Aircraft Started with the Wright Materials

From 1903 to 1909, six years after the historic first flight of the Wright Brothers, the main constituents of aircraft were wood, silk or cotton fabric, and steel guy wires.

Wood was used to construct the aircraft frame instead of aluminum because of its unreliability when subjected to heavy stresses during landing. Although aluminum was used in the motor of the *Wright Flyer*, it was not widely used until the 1930s.

Steel tubing handled stresses better than pure aluminum tubing, but even steel tubing buckled under the shock of landing. Therefore, the need for a strong, lightweight material resulted in some manufacturers' using bamboo for aircraft frames. However, wood was preferred over bamboo because it was easier to use and was more easily replaced.

The wooden wings, rudders, and fuselage were covered with fabric made of silk or cotton thread that was "proofed" (insulated) with either rubber or celluloid. The fabric was closely woven so as to be nearly airtight. This lowered the air resistance and provided a tough, tear resistant covering that could be stretched over the framework.

Steel piano wire was used in the guy wires and served to carry tension between struts in the wooden frame. This combination of wood, fabric, and steel wire was used for both monoplanes and biplanes—in 1909 neither the monoplane or the bioplane showed significant advantage over the other. Materials had to work reliably with the stress loadings incurred at the then "breakneck speed" of 45 to 50 miles an hour.

Wood continued to be used in aircraft structures until World War II. In 1937 the British de Havilland DH91 Albatross airliner was molded as a plywood-balsa-plywood sandwich laminate. In 1940 the de Havilland DH98 Mosquito fighter plane, using a similar plywood-balsa-plywood laminate, represented the high point of wood aircraft construction.

By 1950, aluminum, magnesium, steel, and plastic had become the mainstay of aircraft construction. The nonferrous materials (those that are made without iron, i.e., aluminum and magnesium), were supplemented with new materials being explored for use by the aircraft industry, such as titanium and beryllium. These lightweight metals were strengthened and made corrosive resistant by alloying them with zinc, manganese, and zirconium. This strengthening and anticorrosion process could also be accomplished by cladding, or coating one material with another.

The nonmetallic materials used in constructing aircraft included plastics, glass fabrics, and synthetic rubber. By the 1950s the requirements for engine parts capable of withstanding high temperatures drove the development of ceramics and ceramic coatings to protect metal.

In the early 1960s the invention of graphite fiber and boron fiber made available advanced composite materials for use in aircraft construction. These advanced composites were made with an epoxy matrix. The composites were superior in both strength and stiffness to conventional aircraft materials.

Composites are made up of two or more materials that, when combined, generally have superior properties to the original materials alone. The simplest composite consists of a matrix and a reinforcing material. The matrix serves as a bonding substance and is generally in liquid form when combined with the reinforcing agent, which is usually solid.

By 1970 the horizontal tail of the General Dynamics F-111 fighter-bomber and some McDonnell Douglas F-4 rudders were made of boron-epoxy composites. The same composites were used in the horizontal and vertical tails of the McDonnell Douglas F-15 fighter.

With an increasing demand for its use, the price of boron-epoxy composites soared until 1979 when it reached $180 a pound, compared to $40 a pound for graphite-epoxy composites. Mostly because of this increase in cost, the United States switched to using graphite-epoxy composites in its aircraft. Graphite-epoxy composites were used in the horizontal and vertical tails, as well as for some control surfaces, of the General Dynamics F-16 fighter, and were used even more extensively in the F-18 fighter.

Carbon (graphite) fiber reinforced epoxy resins, or CFRPs, account for 90% of all composites used in today's aircraft construction. The benefits of these composites include high stiffness and strength to weight ratio, tailored directional mechanical properties, a reduced number of parts as compared to their metallic equivalents, dimensional stability, and resistance to fatigue.

In jet engine applications, boron fibers in an aluminum matrix are being studied for use in fan blades; tungsten-superalloy composites are a possibility for use in turbine blades.

Modern advanced aircraft designs incorporate features such as forward-swept wings which are made possible only by composite materials. Forward-swept wings show great advantage over conventionally swept wings at high-subsonic speeds, mostly due to reducing shock strength and having lower wing drag. This greatly increases maneuverability, improves the turn rate, increases the cruise performance, and allows for a smaller wing to be used.

Forward-swept wings must have bending and torsional characteristics to counter spanwise twisting (where the wing tips twist up), yet be lightweight. The wing skins are constructed from high-strength, low-weight carbon-fiber laminates built up in layers arranged at 0, 45, and 90 degrees from the unidirectional ply. (A unidirectional ply is where the fibers are aligned in one direction.) The matrix of layers are "aeroelastically tailored" by superimposing a sweep forward; that is, the layers are biased to the angle of sweep during the manufacturing process to oppose the forward-swept wing's tendency to twist.

In the future, advances in computer modeling, numerical control of ply profiling, and strengthened bonding joints promise to extend the use of composites in aircraft even further.

DOUG BEASON

FOR FURTHER READING: Robert W.A. Brewer, *The Art of Aviation: A Handbook Upon Aeroplanes and Their Engines With Notes Upon Propellers* (McGraw-Hill, New York, 1910); *Composite Materials in Aircraft Structures*, edited by Donald H. Middleton (Longman Scientific & Technical, John Wiley & Sons, New York, 1990); H.J. Gough, "Materials of Aircraft Construction," *J. of the Royal Aeronautical Society* **42** (1938) pp. 922–1032.