What They're Made Of

Flying Magazine

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The 1930 Northrop Alpha — 420 hp, seven passengers, 130-knot cruise — proved that metal airplanes can be both light and beautiful.

During World War II the British adopted the term boffin for scientists or engineers secretly developing novel weapons, inventing radar, breaking codes and so on. Frank Whittle, one of the creators of the jet engine, was a notable boffin. Another, less well-known than Whittle although, like him, later to be the subject of a motion picture, was Barnes Wallis. His principal claim to fame was the dam-buster bomb, which was dropped on Ruhr Valley reservoirs by very low-flying RAF Lancasters. Made to spin rapidly before release, the barrel-shaped bombs would roll along the water surface like skipping stones until they encountered the dam, sank and exploded.

Another Wallis innovation was a style of aircraft structure called geodetic. It consisted of a great many short pieces of sheet aluminum, bent up along their edges for stiffness and connected at their ends with riveted gussets to form a network resembling a loosely woven basket. Wooden stringers and fabric cover were added for streamlining and to keep the rain out. Vickers used this unusual style of construction on a couple of types of bombers, notably the Wellington.

Wikipedia waxes rhapsodic over the geodetic structure: "The metal lattice-work gave a light structure with tremendous strength; any one of the stringers could support some of the load from the opposite side of the aircraft. Blowing out the structure from one side would still leave the load-bearing structure as a whole intact. As a result, Wellingtons with huge areas of framework missing continued to return home when other types would not have survived."

This kind of mythmaking prose clings like a graveyard fog to all sorts of defunct schemes. To start with, all aero structures are light and strong; the strength of geodetic structures was no more "tremendous" than that of other kinds of structures designed to the same requirements, and at any rate excess strength in an airplane is not something to brag about. Perhaps the writer meant that the geodetic structure had a very high strength-to-weight ratio; that may be so, although the non-load-bearing outer covering didn't help.

As for damage tolerance, battle is not a controlled experiment. B-17s too came back with huge pieces shot away. Geodetic structures had, to be sure, the virtue of being made of lots of small pieces, so that local damage did not spread quite as far as cracks might in a sheet-metal structure. They also had the purely specious advantage that blowing or burning away the fabric skin created a visual impression of enormous damage even if the underlying structure remained intact.

Whatever their merits may have been, Wallis' geodetics remained a sidetrack. The history of airframe structures boils down to only two great threads: truss-work frame and stressed skin. Most of the airplanes built before 1930, and decreasing numbers thereafter, incorporated a trusslike frame of wood or steel, sometimes braced by diagonal wires, which was covered by a nonstructural fabric shell for streamlining. Not all: Even during the First World War the German firms of Roland, Pfalz and Albatros built elegantly streamlined hollow fuselages out of spiral-wound plywood, and as early as 1915 Hugo Junkers was skinning his airplanes with sheet metal.

Airframe design is theoretically dominated by lightness, strength and rigidity. From the beginning, however, where the strength-to-weight ratios of different structural materials and systems were similar, choices were guided by secondary considerations like cost, availability of an appropriately skilled labor force, ease of fabrication and repair, resistance to damage and so on. Some pretty weird stuff has found its way into aero structures; Goodyear Tire & Rubber Co., for instance, developed a couple of airplanes made of rubber.

The familiar old truss of welded steel tubing, exemplified by Cubs and Champs and countless vintage and homebuilt biplanes, is attractive for many reasons. Its design and analysis are straightforward. It's structurally efficient; easy to construct, modify, inspect and repair; and cheap and durable. It lends itself to "hard points" for concentrated loads, like wing and landing gear attachments. But it has disadvantages as well. The streamlined outer shape that must be added over it is so much dead weight, and it does not make the best use of all of the space available inside that outer shape. Internal space is important not only for payload capacity but also structurally, because the farther apart load-carrying members are, the greater the rigidity of the whole.

The long-prevalent stressed-skin metal structure is based on two principles. First, the skin, which is the largest component of the airplane, is going to be there anyway, so you might as well make it work for you; and second, the skins are as far apart as it's possible to be and therefore provide the most rigidity for the weight. Jack Northrop's 1930 Alpha is often credited with pioneering stressed-skin metal structures, but Northrop certainly didn't invent them. Credit for that probably belongs to Junkers and Fokker, and to plywood- or metal-skinned cantilever wings in which twisting loads – and, in the case of Junkers' remarkably futuristic J.1, bending loads as well — were borne by the skin itself, not by internal members.

Stressed-skin airframes are sometimes called semimonocoque because they are a hybrid of monocoque and framed structures. Pure monocoque, strictly speaking, means that all loads are borne by the skin and its local stiffeners; think of an eggshell, a famously strong and light structure. Unfortunately, the smaller an airplane is the thinner its skins, for reasons of weight, and the less useful these skins are for resisting stresses. Relatively massive and compact members, like wing spars and fuselage longerons, are needed to carry compressive loads without buckling.

In the 1930s much ingenuity went into ways of making the light skin material of wings support compression, for instance by riveting bent-up or corrugated material to the inside of skins to form closed spanwise tubes. The seemingly indestructible wings of DC-3s are an example of this approach. Spar caps made from massive extrusions were an alternative approach. Eventually the two styles merged in larger airplanes in the form of one-piece skins machined out of huge slabs of metal; the wing skins of most jets, for example, are a single piece from root to tip, with stiffeners and attachment flanges milled into their inner surfaces.

Another method of stiffening skins is sandwich construction, in which thin sheets are bonded to both sides of a "core" of very light material. Sandwich structures have been made with all sorts of materials, from the -surfboardlike fiberglass and plastic foam wings of composite homebuilts to the brazed stainless-steel and titanium honeycombs of the trisonic SR-71.

The universal shift to stressed-skin structures in aviation was due to the rapidly increasing supply of metallic aluminum and its alloys in the early 20th century. The strongest modern alloys, originally developed by the Japanese during World War II, are comparable in tensile strength to common steels but weigh only a third as much. Aluminum has only a third of the stiffness of steel, however, and today it is gradually being displaced by carbon fiber (also sometimes called graphite) composites, which have greater strength and stiffness than steels and half the weight of aluminum.

Just as aluminum begins to cede to composites in airplanes, it is being taken up by automobile manufacturers. The Jaguar XJ sedan and the Audi S8 are entirely aluminum--bodied, and feel and sound funny if you rap on them with a discreet knuckle. The Ford F-150 pickup, the biggest-selling car in America, is going aluminum--bodied, and other makers, currently using the metal mainly for hoods and trunk lids, will no doubt follow suit. Hundreds of pounds are removed, with consequent reductions in fuel consumption to meet increasingly drastic federal mandates.

Though composites are gradually overtaking aluminum as the default material for airframes, aluminum airplanes will still be around for a long time. For us who take an interest in craftsmanship, that's a good thing: The pleasure given by a well-riveted wing skin, a precise butt-joint or a skillfully formed metal panel will always have a special value that composites, with their inhumanly perfect surfaces, will never provide.