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DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Gaps Between Civilian and DoD in Certifying Additive Manufacturing (AM) Parts

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The U.S. Department of Defense (DoD) has made some progress certifying additive manufacturing (AM) parts for airworthiness, but certification has been limited to the lab, with significant engineering and inspections required for each part. Over the last two decades, each branch of the DoD developed their own processes for AM certification, thus fragmenting certification and slowing the widespread acceptance of AM. The Federal Aviation Administration allows repair and replacement of parts using AM if they have the same quality and strength characteristics as the original parts. The National Aeronautics and Space Administration recently issued its in-depth standard governing AM parts. However, it remains unclear which, if any, aerospace companies are currently following this standard. There are no known general standards or procedures publicly available to understand how private companies certify AM parts. Therefore, we recommend establishing a working group of subject matter experts from industry to directly discuss strategies for certifying AM parts with the DoD.

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

Abstract

The U.S. Department of Defense (DoD) has made some progress certifying additive manufacturing (AM) parts for airworthiness, but certification has been limited to the lab, with significant engineering and inspections required for each part. Over the last two decades, each branch of the DoD developed their own processes for AM certification, thus fragmenting certification and slowing the widespread acceptance of AM. The Federal Aviation Administration allows repair and replacement of parts using AM if they have the same quality and strength characteristics as the original parts. The National Aeronautics and Space Administration recently issued its in-depth standard governing AM parts. However, it remains unclear which, if any, aerospace companies are currently following this standard. There are no known general standards or procedures publicly available to understand how private companies certify AM parts. Therefore, we recommend establishing a working group of subject matter experts from industry to directly discuss strategies for certifying AM parts with the DoD.

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1.0 TI Request

What gaps are there between civilian and U.S. Department of Defense (DoD) aerospace for determining airworthiness of additively manufactured (AM) parts and repairs?

2.0 TI Response

Defense Systems Information Analysis Center (DSIAC) staff researched the steps private industry and non-DoD government organizations take to determine airworthiness of AM parts and compared them to current efforts undertaken by the DoD, particularly the U.S. Air Force.

2.1 The State of AM

AM, by nature, is a layer-by-layer manufacturing process that offers unique advantages over traditional manufacturing methodologies. These advantages include printing of obsolete or difficult to acquire parts, eliminating long lead times, and light-weighting through geometry optimization. The challenge of using AM components derives from the potential formation of defects during the printing process that can detrimentally affect the material properties compared to their machined, cast, wrought, stamped, or otherwise traditionally manufactured counterparts. The older certification processes need to be updated or replaced to allow AM parts. For example, a split-second power fluctuation delivered to an AM machine laser can result in unmelted powder, leaving porosity within the interior of the part and potentially leading to crack growth. Subsurface crack propagation is very atypical for more “homogeneous,” traditionally manufactured parts and difficult or more expensive to detect or predict.

According to an audit of the DoD’s AM capabilities and issues [1], replacing or repairing flight-critical parts is too risky for military applications without substantially increased investments in engineering costs. The risk associated with using AM components reinforces traditional manufacturing approaches as the best path forward.

Even though the DoD tends to gravitate to safer manufacturing routes, it has made large investments in progressing toward wider AM adoption. Many noncritical parts have been implemented into systems, but they have been low risk. In 2016, the Navy printed and flew one “essential” link as part of the structure of a V-22 nacelle [2]. Although this part was redundant, it still required significant engineering costs and time to certify in a lab. A 2017 paper by Seifi et al. [3], done in collaboration with the National Institute for Standards and Technology, noted that despite a greater adaptation of AM components, there are still no standards for integrating fatigue-critical AM components.

Each branch of the DoD has independently developed their own processes, procedures, and systems for dealing with AM. The lack of visibility and awareness has slowed the process of widespread DoD acceptance. In June 2021, the DoD published policy in DoD instructions 5000.93 on the use of AM within the DoD [4]. DoDI 5000.93 has the stated purpose, "In accordance with the authority in DoD Directive 5137.02, this issuance establishes policy, assigns responsibilities, and details procedures regarding the implementation and use of additive manufacturing (AM) within the DoD." The policy aims to use AM to support joint force commanders, increase logistics resiliency, improve self-sustainment, ensure AM plans and programs are resourced, train the DoD workforce for AM, develop and adapt new AM technologies, and collaborate to share best practices in the AM community.

2.2 Federal Aviation Administration (FAA)

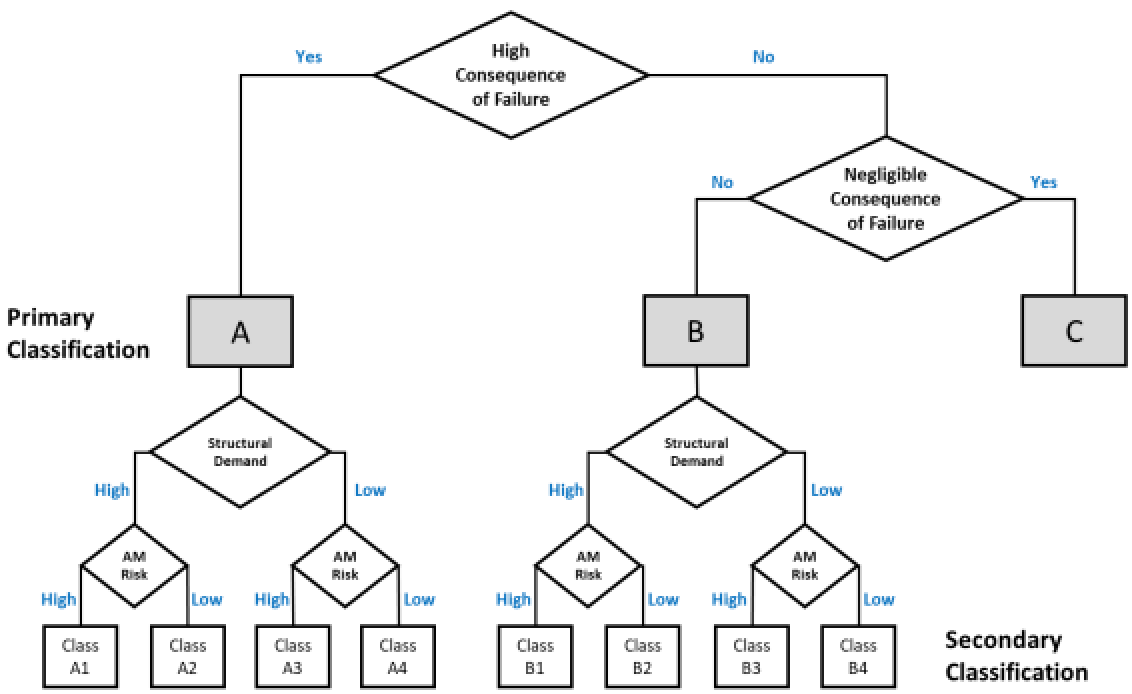
The FAA's perspective has been more laissez-faire than the DoD on repair and part replacement. According to a notice (N 8900.391) issued by the FAA regarding AM repairs and alterations [5], the certification of parts is determined by the manufacturers. The document states that all maintenance must be performed in the "same quality as original or properly maintained condition" and provides no standard guidelines to follow outside of what a manufacturing company deems necessary. The FAA also states that AM repairs and replacements, at a minimum, should be as good in strength and quality as traditionally manufactured parts. This means that an engineer who reverse engineers an existing part on an aircraft with the intent of replacing it with an AM part must prove its quality and develop a technical data package to match the vague guidelines set by the FAA.

This lack of standards hinders advancements in the supply chain for adapting AM components across private and public sectors and leads to the development of proprietary, internal processes only the manufacturers can resource.

2.3 NASA Standards

NASA recently approved NASA-STD-6030 [6], which outlines specific AM requirements for spaceflight systems for NASA and Jet Propulsion Lab part suppliers. This document defines the minimum requirements and outlines the policy framework for both manned and unmanned systems. It also establishes requirements to be met by a cognizant engineering organization (CEO), including a part-agnostic section called "Foundational Process Controls" and a part-specific portion called the "Equipment and Facility Control Plan (EFCP)" to ensure proper calibration and qualification according to NASA-STD-6033 [7].

NASA assigns AM parts into three categories—A, B, and C (Figure 1). Class A parts have a high consequence of failure, leading to loss of life or high monetary loss. Class A parts shall not be made from polymeric materials, contain printed threads, or be fasteners. A quantitative nondestructive evaluation (NDE) inspection of each part and a preproduction plan (PPP) are required before manufacturing begins. Class B parts can still be classified as high consequence, critical parts; however, they are associated with less catastrophic failure relative to Class A parts. Class B can be made from polymeric materials. Process control NDE and a PPP should be in place before production. Class C parts are considered to have nonhazardous failure



consequences; therefore, less stringent controls are required than in Classes A or B.

Figure 1. AM Part Classification *(Source: NASA)*.

CEOs should employ in-situ process modeling and digital threads to account for any variation or defects over the part's life cycle. Qualified materials should be in place and quality of raw materials ensured. CEOs should submit all relevant information to NASA before approval.

2.4 AM in the Aerospace Industry

Since Congress imposed a regulation moratorium on commercial human spaceflights in 2004, start-up aerospace manufacturing companies like Relativity have been seeing AM as a powerful asset [8]. Rocket engines are notoriously complex, requiring hundreds of high tolerance and expensive parts. Relativity claims to "disrupt" 60 years of aerospace technology with 100× fewer parts, 10× faster fabrication, and a simple supply chain by three-dimensional (3-D) printing their own rocket engines. However, it is unclear if companies like Relativity follow NASA-STD-6030.

In the terrestrial aerospace industry, there have been successes with AM, but AM components do not follow any posted standard. Instead, aerospace companies have close relationships with manufacturers and outline very specific instructions that must be carefully followed. These instructions are thorough, proprietary, and require significant investment. For example, the next-generation GE9X turbofan from GE Aviation will use 19 3-D-printed fuel nozzles, which have gone through GE's own internal, proprietary, airworthiness certification [9].

Senior application engineer Tommy Lynch from Xometry, a company that provides widespread production support of AM parts, states that there is no "standard" used for part certification [10]. Large companies try to keep most AM in house since they have the engineering base to outline every single part and typically work with new designs accounting for AM from the start.

When asked about collaborating with federal supplier customers and why it is difficult to get AM parts delivered, Mr. Lynch stated, "Unless the customer has the means (or equipment) to fully validate the design, support strategy, and process requirements in house, it will be tough to hand over an unproven design to the typical service bureau and expect them to get it right on the first try. Metal printing still has a collaborative development process that can take a few iterations" [10]. Therefore, producing AM parts for end use requires building prototypes before all the material and machine controls and variables can be centralized and production becomes repeatable.

Big Metal Additive, a company founded by former Lockheed Martin Skunkworks engineer Dr. Slade Gardner, invented a large-scale printer capable of high criticality and complex geometries. Dr. Gardner expressed his concern and frustration with the DoD and other federal agencies' lack of acceptance of AM [11]. He stated that his team pushed hard to fly AM parts on military aircraft in the early 2000s and were successful, yet not much has changed in the two decades since. He said a key issue is the current requirement to use legacy inspection methods on AM parts, which limits certification of viable AM products. Additionally, he stressed the importance of building an AM infrastructure that can support the mass production phase of AM as compared to the current “laboratory-scale operations.”

2.5 DoD Efforts

Two ongoing DoD efforts specifically focused on quality certification of AM parts for aerospace usage should be highlighted. One effort is a Small Business Innovation Research program titled “Certification of Structural Additive Manufacturing Parts for DoD Applications Through Well-Defined Durability and Damage Tolerance Requirements” [12]. The Defense Logistics Agency is sponsoring this research effort, which ended in July 2022. The second effort, in partnership with the FAA, was announced in March 2022 and consists of a $4.3 million grant from the Army to Auburn University’s National Center for Additive Manufacturing Excellence to help establish materials, AM parts, and process qualifications [13].

3.0 Conclusion

Narrowing down the exact reasons why AM has yet to be proven as a repeatable and powerful tool fully accepted by the DoD cannot be solved in one report. This report forms a basis for more in-depth analysis. As such, DSIAC recommends establishing a working group of industry SMEs and AM industry leaders to facilitate responses and conversations with the DoD for advancing and adopting airworthiness certification of AM components.

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Biography

Matt Seidel is a mechanical engineer and metrology analysist working within the Metrology group at SURVICE Engineering, where he uses his reverse engineering (RE) and 3-D printing knowledge and expertise to support the company. He was an intern for the Navy at Pax River Naval Air station and then became a Navy civilian, where he was involved with additive manufacturing at the government level, worked in obsolescence management, and used RE methods to successfully solve many supply chain issues. He has also authored papers on 3-D printing.

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