March 2015

AEROSPACE AMERICA

NEXT-GEN SATELLITES

through robotics and additive manufacturing

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A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Satellite manufacturers are beginning to equip spacecraft with metal parts made on 3-D printers. Someday, those additively manufactured parts might be assembled into spacecraft largely by robots operating in clean rooms. Debra Werner looks at the coming satellite manufacturing revolution.

Reimagining satellite

Lockheed Martin's booth at the annual Defense Manufacturing Conference in San Antonio was a popular stop for the curious. Inside a plexiglass box, a 6-foot-tall orange robotic arm deposited tiny beads of a carbon fiber-reinforced polymer a layer at a time. Within minutes, a satellite model the size of a small refrigerator began to take shape, although the whole process took hours. A second robot carved away excess material and used a laser tracker to inspect its work and verify the dimensions of the final product.

This is how Lockheed engineers think they will eventually build satellites: by marrying additive manufacturing with robotics. That would be a radical departure from today's processes, which go something like this:

Engineers and technicians in clean suits typically receive structures made by vendors or subcontractors in far-off factories or in house. A small but increasing fraction of those parts are today made by additive processes, but joining them together into a functioning spacecraft, called integration in industry parlance, is still done almost entirely by hand. It is as though a great sculpture slowly takes shape, and indeed, even commercial communications satellites — among the fastest to build — take two to three years to complete.

Lockheed insists that an entirely new approach is no longer a far off dream. The revolution will start with the frame and subsystems including power propulsion and communications gear, collectively called the bus.

"Our goal is to print an entire satellite bus with additive manufacturing in the next four years, and we may accelerate that goal," says materials engineer Slade Gardner, a Lockheed Martin fellow focused on advanced manufacturing and materials.

Lockheed Martin engineers don't plan to build a satellite's advanced optics or electronics on additive machines, but they do envision a turntable surrounded by ro-

by Debra Werner

construction

Robotic arms build a satellite model at the Lockheed Martin booth at the the Defense Manufacturing Conference in San Antonio.

Lockheed Martin

bots working together to build a lightweight spacecraft bus embedded with many of its subsystems including propulsion and antennas.

"Where it makes sense, a human will install payload elements and cabling," Gardner says.

Lockheed is not alone in seeing this potential. Satellite manufacturers including Space Systems/Loral of Palo Alto, California, are vying to convince customers that reliable spacecraft can be built through additive processes, and someday with robotics. The payoff for manufacturers could be an edge in the lucrative but crowded market for construction of communications satellites, spy satellites and scientific spacecraft.

Time is money, and building a satellite faster is one way to reduce costs and win a competition. Trimming component weight through additive processes could also let engineers pack more equipment on a satel-

Space Systems/Loral produced a 3-D printed titanium antenna bracket, at left, that has half the mass of its 0.4-kilogram conventionally machined titanium counterpart. A computer-aided design optimization process minimizes the material needed to meet strength and stiffness requirements.

Space Systems/Loral

lite or alternatively a customer could reduce the spacecraft's overall mass to reduce launch costs, given that rocket providers charge customers partly by the weight of their spacecraft.

Part of the mass of a conventional component comes from limitations in the dexterity of the machining tools, limitations in the details that can be cast in a mold, and the need to make multiple parts and assemble them. Some material is designed not for strength or insulation, but simply because of manufacturing constraints or to provide surfaces to join parts together. Additive manufacturing could reduce parts counts and lead to streamlined components.

"As we start to permeate this technology through the satellite, we can take out 15 percent of the mass in most cases and often 50 percent," says Derek Edinger, director of advanced materials and structural technology for Space Systems/Loral, a subsidiary of Richmond, British Columbia-based MDA Corp. and one of the world's largest manufacturers of commercial communications satellites. "That is the real draw for our customers, because reduced satellite mass means more room for radio frequency payloads, which generate revenue, and more fuel to extend the satellite's life."

Moving cautiously

Although 3-D printing promises savings, satellite builders are proceeding cautiously as they move additively manufactured parts from their ground-based applications into space. NASA's Juno mission, which launched in 2011 on its way to a 2016 rendezvous with Jupiter, carried the first ones: four sets of waveguide brackets printed using electron beam melting, an additive process that turned a powdered titanium alloy into the finished product. That success prompted Juno prime contractor Lockheed Martin to expand its use of additive manufacturing and to install equipment used in 3-D printing of polymers and metals in its factories in Colorado, California, Louisiana and Mississippi.

Additive parts are happening now, but a shift to robotics is expected to take longer, because each satellite is different and requires painstaking assembly. Vendors such as MDA and Wolf Robotics are working to perfect robots for satellite assembly.

Space Systems/Loral is preparing to send its first titanium parts created through additive manufacturing into space later this year and to include 3-D printed metal parts on almost all subsequent satellites. The first parts destined for space are identical fittings that go on each end of the struts that crisscross a satellite's interior. Although the fittings do not look very complex, the simple fact that manufacturers are trusting additive manufacturing to build load-bearing elements of a spacecraft is significant because satellite customers are notoriously risk-averse. Space Systems/Loral can't yet reveal publicly which satellite will carry the parts, but executives confirm that they are destined for a communications satellite slated for launch into geostationary orbit in late 2015.

Commercial communications satellites cost hundreds of millions of dollars to build and launch. To become profitable, satellite operators need their spacecraft to remain healthy for more than a decade in an environment where temperature extremes and punishing radiation are the norm. Satellite customers typically want manufacturers to use only flight-proven parts on their spacecraft, says David Bernstein, Space Systems/Loral senior vice president of program management.

To reduce the risk inherent in introducing any new satellite components, manufacturers conduct extensive testing. Last year, Lockheed Martin worked with Sciaky Inc., a company based in Chicago that specializes in electron beam welding and additive manufacturing, to build a large propellant tank simulator for a new satellite design. Lockheed Martin tested the tank at its maximum expected operating pressure on 50 separate occasions and then subjected it to pressure levels 25 percent beyond that anticipated maximum pressure 12 more times. Finally, Lockheed Martin conducted destructive testing, adding pressure until the tank burst, which occurred at more than twice its anticipated maximum pressure.

"Customers love to see data because it builds confidence," Gardner said.

Saving time, money and weight

Satellite customers are eager to realize the potential savings additive manufacturing promises. In general, it cuts the cost of producing metal components in half and reduces the time it takes to build them by 80 percent, Gardner says.

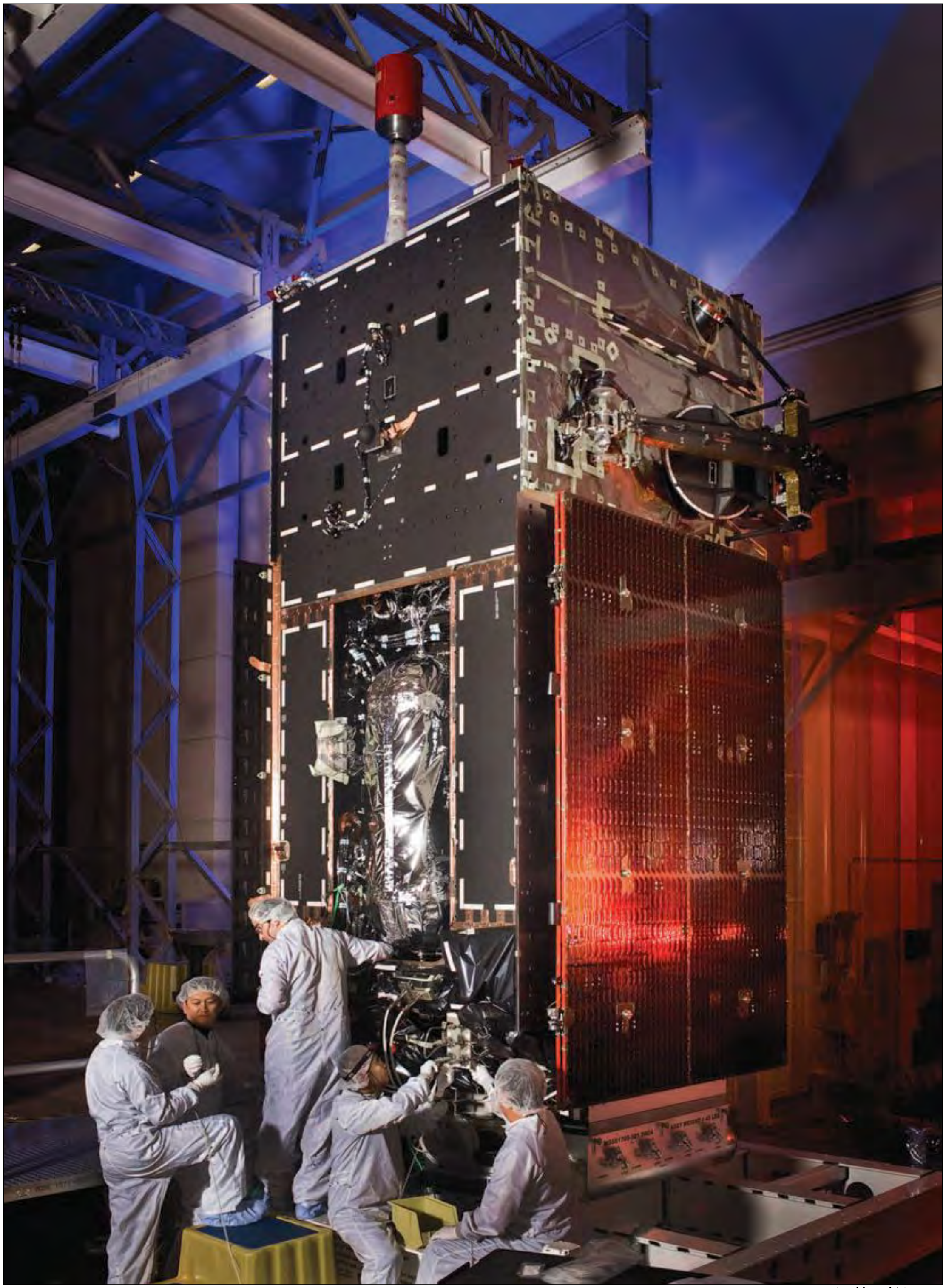
In many cases, companies can save time and money because additive manufacturing allows them to print complex designs that marry several individual compo-

European Space Agency

Thales Alenia Space used a 3-D printer to produce a prototype deployment mechanism for satellite solar panels. The titanium device has fewer parts and about one-fifth the mass of a similar, conventionally produced mechanism, according to the European Space Agency.

nents into a single unit. Reducing the total number of parts leads to cost, schedule and weight reductions. "Fewer parts mean less material, fewer assembly operations and fewer part numbers," Gardner said. "Each part number requires engineering attention, testing and quality inspection."

Over the last decade, satellite manufacturers have used 3-D printed parts in their ground-based operations. Space Systems/Loral uses 3-D printers to turn plastic polymers into the type of complex tools and fixtures engineers need for various jobs, such as holding spacecraft parts in place until they can be bolted down or serving as a stand-in for a component not



Lockheed Martin engineers work on a Space-Based Infrared System satellite. In the near future, experts say, 3-D printing and robotics will reduce the number of people and the amount of time needed to build satellites.

Lockheed Martin

yet built. With the temporary parts in place, workers can lay out wiring and perform other assembly tasks without waiting for the finished parts.

Before 3-D printing, manufacturers built the same types of custom tools and fixtures on machines using aluminum. That process often took months. Their replacements can be designed in a week and printed in a couple of days.

"This is the unsung hero of additive manufacturing," Edinger says. "In addition to cost and schedule savings, it has enabled us to make much more complicated satellites."

Space System/Loral's Ka-band data satellites, for example, which use powerful beams to broadcast communications to small antennas on Earth, carry radio frequency payloads composed of thousands of parts. That level of complexity would not have been possible without 3-D printing and other sophisticated manufacturing tools, Edinger says.

Within the last year, Space Systems/Loral also began using 3-D printers to produce lightweight brackets and thermoplastic shields to protect motors and optical lenses.

"We can make complex parts more quickly and inexpensively than we did with machined aluminum or fiberglass," Edinger says.

Engineers use software tools to determine the desired characteristics of the new parts, including the forces they will need to withstand. Then the engineers design the components to withstand those forces in a compact, lightweight form.

Now that printed parts are beginning to move from the factory floor to satellites, manufacturers and suppliers expect their use and complexity to grow rapidly.

"We haven't even scratched the surface of where we will be two to five years from now," says Joel Smith, strategic account manager for aerospace and defense at Stratasys Direct Manufacturing of Minneapolis, which makes 3-D printers and production systems.

In November, Stratasys began working with NASA's Jet Propulsion Laboratory to print 30 antenna supports for a joint U.S.-Taiwan satellite project designed to use GPS radio occultation systems on forthcoming clusters of small satellites to improve weather forecasts. GPS radio occultation systems measure the refraction of GPS signals traveling through the atmosphere to obtain information on temperature and water vapor. Clusters of Taiwanese Formosat-7 spacecraft — six to be launched in 2016 and six in 2018 — will carry U.S. supplied COSMIC-2 instruments, short for Constellation Observing System for Meteorology, Ionosphere and Climate-2. The satellites will be built with "the first additively manufactured parts on the outside of a spacecraft," says Jim Bartel, Stratasys senior vice president for direct manufacturing.

Stratasys' 3-D printers can produce objects in a variety of materials, including ULTEM 9085, a thermoplastic the company uses to print antenna supports for Formosat-7 satellites. Stratasys

Stratasys is building the supports, which will be used to attach two phased array antennas to each one of the 12 satellites, using a strong thermoplastic called ULTEM 9085 that is similar in strength to metal but weighs less. The same material is used in commercial aircraft and approved by the FAA because it meets the agency's flame, smoke and toxicity requirements. NASA plans to coat the 3-D printed parts with a paint designed to shield them from ultraviolet radiation.

The mission is technically daring, with a potentially large payoff, says Bartel: "If we can make parts that hold up on the outside of a spacecraft, we can make parts that go pretty much anywhere else."