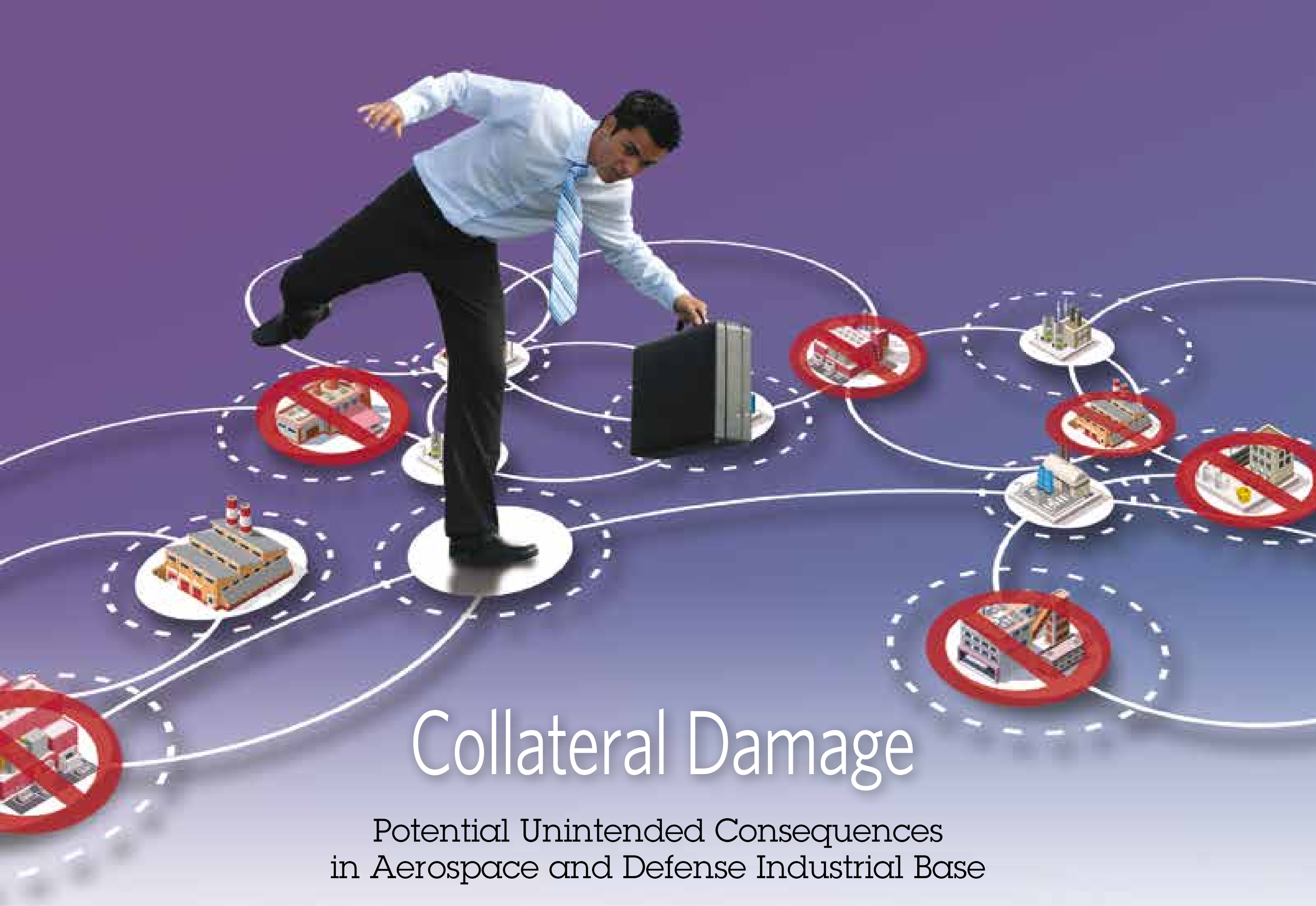

Collateral Damage

Potential Unintended Consequences in Aerospace and Defense Industrial Base

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Researchers at the University of Alabama in Huntsville (UAH) and the Defense Acquisition University-South Region conducted separate studies (Sullivan, et al., 2015 and Rice, 2016) that evaluated the potential impacts of additive manufacturing (AM) on the U.S. rocket propulsion industrial base. The combined efforts provide a deep dive into a question that has arisen with the increased interest in AM technology: "Could adverse impacts or collateral damage to the aerospace and defense industrial base emerge as AM expands throughout the U.S. manufacturing sector?" The primary objective of the studies, and this article, is to begin determining AM's applicability to the aerospace and defense industry and the risks and opportunities for the U.S industrial base.

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Right: AM model contrasted with computer numerical control (CNC).
Facing page, left: Traditional machining via CNC.
Photos courtesy of Ace Clearwater Enterprises in Torrance, California

Facing page right: A 3D-Printed RL10 Rocket Engine Gearbox.
Photo by author with permission of Aerojet Rocketdyne

The study concluded that the rocket propulsion industry was an attractive market for the AM sector due to the low volume and potential part reduction for complex parts (thus potentially increasing the factors of safety); however, process certification and qualification standards would have to be developed. In fact, certification and qualification in this domain is the major issue that concerns the Federal Aviation Administration, NASA, and the Department of Defense (DoD). Of specific concern is the integrity of AM processes used and repeatability of resultant products for same (or better) quality as the part produced through traditional manufacturing. The study concluded that injectors, thrust chambers, nozzles and housings were the best candidates for the use of AM technology in producing propulsion systems.

As a disruptive technology, AM could have the following impacts on the propulsion industry, all of which could foreshadow similar and more extensive disruptions in the broader aerospace and defense industries:

- AM technologies could allow original equipment manufacturers (OEMs) to produce parts in-house rather than rely on the current manufacturing industrial base.
- The ability to produce more complex designs may lead to redesign of subassemblies that could result in overall part count reduction. This could reduce the demand for the services provided by small and medium-size manufacturers, causing further reductions in the industrial base.
- Manufacturers of non-propulsion parts could shift to using AM, potentially eroding the need for traditional manufacturing processes (e.g., computer numerical control (CNC) machining). This could, in turn, result in consolidation or even closures of suppliers who supply parts to the propulsion industry.

Table 1 provides a more complete list of the possible impacts of AM technologies on the aerospace and defense industrial base and the potential collateral damage of these impacts. The remainder of this paper will review each of these in more detail.

Table 1. Potential Impacts on the Aerospace and Defense Industrial Base

Possible Impact	Potential Collateral Damage
Fallout from AM benefits	Reduced tooling, piece parts, etc.
Impact on lower-tier suppliers	Reduced castings, forgings, material processing
Impact on raw material suppliers	Material to be provided in powder form
OEM performing additive manufacturing (AM) in-house	Reduction in subcontractor manufacturing
Suppliers loss of non-DoD business to AM	Increased overhead cost or even closue due to business base erosion

Possible Impacts

Fallout from AM Benefits: Early discussions regarding the benefits of AM focused on the cost savings due to part count reduction and the elimination of tooling. However, the uncertainty still to be addressed is, "where are the savings coming from?" If parts and/or subassemblies are manufactured using AM, then the reduction in work leads to the questions, "who is not making the tooling?" and "who is not making the reduced parts?"

Impact on Lower-Tier Suppliers: Utilizing AM will also impact secondary providers. A recent study by two of the authors focused on the impact of AM technology on the forging sector of the DoD industry base. Based on the interviews with forging industry leaders, the authors did not perceive an immediate threat to their market. However, they did believe the casting industry is more vulnerable in the near term, especially for

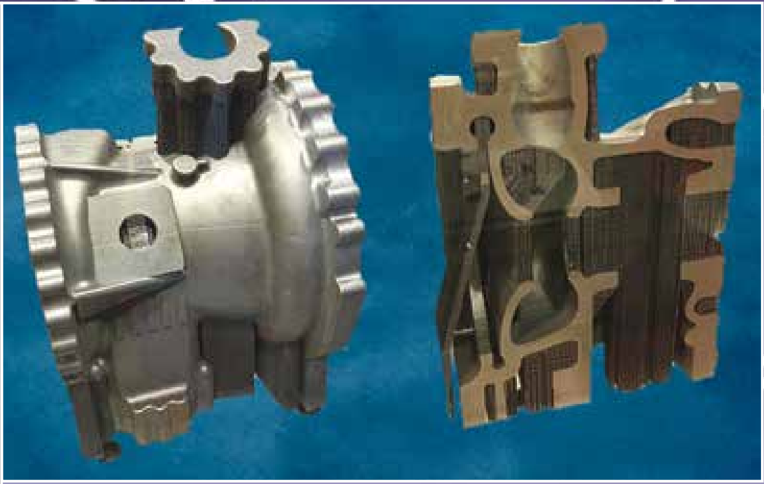

Table 2. Machine Shop Supporting Aerospace and Defense Industrial Base (Example)

Sales	Metrics
Energy	20% of Business Base ($20M)
DoD OEM 1 (criticality one hardware)	20% of Business Base ($20M)
DoD OEM 2 (criticality one hardware)	20% of Business Base ($20M)
Commercial Aviation	40% of Business Base ($40M)
Current Overhead Rate	175%
General and Administrative Rate	10%

OEM = original equipment manufacturer

mid-size to small production runs. Supporting this conclusion, initial testing indicates that the "sweet spot" of AM-produced parts falls between cast and forged parts. That is, AM-produced parts appear to be stronger than cast parts but not as strong as forged parts. This study also found that lower-tier suppliers impacted could be those organizations that do heat treatment and other surface processing. The impact will be dependent upon the material characterization and function of the AM-produced parts.

Impact on Raw Material Suppliers: With greater widespread use of AM, raw material will no longer be purchased in billets from mills. Depending upon which material of the AM-produced parts has the highest success rate, a determination will follow as to which type mills (aluminum, steel, etc.) are initially impacted. Also, as AM use becomes more ubiquitous, demand may increase for powder and/or wire. This is not a problem at present since early studies indicate that AM currently only accounts for 1 percent of the demand for metal powder. But, as the industry grows, this will change.

OEM Performing AM In-House: According to a study by the Massachusetts Institute of Technology, OEMs subcontract more than 70 percent of their manufactured hardware. However, with the increased use of AM by OEMs, the unscientific observed trend has been for them (e.g., General Electric) to build the AM-produced hardware in-house. Should this prove to be a trend, the percentage of subcontract work will decrease as AM grows. Thus, industries with higher use of AM could see greater vertical integration.

Supplier Loss of Non-DoD Business to AM: A key issue for the DoD is the reduction in the industry base at large. This is partially driven by low quantities that the DoD requires compared to commercial product OEMs. The data in Table 2 exemplify the percentage of the business base generated by aerospace and defense sectors. As shown, the DoD typically only accounts for about 20 percent of a small machine shop's business; its commercial business generates sustaining income. Thus, if the commercial OEMs' in-house use of AM increases, it could further erode business, resulting in small machine shops closing—eliminating them as DoD suppliers.

Table 2 represents a machine shop that supports the DoD. Owing to reduction in DoD demand, the firm must diversify to other sectors to maintain its business base. Assuming that its

commercial aviation customer reduces its orders (from utilizing AM) by 75 percent, the the revenue stream shrinks to $10 million instead of $40 million. The immediate impact on the overhead rate and the general and administrative (G&A) rate sees them rise to 200 percent and 15 percent, respectively. Given a typical firm fixed-price environment, the other jobs can easily shift from profitable to unprofitable just through rate adjustments. Unless the machine shop quickly replaces the lost work or reduces overhead and G&A cost (and it is challenging to do so in a machine shop due to capital investments), it probably will yield a loss for that period. In addition, the increased overhead rate can affect the shop's estimates and the likelihood of its success on contract bids. This could easily start a downward spiral toward consolidation or closure.

Impacts of Previous Disruptive Technologies: "The past is prologue," so the downside to existing suppliers is predictive. Similar cases of disruptive technologies have included space transportation, plastics in the automotive industry, and advanced composite materials in aviation and aerospace.

The Space Transportation System (i.e., the Space Shuttle) introduced disruptive technologies to traditional parts and assembly manufacturers. The need for lighter, stronger structural materials to reduce the cost of a delivered pound to orbit, disrupted conventional rocket manufacturing and material sourcing. Advanced alloys and specialty metals yielded improved strength and reduced density of highly stressed components. This translated into a disruption among stainless and aluminum machine shops supporting product development for launch vehicles.

Plastics in the automotive sector substituted for metal components resulting in lighter, more flexible molded assemblies. The plastics manufacturing process is more straightforward, with parts typically injection-molded or blow-molded from plastic resin, as opposed to the welding, stamping and other processes for shaping metal in automotive manufacturing. This, of course, resulted in higher fuel efficiencies compared to earlier models and forced traditional metal manufacturers to reassess their core businesses.

Advanced composite materials in aviation and aerospace led to lighter, stiffer airframe characteristics for significantly improved performance. Traditional flight structure manufacturers were forced to adapt, consolidate or liquidate as a consequence of the fiber/resin technology.

Preparing for AM

While AM technologies are exciting and could revolutionize manufacturing, we should not be so naive as to think that this "revolution" will be painless. This article seeks to raise awareness and stimulate thinking regarding the risks associated with the insertion of this disruptive technology. Leaders across the aerospace and defense supply chain need to consider and prepare for the possible AM impact on their businesses. Below are organizational considerations based on positions in the supply chain.

The U.S. Government and prime contractors need to collaboratively monitor supply chain (at all levels) to determine if their existing business base is at risk with the growth of AM. Further, the U.S. Government and suppliers need to determine if the prime contractor's strategic plan for AM involves outsourcing or performance in-house. And government and OEMs may need to assist a firm's subject-matter experts (SMEs) in becoming "hybrid" shops, combining both AM and traditional manufacturing.

Given insourcing opportunities, the government should determine if organic capability exists (possibly across Services) as supplier capabilities decrease. It should also assess whether organic capabilities can support demand or new AM process need to be certified.

Finally, SMEs need to investigate if products they manufacture for their customers or the material they use to manufacture their hardware is a candidate for AM.

Conclusion

While the authors fully support the use of AM technology, more attention should be given to the development of strategies and policies that will mitigate risks to the aerospace and defense industry. We hope this article provides a foundation and compelling case for further discussions on this topic.

Note: For further information on AM, DAU's AM Community of Practice includes related processes and procedures; organizations and consortiums; reports, papers and articles; and professional development opportunities. Please visit https://acc.dau.mil/am.

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