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Report to Congressional Committees

October 2015

DEFENSE ADDITIVE MANUFACTURING

DOD Needs to Systematically Track Department-wide 3D Printing Efforts

GAO-16-56

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GAO Highlights

Highlights of GAO-16-56, a report to congressional committees

Why GAO Did This Study

Additive manufacturing—building products layer-by-layer in a process often referred to as three-dimensional (3D) printing—has the potential to improve aspects of DOD's mission and operations. DOD and other organizations, such as America Makes, are determining how to address challenges to adopt this technology throughout the department.

Senate Report 113-44 directed DOD to submit a briefing or report on additive manufacturing to the Senate Armed Services Committee that describes three elements. Senate Report 113-176 included a provision that GAO review DOD's use of additive manufacturing. This report addresses the extent to which (1) DOD's briefing to the Committee addresses the directed elements; (2) DOD has taken steps to implement additive manufacturing to improve performance, improve combat capability, and achieve cost savings; and (3) DOD uses mechanisms to coordinate and systematically track additive manufacturing efforts across the department. GAO reviewed and analyzed relevant DOD documents and interviewed DOD and academia officials.

What GAO Recommends

GAO recommends that DOD designate an Office of the Secretary of Defense lead to be responsible for developing and implementing an approach for systematically tracking department-wide activities and resources, and results of these activities; and for disseminating these results to facilitate adoption of the technology across the department. DOD concurred with the recommendation.

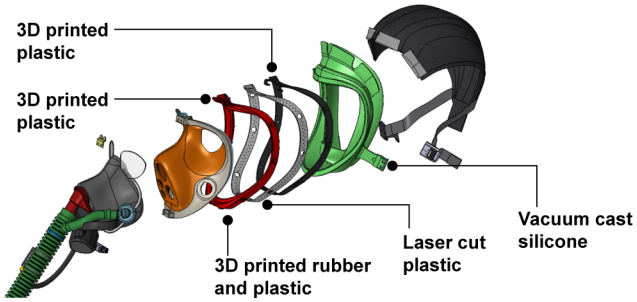
View GAO-16-56. For more information, contact Zina Merritt at (202) 512-5257 or merrittz@gao.gov.

What GAO Found

GAO determined that the Department of Defense's (DOD) May 2014 additive manufacturing briefing for the Senate Armed Services Committee addressed the three directed elements—namely, potential benefits and constraints; potential contributions to DOD mission; and transition of the technologies of the National Additive Manufacturing Innovation Institute ("America Makes," a public-private partnership established to accelerate additive manufacturing) for DOD use.

DOD has taken steps to implement additive manufacturing to improve performance and combat capability, and to achieve cost savings. GAO obtained information on multiple efforts being conducted across DOD components. DOD uses additive manufacturing for design and prototyping and for some production, such as parts for medical applications; and it is conducting research to determine how to use the technology for new applications. For example, according to a senior Air Force official, the Air Force is researching potential performance improvements that may be achieved by embedding devices such as antennas within helmets through additive manufacturing that could enable improved communications; and the Army used additive manufacturing to prototype aspects of a Joint Service Aircrew Mask to test a design change, and reported thousands of dollars thereby saved in design development (see figure).

Aspects of Army's Joint Service Aircrew Mask Prototyped Using Additive Manufacturing



Source: Department of Defense (DOD). | GAO-16-56

DOD uses various mechanisms to coordinate on additive manufacturing efforts, but it does not systematically track components' efforts department-wide. DOD components share information regarding additive manufacturing via mechanisms such as working groups and conferences that, according to DOD officials, provide opportunities to discuss challenges experienced in implementing additive manufacturing—for example, qualifying materials and certifying parts. However, DOD does not systematically track additive manufacturing efforts, to include (1) all activities performed and resources expended by DOD; and (2) results of these activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned. DOD has not designated a lead or focal point at a senior level to systematically track and disseminate the results of these efforts, including activities and lessons learned, department-wide. Without designating a lead to track information on additive manufacturing efforts, which is consistent with federal internal control standards, DOD officials may not obtain the information they need to leverage ongoing efforts.

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Abbreviations

3D	Three-dimensional
DOD	Department of Defense
GO Additive	Government Organization for Additive Manufacturing
OSD	Office of the Secretary of Defense
RDECOM	Research, Development and Engineering Command

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Congressional Committees

The Department of Defense (DOD) is determining how additive manufacturing, often referred to as three-dimensional (3D) printing,[1] might improve aspects of the department's mission and operations, such as supply chain management.[2] The term "additive manufacturing" refers to a layer-by-layer approach for producing 3D objects from a digital model using materials such as metal powders, plastic, and foundry sand. Since its inception in the 1980s, additive manufacturing has been used by private industry as a tool for design and prototyping—that is, building an early sample or model in order to test a concept or process to be replicated or learned from. Today, private industry is using additive manufacturing to produce finished end-parts. DOD uses additive manufacturing primarily for designing and prototyping, as well as for producing parts for some medical applications. Further, DOD is researching how the technology may be used to produce, among other things, such items as flight critical parts for aircraft.

The federal government, private industry, and universities have been involved in efforts to address challenges related to advancing DOD's use of additive manufacturing, such as those related to qualifying the materials and processes used to make parts (that is, ensuring that manufacturers can repeatedly make the same part and meet exactness and consistent performance standards on the same machine or on different machines), and certifying that they meet DOD's standards,[3] as noted by participants of the October 2014 Comptroller General forum on

[1]The terms "additive manufacturing" and "3D printing" are often used interchangeably. For purposes of this report, we use the term "additive manufacturing."

[2]The term "supply chain management" refers to the flow of materiel, services, and equipment from one point to another.

[3]For example, DOD requires that parts it purchases, such as aircraft engine parts, meet specific standards or performance criteria, as specified in their solicitations and contract awards. Manufacturers might need to have these parts, made via additive manufacturing, certified to meet DOD's standards.

additive manufacturing.[4] In August 2012, as a part of a presidential initiative focused on advanced manufacturing, the National Additive Manufacturing Innovation Institute (generally referred to as "America Makes"[5]) was established as a public-private partnership to accelerate the research, development, and demonstration of additive manufacturing technology and to transition it to the U.S. manufacturing sector.[6] As a participating member of America Makes, DOD is one of multiple federal agencies that collaborate with this institute's private industry and university members to discuss advances and successes in material development, technology development, and part production, according to Army officials, and to address challenges related to additive manufacturing.

Senate Report 113-44, accompanying a bill for the National Defense Authorization Act for fiscal year 2014, directed DOD to submit a briefing or report to the Senate Armed Services Committee addressing specific elements related to additive manufacturing.[7] In response, DOD provided a briefing in May 2014 on DOD's use of additive manufacturing.[8]

Senate Report 113-176, accompanying a bill for the Carl Levin National Defense Authorization Act for fiscal year 2015, included a provision for GAO to review DOD's May 2014 briefing and its efforts and processes to

[4]GAO, *3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing,* GAO-15-505SP (Washington, D.C.: June 24, 2015). GAO, with the assistance of the National Academies, selected officials from government, business, academia, and nongovernmental organizations to represent a range of viewpoints and backgrounds and held a forum to discuss additive manufacturing issues in October 2014.

[5]America Makes is part of the President's broader National Network for Manufacturing Innovation initiative that is designed to stimulate advanced manufacturing technologies and accelerate their commercialization in the United States. According to Navy officials, America Makes is one of many venues DOD partners with to address additive manufacturing challenges.

[6]For the purpose of this report we henceforth use the name "America Makes."

[7]The Senate Report directed DOD to include the following three elements in its briefing or report on additive manufacturing: (1) potential benefits and constraints of additive manufacturing, (2) how the additive manufacturing process could or could not contribute to DOD missions, and (3) what technologies being developed at America Makes are being transitioned for DOD use.

[8]The briefing document was entitled *Department of Defense Manufacturing and Industrial Base Policy (MIBP): Additive Manufacturing – Benefits and Opportunities for the Department of Defense* (May 1, 2014).

use additive manufacturing. This report discusses the extent to which (1) DOD's briefing to the Senate Armed Services Committee (henceforth referred to as "the Committee") on additive manufacturing addresses the three directed elements; (2) DOD has taken steps to implement additive manufacturing to improve performance, improve combat capability, and achieve cost savings; and (3) DOD uses mechanisms to coordinate and systematically track additive manufacturing efforts across the department.

DOD provided its briefing document on additive manufacturing to GAO on July 30, 2014.To determine the extent to which the briefing document addresses the three directed elements, two GAO analysts concurrently assessed DOD's May 2014 briefing document to determine whether it included the following elements: (1) potential benefits and constraints of additive manufacturing, (2) how the additive manufacturing process could or could not contribute to DOD missions, and (3) what technologies being developed at America Makes are being transitioned for DOD use. The analysts were consistent in their respective assessments of whether the briefing included the directed elements, and therefore it was not necessary for a third analyst to resolve any differences. We assessed the briefing document, with the recognition that it was not meant to be a stand-alone document but rather accompanied an oral briefing. We met with officials from the Office of Manufacturing and Industrial Base Policy, America Makes, and the military services to determine the extent to which they were involved in creating the briefing document and to obtain additional information about additive manufacturing. We also shared with the DOD officials, including Office of Manufacturing and Industrial Base Policy officials, our preliminary assessment of DOD's briefing document to obtain their comments.

To determine the extent to which DOD has taken steps to implement additive manufacturing to improve performance, improve combat capability, and achieve cost savings, we reviewed DOD documents, such as the December 2014 DOD Manufacturing Technology Program report[9] and briefing reports documenting the status of DOD's additive manufacturing efforts, as well as examples of any actual or potential performance and combat capability improvements, and examples of actual or potential cost savings. We also interviewed officials within the military services, Defense Logistics Agency, and Walter Reed National

[9]*DOD ManTech: Balancing National Security with Fiscal Realities* (December 2014).

Military Medical Center to further discuss any current or potential applications of additive manufacturing, and any improvements and cost savings associated with using the technology.

To determine the extent to which DOD uses mechanisms to coordinate[10] and systematically track additive manufacturing efforts across the department, we reviewed DOD coordination-related documents, such as charters and briefing slides, summarizing the goals and results of any current DOD efforts related to advancing the department's use of additive manufacturing—that is, efforts by the Office of the Secretary of Defense (OSD), Defense Logistics Agency, Defense Advanced Research Projects Agency, and the military services.[11] We also reviewed GAO's key considerations for implementing interagency collaborative coordination mechanisms,[12] and we reviewed the *Standards for Internal Control in the Federal Government*.[13] We identified examples of coordination groups that meet to discuss ongoing additive manufacturing efforts. Additionally, we discussed with OSD, Army, Navy, Air Force, Defense Logistics Agency, and Defense Advanced Research Projects Agency officials any actions that have been taken for coordinating additive manufacturing

[10]For the purpose of this report we use the term "coordination" broadly to include department-wide or intra-agency activities that others have variously defined as "cooperation," "collaboration," "integration," or "networking." We have done so as there are no commonly accepted definitions for these terms and as we are unable to make definitive distinctions between these different types of department-wide activities. We use the terms "coordination" and "collaboration" interchangeably throughout the report.

[11]While DOD coordinates with entities outside the department through government-wide additive manufacturing coordination mechanisms, we primarily focused on coordination within DOD.

[12]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C., Sept. 27, 2012). GAO, *Results-Oriented Government: Practices That Can Help Enhance and Sustain Collaboration among Federal Agencies,* GAO-06-15, (Washington, D.C., Oct. 21, 2005).The reports outline mechanisms that the federal government uses to facilitate interagency collaboration and the key issues to consider when implementing them, which can also be applied to intra-agency collaboration within a large agency like DOD, as well as practices for enhancing and sustaining an agency's collaborative efforts.

[13]GAO, *Standards for Internal Control in the Federal Government*, GAO/AIMD-00-21.3.1 (Washington, D.C.: November 1999).

efforts across the department and the extent to which DOD systematically tracks additive manufacturing efforts.[14]

We conducted this performance audit from July 2014 to October 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. We provide additional information about our scope and methodology in appendix I.

Background

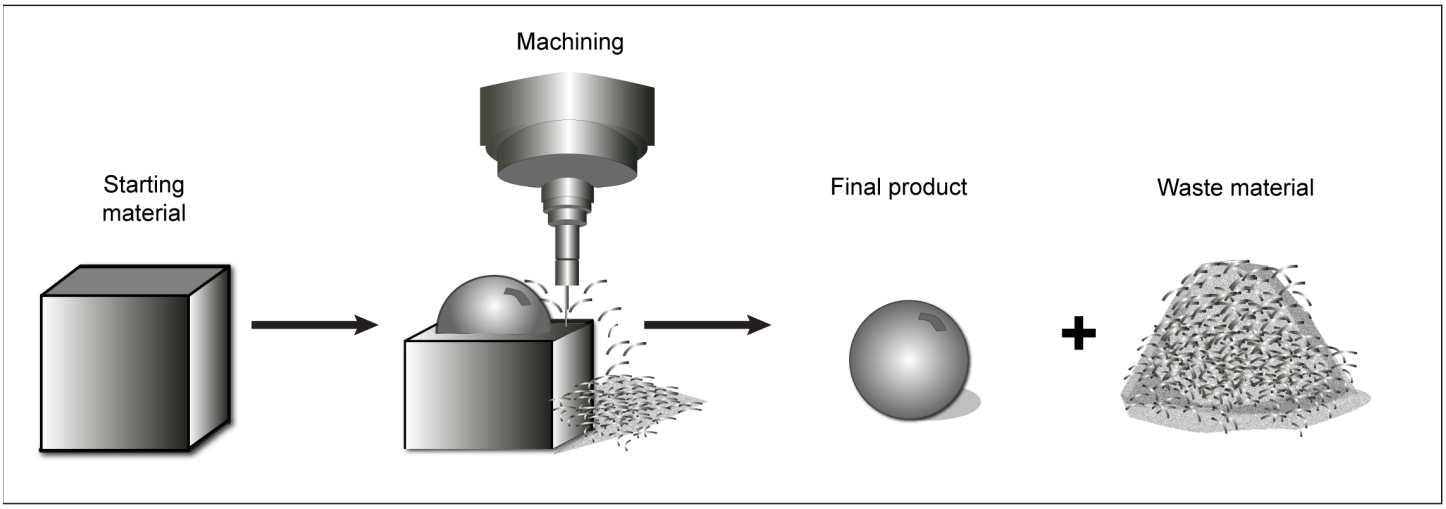
Additive Manufacturing

Unlike conventional, or subtractive, manufacturing processes—such as drilling or milling—that create a part or product by cutting away material from a larger piece, additive manufacturing builds a finished piece in successive layers, generally without the use of molds, casts, or patterns. Additive manufacturing can potentially lead to less waste material in the manufacturing process, as shown in figure 1.

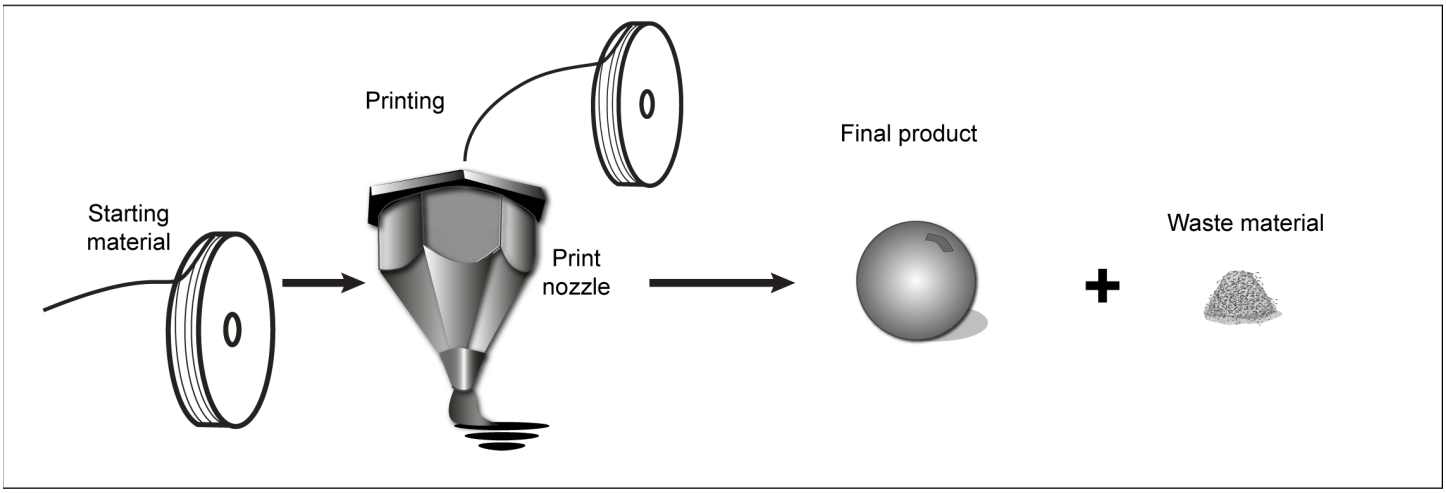
[14]We do not include the Marine Corps in this report because Marine Corps officials told us during the course of our review that they had not funded any additive manufacturing efforts (as of May 2015) and were just beginning to plan and evaluate the use of additive manufacturing.

Figure 1: Conceptual Comparison between Subtractive and Additive Manufacturing

Subtractive manufacturing



Additive manufacturing



Sources: GAO (analysis); Art Explosion (images). | GAO-16-56

ASTM International, an international standards development organization, has identified seven categories of additive manufacturing processes to

group the different types of technologies used, as shown in table 1.[15] According to DOD officials, the first six of the categories described are the ones of greatest use to DOD.

Table 1: Types of Additive Manufacturing Processes

Process name	Description
1. Binder jetting	A liquid bonding agent is selectively deposited to join powder materials.
2. Directed energy deposition	Focused thermal energy, such as a laser, is used to fuse materials to form an object by melting as the materials are being deposited.
3. Material extrusion	Materials are heated and selectively dispensed through a nozzle or orifice.
4. Material jetting	Materials, such as photopolymers or wax, are selectively deposited.
5. Powder bed fusion	Thermal energy selectively fuses regions of a powder bed.
6. Vat photopolymerization	Certain types of light, such as lasers, are used to selectively solidify liquid photopolymers.
7. Sheet lamination	Sheets of materials are bonded to form an object.

Source: GAO analysis of ASTM International data. | GAO-16-56

Note: Photopolymers are materials that transform from liquid to solid when exposed to certain types of light.

America Makes (National Additive Manufacturing Innovation Institute)

In August 2012, as part of a presidential initiative focused on advanced manufacturing, America Makes—the National Additive Manufacturing Innovation Institute—was established as a public-private partnership between federal government agencies (including DOD), private industry, and universities to collaboratively address additive manufacturing challenges; accelerate the research, development, and demonstration of additive manufacturing; and transition that technology to the U.S. manufacturing sector.[16] According to the government program manager of America Makes, funding to establish America Makes consisted of a federal government investment of $55 million (fiscal years 2012 through 2017), and it is managed by the U.S. Air Force Research Laboratory.[17]

[15]ASTM International, formerly known as the American Society for Testing and Materials, develops and delivers international consensus standards.

[16]According to the America Makes government program manager, the Army, the Navy, the Air Force, and the Defense Logistics Agency have committed to partnering with America Makes to develop a department-wide roadmap for additive manufacturing, in addition to their individual roadmaps, to begin approximately in December 2015.

[17]The initial federal government investment for America Makes was to be up to $30 million for fiscal years 2012 through 2014 combined, with a desire for 50/50 cost sharing with the recipient of the award.

The official also stated that America Makes receives additional funding through publicly and privately funded projects.

DOD Components Involved in Additive Manufacturing Efforts

Multiple DOD components—at the OSD, military department (Army, Navy, and Air Force), Defense Logistics Agency, and Defense Advanced Research Projects Agency levels—are involved in additive manufacturing efforts. At the OSD-level, the Office of the Assistant Secretary of Defense for Research and Engineering develops policy and provides guidance for all DOD activities on the strategic direction for defense research, development, and engineering priorities and coordinates with the Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy to leverage independent research and development activities, such as additive manufacturing research activities. The Defense Advanced Research Projects Agency's Defense Sciences Office and the military departments—through the U.S. Army Research, Development and Engineering Command (RDECOM); the Office of Naval Research; and the U.S. Air Force Research Laboratory—have laboratories to conduct additive manufacturing research activities. According to Navy officials, the military depots use additive manufacturing for a variety of applications using various material types. These efforts largely include polymer, metal, and ceramic-based additive manufacturing processes for rapid prototyping, tooling, repair, and development of non-critical parts. The DOD components lead and conduct activities related to several types of technology research and development and advancements. Additive manufacturing is one of these activities, and the components are involved to the extent that some of the broader activities include additive manufacturing. See appendix II for a more detailed description of the key DOD components involved with additive manufacturing.

Comptroller General's Forum on Additive Manufacturing

In October 2014, with the assistance of the National Academies, we convened a forum of officials from federal government agencies, including DOD; private-sector organizations; academia; and non-governmental organizations to discuss the use of additive manufacturing for producing functional parts, including opportunities, key challenges, and key considerations for any policy actions that could affect the future use of additive manufacturing for producing such parts. In June

2015 we issued a report summarizing the results of that forum.[18] During the forum, participants noted that the use of additive manufacturing has produced benefits such as reduced time to design and produce functional parts; the ability to produce complex parts that cannot be made with conventional manufacturing processes; the ability to use alternative materials with better performance characteristics; and the ability to create highly customized, low-volume parts. Furthermore, forum participants identified as a key challenge the need to ensure the quality of functional parts—for example, ensuring that manufacturers can repeatedly make the same part and meet precision and consistency performance standards on both the same machine and different machines. During the forum, participants also indicated that before a product can be certified, manufacturers must qualify the materials and processes used to make the part, which involves manufacturers conducting tests and collecting data under very controlled conditions. For example, DOD requires that parts it purchases, such as aircraft engine parts, meet specific standards or performance criteria. Manufacturers might need to have these parts certified to meet DOD's standards. According to participants in the forum, the National Institute of Standards and Technology is funding research to provide greater assurance with regard to the quality of parts produced using additive manufacturing. It is also leading efforts on additive manufacturing standards through ASTM International's committee on additive manufacturing, which was formed in 2009. Participants also identified some future applications for additive manufacturing, including the construction of tooling for conventional manufacturing lines, for enhancing education, and for enhancing supply chain management.

[18]GAO-15-505SP.

DOD's Briefing on Additive Manufacturing Addressed the Elements Directed by the Committee

DOD in its May 2014 briefing document on additive manufacturing addressed the three directed elements: that is, (1) potential benefits and constraints of additive manufacturing; (2) how the additive manufacturing process could or could not contribute to DOD missions; and (3) what technologies being developed at America Makes are being transitioned for DOD use.[19] In summary, we found the following:

- First, the briefing document noted potential benefits and constraints. For example, DOD noted a potential benefit to be derived in some cases from additive manufacturing yielding lighter parts for use in aircraft, for instance; thereby potentially lowering fuel costs. DOD also noted a potential constraint reflected in the fact that DOD has yet to establish qualification and certification protocols for additively manufactured parts.

- Second, the briefing document noted potential contributions to DOD's mission. For example, DOD noted that additive manufacturing may be capable of producing equivalent replacements for obsolete parts.[20]

- Third, the briefing document identified America Makes projects that DOD anticipated would be transitioned for DOD use.[21] For example, DOD noted a collaborative effort involving Pennsylvania State University's Applied Research Lab, Pratt & Whitney, Lockheed Martin, and General Electric Aviation on thermal imaging for process monitoring and control of additive manufacturing. DOD noted that this project would help enable DOD to ensure process and part

[19]The briefing document is entitled *Department of Defense Manufacturing and Industrial Base Policy (MIBP): Additive Manufacturing – Benefits and Opportunities for the Department of Defense (May 1, 2014).*

[20]While the briefing document did not include examples of an obsolete part, according to DOD officials, examples may include the legacy circuit card clip that is no longer produced by its original equipment manufacturer for the servers installed onboard submarines; and may include dust caps for radios. Later in this report we provide additional information about these examples.

[21]According to the America Makes government program manager, an America Makes applied research project is considered a successful transition to DOD if either: (1) the technology is used in the production of defense systems, or (2) a defense manufacturer, defense program office, or other defense agency funds follow-on work in order to mature the technology.

repeatability, and would reduce the costs and time for post-process inspection.[22]

As shown in table 2, the DOD briefing document noted additional examples of potential benefits and constraints; potential contributions to DOD's mission; and some other America Makes projects that DOD anticipates will be transitioned for its own use.[23]

[22]At the time of the briefing, no projects had yet been transitioned to DOD.

[23]According to the America Makes government program manager, other America Makes projects will be transitioned for DOD's use.

Table 2: GAO's Assessment of the Extent to Which the Department of Defense's (DOD) Additive Manufacturing Briefing Document Addressed the Elements as Directed by the Senate Armed Services Committee

Report elements	GAO assessment	Examples of inclusion from DOD briefing[a]
Potential additive manufacturing benefits and constraints	Addressed	**Benefits:** • Focused logistics—the right part, at the right place, at the right time • Rapid manufacturing • Enabling of design complexity • Shortening of supply chain • Enabling of mass customization **Constraints:** • Need for an understanding of potential defects • Need for additive manufacturing standards (materials, process, machine, quality) • Need for improved process control and repeatability • Need for design tools for additive manufacturing components
The extent to which additive manufacturing could contribute to DOD missions or advance DOD in performing its missions	Addressed	**Contributions:** • Strengthening of the U.S. industrial base, boosting of the manufacturing sector of the U.S. economy, and support for science, technology, engineering, and mathematics education • Enabling new lightweight designs and reducing fuel costs • Increasing operational stability of weapon systems by reducing cost and repair time
Which America Makes[b] projects will be transitioned for DOD's use	Addressed	**Projects:** • Rapid qualification methods for powder bed direct metal additive manufacturing processes—which will be of benefit to DOD by (1) reducing time to qualify additively manufactured defense aerospace components, thereby allowing such parts to be used; and (2) reducing part weight, which reduces fuel consumption and saves fuel costs over aircraft's entire life cycle. • Qualification of additive manufacturing processes and procedures for repurposing and rejuvenation of tooling—which will benefit DOD by extending tool life, saving capital investments in tooling, and allowing shorter production lead times. • Optimization of parallel consolidation methods for industrial additive manufacturing—which will benefit DOD by reducing part production lead times by increasing production speed of 3D printed aluminum parts by 10 times.

Source: GAO analysis of DOD data. | GAO-16-56

Note: "Addressed" indicates that the DOD briefing document included the directed element.

[a]The table shows only excerpted examples of inclusion. It does not show all the examples for each of the three elements addressed in DOD's additive manufacturing briefing document.

[b]America Makes was established as a public-private partnership to accelerate the research, development, and demonstration of additive manufacturing and to transition technology to the U.S. manufacturing sector.

DOD Has Taken Steps to Implement Additive Manufacturing to Improve Performance, Improve Combat Capability, and Achieve Cost Savings

DOD has taken steps to implement additive manufacturing to improve performance and combat capability, as well as achieve associated cost savings. We obtained information on multiple efforts being conducted across DOD components. For example, the Army used additive manufacturing, instead of conventional manufacturing, to prototype aspects of a Joint Service Aircrew Mask to test a design change, and it reported thousands of dollars saved in design development and potential combat capability improvements. According to a senior Navy official, to improve performance, the Navy additively manufactured circuit card clips for servers on submarines, as needed, because the original equipment manufacturer no longer produced these items. This official also stated that the Navy is researching ways to produce a flight critical part by 2017. According to a senior Air Force official, the Air Force is researching potential performance improvements that may be achieved by embedding devices such as antennas within helmets through additive manufacturing that could enable improved communications. According to Defense Logistics Agency officials, they have taken steps to implement the technology by additively manufacturing the casting cores for blades and vanes used on gas turbine engines. According to a senior Walter Reed National Military Medical Center official, the Center has used additive manufacturing to produce cranial implants for patients. See additional information on DOD's additive manufacturing efforts below, listed by component. DOD uses additive manufacturing for design and prototyping and for some production—for example, parts for medical applications—and it is conducting research to determine how to use the technology for new applications, such as printing electronic components for circuitry and antennas. DOD is also considering ways in which it can use additive manufacturing in supply chain management, including for repair of equipment and production of parts in the field so as to reduce the need to store parts; for production of discontinued or temporary parts as needed for use until a permanent part can be obtained; and for quickly building parts to meet mission requirements. According to DOD officials, such usage will enable personnel in the field to repair equipment, reduce equipment down-time, and execute their missions more quickly.

Some examples that DOD officials provided include the following:

Army Efforts

- The U.S. Army RDECOM Armament Research, Development and Engineering Center, according to Army officials, plans to achieve performance improvements by developing an additively manufactured material solution for high demand items such as nuts and bolts, providing the engineering analysis and qualification data required to make these parts by means of additive manufacturing capability at the

point of need in theater. These officials stated that this solution could potentially reduce the logistics burden on a unit and improve its mission readiness, thus enabling enhanced performance. The U.S. Army RDECOM Armament Research, Development and Engineering Center, in conjunction with the Defense Logistics Agency, evaluated high-demand parts in the Afghanistan Theater of Operations and determined that nuts and bolts were high demand parts that were often unavailable due to the logistical challenges of shipping parts. According to Army officials, additive manufacturing offers customers the opportunity to enhance value when the lead time needed to manufacture and acquire a part can be reduced. According to these officials, in military logistics operations in theater, the manufacture of parts to reduce the lead time to acquire a part is of paramount importance. As of August 2015 the Center had additively manufactured several nuts and bolts to demonstrate that they can be used in equipment (see figure 2), and it plans to fabricate more of these components for functional testing and qualification. The officials also stated that this testing will verify that the additively manufactured components can withstand the rigors of their intended applications.

Figure 2: Army Nuts and Bolts Additively Manufactured

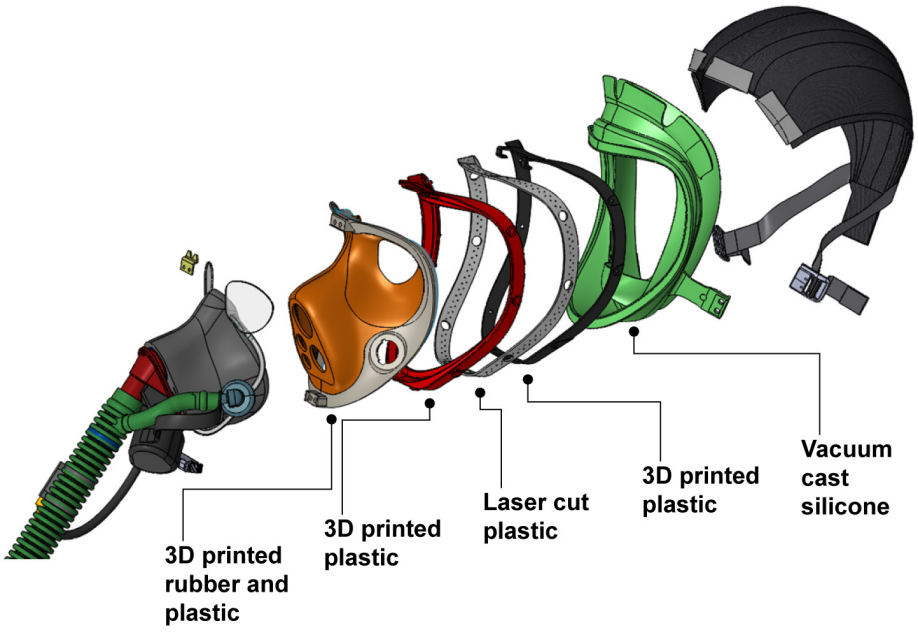
Source: Department of Defense (DOD). | GAO-16-56

- The U.S. Army RDECOM Edgewood Chemical Biological Center prototyped aspects or parts of a Joint Service Aircrew Mask (as shown in figure 3) via additive manufacturing to test a design change, which officials stated has resulted in thousands of dollars saved and

potential combat capability improvements.[24] A new mask ensemble was built using these parts and was worn by pilots to evaluate comfort and range of vision. Once confirmed, the parts were produced using conventional manufacturing. Since this example was one in a prototyping phase, only low quantities were needed for developmental testing, and additive manufacturing combined with vacuum silicone/urethane casting allowed the Army to obtain a quantity of parts that was near production level. According to Army officials, if conventional production level tools (also called injection molds) had been developed and used in this prototyping phase, costs might have ranged from $30,000-$50,000, with a 3- to 6-month turnaround. These officials stated that additive manufacturing and urethane casting comprised a fraction of the cost—approximately $7,000–$10,000—with a 2- to 3-week turnaround. Had the Army alternatively developed a production tool at this proof-of-concept phase, time and financial investment might have been wasted if the concept had to be changed or started over from the beginning of the design phase, according to the officials.

[24]According to Army officials, a Joint Service Aircrew Mask is used to protect pilots from chemical and biological agents.

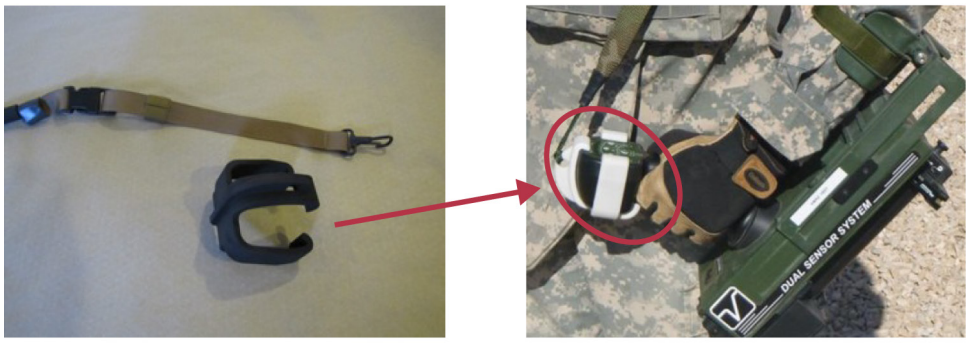
Figure 3: Aspects of the Army's Joint Service Aircrew Mask Prototyped Using Additive Manufacturing



Source: Department of Defense (DOD). | GAO-16-56

- The U.S. Army RDECOM Edgewood Chemical Biological Center achieved combat capability improvements by designing holders (as shown in figure 4), through additive manufacturing, to carry pieces of sensor equipment in the field, according to Army officials. The Center coordinated with the U.S. Army Research Laboratory to develop the holder to carry a heavy hand-held improvised explosive device detection sensor. According to Army officials, the lab wanted a holder that would cradle the handle so as to distribute more weight to the soldier's vest and back rather than confining it to the soldier's forearm. Officials at the Center stated that they had additively manufactured many prototypes that were tested by soldiers at various locations around the country within 1 to 2 weeks. According to Army officials, after achieving positive testing results the Center used additive manufacturing to produce the molds that otherwise would have added weeks or months to the process via conventional manufacturing. The final products—10,000 plastic holders—were then produced at the Center through conventional manufacturing.

Figure 4: Army Sensor Equipment Holders Additively Manufactured



Source: Department of Defense (DOD). | GAO-16-56

- The Army Rapid Equipping Force[25] achieved combat capability improvements by using additive manufacturing, as part of its expeditionary lab capability,[26] to design valve stem covers for a military vehicle, according to Army officials. An Army unit had experienced frequent failures due to tire pressure issues on its Mine-Resistant Ambush Protected vehicles caused by exposed valve stems; for example, during missions, the tires would deflate when the valve stem was damaged by rocks or fixed objects. The additive manufacturing interim solution was developed in just over 2 weeks, because the additive manufacturing process allowed them to prototype a solution more quickly, according to Army Rapid Equipping Force officials. As shown in figure 5, the Army additively manufactured prototypes for versions 1 through 4 of the covers before a final part was produced in version 5 through conventional manufacturing processes.

[25]The Army Rapid Equipping Force uses technology, such as additive manufacturing, to rapidly prototype solutions to solve some problems soldiers have experienced in-theater, such as the tire pressure issue noted above. However, it does not provide long-term, vetted products to Army soldiers.

[26]The expeditionary labs include additive manufacturing machines to enable the Army Rapid Equipping Force teams to work with soldiers in-theater to quickly design and prototype solutions locally.

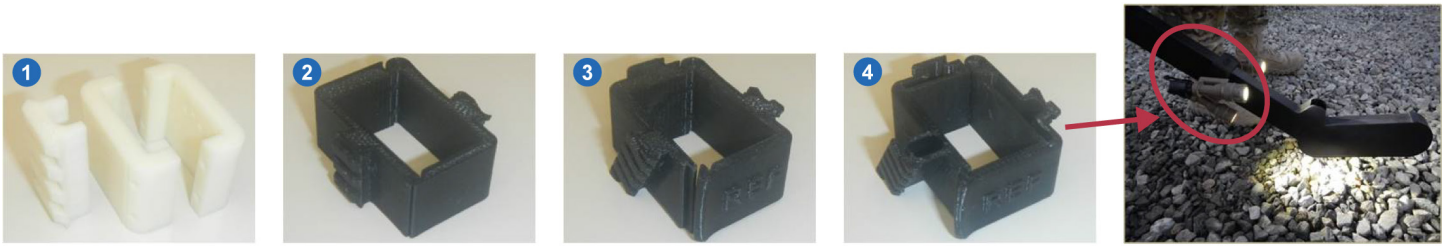
Figure 5: Army Valve Stem Cover Additively Manufactured for Interim Solution

The Army additively manufactured versions 1 through 4 of the covers before a final part was produced through conventional manufacturing (shown in version 5).

Source: Department of Defense (DOD). | GAO-16-56

- The Army Rapid Equipping Force also achieved combat capability improvements, through its expeditionary lab, by producing prototypes of mounting brackets using additive manufacturing, according to Army officials. Army soldiers using mine detection equipment required illumination around the sensor sweep area during low visibility conditions in order to avoid impact with unseen objects resulting in damage to the sensor. Using additive manufacturing, a mounting bracket was prototyped for attaching flashlights to mine detectors in several versions, as shown in figure 6. According to Army officials, due to requests exceeding the expeditionary lab's production capability, the Army coordinated with a U.S. manufacturer to additively manufacture 100 mounting brackets at one-fourth the normal cost.

Figure 6: Army Flashlight Mounting Brackets Additively Manufactured



The Army additively manufactured mounting brackets for attaching flashlights to mine detectors in four versions.

Source: Department of Defense (DOD). | GAO-16-56

- Tobyhanna Army Depot achieved performance improvement by using additive manufacturing to produce dust caps for radios, according to Army officials, as shown in figure 7. These officials stated that a shortage of these caps had been delaying the delivery of radios to

customers. Getting the part from a vendor would have taken several weeks, but the depot additively manufactured 600 dust caps in 16 hours. According to the depot officials, the dollar savings achieved were of less importance than the fact that they were able to meet their schedule.

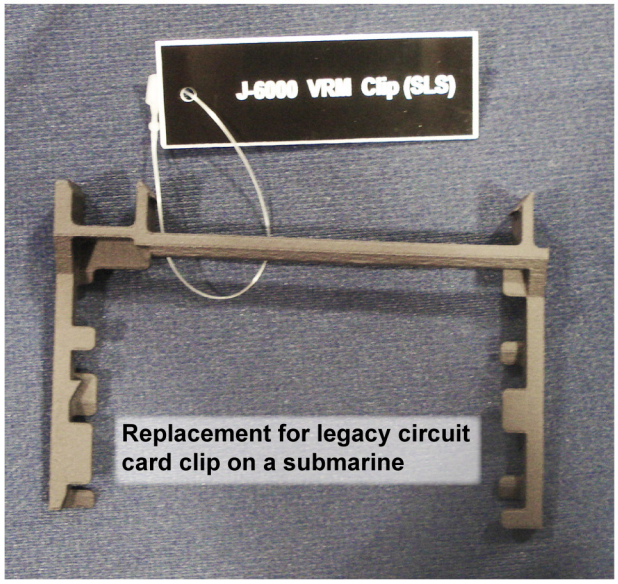
Figure 7: Tobyhanna Army Depot Dust Caps for Radios Additively Manufactured

Source: Department of Defense (DOD). | GAO-16-56

Navy Efforts

- The Navy is increasingly focused on leveraging additive manufacturing for the production of replacement parts to improve performance, according to Navy officials. When the original equipment manufacturer was no longer producing these parts, the Navy used additive manufacturing to create a supply of replacement parts to keep the fleet ready. This was the case for the Naval Undersea Warfare Center-Keyport, which used additive manufacturing to replace a legacy circuit card clip for servers installed on submarines, as needed (see figure 8).

Figure 8: Navy Replacement Part for Legacy Circuit Card Clip Additively Manufactured



Source: Department of Defense (DOD). | GAO-16-56

- The Navy installed a 3D printer aboard the USS Essex to demonstrate the ability to additively develop and produce shipboard items such as oil reservoir caps, drain covers, training aids, and tools to achieve performance improvements, according to a senior Navy official (see figure 9). According to Navy officials, additive manufacturing is an emerging technology and shipboard humidity, vibration, and motion may create variances in the prints. Navy officials also stated that while there is not a structured plan to install printers on all ships, it is a desired result and vision to have the capability on the fleet. These officials stated that the Navy plans to install 3D printers on two additional ships.

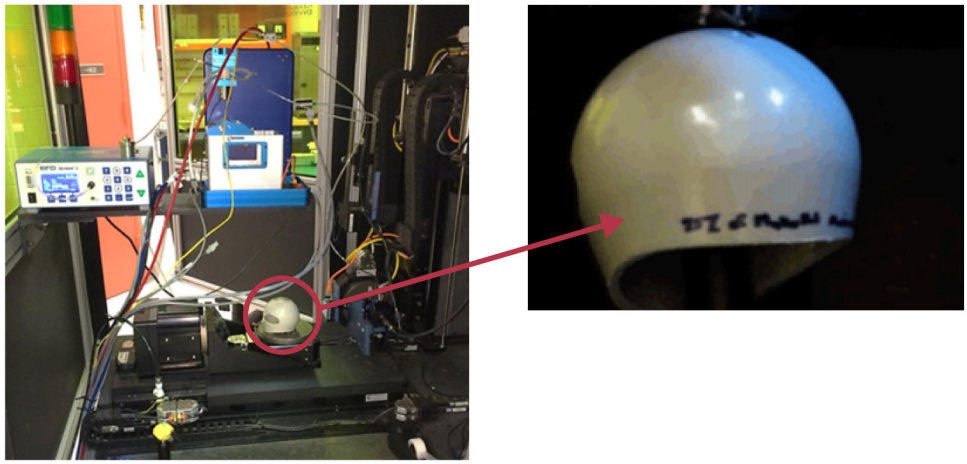
Figure 9: Navy Oil Reservoir Cap Additively Manufactured

Source: Department of Defense (DOD). | GAO-16-56

Air Force Efforts

- The U.S. Air Force Research Laboratory, according to a senior Air Force official, is researching potential performance improvements that may be achieved by (1) additive manufacturing of antennas and electronic components; and (2) embedding devices (such as antennas) within helmets and other structures through additive manufacturing, as shown in figure 10, thereby potentially enabling improved communication. The laboratory has a six-axis printing system that has demonstrated the printing of antennas on helmets and other curved surfaces, according to the official. The official also stated that the laboratory conducts research and development in materials and manufacturing in order to advance additive manufacturing technology such that it can be used affordably and confidently for Air Force and DOD systems. Additionally, according to Air Force officials, the Air Force sustainment organizations use additive manufacturing for tooling and prototyping.

Figure 10: Air Force Is Researching How to Additively Manufacture and Embed Antennas within Helmets



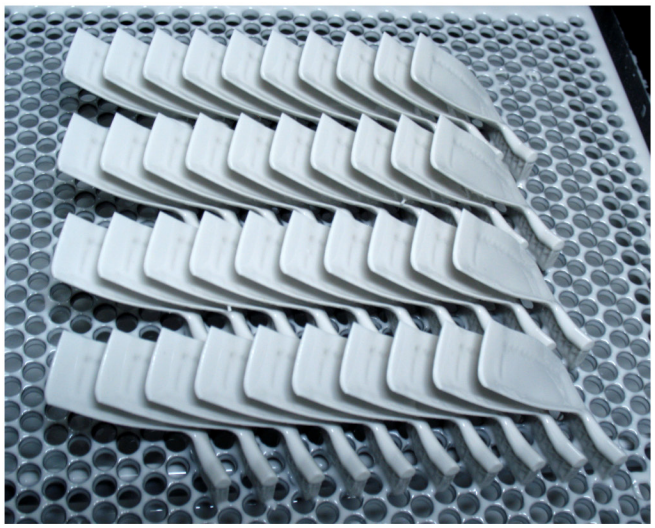
Source: Department of Defense (DOD). | GAO-16-56

Defense Logistics Agency Efforts

- According to the December 2014 DOD Manufacturing Technology document,[27] the Defense Logistics Agency projected cost savings of 33-50 percent for additively manufacturing casting core tooling, as shown in figure 11. The Defense Logistics Agency—working with industry, including Honeywell, and leveraging the work of military research labs—helped refine a process to additively manufacture the casting cores for engine airfoils (blades and vanes) used on gas turbine engines, according to Defense Logistics Agency officials. According to these officials, printing these casting cores will help reduce the cost and production lead times of engine airfoils, especially when tooling has been lost or scrapped or when there are low quantity orders for legacy weapon systems.

[27] *DOD ManTech: Balancing National Security with Fiscal Realities* (December 2014).

Figure 11: Defense Logistics Agency Casting Cores for Engine Airfoils (Blades and Vanes) Additively Manufactured

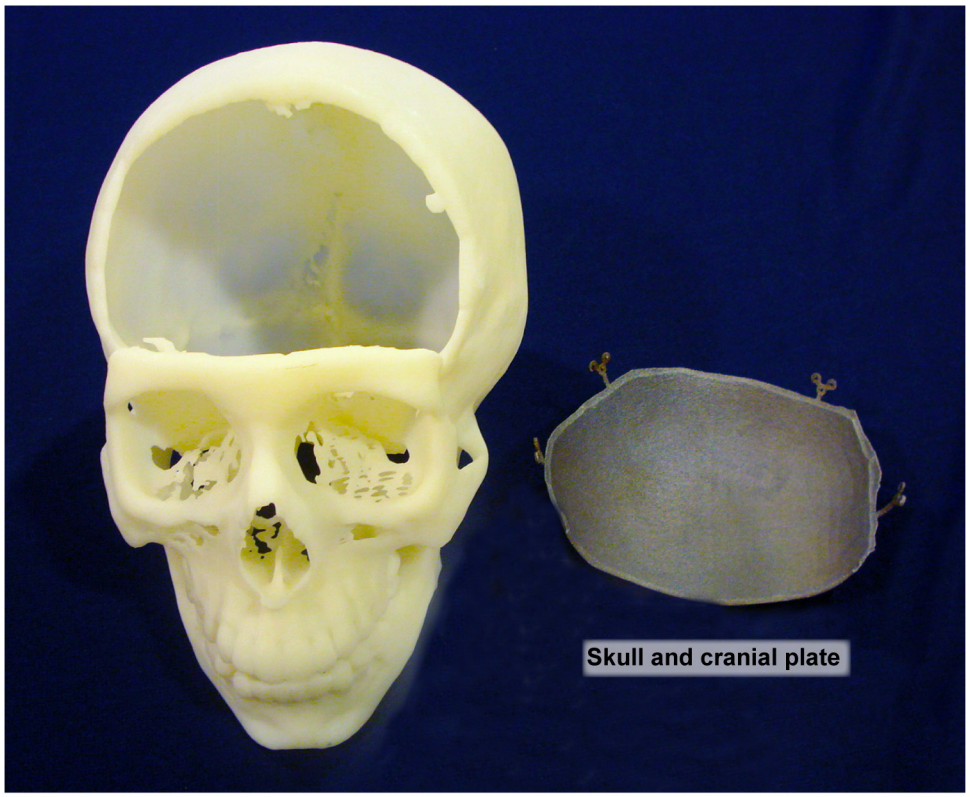


Source: Honeywell. | GAO-16-56

Walter Reed National Military Medical Center Efforts

- The Walter Reed National Military Medical Center achieved performance improvements by additively manufacturing items that include customized cranial plate implants and medical tooling and surgical guides, according a senior official within the Center. According to the official, additive manufacturing offers a more flexible and applicable solution to aid surgeons and provide benefits to patients. Since 2003, according to the official, the Walter Reed National Military Medical Center has additively manufactured more than 7,000 medical models, more than 300 cranial plates, and more than 50 custom prosthetic and rehabilitation devices and attachments, as well as simulation and training models. The official stated that using additive manufacturing enables each part to be made specifically for the individual patient's anatomy, which results in a better fit and an implant that is more structurally sound for a longer period of time, which, in turn, leads to better medical outcomes with fewer side effects. Furthermore, the official stated that additive manufacturing has been used for producing patient-specific parts, such as cranial implants, in 1 to 5 days, and these parts are being used in patients. See figure 12.

Figure 12: Walter Reed National Military Medical Center Cranial Implant Additively Manufactured



Source: Department of Defense (DOD). | GAO-16-56

DOD Uses Various Mechanisms to Coordinate on Additive Manufacturing Efforts but Does Not Systematically Track Additive Manufacturing Efforts Department-wide

DOD uses various mechanisms to coordinate on additive manufacturing efforts, but it does not systematically track components' efforts department-wide. DOD components share information regarding additive manufacturing through mechanisms such as working groups and conferences that, according to DOD officials, provide opportunities to discuss challenges experienced in implementing additive manufacturing—for example, qualifying materials and certifying parts. However, DOD does not systematically track additive manufacturing efforts, to include (1) all projects, henceforth referred to as activities, performed and resources expended by DOD; and (2) results of their activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned. DOD has not designated a lead or focal point at the OSD level to systematically track and disseminate the results of these efforts, including activities and lessons learned, department-wide. Without designating a lead to track information on additive manufacturing efforts, which is consistent with federal internal control standards, DOD officials may not obtain the information they need to leverage ongoing efforts.

DOD Components Use Various Mechanisms to Coordinate Information on Successes,Challenges, and Other Aspects of Additive Manufacturing

DOD components use various mechanisms to coordinate information on successes and challenges of additive manufacturing along with other aspects of additive manufacturing. These mechanisms include coordination groups,[28] DOD collaboration websites (such as milSuite), conferences,[29] and informal meetings to coordinate on additive manufacturing-related efforts. Some of these groups or meetings focus on broad issues, such as manufacturing technologies in general (in which additive manufacturing may be included), and others focus solely on additive manufacturing. Participants in these groups have included officials from OSD, the military departments, other governmental agencies, private industry, and universities that support the research and development and operational use of additive manufacturing. DOD officials explained that these groups and conferences provide opportunities to discuss challenges experienced by the components in implementing additive manufacturing, such as the challenges of qualifying materials and

[28] We used the term "coordination groups" to include panels, working groups, integrated product teams, communities of interest, and communities of practice.

[29] According to Navy officials, DOD-mandated travel restrictions hinder and restrict efforts to plan and participate in conferences.

certifying parts, and to discuss the efforts they are making to address these challenges, as well as other aspects of additive manufacturing.

See table 3 for examples of eight coordination groups we identified that meet to discuss ongoing additive manufacturing efforts, including ways to address technical challenges.

Table 3: Description of Key Coordination Groups in Which the Department of Defense (DOD) Participates That Share Information on Additive Manufacturing

Coordination group	Description and results
Joint Defense Manufacturing Technology Panel (The panel is not specific to additive manufacturing but covers all manufacturing technologies.)	The Panel is a group chartered to, among other things, conduct joint program planning and develop joint strategies. The Panel is comprised of one Principal representative from the Army, Navy, Air Force, Defense Logistics Agency, and Office of Secretary of Defense (OSD). Chairmanship is a rotating position among the Principals. Each Principal manages a Manufacturing Technology program specific to that Principal's component, and OSD manages a Defense-wide Manufacturing Science and Technology program, which addresses cross-cutting activities that are beyond the scope of any one military department or defense agency. Each Manufacturing Technology program manages technical activities, such as additive manufacturing research efforts.
DOD Metals Additive Manufacturing Qualification and Certification Working Group	The working group is chartered to lead efforts for technical coordination and standards development supporting materials, process, and product qualification for additive manufacturing processes. The group falls under the Metals Processing and Fabrication subpanel, which is a subpanel of the Joint Defense Manufacturing Technology Panel. For purposes of this group, additive manufacturing processes are limited to producing structural components having a metals-based composition. The group is currently discussing whether its scope should extend beyond metals. The group works with appropriate military, government, and industry groups to help facilitate the specifications and standards necessary to reference in engineering product requirements so that DOD customers can have confidence that additive manufacturing parts have the same standards of quality as are expected from parts made by conventional manufacturing.
Additive Manufacturing for Maintenance Operations Working Group	The working group is chartered to facilitate coordination of additive manufacturing efforts related to repair and maintenance of parts. The group falls under the Metals Processing and Fabrication subpanel, which is a subpanel of the Joint Defense Manufacturing Technology Panel. Its overarching goal is to promote the development and adoption of additive manufacturing capabilities that support DOD's maintenance mission—sustaining materiel readiness at best cost.
Materials and Manufacturing Processes Community of Interest (The community of interest is not specific to additive manufacturing but covers science and technology areas within the department.)	The community of interest group is one of 17 department-wide coordination groups organized by the Office of the Assistant Secretary of Defense for Research and Engineering to encourage collaboration and allow for broad oversight of the DOD components' efforts in the Science and Technology areas, including additive manufacturing research efforts. In addition to periodic meetings of the Steering Group, representatives of the larger community meet once a year to ensure that the programs are well coordinated and complementary, to avoid duplications, and to ensure that strong networks of subject matter experts are maintained. The products of this engagement are captured in briefings that are given to the DOD Science and Technology Executives. The community of interest has eight Technical Area Teams—i.e., Structures and Protection; Propulsion and Extreme Environments; Sensors and Electronics; Power and Energy; Readiness; Individual Warfighter; Civil Engineering; and Corrosion. According to the chair of the group, while the teams each have some level of activity in additive manufacturing, it is not identified as one of the teams.

Coordination group	Description and results
Commercial Technologies for Maintenance Activities/Rapid Access to Readiness Essential Parts Team	The team promotes collaborative technology development, such as additive manufacturing efforts, between industry and the DOD maintenance and repair facilities. It is comprised of industry and government members. Team members provide support to one another for depot activities and engineering development efforts. The team primarily focuses on additive manufacturing to rapidly produce components that are needed for repair, replacement, molds, prototyping, and concept development.
Military Department Additive Manufacturing • **Army community of practice** • **Air Force integrated product team** • **Navy Executive Committee and working group**	The military departments have additive manufacturing coordination groups. An Army official stated that through the U.S. Army Research, Development and Engineering Command community of practice it was able to further its research, such as researching the capability of embedding sensing into products. The community of practice has meetings that include external representatives as well, such as the Air Force and Navy. According to Army officials, they have been attending the Navy's meetings, and the Air Force and Navy have been attending the Army's meetings. These officials stated that, during its recent community of practice meeting, the Army briefed on the equipment at the Army Research, Development, and Engineering Center and at military depots. Also, according to an Air Force official, the Air Force established an integrated product team to discuss key additive manufacturing topics and ensure that the right people are connected to each other and to the most relevant additive manufacturing activities. It is centric to the U.S. Air Force Research Laboratory's Materials and Manufacturing Directorate, mainly because most of the current technical issues for additive manufacturing are materials and manufacturing-based. While members are primarily from this directorate, representatives from the other Air Force components also participate on the team. Further, according to Navy officials, the Navy chartered a governance body, known as the Navy Additive Manufacturing Executive Committee, and established a working group, known as the Naval Additive Manufacturing Technology Interchange. The Navy officials also stated that both the Executive Committee and Naval Additive Manufacturing Technology Interchange meet at least annually to discuss the current state of additive manufacturing efforts in the Department of Navy, desired future capabilities, gaps, and remaining challenges that must be addressed.

Source: GAO analysis of DOD data. | GAO-16-56

Furthermore, DOD components participate in defense manufacturing conferences and defense additive manufacturing symposiums; informal meetings; and America Makes discussions, known as program management reviews. We observed the September 2014 America Makes program management review, during which representatives from the government, private industry, and academia discussed the status of the America Makes research projects and their additive manufacturing efforts. We also observed an additive manufacturing meeting that included participants from OSD, the Army, the Navy, and the Defense Logistics Agency to discuss the status of their ongoing additive manufacturing efforts and collaboration opportunities. For example, the Navy and the Defense Logistics Agency discussed their efforts to survey existing parts that would be candidates for additive manufacturing. The officials stated that they are willing to share information but are focusing on their service-specific efforts. Additionally, DOD participates in the Government Organization for Additive Manufacturing (GO Additive), which is an informal, government-wide voluntary-participation group. The purpose of

the group is, among other things, to facilitate collaboration among individuals from federal government organizations, such as DOD, that have an interest in additive manufacturing. According to Air Force officials, the group may develop a list of qualified materials and certified parts.

DOD Does Not Systematically Track Components' Additive Manufacturing Efforts Department-wide

Although DOD components use various mechanisms to coordinate information on additive manufacturing, DOD does not systematically track the components' additive manufacturing efforts department-wide. Specifically, DOD does not systematically track additive manufacturing efforts, to include (1) all activities performed and resources expended by DOD, including equipment and funding amounts; and (2) results of their activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned.

Standards for Internal Control in the Federal Government state that it is important for organizations to have complete, accurate, and consistent data to inform policy, document performance, and support decision making. The standards also call for management to track major agency achievements, and to communicate the results of this information.[30] In addition, our past work has identified practices for enhancing and sustaining agency coordination efforts that include, among other things, designating leadership, which is a necessary element for a collaborative working relationship.[31]

However, DOD officials whom we interviewed could not identify a specific DOD entity that systematically tracked all activities or resources across the department, including equipment and funding amounts, related to additive manufacturing. Further, while Army, Navy, and Air Force Manufacturing Technology program officials provided us a list of their respective additive manufacturing activities and some funding information, variances in the types of information provided caused it not to

[30]GAO, *Standards for Internal Control in the Federal Government*, GAO/AIMD-00-21.3.1 (Washington, D.C.: November 1999). GAO, *Executive Guide: Effectively Implementing the Government Performance and Results Act,* GAO/GGD-96-118 (Washington, D.C.: June 1996).

[31]GAO, *Results-Oriented Government: Practices That Can Help Enhance and Sustain Collaboration among Federal Agencies*, GAO-06-15, (Washington, D.C., Oct. 21, 2005).

be comparable across the services.[32] Since no one DOD entity, such as OSD, systematically tracks all aspects of additive manufacturing, DOD officials could not readily tell us the activities underway or the amount of funding being used for DOD's additive manufacturing efforts. According to an OSD official within the Office of Manufacturing and Industrial Base Policy, the department does not identify investments of additive manufacturing in the budget exhibits to this level of detail. The official stated that the department identifies overall manufacturing technology investments, but it does not specifically break out additive manufacturing. In addition to the research and development efforts, the official stated that DOD has ongoing additive manufacturing activities within the operational communities, such as military depots and arsenals, and it does not systematically track these communities either.

Additionally, while DOD components share information on the additive manufacturing equipment they own, DOD does not systematically track these machines to ensure that the components are aware of each other's additive manufacturing equipment. DOD has additive manufacturing machines whose costs range from a few thousand dollars to millions of dollars. In a constrained budget environment, it is also important to leverage these resources. According to officials within the U.S. Army RDECOM, through coordination groups, such as that command's community of practice, officials share and understand each other's equipment and capabilities. In addition, according to these officials, the Navy and Air Force have provided information to the Army regarding their respective departments' equipment. According to Army and Navy officials, the Army and Navy also have equipment lists posted on a DOD collaboration website called milSuite. According to an official at the U.S. Air Force Research Laboratory, the Air Force does not have an official inventory listing of additive manufacturing equipment. However, the official added that a team has accomplished a recent tasking and visits to the Air Logistics complexes to determine the equipment and capabilities available and in use.

Furthermore, DOD does not systematically track actual or potential performance and combat capability improvements, cost savings, or lessons learned. DOD component officials we interviewed have shared—

[32]According to Navy officials, the Navy conducts an annual data call to maintain a master list of Navy-wide additive manufacturing projects and equipment.

within their respective components and to a lesser degree with other components—information on their individual performance and combat capability improvements, as well as on some cost savings attributable to additive manufacturing. For example, according to Army Rapid Equipping Force officials, they participate in a community of practice to share their lessons learned so that others can be informed about the needs of end users when developing their research priorities. The various DOD components are at different stages of research and implementation. However, DOD does not have a systematic process to obtain and disseminate the results and lessons learned across the components. Without this information, the department may not be able to leverage the components' respective experiences.

U.S. Army RDECOM officials agreed that it is important to improve cross-communication among the services and agencies, to avoid having to re-invent advances while they continue to expand the implementation of these technologies and capabilities. The officials added that the Materials and Manufacturing Processes Community of Interest already reports to the Office of the Assistant Secretary of Defense for Research and Engineering and to the DOD Science and Technology executives on the science and technology funding associated with materials and manufacturing. Therefore, the Army believes that DOD already has oversight and awareness. According to its chairperson, the Materials and Manufacturing Processes Community of Interest (a group that comprises eight technical teams) performs some level of activity in additive manufacturing, but it does not have a team that focuses solely on additive manufacturing. The chairperson added that this community of interest does not systematically track all aspects of additive manufacturing, such as medical, and that the information that is tracked and communicated to OSD is rolled up to a high level and submitted to the Office of the Assistant Secretary of Defense for Research and Engineering. An official within that office agreed that additional coordination of additive manufacturing efforts across the department would be helpful. The official stated that the office does not track all aspects of additive manufacturing.

DOD does not systematically track all department-wide additive manufacturing efforts because the department has not designated a lead or focal point at a senior level, such as OSD, to oversee the development and implementation of an approach to department-wide coordination. Specifically, the department has not established a lead to develop and implement an approach for systematically (1) tracking department-wide activities and resources, including funding and an inventory of additive manufacturing equipment; and results of these activities, such as additive

manufacturing performance and combat capability improvements and cost savings, along with lessons learned; and (2) disseminating the results of these activities, and an inventory of additive manufacturing equipment. A senior official within the Office of Manufacturing and Industrial Base Policy was aware of the various coordination groups. The official also saw value in collecting certain types of additive manufacturing information. We recognize that while additive manufacturing has been in existence since the 1980s, it is still in its early stages as compared with the techniques of conventional manufacturing, especially with respect to producing critical parts such as those for aircraft. As the technology evolves, it is important for OSD to systematically track and disseminate the results of these additive manufacturing efforts department-wide. Without designating a lead or focal point responsible for developing an approach for systematically (1) tracking department-wide activities and resources, and results of these activities; and (2) disseminating, department-wide, the results of these activities and an inventory of additive manufacturing equipment, DOD officials may not obtain the information they need to leverage resources and ongoing experiences of the various components.

Conclusions

Additive manufacturing has been in existence since the 1980s, and DOD has begun looking toward utilizing it to make existing product supply chains more efficient by enabling on-demand production, which could reduce the need to maintain large product inventories and spare parts; and enabling the production of parts and products closer to the location of their consumers, thereby helping DOD to achieve its missions. The technology is in its relative infancy, and it may be years or decades before it can achieve levels of confidence comparable to those available from conventional manufacturing processes. Across the department the various DOD components are engaged in activities and are expending resources in their respective efforts to determine how to use additive manufacturing to produce critical products. However, DOD does not systematically track and disseminate the results of additive manufacturing efforts department-wide, nor has it designated a lead to coordinate these efforts. As a result, DOD may not have the information it needs to leverage resources and lessons learned from additive manufacturing efforts and thereby facilitate the adoption of the technology across the department.

Recommendation for Executive Action

To help ensure that DOD systematically tracks and disseminates the results of additive manufacturing efforts department-wide, we recommend that the Secretary of Defense direct the following action:

- Designate a lead or focal point, at the OSD level, responsible for developing and facilitating the implementation of an approach for systematically tracking and disseminating information. The lead or focal point should, among other things,
  - track department-wide activities and resources, including funding and an inventory of additive manufacturing equipment; and results of these activities, such as additive manufacturing performance and combat capability improvements and cost savings, along with lessons learned; and
  - disseminate the results of these activities, and an inventory of additive manufacturing equipment.

Agency Comments and Our Evaluation

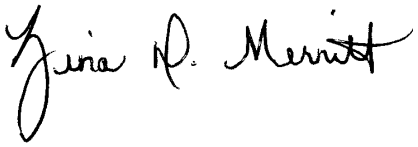
We provided a draft of this report to DOD for review and comment; the department provided technical comments that we considered and incorporated as appropriate. DOD also provided written comments on our recommendation, which are reprinted in appendix III.

In commenting on this draft, DOD concurred with our recommendation that DOD designate an OSD lead or focal point to be responsible for developing and implementing an approach for systematically tracking department-wide activities and resources, and results of these activities; and disseminating these results, and an inventory of additive manufacturing equipment, to facilitate adoption of the technology across the department. In response to this recommendation, DOD stated that within 90 days the department will make a determination and designation of the appropriate lead or focal point within OSD to be responsible for developing and facilitating the implementation of an approach for systematically tracking and disseminating information on additive manufacturing within the department.

We are sending copies of this report to appropriate congressional committees; the Secretary of Defense; the Secretaries of the Army, Navy, and Air Force, and the Commandant of the Marine Corps; the directors of Defense Logistics Agency and Defense Advanced Research Projects Agency; the Assistant Secretaries of Defense for Research and Engineering, and Health Affairs; Deputy Assistant Secretaries of Defense for Manufacturing and Industrial Base Policy, and Maintenance Policy and

Programs; and other interested parties. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-5257 or merrittz@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made contributions to this report are listed in appendix IV.



Zina D. Merritt
Director
Defense Capabilities and Management

List of Committees

The Honorable John McCain
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Thad Cochran
Chairman
The Honorable Richard J. Durbin
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Mac Thornberry
Chairman
The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Rodney Frelinghuysen
Chairman
The Honorable Pete Visclosky
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

Appendix I: Scope and Methodology

The Department of Defense (DOD) provided its briefing document to GAO on July 30, 2014. To determine the extent to which the briefing document to the Senate Armed Services Committee (henceforth referred to as "the Committee") addresses the three directed elements, two GAO analysts concurrently assessed DOD's May 2014 briefing document to determine whether it included the following Committee-directed elements: (1) potential benefits and constraints of additive manufacturing, (2) how the additive manufacturing process could or could not contribute to DOD missions, and (3) what technologies being developed at America Makes are being transitioned for DOD use. The analysts were consistent in their respective assessments of whether the briefing included the elements and therefore it was not necessary for a third analyst to resolve any differences. We assessed the briefing document, with the recognition that it was not meant to be a stand-alone document, but rather accompanied an oral briefing. We met with officials from the Office of Manufacturing and Industrial Base Policy, America Makes, and the military services to determine the extent to which they were involved in creating the briefing document and to obtain additional information about additive manufacturing. We also shared with the DOD officials, including Office of Manufacturing and Industrial Base Policy officials, our preliminary assessment of DOD's briefing document to obtain their comments.

To determine the extent to which DOD has taken steps to implement additive manufacturing to improve performance, improve combat capability, and achieve cost savings, we reviewed DOD planning documents, such as the December 2014 DOD Manufacturing Technology Program report[1] and briefing reports documenting the status of DOD's additive manufacturing efforts, as well as examples of any actual or potential performance and combat capability improvements, and examples of actual or potential cost savings. We also interviewed officials within the military services, Defense Logistics Agency, and Walter Reed National Military Medical Center to further discuss any current and potential applications of additive manufacturing, and any improvements and cost savings associated with using the technology. We did not review efforts related to additive manufacturing conducted by contractors for DOD.

[1] *DOD ManTech: Balancing National Security with Fiscal Realities* (December 2014).

To determine the extent to which DOD uses mechanisms to coordinate and systematically track additive manufacturing efforts across the department, we reviewed DOD coordination-related documents, such as charters and briefing slides, summarizing the purpose and results of any current DOD efforts related to advancing the department's use of additive manufacturing—that is, efforts by the Office of the Secretary of Defense (OSD), Defense Logistics Agency, Defense Advanced Research Projects Agency, and the services.[2] We reviewed GAO's key considerations for implementing interagency collaborative mechanisms,[3] such as designating leadership, which is a necessary element for a collaborative working relationship. We identified examples of coordination groups that DOD participates in to discuss ongoing additive manufacturing efforts. While we did not assess these groups to determine whether there were any coordination deficiencies, we made some observations based on GAO's reported collaborative mechanisms and practices for enhancing and sustaining these efforts. We also reviewed the *Standards for Internal Control in the Federal Government*,[4] which emphasizes the importance of top-level management tracking the various components' achievements, to assess the extent to which DOD systematically tracks additive manufacturing efforts department-wide. Additionally, we discussed with OSD, Army, Navy, Air Force, Defense Logistics Agency, and Defense Advanced Research Projects Agency officials (1) any actions that have been taken for coordinating additive manufacturing efforts across the

[2]While DOD coordinates with entities outside the department through government-wide additive manufacturing coordination mechanisms, we primarily focused on coordination within DOD.

[3]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C., Sept. 27, 2012). GAO, *Results-oriented Government: Practices That Can Help Enhance and Sustain Collaboration among Federal Agencies,* GAO-06-15, (Washington, D.C., Oct. 21, 2005).The reports outline mechanisms that the federal government uses to facilitate interagency collaboration, and the key issues to consider when implementing them, which can also be applied to intra-agency collaboration within a large agency like DOD, as well as practices for enhancing and sustaining agency's collaborative efforts.

[4]GAO, *Standards for Internal Control in the Federal Government*, GAO/AIMD-00-21.3.1 (Washington, D.C.: November 1999).

department, and (2) the extent to which DOD systematically tracks additive manufacturing efforts.[5]

Tables 4 and 5 present the DOD and non-DOD organizations we met with during our review.

Table 4: Department of Defense (DOD) Organizations Visited or Contacted during GAO's Review

Office of Secretary of Defense	• Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy
	  • Manufacturing Technology Program
	  • Defense Production Act Title III Program
	• Office of the Deputy Assistant Secretary of Defense for Maintenance Policy and Programs
	• Office of the Assistant Secretary of Defense for Research and Engineering

Department of the Army	• U.S. Army Research, Development and Engineering Command
	  • U.S. Army Research Laboratory
	  • Edgewood Chemical Biological Center
	  • U.S. Army Armament Research, Development and Engineering Center/Picatinny Arsenal[a]
	  • U.S. Natick Soldier Research, Development and Engineering Command
	• U.S. Combined Arms Support Command
	• Army G-4 (Logistics)
	• Army Rapid Equipping Force
	• Tobyhanna Army Depot[a]

United States Navy	• Office of Naval Research • Office of the Chief of Naval Operations N415 • U.S. Navy Naval Air Systems Command • U.S. Naval Sea Systems Command • Space and Naval Warfare Systems Command • Office of the Deputy Under Secretary of the Navy for Management, Office of Strategy and Innovation
United States Marine Corps	• U.S. Marine Corps Systems Command
Department of the Air Force	• Secretary of Air Force Technology Development Branch • U.S. Air Force Research Laboratory • F-35 Joint Strike Fighter Science and Technology Team

[5]We do not refer to the Marine Corps in this report because Marine Corps officials told us during the course of our review that they had not funded any additive manufacturing efforts (as of May 2015) and were just beginning to plan and evaluate the use of additive manufacturing.

Defense Logistics Agency	• Logistics Research and Development
Defense Advanced Research Projects Agency	• Defense Sciences Office
Walter Reed National Military Medical Center	• 3D Medical Applications Center

Source: GAO. | GAO-16-56.

[a]We selected one military depot and one arsenal based on their close proximity to each other and their ongoing additive manufacturing efforts. We also collected information on other military depots' additive manufacturing efforts.

Table 5: Non-Department of Defense (DOD) Organizations Visited or Contacted during GAO's Review

Non-DOD Organizations	• National Additive Manufacturing Innovation Institute (America Makes) • Wohlers Associate, Inc. • Pennsylvania State University Center for Innovative Materials Processing Through Direct Digital Deposition • National Center for Manufacturing Sciences

Source: GAO. | GAO-16-56.

We conducted this performance audit from July 2014 to October 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Key DOD Components Involved in Additive Manufacturing Efforts

- **The Office of the Secretary of Defense (OSD) Office of the Under Secretary of Defense for Acquisition, Technology and Logistics,** reporting to the Secretary of Defense, is responsible for all matters relating to departmental acquisition systems, as well as research and development, advanced technology, and developmental test and evaluation, among other things.

- **The OSD Office of the Assistant Secretary of Defense for Research and Engineering**, reporting to the Under Secretary of Defense for Acquisition, Technology and Logistics, is responsible for providing science and engineering integrity leadership throughout DOD and facilitating the sharing of best practices to promote the integrity of DOD scientific and engineering activities. According to DOD senior officials, the Materials and Manufacturing Processes community of interest is one of 17 department-wide coordination groups organized by the Office of the Assistant Secretary of Defense for Research and Engineering to provide broad oversight of the DOD components' efforts in the Science and Technology areas for which the department has responsibilities. The senior officials added that this community of interest does not track all aspects of additive manufacturing and that the information that is tracked and communicated to the Office of the Assistant Secretary of Defense for Research and Engineering is rolled up to a high level.

- **The OSD Office of the Deputy Assistant Secretary of Defense for Maintenance Policy and Programs** provides the functional expertise for centralized maintenance policy and management oversight for all weapon systems and military equipment maintenance programs and related resources within DOD.

- **The OSD Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy**, reporting to the Under Secretary of Defense for Acquisition, Technology and Logistics, develops DOD policy and provides guidance, oversight, and technical assistance on assessing or investing in defense industrial capabilities, and has oversight responsibility for the Manufacturing Technology program, among other programs, which develops technologies and processes that ensure the affordable and timely production and sustainment of defense systems, including additive manufacturing. In addition, OSD manages the Defense-wide Manufacturing Science and Technology program, which seeks to address cross-cutting initiatives that are beyond the scope of any one military service or defense agency. The Army, the Navy, the Air Force, and the Defense Logistics Agency each have their own manufacturing technology programs,

which select and execute activities, such as additive manufacturing research activities.[1]

- **The Army, the Navy, and the Air Force have research and development laboratories—that is, U.S. Army Research, Development and Engineering Command; Office of Naval Research; and U.S. Air Force Research Laboratory—**for projects on the use of new materials, processes, and applications for additive manufacturing.

- **Army, Navy, and Air Force depots and arsenals** use additive manufacturing to produce plastic parts and prototypes for tooling and repairs, such as dust caps for radios, to reduce costs and turnaround time.

- **The Army Rapid Equipping Force** will be reporting to the U.S. Army Training and Doctrine Command in October 2015, according to Army officials. It uses additive manufacturing to produce prototypes for repairs, such as tooling and fixtures, to reduce costs and turnaround time.

- **Navy components, including the Office of the Chief of Naval Operations, Navy Business Office; the Naval Air Systems Command; and Naval Sea Systems Command**, plan to use additive manufacturing to enable a dominant, adaptive, and innovative Naval force that is ready, able, and sustainable. According to Navy officials, in November 2013, the Chief of Naval Operations directed the Deputy Chief of Naval Operations for Fleet Readiness and Logistics to develop, de-conflict, and manage additive manufacturing efforts across the Navy. That office has since developed Navy's 20-year additive manufacturing vision, according to Navy officials.

- **The Defense Advanced Research Projects Agency Defense Sciences Office** identifies and pursues high-risk, high-payoff fundamental research initiatives across a broad spectrum of science and engineering disciplines, and transforms these initiatives into radically new, game-changing technologies for U.S. national security. According to a senior Defense Advanced Research Projects Agency

[1] Marine Corps officials stated during the course of our review that they are not currently part of the Navy Manufacturing Technology program and were just beginning to plan and evaluate the use of additive manufacturing.

official, the agency has initiated the Open Manufacturing program, which allows officials to capture and understand the additive concepts, so that they can rapidly predict with high confidence how the finished part will perform. The program has two facilities—one at Pennsylvania State University and the other at the U.S. Army Research Laboratory—establishing permanent reference repositories and serving as testing centers to demonstrate applications of the technology being developed and as a catalyst to accelerate adoption of the technology.

- **The Defense Logistics Agency** procures parts for the military services and is developing a framework to determine how to use additive manufacturing, according to Defense Logistics Agency officials.

- **The Walter Reed National Military Medical Center 3D Medical Applications Center** is a military treatment facility that provides, among other things, computer-aided design and computer-aided manufacturing for producing medical models and custom implants through additive manufacturing. The Walter Reed National Military Medical Center falls within the National Capital Region Medical Directorate and is controlled by the Defense Health Agency, which in turn reports to the Assistant Secretary of Defense for Health Affairs.

Appendix III: Comments from the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

OCT 2 2015

Ms. Zina Merritt
Director
Defense Capabilities and Management
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Ms. Merritt:

This is the Department of Defense (DoD) response to the Government Accountability Office (GAO) Draft Report, GAO-16-56, "DEFENSE ADDITIVE MANUFACTURING: DOD Needs to Systematically Track Department-wide 3D Printing Efforts" dated September 2, 2015 (GAO Code 351966). Detailed comments on the report recommendations are enclosed. Thank you for the opportunity to review and comment.

Sincerely,

for André J. Gudger
Deputy Assistant Secretary of Defense
Manufacturing and Industrial Base Policy

Enclosure:
As stated

GAO DRAFT REPORT DATED SEPTEMBER 2, 2015
GAO-16-56 (GAO CODE 351966)

"DEFENSE ADDITIVE MANUFACTURING:DOD NEEDS TO SYSTEMATICALLY TRACK DEPARTMENT-WIDE 3D PRINTING EFFORTS"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATION

RECOMMENDATION: The GAO recommends that the Secretary of Defense direct the following action: Designate a lead or focal point, at the OSD level, responsible for developing and facilitating the implementation of an approach for systematically tracking and disseminating information. The lead or focal point should, among other things,

- track department-wide activities and resources, including funding and an inventory of additive manufacturing equipment; and results of these activities, such as additive manufacturing performance and combat capability improvements and cost savings, along with lessons learned; and

- disseminate the results of these activities, and an inventory of additive manufacturing equipment.

DoD RESPONSE: Concur. Within 90 days, the DOD will make a determination and designation of the appropriate lead or focal point within OSD to be responsible for developing and facilitating the implementation of an approach for systematically tracking and disseminating information on additive manufacturing within the DOD.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Zina D. Merritt, (202) 512-5257 or merrittz@gao.gov

Staff Acknowledgments

In addition to the contact named above, Marilyn Wasleski, Assistant Director; Dawn Godfrey; Richard Hung; Carol Petersen; Andrew Stavisky; Amie Steele; Sabrina Streagle; Sarah Veale; Angela Watson; Cheryl Weissman; and Alexander Welsh made key contributions to this report.