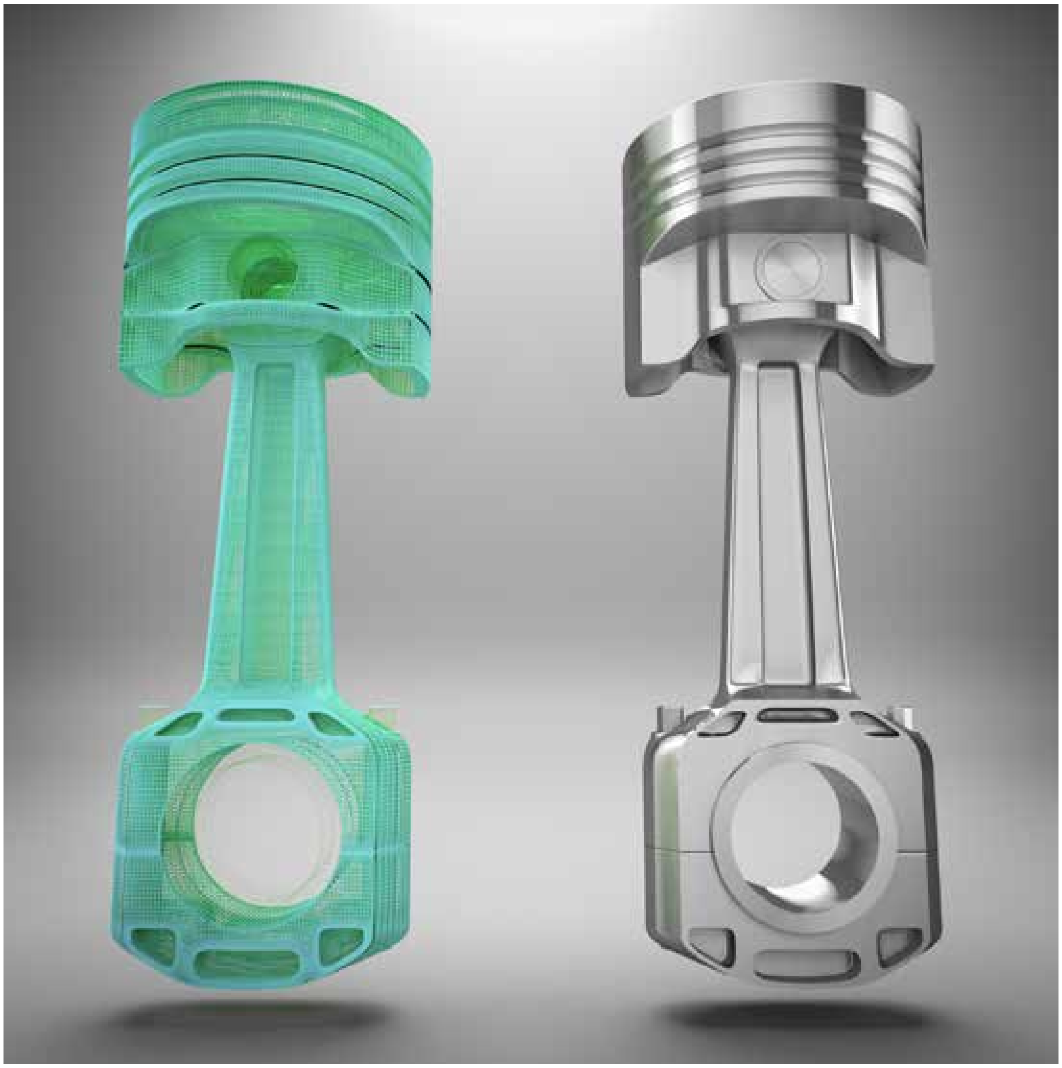
Characterizing AM by Processes Used

In general, the AM process starts with a three-dimensional (3D) model of the object to be built. This is usually created by computer-aided design (CAD) software, or from a 3D scan of an existing object. 3D scans can be especially useful in the case of repair or rebuild tasks, because the scan will capture changes to the article due to use—which is useful feedback for designers of the article. Examples of both a wireframe and a solid model are shown in Figure 1.

[1] *The Economist*, April 21, 2012, http://www.economist.com/node/21553017.

[2] http://www.ted.com/talks/lang/en/lisa_harouni_a_primer_on_3d_printing.html.

Figure 1. Example of Step 1 in Additive Manufacturing—a Wireframe (on the left) and a Solid Model (on the right)



The next step in almost all cases is converting the file containing the 3D model (generally in a format used by CAD software) into a standard file format, such as .STL.[3] The resulting file is then sent to "slicing" software, which creates the layers for the AM process. After these three steps, the actual AM process takes place.

[3] For more information, see ISO/ASTM52915–13, "Standard Specification for Additive Manufacturing File Format."

Many different AM processes exist; Table 1 provides a sampling of some common processes.

Table 1. Characteristics of AM Types

Type of AM	Process name	Materials	Process
Deposition of molten material	Fused deposition modeling	Metal or plastic wire	Material is melted and extruded in layers to build up the object.
Binding of granular materials	Electron beam melting	Titanium alloys, including gamma titanium aluminide	The electron beam melts metal powder in thin layers in a vacuum.
	Selective laser sintering (SLS) and direct metal laser sintering (DMLS)	For SLS, metal or polymer powder For DMLS, powdered stainless steels, mar-aging steel, cobalt chromium, inconel, and titanium Ti6Alv4	Lasers are used to sinter metal or plastic powders. Sintering is the process of heating material (below its melting point), causing atomic diffusion of the particles in the powder.
	Binder jetting	Plaster or resin	Thin layers of material powder are spread across the build platform, and a binder is sprayed through the inkjets to set the powder for the solid area on each layer.
Photopolymerization	Stereolithography	Polymers	Lasers are directed into a vat of polymer.
	Digital light processing	Polymers	Safelight is used with masks to expose a vat of poly-mer to digital light.
	Inkjet printer	Polymers	Each layer is cured by ultraviolet light upon deposition.
	Photolithography	Synthetic resin	Light-emitting diodes are focused on a block or vat of resin on a block or vat of resin.

Advantages of AM

One of the early uses of AM was for rapid prototyping. Studies have shown that the use of 3D modeling software, combined with rapid prototyping, results in significant savings of both time and money.[4] Businesses that used both approaches typically got products to market earlier and saved significantly on product development costs. When a business uses AM to build prototypes, it can save 50 percent of the time normally required to produce the prototype. Sending an article out for fabrication, it will typically take 2 to 3 weeks until the prototype is in hand. When using in-house AM, the time can be cut to 2 to 3 days. Using AM to build a wireframe physical model (versus a solid model of the prototype) can cut this time even further.

Another advantage of AM is its flexibility, which gives businesses the ability to make modifications to prototypes or customize products for different customers. Finally, the processes employed in AM allow freedom of geometry, and that changes the rules of design. The "design for manufacturability" step can be greatly simplified, and items can be produced with significantly fewer process steps. That, in turn, makes it possible to produce highly complex geometries economically.

Labor savings also are significant, because once the design files are loaded to the AM process, little labor is involved, except for a finishing process for some products. AM also allows far more freedom in design. For example, GE Research invested $50 million in a 3D printing facility in Auburn, Alabama, to produce fuel nozzles for the new LEAP jet engine. To start, it will print 1,000 nozzles a year, but eventually the number may reach 40,000. The fuel nozzle in a jet engine is a complex part that has to withstand high temperature and pressure. Normally it is made from 20 different components. GE instead prints the part in a single AM process, using a laser to fuse layers of a powdered alloy made up of cobalt, chrome, and molybdenum. The resulting nozzle is 25 percent lighter and 5 times more durable than the traditionally manufactured one.

Finally, AM has positive logistical impacts. By building items close to where they will be used, much of the transportation of the finished object can be eliminated. For example, the National Aeronautics and Space Administration (NASA) has tested 3D printing in zero-gravity flight; its aim is to develop AM for the International Space Station to reduce the number of spare parts required to be transported to, and stored on, the station. NASA also recently awarded three teams a total of $40,000 in the first stage of the 3-D Printed Habitat Challenge Design Competition, to produce architectural concepts for a habitat on Mars using AM and materials found on Mars.

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[4] Aberdeen Group, *The Transition from 2D Drafting to 3D Modeling Benchmark Report*, September 2006.

Disadvantages of AM

AM has a few limitations. In particular, the size of the build platform is limited. Typically, objects are smaller than a cubic yard, although with electronic beam melting, the build platform can be up to about 5 feet long, 3 feet wide, and 5 feet high. Further, some larger build platforms—several meters in all three dimensions—are used for "printing" buildings in sandstone or concrete. The availability of materials in the proper form for AM is another limitation. Table 2 shows some of the materials available now, and new materials are being added continually.

Table 2. Types of Materials Used in Additive Manufacturing Processes

Process	Materials used
Material extrusion	Thermoplastic; may require support structures.
Material jetting	Photopolymers/thermoset plastic or wax-like materials for investment casting patterns.
Binder jetting	Plaster powder with water as binding agent. Metal powder or sand, with glue-like binding agents: finished by sintering in a furnace. Acrylic polymer, with a monomeric liquid binder.
Sheet lamination	Paper, with adhesives. Metal tapes and foils, with ultrasonic welding.
Vat photopolymerization (also known as stereolithography)	Liquid photopolymer, including ceramic-filled photopolymer. Cured with light (usually lasers). Digital light processing uses micromirrors to project an image of the layer onto the vat, curing an entire layer at once.
Powder bed fusion (also known as laser sintering, selective laser melting, direct metal laser sintering, and electron beam melting)	Polymer and metal powders, and more rarely, sand. Uses thermal fusion, usually from a laser or an electron beam.
Directed energy deposition	Metal powders and focused thermal energy.

Finally, AM is not the optimal process for high-volume manufacturing, unless some customization is required. For example, AM is used to mass produce the clear plastic "aligners" used to straighten teeth. These are built from a model of a client's teeth, and then the model is changed very slightly over many iterations, to gradually align the teeth to the desired "bite." But typical assembly-line methods are more suited for mass-producing products that are identical for every customer.

Current Applications of AM

Rapid prototyping is an example of AM integrated with traditional manufacturing processes. Even when mass production is needed, AM can shorten cycle times for engineering reviews by providing a physical prototype in much less time than getting prototypes developed by an outside firm. Reverse engineering is used to (for example) reproduce items if the design documentation has been lost. When technology is used to create a 3D model of the item (whether by laser scanning, x-ray, or magnetic resonance imaging), the 3D model can be used as input to the AM process.

Medical and dental device applications are plentiful, due to AM's customization capabilities. For example, AM is used to develop surgical guides, customized prostheses, and engineered tissue scaffolds. In addition, AM is used in some applications to create geometries not possible with traditional manufacturing techniques, resulting in new designs with higher strength and lower weight. AM also supports manufacturing of electronic items, by printing the electronics embedded into the final product.

DoD Applications of AM

Additive manufacturing is already in use by DoD and its supply chain. Original equipment manufacturers routinely use AM for rapid prototyping of new products, for molds and casting patterns, and for direct part production. The Joint Strike Fighter contains many parts manufactured using laser sintering and other AM techniques. DoD is using AM in medical applications as well, for example, to plan surgeries and to visualize reconstructive surgery, surgical implants, and prosthetics.

The Army's Rapid Equipping Force has deployed mobile laboratories to the war zone in Afghanistan. Each mobile lab—a roughly $2.5 million investment—is a 20-foot container and can be transported by truck or helicopter to any location. These labs speed up the design and production processes; the warfighter can provide feedback to the designer and, with rapid iterations, can proceed to a design for a complete solution. Engineers can work together inside each mobile lab to create needed items or repair parts made of plastic, steel, and aluminum. If the end item is going to be mass produced, the design can be transmitted back to the United States for procurement and production.

About the Author

Denise Duncan is a senior fellow at LMI with more than 30 years of information systems management experience. She has managed a wide variety of projects, from assisting senior leaders with portfolio management to strategic planning for chief information officers. For the past 12 years, Ms. Duncan has worked extensively on the application of data management principles to engineering and scientific data. She has authored standards, handbooks, and training materials in enterprise-level data management and information management. Ms. Duncan has been honored as a technical fellow of TechAmerica and is the vice president for programs in the local chapter of Data Management Association–International.