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The Boeing Company
Innovative Technologies in Advanced Manufacturing Hearing
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Introduction

Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee, thank you for this opportunity to speak to the innovative technologies in advanced manufacturing in the aviation industry. I am Leo Christodoulou, Director, Engineering, Materials and Structures at The Boeing Company.

Company Introduction

The Boeing Company is the world's largest aerospace company, the largest U.S. manufacturing exporter and leading manufacturer of commercial jetliners and defense, space and security systems. Boeing has over 152,000 employees in the U.S. In 2015, Boeing paid nearly $50 billion to approximately 15,000 businesses, supporting an additional 1.5 million supplier-related jobs across the country. Our business contributes nearly $1 billion into the U.S. economy each week.

Boeing has a proud history of excellence in aerospace that goes back nearly 100 years. William Boeing first began making twin-float seaplanes in 1915 from a small red boathouse, and while much has changed since then, our company remains unique in that we assemble, test and deliver all of our highly-competitive products right here in the United States. The final assembly facilities for our commercial products are located in the states of Washington and South Carolina, but we have facilities for engineering and manufacturing major components in multiple states beyond those two – including Oregon, Florida, California, Montana and Utah, where we have a growing presence. Our defense and space – related production primarily is located in the states of California, Missouri, Pennsylvania, Texas, Arizona, Florida and Alabama.

Boeing has used technological innovation and a highly skilled workforce to create market-leading products that meet the demands of a diverse and growing global customer base. We evolve constantly to meet our customers' requirements. As an example, in 2014 we launched the 777X with 259 orders and commitments, marking the largest product launch in commercial jetliner history by value. The tremendous market response to the 777X was due to the numerous features that make it 12 percent more fuel efficient than its competitor. They include an all-new composite wing based on the innovative wing developed for the super-efficient 787 Dreamliner, aerodynamic advances such as a hybrid laminar flow control vertical tail and natural laminar flow nacelles, and all-new GE9X engines developed by GE Aviation.

Commitment to Energy Efficiency

Boeing has a clear strategy and commitment to take action to address concerns about energy efficiency in the manufacturing process as well as in the operation of aircraft. Boeing investments within our manufacturing processes include out-of-the-autoclave composites; additive manufacturing that reduces the energy-density of materials; as well as advanced metal machining and fabrication techniques.

Fuel efficiency is central to aviation's business strategy, and the efficiency of aircraft and flight operations have consistently improved throughout our industry's history. This is good for our business, customers, employees and Boeing communities around the world.

The commercial aviation industry has a strong track record of steady technology improvements in reducing aircraft emissions over time. The commercial aviation industry has achieved greater fuel efficiency (and lower emissions) even as it has grown. Today's commercial aircraft are 70 percent more fuel efficient than aircraft flying fifty years ago.

Our airplane family will offer double digit emissions reductions from the airplanes they replace, making them the most fuel efficient fleet in the world. Our new commercial airplanes have been designed to meet and even exceed challenging emission requirements. The 787 Dreamliner family reduces fuel use and CO2 emissions by 20 to 25 percent compared to airplanes it replaces. The new 737 MAX, with first delivery expected in 2017, will reduce fuel use and emissions by 20 percent compared to the original Next-Generation 737. The 777X, with first delivery expected in 2020, will be the world's largest and most fuel-efficient twin-engine jet.

Innovative Technologies

The Evolution of Composites in Commercial Aviation

Aluminum structures have been a mainstay in commercial airplane design for many years. While the evolution of aluminum designs has improved the strength-to-weight ratio, the industry has been seeking double-digit performance improvements in fuel efficiency for new airplanes. Composites, combined with other improvements, have helped provide the path to such improvements.

A composite is a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder) differing in form or composition on a macro scale. The constituents retain their identities: While they act in concert, they do not dissolve or merge completely into one another.

Composites also offer strength-to-weight ratios that enable lighter weight structures that allow the airplane design to feature items such as larger windows and lower altitude pressures in the cabin. In addition, a composite airplane structure has inherent resistance to fatigue damage and corrosion.

Composites are not new to commercial aviation. In fact, composites have been used in airframe structures since the 1950s, and their use has been increasing steadily over the last 45 years. Composite structures on commercial airplanes can be all fiberglass layers, all carbon layers, a mixture of the two (often referred to as hybrid parts), or cured with honeycomb core.

Carbon Fiber in Aviation

Carbon fiber was developed in the 1960s and 1970s for defense aerospace applications, and commercialized in the 1980s. This timeframe from inception; to product development; to implementation is typical for the incorporation of new technologies for aviation applications.

Carbon fibers are reinforcing fibers produced by the pyrolysis of organic precursor fibers such as polyacrylonitrile (PAN), rayon, or pitch. These precursors are transformed through heating and stretching to create carbon fiber, which is then combined with various resins and plastics to create “carbon fiber reinforced polymers” (CFRP). The incorporation of CFRP in aircraft design significantly improves performance, reduces lifecycle fuel consumption, reduces the complexity of the supply chain through integrated structures, and improves corrosion resistance and damage tolerance.

Use of Composites on the Boeing 787 Dreamliner

At Boeing, the use of carbon fiber in our products has resulted in significantly reduced fuel consumption during the lifetime of our airplanes. For example, carbon fiber composite materials make up 50 percent of the Boeing 787 Dreamliner, including the fuselage and wing. In developing the 787, Boeing determined the most effective use of composites by evaluating every element of the airplane’s structure for function, load carrying capability, and durability. This evaluation resulted in composite materials being used extensively on the 787 airframe, making these materials dominant in areas that are traditionally aluminum. Due to its use of toughened carbon materials, solid laminate composite structure is inherently very durable. Tests have shown the 787 fuselage can resist damage that would easily occur in an aluminum fuselage.

Exploring the Future Use of Ceramics in Engines

In 2014, Boeing successfully flight tested an innovative engine nozzle made of ceramic composites designed to reduce noise, weight, and lower fuel use. The ceramic matrix composite (CMC) nozzle went through a series of tests on a 787 Flight Test Airplane, including community noise testing, passing over a large acoustic array in Moses Lake, Washington. Boeing engineers had been working on the technology for over five years prior to the test flight. The program began several years before that with small samples in labs, and resulted in a flight test of the largest built oxide CMC structure in the world, and it performed at a very high level.

Boeing is interested in CMC technology for engine nozzles because it may lead to significant improvements in performance. Modern engines have higher operating temperatures to achieve improved fuel efficiency and reduce emissions. However, these hotter temperatures are pushing the capabilities of current metallic components. CMC technology is lighter than current metallic components and can last longer in the higher temperatures. Special CMC designs are also capable of having acoustic treatments built into them that help make engines quieter, lighter and more efficient. This technology can also enable new, dramatically different engine designs in the future.

Opportunities in Additive Manufacturing

Additive manufacturing (AM) has been defined as “the process of joining materials to make objects from three-dimensional model data, usually layer upon layer.” After many years of development, AM has evolved from applications mostly limited to rapid prototyping of polymeric objects to commercial production of both polymeric and metallic components. Early adopters include the aerospace, medical, and automotive industries, which use a variety of different polymers and metals for AM components, the latter of which include steel, aluminum, nickel, and titanium alloys.

Compared to conventional manufacturing (CM) processes such as thermoforming, injection molding, and blow molding (for polymeric components) and casting, forging, machining, and finishing (for metallic components), AM holds at least three promising advantages. First, AM enables designs with novel geometries that would be difficult or impossible to achieve using CM processes, which can improve a component's engineering performance. Second, AM can reduce the “cradle-to-gate” environmental footprints of component manufacturing through avoidance of the tools, dies, and materials scrap associated with CM processes. Third, novel geometries enabled by AM technologies can also lead to performance and environmental benefits in a component's product application. For example, the aircraft industry has adopted a number of different AM components for reducing aircraft mass—including flight deck monitor arms, seat buckles, and various hinges and brackets—which can contribute to greater aircraft fuel efficiency. Boeing is actively working toward utilizing AM for structural aircraft components as well. In addition, we have already used AM for satellite components that have reduced cost and weight by 50% while maintaining performance.

Workforce Development Activities Support Advanced Manufacturing

Future development and implementation of innovative technology relies on a robust workforce with 21st century, globally competitive skills. These skills can be defined not only as STEM (science, technology, engineering, and math) skills, but also as the ability to think critically and solve problems, collaborate well, be creative and communicate effectively.

As a global industrial and technology company, Boeing is constantly competing for highly skilled talent. Advanced manufacturing, especially aerospace manufacturing, requires a robust pipeline of students with 21st century globally competitive skills. This is because today’s assembly line mechanics are more and more likely to work with state-of-the-art equipment, including robotics, and advanced materials such as composites as they assemble cutting-edge products like the Boeing Dreamliner. Further, this pipeline is only becoming more critically important as the highly experienced workforces across the advanced manufacturing sector near retirement. Boeing is addressing this current and future need in a variety of innovative and market leading ways, including through the development of employer driven workforce training programs.

Boeing operates a number of highly successful workforce training partnerships in conjunction with regional educational institutions across the country. In an employer driven training partnership, a company like Boeing will work with partner schools to communicate skills needs, assist in curriculum design and program implementation and ultimately hire from the pipeline that is trained by the partner school. This highly effective model ensures students have the skills employers require for in demand jobs. Further, these employer driven training partnerships provide high quality career and technical education not only for future Boeing employees but also for individuals hired by our supplier partners –many of whom are small and medium sized businesses.

One of these highly successful employer driven training programs is the Washington Aerospace Training Resource Center ("WATR Center"). The WATR Center is operated by the Edmonds Community College and the Renton Technical College. The Boeing Company worked closely with both schools to develop curriculum supporting six aerospace industry certifications and provided more than $2.5 million worth of materials and equipment to create a simulated work environment. To date, the WATR Center has provided certificate level training to more than 3,050 students since 2010. Of these students, more than 1,950 applied for a job and more than 1,680 were then hired. Approximately 58% of these students were hired by Boeing and 29% were hired by other aerospace companies, such as our supplier partners.

Boeing has also developed partnerships with school districts to begin providing relevant advanced manufacturing skills education at the high school level, and in some cases enrolling these students in work-based learning programs such as internships before ultimately hiring them upon graduation. These partnerships exist in states such as Oregon, Utah, South Carolina and also in Washington where more than 150 local high school and skill center students were hired last year. In these ways, and others, The Boeing Company is working to ensure a robust pipeline of students with globally competitive 21st century skills.

Closing

We are proud of the position that Boeing holds in the global economy and what our employees all across the country achieve on behalf of the company's research and technology efforts. Again, I thank the Committee for examining these issues and allowing me the opportunity to testify today.