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THE FUTURE OF ADDITIVE MANUFACTURING IN AIR FORCE ACQUISITION

by

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Biography

Lieutenant Colonel Benjamin D. Forest is a U.S. Air Force acquisition program management officer assigned to the Air War College, Air University, Maxwell AFB, AL. He graduated from Park University in 1997 with a Bachelor of Science degree in Computer Science, the University of Oklahoma in 1999 with a Masters of Human Relations, the Naval Postgraduate School in 2008 with a Masters of Systems Engineering Management, and the Air Command and Staff College in 2010 with a Masters of Military Operational Arts and Science. He has served in aircraft and satellite program offices, the Air Staff, Iraq and Afghanistan, and is a graduated squadron commander.

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Abstract

Air Force acquisition experiences frequent criticism for its perceived shortcomings in the areas of cost, schedule, and performance. While not a panacea to the myriad of complex Air Force acquisition challenges, additive manufacturing provides significant potential benefits to cost, schedule, and performance in future Air Force acquisition if implemented methodically across every phase of the acquisition lifecycle. Applied to the *Material Analysis* acquisition phase, additive manufacturing provides the possibility to enable game-changing system design via lower production costs, enhanced performance possibilities, and rapid replenishment. In the *Technology Maturation and Risk Reduction* phase, additive manufacturing enables rapid prototype redesign to quickly test modifications to enhance capability and performance. During *Engineering*, *Manufacturing*, *and Development*, additive manufacturing is poised to yield both significant schedule reduction over traditional manufacturing as well as major cost savings via reduction of required materials, unique tooling, specialized production plans, and segments of the workforce. Furthermore, the *Production* phase of acquisition could be potentially revolutionized by additive manufacturing, enabling concepts such as a virtual aircraft fleet and on-orbit satellite production. Finally, additive manufacturing provides the following promise in *Operations and Sustainment*: resolving diminishing manufacturing and supply problems, transformation of the warehouse, and expeditionary parts production.

While additive manufacturing is not a silver bullet to Air Force acquisition problems, the prospective cost, schedule, and performance benefits cannot be ignored. The Air Force must continue to invest in and explore the technology, with particular attention to the following issues: training and education, data/software rights, standards, research cooperation, process and policies and cybersecurity environment.

The Current Acquisition Environment

"…the cost of developing a weapon system continues to often exceed estimates by tens or hundreds of millions of dollars. This, in turn, results in fewer quantities than initially planned for, delays in product delivery, and performance shortfalls. Not only is the buying power of the government reduced and opportunities to make other investments lost, but the warfighter receives less than promised. DOD is depending on the weapons currently under development to transform military operations for the 21st century. The size and scale of current planned investment necessitate better results than we have seen in the past."[1]

GAO report number GAO-07-406SP

Defense Acquisitions: Assessments of Selected Weapon

March 30, 2007

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Although this quote is a decade old, the fundamental message remains the same and the U.S. Air Force, with its inherent emphasis on advanced technology, has endured its share of acquisition woes. To some degree, this is to be expected. Developing cutting-edge weapon systems is a complicated business exasperated by changing (and sometimes conflicting) direction, requirements growth driven by changing threats, uncertain and unstable funding, immense bureaucracy, an industrial base that lacks broad competition for complex systems, and rapid technological development.

The critical narrative of Air Force acquisition over the last 15 years is essentially as follows. The F-22, derived from a 1981 requirement set to combat the Soviet Union, took over two decades to achieve initial operational capability, experienced repeated cost overruns, and, since fielding, has endured operational problems that resulted in multiple fleet groundings.[2] More recently, the F-35 program's soaring costs and technical problems have garnered enduring attention, repeatedly earning criticism from Congress and more recently from President Trump prior to his inauguration.[3] Air Force satellite acquisition has not fared much better in terms of avoiding cost, schedule, and performance criticisms. The Space-Based Infrared System (SBIRS) program endured three Nunn-McCurdy breaches driven by cost overruns from 2001 to 2005.[4] The Global Positioning System (GPS) ground system, the GPS next-generation Operational Control System (OCX), was beset by so many challenges that in 2015, Gen John Hyten, commander of US Air Force Space Command, publicly stated, "The OCX program is a disaster, just a disaster, and it's embarrassing to have to stand in front of people and try to defend it, so I won't."[5] Meanwhile, legacy aircraft are being extended far beyond their initial projected lifespan, creating serious problems of Diminishing Manufacturing Sources and Material Shortages (DMSMS). Many of these systems listed above have, despite their challenges, progressed to provide vital capability to the warfighter, the nation, and our allies. Nevertheless, the negative narrative in congress, the media, and the GAO remains the same—Air Force acquisition is broken and requires dramatic remedy.

Attempts at acquisition improvements over the years (e.g., Better Buying Power, Bending the Cost Curve, the Weapon System Acquisition Reform Act of 2009, and many others) have yielded varying degrees of positive and mixed results, but the calculus of fiscal constraints, mixed with the increased cost of developing, producing, and sustaining weapons systems, remains daunting. Meanwhile, the call for "better, faster, cheaper" seems to get louder every year. It is tempting then to seek a game-changing technology to bring about the acquisition revolution to heal, if not cure, the acquisition woes and financial death spiral.

Additive Manufacturing as a Partial Solution to Acquisition Woes

"As we plan for the future, the rapid pace of change occurring throughout the world compounds the uncertainty and complexity of the future environment. If we are to continue to succeed in our purpose, we must consider both the challenges and the opportunities we will face in air, space, and cyberspace. We must ask ourselves, 'How will future Air Force forces deliver responsive and effective Global Vigilance—Global Reach—Global Power in the anticipated environment of 2035?'"[6]

Air Force Future Operating Concept:

A View of the Air Force in 2035

September 2015

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There is no simple or sole solution, technological or otherwise, to the Air Force's acquisition challenges. To view additive manufacturing, commonly referred to as three-dimensional (3D) printing, as a silver bullet would be an error, since the technology itself does nothing to address process, political, and workforce challenges. However, while not a panacea, additive manufacturing provides significant potential benefits to cost, schedule, and performance in future Air Force acquisition if implemented prudently and methodically across every phase of the acquisition lifecycle.

Additive manufacturing is defined as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies."[7] Additive manufacturing starts with a 3D model, derived either from a 3D scanner or created via software such as a Computer Aided Design (CAD) program, which is finalized into an STereoLithography (STL) file. A 3D printer, which can be a simple $200 consumer device focused on small plastics or as complicated as a robust industrial printer for large specialized metals, then prints and finishes the final product based on the specifications found in the STL package. A myriad of different additive manufacturing technologies exist and can be tailored to the nature of the desired end material, which can range from nylon and paper to stainless steel and metal alloy. While it has its disadvantages and limitations, additive manufacturing, compared to traditional subtractive manufacturing, has demonstrated proven promise for increased innovation and specialization, reduction of tooling/assembly, lead time reduction, minimization of material waste, and supply chain efficiency.

Although additive manufacturing has existed for over 30 years, recent advances and investments have led to a flurry of interest in additive manufacturing over the last half decade, with some futurologists going so far as to declare the beginning of the third industrial revolution. Ripe with possibility yet susceptible to overhype, additive manufacturing is a disruptive technology that has inspired grandiose sci-fi visions and promises of revolutionizing everything from medicine to food production to warfare. While its benefits can be oversold, the promise of better, faster, cheaper is beginning to deliver and the Department of Defense, along with its commercial partners, is increasingly embracing the research, development, and deployment of the technology.

The military, the larger U.S. government, industry, and partner nations have each demonstrated to varying degrees the realized potential of additive manufacturing in real-world applications in the last several years. Follow is a sampling of recent developments.

- U.S. Army: As early as 2013, the Army began deploying rapid prototyping labs to Afghanistan in the form of a 20-foot shipping container equipped with a 3D printer and supporting materials, enabling rapid on-site material solutions. “It's really difficult to connect the guy who is building the product to the kid who really needed it to begin with, so what we went after is to connect the scientist to the soldier,” said Col. Pete Newell, then-commander of the Army's Rapid Equipping Force at Fort Belvoir, Va. “Rather than bringing the soldier home to the scientist, we have uprooted the scientist and the engineer and brought them to the soldier.”[8]

- U.S. Navy: In 2014, the Navy put its first 3D printer on a warship, the USS Essex.[9] Although the initial utility of the initiative was limited, primarily intended to address simple parts and ascertain the impacts of the environmental conditions of seaborne manufacturing, the experiment was the first step towards printing parts at sea, hundreds of miles from land and supply depots. More recently, in July 2016, Naval Air Systems Command (NAVAIR) conducted MV-22B Osprey test flight using a safety-critical engine nacelle manufactured with a 3D printer. “The flight today is a great first step toward using AM wherever and whenever we need to. It will revolutionize how we repair our aircraft and develop and field new capabilities - AM is a game changer,” says Liz McMichael, leader of the NAVAIR Additive Manufacturing Integrated Product Team. “In the last 18 months, we've started to crack the code on using AM safely. We'll be working with V-22 to go from this first flight demonstration to a formal configuration change to use these parts on any V-22 aircraft.”[10]

- <u>NASA</u>: In 2014, astronauts on the International Space Station used an on-site 3D printer to manufacture a ratchet wrench, the first tool ever manufactured in space. “In less than a week, the ratchet was designed, approved by safety and other NASA reviewers, and the file was sent to space where the printer made the wrench in four hours,” stated Niki Werkheiser, program manager of ISS additive manufacturing at NASA's Marshall Space Flight Center.[11] While only a small step, development of additive manufacturing is essential to interplanetary space travel and could be a lifesaver in an Apollo 13 type scenario.

- <u>Lockheed Martin and Boeing</u>: Both of the largest U.S. Air Force defense contractors have demonstrated significant investments and capability in additive manufacturing in recent years. While their military aircraft are lagging behind in usage, Boeing has produced “more than 20,000 additive manufactured parts on airplanes that have been delivered to their customers” as of mid-2016.[12] Meanwhile, Lockheed Martin stood up five Additive Manufacturing Innovation Centers, began manufacture of 3D printer parts for the F-35, and boasts of having manufactured the first 3D-printed parts for space travel in a vehicle (Juno) which has travelled over 1,700,000,000 miles.[13]

- <u>SpaceX</u>: A company known for pushing the envelope in cost-effective space technology, SpaceX successfully completed test of the SuperDraco rocket engines in 2015, making extensive use of additive manufacturing in order to cut down on cost, weight, and schedule.[14] The tests were significant not only for their critical utility in space, but because they demonstrated the feasibility and potential of 3D printing metals, a

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material which historically been more difficult to produce via additive manufacturing compared to plastic and other less robust materials.

- Israel: The Israeli armed forces has arguably embraced 3D printing more than any other nation's military currently. With a far more limited budget than the U.S., they have leveraged additive manufacturing to refurbish aging aircraft to new and improved state. "A new plane can cost tens of millions of dollars, and the delivery time can take years," stated a senior official with the Israeli Air Force (IAF) Aerial Maintenance Unit. "We don't have the money or the time to spend on such projects. Here in this unit we can turn an old plane into something that is quite capable of competing on the battlefield with new planes, and in fact we can ensure that these planes will remain competitive and mission-worthy for another decade."[15] The IAF has also made significant progress towards producing drones via additive manufacturing, although their military utility remains to be seen.[16]

This paper envisions the possible future impacts of additive manufacturing in Air Force acquisition in 2035 by extrapolating on these current trends. These predictions are binned within the acquisition phases outlines in DoD Instruction 5000.02, Operation of the Defense Acquisition System: Material Solutions Analysis; Technology Development; Engineering and Manufacturing Development; Production and Deployment; and Operations and Support. Finally, the paper concludes with recommendations and proposed areas for further research.

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Materiel Solution Analysis Phase

"The purpose of this phase is to conduct the analysis and other activities needed to choose the concept for the product that will be acquired, to begin translating validated capability gaps into system-specific requirements including the Key Performance Parameters (KPPs) and Key System Attributes (KSAs), and to conduct planning to support a decision on the acquisition strategy for the product. AoA solutions, key trades among cost, schedule, and performance, affordability analysis, risk analysis, and planning for risk mitigation are key activities in this phase."[17]

DoD Instruction 5000.02, Operation of the Defense Acquisition System (p. 16)

Although the material solution analysis phase does not initially appear to be the most promising area for applicability of additive manufacturing, this phase is critical in that it provides the first opportunity to begin exploration of the technology's potential impacts across the weapon system lifecycle. Additive manufacturing can have either positive or negative impacts to affordability, risk, and the ability to meeting KPPs and KSAs. The earlier these considerations undergo evaluation, the more optimal the use of additive manufacturing. Looking ahead to 2035, additive manufacturing has the potential to be a game-changer even in something as fundamental as an Analysis of Alternatives (AoA).

To use a space acquisition example, a satellite AoA considers, among other factors, the capabilities, quantities, and orbital factors within the normal constraints of cost, schedule, performance, and risk. If an entire satellite can be 3D-printed, the cost per satellite can theoretically be dramatically driven down which in turn can enable increased quantity. With the increased quantity, performance can be increased (more satellites, more capability, different orbits) and operational risk reduced (elimination of single points of failure). Furthermore, additive manufacturing provides increased and easier ability to customize components and systems, thus satellites capabilities could be tailored to the needs of a specific region (additional sensors or hardening, for example).

Aircraft acquisition material solution analysis could be similarly revolutionized. Current and planned air vehicles are currently designed for maximum survivability, a high-cost requirement necessary for mission success, preservation of pilot life, and mitigating the loss of an extremely expensive aircraft with sensitive technology. Additive manufacturing could potentially change the survivability calculus if the mission of an expensive manned aircraft could be replaced by a swarm of disposable drones. While swarming drones could certainly be produced via traditional manufacturing, additive manufacturing provides the potential for low-cost, mission tailored, and on-demand production, thereby altering each component of the acquisition trinity of cost, schedule, and performance.

This is not to say that additive manufacturing will be a total or even partial aspect of every weapon system material solution. There may be acquisition programs where traditional manufacturing is optimal. To force an additive manufacturing material solution where an existing manufacturing base can cheaply mass produce an item would likely not make sense. Rather, the Materiel Solution Analysis Phase is where such considerations should be evaluated and adjudicated, vice trying to retrofit the manufacturing approach later in the process. This is also the phase where intellectual property rights and data standards must be defined to ensure the government retains the ability to produce replacement parts for systems which may otherwise experience diminishing manufacturing and supply problems down the road.

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Technology Maturation & Risk Reduction (TMRR) Phase

"The purpose of this phase is to reduce technology, engineering, integration, and life-cycle cost risk to the point that a decision to contract for EMD can be made with confidence in successful program execution for development, production, and sustainment."[18]

DoD Instruction 5000.02, Operation of the Defense Acquisition System (p. 19)

Given the relative immaturity of additive manufacturing compared to traditional manufacturing, the technology maturation phase is essential in proving out its real-world applicability and reliability, particularly through the production, operation, and evaluation of prototypes. Well-suited to such endeavors, additive manufacturing enables the low-cost development of prototypes by avoiding the costs incurred with unique tooling and facility standup. Furthermore, the prototype process benefits from the ability to make modifications to the prototype via additive manufacturing techniques, driven by evaluation and validation, with relative ease.

This phase also provides the opportunity to evaluate technology risk, life-cycle cost risk, and evaluation of the manufacturing process risk. In technology demonstration, acquisition program managers will make key decisions on which parts are candidates for additive manufacturing versus traditional manufacturing. For mass production parts and systems, traditional manufacturing may well be more cost-effective. Acquisition leaders will also assess technology readiness of various parts and materials for additive manufacturing, doing so in coordinate with the Air Force Research Laboratory, which is already "rapidly prototyping a variety of components including flexible electronics, sensors, fuzes, energetic materials (often the explosive portion of the weapon), and warheads achieving the long-term goal of rapidly prototyping fully functional advanced capabilities for the warfighter."[19] As part of technology maturation, acquisition leaders must evaluate manufacturing processes. AM should be a mandatory consideration in this evaluation in all material solutions with the exception of software and certain Commercial Off-the-Shelf (COTS) components. This evaluation should be a part-by-part cost-benefit analysis. Such an analysis must be mandatory, as the disruptive threat additive manufacturing poses may be resisted to some degree by the prime contractor. Maximizing the use of AM parts, when technically and economically feasible, will provide competition in sustainment, either by organic or third-party companies. This increase in competition will drive down costs regardless of a prime, organic, or third-party sustainment solution. A flexible, cost-effective sustainment solution must be "baked-in" to the program starting in the technology development phase.

Today, we see additive manufacturing retrofitted into legacy programs and systems already past their milestone B decision point. For example, Lockheed Martin and its partners have invested hundreds of thousands of dollars in additive manufacturing to bring down the production costs of is F-35, potential saving over $30 million dollars.[20] By 2035, such decisions should be made in earlier phases, thus yielding more informed and optimal decision-making as early as the Material Solutions Analysis Phase.

Engineering & Manufacturing and Development (EMD) Phase

"The purpose of the EMD Phase is to develop, build, and test a product to verify that all operational and derived requirements have been met, and to support production or deployment decisions… EMD completes all needed hardware and software detailed design; systemically retires any open risks; builds and tests prototypes or first articles to verify compliance with

capability requirements; and prepares for production or deployment. It includes the establishment of the initial product baseline for all configuration items."[21]

DoD Instruction 5000.02, Operation of the Defense Acquisition System (p. 25)

Focused on completing the development of a system, EMD is where the aircraft or satellite is fully built and formally evaluated, where the reality of additive manufacturing is put to the final test. In early test cases, additive manufacturing will likely be used to a limited degree, for specific parts and components where the logistics and risk warrants its use. As the technology, processes, and confidence matured, Air Force acquisition may ultimately embrace the use of additive manufacturing for the building of total systems.

During EMD, additive manufacturing is projected to yield significant cost savings. At the most basic level, there is inherently less material via additive manufacturing, using only precisely the materials required, versus subtractive manufacturing, where material removal and waste is intrinsic to the process. Additionally, the increased use of additive manufacturing mitigates the cost of developing unique tooling, specialized production plants, and portions of the workforce. Finally, additive manufacturing provides potential for new-entry manufactures to compete against traditional defense manufacturers via the decreased cost of entry enabled by the elimination of high-cost traditional manufacturing facilities.

In terms of schedule during the EMD phase, reduction in time for tooling fabrication is dramatic, estimated at between 40 to 90 percent depending on the nature of the product.[22] Another significant schedule advantage of additive manufacturing is the turn time for system modifications, particularly resulting from issues discovered during test and evaluation. Rather than investing in creating or refashioning physical tooling to address a part or component problem uncovered in testing, a relatively minor modification to a technical data file could resolve the issue. A change that might take weeks or months in traditional manufacturing could be resolved in minutes or hours.

While cost and schedule are likely the most significant advantages, additive manufacturing also provides potential performance gains. One example is greater maneuverability and range of aircraft enabled by the use of lighter materials. Another is easier customization of individual aircraft, satellites, and munitions to specific operational needs. Although the focus of much of current Air Force acquisition literature is on cost and schedule, performance remains a significant growth area for additive manufacturing that merits further exploration.

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Production and Deployment (PD) Phase

"The purpose of the P&D Phase is to produce and deliver requirements-compliant products to receiving military organizations... In this phase, the product is produced and fielded for use by operational units. The phase encompasses several activities and events: LRIP, Limited Deployment, OT&E, and the Full-Rate Production Decision or the Full Deployment Decision followed by full-rate production or full deployment."[23]

DoD Instruction 5000.02, Operation of the Defense Acquisition System (p. 28)

Perhaps more than any other area, production is where additive manufacturing has the potential to generate the most revolutionary effects on Air Force acquisition, dramatically altering the equation of schedule and cost, as well as the fundamental "build to worst case" production paradigm.

In terms of schedule, the ability to rapidly produce end-products, be it components or even entire systems, could be increased substantially. In 2013, the University of Virginia proved the ability to fabricate a small military-grade drone aircraft in approximately 30 hours; today, the U.S. Army Research Laboratory and Georgia Technical Institute have entered a partnership to "give soldiers the ability to 3D-print swarms of mini-drones to specific specifications within 24 hours."[24] As technology advances in future decades, it is not unthinkable that a larger-scale drone or even a manned aircraft could be produced in a similar time frame.

The advent of print-on-demand unmanned and manned aircraft is a potential game-changer that could revolutionize how the USAF prepares for conflict. Today, the DoD is collectively procuring 2,183 copies of various F-35 Joint Strike Fighters variants at the approximate cost of $100 million each. The large quantity, and the additional $1 trillion sustainment tail, is a necessity as the U.S. prepared for worst-case warfare with near-peer nations possessing Anti-Access and Area Denial (A2AD) defenses. Additive manufacturing, in the decades ahead, could mitigate such massive procurements. If the worst case scenario comes, the nation could rely instead on a "virtual aircraft inventory" instead of a physical one, with the bulk of the aircraft inventory printed on demand. In other words, have a physical inventory of only the aircraft a nation needs for training, exercises, and limited operations; print the additional worst-case warfighting aircraft only if world events necessitate it and save the costs association with production and sustainment.

Print-on-demand systems could also be a significant cost-saver in the space domain. To provide a real-world example of how the virtual satellite inventory program could work, the Defense Meteorological Satellite Program (DMSP) program contracted for the production of a DMSP satellite, DMSP F20, through Lockheed Martin Space Systems in the 1990s. The F20 satellite was stored for nearly 20 years, at an estimated $40 million annually, before the decision was finally made in 2016 not to launch the satellite at all.[25] The satellite was produced and stored by Lockheed Martin at the cost of hundreds of millions of dollars and ultimately yielded zero operational capability. In the future, additive manufacturing could completely change this scenario. Such as satellite could be stored virtually, awaiting actual need, avoiding significant production and storage cost. If the virtual satellite is ultimately not needed for its intended purpose, the space vehicle can simply remain unused in cyberspace or electronically modified at minimal cost to meet the changing operation requirements.

Another area where additive manufacturing could transform satellite acquisition is via the production on satellites on-site in space. To launch a satellite from the ground into orbit costs on the order of $200 million dollars and the scheduling of such launches is done months, if not years, in advance. Launches thus become one of several limited factors in operationally responsive space for the nation's military. Imagine then the ability to manufacture a satellite in space as the need arises and propel it directly into orbit, eliminating launch cost and scheduling. Although "the ability to develop a space-based additive manufacturing capability able to produce fully functional, operational Air Force satellites in orbit anytime in the reasonable future is well beyond the current state of the art or, for that matter, any current technology plans," the National Research Council has studied the idea and printed a report on it as early as 2014.[26] It is unlikely to occur by 2035, but an attractive production concept for investment and research nevertheless for the intervening years.

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Operations and Support (O&S) Phase

"The purpose of the O&S Phase is to execute the product support strategy, satisfy materiel readiness and operational support performance requirements, and sustain the system over its life cycle (to include disposal). The O&S Phase begins after the production or deployment decision and is based on an MDA-approved LCSP. Enclosure 6 includes a more detailed discussion of sustainment planning; Enclosure 7 addresses planning for human systems integration."[27]

DoD Instruction 5000.02, Operation of the Defense Acquisition System (p. 29)

In the realm of in U.S. Air Force aircraft operations and sustainment, current trends in additive manufacturing indicate three groundbreaking trends for the future: (1) the end of diminishing manufacturing and supply problems, (2) the transformation of the warehouse, and (3) expeditionary parts production.

Although it sounds like an audacious claim, additive manufacturing should, in theory, mean the end of DMSMS and other hard-to-source parts creation issues. With the proper data file, software, and materials, a part designed once could be produced infinitely at steady cost with minimal wait times. Initially, additive manufacturing will enable the scanning and production of existing part. For example, the decades-old B-52 lacks required production lines for many of its parts and spares are frequently unavailable. Additive manufacturing enabled the digital scanning and reproduction of the part, potentially saving millions compared to standing up a new production line and extending the service life of the aging aircraft. Eventually, no scanning will be required and the parts can be created via the original Technical Data Packages (TDP) file. For maximum flexibility, to include the ability to reproduce parts organically or through a third-party contractor, standards for TDPs, government access to TDPs, and government access to intellectual property rights must be built into contracts at the outset. Additionally, non-proprietary standards for three-dimensional TDP must be clearly adhered to ensure their utility.[28]

At the peak of its sustainment promise, additive manufacturing promises the near-end of the physical warehouse as we know it. In the year 2035, the Air Force depot warehouse will be in the processing of transforming to a virtual warehouse--memory drives with terabytes of data files attached to an array of 3D printers supported by a stockpile of required raw materials. While the virtual warehouse will require a more skilled workforce and equipment, it will eliminate physical and economic waste. This paradigm shift will "reduce unnecessary parts purchases and reduce parts inventory by printing replacement parts on demand in the field," which raises the final benefit of additive manufacturing in the area of operations and sustainment.

In addition to solving the enduring Diminishing Manufacturing Sources And Material Shortages (DMSMS) and warehousing challenges, additive manufacturing also enables part production on demand to support operations in an expeditionary environment, reducing wait times, cost, and operational risk. The Air Force Future Operating Concept (AFFOC) itself paints the envisioned scenario—a deployed Air Force unit requires a part, a secure comm link delivered the needed software file to the field, an airdrop of polymer follows, and the critical part is printed in the field. Millions of dollars and days of time are saved.[29] The U.S. Army and Navy have already experimented with additive manufacturing in war zones and at sea, respectively; by 2035, 3D parts printing in the field will be the norm for each of the military departments.

Recommendations Areas for Further Research

This paper has only scratched the surface on the range of additive manufacturing issues associated with Air Force lifecycle acquisition. To ensure continued progress on this topic, the following topics are recommended for future research:

- Cybersecurity for additive manufacturing technology
- Adversary use of additive manufacturing
- Incentivizing industrial base to embrace additive manufacturing
- Establishing standards for quality assurance of additive manufacturing
- Ensuring government intellectual property rights to additive manufacturing data
- Designing and deploying a virtual aircraft fleet for future conflict
- Space-based satellite production for defense capabilities via additive manufacturing
- Additive manufacturing in the deployed environment

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Conclusion and Recommendations

As stated at the outset, additive manufacturing as a technology does nothing to address process, political, and workforce challenges and is not a panacea to Air Force acquisition challenges. However, additive manufacturing promises to provide significant benefits to cost, schedule, and performance in Air Force acquisition if implemented prudently and methodically across every phase of the acquisition lifecycle. Figure 1 below depicts the future of additive manufacturing benefits across the DoD acquisition management framework.

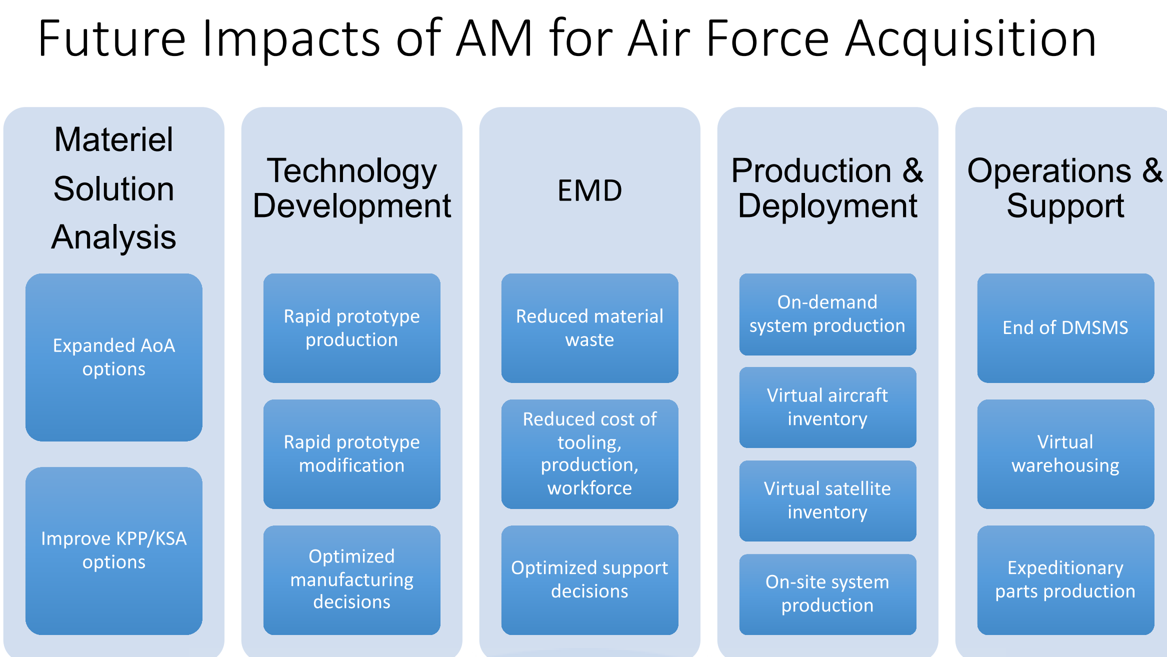

Figure 1 - Future Impacts of AM for Air Force Acquisition

The realization of these future benefits are not guaranteed or without challenges. To address and mitigate the challenges association with additive manufacturing in Air Force acquisition, the following measures are recommended:

- Enhance the acquisition and logistics workforce through **training and education** on additive manufacturing
- Ensure future contracts include appropriate **data/software rights** and **non-proprietary standards** to enable the government produce systems, subsystems, and parts organically or via third parties through additive manufacturing
- Continue **research cooperation** with industry and academia to increase technology readiness and establish robust industry standards
- Establish **process and policies** for additive manufacturing materials, risk reduction,

and quality assurance

- Implement a robust **cybersecurity environment** to ensure data security and integrity of associated files, software, and systems

One final recommendation is for the Air Force acquisition enterprise to capitalize on the low-hanging and low-risk fruit of additive manufacturing. Doing so will intrinsically enhance workplace expertise, build confidence in the technology, and create momentum. Success breeds success, and a failure to succeed in additive manufacturing will leave the Air Force behind its competitors and peers in optimizing cost, schedule, performance, and risk for future weapon systems that ensure the defense of our nation.

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Notes

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