AEROSPACE & DEFENSE

PRODUCT-READY INNOVATION

READY FOR GROWTH

With increased global pressures reshaping the structure of the Aerospace and Defense (A&D) industry, demand for new technology is creating a culture built on innovation.

A Resurgence in Defense Spending

After decades of declined defense budgets from the US Department of Defense, instability among several countries is creating a stronger future for defense contractors. This is partly due to increased tension between the Middle East, North Korea, Eastern Europe and the United States over nuclear power development and territory disputes. National securities threats over the Islamic State (ISIS) have also been key drivers of defense growth as terrorism plagues Europe, the US and elsewhere. Countries such as China, Russia, Korea and Japan have already begun to increase their defense budgets to meet future military demands.[i]

DASSAULT SYSTEMES

With nuclear power, aggressive rocket launches and national securities threats creating heightened tensions across the world, a new opportunity arises for defense contractors. Recent programs such as the Ohio Class Submarine replacement, the Long Range Strike Bomber, the T-X trainer and the Rafale fighter jet are only a few examples of how countries are seeking to bolster their defense programs.[i] As the global environment becomes more unstable, defense companies are being presented with several growth opportunities through foreign military sales, acquisitions, new product introductions and the development of new innovative technologies that meet government requirements.

New Competition from Emerging Markets

As demand increases in the A&D market from an unstable global environment, new opportunities arise for manufacturers in emerging markets. Previously, manufacturers in developing countries were already playing a pivotal role by helping aircraft makers cut costs and reduce time-to-market, but now companies within these same markets pose a threat to established aerospace companies like Boeing and Airbus. Brazil, India, China and Russia are now emerging as significant players in the aerospace industry and that role will only grow with time.

Contributing factors to this shift in the industry are surging demand, rising backorders and the compelling cost advantages that these markets present. China, India and Russia are expected to purchase more than 3,500 planes (roughly 15% of global demand) in the next two decades. Instead of handing this demand over to already established companies, these countries want to capitalize on this opportunity. With the cost of manufacturing aircraft structures being roughly 20 to 25 percent lower in these emerging markets, the environment is attractive for growth and innovation. Companies like Sukhoi in Russia and Embraer in Brazil are only two examples of companies that are creating top-of-the-line aircrafts built to compete in this new arena.[i]

Emerging markets also highlight the growth in the global commercial aerospace subsector which is expected to see growing demand for next-generation aircrafts. Passenger traffic has steadily increased over recent years, especially in the Asia-Pacific and Middle East regions due to expanding economies in India, China and the Middle East. Annual growth rate for global commercial traffic is estimated to grow at an average of 4.6 percent as more affordable pricing strategies unfold along with new route availability. Over the next 20 years alone, it is expected that new aircraft production will rise to 35,318 aircraft (excluding regional jets.)[i]

Backlog of Commercial Aircraft

In addition to growing passenger demand, there are also roughly 13,500 commercial aircraft backlogged which equates to 9.6 years of aircraft production on top of current demand. This number has increased rapidly compared to 2009 when there were only 6,913 units backlogged.[ii]

This new demand is driving increased competition between Original Equipment Manufacturers (OEMs) to meet program requirements at a faster rate. Airlines are able to take advantage of the increased competition to further drive down costs and improve their bottom-line. In order to capitalize on this growth companies like COMAC have introduced new products like the C919 commercial airliner. With the help of western suppliers, the C919 airliner used products from General Electric, SAFRAN, Honeywell and others to build a network of suppliers and technology that can compete with established companies.[iii] This is just one example of how OEMs are looking for new partnerships and strategies to accelerate innovation to win more business.

PAVING THE WAY WITH TECHNOLOGY

Despite the positive outlook for the future of the A&D industry, barriers to entry for companies entering the market remain relatively high.[i] Today, only a few large firms dominate the commercial aviation and defense sectors, with hundreds of smaller manufacturers and suppliers supporting their needs, but that may be changing. Substantial investment costs, sourcing issues and extensive technical knowledge prevented more businesses from pursuing the industry in the past.

This dynamic may be changing with the introduction of new technologies that will lower the cost of capital needed to be a competitive player in the market. For example, instead of funneling money into physical prototyping, new engineering and simulation software is available to increase productivity and execute virtual prototyping. The benefit of using virtual prototyping is the ability to analyze and test products at a faster rate and lower cost while reducing errors. This mentality of being able to design anywhere, in less time and at a lower cost is revolutionizing how aerospace companies build new products.

On the production side, technology revolving around lean and additive manufacturing is also playing a pivotal role for existing businesses and new entrants. As backlog orders mount within the industry, the need for more efficient processes is a highly valued resource. Joby Aviation, a young aerospace start-up, realized how additive manufacturing could boost their business by using simulation technology to create a holistic approach to design.

Having access to these new technologies allows companies like Joby Aviation to enter and compete in the light aircraft market without massive capital investment. Emerging players like Sukhoi in Russia, Embraer in Brazil and COMAC in China can transform their development process by leveraging new engineering capabilities to compete head-to-head with Boeing and Airbus in the upcoming years.

THE BACKBONE OF PRODUCT-READY INNOVATION

Before a company can successfully compete in this arena, a system of business processes must be in place in order to create an environment for growth. To achieve product-ready innovation, there are six fundamental elements that companies can utilize to consistently meet requirements while still driving innovation initiatives. When combined, these six business processes can create the foundation for building a program that can compete in the highly competitive A&D industry.

Moving to a Model-Centric Paradigm

The first component that supports driving product-ready innovation is moving towards a model-centric paradigm. For businesses this means unifying processes, methods, organizational infrastructure and information models by creating a cohesive program that focuses on sharing information across departments. Currently, companies are struggling to make clear, effective decisions due to a lack of coordination across departments and systems. In return, this slows down innovation efforts as business and program execution becomes halted by inefficiency. Instead Model-Based Enterprises (MBEs) use an approach that helps people across the entire company explore and qualify stronger business decisions. This is accomplished through using models that account for the interconnectedness of business processes.[iv]

Prior to the MBE approach, businesses typically used a document-based method that analyzed problems based on independent disciplines rather than understanding how each department's information is connected. This approach has higher program failures because problems are isolated within their department, leading to even greater issues across the business. It also creates greater organizational competition for resources as each department, isolated from others, pits themselves against each other. The goal of using a model-centric paradigm is to break down business barriers that result from a document-based approach by bringing data from multiple functions together to create better program results. By using the MBE approach, there is also more opportunity for collaboration and innovation through the integration of systems.

Improving Material Requirements: Composites and Ceramics

A key area of growth within aerospace design is the use of stronger, more resistant materials to create longer-lasting airplanes that improve safety. One of the latest developments in the composite evolution is Ceramic Matrix Composites (CMC).[v] These composites were developed to withstand high temperatures and pressures which can be applied to propulsion systems, for thermal protection and other primary structure applications.

Currently, there are thousands of patents in place for aerospace-grade ceramics which has increased the competition for creating innovative materials. General Electric is in the lead with over 1,400 individual patents, while other competitors, such as United Technologies and SAFRAN, have fewer than 800 patents each. Other key competitors, such as Rolls-Royce and Boeing, only hold 200 patents each. These patents are specifically for aerospace-grade ceramics, not other material components.[vi]

Composites and new polymers are also making a significant impact in aerospace innovation in terms of weight, strength and design flexibility. While fiberglass composites have existed since World War II, use of advanced composites were limited to mainly military applications due to cost. Growing fuel prices and environmental concerns drove stronger interest in using composites for commercial aircraft. In 2012, Boeing launched its new 787 Dreamliner reportedly made up of 50 percent composite material to drive down fuel and maintenance costs.[vii] Now six years later, aerospace structures are commonly made up of 50 to 70 percent composite material.[viii] Companies are looking for new innovations to accelerate composite development and manufacturing while pushing down production costs.

The primary advantage for using ceramics and composites in the A&D industry is for heat resistance, their noncorrosive qualities and their ability to be made into lightweight designs. Certain materials, such as carbon fiber, also give designers the ability to be more flexible with their designs. With these innovations becoming more popular in the industry, we can expect the fight over patents to become more intense in the years to come.

Leveraging Simulation across the Development Process

For companies seeking to create new innovative products, simulation technology has become an integral part of optimizing design and improving product quality. Simulation technology gives businesses the opportunity to virtually design and optimize new products through models that represent the product's key characteristics, behaviors and functions. This helps companies fully understand the best design for the product while also giving them the option to compare and contrast different product features more easily.

Traditional methods, such as physical testing, have higher errors associated with manual calculations and human error. This creates longer development times and higher product costs. In order to increase program success, simulation can be used across program lifecycles to gain greater insight and avoid multiple rounds of testing which increase delivery times and program budgets. With simulation technology, designers now have the ability to make more accurate, faster decisions that improve product quality while reducing costs.

In the past, simulation has been associated primarily with the verification and validation stages of program development, but there are other areas where simulation can create an impact. For instance, when winning new contracts, suppliers and contractors can make more informed decisions by using simulation to better understand how a potential solution will perform in its operating environment.[ix] Other areas where simulation can be used are in the concept design phase, detailed design phase and the prototyping and testing phases. Moving forward, the competitive advantage gained from this software will be vital for companies as they aim to achieve greater accuracy, lower costs and better product quality.

Rapid Prototyping of Parts

Building off of simulations, rapid prototyping is another tactic companies can use to turn their ideas into successful products at a faster rate. Since the late 1980s, rapid prototyping has transformed from an unknown field to one that has a wide range of applications, everything from building airplanes to printing human organs.[x] Rapid prototyping previously involved using

three-dimensional Computer-Aided Design (CAD) data to create a physical mold of a part or product. A series of tests would then be run to further understand the durability, performance and difficulty of producing the product. This process was everything but rapid, taking months to complete. If during the process the item failed, the entire process needed to be started over, creating additional time and cost to complete.

Now, rapid prototyping has become more widely used as program improvements have extended its applications and increased the quality of products. Replacing physical molds, users are now able to optimize parts virtually through simulation while still using CAD data to build the parts. Once the model is tailored to meet product objectives and quality requirements, assembly can then be completed using additive manufacturing.

Compared to previous methods of rapid prototyping, a physical product is not introduced into the process until the final stages. This enables designers to evaluate the quality, ergonomics and aesthetics of their design early on for avoiding errors. Across the development process—from the beginning of an idea to the end-product—rapid prototyping is helping companies bring their ideas into fruition at a faster-rate.

Immersive System Development

Along with simulation and rapid prototyping, the goal of immersive system development is to aid in the acceleration of product development. When referring to immersive system development the most common name for the process is Digital MockUp or DMU. There are, however, other associated terms such as the digital twin. The purpose of the DMU is to create a digital model of a product which is a replication of the physical asset, processes and systems. This is highly valuable, especially in the A&D industry, because it allows companies to avoid errors and test performance capabilities while creating a higher-quality product in less time.

Over the years, the benefits of using a DMU to assist in product development have become clearer as more companies implement the process. Compared to physical prototypes, DMUs help companies more effectively evaluate a program's current and future capabilities throughout the product lifecycle. Through this process, system errors can be discovered early on by simulating the results for the product. As defects are found, programs can be continuously updated and improved upon in order to achieve more accurate system information.

Recently, Airbus has converted to using only one DMU for their product development cycle. In previous years, Airbus used one DMU for each site, creating a lack of communication across departments and increasing design time. To achieve greater collaboration and accuracy, Airbus implemented one DMU when designing the A350 XWB. With a global presence, this meant that despite location differences, employees could work as a virtual team throughout the process. With the latest data always readily available, development times were quickly reduced.

On-Demand Certification

The last component for creating the foundation for product-ready innovation is being able to meet program requirements with on-demand certification. Creating a product that excels in the industry is only part of the development process. On-demand certification seeks to accomplish the simplification of the end-to-end certification process through technology. For example, companies can now use one platform that connects engineering and certification teams, allowing for greater visibility of the process for all members. Furthermore, it also automates the search and collection of regulations, standards and recommended practices to ensure information is standardized across departments. This allows companies to take their ideas and transform them into a working program while expediting certification.

Currently, the certification process in the A&D industry is highly fragmented due to changes in regulations and overall program complexities. Once a company has finalized the conceptual development of the new product, the next step is giving the authorization to offer. This happens when the company approves the program and the process can truly begin. For certification, the next step is applying for a type certification which is where time begins to become a bigger issue. The type certification is essentially an agreed set of airworthiness requirements that a product must meet before receiving its Type Certificate. Typically, it is roughly three to five years for a company to become certified or else the process must be re-negotiated which can result in hundreds of millions USD in additional costs.[xi]

This is why having a system in place for on-demand certification is equally as important as having an innovative idea. Without a certification program, failure is inevitable in the Aerospace & Defense industry. To avoid these penalties, companies can utilize on-demand certification technology that provides controlled access to information. It also provides access to certification timelines on a simple and dynamic dashboard for each certification project. With full traceability across the supply-chain of requirements and updated submission feedback, companies can have more power over the process than ever before.

CREATING WINNING PROGRAMS

Once a set of systems are in place that generate an environment for growth and innovation, the next step is creating programs that develop new or existing business. Managing new program proposals is important for companies in order for them to execute on-time and within budget, while delivering a high-quality product. This is all an integral part of the innovation process because as ideas are developed, they can be implemented faster if there are supportive systems in place.

In the beginning stages of product ingenuity, understanding the importance of maintaining full requirements and traceability is essential for program success. This process is also critical because 70 percent of cost decisions made during a program's concept and preliminary design phase impact 80 percent of the total lifecycle cost.[xii] Ensuring that the best design is chosen early on helps companies stay within their budget while creating solutions that maintain customer satisfaction.

This is critical for product-ready innovation because similar to the fundamental business processes mentioned earlier, it allows you to have a foundation for program success. With the Dassault Systèmes Winning Program solution, companies have the ability to define and manage proposed system configurations from the end-to-end proposal process. In the future, it also allows for full reuse of offer or proposal data, system concepts, trade studies and more to support future program success. Moving forward, this allows Aerospace & Defense companies to focus more on product innovation and less on program errors. (Learn more about the Winning Program solution here.)

GEORGIA TECH CASE STUDY: A NEW WAY TO PRODUCE VIRTUAL PROTOTYPES

Using the Winning Program solution outlined above, researchers at the Georgia Institute of Technology Aerospace Systems Design Laboratory (ASDL) took a new approach to designing complex drone systems in order to help soldiers. Drones, or Unmanned Aerial Systems (UASs), have become a useful tool in unknown territories, allowing soldiers to view areas before entering them. For drones to have the capabilities required in these challenging conditions, researchers at ASDL wanted to bring more information and knowledge into the concept phase of designing UASs.

Previously, designing such sophisticated systems had resulted in long development times, increased risk and cost overruns. The complexity of mission required a highly modular UAS that could be configured in the field. The number of permutations would have required a highly time-consuming and expensive physical prototyping process to develop a combat-ready UAS. After partnering with the US Army Research Laboratory (ARL), ASDL was determined to find a better solution for creating more sophisticated drones.

After reevaluating their innovation process, ASDL decided that they needed a different approach for designing UASs that used an integrated process which was more iterative and less sequential. In the past, ASDL researchers used a process for conceptual design that followed a repetitive pattern of designing, building, testing and then rebuilding. This was both timely and costly, with minimal adaptability in the process. Being able to have a process that was flexible for the variety of environments faced by soldiers in combat would be an important development in creating a stronger UAS system.

To accomplish these goals, ASDL began by using a model-based approach to designing three different versions of the drone, each designed for specific tasks, while factoring in possible changes in the environment. The three main UAS characteristics that were focused on were payload capacity, size and endurance. With these components in mind, ASDL researchers were able integrate the data on combat environments and required drone characteristics to create a variety of conceptual designs. This gave them the ability to find the optimal design at a faster rate while tracking program requirements.

The second step in ASDL's mission to develop a UAS with real-time intelligence was creating virtual prototypes of their conceptual designs. This framework would allow researchers to simulate and predict more accurate information for a larger variety of combat missions while at the same time reducing the time and cost to market. Through this process, researchers were able to create an UAS that served a multi-mission purpose with greater adaptability to soldiers' needs. This was accomplished by using a generic drone kit designed to be custom-tailored to the environment through add-on components.

A key part of the researchers' success throughout the process was being able to measure program requirements against conceptual design studies and end-to-end proposal information using the Dassault Systèmes Winning Program. This kept them on track for certification and avoided system errors that would put them over budget. While this program directly affected the lives of soldiers, the demand for UASs continues to grow in the consumer, commercial and military sectors as well. Moving forward, drones can continue to become more flexible and take on even greater challenges, reshaping the way drones are designed and used.

AIRBUS A350 XWB CASE STUDY: FINDING QUALITY AND CONSISTENCY THROUGH COLLABORATIVE INNOVATION

When Airbus asked 20,000 people at airshows, events and online what they expected from travel in 2050 their answers were not surprising: they wanted a cheaper, quieter, more sustainable traveling experience. For Airbus, that meant creating an airplane that not only met their customers' needs, but also delivered on time, on spec and within their budget constraints. The A350 XWB was designed with all of this in mind. With the latest advances in aerodynamic wing design, the A350 XWB provides a quieter and more aerodynamically efficient aircraft.

To create a lighter and stronger design, both the fuselage and wing structures are made of carbon fiber. This not only makes the plane quieter, but it also significantly increases fuel efficiency. With a 25% reduction in carbon emissions and a wider body for customer comfort, the A350 is the next-generation flying experience.

Recently, carbon fiber has become increasingly popular for companies like Airbus due to its ability to give designers the freedom to be more flexible with their designs. For example, Airbus has experimented with creating a plane that has a fatter fuselage which is curved to provide improved airflow and more internal space. Other designs that have been created include a U-shaped tail section that acts as a shield for cutting down on engine noise while saving on fuel.[xiii] These innovations in design are helping companies like Airbus align themselves with customer needs while still being able to stay competitive. (Read more about how carbon fiber is changing the aerospace industry here.)

Along with carbon fiber, Airbus used the Dassault Systèmes **3D**EXPERIENCE® platform to further drive their innovation initiative. This global collaborative solution allowed Airbus to use a single platform throughout their value chain which enabled them to integrate new improvements over previous programs. Previously when Airbus was working on a new plane, everyone worked separately, resulting in a lack of communication that not only extended the design time but introduced new errors that increased costs. Instead, the A350 XWB program used the Dassault Systèmes **3D**EXPERIENCE platform which connected up to 4,000 people daily, with 85% of them coming from the supply chain. This integration of communication, collaboration and innovation created harmony among all users.

On June 14th, 2013 the A350 XWB plane was successfully launched and since then Airbus has received over 800 orders. Beyond the first flight, Airbus also wanted to ensure that they implemented a system for efficient repair and maintenance. To help achieve this goal, a Structural Repair and Maintenance (SRM) system was put into place using the **3D**EXPERIENCE platform. This will help the longevity of the program through creating a system for identifying structural parts that need repair. Now that an interconnected system is in place, Airbus can focus less on overcoming unexpected errors and more on creating an aircraft that exceeds customer expectations.

EMBRAER CASE STUDY: INTEGRATING PEOPLE AND IDEAS TO REIMAGE THE FLYING EXPERIENCE

For a growing company like Embraer, innovation is not only a means of survival but a competitive differentiator that allows them to win more business. Since Embraer was founded in 1969, they have become a leading manufacturer of commercial and executive jets, along with having large stakes in the defense and security segment. Their success can be attributed to years of trial and error as they work to perfect the product-ready innovation process. This has allowed them to become a key player in the aerospace industry alongside competitors like Airbus and Boeing.

In 1997 Embraer began its partnership with Dassault Systèmes to implement CATIA® 3D modeling software to help develop the Super Tucano light attack aircraft. Since then, this partnership has continued to grow as Dassault Systèmes helps Embraer to find new ways to improve the process of creating, developing and manufacturing new products.

Recently, Embraer was faced with the challenge of increasing pressures to efficiently create new designs that exceeded their customers' continuously-evolving expectations. Like any other company today, Embraer has also been focused on accelerating their innovations to remain competitive in the aerospace industry. This is not an easy task, especially as more companies entering the market despite the complexities of the industry. To address these challenges, Embraer needed to find a way to anticipate customer needs on future programs while also innovating at a faster rate.

An added component of this challenge was integrating data from three different segments of the market that Embraer serves: the civil, business aviation and military markets. To implement their ideas throughout the company, Embraer needed to ensure that data could be integrated across all departments and functions. Not only did Embraer need to consider the markets they served, but they also had to consider their value chain, supplier bases and operations.

Using a model-based approach—from program design to launch—Embraer has successfully overcome this challenge by incorporating information across their business to make more informed decisions with fewer errors. Previously, Embraer used a document-based system where work orders would need to be converted as many as three times based upon their intended recipient. If a design was in 3D, but a department needed it in 2D, it would have to be manually converted back and forth to meet business requirements. This introduced greater opportunity for errors.

By using the Dassault Systèmes **3D**EXPERIENCE platform, Embraer's design, data management, simulation and manufacturing information was compiled into one collaborative platform. This platform creates an integrated system for real-time access to accurate product information which accelerates development time and improves quality and design innovation. It also reduced errors associated with converting documents multiple times, resulting in improved program processes.

Embraer's adoption of the **3D**EXPERIENCE platform has not only improved their design and decision-making process, but has also allowed them to reuse product data to accelerate innovation. The Legacy 500 Executive Jet was the first aircraft fully designed to reuse product engineering data through the development process. This allowed Embraer to use data-driven, sophisticated models to create a superior interior design for the Legacy 500. Part of the process of designing the interior also included linking simulation technology to further envision what characteristics would be included on the Legacy 500 for customers. Using simulation, designers could virtually build and compare designs to find the best-fit for customer needs. This created a roadmap for Embraer for future programs, aligning their systems and people to improve their innovation process.

CREATING CENTERS FOR INNOVATION: TRANSFORMING PEOPLE, PROCESSES AND INFRASTRUCTURE IN 90 DAYS

Taking a leading role with innovation, Dassault Systèmes has several partnerships that create facilities for accelerating aerospace innovation. These **3D**EXPERIENCE centers are specifically designed to support companies in developing next-generation materials and technology that will lead the way to advanced development and manufacturing. With increasing pressures to deliver more affordable products faster, aerospace companies are looking for new ways to innovate.

One of the benefits of creating an innovation center is having access to an interconnected community of top researchers. The first **3D**EXPERIENCE Center was created in partnership with the Wichita State University's National Institute for Aviation Research (NIAR) which spans 120 acres. This facility includes nine partner buildings, one of which is occupied by Airbus. From startups to established OEMs, companies are given the opportunity to innovate from initial requirements through production and certification. Some of the key components located within the **3D**EXPERIENCE Center at NIAR are customer collaboration rooms, virtual reality technologies, additive manufacturing and Multi-Robotic Advanced Manufacturing (MRAM). These capabilities allow companies to leverage the latest technology without the risk. This ambitious initiative will help address industry issues while also forming the next-generation workforce.

What makes these **3D**EXPERIENCE Centers unique is their global outreach of knowledge. Outside of Wichita State University, Dassault Systèmes is expanding their partnerships to include more locations. In July, 2017 a **3D**EXPERIENCE Center in Hamburg, Germany was opened which will further create an ecosystem of collaboration. Having a global network goes beyond providing next-generation technology though, it creates the foundation for companies to grow and remain competitive while creating the factory of the future. (Learn more about the **3D**EXPERIENCE Centers here.)

CONCLUSION

With innovation being at the forefront of company agendas, the time for change is now. Winners in the A&D industry will not only be the ones who innovate, but the ones who innovate at the fastest rate. Accelerating innovation requires a network of supportive business systems in place to drive MBE, simulation, rapid prototyping, immersive system development and on-demand certification. These initiatives have significantly impacted the performance of companies like the United States Army, Embraer, Airbus and many others. Who will come out at the top is yet to be decided.

ENDNOTES

[i]Deloitte. Global aerospace and defense sector outlook "Poised for a rebound" 2016. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Manufacturing/gx-manufacturing-2016-global-ad-sector-outlook.pdf

[ii]Deloitte. Global Commercial Aerospace Defense Industry, "Aircraft order backlog analysis" July 2016. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-manufacturing-aircraft-order-backlog-analysis.pdf

[iii]Bloomberg. "China's New Plane Will Be Helped Aloft by U.S. Technology" May, 2017. https://www.bloomberg.com/news/articles/2017-05-04/china-s-first-jet-to-rival-boeing-is-helped-by-u-s-technology

[iv]Christensen, Brian. Thurston, Garrett. "A Holistic Approach For Realizing Model-Based Enterprises (MBE)" https://www.3ds.com/fileadmin/Industries/Aerospace-Defense/Pdf/Whitepapers/model-based-enterprises-whitepaper.pdf

[v]Aviation Week. "GE Advances Ceramic Matrix Composites Use" April 2016. http://aviationweek.com/advanced-machines-aerospace-manufacturing/ge-advances-ceramic-matrix-composites-use

[vi]Nichols, Megan. "How Important Are Ceramics in Aerospace Design?" August, 2016. American Machinist. http://www.americanmachinist.com/machining-cutting/how-important-are-ceramics-aerospace-design

[vii]Houston, Sarina. "Aircraft Profile: Boeing 787 Dreamliner" July 2017. https://www.thebalance.com/aircraft-profile-boeing-787-dreamliner-282821

[viii]Houston, Sarina. "Advantages and Disadvantages of Composite Materials on Airplanes." October, 2017. https://www.thebalance.com/composite-materials-aircraft-structure-282777

[ix]Jackson, Chad. "Improve Program Execution with Integrated Simulation" 2016. https://www.3ds.com/fileadmin/Industries/Aerospace-Defense/Pdf/ebook/improve-program-exeeution-aerospace-ebook-2016.pdf

[x]Deloitte. "3D opportunity in aerospace and defense- additive manufacturing takes flight" 2014. https://www2.deloitte.com/content/dam/insights/us/articles/additive-manufacturing-3d-opportunity-in-aerospace/DUP_706-3D-Opportunity-Aerospace-Defense_MASTER2.pdf

[xi]Thurber, Matt. "The aircraft certification process". December 2016. Business Aviation. https://www.ainonline.com/aviation-news/aviation-international-news/2006-12-18/aircraft-certification-process

[xii]Roland Berger GMBH. "Aerospace & Defense Top Management Issues Radar 2017". 2017. https://www.rolandberger.com/publications/publication_pdf/roland_berger_aerospace_and_defense_top_management_issues_radar_2017.pdf

[xiii]Bowler, Tim. "Carbon fibre planes: Lighter and stronger by design". January, 2014. BBC News. http://www.bbc.com/news/business-25833264