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Additive Manufacturing Taking Flight 2016

A WHITE PAPER REVIEW OF ADDITIVE MANUFACTURING IN AEROSPACE APPLICATIONS

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This White Paper is based on market research and industry analysis carried out for ***SmarTech's*** *reports "Opportunities for Additive Manufacturing in Commercial and General Aviation" and "Additive Manufacturing in Space and Defense Aerospace Markets." More information on these reports can be found at:* *http://www.smartechpublishing.com/reports/category/aerospace*

The Expansion of 3D Printing Technology in Aerospace

The aerospace industry has long been regarded as a leading adopter of 3D printing and additive manufacturing technology, but for some time lagged behind other key markets in terms of utilization and acceptance. Today, the tide has shifted, with the aerospace industry is now among the most innovative users of additive manufacturing technologies as a tool for end-use component manufacturing in aircraft and other applications. Since 2015 especially, the aerospace industry has undergone a significant shift from "healthy skepticism" regarding the widespread use of AM technology for aircraft and spacecraft production, to what increasingly appears to be an all-in acceptance for developing its use in major areas of the aerospace industry.

This has led to an increasingly diverse market scenario for AM technology in the aerospace category, ranging from commercial and general aviation, to government-related space and defense aerospace applications. A high degree of focus and innovation still stems from major commercial aircraft manufacturers today, however it is becoming more and more important for stakeholders to understand how AM can be applied across a number of other aerospace related markets in order to maximize the effectiveness of investments and research.

In particular, the collective aerospace industry provides an excellent case study on two of the primary trends that are driving the total AM industry to continued year-over-year growth. Before we can analyze an in-depth segmentation of opportunities for AM in the aerospace sector, we must first understand the specific factors that have catalyzed the explosion in acceptance and ultimately expansion of AM in this industry over the last eighteen months.

Rapid Prototyping to Additive Manufacturing in Aerospace

The role that 3D printing has played as a rapid prototyping tool for aerospace suppliers and aircraft OEMs cannot be forgotten as the industry transitions towards use of these technologies for production of end-use parts. The transition from using what are largely the same technologies once used almost exclusively for prototyping now for manufacture of usable components continues to be the largest growth factor for AM in aerospace.

Competencies developed from two decades of rapid prototyping experience with stereolithography, material extrusion, and powder bed fusion technologies (among others) have aided in the gradual acceptance of AM in aerospace. This is thanks mostly to experiments for non-critical spare parts printed using existing rapid prototyping machines which, over time, were integrated into flight-ready aircraft for testing as real end-use parts. Confidence in these typically mundane, non-descript and often polymer parts increased over time and has lead to greater exploration of how to apply similar additive production strategies on a wider scale in both military and commercial aviation markets.

While the commercial aerospace industry appears to be furthest along with transitioning the utilization of AM systems from strictly prototyping to greater roles in manufacturing, other sectors of the aerospace industry are still evolving in this area. Space vehicle, satellite, and missile system manufacturers are only beginning to turn their focus towards the potential for manufacture of end-use components, and still see the majority of value from 3D printing in the shortening of lead times and design costs from rapid prototyping. However, **SmarTech** anticipates that continued innovation on the commercial aerospace front will catalyze a rapid transition in areas of government and military aerospace, where the same lessons learned over a decade of commercial aerospace can be applied more quickly thanks to the involvement of multi-national aerospace corporations in both commercial and government sectors.

Direct Additive Manufacturing and Indirect Additive Solutions in Aerospace

Focusing on the use of additive manufacturing systems as a tool for the production of end-use aircraft, space vehicle, satellite, and missile system components can allow for further analysis of the approaches to value which manufacturers are taking to increase acceptance and utilization of AM. One of the most important factors in increasing the overall acceptance of AM across the entire aerospace industry over the last few years has been a joint understanding of both direct additive manufacturing and indirect additive solutions.

While direct AM aerospace solutions will ultimately always be the preferred route for maximizing benefit to aerospace manufacturers, until barriers to widespread adoption are completely overcome, applying additive manufacturing systems for use in indirect manufacturing solutions such as tooling will continue to build confidence and value for AM in the aerospace industry—similar to how rapid prototyping has done for several decades.

3D printed tooling (sometimes referred to as "rapid tooling" applications) has become more widespread across the aerospace industry as a near-term opportunity while direct part production research is ongoing. This is especially relevant in the

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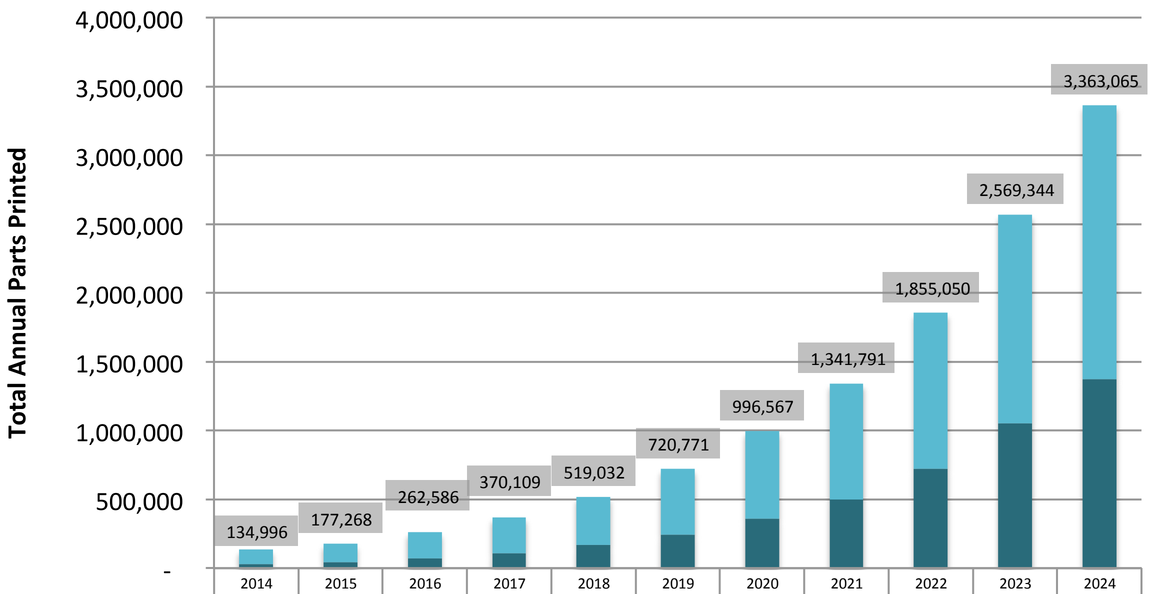
areas of military and commercial aircraft, where the printing of more advanced casting patterns and cores can help bring some of the geometric complexity benefits of AM to a more familiar final manufacturing process—all while saving time and costs. Meanwhile, assembly tooling, which is printed on-demand during production or repair of aircraft, has become standard practice in larger aerospace suppliers and OEMs, and continues to trickle down to the rest of the supply chain.

As a hybrid solution, the use of directed energy deposition AM technology has seen a significant increase in use within the aerospace industry. This technology allows for the selective remanufacture and repair of large, high-value aerospace components to either add features for improved performance, or to remanufacture surfaces to get aircraft back in service at a lower cost and reduced down times.

Ultimately, growth in direct AM solutions is expected to be the holy grail for the aerospace industry, especially through technologies such as powder bed fusion of both metals and polymers, as well as directed energy deposition and material extrusion.

Exhibit 1, compiled from data of **SmarTech's** most recent studies on AM in the aerospace industry, reveal total projections for 3D printed components across the aerospace industry by both direct and indirect applications.

Exhibit 1: Total Projected 3D Printed Manufacturing Parts, All Aerospace Applications, 2014-2024



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Total manufacturing parts	134,996	177,268	262,586	370,109	519,032	720,771	996,567	1,341,791	1,855,050	2,569,344	3,363,065
Indirect parts	105,658	132,765	190,578	261,162	352,494	475,477	637,693	842,926	1,134,620	1,518,538	1,991,267
Direct parts	29,338	44,503	72,008	108,946	166,538	245,294	358,874	498,865	720,430	1,050,805	1,371,798

Source: SmarTech Markets Publishing

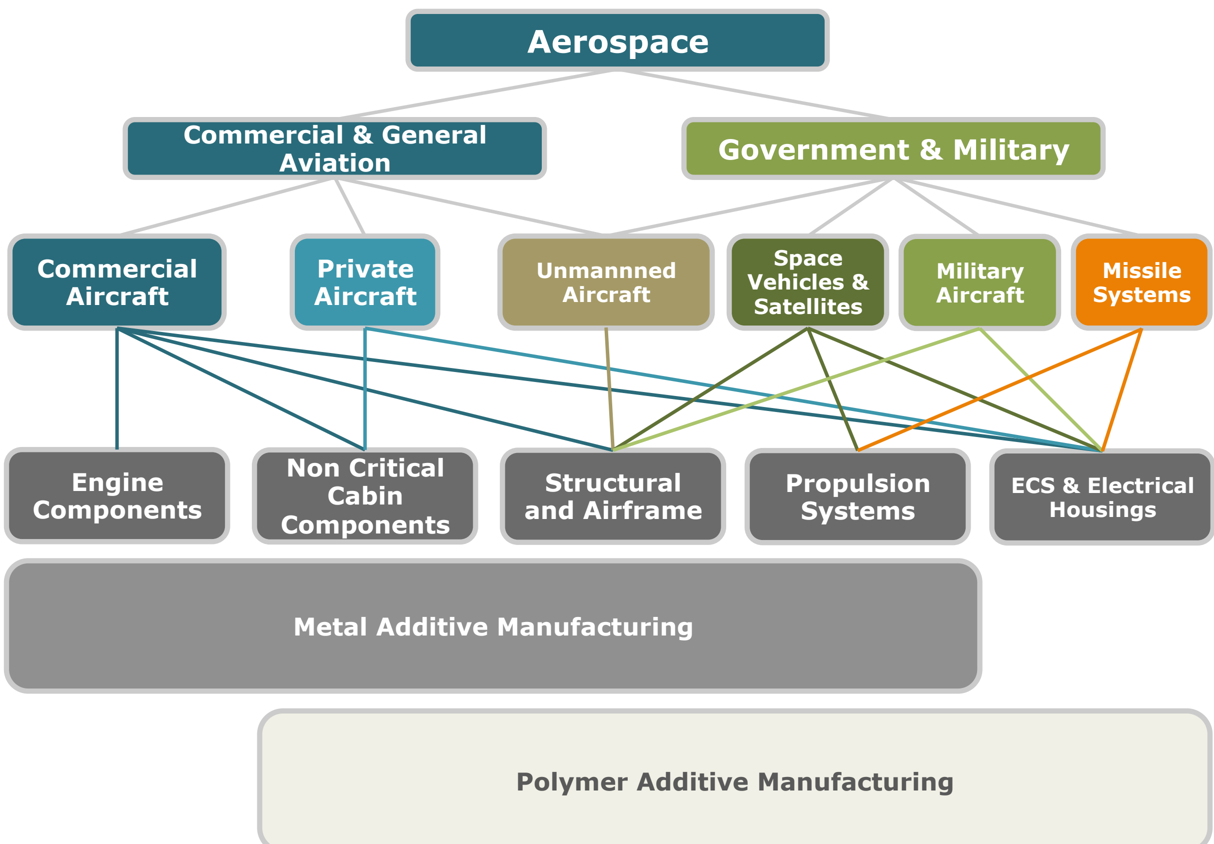
Segmenting the Additive Aerospace Opportunity in 2016

What was once a study of a few manufacturer's uses of 3D printing for a handful of parts in the commercial aerospace industry has now grown into a massively diverse market opportunity with potential to disrupt the entire aerospace industry—from airliners, to UAVs, to satellites, and more.

SmarTech has produced the most encompassing study available of 3D printing and additive manufacturing applications across the entirety of the aerospace industry, and believes that understanding the differences and similarities in how additive technologies are being applied across the entire aerospace industry is critical for stakeholders targeting the aerospace industry—especially for AM equipment manufacturers, materials developers, service providers, software developers, and aerospace suppliers looking to diversify or specialize in 3D printing.

Therefore, SmarTech has created a segmentation model spanning the seven major areas of application for additive technologies in the broader aerospace industry. This segmentation is visualized in Exhibit 2 below.

Exhibit 2: Segmenting the Additive Aerospace Opportunity



Source: SmarTech Markets Publishing

Seen above, the first subsegmentation of additive technologies within the aerospace industry separates government and military aerospace sectors from commercial and general aviation sectors. This is a primary distinguishing factor for segmentation due to the differences in budgeting and R&D spending, and the influence of political initiatives that guide certain aerospace products, and which ultimately guides the application of new manufacturing technologies.

The second subsegmentation for additive technologies in the aerospace industry deals with broad application categories by aerospace product group. Note that a

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particularly interesting area is in unmanned aerial vehicles (UAVs) which are shared by both government and military as well as commercial segments.

A third segmentation looking at application groups which encompass the majority of research areas for additive technologies in aerospace are subsequently shared across these aerospace product categories. Commercial aircraft still represent the widest array of applications currently underway in terms of serial production for flight parts or development, and include everything from engine components, non-critical cabin and structural parts, major structural or airframe parts, and environmental control systems and electrical housings. These applications are not relegated to just the largest commercial jetliners, but are also being utilized by helicopter manufacturers.

Propulsion system components are being lead by the space vehicle and satellite category, where leading launch vehicle manufacturers such as Aerojet Rocketdyne have already engaged in test firing of printed propulsion systems. An interesting potential adopter of printed propulsion systems also comes from the missile systems product category, where experimental printing of fuel grain cells and propulsion components are creating potential for very disruptive defense products.

At the bottom of Exhibit 2, a visualization of coverage by additive technology type stretch from left to right to illustrate how broadly *both* polymer and metal AM technologies are being applied. With few exceptions, both advanced polymer printing and metal printing systems covering a wide variety of individual printing processes are finding acceptance and opportunity in all areas of the aerospace sector.

Value Centers for Additive Manufacturing Across Aerospace Applications

The use of additive technologies creates value in many different ways among the subsegments presented in the previous section, where certain processes or print materials may create value in a way that is especially impactful in a particular aerospace application when compared to other aerospace subsegments. Some of the most impactful or disruptive value centers for additive manufacturing are compared and contrasted by **SmarTech** across the entirety of the aerospace sector.

Supply Chain Flexibility and Implications Across Segments

Introducing greater flexibility into the aerospace supply chain is of key importance in the value considerations for additive manufacturing technology. This has long been realized in the area of rapid prototyping activity within the industry, which has

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reduced overall costs and development time for aircraft development and evolutionary design. To a somewhat lesser degree, rapid tooling applications for 3D printers have also been appreciated for some time in this regard, with benefits of new or more advanced tooling only just starting to be realized. Much of this early supply chain flexibility, most well noted in the commercial aerospace industry, does not speak to the potential of supply chain flexibility afforded by true serial manufacture of flight parts via AM.

On the military side, however, flexibility in the supply chain for military aircraft, missile systems, and unmanned aerial vehicles takes on an entirely new meaning through additive technologies. Strategic advantage can be a benefit that often may trump all other considerations (such as cost) in military operations. This has helped drive significant interest in 3D printing technologies for their ability to introduce flexibility in the supply chain for military aerospace products and thus achieve a strategic advantage. Examples include unmanned vehicles that can be manufactured on demand closer to front lines at minimal cost, military aircraft which can be kept in service longer through remanufacture of parts, and missile systems that can be manufactured on demand to reduce munitions storage requirements.

Reduction of Lead Time and Cost Reduction – Impact Considerations in Military versus Commercial Markets

As a rule of thumb, AM experts in the commercial aerospace industry now believe that additive technologies can reduce the lead-time for a part by 80%, compared with conventional manufacturing methods. This may allow aerospace manufacturers as many as five times more opportunities to redesign a single part during a standard component development cycle, leading to significant performance improvements of the components.

Manufacturers are already realizing dramatic cuts in lead-time for AM produced parts. For example, Kelly Manufacturing Company was able to reduce the production time for 500 housing components from three-to-four weeks to just three days using plastic laser sintering technology. Applications like these will create significant value in the commercial industry over the next decade.

This advantage is perhaps even more significantly appreciated in the government and military aerospace sector, where budget cuts are a constant threat requiring continued innovation to reduce total costs. This is especially relevant in the context of large and extremely high value, low volume parts used in propulsion and structural elements of military aircraft and space vehicles, where the ability to integrate 3D printing to reduce lead times for parts through both rapid prototyping,

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rapid tooling, and even direct additive manufacturing of flight parts can be achieved.

With record anticipated demand for aircraft in the commercial sector, and ever increasing cost pressures in the military and government sector, use of additive technologies appear to be a sure thing in the future of the aerospace industry even if based solely on manufacturing efficiency and cost reduction abilities.

Design Optimization and Barriers to Full-Scale Additive Manufacturing

Ultimately, the concept of "design for additive manufacturing," in which parts are designed around the capabilities of AM rather than more limited subtractive technology, represents the pinnacle of utilization for additive technologies in the aerospace industry. This approach involves identification of aircraft and other aerospace components well suited for additive manufacturing, and then designing these parts with the most ideal geometric features for performance on the expectation that additive manufacturing technologies will be able to reliably produce these designs.

A number of barriers exist to achieving this goal today, making design for additive manufacturing in the aerospace industry one of the long-term initiatives among a slew of other 'low hanging fruit' benefits currently driving adoption.

One key challenge that **SmarTech** believes is under-served in terms of research and development to this end is the development of manufacturing software tools that are made specifically for the design of 3D printable aircraft components.

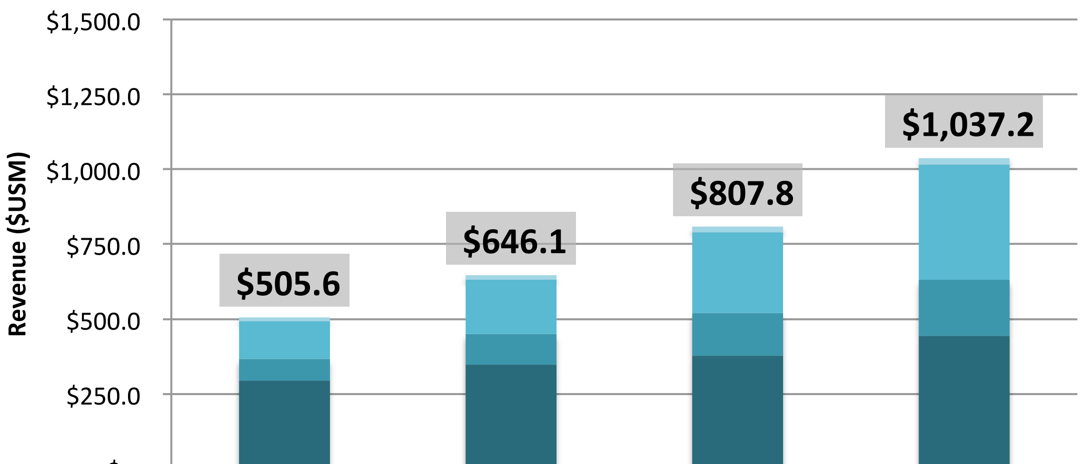
The advantages of additive manufacturing include both shape complexity and material complexity within a single part or component. With regards to shape complexity, this means that aerospace engineers utilizing AM processes can always have access to the internal features of their components due to the layer based printing process. A hierarchal complexity can be achieved with internal features of a component having internal features of its own—the “features within features” principle. However, current parametric modeling solutions in CAD tools utilized by most aerospace engineers aren’t sufficient for this type of design approach, and therefore often eliminate or reduce the possibility to take advantage of the potential benefits of additive fabrication right from the design stage.

Looking to the Future of Additive Technologies in Aerospace

In total, SmarTech anticipates that the aerospace industry generated nearly $650 million dollars in revenue through its use of additive technologies in 2015, making it one of the most salient opportunity segments for the entire AM industry. This revenue encompassed hardware, materials, specialty aerospace 3D printing services, and software.

Looking to the future, **SmarTech** anticipates that total opportunity for AM in aerospace will continue to grow rapidly over the next several years, reaching over $800 million in 2016. Exhibit 3 below demonstrates **SmarTech's** overall aerospace industry opportunity forecasts, encompassing both commercial and military/government aerospace markets.

Exhibit 3: Total Projected AM Revenues by Category, All Aerospace Applications, 2014-2017



	2014	2015	2016	2017
Total	$505.6	$646.1	$807.8	$1,037.2
Software	$12.6	$15.3	$17.7	$21.1
Services	$125.3	$180.3	$270.4	$385.1
Materials	$72.7	$103.6	$142.0	$188.3
Hardware	$295.0	$346.8	$377.6	$442.8

Source: SmarTech Markets Publishing

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About the Analyst

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Scott Dunham is Vice President of Research at SmarTech Markets Publishing, bringing with him years of research experience in the areas of advanced manufacturing and 3D printing. Scott holds a Bachelor's degree in marketing and research from the University of Kentucky's Gatton School of Business & Economics, and has been a featured speaker at 3D printing industry events around the world.

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	Bio-printing	
	Low-volume manufacturing	
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SmarTech Markets Publishing delivers industry analysis and market forecasts for the 3D printing/additive manufacturing industry. Our coverage provides insight for those companies offering 3D printing services, materials and software sectors, as well as those that make the 3D printers themselves.

SmarTech Markets Publishing is the leading provider of market research and industry analysis in the 3D printing/additive manufacturing sector. We have published reports on most of the important revenue opportunities in the 3D printing sector including personal printers, low-volume manufacturing, 3D printing materials, medical/dental markets and other promising 3D market segments. Our client roster includes some of the largest 3D printer firms, materials firms and investors in the world. And you can follow SmarTech on Twitter where we discuss technology trends, company announcements and the industry's on-going progress.

The SmarTech Team

The team at SmarTech has had decades of experience providing information for high-tech industry sectors and our forecasting and research methodology has been tried and tested over more than 30 years. We realize how easy it is to be lured into unrealistically bullish revenue projections. So we go the extra mile to ensure our forecasts are hype free.

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