The Birth of Advanced Composites

New structural materials continually strengthen weapon systems.

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Over the past hundred years, the powered airplane has evolved from a relatively fragile wood and fabric structure to a fast and rugged flight vehicle. In the beginning, the lack of better construction materials with higher strength capabilities limited the pace of new aircraft designs. When the design and construction of metal airplanes began in earnest in the early 1930s, speed, carrying capacity, and ruggedness jumped significantly. The resulting new air power ultimately turned the tide in World War II. In the post-war years, both aircraft design technology and aircraft metal improvements led to a new generation of higher performance jet-powered aircraft.

However, the dream of many materials engineers has always been to discover a new material that would possess the most important attributes needed for air vehicles of the future—high strength and stiffness, low weight, ease in shaping into complex geometries, and affordability. Literally, this material would consist of a composite of properties not found in any single conventional structural material.

The development of airborne radar in World War II included a need for an electrically transparent radome material to protect the radar unit. Researchers initially chose Plexiglass™, but it proved to be insufficiently stiff to retain its shape in the service environment. Thus, they selected a more stable polyester material (thermosetting resin) and then reinforced it with fine glass fibers, developed by Owens-Corning Fiberglass Corporation, to make a stiffer composite material.

Throughout the 1950s, Mr. Robert T. Schwartz, a pioneer in organic materials engineering with one of AFRL's predecessors, the Air Force Materials Laboratory (AFML), led the effort to develop glass fibers with higher stiffness, enabling lighter weight composite materials to compete structurally with aluminum. The one important success in this period was the development by Owens-Corning Fiberglass Corporation, under AFML contract, of a higher strength glass fiber (S glass), which had a slight increase in stiffness as well. In the late 1950s, engineers introduced S glass filament-wound rocket motor cases in the third stage of the Minuteman II intercontinental ballistic missile to utilize the higher strength and reduce the weight in this critical stage of the vehicle. However, follow-on pilot production efforts on higher stiffness continuous glass fibers proved to be unsuccessful; thus, researchers abandoned further development efforts. Mr. Schwartz wrote, "At this point, I observed from the scientific literature that there were various compounds and elements that had very high modulus of elasticity together with relatively low density. These were mostly in bulk, solid form..." He continued, "I knew that by one means or another most of these materials could be fiberized such as by drawing from a melt, vapor deposition, and other means." Under Mr. Schwartz' leadership, three research efforts were initiated: one with Texaco

Experiment Company to produce an experimental boron fiber, which was five times stiffer than aluminum; one with Beryllium Corporation for an experimental beryllium oxide fiber; and one with Celanese Corporation for carbon fibers made from a polyacrylonitrile precursor fiber. Following a series of laboratory stage boron and carbon fiber composite materials evaluations, Mr. Schwartz declared that "boron (and carbon) fiber-reinforced plastic composites (unidirectional) had the strength of steel, the stiffness of aluminum, and the density of beryllium." Composites made from early production quantities demonstrated the desired stiffness, strength, and low density. He coined the term "advanced composites" for this new class of materials.

In 1963, during the Air Force Systems Command (AFSC) Project Forecast initiative formed by General Bernard Schriever, AFSC Commander, which identified the most promising breakthrough technologies for aggressive further development, participants selected advanced composites. The focus for the advanced development efforts that followed was to make further improvements in the materials; reduce processing complexities and costs; develop optimum component design, manufacturing, and production processes; and perform evaluation and validation tests. By this time, the AFML had succeeded in developing and demonstrating a unique chemical vaporplating process for continuous pyrolytic synthesis of boron, silicon carbide, graphite, and titanium diboride filaments. This development of continuous filaments was considered a major breakthrough, which made reproducible production of critical high modulus (stiffness), high tensile strength filaments a reality. Researchers subsequently developed a standard tape form of the material to assist in the fabrication of parts. In addition, researchers automated the placement of the tape to reduce the hand placement of the multiple layers and multiple directions of tape required to fabricate parts.

A newly formed Advanced Filaments and Composites Division in AFML, headed up by Mr. George P. Peterson, set out to further accelerate the advanced development and transition pace for this new candidate material. Mr. Peterson's key strategy was to "lead the charge to demonstrate the improved performance of realistic hardware as the key path toward production." Structural demonstrations of advanced composites included an F-111 horizontal stabilizer, CH-47 rotor blade, OV-10 wing box, re-entry vehicle substructure, and a satellite antenna dish. Researchers successfully flight-tested the horizontal stabilizers and rotor blade. Both exhibited a 20% weight savings over their metal counterpart and, in the case of the rotor blade, a fatigue life of four to five times that of current metal blades. The satellite dish utilized a carbon fiber composite to take advantage of its unique dimensional stability over the range of temperatures experienced in space.

Following successful demonstrations of the new materials, researchers introduced boron fiber composites into the empennage of the F-15 and carbon fiber composites into the empennage of the F-16 production articles. Following additional demonstration programs, researchers introduced advanced composites into the B-1B aircraft (see Figure 1) to stiffen longerons and into weapon bay doors. Demonstration programs continued with an increased emphasis on the insertion of advanced composites in missiles, spacecraft, and turbine engines. Use of advanced composites in Air Force weapon systems increased from the initial 2-3% structural weight in the empennage of high-performance fighters to the 38% used on the B-2 bomber. The ability to produce variable structural shapes and surfaces precisely with advanced composites and eliminate most fasteners from the outer surfaces made this material particularly effective in the design and manufacture of low observable structural members for aircraft such as the B-2 and F-22 (see Figure 2).

Following the lead of the Air Force, both commercial and civil aviation adopted the use of composites, and Boeing and AirBus incorporated them in their last three models of transports. Commercial launch systems and satellite systems employ advanced composites, sometimes in amounts that exceed military use. The establishment of a viable composites industrial base allows manufacturers to develop composites in a wide variety of commercial applications such as in sporting goods.

The single most inhibiting factor remaining in the still broader use of advanced composites is affordability. In the mid-1990s, the Materials and Manufacturing Directorate established a government-industry consortium to identify how to achieve a 50% cost reduction in composites that were in production at that time. In this effort, called the Composites Affordability Initiative (CAI), the team identified the principal approach to achieve this goal—the introduction of large integrated and bonded composite structures. The team considered pervasive technologies including improved analysis methods for bonded structures, new and unique resin infusion processes, and structurally integrated designs to reduce fabrication and assembly costs. Completion of CAI will provide the validated technology for the insertion of affordable advanced composites in all future Air Force weapon systems and provide the warfighter with improved performance and capability.

Figure 1. B-1B Lancer

Figure 2. F-22 Raptor

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