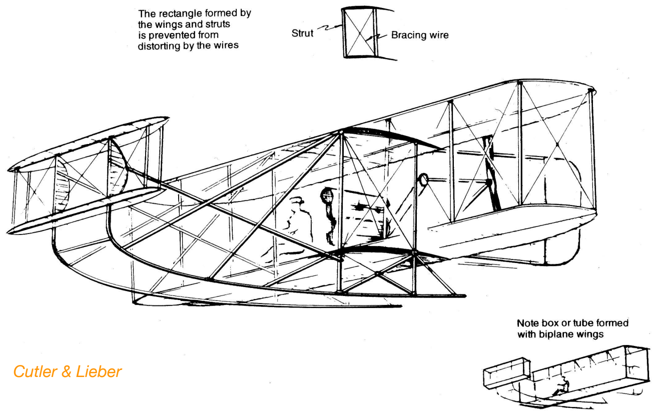
1

Aircraft structural types – 1



Cutler & Lieber

Fig. 2.1 Wright Flyer (1903).

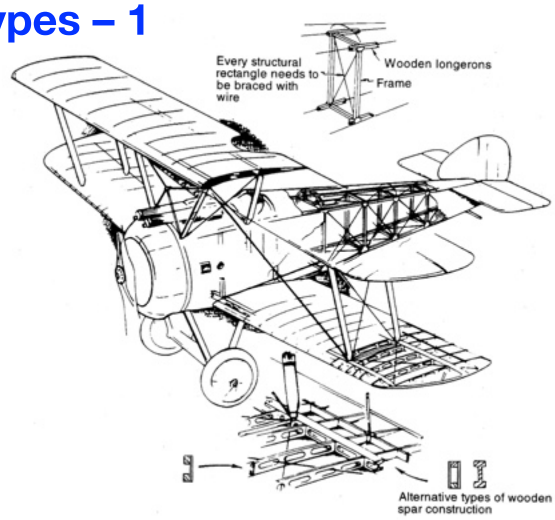


Fig. 2.2 Sopwith Camel (1917).

Early aircraft structures were mainly based ideas from civil-engineering-type trusses with first wood, and later metal, compression elements braced with wire tension elements. This is comparatively light and strong, but exposed wires produce a lot of drag.

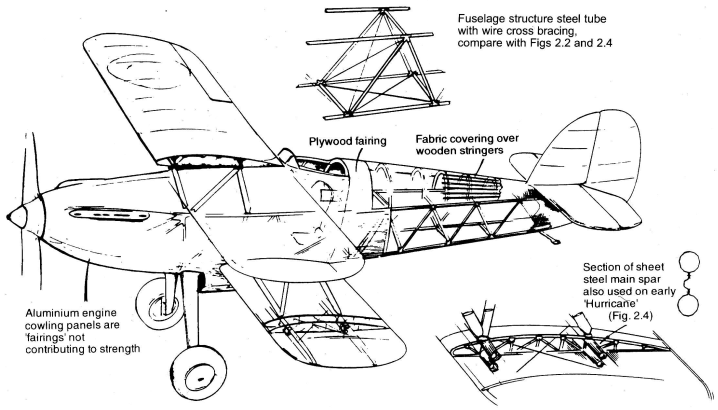


Fig. 2.3 Hawker Fury (1931).

Thin airfoils and biplane wing structures were dominant.

2

Aircraft structural types – 2

Cutler & Lieber

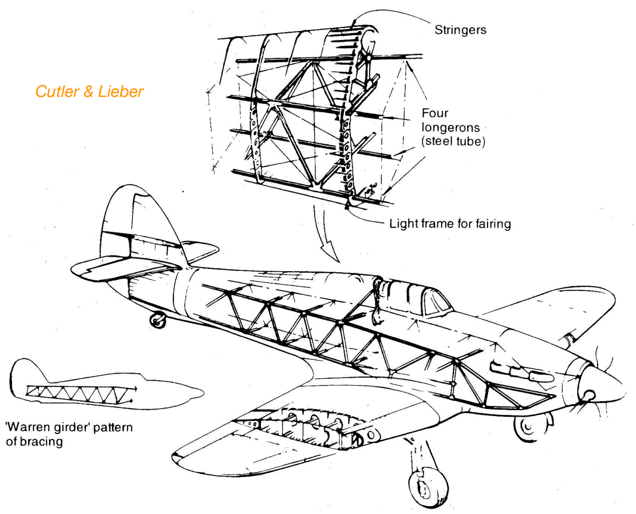


Fig. 2.4(a) Hawker Hurricane (1935).

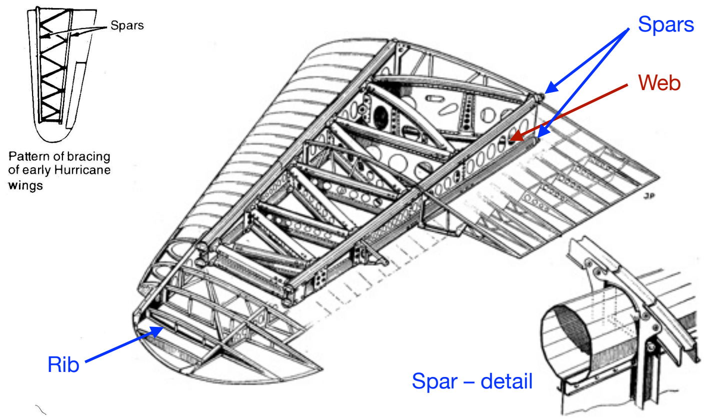


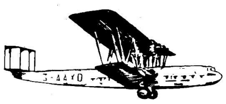
Fig. 2.4(b) Hawker Hurricane wing construction. (From 'Aircraft Production' courtesy c *IPC Transport Press*.)

After it was established that relatively thick airfoils are more efficient than thin ones at typical flight Reynolds numbers, monoplane wings with internal beams based on spars and shear webs became an established structural type. This also eliminated the drag produced by external bracing wires. Fuselage structures remained of truss type, with external aerodynamic fairings.

Structural wing beams here made from tubular metal spars joined with sheet metal shear webs. Additional diagonal structure for torsional and drag bracing. Ribs for aerodynamic shape.

STRUCTURES

Aircraft structural types



A contemporary of the DC3
HP 42 – 1931

Cutler & Lieber

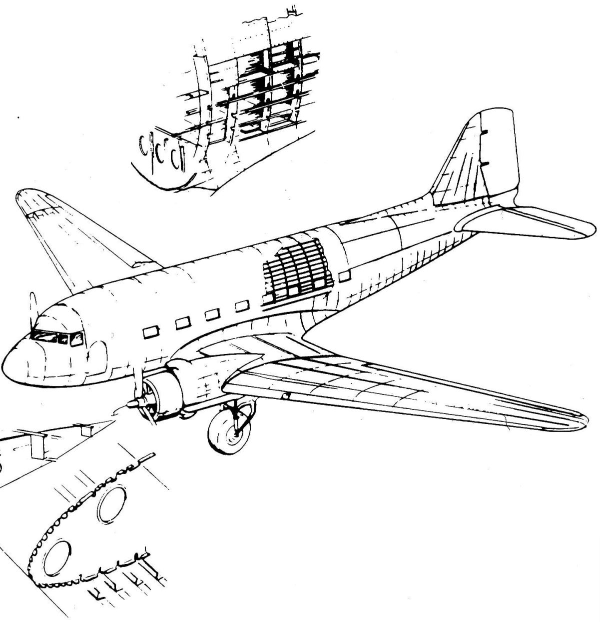
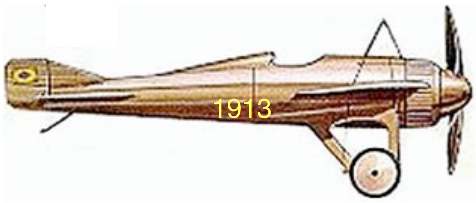


Fig. 2.5 Douglas DC.2/3 (1933).



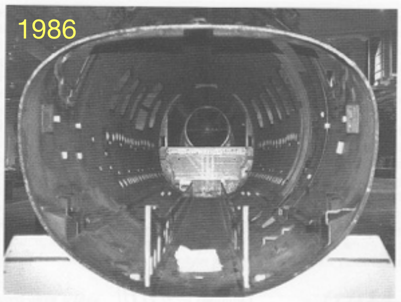
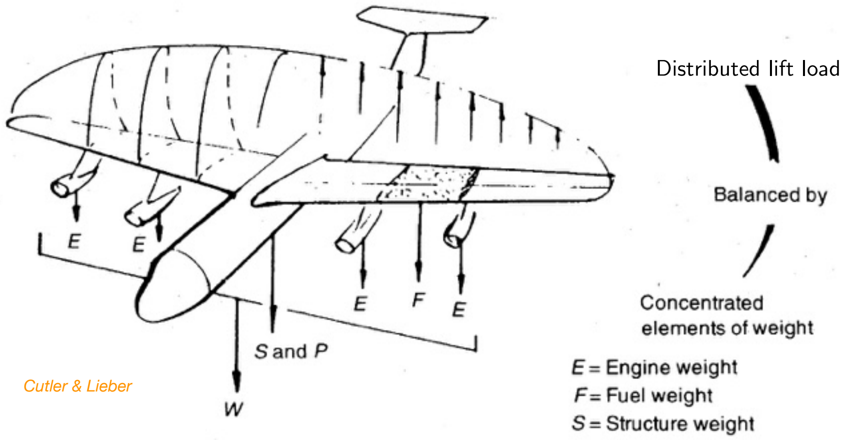


Fig. 2.6(a) Starship fuselage structure. (Courtesy of Beech Aircraft Corporation.)

The next (and basically, final) advance was to transmit as much of the load as possible through the aerodynamically shaped skin of the aircraft. This is done with metal `stressed skin' construction (which has lightweight metal stiffeners to avoid buckling of thin skins), or via fibre-based composites, either with stiffeners or in sandwich panels.

The logical evolution of these ideas is to use monocoque (single shell) structures which are light, strong and stiff (though possibly costly). Originally made from plywood, then plywood skinned + balsa cored sandwich panels, and more recently fibre composites skinned + honeycomb cored sandwich panels.

Aircraft structural loads



Cutler & Lieber

E = Engine weight
F = Fuel weight
S = Structure weight
P = Load weight
$W = E + F + S + P$

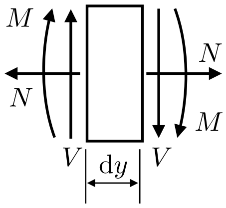
Typical loads in normal flight operations are provided by lift (upwards) balanced against weight and/or inertia loads (downwards). These have to be resisted by and transmitted through the structure.

From a structural viewpoint, wings behave essentially as beams in bending (but also must be able to resist torsion produced by aerodynamic and/or propulsion-based twisting moments). So, usually, the top skins of the wing are in compression while the lower skins are in tension; these are in turn connected to each other in shear.

Designers will often try to reduce wing bending loads by distributing weights such as engines and fuel along the span of the wing – which is known as `load relief'. This leads to lighter wing structures.

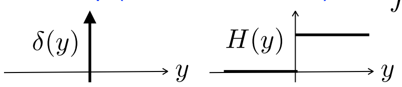
Wing as a simple beam – shear and bending loads

Sign conventions for positive loads on a beam element:



Integration of an impulse (point load, delta function) produces a step (Heaviside function):

$$\int_{x-\epsilon}^{y+\epsilon} \delta(y-a)\,\mathrm{d}y = H(y-a) \quad (1)$$



(y is spanwise coordinate.)

For a distributed load (+ve upwards): $\dfrac{\mathrm{d}V}{\mathrm{d}y} = l$ (2) where l is load/unit length.

Bending moment: $\dfrac{\mathrm{d}M}{\mathrm{d}y} = V$ (3) so that $\displaystyle\int_A^B \mathrm{d}M = \int_A^B V\,\mathrm{d}y$ (4)

Wing (massless) with fuselage point load W in steady level flight:

$$l = \tfrac{1}{2}\rho V_\infty^2 C_l c(y) = \rho V_\infty \Gamma(y)$$

$$\int_{-b/2}^{+b/2} \rho V_\infty \Gamma(y)\mathrm{d}y = W \quad (5)$$

(Lift = Weight)

Loading

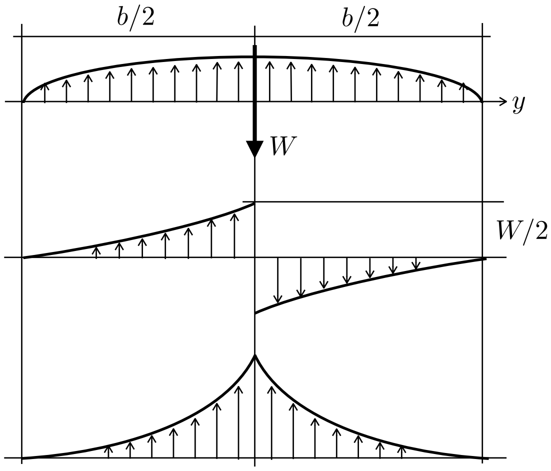
distributed lift (l)
balances point load weight (W)

Shear force V

obtained by integrating (2);
for point loads, use (1)

Bending moment M

obtained by integrating (3)

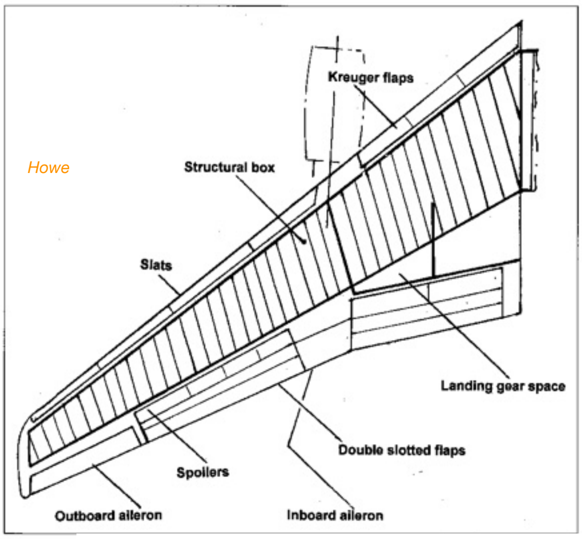


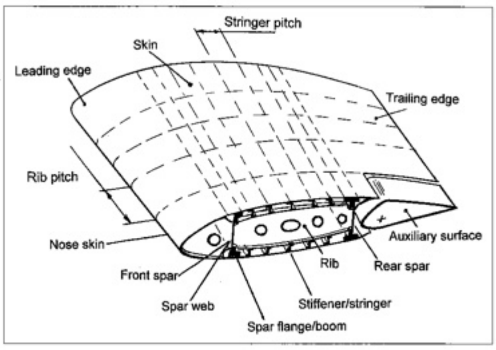
Integrates to zero owing to (5).

Must be zero at each tip owing to (4).

Simple to generalise for further distributed/point wing inertia loads.

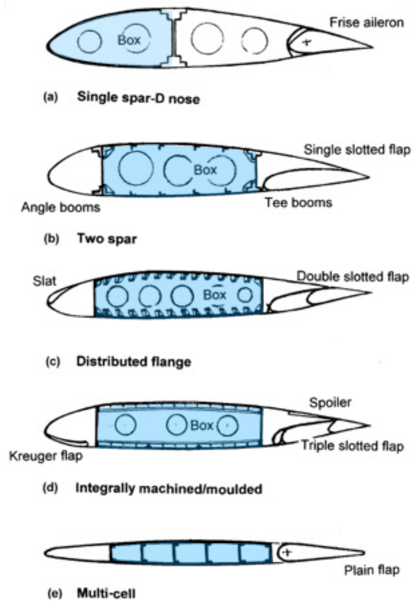
Wing structural layout – 1



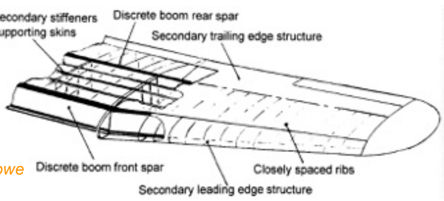


Wings for many modern aircraft are conceived as a structural `wing box' beam from which moveable surfaces and perhaps landing gear and engines are mounted. Span-wise and chord-wise this wing box beam must possess adequate bending and torsional stiffness to support loads. This beam must also be coupled to the fuselage: typically the wing box must pass through the fuselage in order to support bending loads.

Different structural forms for the `wing box'.



Wing structural layout – 2



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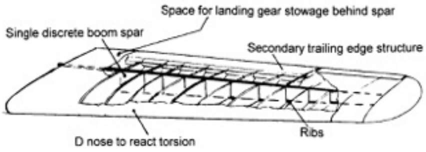
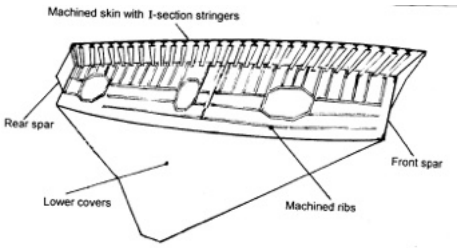
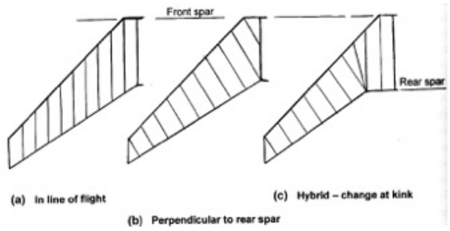


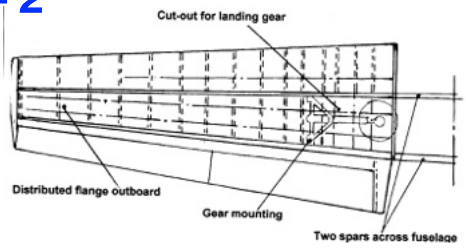
Wing box structure may vary along the span, and may have to accommodate fuel, landing gear, and engine mountings.

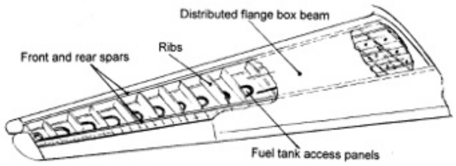


Modern metal wings may be built up from heavily machined components in order to achieve low weight along with high strength and stiffness.



(Swept) wing rib orientation may change along the span.





Highly swept, low aspect ratio wings may not employ a wing box at all.